CITY OF BOULDER
CITY COUNCIL AGENDA ITEM

MEETING DATE: April 16, 2019

AGENDA TITLE: Building Code Update

PRESENTERS
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1. EXECUTIVE SUMMARY

The City of Boulder's base building codes were last updated in early 2014. At that time, the following building codes were adopted:

- 2012 International Building Code (IBC)
- 2012 International Residential Code (IRC)
- 2012 International Energy Conservation Code (IECC)
- 2012 International Fire Code (IFC)
- 2012 International Wildland Urban Interface Code (IWUIC)
- 2012 International Mechanical Code (IMC)
- 2012 International Plumbing Code (IPC)
- 2012 International Fuel Gas Code (IFGC)
- 2012 International Property Maintenance Code (IPMC)
- 2011 National Electric Code (NEC)

In 2017, Boulder developed the [2017 City of Boulder Energy Conservation Code (COBECC)] using the 2012 IECC as the base code and then increasing the stringency and altering compliance paths to create a code that was 20 to 30 percent better than the national code. Also, in 2017, the city adopted local amendments to the International Building, Residential and Plumbing codes to advance energy and sustainability issues.

Staff is proposing adoption of the 2018 International Building Codes with a number of local amendments consistent with current amendments to the 2012 codes. Staff is also proposing adoption of the 2020 City of Boulder Energy Conservation Code (2020 COBECC), which is a localized version of the 2018 International Energy Conservation Code that will be effectively 20 percent more efficient than the national code. The city has committed to updating the local energy code on a three-year cycle with the goal of getting to net zero energy (NZE), outcome-verified codes by 2031.

Anticipated updates to the COBECC include:

- Net-zero energy requirements for all new residential construction larger than 3,000 square feet;
- Adoption of performance-based requirements by specific building class for commercial construction;
- Introduction of an outcome-based compliance pathway for commercial construction;
- Introduction of an offset pathway for achieving code compliance; and
- Tailoring the commercial electric vehicle–ready requirements based on building use.

QUESTIONS FOR COUNCIL

1. In response to feedback regarding the impact of large homes and large lots, staff is proposing to accelerate net zero energy (NZE) requirements for residential new construction. All new homes larger than 3,000 square feet would be required to be NZE. Currently all homes larger than 5,000 square feet are required to be NZE. Does council support this NZE acceleration?
2. In an effort to ensure construction waste reuse and recycling occurs, staff is proposing new enforcement mechanisms for the construction and demolition waste requirements. Does City Council support a financial penalty (in the form of a deposit that has been withheld) for non-compliance?
3. Currently construction and deconstruction waste requirements only apply to residential projects. Does staff support expanding these requirements to commercial construction?
4. Does City Council support expansion of the Energy Impact Offset Fund (EIOF) as a last resort compliance pathway when projects are unable to meet net zero energy code requirements on-site and when off-site solar is unavailable?
5. Does council support a local amendment to allow or require gender neutral restrooms?
6. Does council support continuing the current amendment exempting one-and-two family dwellings from the sprinkler requirement or does council support revisiting the requirement for all newly constructed single-family dwellings to be protected with automatic sprinkler systems?

2. BACKGROUND

The City of Boulder adopted the Climate Commitment in December 2016 that set a goal of reducing community emissions 80 percent by 2050. The city has developed and continues to develop regulatory and voluntary energy saving programs to realize this goal. Advancing the city's energy code is a key component to achieving the community emission reduction target. Between 65-70 percent of community emissions are associated with buildings in Boulder (refer to Figure 1 below).

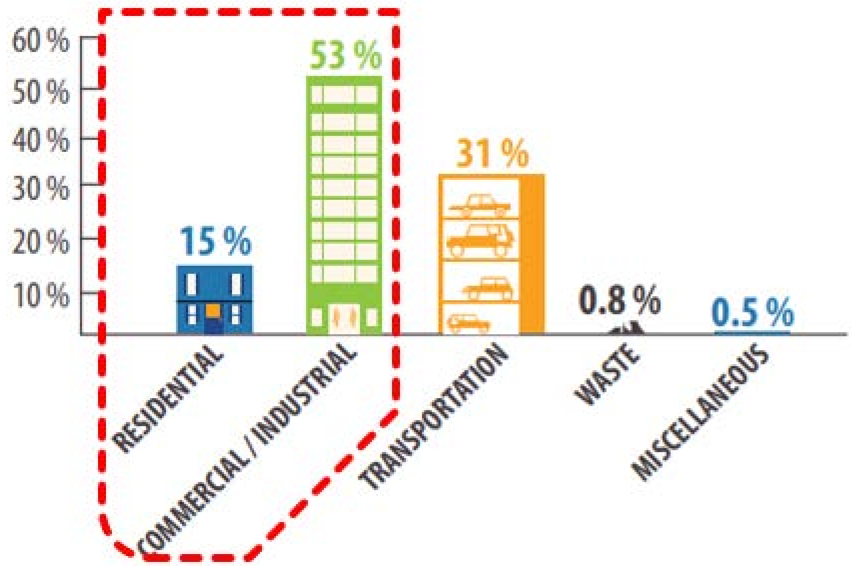

Figure 1: City-wide Emissions by Sector

Steady improvement in building codes and continued improvement in building performance is important to achieving the city-wide emission reduction goal. To formalize our long-term energy code roadmap as well as develop code language for the 2020 energy code update, the city contracted with New Buildings Institute (NBI) and TRC Solutions. NBI is a nonprofit organization driving for better energy performance in buildings nationwide. They work collaboratively with industry market players—governments, utilities, energy efficiency advocates and building professionals—to promote advanced design practices, innovative technologies, public policies and programs that improve building energy efficiency. They have become the national expert on developing policies and code strategy that bridge the gap between city climate goals and vision and effective measures to achieve those goals. TRC Solutions has been instrumental in developing cost effectiveness studies for many California cities on the path to net zero energy homes.

Boulder's energy code roadmap (**Attachment A - Boulder's Energy Code Roadmap**[1]) sets an aggressive goal of reaching Net Zero Energy (NZE) outcome-verified construction through building and energy codes by 2031. An NZE building has zero net energy consumption, meaning the total amount of energy used by the building on an annual basis is equal to the amount of renewable energy created on the site[1]. An outcome-verified code requires that compliance with the energy performance requirement be demonstrated by annual metered data. To achieve an NZE outcome-verified code, the roadmap outlines three fundamentals shifts: 1) incrementally increasing code stringency to minimize building energy use, 2) increasing deployment of renewable energy resources to offset remaining building energy use, and 3) transitioning to a focus on actual building energy use rather than theoretical or modeled energy consumption. Specific key elements of the roadmap include:

[1] Boulder's energy code allows alternate compliance through a solar garden subscription if this is not feasible.

- **Increased Building System Performance**. The energy code requires that all systems become increasingly efficient. Through advancements in technology and system design, lighting, heating, cooling, and water heating systems in buildings are required to use less and less energy.
- **Renewable Offset**. With each code-cycle, the energy code roadmap requires that more and more on-site solar be deployed to begin to offset building's energy consumption.
- **Energy Storage**. As more and more buildings begin to incorporate solar, electric grid compatibility will be increasingly important. Battery storage, demand shifting and smart technology to ensure energy is exported to the grid at meaningful times will be phased into Boulder's code over time. The 2023 code update will include residential and commercial requirements for battery storage infrastructure.
- **Envelope Backstop**. With the cost of renewables dropping, some projects simply deploy large solar arrays instead of emphasizing basic building efficiency. The backstop code creates a maximum allowable total energy use per square foot to ensure design teams invest in the building envelope and systems first.
- **Transition to Outcome Codes**. Data has shown that many buildings perform worse in actual operation than was predicted in the permit application. As building performance requirements become more stringent, it is necessary to consider actual building energy use as a basis for energy code compliance, rather than rely on predictions of performance.
- **Enforcement Mechanisms**. To focus on building performance outcomes, new enforcement strategies will need to be developed. Collaboration between city departments currently enforcing the energy code and staff enforcing the Building Performance Ordinance will need to be further developed. As the city requires better alignment between predicted and actual building performance as a condition of energy code compliance, new enforcement mechanisms will be needed to ensure compliance, and to provide projects with remediation mechanisms to resume compliance.
- **Three-year energy code-cycle**. Getting to an NZE code represents a significant challenge requiring transition from prescriptive requirements or comparative design predictions as a basis for code compliance, to a focus on actual building performance outcome as a compliance metric. This challenge needs to be addressed systematically over multiple code cycles to bring actual building performance into line with performance goals and predictions.

Figure 2 illustrates how these strategies combine to incrementally move Boulder's building performance towards NZE. NBI's full analysis and report can be found in **Attachment A: Boulder's Energy Code Roadmap**.

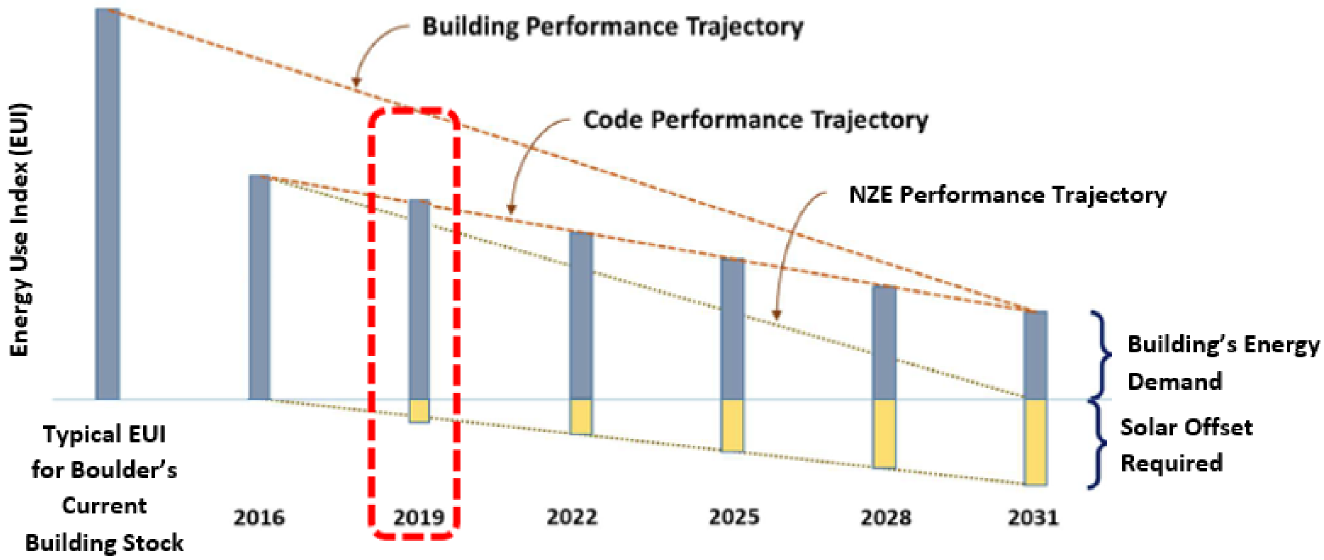

Figure 2: Representation of increasing code stringency, renewable deployment, and building performance improvement through multiple code cycles to achieve NZE.

In addition to supporting the development of the Energy Code Roadmap, NBI is also working with staff to develop the proposed 2020 residential and commercial code updates. As outlined in the roadmap, to achieve the long-term goal of getting to NZE outcome-based codes, advancements and improvements will need to be made every three-year code cycle between now and 2031 to keep up with technology and to incrementally advance building performance requirements in cost effective ways.

Energy Code Format

The International Code Council publishes a robust energy code within their suite of building codes, the International Energy Conservation Code (IECC). However, the IECC is significantly less stringent than where Boulder needs to be with regard to building performance to meet our city-wide climate commitment goals. Boulder has a long-standing history of being committed to high performance buildings and a local energy code that requires design teams deliver energy efficient and sustainable residential and commercial designs. In 2017, Boulder developed the 2017 City of Boulder Energy Conservation Code using the 2012 IECC as the base code and then increased stringency and altered compliance paths to create a code that was 20 to30 percent better than the national code. Feedback from design professionals, contractors, and builders was generally favorable; customers appreciate the familiarity with the national code.

Again, with the 2020 code update, staff is proposing Boulder's code be developed from the 2018 IECC and the same approach applied to create a code that will be about 20 percent more stringent than the current national code.

3. ANALYSIS: PROPOSED 2020 ENERGY CODE UPDATES

Residential Energy Code Updates

For the residential code, the most significant changes being proposed are:

- **More stringent Energy Rating Index (ERI) requirements**. An ERI score is the same as a Home Energy Rating System (HERS) score. This is a numerical score where 100 equates to the efficiency levels prescribed in the 2006 International Energy Conservation Code and 0 is equivalent to a net-zero-energy home. Currently, and in the proposed 2020 code, new construction and major alteration projects must demonstrate compliance with Boulder's energy code by using the prescribed ERI compliance path. In the 2017 City of Boulder Energy Conservation Code, an ERI sliding scale was established that set more lenient ERI requirements for smaller homes and more stringent requirements for larger homes. The 2017 COBECC resulted in just over half of the new homes being constructed achieving net zero. For this code cycle, staff is proposing a reduction in ERI requirements represented in Figure 3 below such that all new homes over 3,000 square feet would be required to achieve net zero. Figure 3 illustrates both the 2017 and proposed 2020 ERI requirements for comparison.

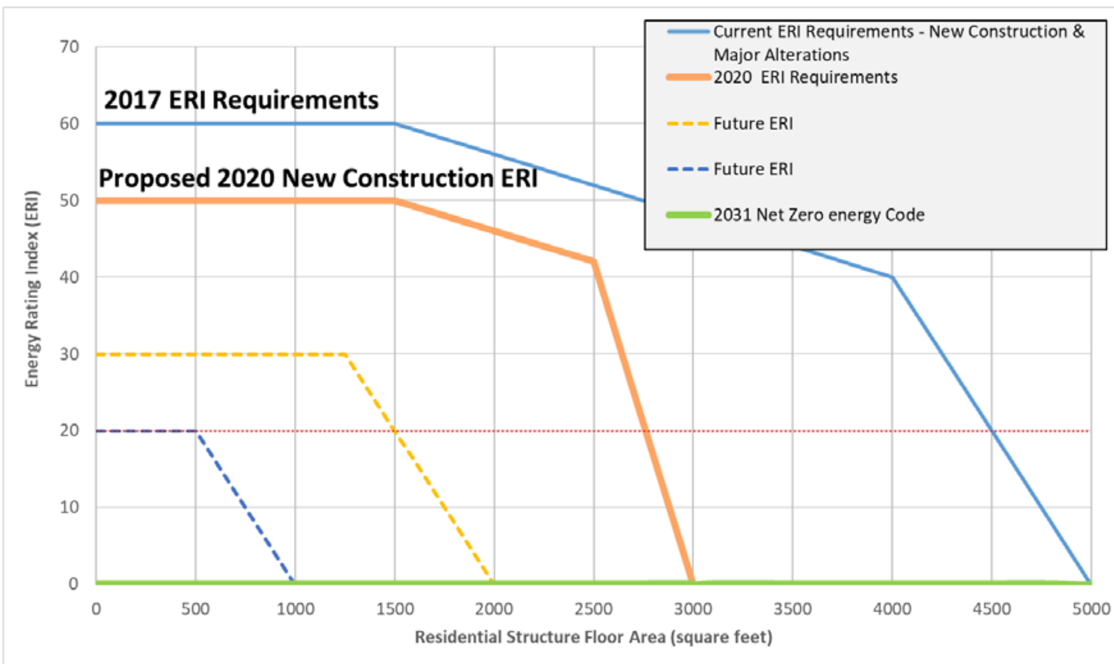

Figure 3: Proposed 2020 ERI Requirements for Residential Energy Code

The proposed 2020 requirements reflect analysis around the cost effectiveness of the measures required to achieve these ERI scores as well as feedback solicited from local design professionals. Refer to **Attachment B** for detailed information about the residential cost effectiveness study.

Another consideration in setting these ERI targets was the land use code project addressing large homes and large lots, as well as a desire to preserve existing structures to the greatest extent possible. Staff is proposing an acceleration of the NZE requirements for new construction, such that all homes greater than 3,000 square feet would now be required to be net zero. Staff is also proposing that 2017 ERI levels for renovations are not made more stringent as a way of incentivizing retention of existing homes.

- **Envelope Backstop**. With the cost of renewables dropping, some projects simply deploy large solar arrays instead of investing in basic building efficiency. With this code update, an envelope backstop is being introduced that will ensure a sound thermal envelope regardless of on-site renewables. All projects will need to comply with prescriptive building envelope requirements in the code.

- **Renewable Offsets.** Similar to requirements that already exist for Boulder County projects, staff is proposing all residential pools, spas, outdoor radiant heating, and snow melt systems be required to offset 100 percent of the system's annual energy use by on-site renewable energy generation. Alternate compliance through a solar garden subscription is allowed if this is not feasible on-site.

- **Construction & Demolition Waste Requirements**. Construction and demolition waste requirements for residential project have been in place for over a decade in Boulder's codes. With this code update, staff is proposing several improvements to code provisions and enforcement.

  Under the current requirements, all residential demolition projects must show, through a deconstruction plan, that they will recycle or donate for reuse 100 percent of concrete and asphalt and 65 percent of all other waste. Concrete and asphalt are excluded from the 65 percent diversion calculation because these materials are so heavy that many projects would easily exceed the diversion requirement from concrete alone, and thus eliminate the incentive to carefully deconstruct and separate other usable materials for recycling and reuse. A consequence of this requirement is that without incorporating concrete and asphalt into the diversion calculation, achieving 65 percent diversion is not feasible for many projects due to various factors such as the age of the building, type of structure, condition of materials, or environmental issues such as asbestos. The 2020 code cycle aims to adjust the diversion requirements to be achievable by more projects yet still encourage deconstruction and recycling of more than just concrete.

  This update proposes to increase the total diversion requirement from 65 to 75 percent but allow concrete and asphalt to be included in the calculation. In addition, the applicant will be required to show that they diverted at least three "waste material types" from a city-approved list. This will ensure that contractors are not simply recycling concrete but are also diverting other materials such as wood and metal. Both the 75 percent and the material types requirement align with current Leadership in Energy and Environmental Design (LEED) standards, which should align with requirements already familiar to many contractors.

  This update also contains improvements to the permitting process that aim to increase accountability and apply consequences for negligence in demolition. Staff propose instituting a deposit that would be returned in full (minus an administrative fee) if the requirements are achieved or withheld if a project fails to provide the required documentation at the end of the project proving they have reused and recycled adequately. The exact amount of the deposit has not yet been determined, and will be informed by benchmark research, stakeholder engagement and consultation with the City Attorney.

These changes fill in gaps and issues that have been identified with the existing code. Staff is attempting to automate the waste reporting process to track and enforce compliance. However, it may be necessary in the future to request fixed-term staff to support these construction and demolition waste requirements. If necessary, staff will include any such request in the regular budget process or will have to reduce the compliance and enforcement efforts for this requirement.

- **Code Provisions for Alterations**. The International Building Code provides definitions for renovations to existing buildings and classifies three levels of alterations depending on the scope of the alteration. Currently, the 2017 COBECC requires that additional energy efficiency improvements be made when renovating the home. The requirements are currently based on the construction value of the project; the higher the construction value, the more significant the energy efficiency requirements.

  Staff recommends continuing to require energy efficiency improvements for home renovations. However, based on feedback staff have received from design professionals, homeowners, and builders, staff is proposing the energy efficiency improvements be determined based on definitions for alterations instead of construction value. Accurate construction values are difficult to ascertain at the time of permit, and community feedback suggests the code requirements are unevenly levied on projects across the city. The proposed code will require Level 1 & 2 alterations (see Figure 4) comply with the mandatory and prescriptive requirements in the code. Level 3 alterations will need to comply with the mandatory and prescriptive requirements in the code and demonstrate an ERI reduction of 20 percent. Level 4 alterations[2], which are complete gut renovations, will be required to meet new construction ERI requirements. Figure 4 below illustrates the code paths for alterations.

[2] The proposed definition for a Level 4 alteration is: construction alterations to existing buildings, consisting of complete removal, replacement or reconfiguration of at least four building systems: interior partitions and walls; ceiling and floor finishes; building mechanical system, building electrical system; structure and exterior wall systems, including window and exterior door replacements and new building insulation

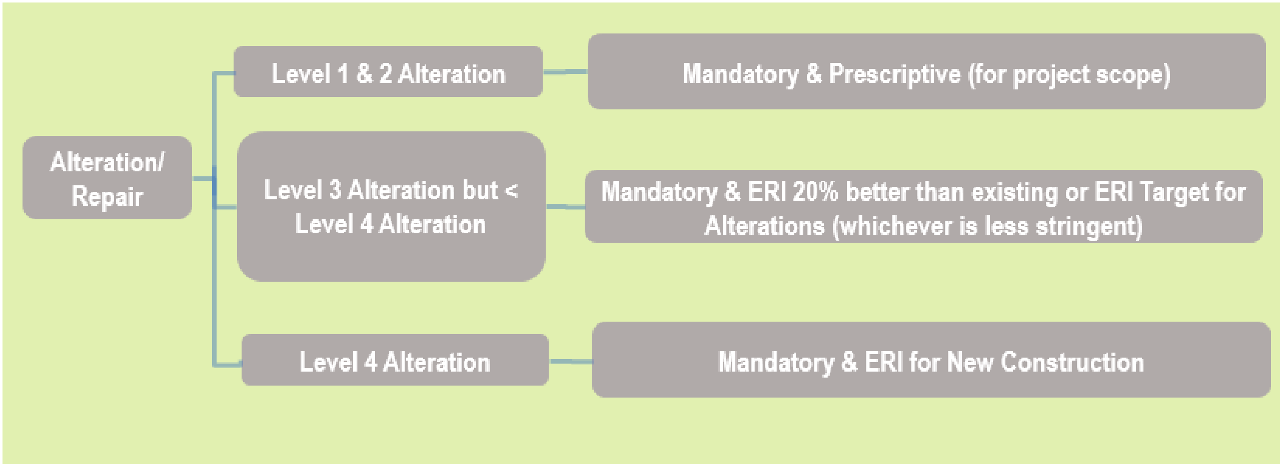

Figure 4: Energy Code Requirements for Residential Alterations

Revising the code provisions for alterations is also in response to feedback staff have received relative to the large homes and large lots project, asking that staff consider removing barriers to home renovation and building reuse as a strategy to discourage home scrapes. In some instances, older homes are too difficult and the scope too costly to bring up to current code standards. By changing how alterations comply with the energy code, staff are recognizing the limitations that exist with older existing homes and allowing greater flexibility on home energy improvements.

- **Energy Offsets.** Staff expect there will be a small number of projects where installing the necessary solar on-site to meet the new, lower ERI scores will be technically infeasible due to shading and/or roof constraints. For these projects, participation in a verified community solar program can be used to meet the code requirements. However, staff are aware that community solar options are limited and not always available. Therefore, in these instances, staff are proposing applicants pay a 2.16 cent charge per kWh necessary to offset the home's energy use. The fee would go into the City of Boulder's Energy Impact Offset Fund (EIOF). This fund was originally created as an offset fund for marijuana growers unable to meet their renewable energy requirements onsite and is being used to fund carbon offset projects such as the development of local renewable energy.

  To ensure this fund is only used when NZE cannot be achieved on-site, staff proposes furthering the definition of "technically infeasible" to require projects to: 1) optimize energy efficiency in the home by demonstrating an ERI score of 40 or less without solar, 2) demonstrate that on-site solar is not feasible due to shading, zoning restricted orientation, or existing roof constraints, by providing a solar analysis from a solar provider that demonstrates the system is not cost effective and 3) demonstrate that community solar is not currently available. With this firm definition, staff can ensure on-site and solar garden solutions are exhausted before the EIOF is considered.

Commercial Energy Code Updates

The proposed updates to the commercial energy code focus on making progress toward outcome-verified high-performance buildings. More detailed analysis and rationale for these code changes can be found in **Attachment C: NBI's 2020 Boulder Commercial Code Protocol**. The most significant changes being proposed for commercial projects are:

- **Energy Use Index (EUI) Performance Path**. In Boulder's current energy code, new construction and major renovation projects demonstrate compliance by using energy modeling software to build a theoretical code compliant (IECC 2012/ASHRAE 90.1-2010) building that's referred to as the Baseline Model. The energy modeling consultant then builds a theoretical energy model reflecting the proposed building's design performance, following modeling protocols that exist in the code; this is referred to as the Proposed Model. To comply with Boulder's energy code, the Proposed Model must have annual energy costs that are 30 percent less than the Baseline Model.

  To reduce the performance gap between the design and the operating building performance, code compliance in the proposed code will be evaluated based on predicted building energy use, rather than on percentage improvement on a theoretical baseline. Each building will be required to set an Energy Use Index (EUI) design target. Energy Use Index is defined as the amount of energy a building uses annually over the square footage of the building:

$$EUI = \frac{Building\ Annual\ Energy\ Consumption\ (kBtu/yr)}{Building\ Area\ (sq.ft)}$$

  The lower the EUI, the more efficient the building. NZE buildings have an EUI of zero. While this metric is new to building codes, it is a familiar term to most design professional, engineers, architects, and increasingly to building owners. Boulder's Building Performance Ordinance requires commercial buildings report their energy annual energy use in terms of EUI as part of their rating and reporting requirements. Buildings are then required to track and make progress toward reducing these values, so building owners have increased understanding around how these targets relate to building performance and energy use. EUIs are specific to building types as different building types can have notably differing internal loads. EUIs are easily calculated and measured at the building level, and account for a building's total annual energy demand, including plug and process loads that can make up a significant portion of building's energy use.

  The EUI targets proposed for the 2020 code update are found below in Figure 5. NBI analyzed numerous datasets in recommending these new construction and major alteration targets. Their analysis looked at various project types in our climate zone, determining the EUI that Boulder's current code is delivering, and what advancements need to be made to achieve EUIs of zero by 2031. Additionally, they examined data from Boulder's Building Performance Ordinance to ensure we are setting meaningful yet achievable targets. The proposed 2020 EUI targets are effectively 25 percent more efficient than IECC 2018/ASHRAE 90.1-2016). More detailed analysis and justification for this strategy and these targets can be found in **Attachments A & C**.

EUI Performance Targets		
Building Type	COBECC 2017	COBECC 2020 New Construction
Medium Office	24	23
Small Office	22	19
Primary School	39	34
Secondary School	32	31
Mid-rise Apartment	35	32
Warehouse	13	11
Retail Store	40	35
Small Hotel	60	40
Hospital	93	88

Figure 5: 2020 Proposed EUI Targets for New Construction where the first column represents the equivalent EUI for the COBECC 2017 and the second represents the proposed targets for the 2020 update.

The first column in the table represents the equivalent EUI that our current code is delivering for each building type, and the second column represents the proposed EUI target for each building type. Comparing the two columns, it’s clear that the new code requirements are not significantly more stringent.

The focus with this code cycle is on project teams establishing and working to achieve aggressive EUI targets and then following through to verify the building performance is being achieved. As noted in the headings, our current code is about 30 percent better than the national standard – American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) 90.1-**2010**, and the new code will be about25 percent better than the most recent national standard ASHRAE 90.1-**2016**.

- **Solar Mandate**. To meet long-term NZE performance goals, it is necessary to encourage the deployment of renewable energy at the project level. In the 2020 code cycle, it is proposed that at least 5 percent of commercial building energy use be supplied by on-site renewables. This requirement is in addition to requirements in the code for the roof to be solar ready. Requiring installed renewables helps ensure buildings are truly solar ready and are positioned for solar expansion for a time when the code will drive them closer to net zero. This requirement would be increased in subsequent code cycles. The renewable offset requirement represents the minimum percentage of total building load that must be met with renewables. Projects may choose to deploy more than the minimum amount of renewables to meet overall code targets, based on cost-benefit calculations and other considerations at the project level.

- **Envelope backstop**. With the availability of inexpensive renewables, some projects simply deploy large solar arrays instead of investing in basic building efficiency. Taken to an extreme, this can deliver inherently inefficient buildings that are at increased risk of excessive energy use if occupants or operators change over time. To discourage this, a backstop code is being developed to set a minimum level of performance (maximum allowable EUI) for building features to make sure that basic building efficiency is not ignored. Backstop requirements for building performance are designed to ensure that basic minimum building efficiency strategies are incorporated into each project, even while projects are given flexibility to determine the best set of building features and renewable energy deployment to achieve building performance targets.

- **Code Provisions for Alterations**. Identical to the residential code, the International Building Code provides definitions for renovations to existing buildings and classifies three levels of alterations depending on the scope of the alteration. Currently, the 2017 COBECC requires commercial alterations make additional energy efficiency improvements when renovating commercial space. The requirements are currently based on the construction value of the project. Staff recommends continuing to require alteration projects make energy efficiency improvements when renovating.

  However, based on feedback staff have received from design professionals, building owners, and builders, staff is proposing the energy efficiency improvements be determined based on definitions for alterations instead of construction value. Accurate construction values are difficult to ascertain at the time of permit and therefore, community feedback suggests the code requirements are unevenly levied on projects across the city's existing building stock. The 2020 proposed code language would require Level 1 & 2 alterations comply with the mandatory and prescriptive requirements in the code for the scope of work proposed. Level 3 alterations would need to comply with the mandatory and prescriptive requirements in the code and demonstrate an EUI reduction of 20 percent for the space being renovated. Projects proposing a change of use for the building or Level 4 alterations[3], which are substantial renovations, where buildings are making substantial building improvements and replacing multiple building systems, will be required to meet EUI requirements for alterations. Figure 6 below illustrates the code paths for commercial alterations. Staff will be available to project teams to help identify alteration levels and code requirements.

[3] The proposed definition for a Level 4 alteration is: construction alterations to existing buildings, consisting of complete removal, replacement or reconfiguration of at least four building systems: interior partitions and walls; ceiling and floor finishes; building mechanical system, building electrical system; structure and exterior wall systems, including window and exterior door replacements and new building insulation.

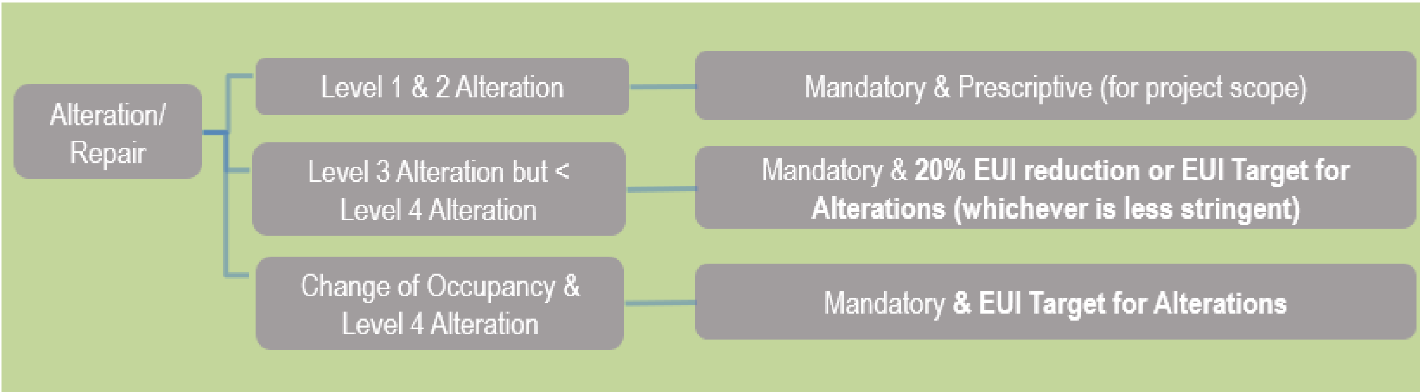

Figure 6: Energy Code Requirements for Commercial Alterations

- **Pilot for Outcome-Verified Code Path**. Staff is proposing an outcome-verified code compliance path be piloted in the 2020 COBECC. Ultimately, the 2031 goal of Boulder's energy code is to set standards that will result in buildings that are NZE, not just in theory and as designed, but verified through metered data once the building is constructed, commissioned, and occupied. The outcome path proposed for this code cycle would achieve this goal for projects that opt into this path. The pilot would serve as a model for the 2031 code, and would allow staff to collect data, evaluate, and make policy adjustments to suit Boulder's commercial construction market. Projects following this path would:
    - **S**et an EUI target during the design phase based on modeling or targets established by building type per code.
    - Demonstrate at time of permit how the project will achieve this EUI target through energy modeling.
    - Construct the project, with an understanding of the energy performance expected of the building.
    - Complete, commission, and occupy the building.
    - Within 24 months of the building being occupied, submit metered data to the building official that verifies the EUI target is being achieved.

  This path would only be available to new construction projects. Projects that are unable to demonstrate that their building's post-occupancy energy consumption complies with the targeted performance will be required to undergo building diagnostics and additional energy modeling to determine how to close the gap between modeled and metered energy use. Enforcement for this code compliance path will require staff to work directly with building owners and design teams to resolve building performance issues. Submitting metered data to the city is already a familiar process for building owners in Boulder. The Building Performance Ordinance currently requires all existing buildings of a certain size and all newly constructed buildings provide their energy consumption. Similarly, many design/build teams are already familiar with performance-based contracting, particularly when participating in rebate programs, such as Xcel Energy's Business New Construction Program. The proposed outcome path will begin to fuse the energy code with the Building Performance Ordinance requirements to help staff understand, analyze, and improve Boulder's commercial and industrial building stock.

To effectively enforce this code compliance path, projects will be required to provide a fully refundable financial guarantee at the time of permit that can, if necessary, be used in case the building is unable to demonstrate compliance. The proposed financial guarantee will be determined based on project size at $2/gross square foot. Projects that demonstrate compliance are immediately refunded the full amount. Project that cannot demonstrate compliance will be permitted to draw down on the financial guarantee to lower operating energy use of the building, including building commissioning, repairs or improvements to the existing energy-consuming systems, or execution of additional energy saving measures. Any remaining funds would be returned to the applicant. For the purposes of the pilot, there would be no fines or other financial penalties beyond requiring investments up to the guarantee amount as a means of remedying the building's performance.

This energy code path also ties in with goals of the Community Benefits Project. The intent of that project is to ensure that new growth and development meets city goals and contributes positively to the community's quality of life. The project is attempting to achieve this by tying specific community benefit requirements to projects requesting greater density or intensity than what's allowed in the underlying zone district. The program being envisioned would include a menu of community benefit options that an applicant could choose from. Selecting this more rigorous energy code performance path is one of the menu items being considered for this project. Staff hope this meaningful incentive will attract applicants to this path. Outcome based energy code compliance can be a win for everyone:

- Gives design teams ultimate flexibility in meeting code requirements
- Supports quality installation, diligent design and construction, and effective operations and maintenance to achieve long-term energy performance
- Provides a framework to help communities, code departments, building owners and design teams realize actual energy savings
- Provides a framework to help communities, code departments, building owners and design teams realize actual energy savings
- Reduces the burden on code departments to enforce difficult, beyond-minimum code requirements

- **Construction & Demolition Waste Management Requirements**. Because commercial projects have the potential to create significant amounts of waste, the proposed 2020 code includes the same requirements that will apply to residential projects: all new construction projects must recycle 100 percent of all useable or recyclable wood, metal, and cardboard. For new construction projects that include a full demolition, contractors will be required to provide a deconstruction plan and prove through documentation that the project recycled or reused 75 percent of all waste, and at least three material types. As with the update to the residential requirements, staff proposes instituting a refundable deposit to increase accountability and adherence to the requirements.

- **Electric Vehicle (EV) Charging Requirements**. In 2017, requirements were added to the code requiring commercial and residential projects provide EV charging infrastructure. Technology has evolved and the demand for EV charging is better understood. Therefore, staff is proposing clarifications and adjustments to these requirements for commercial projects. The new requirements are outlined in Figure 7 below and reflect the importance of providing EV charging infrastructure for multifamily housing development, hotels, and motels. No changes are being proposed for residential construction; new residential homes are required to provide EV charging outlets for all off-street parking. The proposed code would also give projects flexibility in meeting the requirements by allowing applicants to propose equivalent charging solutions to meet the code requirement—specifically, allowing fast charging options in lieu of installed Level 2 EV charging stations.

Figure 7: EV Charging Requirements for Commercial Projects

	Offices >20 Spaces	Retail & Restaurant >20 Spaces	MFU & Hotels/Motels
EV Charger Installed Level 1 or 2 charging station.	2 parking spaces minimum	2 parking spaces minimum	2 parking spaces minimum
EV Ready Full circuits are "ready to go" with the addition of an EV charging station. Full circuit installations include 208/240V 40-amp panel capacity, conduit, wiring, receptacle, and overprotection devices. The endpoint of the system must be near the planned EV charger location.	20% of parking spaces required	10% of parking spaces required	20% of parking spaces required
EV Capable Accessible conduit must be installed during new construction to avoid expensive and intrusive retrofits when additional EV charging capacity is needed in the future.	n/a	n/a	75% Total
Electric Panel Capacity Panels must have space and electrical capacity to accommodate simultaneous charging on a 40-amp circuit per the required number of EV parking ready spaces	Sufficient to supply EV Ready Required	Sufficient to supply EV Ready Required	Sufficient to supply 25% of EV Ready & EV Capable spaces Required

4. ANALYSIS: EMBODIED ENERGY

Boulder has a long history of being environmentally progressive and striving toward its zero-waste goal, but it has been difficult to identify and enforce a policy around reusing and recycling what already exists in our built environment. While embodied energy[4] is an important consideration when seeking to preserve the resources that make up our community's buildings, it is a complex topic that is still relatively new in terms of how best to measure and regulate it. As Boulder's energy code becomes increasingly stringent, the importance of addressing embodied carbon grows. Figure 1 below illustrates that increasing building efficiency shrinks carbon emissions resulting from operational energy demand, which enlarges the portion of total lifecycle emissions caused by the embodied carbon of construction.

[4] Embodied carbon is defined by the Carbon Leadership Forum as the sum impact of all the greenhouse gas emissions attributed to materials throughout their life cycle (extracting from the ground, manufacturing, construction, maintenance and end of life/disposal).

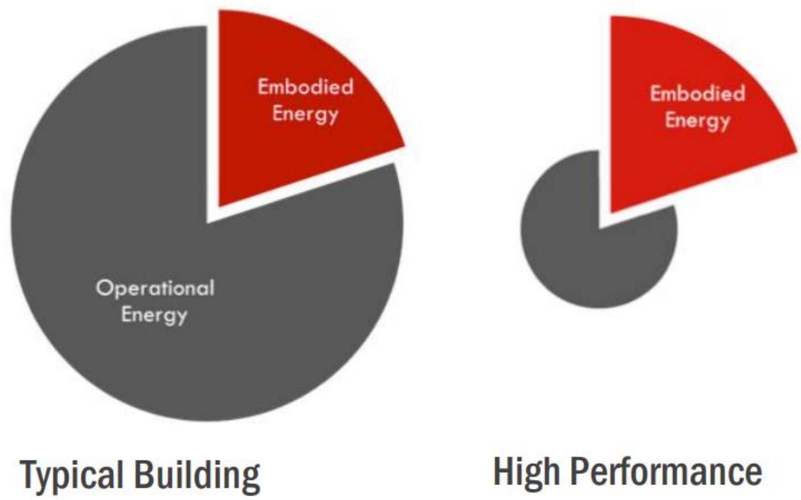

Figure 8: Embodied and operational energy over the life of a building (Source: Carbon Leadership Forum)

Furthermore, new, modern construction is often favored over building retrofits and redevelopments. Because a majority of a building's embodied carbon is accounted for by the foundation, structure, and envelope, it makes sense to encourage reuse of these building parts rather than demolish (which also emits carbon and air pollution) and rebuild when practicable. A report by the Preservation Green Lab, Skanska, and other partner organizations found that new buildings can take anywhere between 10—80 years to pay back the emissions generated from the construction process, even if the new buildings are 30 percent more efficient than average.

Staff is currently working with Carbon Neutral Cities Alliance along with 12 peer cities (including: Portland, Seattle, Vancouver, San Francisco, and New York) to develop a roadmap for embodied carbon policy at a local level. As part of this group, Boulder staff hope to map out policy, better understanding the calculation methodologies, exploring procurement solutions, and collaborate with cities that are making progress in this area.

As illustrated in Figure 2 below, the life cycle of a building begins with mining and extraction of the raw materials; continues through the energy used during the building's life; and ultimately includes the deconstruction of the building. Of these stages, there are three areas that can potentially be addressed through changes to city building code:

1. Construction
2. Refurbishment
3. Demolition

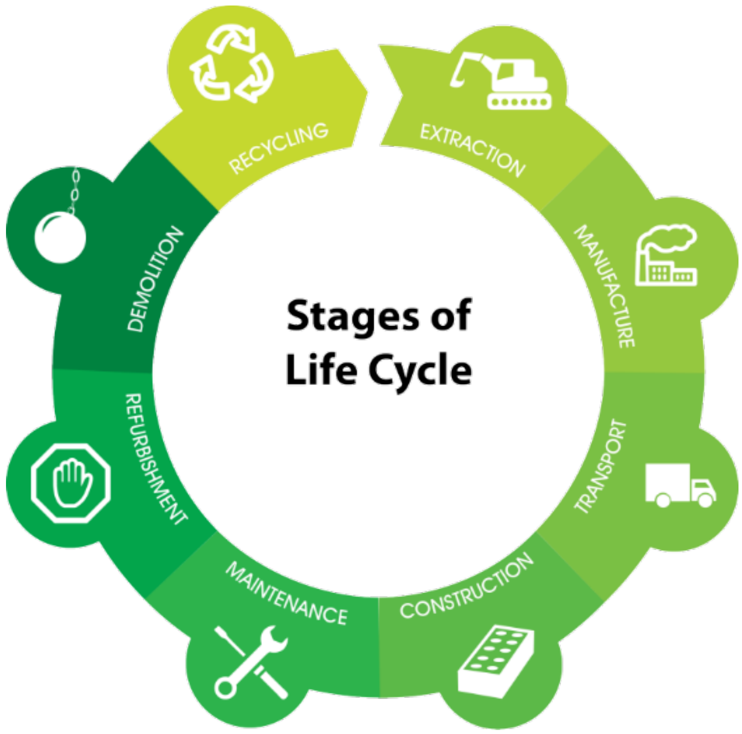

Figure 9: Building Life Cycle Stages

As part of this code update, the following updates are proposed to address embodied energy:

- Improving existing construction and demolition waste requirements and increasing the consequences for non-compliance;
- Expanding construction and demolition waste requirements to commercial projects;
- Encouraging smaller residential construction by accelerating net zero energy requirements for homes greater than 3,000 square feet; and
- Reducing barriers to building reuse. Recognizing that expensive energy-efficiency upgrades to existing homes and commercial structures can be a barrier to reuse and remodel, requirements for renovations/alterations are eased to encourage reuse in lieu of building scrapes.

Staff plans to expand embodied energy regulations as local policy options are better understood. Likely first steps include: embodied energy tracking, purchasing guidelines and embodied energy limits for the most impactful materials (concrete and steel). More information can be found in **Attachment E:** City Council memo from December 14, 2018 addressing embodied energy and code strategies.

5. ANALYSIS: 2018 ICC BUILDING CODE ADOPTION AND PROPOSED AMENDMENTS

Collectively, as a comprehensive family of codes which complement one another, the International Building Codes are designed to protect the public health and safety in the built environment. Currently, the city has adopted the 2012 edition of the following International Building Codes:

- International Residential Code (IRC)
- International Building Code (IBC)
- International Fuel Gas Code (IFGC)
- International Mechanical Code (IMC)
- International Plumbing Code (IPC)
- International Property Maintenance Code (IPMC)
- International Fire Code (IFC)
- International Wildland-Urban Interface Code (IWUIC)

The International Energy Conservation Code (IECC) is currently replaced with the 2017 City of Boulder Energy Conservation Code (COBECC). The International Existing Building Code (IEBC) is not currently adopted by the city but is recommended for adoption, as it replaces provisions previously contained within the IBC.

The International Codes are developed and vetted through a national public consensus process and are utilized by most jurisdictions in Colorado and the United States. The International Building Codes are revised and updated on a three-year cycle. Boulder has adopted new codes every six years. Staff recommends council approve adoption of the 2018 edition of the International Building Codes, with the potential of local amendments as necessary.

Staff is currently in the process of reviewing the 2018 International Codes to identify significant changes, as well as any proposed local amendments. The 2018 codes with any proposed local amendments will be presented to City Council with recommendation for adoption, after staff have facilitated a transparent and public process including education, collaboration and feedback with the community.

Staff suggests there are five significant reasons to consider a local amendment:

1. To provide consistency with other regulatory departments and agencies
2. To address concerns of City Council
3. To address concerns of stakeholders
4. To incorporate local information and/or current data into the Codes
5. To address significant changes compared to current requirements

Staff have currently identified the following two issues of local concern and requests direction from council on whether to prepare local amendments and incorporate into the public process.

- **Gender neutral restrooms.** Both the IBC and the IPC have requirements specifying when restrooms are required to be provided for employees and for the public. When an area has no more than 15 employee and public occupants, one single-user restroom is all that is required, and it is required to be identified as gender neutral. Areas having higher numbers of occupants typically require gender specific restrooms. When gender specific restrooms are required in smaller areas, often both are single-user, and both are required to be identified with signage as being gender specific. To make existing single-user restrooms gender neutral would typically only require changing the signage. Code provisions also specify the numbers and types of plumbing fixtures required (sinks, toilets, urinals), resulting in multiple-user restrooms. The 2012 and 2018 editions of the codes do not allow multiple stall restrooms to be used as gender neutral rather than gender specific without going through a code modification request. To help ensure inclusivity in restroom availability and counts and provide more flexibility, staff is evaluating the need for future code amendments to address this issue.

Staff have received multiple requests for code modifications to approve multiple stall restrooms as gender neutral instead of gender specific as required by the building codes. Rather than requiring applicants to apply for and staff to review modification requests, a local amendment may be proposed to allow or require gender neutral restrooms. Staff requests council's direction regarding a local amendment to address this concern.

Should council agree with moving forward with a local amendment to address this concern, staff will seek community feedback to inform the specific options.

- **Residential sprinkler systems.** Since the 2009 edition of the International Residential code, automatic sprinkler systems have been required in all newly constructed dwellings. This sprinkler requirement does not apply to remodels or additions, unless the dwelling already has an automatic sprinkler system. The issue of residential sprinklers was discussed extensively in 2013, during the process to adopt the 2012 International Building Codes. During that process, council requested and staff provided significant background information, which can found at this link.

  As an outcome of the 2013 process, the City of Boulder currently has an amendment exempting one-and two-family dwellings from the sprinkler requirement. At least seven Colorado jurisdictions have not amended this code requirement and do require all new dwellings to be protected with automatic sprinkler systems including Boulder County, Superior, Golden and Westminster. Staff recommends revisiting this issue as part of the 2018 code adoption process and requests council direction regarding this issue.

6. COMMUNITY SUSTAINABILITY ASSESSMENT AND IMPACTS

Updating current energy and building codes can produce economic, environmental and social benefits at multiple levels across a community. High-performance buildings reduce energy and environmental impacts, improve economic vitality, increase community pride and decrease utility costs for building owners and tenants.

- Economic: Higher performing buildings increase property values, command higher lease prices, cost less to operate and improve occupant comfort, and reduce community greenhouse gas emissions. However, high performance buildings can come at a cost premium as the initial costs to construct these buildings are higher. The recommended residential code changes have been analyzed by our consultants and the resulting efficiency measures the code requires have all been found to be cost effective, with benefit to cost ratios ranging from 1.0 to 2.9. Cost effectiveness was determined over a 30-year lifespan, including first costs, replacements, maintenance, and energy savings. Please see **Attachment B: 2020 Building Energy Code Cost Effectiveness Analysis**. Also, please reference **Attachment F: Rocky Mountain Institute's** recently released

The Economics of Zero-Energy Homes, which shows NZE homes are reaching cost parity with conventional construction and that, as the underlying technologies and design elements continue to improve and scale, these costs will continue to decline.as another resource , which shows NZE homes are reaching cost parity with conventional construction and that, as the underlying technologies and design elements continue to improve and scale, these costs will continue to decline.as another resource

- Environmental: On Dec. 6, 2016, council adopted climate commitment goals for the city, including an overall target of an 80 percent reduction in GHG emission by 2050.[5] In the modeling done by staff to show pathways to that goal, increasing the stringency of energy codes (eventually to net zero status for all new buildings and major alterations by 2031) was the largest contributing factor of any policy or program, other than transitioning our electricity supply to clean, renewable energy. Achieving and implementing net zero energy codes as soon as possible, while balancing economic and social interests, is a crucial step in Boulder's climate commitment. In fact, when staff projected emissions reductions out to 2050, savings from the implementation of progressively more stringent energy codes was the largest of any building efficiency program, including EnergySmart, SmartRegs and the Building Performance Program.
- Social: Improving the energy codes above the minimum standard requires energy conservation in the residential, public and private sectors results in less money flowing to energy costs over time, and more household and business income available for other uses. Additionally, the net outcome of decreased greenhouse gas emissions supports the community's strong value of protecting the environment and living in a sustainable way.

7. PUBLIC ENGAGEMENT AND BOARD FEEDBACK

Once a draft of the 2020 City of Boulder Energy conservation code is complete, staff will provide the proposed code to the Environmental Advisory Board (EAB), the Transportation Advisory Board (TAB), and the Planning Board in Q2 of 2019 for their recommendations.

Additionally, staff has engaged key community stakeholders including design professionals, architects, energy modelers, builders, developers, building owners, etc. through community engagement events, targeted meetings, and consultant interviews. Table 3 summarizes these engagement activities.

Table 1: Public Outreach Activities to Solicit Stakeholder Feedback

	Outreach Activity	Number of Respondents/ Attendees	Description
December 20, 2018	Residential Energy Code Engagement Session	29 (a list of attendees can be found in **Attachment E**)	City staff organized a meeting to invite residential building stakeholders to discuss and give direct feedback on the proposed energy code changes.
February 11 & 20, 2019	Land Use Code Open House	30-50	The city's Energy Code Coordinator participated in the Land Use Code Open Houses to field energy related questions and solicit feedback on energy code changes that could encourage more modest home sizes.
February 21, 2019	Presentation to International Building Performance Simulation Association	86	City staff presented to the local chapter of the International Building Performance Simulation Association (IBPSA), an international society of building performance simulation researchers, developers and practitioners, dedicated to improving the built environment. Technical feedback from this group is important to development of an understandable, effective, and enforceable code.
February 22, 2019	Energy Code Collaboration Session with Denver	20-30	The city's Energy Code Coordinator participated in a collaboration meeting with Denver and local design professionals to discuss code changes and aligning code language where feasible.
February 27, 2019	Commercial Energy Code Engagement Session	38 (a list of attendees can be found in **Attachment D**)	City staff organized a meeting to invite commercial building stakeholders to discuss and give direct feedback on the proposed energy code changes.
Ongoing			The city's Energy Code Coordinator continues to reach out to energy modelers, design professionals, contractors, and peer jurisdiction staff for feedback on the proposed code language.

8. QUESTIONS FOR COUNCIL

- In response to feedback regarding the impact of large homes and large lots, staff is proposing to accelerate net zero energy (NZE) requirements for residential new construction. All new homes larger than 3,000 square feet would be required to be NZE. Currently all homes larger than 5,000 square feet are required to be NZE. Does council support this NZE acceleration?
- In an effort to ensure construction waste reuse and recycling occurs, staff is proposing new enforcement mechanisms for the construction and demolition waste requirements. Does City

Council support a financial penalty (in the form of a deposit that has been withheld) for non-compliance?

- Currently construction and deconstruction waste requirements only apply to residential projects. Does staff support expanding these requirements to commercial construction?
- Does City Council support expansion of the Energy Impact Offset Fund (EIOF) as a last resort compliance pathway when projects are unable to meet net zero energy code requirements on-site and when off-site solar is unavailable?
- Does council support a local amendment to allow or require gender neutral restrooms?
- Does council support continuing the current amendment exempting one-and-two family dwellings from the sprinkler requirement or does council support revisiting the requirement for all newly constructed single-family dwellings to be protected with automatic sprinkler systems?

9. NEXT STEPS

Provided City Council supports the code updates described in this memo, key next steps include:

- April 2019: finalize draft code language and solicit community feedback on the code language.
- May – June 2019: present proposed code changes to Planning Board, the Environmental Advisory Board, and the Transportation Advisory Board for their recommendations.
- June – August 2019: Community engagement and outreach regarding code language and code administration requirements.
- August – September 2019: finalize code language and workflow for implementing code changes.
- October 16, 2019: Return to City Council for first and second readings to adopt new codes to take effect Q1 2020.
- October – December 2019: Provide staff and community outreach training on the changes. Develop supporting documentation and resources on the city's website to help explain the energy codes and the documentation materials required to demonstrate compliance.
- Q1 2020: New codes will take effect.
- 2020: Effort will begin on 2023 code development with a focus on energy storage solutions, embodied energy incentives and regulations, and making progress on reducing building plug and process loads.

ATTACHMENTS:

A: City of Boulder Energy Code Roadmap.

B: City of Boulder 2020 Energy Conservation Code Cost Effectiveness Analysis

C: City of Boulder 2020 Commercial Energy Code Update

D: Commercial Energy Code Engagement Session Summary of Attendees

E: Residential Energy Code Engagement Session Summary of Attendees and Feedback

F: Rocky Mountain Institute's The Economics of Zero-Energy Homes

G: Memo excerpt from December 4 City Council memo on Embodied Energy

Boulder Commercial Code Roadmap

Getting to ZNE by 2031

Prepared by:

New Buildings Institute

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Kevin Carbonnier

Date: February 2019

Prepared for:

City Of Boulder

Christin Witco, Contract Manager

City of Boulder Planning+Sustainability

Contents

Introduction

Boulder has adopted a set of climate goals that depend on continued reduction in the carbon impacts of the building sector. To achieve these goals, steady improvement in building codes and continued improvement in building performance will be needed. This discussion is focused on energy code mechanisms to reduce building energy use and incorporate renewable energy generation at the building scale. This occurs in the context of the City of Boulder's goal to require all new buildings to achieve ZNE performance by the 2031 code cycle, and a set of suggested improvements in the energy code over the course of five code cycles remaining before that date.

As building performance requirements become more stringent, it is necessary to consider actual building energy use as a basis for energy code compliance, rather than rely on predictions of performance. ZNE performance implies a measured outcome of annual net zero energy use. This narrative describes a potential pathway from current code structures to an outcome pathway for code compliance, with a focus on immediate steps for adoption in the next code cycle in Boulder. A more detailed report on specific recommendations for the 2019 code cycle is provided separately. The focus of this narrative is commercial buildings.

Building Performance

The ultimate policy goal for the building sector is to eliminate the carbon impact of energy use in buildings. The intent is to use policy mechanisms to achieve this by reducing individual building energy use, offsetting grid energy use with renewable energy at the building level, and decarbonizing both buildings and the grid by transitioning to non-fossil fuel energy sources. Different jurisdictions target and quantify different aspects of these goals, and may adopt a subset of policy goals in their climate action plans. Boulder has adopted a relatively far-reaching set of policy goals to address all aspects of this larger performance target.

Achieving building sector decarbonization is typically considered a balancing act between reducing building energy use, offsetting building energy use at the building level with renewable energy, reducing combustion fuels use in buildings, and reducing the amount of fossil fuel used to generate electricity at the grid level. The relationship between these issues is nuanced, but there are some general principles that guide building policy in these areas:

- Renewable deployment at the grid level is increasing rapidly, but there is a long way to go to fully decarbonize the electric grid. Despite decreases in the cost of renewable energy, it would take a huge investment and a long time to simply 'replace' all fossil fuel generating resources at the grid scale. Reducing energy use in buildings therefore remains a critical component of large scale decarbonization.
- Decreasing costs for renewable energy at the building scale make renewable deployment more cost effective than in the past. This cost of renewable energy deployment in this way sets a baseline for cost effectiveness calculations for energy efficiency. But a wide range of energy efficiency strategies remain less expensive to deploy at the building level than renewable energy at various scales, so there needs to be a continued policy focus on building energy efficiency even as building-scale renewable deployment increases.

- There are many built and operating examples of extremely efficient and ZNE buildings in the market today, demonstrating that deep efficiency in buildings is widely achievable with the right market and policy incentives and mechanisms.

Challenges to Code in Achieving Net Zero Performance

The imperative to move toward an outcome-based code is driven by several key limitations in the conventional energy code development and deployment process.

Scope of Code

Although we can identify performance levels and physical characteristics associated with buildings that achieve very high performance levels, energy codes are not able to require this level of performance as currently deployed. There are several key limitations to energy code that preclude widespread achievement of very high performance.

- Building design can address a wide range of building features that affect building energy use, but design cannot address what equipment is brought into the building by building occupants, and how they use it. Computer equipment, kitchen equipment, medical devices, printers, task lighting, etc. are all examples of 'unregulated loads' which are outside the scope of energy codes. In buildings that meet current energy code requirements, these unregulated loads typically represent 40-70% of total building energy use, depending on building type. Unregulated loads set a practical limit on how much more stringent energy codes can become without structural changes to address unregulated loads through the code process. (See Figure 1 below.)
- In the design process, assumptions are also made about how building systems will be operated and used. But once the building is operational, the design intentions have little influence on building use patterns. Thermostat set points, operating schedules, maintenance strategies, and a host of other operational characteristics have a major impact on building energy use patterns that is outside the scope of energy code regulations.
- Some aspects of building performance are pre-empted by federal regulations, and cannot be modified within prescriptive code requirements. Heating equipment efficiency is a critical example which is particularly important in heating climates. Heating efficiency standards have not been modified for decades, in part due to industry pressure to maintain a pathway for inexpensive rooftop air handling equipment in code. No matter how stringent prescriptive code language is, by federal law it must include the option of using minimum efficiency rooftop package equipment as a viable alternative. Building designers may choose to exceed this performance level, but code cannot explicitly require it.

When a code strategy becomes focused on a specific performance outcome with increased flexibility for how to achieve this outcome, the limits of code scope become less restrictive in achieving increased code stringency.

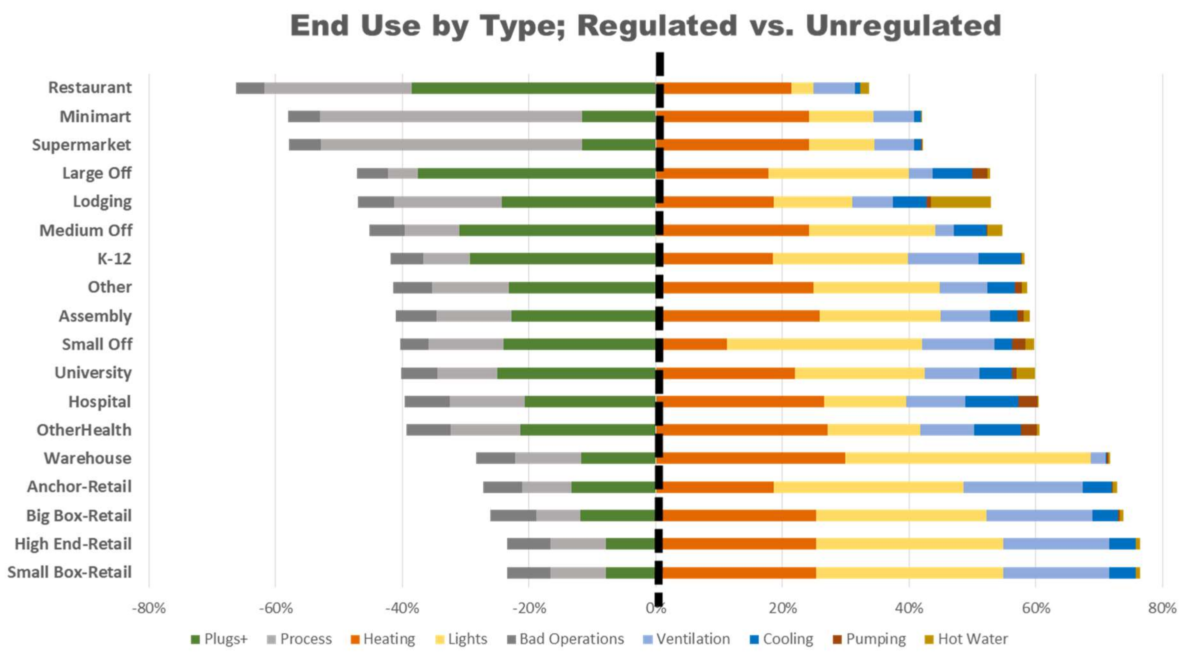

Figure 1: Unregulated Loads: In this diagram, the loads to the left of the dashed vertical line represent building loads outside the scope of energy code requirements, by building type, based on recent code stringency requirements. These loads have become a significant percentage of total building load, representing a challenge to increased code stringency goals.

Design Predictions vs. Performance Outcomes

Although we target low energy use in building design, in these buildings there is typically a disconnect between the level of performance anticipated in the design process and what we actually see when the building is operating. This is a critical issue to understand in the context of using energy codes to set aggressive performance targets for buildings.

The disconnect between design predictions and actual performance is driven by two key issues: 1) assumptions made about system control, integration, and operation; and 2) actual occupant use patterns in the building compared to those assumed by the modeling.

System Control, Integration, and Operation

When we calculate energy loads for a building, we make assumptions about how well the building envelope is insulated, how efficiently the heating and cooling systems will operate, and how systems will be controlled to meet these expectations. By its nature, energy modeling predictions about building energy use assume that everything will work exactly as planned. In reality a whole range of performance issues tend to degrade the actual performance characteristics. Thermal bridging in envelope details may lead to lower thermal performance than anticipated, air leakage through the envelope may increase heating loads, thermostat placement may lead to zone overlap and result in simultaneous heating and cooling loads, economizers may not work as anticipated, maintenance practices may not occur frequently enough to keep system running optimally; these are all well documented building characteristics that adversely affect actual building energy use compared to design assumptions. Good design, construction, and operating strategies can minimize these impacts, but not necessarily eliminate them.

Occupant Use Patterns

To insure consistency in comparing building performance to code requirements, energy modeling procedures make a number of assumptions about how buildings are typically operated that set up expectations in the design process for performance outcomes. These assumptions seldom align directly with actual operating parameters. For example, in actual use, buildings tend to be occupied for longer hours than assumed in design modeling, with consequent increases in lighting and space conditioning loads. Thermostat set points are often controlled to much narrower temperature bands than the modeling guidelines suggest, and office equipment is frequently left on all night. These loads add significantly to building energy use, leading to substantially higher actual energy use than anticipated in modeling assumptions about buildings that meet code requirements.

The deployment of new types of office equipment, combined server closets, and other types of equipment also reflect loads that are typically not anticipated in the building modeling process, and which can increase actual building energy use compared to that anticipated in the design process.

Code Implications

The critical implication of this disconnect between predicted and actual building energy use is that policies designed around code performance of buildings tend to under-estimate actual building sector energy use. When code stringency is evaluated with national models under DOE determination protocols (or in any local analysis based on standardized determination protocols), these optimistic assumptions about system operation and occupant use patterns lead to overly optimistic predictions about what level of performance in buildings is being delivered by energy codes. (Note that optimistic assumptions about overall code performance are not the same as broader variability in individual building energy use, which can over- or under-estimate individual building energy use.)

The gap between code predictions of building energy use and actual building energy use represents a significant challenge as we contemplate a transition from prescriptive requirements or comparative design predictions as a basis for code compliance, to a focus on actual building performance outcome as a compliance metric. This challenge needs to be addressed systematically over multiple code cycles to bring actual building performance into line with performance goals and predictions.

To address these code challenges, Boulder has determined that the city will move from current code approaches to a method whereby compliance relies on the demonstration of actually achieving the energy performance targets identified in policy goals. Moving to an outcome based strategy will require several iterations of code to prepare the market for a ZNE outcome. These are the steps in that process:

- Introduce building performance metric based on measured energy use
- Incorporate renewable energy systems into compliance strategies
- Enforcement follow up on actual building performance outcomes to improve alignment with performance targets
- Require full offset of energy use with renewable systems

Current Building Performance Conditions

Current Code Performance

The current Boulder Energy Code represents the starting point for a series of improved building performance targets in subsequent code cycles that eventually achieves net zero energy performance. Energy code stringency is typically evaluated through the development of a determination analysis, which uses energy modeling tools to predict the expected stringency of a code when applied to a series of standardized building prototypes. The US DOE conducts this analysis through PNNL on each new national model code. The City of Boulder has conducted a similar analysis on its code in comparison to national model code, in this case ASHRAE 90.1-2010. The results of several federal analyses, and the Boulder analysis are presented in Table 1 below. Boulder's current code targets a 30% improvement over the national model code from 2010.

Although most of the analysis values in the table below align well between the Boulder analysis and the national analysis, note that there is a significant discrepancy in the anticipated energy performances for office buildings. Modeling from Pacific Northwest National Labs (PNNL) shows the expected performance for the 90.1-2010 code to be significantly better than predicted by the City of Boulder analysis. Because office buildings are an important use type in the City of Boulder, this discrepancy will need to be explored in the context of setting realistic new performance goals for this building type. All other building types with matching prototypes in the PNNL modeling are in agreement.

Building Type	**Boulder 90.1-2010 Prediction**	**Boulder 30% Better Prediction**	**PNNL 90.1-2010, 5B Climate**	**PNNL 30% Better, 5B Climate**
Education (primary)	46 - 57	32 - 40	56	39
Education (secondary)	40 - 49	28 - 34	46	32
Food sales/ Grocery	180 - 220	126 - 154	NA	NA
Full Service Restaurant	355 - 434	248 - 304	396	277
Hospital (Inpatient)	117 - 144	82 - 100	133	93
Outpatient Health Care	104 - 127	73 - 89	114	80
Lodging/ Hotel	85 - 104	59 - 73	103	72
Retail (other than mall)	51 - 62	35 - 43	57	40
Retail (enclosed and strip malls)	53 - 64	37 - 45	60	42
Office (small-5,000 sf range)	48 - 59	34 - 41	31	22
Office (medium- 50,000 sf range)	48 - 59	34 - 41	34	24
Public assembly	62 - 75	43 - 53	NA	NA
Public order and safety	66 - 81	46 - 56	NA	NA
Religious worship	40 - 49	28 - 34	NA	NA
Service (vehicle maint/dry clean/ beauty, etc.)	45 - 55	31 - 38	NA	NA
Warehouse and storage (non-refrigerated)	27 - 33	18 - 23	19	13
Vacant	9 - 11	6 - 7	NA	NA
Multifamily residence	43 - 52	30 - 36	50	35

Table 1: Code Stringency Comparison for Boulder (EUI)

Performance Variability

Although it is typical to compare code stringency for individual building types with a single EUI number, the reality is that there is a great deal of variability among buildings, even of the same building type. Some of this variability is a function of different ways the building is used. Two identical-seeming office buildings may house community kitchens, data centers, 24 hour tenants, vacant spaces, communications gear, etc., that drive significantly different energy use patterns. Mixed use buildings especially can house tenants with substantially different energy needs. This complicates the determination of specific energy performance targets. To account for routine variability, performance outcomes must consider reasonable variables to adjust specific energy targets. This process of adjusting fixed targets to account for customized use and consumption patterns is referred to as normalization.

In the context of outcome based codes, normalization may occur in the design process when specific performance goals are identified, and after the building is occupied when unanticipated factors change performance expectations. Normalization in the design process occurs by manipulating energy model inputs to more accurately reflect expected use and operating conditions. Normalization in the occupancy phase allows project performance to be evaluated in the context of unusual weather conditions, alternate building uses, and actual occupancy patterns.

Performance of Boulder's Existing Building Stock

Although new buildings subject to more stringent codes tend to be more efficient than older buildings, there is a wide range of energy performance observed even in new construction. As Boulder moves toward more closely reviewing and regulated the performance of new buildings, the gap between anticipated and actual building performance will become more critical, and steps will need to be taken to encourage a more accurate assessment of performance expectations. For context, the graphs below show the performance of buildings in Boulder, as reported under the city's energy disclosure ordinance. The first graph, Figure 2 shows data from buildings built since the 1950's. There is wide variability in energy use in existing buildings, with a very slight downward trend for newer buildings. The second graph, Figure 3 shows only those buildings built in Boulder since 2000. This graph suggests that the more recent trend in building performance has a steeper downward slope than is seen when older buildings are included. This data is encouraging, given that the impact of more aggressive energy codes would be expected in this newer set of buildings. Nevertheless, even buildings built to the newest and most stringent Boulder Energy Code demonstrate a wide range of performance, and may not seem to be performing at the EUI performance levels anticipated by the determination analyses that predict code stringency. This complicates the transition to an outcome based code enforcement strategy, since there is a gap between expected code performance and actual building performance outcome. The transition to outcome code will need to recognize that it will take several code cycles to close the gap between optimistic code expectations and actual performance outcomes.

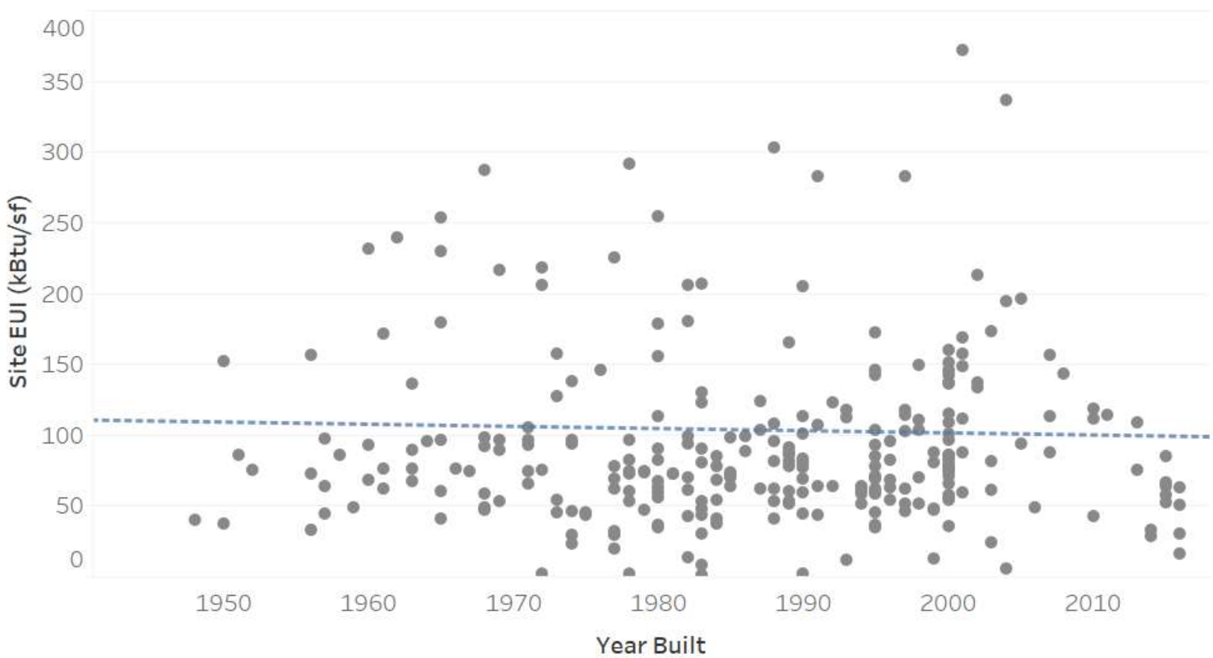

Figure 2: EUI data from Disclosure for all building ages

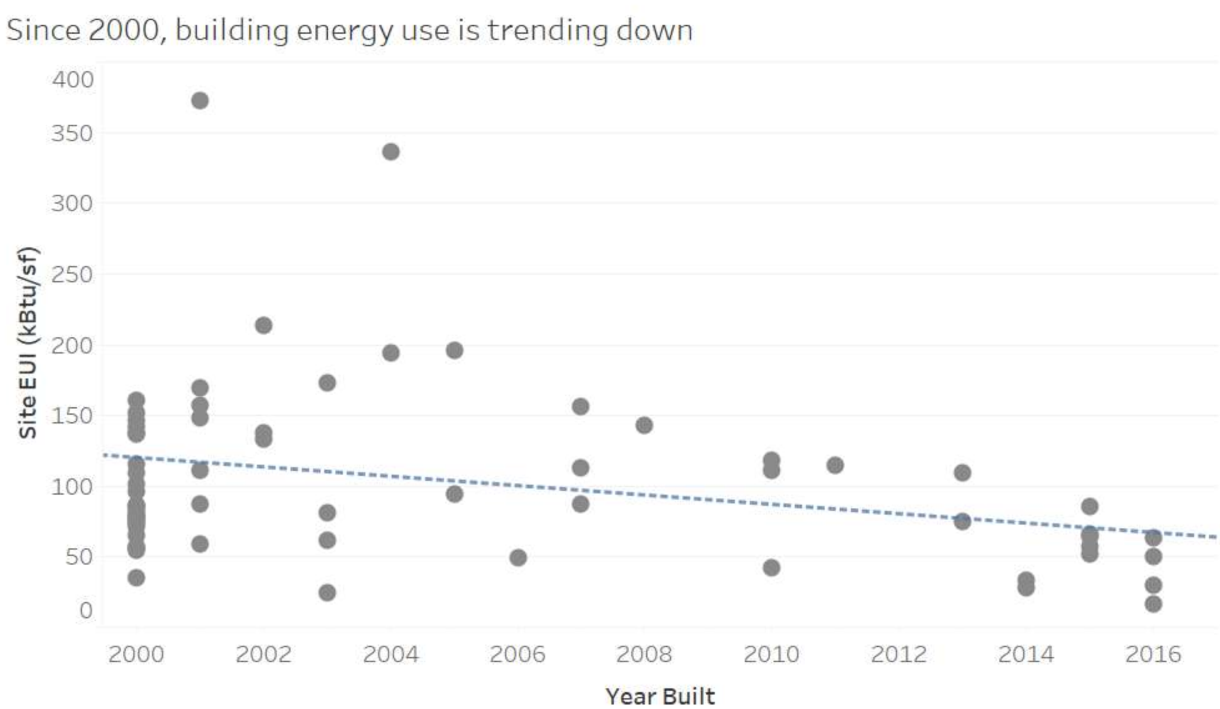

Figure 3: EUI data from Disclosure for all building ages

Setting Building Maximum Performance Targets

In the year 2031 energy code cycle, new buildings will be required to offset all of their annual energy use by deploying renewable energy systems that generate as much energy as the building uses on an annual basis.

When we refer to net zero energy use in buildings, we are usually talking about a very efficient building that offsets remaining energy use by incorporating renewable energy generation. (On site or off site.) There are technical and physical limits to how low building energy use can get, based on the fact that even the most efficient buildings still require some level of lighting, space conditioning, and equipment use to maintain occupancy conditions. In referring to the very most efficient buildings that can be achieved with current technologies, we refer to the ***maximum technical potential*** for efficiency, or '***max-tech***'. This serves as the end goal for regulating building performance, which can then be combined with renewable energy requirements to achieve net zero energy performance.

Max-Tech is not necessarily a static number, but may continue to decline with advances in technology and new building system innovations. Several recent studies have attempted to quantify *max-tech* performance numbers for buildings. We have used these studies as a basis for the *max-tech* targets identified in this analysis.

While *max-tech* represents the ultimate performance targets for buildings (before energy use is offset by renewables), the City of Boulder anticipates that a series of interim targets will be set for the energy code cycles between now and 2031, as new building targets ramp down to net zero energy use.

Comparing Data on *Max-Tech* Performance

A number of studies have attempted to estimate or quantify the *max-tech* performance values for a variety of building types in different climate zones. NBI has also collected a significant set of data on currently built ZNE buildings. This data includes information about base building performance, before renewables are used to offset building energy use. In this section, we compare the values of topical *max-tech* studies and data from the NBI ZNE building database to help establish *max-tech* performance targets for the City of Boulder. This section includes a number of building prototypes representing typical building types in the City of Boulder. All energy performance values shown are for climate zone 5B, and are represented in site energy use intensity (EUI), in kBtu/sf/yr. Note that not all data sources are represented in each building type.

Data Sources

The data used to compare building performance come from the sources identified in Table 2 below. This data represents a broad array of analysis and actual performance data collected to identify building performance patterns, determine code stringency, and support deep efficiency targets.

Building Performance Data Sources		
Data Label	**Data Source**	**Description**
Boulder Disclosure	City of Boulder, collected performance data	Actual energy use data for office buildings in Boulder reporting annual energy use under disclosure ordinance requirements
CBECS 2012	CBECS 2012[1]	National representative data set of office building energy use (for Boulder climate zone 5b) collected by DOE.
Standard 100	ASHRAE Standard 100[2]	ASHRAE Standard 100 energy targets developed to represent existing building energy use in individual climate zones (climate 5b)
ASHRAE 90.1-2004		Anticipated performance of prototype office buildings meeting 90.1-2004 for climate zone 5b according to PNNL determination analysis of code stringency.
ASHRAE 90.1-2016	PNNL Modeling Data for 90.1-2016[3]	Anticipated performance of prototype office buildings meeting 90.1-2016 for climate zone 5b according to PNNL determination analysis of code stringency.
GTZ Tracker	NBI Getting to Zero Tracker[4]	Actual performance data of buildings in NBI's ZNE building database (before accounting for contribution of renewables)
Oregon Bonus	City of Portland, Oregon	Policy performance target for increased density bonus for buildings in the city of Portland, Oregon (modified for climate 5b)
Glazer Max-Tech	GARD Analytics - Max Tech Potential[5]	National study of best anticipated building performance achievable using current best-practice design and operations strategies in climate 5b (not including renewables)
Toronto	Toronto Zero Emissions Framework[6]	Study by Integral Group to identify feasible maximum performance targets for ZNE buildings in City of Toronto to meet climate goals. (Similar climate zone)
ARUP CA Feasibility	ARUP - California Technical Feasibility[7]	Study by ARUP of best achievable building performance (for similar climate zone to Boulder) as a basis for ZNE code targets (not including renewables)
NREL School Feasibility	NREL - School Technical Feasibility[8]	Maximum achievable energy performance study
WA Statutory Code Goals (2031)		Mandated code improvement goal for 20312 code cycle in Washington State in similar climate zone.

Table 2: Building Performance Data Sources and Description

Individual Building Types

The examples below show how NBI has correlated the data for office buildings to identify performance targets. Each graph shows a range of different data sources and studies of building energy use for

[1] https://www.eia.gov/consumption/commercial/data/2012/c&e/cfm/pba3.php
[2] https://info.ornl.gov/sites/publications/Files/Pub49965.pdf
[3] https://www.energycodes.gov/sites/default/files/documents/02202018_Standard_90.1-2016_Determination_TSD.pdf
[4] https://www.energycodes.gov/sites/default/files/documents/02202018_Standard_90.1-2016_Determination_TSD.pdf
[5] https://www.techstreet.com/ashrae/standards/rp-1651-development-of-maximum-technically-achievable-energy-targets-for-commercial-buildings?product_id=1911167#full
[6] https://www.integralgroup.com/projects/city-toronto-zero-emissions-building-framework/
[7] http://www.energydataweb.com/cpucFiles/pdaDocs/904/California_ZNE_Technical_Feasibility_Report_Final.pdf
[8] https://www.nrel.gov/docs/fy17osti/67233.pdf

Boulder's climate zone for individual building types. (Boulder's climate is designated as climate 5b by ASHRAE in national data.)

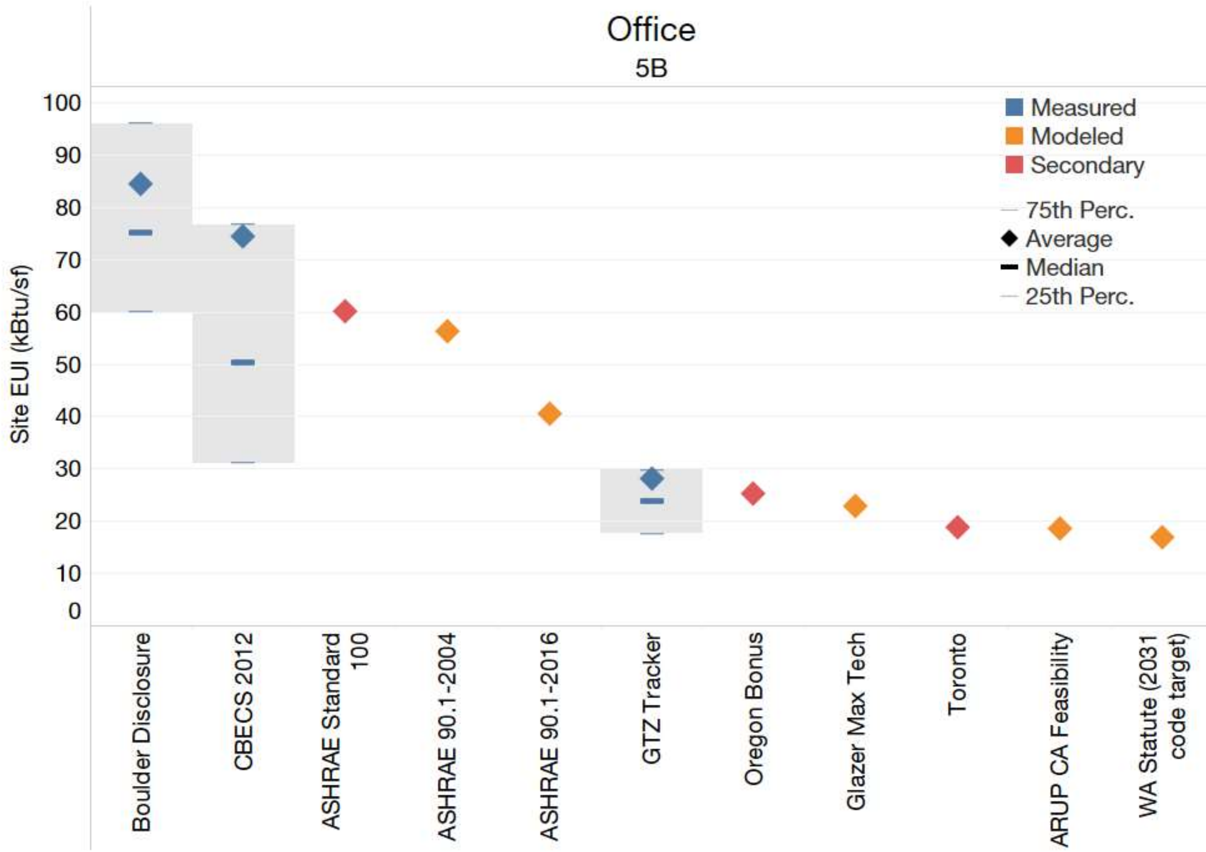

Figure 4: Office building energy performance comparison

Reviewing the data demonstrates that multiple studies and data sources have begun to converge around what the anticipated maximum performance of office buildings looks like, before renewables are accounted for. In this data, EUI values in the low to mid 20's represent the anticipated performance target for buildings before accounting for renewables. (Note that some high performance office buildings have already demonstrated lower EUI performance than this.) The degree of convergence of these data sources provides confidence that a consistent *max-tech* performance target can be identified for this building type.

Office buildings are one of the most widely documented building types, with many studies examining the performance of this building type, and a relatively consistent set of loads driving building energy performance. Other building types lend themselves to similar analyses, though typically with less available data, while many building types demonstrate a wide range of energy use outcomes, making target setting more difficult. Below are some more examples of data comparisons by building type.

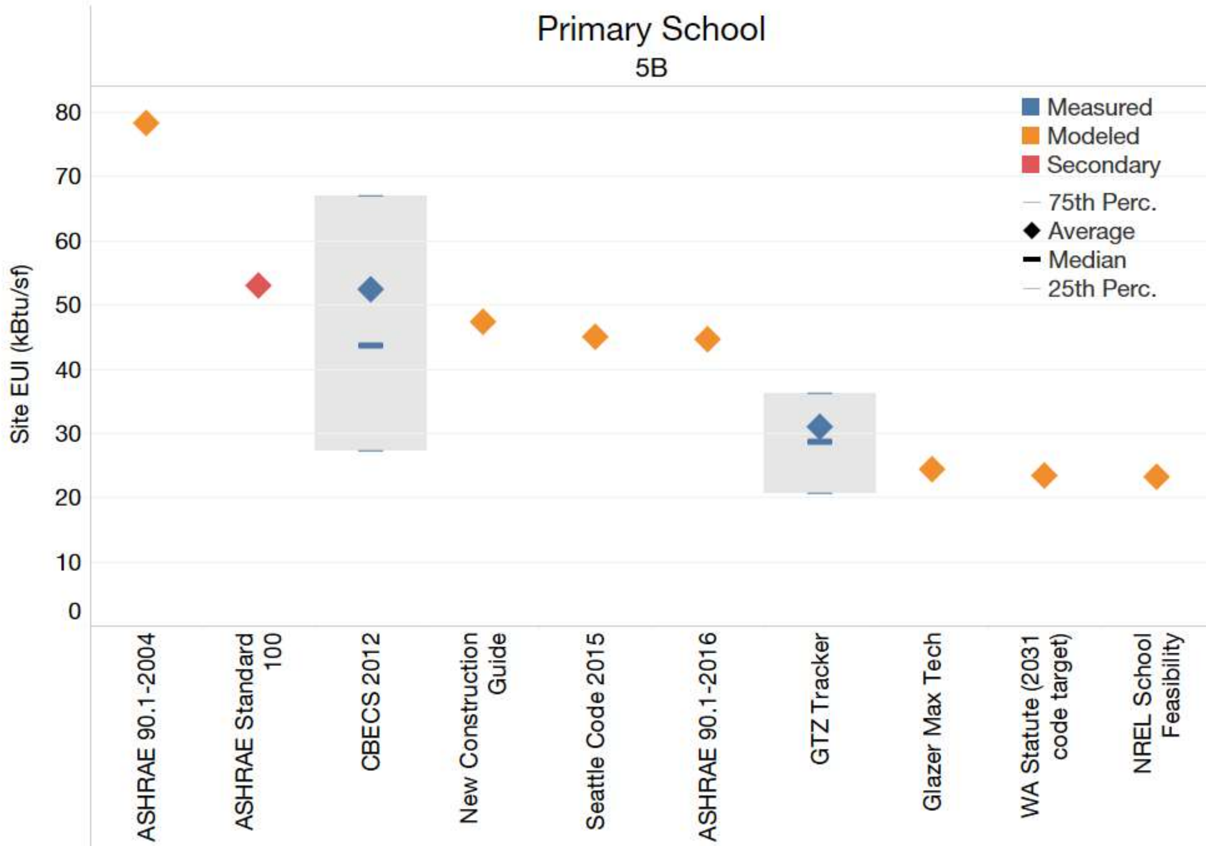

Figure 5: Primary School building energy performance comparison

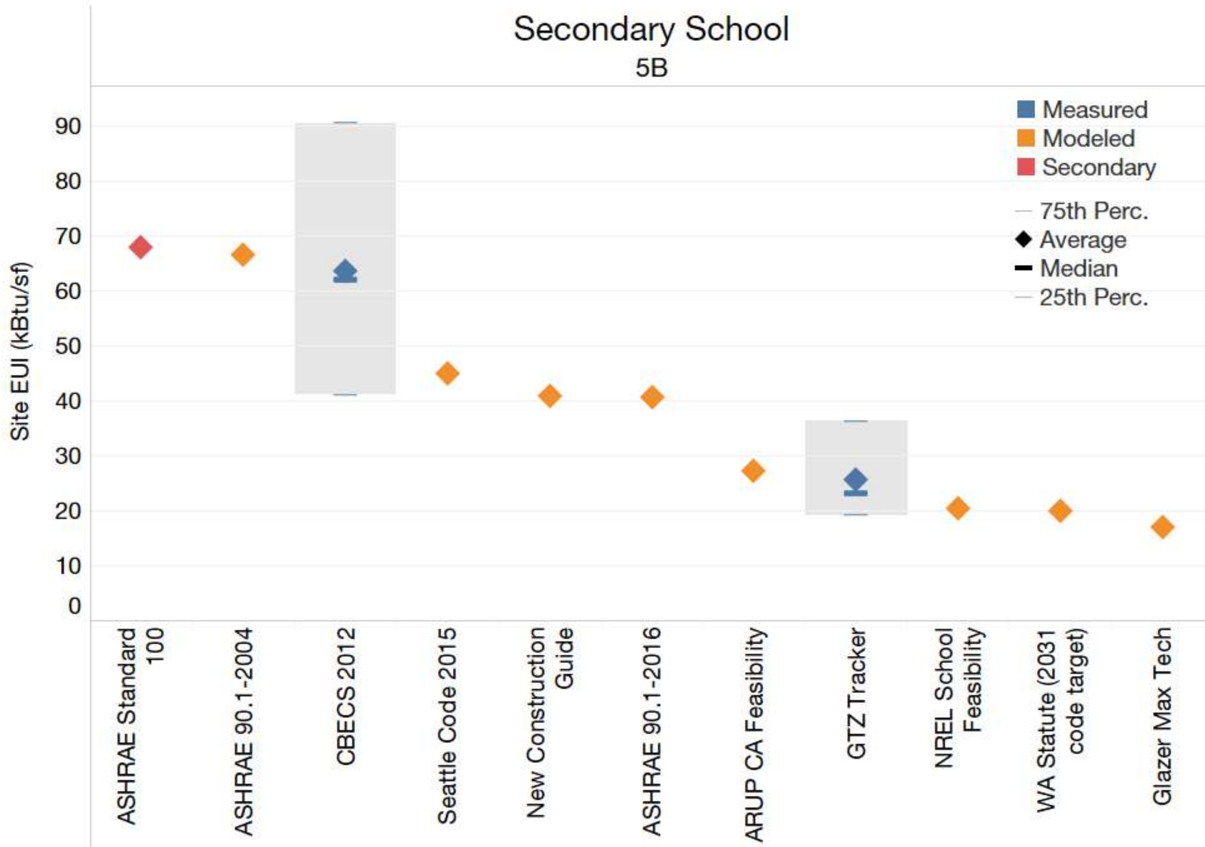

Figure 6: Secondary School building energy performance comparison

Schools are another building type that has been extensively studied, and there are also many examples of schools in NBI's ZNE database that help determine high performance expectations for this building type. The range of performance outcome for this building type is somewhat wider than for office buildings, in part because different schools may include different operating strategies and key features (like cafeteria kitchens) that can introduce more variability into expected performance outcome. Nevertheless, the frequency of available data and the alignment of *max-tech* studies suggests that reasonably consistent targets can be identified for school buildings.

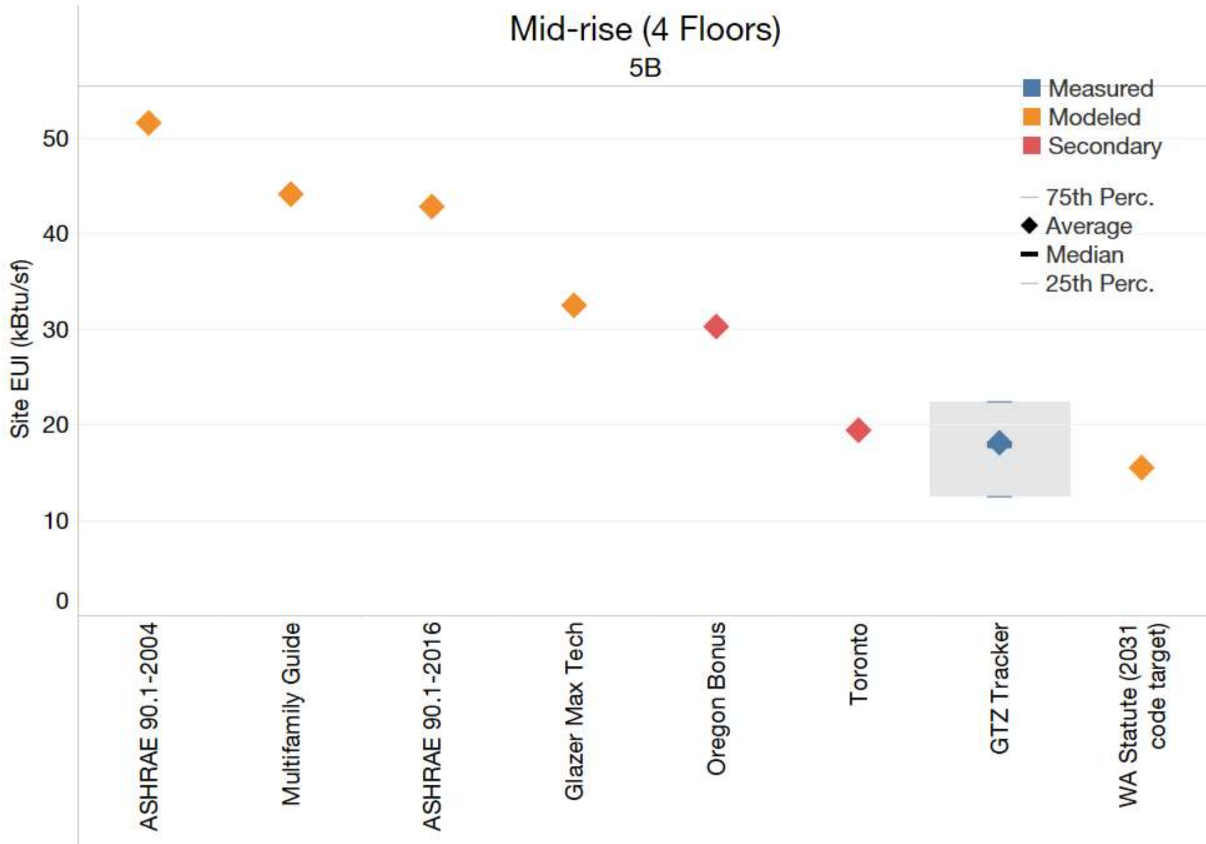

Figure 7: Mid-rise Multifamily building energy performance comparison

Multifamily buildings have also received a fair amount of attention in considering high performance targets, but there is less consistency in the predictions of high performance for this building type, and fewer completed examples of ZNE multifamily buildings. This is due in part to the fact that multifamily buildings can incorporate a wide range of potential amenities, and serve a wide demographic range of residents. High end residential buildings tend to include larger floor areas for fewer residents, and common area amenities not seen in lower income properties. At the same time low income residential projects may include higher individual unit density (each with kitchen and laundry equipment) into a smaller floor area. These factors introduce significant variability into multifamily residential building energy use.

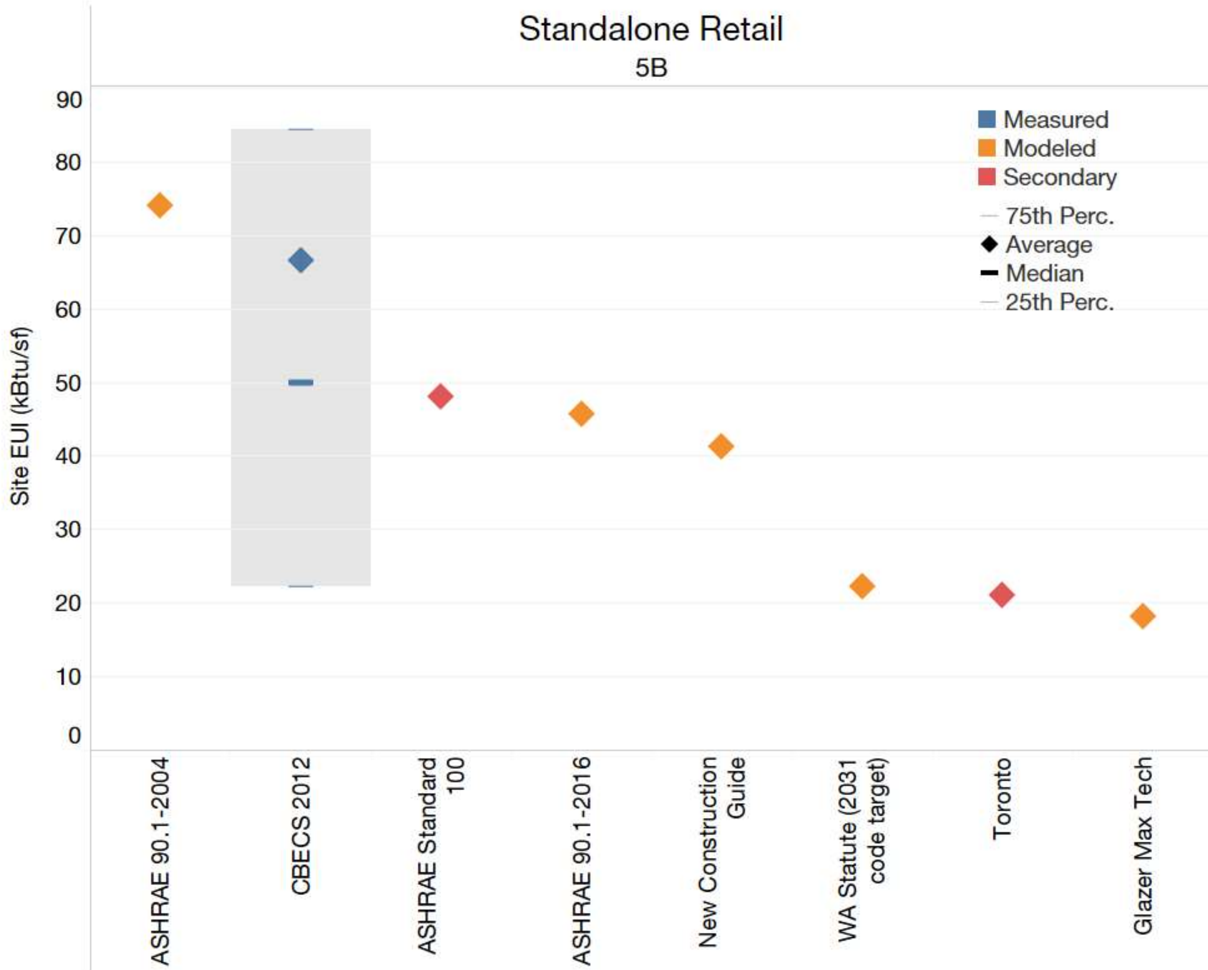

Figure 8: Standalone Retail building energy performance comparison

In standalone retail buildings there is a wide variability in energy use outcome, as can be seen from the extremely wide range of performance outcome seen in the CBECS data below. This building type is not well represented in existing ZNE buildings, so the data on what to expect for high performance for this building type is sparse. Although we identify max-tech targets, varying use and configuration suggests that a wide range of outcome would be expected even in high performing retail buildings.

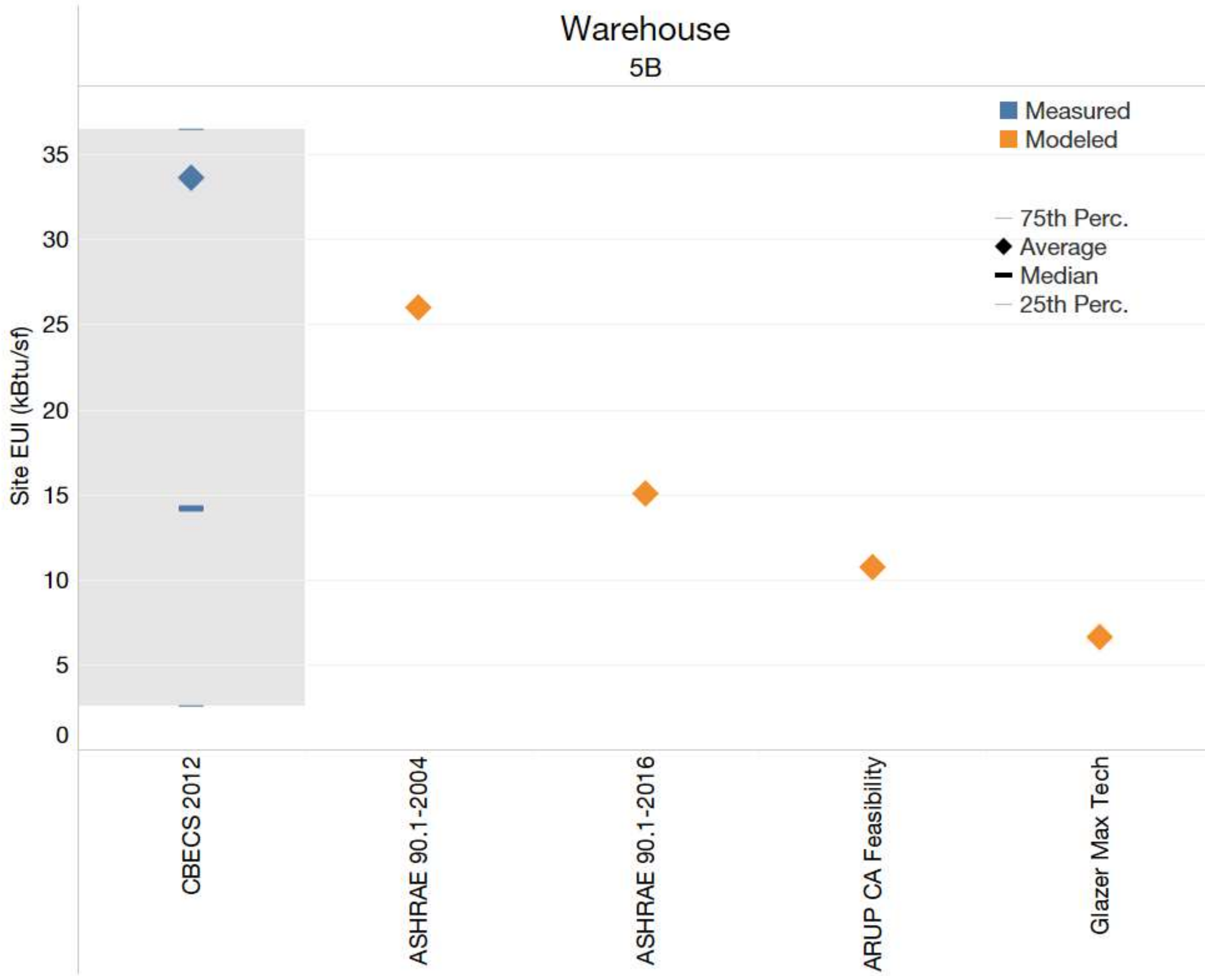

Figure 9: Warehouse building energy performance comparison

Warehouses are another building type that can exhibit a wide range of performance, depending primarily on whether tight climate control (or refrigeration) is needed for parts of the warehouse. This building type may also include varying degrees of processing and manufacturing, adding to energy use variability. However, since warehouses typically include large roof areas, they are often good buildings to deploy PV on.

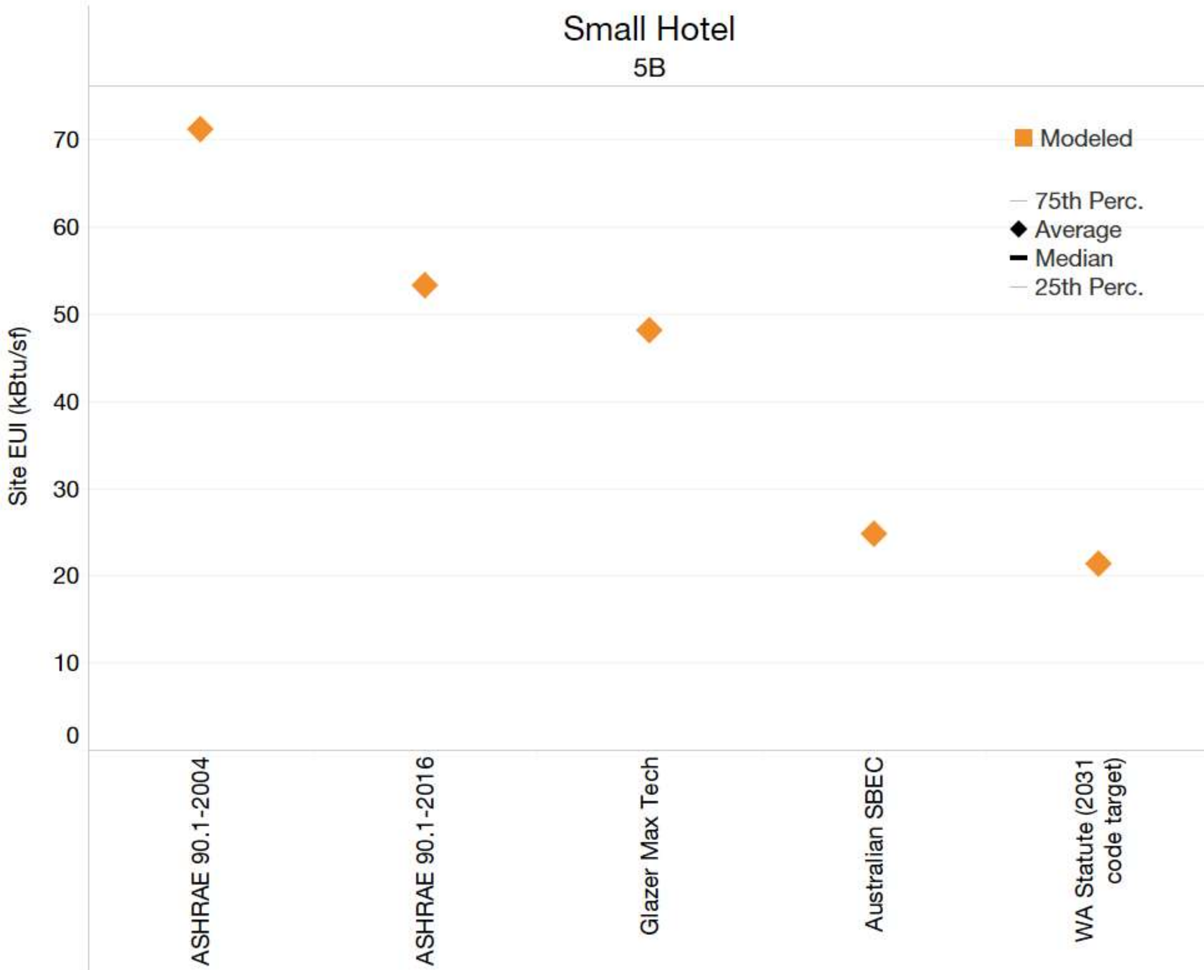

Figure 10: Small Hotel building energy performance comparison

Data sources on small hotel energy use are limited, making performance targets difficult to establish. Hotels may also have widely varying degrees of services, from simple accommodation to luxury facilities with restaurants, pools and spas, etc.

Converging on Max-Tech and Interim Performance Targets

Using the various building performance source data and performance studies demonstrated above, a summary of the predictability of individual building types with respect to max-tech performance is described in Table 3. This table indicates the relative availability of data sources available for each building type, and the range of performance outcome indicated in these data sources. Building types with few data sources and high range of performance prediction are not good candidates for specific performance targets, or mechanisms are needed to adjust the targets for individual building circumstances. Building types with many data sources and low or moderate data variability are better for specific performance targets.

Regardless of data variability, this table identifies the current code performance value and the approximate max-tech performance value for each building type available. Values in the lower portion of the graph are subject to higher uncertainty, and would be more difficult to use as fixed performance targets.

National Base Code and Max-Tech Values for Selected Building Types				
Building Type	**Data Sources**	**90.1-2016**	**Max-Tech**	**Data Range**
Medium Office	Many	30	16	Low
Small Office	Many	25	12	Moderate
Primary School	Many	45	24	Moderate
Secondary School	Many	41	18	Moderate
Mid-rise Apartment	Some	43	20	Moderate
Warehouse	Some	15	8	Low
Retail Store	Some	46	18	Moderate
Small Hotel	Few	53	32	Moderate
(building types below this line are not good candidates for performance targets)				
Hospital	Some	117	67	High
Restaurant	Some	374		
Strip Mall	Some	50	20	High
Clinic	Few	101	62	High
Fast Food	Few	588	415	High
Fire station	Some		30	Moderate

Table 3: Data Availability and Consistency, and EUI Comparison for Key Building Types

Interim Targets

It is anticipated that the City of Boulder will move from its current code stringency to a net zero requirement over the course of five code cycles, culminating in 2031. This suggests a series of increasingly stringent performance requirements as the basis for code targets. The max-tech targets identified above represent the theoretical limit of base building performance. Achieving performance beyond that will require renewable energy to offset building energy use.

In identifying interim code stringency targets, we can consider the impact of increasing stringency beyond the current code. In Table 4 below, the approximate EUI's represented by various stringency increments over ASHRAE 90.1 base code are compared for various building types. Column 2 represents Boulder's current code requirement, a target performance of 30% better than ASHRAE 90.1-2010. In the upcoming code cycle, Boulder will update the national reference to ASHRAE 90.1-2016. Columns 4 through 7 identify potential performance targets above the 90.1-2016 baseline. Note that Column 5 shows a potential target for the upcoming code cycle that represents an incremental improvement over current Boulder code requirements. The max-tech values described previously are indicated in Column

8. Note that a performance target of 50% better than ASHRAE 90.1-2016 (Column 7) represents an EUI very close to max-tech limits for most building types.

The values in this table are meant to provide context for considering code stringency in upcoming code cycles, and do not represent specific recommendations for code performance increments. Code targets must be considered in conjunction with renewable deployment goals.

Comparison of Performance Increments Above Base Code to Max-Tech Targets (EUI)								
	1	2	3	4	5	6	7	8
Building Type	**90.1-2010**	**90.1-2010 +30%**	**90.1-2016**	**90.1-2016 +20%**	**90.1-2016 +25%**	**90.1-2016 +40%**	**90.1-2016 +50%**	**Max-Tech**
Medium Office	34	**24**	30	24	23	18	15	**16**
Small Office	31	**22**	25	20	19	15	13	**12**
Primary School	56	**39**	45	36	34	27	23	**24**
Secondary School	46	**32**	41	33	31	25	21	**18**
Mid-rise Apartment	50	**35**	43	34	32	26	22	**20**
Warehouse	19	**13**	15	12	11	9	8	**8**
Retail Store	57	**40**	46	37	35	28	23	**18**
Small Hotel	85	**60**	53	42	40	32	27	**32**
Hospital	133	**93**	117	94	88	70	59	**67**
Restaurant	396	**277**	374	299	281	224	187	
Strip Mall	60	**42**	50	40	38	30	25	**20**
Clinic	114	**80**	101	81	76	61	51	**62**

Table 4: Impact of Incremental Code Stringency Increase on EUI

Proposed Code Roadmap

The issues described above set up an approach to the transition to ZNE outcome codes described in this section. At the highest level, this transition is based on three elements:

- Incremental increases in code stringency to require reduced building energy use
- Increasing deployment of renewable energy resources to offset remaining building energy use, culminating in ZNE performance
- Transition to a focus on actual building energy use, first as a predicted value, but increasingly verified as a performance outcome

The overall strategy for this transition is represented in Figure 11 below. On the left side of the chart, the 'Current EUI' bar represents actual building performance of buildings built to current code, while the second bar labeled '2016' represents the 'determination value EUI' assumed for the energy code itself. As discussed above, there is a large variability in actual building energy use compared to code expectations. To achieve a performance outcome of ZNE, the Building Performance Trajectory and the Code Performance Trajectory lines need to converge on delivering 'Max Tech EUI' on the right side of the graph. And by 2031, all of the energy used by these buildings should be offset by renewable energy, labeled 'Solar EUI' in the graph.

This sets up a series of trends to be encouraged by interim codes from 2019 to 2028. First of all, buildings will begin to focus on EUI starting in the immediate code cycle of 2019. This cycle will require that all buildings evaluate anticipated EUI, and achieve targets aligned with the 'ZNE Performance Trajectory'. These targets will also include specific minimum required deployments of renewable energy that increase in subsequent code cycles. Within another cycle or two, buildings will also be required to follow up with actual performance data, and will be required to demonstrate that they are reasonably close to the predicted targets. In each cycle, the actual building performance trajectory will be required to converge more closely to predictions, to maintain progress toward ZNE goals. Recommendations for code improvement strategies are described in more detail in the sections below.

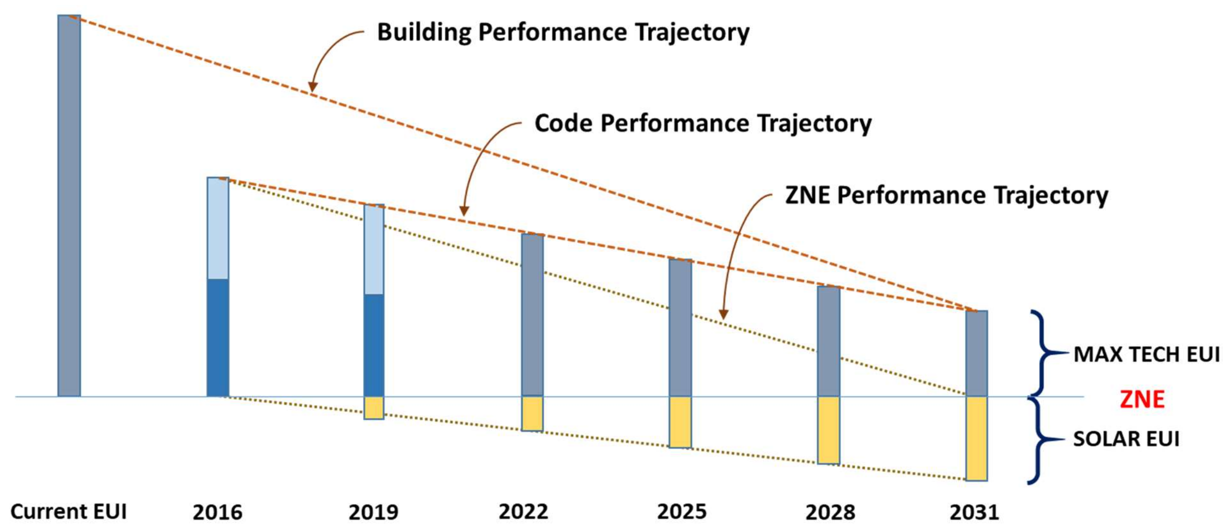

Figure 11: Representation of increasing code stringency, renewable deployment, and building performance improvement through multiple code cycles to achieve ZNE.

Elements of the Code Roadmap

This section describes in more detail the individual components of the code that should evolve over the five code cycles between now and 2031 to achieve a ZNE outcome code. Table 5 below indicates the transition of each code element through the individual code cycles, and the potential relationship of these transitions to each other through the various code cycles. Each code element is discussed in more detail in the sections below.

A more specific explanation of the proposed details of the upcoming 2019 code cycle are provided in a separate document.

Proposed Boulder Code Roadmap						
	2016	**2019**	**2022**	**2025**	**2028**	**2031**
Anticipated Stringency	90.1-2010+30%	90.1-2016+25%	90.1-2016+40%	90.1-2016+60%	90.1-2016+75%	ZNE
Renewable Offset (min.)	Not Required	5%	10%	25%	50%	100% (ZNE)
Energy Storage	Not Required	Not Required	Encouraged	Encouraged	Required	Required
Back Stop Code	none	90.1-2016	90.1-2016	90.1-2019	90.1-2022	90.1-2025
Modeling	Not required	Model to establish EUI target	Model to EUI target	Model to EUI target	Model to EUI target	Model to EUI target
Unregulated Loads in Modeling	Not Addressed	Some flexibility w/ pre-approval	Flexible w/ pre-approval	Flexible w/ pre-approval	Flexible	Flexible
Outcome Requirements	none	Report on discrepancy in disclosure data	Within 15% of target	Within 10% of target	Achieve target	Achieve ZNE
Normalization to Modify Target	N/A	Report on discrepancy	Document use changes in model	Document use changes in model	Document use changes in model	Not allowed
Enforcement Mechanism	Certificate of Occupancy	Certificate of Occupancy, Disclosure	Disclosure; Bond or Solar Credit	Disclosure; Bond or Solar Credit	Bond or Solar Credit	Bond or Solar Credit
Prescriptive Path	Small/Remodel Projects only	Small /Remodel Projects only	Add renewables	Add renewables	Not Allowed	Not Allowed

Table 5: Incremental changes to energy code elements on the path to ZNE through five code cycles to 2031

Anticipated Stringency

Energy code stringency will continue to increase to achieve ZNE in the 2031 code cycle. Boulder already implements an energy code that is well along on the path to ZNE. This code is currently linked to ASHRAE 90.1-2010, requiring projects to achieve 30% savings over that standard. Linking to 90.1 allows the jurisdiction to utilize important ASHRAE resources like Appendix G, which provides a basis for performance submittals required by the jurisdiction. As ASHRAE 90.1 continues to increase in stringency, Boulder can update the version of 90.1 referenced by the city code.

In the upcoming code cycle, the code reference will be updated to reflect the 90.1-2016 standard. NBI recommends a performance increment above 90.1-2016 of 25%. (This issue is discussed in more detail in the separate report focused on the 2019 code cycle.) This stringency will increase incrementally until ZNE is achieved. Because building performance requirements are approaching technical limits, an increasing fraction of building performance goals are anticipated to be provided by renewable energy. Projects may choose to deploy more or less renewable to achieve the targets, with increasing minimums for renewable deployment in subsequent code cycles. Basic building performance will be insured by backstop code requirements to prevent over-dependence on renewables.

Deployment of Renewables

Over time, it will be necessary to deploy renewable energy to offset building energy use to achieve ZNE performance. By the 2031 code cycle, the goal is that renewable energy will offset 100% of building energy use for buildings permitted under the code. Renewable energy installations are already proliferating, and there is no reason to delay accounting for renewable installations in the code process. It is desirable to start requiring increasing levels of renewable energy offset in the code cycles leading up to 2031. This supports steady market growth over time, giving designers and installers more time to become familiar with renewable technologies and providing a steady and predictable market growth trajectory.

Renewable offset requirements represent the minimum percentage of total building load that must be met with renewables, which increases in subsequent code cycles. Projects may choose to deploy more than the minimum amount of renewables to meet overall code targets. In the 2031 code cycle, buildings must offset 100% of annual energy use with renewables to achieve ZNE performance. As renewable deployment requirements increase, solutions will be needed to current restrictions on off-site solar deployment, to support projects with large loads that cannot be met on-site.

However, it is important to make sure that renewables are not used to offset basic building performance to a significant degree. For this reason NBI recommends the adoption of a 'backstop code' as described below, in which renewable deployment cannot offset basic building performance.

Energy Storage

Energy storage systems will become increasingly critical to reducing carbon impacts of building operation and supporting grid performance. As renewable deployment increases, the value of being able to spread building loads to time periods when renewables are not available increases significantly. Storage also allows surplus daytime power generation to more directly offset nighttime carbon-intensive electricity generating strategies. The cost of energy storage is anticipated to drop significantly over the next decade, making the inclusion of storage systems more feasible in subsequent code cycles. In the near term, strategies to give performance credit to storage systems can be incorporated in code to encourage deployment, perhaps by lowering the amount of renewables needed when storage is deployed, or magnifying the assumed impact of renewables on total energy use when deployed in conjunction with storage.

Back-Stop Code

Deep building efficiency requires the successful management of building operating characteristics. As actual performance targets are set for buildings, projects will begin to recognize that significant savings can be achieved independent of building design characteristics. With the availability of inexpensive renewables, some projects may decide to deploy large solar arrays instead of emphasizing basic building efficiency. Taken to an extreme, this can deliver inherently inefficient buildings that are at increased risk of excessive energy use if occupants or operators change over time.

To discourage this, a backstop code should be deployed to set a minimum level of performance for building features to make sure that basic building efficiency is not ignored. In this example, the requirements of the ASHRAE 90.1-2016 energy code will continue to serve as the back stop in subsequent code cycles, eventually moving forward with new editions of the 90.1 Standard. No building will be allowed to incorporate features in subsequent code cycles that don't at least meet the backstop requirements, even as creative efficiency strategies are encouraged to meet more stringent performance goals.

The backstop code is applied to projects submitted using the performance modeling submittal pathway. Projects will not be allowed to trade off lower building performance features below the prescriptive backstop requirements.

Modeling

To take advantage of integrated system efficiencies and creative design solutions, the city will continue to require that most projects demonstrate code compliance with energy modeling. In the 2019 code cycle, projects will be required to use energy modeling tools to predict the anticipated energy use intensity (EUI) performance outcome of the building. This is a transition from comparing building performance to a baseline as a 'percent better than' performance metric. Predicted EUI's will be required to meet specific targets set by the jurisdiction, either based on a look-up table, or on a modeling process that identifies the EUI target to be achieved. This will encourage the market to more broadly adopt energy modeling in the design process, increase familiarity with performance outcome predictions, and begin the transition to more explicit modeling and performance outcome requirements.

The 2019 code cycle will be a subtle transition from comparative performance modeling that will encourage more attention to performance outcome by design teams and building owners. To reinforce this trend, beginning with the 2019 code cycle, the city will require that disclosure data submitted under the city's disclosure ordinance be compared to the modeling data under which the building was permitted. Buildings built under the 2019 code cycle will be required to provide a narrative explanation of how the performance of the building differed from the performance predicted by the modeling, with a simple analysis of why the variance occurred. Over time, subsequent code cycles will require more comprehensive review of actual performance, and adjustments to building performance or renewable deployment to meet required performance targets.

Note that the accuracy of EUI predictions submitted in the design process is not likely to be very high until the market becomes more accustomed to modeling strategies that improve accuracy. As the market becomes more used to the EUI metric, and to tracking performance outcomes, it is anticipated that the modeling process will become more accurate.

Unregulated Loads

Deciding how to handle unregulated loads in energy modeling is one of the biggest challenges to the transition to a performance outcome code. For the most part, modeling protocols and the code submittal practices associated with them have been designed to focus on those aspects of the building that are regulated by code. Strategies to reduce operating energy by managing plug loads or unregulated equipment energy have been discouraged in most energy modeling, to reduce the opportunity for projects to manipulate unregulated loads to make the building appear more efficient for code compliance. In the early stages of the transition to outcome codes, manipulation of unregulated loads in the modeling process will be limited, and specific schedules will be provided as the basis for modeling. But as we encourage increased attention on total building energy use, strategies to reduce plug loads and other unregulated loads should be encouraged as part of the code process.

The most widely adopted protocol describing modeling strategies is ASHRAE 90.1 Appendix G. This standard explicitly requires comparative modeling to use the same plug loads in the proposed building model as in the baseline building model, except with special permission from the code authority. This strategy will form the basis of the review of unregulated loads in this code process.

To encourage projects to begin to address the impact of unregulated loads on building energy use, specific credits may be allowed in the modeling process to account for commitments by the project to reduce unregulated load energy use. In the early stages of this, credit for unregulated load reduction will be limited to a small percentage of anticipated loads. As the building department and projects become acquainted with strategies to pursue and document reduction in unregulated loads, the amount of savings allowed in this category may be increased. By the 2031 cycle, managing unregulated loads will be an integral part of achieving ZNE building performance.

Outcome Requirements

Outcome requirements refer to the degree to which projects are held accountable for achieving the performance goals identified during the modeling submittal process. By the 2031 code cycle, the intent is that projects are directly responsible to prove that they are achieving ZNE performance, and that enforcement mechanisms are focused on that outcome. In the meantime there is a transition to ZNE based on increasing levels of attention of building performance outcomes.

To start this process, the transition to EUI compliance targets brings a focus onto individual building performance metrics. To encourage this process, NBI strongly recommends that projects submitted under the 2019 code be required to review and report on actual performance of the building, compared to the performance predicted in the code submittal. (Boulder's disclosure ordinance already requires all projects to report on actual energy use.) No other enforcement mechanism is proposed for this cycle, but an important goal is achieved if projects actually follow up to understand how their modeling diverged from actual outcome. This is an important step to push the industry toward more accountability on predictive modeling. In subsequent code cycles, buildings will be required to demonstrate that they are within increasingly constrained ranges near the predictive modeling, or take additional steps to reduce or offset building energy use.

The focus on actual performance outcome also encourages continued attention to efficient building operation once the building is occupied.

Normalization

Despite the best intentions of designers, energy modelers, and building operators, building energy use can vary from year to year based on factors outside the control of these groups. Changing weather from year to year will introduce variability, as will changes in tenants, occupant density, building use, etc. These are perfectly normal reasons for building energy use to fluctuate, and must be accounted for in considering whether a building is achieving its performance goals/requirements. Adjusting building energy targets based on these factors is called 'normalization' of performance expectations. Once enforcement mechanisms focus on measured building performance data, performance targets will need to be able to account for normalization strategies so that buildings can carry on with their typical market function of adding and reducing occupants, changing use types (like adding a deli on the main floor), and maintaining comfort in a particularly cold winter.

Normalization accounts for routine weather and market variability that is an expected part of building operation. NBI is developing specific normalization factors to account for performance variability that is not the result of poor operations and inefficient system operation, so that buildings can adjust performance targets over time based on actual weather and use characteristics. It is to be anticipated that individual projects may request specific adjustments to performance criteria based on unanticipated tenant and operating characteristics. This ability to adjust performance targets will become more critical over multiple code cycles, as buildings are expected to perform more closely to the performance targets set in the design process.

Enforcement Mechanisms

By transitioning the energy modeling process to focus on building performance outcomes, the city sets in motion a series of adjustments to enforcement strategies that will need to be developed and deployed over the course of the transition to ZNE performance outcomes in the commercial sector.

As described above, the energy modeling used for permit submittals will be focused on predicted annual energy use (EUI) compared to a code baseline. To implement the backstop code and prevent manipulation, additional restrictions on modeling assumptions will be deployed in the submittal process. This represents a small change to the existing model submittal process.

Code enforcement at time of permitting will also need to include review of required renewable energy systems.

In order to begin to focus on building performance outcomes, new collaboration between city departments currently enforcing the energy code and the disclosure ordinance will need to be developed. Over time the city will need to develop specific feedback mechanisms that track and target recently permitted buildings for review of performance achievement in association with disclosure requirements. In later code cycles, as the city requires better alignment between predicted and actual building performance as a condition of energy code compliance, new enforcement mechanisms will be needed to insure compliance, and to provide projects with remediation mechanisms to resume compliance.

Several scenarios might be considered to serve as enforcement mechanisms for buildings in operation. These include options such as:

- Performance bond, collected at the time of permit, that is released back to the project when compliance with actual performance requirements is demonstrated, or invested in additional renewable energy resources to make up for the performance shortfall
- Temporary Certificate of Occupancy, granted at the time of project completion, is not converted to a permanent status until performance is proved
- Tax or utility fee structure for projects that are not in compliance within the specified compliance window
- Detailed audit and retro-commissioning requirements for projects not meeting performance goals

Any of the enforcement mechanisms identified above will require new policy and enforcement scope for city departments in order to implement.

Any project that is out of compliance with performance requirements is potentially likely to request modifications to performance targets based on normalization criteria described above. This will require additional review of modified modeling submittals and proposed adjustments to performance requirements.

Although there are many variations on potential enforcement mechanisms for building performance outcome, these will require careful consideration in the context of the city's organizational structure, legal context, and community goals. It should be noted that city efforts to encourage or require performance improvements in existing building stock will grow in parallel to the strategies to require new building performance outcomes. Many of the same strategies and mechanisms that the city might deploy for an outcome code will also support broader efforts to improve the existing building stock. As building performance disclosure data becomes the basis for new incentives or mandates for existing buildings, the city mechanisms to track and deploy these strategies will be directly related to the new construction code advancements described in this section.

An extensive discussion of jurisdictional options for transitioning to building performance enforcement can be found in the report '*Addressing Building Life-Cycle Energy Performance: A Framework for Cities*', from NIBS and NBI, 2016.

Prescriptive Path

Continued increases in the stringency of the prescriptive path for many building types is reaching the end of its evolution. Continued improvement in building performance requires consideration of system integration not addressable by prescriptive requirements, federal preemption of equipment efficiency precludes additional progress, and unregulated loads (outside the scope of prescriptive codes) have become a major element of building energy use.

Boulder already requires that most new construction projects use the performance pathway to demonstrate code compliance. Only small commercial buildings and remodel projects are allowed to use the prescriptive path for compliance. In the 2019 code cycle, NBI proposes that the threshold for prescriptive compliance remain the same as the previous version. Stringency modifications to the prescriptive requirements themselves will be incorporated into the updated Boulder Code. Subsequent efforts will focus on adding renewable requirements to prescriptive compliance requirements. Eventually the prescriptive pathway will be phased out.

Note that prescriptive compliance may continue to be allowed to demonstrate achievement of the back stop code.

Summary

This document describes the elements of a pathway to a ZNE commercial building code. Several aspects of the code and enforcement process must evolve together to achieve the levels of stringency envisioned by the City of Boulder. By describing the incremental steps on this pathway, it is possible to envision a successful strategy to achieve ZNE goals by the 2031 code cycle. This is a critical transition to achieve the climate goals that the City of Boulder has adopted. The city is in a strong position to successfully implement this strategy, based on the strength of its current energy code, and the deep commitment of the city to these goals.

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City of Boulder 2019 Residential Building Energy Conservation Code Cost Effectiveness Analysis

April 1, 2019

Submitted To:

City of Boulder
Christin Whitco
Energy Code Coordinator
1777 Broadway, Boulder CO 80302

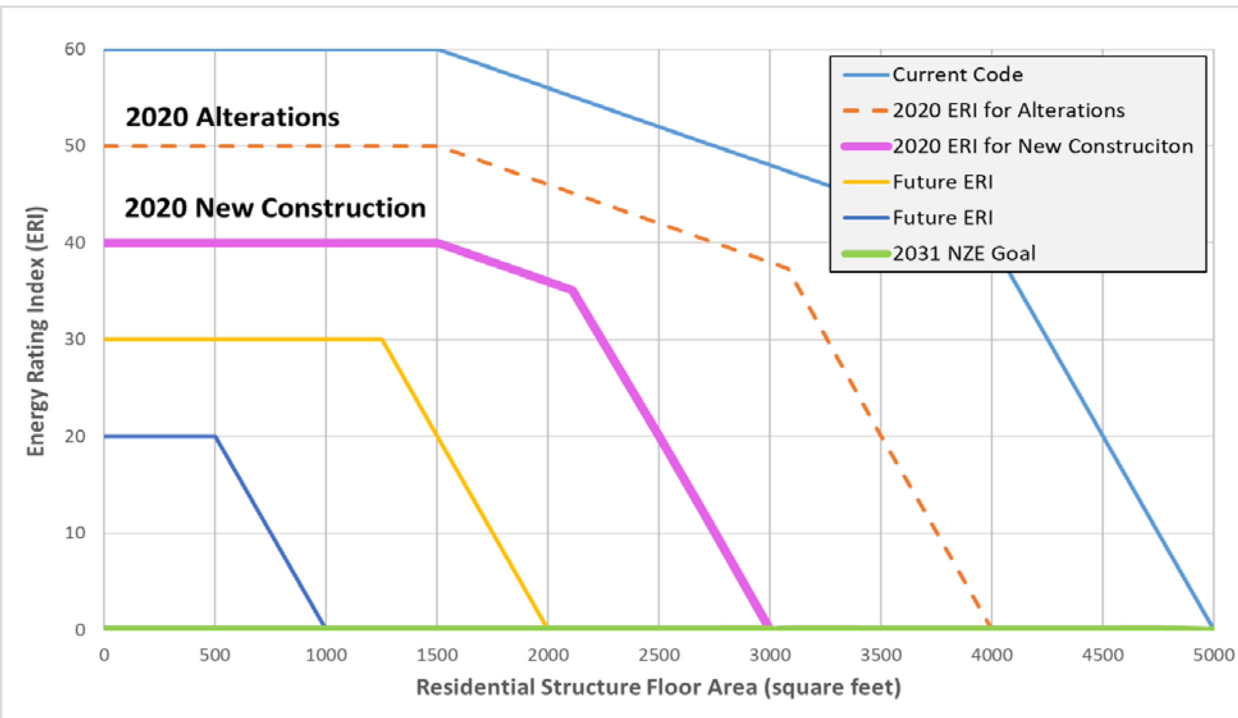
Table of Contents

1 Introduction

The City of Boulder has demonstrated leadership in targeting energy conservation code advancement, and in deploying new approaches to building energy use regulation. The City of Boulder engaged TRC and New Buildings Institute (NBI) to research and analyze the cost effectiveness of residential energy code measures exceeding 2018 International Energy Conservation Code (2018 IECC).

Boulder policy goals require higher energy performance as single-family residence size increases. For homes 3,000 ft^2 or greater, this includes Zero Net Energy (ZNE) by using on-site solar photovoltaics (PV) to offset annual energy usage, as measured by an Energy Rating Index (ERI), as show in Figure 1.[1] Figure 1 also depicts future code targets that reduce the maximum home size required to achieve ZNE.

Figure 1. Current and Targeted Boulder Energy Conservation Code



Because solar PV is limited in size to 120% of the total kWh electricity consumption of the building according to Xcel utility rate interconnection rules, mixed fuel buildings may not be able to achieve ZNE by generating enough electricity to offset their natural gas consumption.

1.1 Scope

TRC has assessed the cost effectiveness of packages of energy efficiency measures and solar PV relevant to new construction single family buildings. TRC determined cost effectiveness by comparing the costs of the packages with the on-bill energy savings benefits, described in more detail in *Section 2: Methodology*. The City of Boulder intends to use TRC's analysis to identify cost effective Energy Rating Index (ERI) values for single family homes that are mixed-fuel and all-electric.

[1] More information available: https://bouldercolorado.gov/plan-develop/residential-construction-energy-conservation-code

The development and adoption of an ERI approach to regulating residential energy performance has allowed jurisdictions to incorporate a broader range of features into residential building regulation, providing a pathway to deep efficiency and path to ZNE. The structure of the ERI allows for incremental increases in efficiency accounting all energy using features of the building and the gradual incorporation of renewable resources to meet the net zero goal. The current ERI structure requires a minimum level of efficiency for the building envelope to ensure that efficiency is not traded away for renewables which will encourage building innovation as the ERI scores are made more stringent.

TRC's analysis uses the ERI compliance approach looking at prototype homes with and without renewables to determine feasibility. The 2018 IECC performance path allows building developers to run simulations to determine the ERI of their building. The 2018 IECC performance path sets a maximum ERI of 61 on a 0 to 100 scale, however the 2018 IECC has an intentionally enhanced stringency of the ERI performance compliance pathway relative to the IECC prescriptive pathway. As a result, homes modeled solely with prescriptive features do not achieve IECC's ERI performance standard for climate zone 5b, an ERI=61. Further description on how this affected methodology is included in *Section 2.1*.

1.2 Limitations

This study has the following limitations:

- **Applicability.** All analysis performed is intended to be relevant to Boulder climate, utility rates, and labor/material costs.
- **Prototypes.** The prototypes studied are single family residential. Findings may not pertain to accessory dwelling units or multifamily residential.
- **Federal Pre-emption.** The Department of Energy (DOE) regulates the minimum efficiencies required for all appliances, such as space conditioning and water heating equipment. State or city codes that mandate appliance efficiencies higher than the DOE's may risk litigation by industry organizations. Thus, TRC used baseline equipment and appliance efficiencies for energy conservation code measures, even though efficiency increases are often the simplest and most affordable ways to improve building performance.
- **Sensitivity.** The study assumes one set of market conditions at one specific point in time, including utility rates and equipment costs. This study does not analyze potential cost-effectiveness outcomes under a variety of market conditions.

2 Methodology

TRC analyzed the cost effectiveness of potential energy efficiency and solar PV measures by simulating them in prototype single family buildings to determine annual energy impacts. Construction and replacement costs and on-going energy bill impacts were assessed over a 30-year period.

2.1 Prototypes

TRC estimated the energy impacts of most measures using Ekotrope version 3.1.1 to simulate a set of residential prototypes in Boulder, Colorado (ASHRAE climate zone 5b). TRC used the following three prototypes to determine cost effectiveness in coordination with the City of Boulder:

- 1,500 ft^2 single family single-story home
- 3,000 ft^2 single family two-story home
- 4,500 ft^2 single family three-story home, two-stories above grade and one-story conditioned basement

Each prototype has the same 1,500 ft^2 floorplate and an attached garage. TRC used a box floorplate that is 50-feet wide by 30-feet deep, with 9-foot ceilings, and an attached garage that covers the entirety of the 1st floor's left wall. The roof is 1,875 ft^2 and estimated to be able to accommodate a 9 kW PV system.

Each home has an 20% window-to-floor area glazing ratio for the above grade stories. All windows have RESNET standard shading with no overhangs or side-fins. TRC modeled the 1,500 ft^2 and 3,000 ft^2 prototypes with an enclosed vented crawl space, while the 4,500 ft^2 prototype has a below-grade conditioned basement. Each home is modeled with an exhaust-only mechanical ventilation system that meets ASHRAE standards. TRC made each of these home-geometry decisions based on a consensus opinion between TRC, NBI, and City of Boulder employees that they represent a typical Boulder home.

TRC developed a mixed fuel and an all-electric version of each home. The mixed fuel home uses a gas-fired water heater, space heating furnace, and cooking range. The all-electric home uses air source heat pumps for water heating and space conditioning, and an electric cooking range. New construction prototype baseline characteristics are summarized in Figure 2, and are based on prescriptive 2018 IECC requirements. The one characteristic that changes when layering on efficiency measures is that the ducts would be located in conditioned space, as described further in Figure 4.

TRC developed the 2018 IECC prescriptive code model by first applying the 2018 IECC prescriptive energy efficiency measure mix for all wall and roof assembly U-factors, equipment efficiencies, duct location, appliance efficiencies, lighting efficacies, air-sealing, and hot-water distribution system efficiencies. The 2018 IECC has an intentionally enhanced stringency of the ERI performance compliance pathway relative to the IECC prescriptive pathway. As a result, homes modeled solely with prescriptive features do not achieve IECC's ERI performance standard for climate zone 5b, an ERI=61. TRC added enough solar PV generation for each model so that the baseline code prototypes have an ERI of 61 using a combination of the prescriptive energy features plus some solar. TRC selected solar PV in lieu of energy efficiency measures because solar PV will not have an impact on the energy consumption of the baseline building and will allow for more accurate analysis of energy efficiency measures above and beyond 2018 IECC.

Figure 2. Residential Baseline Prototypes Summary

Building Attribute	One-Story	Two-Story	Three-Story
Area (ft^2)	1,500	3,000	4,500
Roof Area (ft^2)	1,875	1,875	1,875
Foundation	Enclosed vented crawlspace	Enclosed vented crawlspace	Conditioned basement with slab flooring
Window-to-Floor Area Ratio	20%	20%	20%
HVAC System – Mixed Fuel	Central Ducted Split Air Conditioner (13 SEER) with Gas Furnace (80 AFUE)		
HVAC System – All-electric	Central Ducted Air Source Heat Pump (14 SEER, 8.2 HSPF)		
HVAC Distribution System	Ducts in Attic		
Domestic Water Heating – Mixed Fuel	Natural Gas Storage Water Heater (66 gallon, 0.69 EF)		
Domestic Water Heating – All-electric	Heat Pump Water Heater (55 gallon, 2.0 COP)		

2.2 Cost Effectiveness

TRC determined cost effectiveness by assessing the incremental costs of each measure above and beyond the 2018 IECC minimum requirements, and compared them to the energy cost savings, over 30-years. The baseline building in each case is an ERI=61 building – the mixed-fuel building cost effectiveness is compared to a mixed-fuel building with an ERI=61, and the all-electric building cost effectiveness is compared to an all-electric building with an ERI=61.

Incremental costs represent the equipment, installation, replacements, and maintenance costs of the proposed measure. TRC obtained measure costs through several online resources, including:

- Department of Energy Building Component Cost Community (DOE BC3)
- National Renewable Energy Laboratory Residential Efficiency Measures Database (NREMD)
- Online retailers such as Home Depot
- Previous cost effectiveness analysis including California IOU Codes and Standards Enhancement (CASE) Studies for California building standards cost effectiveness analysis and code development. TRC used CASE reports when other sources did not provide adequate information, and adjusted values both using inflation and locational factors from DOE BC3.[2]

[2] DOE BC3 Locational adjustment factors: https://bc3.pnnl.gov/location-factors

TRC estimated energy cost savings using Xcel utility rates for each calendar month for electricity and natural gas consumption using Ekotrope simulation software outputs.[3,4] TRC used the electric rate schedule R and gas rate schedule RG as summarized in Figure 3 below to estimate bill impacts. TRC coordinated various adjustment factors and simplifications to the rate schedules in co-ordination with the City of Boulder.

Figure 3. Xcel Rate Schedule Structure Summary

	Electric		Gas
Xcel rate schedule	R		RG
Commodity charge	Summer (First 500 kWh)	$ 0.10859/kWh	$0.48473 per therm
	Summer (>500 kWh)	$ 0.15602/kWh	
	Winter	$ 0.10859/kWh	
Fixed charge	$7.00512 per month[5]		$15.79604 per month

The scope of this study includes solar PV installation on all residential models. TRC assumed that the production meter charge is added in the overall electric costs shown above. [6] There is no requirement for residential PV customers to be on a specific rate schedule. Under the rates selected, excess kWh generation is compensated at the full retail rate and the credit is carried over to consequent months.

TRC performed a net present value (NPV) calculation over 30 years, assuming a 3% discount rate and a 2% energy escalation rate. TRC used benefit-to-cost ratio (B/C ratio) as the cost effectiveness metric. If the benefits of a measure package are greater than the costs, then the B/C ratio is greater than 1.0 and the package is considered cost effective.

[3] Xcel electric rates: https://www.xcelenergy.com/staticfiles/xe/PDF/Regulatory/CO-Rates-&-Regulations-Entire-Electric-Book.pdf
[4] Xcel gas rates: https://www.xcelenergy.com/staticfiles/xe/PDF/Regulatory/CO-Rates-&-Regulations-Entire-Natural-Gas-Tariff-Book.pdf
[5] Monthly fixed charge includes production meter charge in addition to service and facility charges.

3 Measure Descriptions

TRC categorically analyzed the 2018 IECC baseline and identified market-ready opportunities for efficiency improvements based on proposed IECC code updates, and other codes including California's Title 24, Parts 6 and 11, publicly available measure databases, and City planning department experience. Figure 4 summarizes the measures the 2018 IECC baseline, the estimated measure cost, and the cost sources. Measure categories are envelope, HVAC (heating, ventilation and air conditioning), DHW (domestic hot water), lighting, and renewables (solar PV) measures. All measures in Figure 4 were applied to all three single family prototypes.

There were several measures that were investigated but not ultimately included in the measure package due to low cost effectiveness in the Boulder climate, including R-60 ceiling insulation, R36 floor insulation, door U-factor, and heat recovery ventilation.

TRC performed the solar PV sizing differently for the mixed-fuel building versus the all-electric building. Solar PV is limited in size to 120% of the total kWh electricity consumption of the building according to Xcel utility rate interconnection rules. Because mixed-fuel buildings also include gas consumption, they are not able to achieve an ERI=0 without violating the Xcel utility rules. All-electric buildings, however, can achieve an ERI=0 by generating 100% of the kWh consumption. Thus, the PV size limit for a mixed-fuel building is 120% of the kWh electricity consumption, while it is 100% for an all-electric building.

In addition to the efficiency measures in Figure 4, TRC modeled appliance efficiency improvements as a 'market package.' The 'market package' represents additional measures that achieve ERI reductions but cannot be prescriptively required by the City of Boulder due to potential for federal pre-emption (see *Section 1.2 Limitations*). Although these strategies cannot be explicitly required by code, they are routinely deployed by builders in the market to achieve performance goals. Modeled appliance efficiency improvements included:

- Energy Star refrigerator, dishwasher, clothes washers and clothes dryer
- SEER 16 air conditioner with an electronically commutated motor (ECM) for cooling
- Mixed-fuel homes
    - 96% AFUE furnace with an ECM motor for gas heating
    - 95% EF condensing tankless gas water heater for gas water heating
- All-electric homes
    - 10.0 HSPF/ 16 SEER air source heat pump with an ECM
    - COP 3.4 heat pump water heater for electric water heating

Figure 4. Single Family Energy Efficiency Measures

Measure Category	Measure	2018 IECC Baseline	Incremental Measure Cost	Cost Source
Envelope	Fenestration U-factor = 0.27	U-factor = 0.30	$1.42/ft^2 of window	DOE BC3[7]
	Exterior wall R13 cavity + R13 exterior insulation	R13 cavity + R5 exterior insulation	$0.39/ft^2 of wall	Home Depot
	Below roof deck radiant barrier	No radiant barrier	$0.43/ft^2 of roof	NREMDB[8]
HVAC	Dropped ceiling ducts in conditioned space / soffit	Exposed ducts in the attic	$0.50/ft^2 of conditioned floor area	CASE[9]
DHW	Tankless water heater, Energy Factor = 0.81	Gas storage water heater, EF = 0.76	$300/appliance	CASE[10]
	Distribution horizontal length to furthest fixture = 30 feet	Distribution horizontal length to furthest fixture = 77 feet	$263/home	CASE[11]
	Low-flow fixtures	Normal flow fixtures	$0/home	Home Depot[12]
Lighting	100% LED	90% Compact fluorescent, 10% incandescent	$0.10/ft^2 of conditioned floor area	CASE[13]
Renewables	Solar PV to achieve either: 1. 120% of kWh generation for mixed-fuel home, or 2. ERI = 0 for all-electric home	Solar PV to achieve ERI=61	$2.58/W including inverter replacements, maintenance, and federal income tax credit	NREL[14] CASE[15]

[7] https://bc3.pnnl.gov/component-database
[8] https://remdb.nrel.gov/measures.php?gId=13&ctId=51&scId=643&acId=644
[9] http://title24stakeholders.com/wp-content/uploads/2018/07/2016-CASE-Study-Results-Report-HPA-DCS-v2.pdf
[10] http://title24stakeholders.com/wp-content/uploads/2015/02/2016-T24-CASE-Report-Res-IWH-Feb-2015-V2.pdf
[11] Ibid
[12] TRC found that the majority of kitchen and bathroom faucets are under 2.0GPM flow rate and cost varies widely depending on quality, not flow rate. Showerhead flow rate and cost are also dependent on quality rather than flow rate.
[13] http://title24stakeholders.com/wp-content/uploads/2018/07/2016-CASE-Study-Results-Report-Res-Ltg-v2.pdf
[14] https://www.nrel.gov/docs/fy17osti/68925.pdf.
[15] https://efiling.energy.ca.gov/getdocument.aspx?tn=221366

4 Cost Effectiveness Results

Figure 5 through Figure 7 present the cost effectiveness results for each prototype building. Cost effectiveness is shown for energy efficiency packages alone and for energy efficiency plus solar PV in terms of a benefit-to-cost (B/C) ratio. Cost effectiveness is determined over a 30-year lifespan, including first costs, replacements, maintenance, and energy savings. The 'market package' was not explored for cost-effectiveness because of federal pre-emption limitations.

The baseline building in each case is an ERI=61 building – the mixed-fuel building cost effectiveness is compared to a mixed-fuel building with an ERI=61, and the all-electric building cost effectiveness is compared to an all-electric building with an ERI=61. Note that solar PV system sizes for the "EE measures alone" packages were sized to achieve an ERI=61 per the 2018 IECC performance requirements as described in *Section 2.1*. These PV systems are considered part of the baseline building, and thus do not have associated incremental costs. Incremental costs for additional PV to achieve lower ERI values are included in "EE measures + solar PV" packages.

Figure 5 through Figure 7 show that all prototypes are cost effective with the efficiency measures listed in Figure 4, with benefit to cost ratios ranging from 1.0 to 2.9. Other key takeaways:

- All-electric buildings generate significantly higher kWh savings than mixed-fuel buildings because they include heat pump water heating and heat pumps space heating, and many of the efficiency measures applied save space heating and water heating loads.
- All-electric prototype bill savings are significantly higher than mixed-fuel scenarios because electricity rates are higher than gas in terms of $/Btu.
- Adding solar PV generally increases the B/C ratio for mixed-fuel buildings but reduces the B/C ratio for all-electric buildings. It appears that EE measures applied to the all-electric building have a higher B/C ratio than the solar PV B/C ratio. These findings highlight the importance of both EE measures and renewable generation to cost effectively designing high-performing buildings.
- In some instances, the PV system size exceeds the size that can fit on the prototype roof (9 kW). In these instances, TRC has assumed that a ground-mounted array can be installed at similar costs to a roof-mounted system.

Figure 5. 1500 ft^2 Cost Effectiveness Results

Fuel Scenario	Package	PV System Size (kW)	ERI	kWh Savings	Therms Savings	Incremental Package Costs	Energy Bill Savings	B/C Ratio
Mixed Fuel	EE measures alone	2.0	46	493	129	$2,938	$2,948	1.0
	EE measures + solar PV	4.3	21	3,968	129	$8,868	$12,521	1.4
All Electric	EE measures alone	1.8	47	2,098	0	$2,938	$5,864	2.0
	EE measures + solar PV	6.4	0	9,046	0	$14,797	$25,011	1.7

Figure 6. 3000 ft2 Cost Effectiveness Results

Fuel Scenario	Package	PV System Size (kW)	ERI	kWh Savings	Therms Savings	Incremental Package Costs	Energy Bill Savings	B/C Ratio
Mixed Fuel	EE measures alone	3.5	43	873	242	$4,713	$5,586	1.2
	EE measures + solar PV	6.4	21	5,253	242	$10,415	$17,657	1.7
All Electric	EE measures alone	3.8	40	4,737	0	$4,713	$13,492	2.9
	EE measures + solar PV	9.6	0	13,498	0	$17,891	$37,693	2.1

Figure 7. 4500 ft2 Cost Effectiveness Results

Fuel Scenario	Package	PV System Size (kW)	ERI	kWh Savings	Therms Savings	Incremental Package Costs	Energy Bill Savings	B/C Ratio
Mixed Fuel	EE measures alone	3.8	46	1,039	201	$5,605	$5,821	1.0
	EE measures + solar PV	8.2	21	7,610	201	$14,153	$24,265	1.7
All Electric	EE measures alone	4.4	42	5,734	0	$5,605	$16,527	2.9
	EE measures + solar PV	12.4	0	17,818	0	$23,562	$50,231	2.1

The lowest ERI achieved is approximately ERI=21 for the mixed fuel buildings and ERI=0 for all-electric buildings, including solar PV. These cost-effectiveness findings support the significant lowering ERI targets from 2018 IECC for Boulder single family new construction in Boulder's climate zone across all building sizes. Further considerations for the solar PV necessary to achieve these ERI targets and the impact of Boulder's energy conservation code are in *Section 5 Policy Context and Recommendations*.

5 Policy Context and Recommendations

In addition to the cost effectiveness analysis, TRC and NBI assessed modeling trends to inform the Boulder Energy Conservation Code, presented for each prototype in Figure 8 through Figure 10. These figures represent the relationship between PV deployment and reduced ERI scores. The figures display the ERI values achieved by mixed fuel homes (represented by reddish lines) and all electric homes (represented by bluish lines) as a function of PV size and three potential measure packages:

- Prescriptive: Measures that achieve ERI=61 per the 2018 IECC performance requirements. As described earlier, this includes some solar PV generation to achieve an ERI=61 in the baseline code prototypes.
- Cost-effective: Measures above 2018 IECC found to be cost effective as a package.
- Market: Appliance efficiency improvements that represent a feasible and readily available approach to reducing ERI but cannot be prescriptively required by the City of Boulder due to potential for federal pre-emption.

The ERI trends for the mixed fuel and all electric prototypes are not significantly different – in other words, the reddish lines generally align with the bluish lines. This analysis demonstrates that there are cost effective packages available to significantly reduce the ERI scores of buildings across all sizes and fuel scenarios. The cost effective packages of energy efficiency measures alone reduce the ERI scores by 14 to 21 points, depending on the building size and fuel.

For all building sizes evaluated, there are pathways to achieve ERI=0 through the incorporation of PV systems to offset energy use. However, due to local utility interconnection rules for PV sizing which allow only 120% of electric load to be offset with renewables, only all-electric buildings will be able to successfully target ERI scores approaching zero. This implies that larger buildings will need to be all-electric to meet Boulder's ZNE policy goals depicted in Figure 1.

The market package analysis demonstrates that appliance efficiency improvements can feasibly reduce ERI scores by approximately 10 points and offset the PV system size by approximately 0.5 kW to 2 kW, depending on the size of the building and fuel.

Figure 8. 1500 ft^2 ERI Trends for Mixed-Fuel and All-Electric Buildings

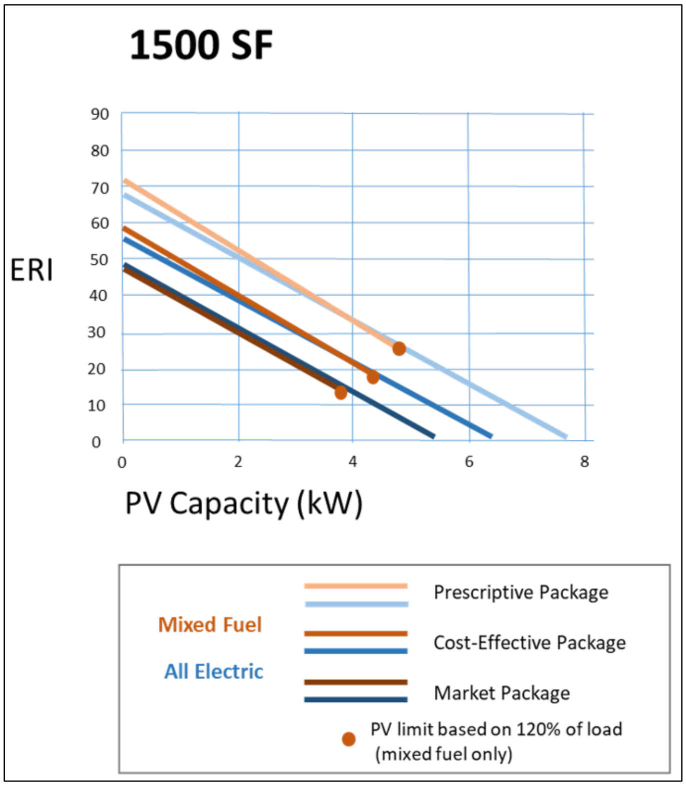


Figure 9. 3000 ft^2 ERI Trends for Mixed-Fuel and All-Electric Buildings

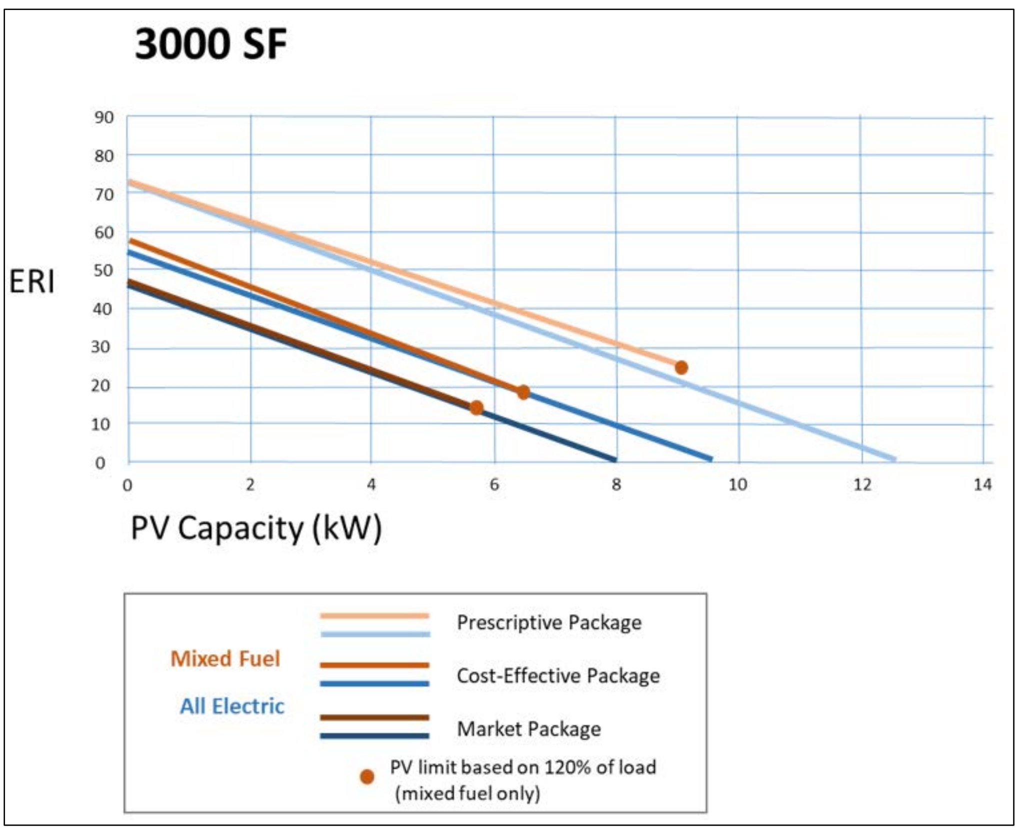
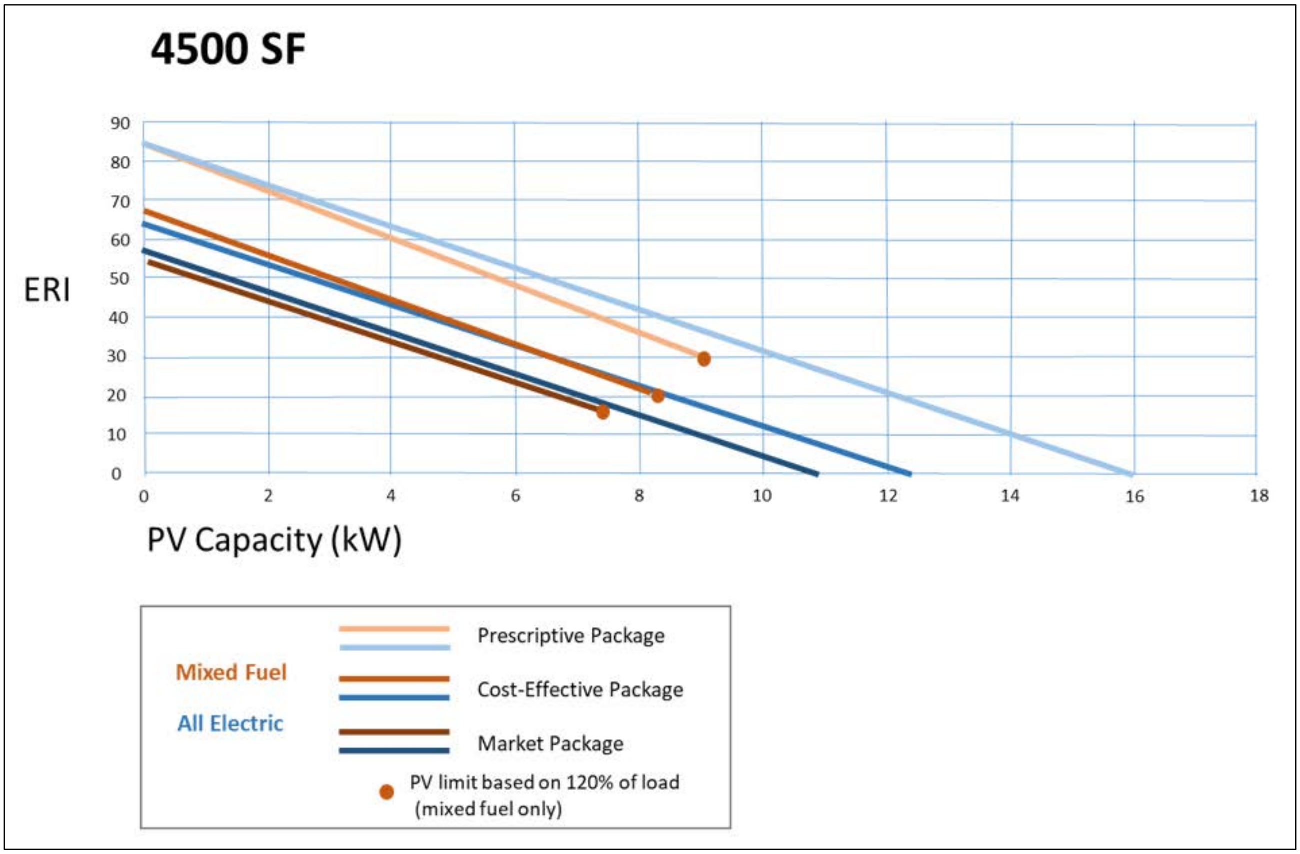


Figure 10. 4500 ft² ERI Trends for Mixed-Fuel and All-Electric Buildings



2020 Boulder Commercial Code Protocol Draft

New Performance Target Approach

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Figures and Tables

INTRODUCTION AND BACKGROUND

The City of Boulder has committed to set of City-wide energy and greenhouse gas (GHG) reduction targets to support the climate commitment goals adopted by City Council on December. 6 2016. This includes a goal of reducing the community's GHG emissions by 80% of 2005 levels by 2050[1] and reducing organizational GHG emissions by 80% of 2008 levels by 2030. To reduce the demands placed on power generation infrastructure and reduce emissions, the City has also planned to increase renewables and community/district energy generation across the city. The goal is to deploy 100% renewable electricity by 2030.

In support of these goals, the City of Boulder has set a target of reaching net zero energy construction for new buildings and major alterations through building and energy code requirements by 2031. NBI and the City of Boulder have developed a strategy to achieve that target; adopting increasingly aggressive performance-based energy codes is a key part of the strategy. This longer term strategy is described in more detail in the report: Boulder Code Strategy Narrative, published separately. This document is focused on proposed changes to the commercial sections of the 2020 City of Boulder Energy Conservation Code.

The 2017 COBECC is based on the 2012 edition of the International Energy Conservation Code® (IECC®), with a specific reference to ASHRAE 90.1-2010 (+30%) as a basis for commercial building code compliance. For the 2020 update, the base code will be the 2018 IECC with reference for commercial buildings to ASHRAE 90.1 2016 with some additions and alterations. The objective of this code cycle is to move away from relative targets (% better than code) and move closer to actual building performance targets based on an energy use intensity (EUI) metric. This will help Boulder to be on track for reaching NZE codes by 2031.

CITY OF BOULDER'S 2020 CODE FRAMEWORK

To meet Boulder's climate targets the 2020 framework represents a shift from the relative building approach (% better than code) in the previous versions of the COBECC to an absolute performance approach. The goal is to reduce the performance gap between the design and the operating building. To achieve this, building performance will be evaluated based on predicted building energy use, rather than on percentage improvement. The sections below provide details about the new metrics and the compliance paths.

Energy Use Metric

Under the new framework, new buildings in Boulder will be required to identify and target specific levels of energy performance, measured as an **Energy Use Intensity (EUI).** This metric provides individual building-specific energy consumption data and encourages higher efficiency in buildings and lower utility costs. EUI is easily calculated and measured at the building level. EUI accounts for a building's total annual energy demand, including plug and process loads that

[1] https://www-static.bouldercolorado.gov/docs/2017_City_of_Boulder_Energy_Conservation_Code_2nd-1-201711151002.pdf?_ga=2.134179533.234461591.1545935870-129887707.1539902798

can make up a significant portion of building's energy use. The metric is calculated with the following units:

$$EUI = \frac{Building\ Annual\ Energy\ Consumption\ (kBtu/yr)}{Building\ Area\ (sq.ft)}$$

This EUI metric is familiar to design teams, building owners, and Boulder staff for two reasons: 1) the current, 2017 energy code requires buildings calculate their EUI as part of the Energy Model Report that must be submitted with permit application, and 2) all new commercial buildings and existing ones>10,000 square feet are required to report their EUI annually to the city as part of the city's Building Performance Ordinance. By moving the energy code in the direction of an EUI outcome focused code, Boulder hopes to close the gap between modeled and metered energy consumption in our building stock.

2020 Performance Targets

Boulder's current commercial building energy code requirement is that buildings demonstrate through energy modeling that the proposed project will achieve a performance of 30% better than ASHRAE 90.1 2010. In the 2020 code cycle, the baseline reference code will be updated relative to ASHRAE 90.1-2016. Although code stringency varies somewhat by building type and climate zone, the 2016 version of 90.1 is approximately 10% more stringent than the 2010 version for the Boulder climate zone (designated 5b). Therefore a performance level of 20% better than 90.1-2016 is approximately equivalent to the current Boulder target of 30% better than 90.1-2010. With this in mind, NBI is recommending a stringency target of 25% better than 90.1-2016 for the 2020 COBECC. We think the performance target of 25% better than ASHRAE 90.1 2016 adds to the stringency required to be on the path to zero and at the same time makes the targets achievable with strategic energy efficiency measures.

Note that with a recommended 5% solar requirement, the actual minimum building performance target is 20% better than 90.1-2016. Also, when using the 90.1 Appendix G modeling process to demonstrate compliance, the reference building performance is calibrated to a 90.1-2004 performance reference. Target performance values will be calibrated accordingly. The table below shows the EUI's associated with the comparative stringency of the proposed code to national code metrics.

Table 1: Comparative Stringency

Comparative EUI Performance Targets						
		Current Requirement			**Proposed Requirement**	
Building Type	**90.1-2010**	**90.1-2010 +30%**	**90.1-2016**	**90.1-2016 +20%**	**90.1-2016 +25%**	**90.1-2016 +30%**
Medium Office	34	**24**	30	24	23	21
Small Office	31	**22**	25	20	19	18
Primary School	56	**39**	45	36	34	32
Secondary School	46	**32**	41	33	31	29
Mid-rise Apartment	50	**35**	43	34	32	30
Warehouse	19	**13**	15	12	11	10
Retail Store	57	**40**	46	37	35	32
Small Hotel	85	**60**	53	42	40	37
Hospital	133	**93**	117	94	88	82
Restaurant	396	**277**	374	299	281	262
Strip Mall	60	**42**	50	40	38	35
Clinic	114	**80**	101	81	76	70

COMMERCIAL SUBMITTAL PATHWAYS

In the 2020 code cycle, commercial building project submittal pathways will be similar to current requirements, with one significant modification: Projects not using the prescriptive pathway will be required to determine EUI performance targets as a basis for compliance, instead of comparing relative performance to a baseline. As a pilot option, and Outcome-Based Pathway will also be adopted. The submittal pathways are described below.

Prescriptive Pathway

Small projects and remodels with total construction cost of $500,000 or less are covered under this track. The prescriptive requirements will be based on updated Boulder commercial code which will be a more stringent version of 2018 IECC, with specific additions to the language to reflect stringency targets set by the City of Boulder. In order to comply with this track, all of the prescriptive requirements (i.e. sections 5.5, 6.5, 7.5, 8.5, 9.5) of the 2020 COBECC should be met.

To achieve a comparable stringency to that required by the performance submittal pathways described below, additional requirements have been added to the IECC 2018 baseline to reflect Boulder's code performance goals. These requirements include the following key features:

- Improved requirements for isolating building envelop elements create thermal bridging
- Increased envelope and fenestration thermal performance
- Advanced occupancy controls for lighting and HVAC
- Expanded heat recovery ventilation requirements
- Improved envelope infiltration performance

Taken together, these and other measures incorporated into prescriptive code requirements should improve building performance by approximately 25% above the base code requirements.

Performance Pathways

All projects with total construction cost of $500,000 and above are required to follow the performance pathway. This pathway includes two options:

Performance Pathway 1: Modeled Performance Target

In this pathway buildings will use the ASHRAE 90.1 2016 Appendix G modeling guidelines (with minor modifications to reflect Boulder code requirements) to determine a baseline building performance requirement, expressed in EUI. Performance values in Appendix G will be adjusted to reflect EUI targets that are 25% lower than the 90.1 2016 baseline. Proposed buildings will be required to demonstrate through energy modeling that they are anticipated to achieve this target EUI, with the following additional requirements:

- No performance trade-offs are allowed below the prescriptive performance tables for individual building elements in 90.1-2016. This code serves as a performance 'backstop' for individual building components. See specific requirements in the Backstop Requirements section below.
- At least 5% of building load must be met by renewables on-site.
- Building schedules and unregulated loads must be modeled using mandatory schedules provided, unless specific alternative schedules are pre-approved by code officials during the permit review process.
- Reductions in unregulated loads of up to 10% of total unregulated load may contribute to the achievement of the EUI targets, provided the project submits and receives approval for a clear plan for specific load reduction strategies to be implemented during occupancy.
- Within 2 years of Certificate of Occupancy, the project must provide a written narrative comparing the proposed building EUI submitted for permit to the actual energy use indicated in annual disclosure data. This narrative should reflect a good-faith effort to understand variations between predicted and actual energy use for the project.

Performance Pathway 2: Fixed Performance Target

For specific project types, NBI has identified EUI performance targets deemed to comply with the intended stringency of this code. Projects may choose to use these targets as a compliance baseline, forgo baseline modeling, and instead provide a proposed building model demonstrating that the building can achieve the listed EUI target, with the following additional requirements:

- No performance trade-offs are allowed below the prescriptive performance tables for individual building elements in 90.1-2016. This code serves as a performance 'backstop' for individual building components. See specific requirements in the Backstop Requirements section below.
- At least 5% of building load must be met by renewables on-site.
- Building schedules and unregulated loads must be modeled using mandatory schedules provided, unless specific alternative schedules are pre-approved by code officials during the permit review process.
- Reductions in unregulated loads of up to 10% of total unregulated load may contribute to the achievement of the EUI targets provided the project submits and receives approval for a clear plan for specific load reduction strategies to be implemented during occupancy.
- Within 2 years of Certificate of Occupancy, the project must provide a written narrative comparing the proposed building EUI submitted for permit to the actual energy use indicated in annual disclosure data. This narrative should reflect a good-faith effort to understand variations between predicted and actual energy use for the project.

EUI Performance Targets for Performance Pathway 2

Some building types have relatively consistent occupancy and usage patterns and therefore may be able to achieve more consistent EUI performance. For these building types, a project may choose to use fixed EUI targets as a basis for code compliance documentation. In these cases, the project will need to demonstrate that the predicted EUI of the proposed building will meet or improve upon the established fixed performance targets. Only the proposed building will need to be modeled in this case, as described in the Modeling Guidelines section below. Buildings identified in Table 2 below are eligible to utilize the Fixed Performance Pathway as a basis for compliance. Alternately, these projects may choose to submit using the Modeled Performance Target pathway.

The establishment of this new pathway helps projects to move toward delivering measured building performance aligned with the city's 2050 GHG reduction goals by encouraging the building industry to begin to consider building performance outcome as a basis for energy code compliance.
In
Table 2 below building types which can utilize the Fixed Performance Pathway are identified, as well as the targets to be used in the compliance documentation. Projects with multiple use types within the building may develop area-weighted targets based on the values in this table.

Table 2: Fixed Performance Targets for Performance Pathway 2.

Site EUI (kBtu/ft²) by Building Type for Boulder Climate (5B)		
Building Type	**90.1 2016**	**90.1 2016+ 25% Better**
Medium Office	30	23
Mid-rise Apartment	43	32
Primary School	45	34
Small Office	25	19
Secondary School	41	31
Warehouse	15	11
Small Hotel	53	40
Hospital	117	88
Retail Store	46	35
Strip Mall	50	38

Optional Outcome-Based Performance Pathway

Over the next several code cycles, the City of Boulder will move to a code strategy where buildings are required to achieve specific performance outcomes, as demonstrated by review of actual energy use data during building occupancy. The EUI Performance Target Pathway is the first step to a focus on measured energy use outcomes. To facilitate additional market transition to measured outcome, the City of Boulder is adopting a zoning density bonus for certain project types. As a requirement of the density bonus, projects will be required to demonstrate achievement of specific energy performance targets during building operation. This will be insured through the collection of a financial surety held by the city until building energy performance is demonstrated.

This zoning incentive effectively sets up an option pilot compliance pathway focused on building performance outcome. The pilot would serve as a model for the 2031 code, and would allow city staff to collect data, evaluate, and make policy adjustments to suit Boulder's commercial construction market. Projects following this path would:

- Set an EUI target during the design phase based on modeling or targets established by building type per code.
- Demonstrate at time of permit how the project will achieve this EUI target through energy modeling.
- Construct the project, with an understanding of the energy performance expected of the building.
- Provide a surety bond at the time of permit, fully refundable to the project if performance is achieved.
- Complete, commission, and occupy the building.
- Within 24 months of the building being occupied, submit metered data to the building official that verifies the EUI target is being achieved.

Projects that are unable to demonstrate that their building's post-occupancy energy consumption complies with the targeted performance will be required to undergo building diagnostics and additional energy modeling to determine how to close the gap between modeled and metered energy use.

REQUIRED DEPLOYMENT OF RENEWABLES

In order to meet long-term ZNE performance goals, it is necessary to encourage the deployment of renewable energy at the project level. In the 2020 code cycle, NBI proposes that at least 5% of commercial building energy use be supplied by on-site renewables. This requirement will increase in subsequent code cycles.

Renewable offset requirements represent the minimum percentage of total building load that must be met with renewables. Projects may choose to deploy more than the minimum amount of renewables to meet overall code targets, based on cost-benefit calculations and other considerations at the project level. However, it is important to make sure that renewables are not used to offset basic building performance to a significant degree. For this reason NBI recommends the adoption of a 'backstop code' as described below, in which renewable deployment cannot offset basic building performance requirements.

The cost of renewable energy deployment at the project level has dropped precipitously in the past decade, with the National Renewable Energy Lab (NREL) estimating that the cost of photovoltaics has declined by two-thirds in the past seven years alone.[2] This has made the on-site installation of photovoltaic generating systems cost-effective at the project level in many cases. For many projects, increased solar installation may be the most cost-effective way to achieve the stringency targets anticipated by this code. By allowing individual projects to incorporate on-site renewable generation into the building, the code sets up significant flexibility for individual projects to evaluate local conditions and efficiency options to identify the least-cost strategy to achieve energy code performance goals.

MODELING GUIDELINES AND BACKSTOP REQUIREMENTS

Projects submitted using the Modeled Performance Target track will be required to use ASHRAE 90.1 Appendix G and Table G3.1 modeling guidelines for calculating baseline and proposed building performance EUI. The baseline building EUI will be used to define the proposed building performance target. The performance target for proposed building will be a 25% EUI reduction compared to baseline EUI.

For the Fixed Performance Target track the proposed building targets will be provided by the jurisdiction. Modelers will use the 90.1 Appendix G guidelines and are required to model the actual building performance to demonstrate that the proposed EUI will meet with the specified targets. The modelers will have the freedom to skip the baseline model building and directly prove the performance through the proposed model. However, they will have to make sure their design meets with the minimum performance requirements through the backstop requirement checklist.

[2] U.S. Solar Photovoltaic System Cost Benchmark: Q1-2017, Ran Fu, David Feldman, Robert Margolis, Mike Woodhouse, and Kristen Ardani, National Renewable Energy Lab, Golden, CO, 2017.

Backstop Requirements and Guidelines

With the availability of inexpensive renewables, some projects may be tempted to deploy large solar arrays instead of emphasizing basic building efficiency. Taken to an extreme, this can deliver inherently inefficient buildings that are at increased risk of excessive energy use if occupants or operators change over time.

To discourage this, a backstop code will be deployed to set a minimum level of performance for building features to make sure that basic building efficiency is not ignored. Backstop requirements for building performance are designed to insure that basic minimum building efficiency strategies are incorporated into each project, even while projects are given flexibility to determine the best set of building features and renewable energy deployment to achieve building performance targets. The backstop requirements include a set of minimum building performance requirements aligned with the prescriptive requirements of ASHRAE 90.1-2016, and a set of standardized schedule assumptions to guide consistent modeling assumptions. No building will be allowed to incorporate features that don't at least meet the backstop requirements, even as creative efficiency strategies are encouraged to meet more stringent performance goals.

The modeling protocol is based on the requirements of ASHRAE 90.1 Appendix G modeling guidelines, with specific adjustments to incorporate backstop performance requirements and standardized building schedule assumptions. Modeling requirements apply to both regulated and unregulated loads, with specific backstop performance or schedule requirements for the following categories:

- Basic Energy Model Requirements
- Infiltration
- Envelope Performance
- HVAC System Performance and Characteristics
- Lighting Power Density
- Domestic Hot Water Equipment Performance
- Plug and Process Loads
- Operating Schedules

More detail on the specific requirements in these categories is provided in the sections below, and in Appendices A and B of this document.

Submetering

To support Boulder's long term goals to improve building energy performance outcomes, projects will be required to install sub-metering to support the on-going evaluation and improvement of building performance. This requirement will also allow projects to separate different load and use types from primary building energy use evaluation. Sub-metering will be required for large and consistent loads such as data centers, restaurant tenants, car charging, and other loads that are likely to significantly complicate the evaluation of building energy use patterns. Sub-metering to determine building energy end use will also be required for larger buildings.

The ability to sort out key building loads will be critical to long-term analysis of building energy use patterns.

Regulated Loads

The IECC as well as ASHRAE 90.1 have regulations on building envelope heat transmission properties, infiltration requirements, lighting power density limits, HVAC and DHW equipment efficiency requirements. Therefore they are categorized under regulated loads.

Most of the backstop requirements are in line with the requirements of Appendix G, except for building envelope insulation and HVAC and DHW system efficiencies. For envelope and HVAC system efficiencies the backstop requires projects to follow the prescriptive requirements from ASHRAE 90.1 2016 i.e. sections 5.5, 6.5 and 7.5. The sections and the tables below summarize the backstop requirements.

Energy Model and Infiltration

ASHRAE 90.1 Appendix G modeling guidelines will be used for the energy modeling and infiltration requirements.

Table 3: Energy Model and Infiltration Backstop Requirements

Building Performance Element		Backstop Requirements
Model	Simulation program that can perform 8760 hourly analysis	Appendix G
	Use Boulder weather TMY3 file	
	Each HVAC zone should be modeled as separate thermal block as per HVAC design drawings	
Building Infiltration	Air leak rate (.4 cfm/sq.ft)	

Other Requirements

The Table 4 below summarizes minimum requirements for building envelop. HVAC, DHW and Lighting end uses.

Table 4: Backstop Requirements for Building Performance

Building Performance Element		**Backstop Requirements**
Envelope Insulation (R Value/U Value)	Roof	Prescriptive requirements, ASHRAE 90.1 2016
	Walls, Above Grade	
	Walls, Below Grade	
	Floors	
	Slab-on-Grade Floors	
	Vertical Fenestration	
	Skylights	
	Window to wall Ratio	Use Appendix G guidelines. No project may exceed 40% total WWR in proposed model.
HVAC	Air side system efficiencies	Prescriptive requirements, ASHRAE 90.1 2016
	Water side system efficiencies	Prescriptive requirements, ASHRAE 90.1 2016
	Minimum Ventilation	CO mechanical code ventilation requirements/ design ventilation
Service Water Heating	Water Heater Efficiency	Prescriptive requirements, ASHRAE 90.1 2016
Lighting	Lighting Power Densities	Appendix G

Unregulated Loads

The codes and standards used by the modeler proscribe specific values for many building components as regulated by the energy code or baseline to which the project is being compared. But there are also a wide range of values that are not regulated or proscribed by the code, and are therefore determined at the discretion of the energy modeler. Although the code and program modeling protocols typically require that the baseline and proposed building models use identical values for these components, the input values themselves are not specified. Current codes and energy modeling protocols have not allowed projects to claim savings from reductions in unregulated loads as part of their code compliance strategy. Hence this end-use is neglected by the designers and the modeling community.

As energy codes become more stringent, the percentage of total building energy use represented by the unregulated loads becomes a more and more significant component of overall building energy use. And the influence of plug loads and other unregulated elements on heating and cooling loads in the building also increase proportionally. In the absence of guidance or regulation on what these loads should be, the variability inherent in the discretion of the energy modeler becomes increasingly significant in the accuracy of the modeled outcome.

The modeling community uses hypothetical numbers and schedules in both baseline and proposed models to account for plug/equipment loads. Since the code does not allow savings in this category, there is little incentive by designers and modelers to accurately determine this number, and no incentive to explore savings strategies. Energy modeling assumptions about these values can vary widely, and can contribute to inaccurate estimation of building electrical and thermal loads. This adversely effects the electrical service sizing and HVAC equipment sizing in the building design, which can generate adverse use energy impacts.

To provide the design community with baseline guidance and to achieve the levels of performance anticipated by Boulder's strategic plan for codes, a mechanism to allow projects to address a wider range of building loads is needed for energy modeling submittals. The sections below address unregulated loads and how they will be handled in the upcoming code cycles.

Plug and Process Loads

For most building types, the main component of unregulated energy loads is plug and process loads. This category includes computers, printers, monitors, and a host of other user electronics. Restaurant and refrigeration equipment also falls in this category. Despite increasing code stringency, unregulated energy consumption from plug and process loads is expected to continue to rise in office buildings and other building types. This is no surprise considering the proliferation of electronic devices and technology advancement. Dependency of building users on high energy consuming gadgets continues to increase. And with the power and influence of newer technologies like multi-function units (MFU) and multiple monitors the energy consumption of offices is expected to go up even more. Building energy codes will need to play a more substantial role in the coming years to curtail the unregulated loads and to bring synergy between the expected and actual energy performance of the buildings.

By incorporating strategies to incentivize reductions in plug and process loads, significant additional energy savings are possible in energy codes. The approach to plug and process loads described below will help the City of Boulder review and deploy measures that directly impact plug and equipment loads. The objective of this approach is to add enforceable code language in the Boulder Code to reduce currently unregulated plug and equipment loads. The goal of bringing this new regulation on plug loads in the Boulder code is to encourage building designers to consider energy efficiency strategies related to equipment and appliances to reduce building energy use during operation. Because the actual deployment of these strategies occur in the occupancy phase of the building, the strategy includes limits on the total savings from plug and process loads that can be accounted for in the submittal process.

NBI is proposing default assumptions for equipment power densities and equipment schedules per building type or space type. Default values will guide the modelers and the building industry on the baselines and industry standards. The possibility of accounting for savings in unregulated loads will encourage the industry to come up with innovative appliance savings strategies/measures to claim savings. The submittals for such measures will be required to have supporting drawings, specification sheets, and sequence of operation etc. with the detailed explanation on how the savings are calculated.

To support a consistent approach to plug and process load calculations, submittals will be required to use standardized baselines. These standardized baselines will be based on the COMNET Modeling Standard. The COMNET Standard was developed as a mechanism to bring consistency to the practice of energy modeling across practitioners and jurisdictions around the country. In the ten years since the first version of the standard was developed, the COMNET Standard has seen increasing recognition and use in the industry. COMENT has proven to be highly influential in the industry and has been widely adopted by major participants in the energy modeling space. The COMNET standard has been worked into modeling protocols published by major jurisdictions and federal organizations to support increased consistency in energy modeling. The building schedules developed by COMNET and anticipated for use in the Boulder energy code are provided in Appendix B.

For plug loads, the COMNET-published default plug loads will be the baselines. The equipment power density (EPD) is estimated for each of the approximate 5,000 sites in the 2003 CBECS dataset using a modification of the procedure described in Section C.14 of NREL/TP-550-41956[3]. For each site in the CBECS dataset, the equipment power was calculated using Equation 1. Four of the independent variables in Equation 1 are taken from Section C.14 of NREL/TP-550-41956.

Equation 1

$$P = (C_{sd} \cdot PD_{sd} + PD_{misc}) \cdot d$$

Where,

P the estimated equipment power density for the space or building in W/ft².

PD_{sd} an estimate of receptacle power for “surveyed devices” including personal computers, monitors, servers, printers and other equipment. Units are W/ft². This term varies for each CBECS site and is based on fields in the CBECS dataset.

PD_{misc} an estimate of miscellaneous receptacle power for equipment not specifically accounted for in PD_{sd}. This is from NREL/TP-550-41956 and varies for each building classification in CBECS.

C_{sd}, a coefficient to scale the P_{sd} power of “surveyed devices”. This coefficient along with PD_{misc} accounts for unreported equipment. This is from NREL/TP-550-41956 and varies for each building classification in CBECS.

d a diversity factor that affects the entire estimate of EPD. For most building classifications this is unity. This is from NREL/TP-550-41956 and varies for each PBAPLUS8 building classification in CBECS.

Specific values for plug loads can be calculated based on whole building energy use patterns, or on a space by space basis, just as with lighting loads. Specific values for baseline plug loads are provided in APPENDIX A: Plug Load Equipment Power Densities.

Schedules

In energy modeling, schedules describe operating characteristics of various building elements, such as when and how many lights are on, what temperature the building is maintained at, what hours occupants are present, etc. To maintain consistency in modeling submittals, NBI recommends adding standardized default requirements for schedules used in models submitted for the performance target tracks. The default schedules included in Appendix B include a set of standardized building operating schedules based on extensive building energy use characteristics research aggregated under the COMNET program.

[3] NREL/TP-550-41956, Methodology for Modeling Building Energy Performance across the Commercial Sector, March 2008.

Projects with special operating hours or other non-standard operating conditions may be allowed to submit alternate schedule assumptions with proper documentation. However, care should be taken to insure that this strategy is not used to artificially inflate EUI targets. Specialized loads, such as server rooms, will be required to be sub-metered to facilitate management and tracking of these loads in the context of overall building operation. Projects proposing custom schedules should also be required to evaluate the EUI impact of proposed schedule changes by comparing the predicted EUI of the building using these proposed schedule changes to the predicted EUI of the building using the baseline schedules. This will allow the reviewer to evaluate the impact of the proposed schedule changes on overall building energy use.

Designers will have the flexibility to adopt innovative savings opportunities related to lighting and equipment control strategies with legitimate documentation. The design team is expected to submit operating guidelines, product cut sheets, supporting drawings, specification sheets etc. with detailed explanation on how the savings is modeled for innovative energy savings strategies which modify the standardized schedule requirements.

The following modeling schedules will be expected to utilize standardized assumptions from COMNET, as provided in the Appendix B: Required Building Schedules document.

- Occupancy Schedule
- Lighting Schedule
- Equipment Schedule
- Cooling Set-point Schedule
- Heating Set-point Schedule
- Service Hot Water Schedule
- Infiltration Schedule
- Servers/ 24/7 Processes Schedule

MODELING FEEDBACK AND BENCHMARKING

The 2020 code update attempts to build stronger relationship between the jurisdiction's energy codes and the actual performance of the building. By adopting Energy Use Index as a compliance metric, the performance target approach will encourage the building industry to take into account the building's energy performance from the conceptual design stage through operation. To provide better feedback to the design community on whether the building are performing as anticipated, beginning with the 2020 code cycle, projects will be required to review actual building energy use in the context of what level of energy use was anticipated in the submittal process.

Benchmarking[4] is the practice of comparing the measured performance of a device, process, facility, or organization to itself, its peers, or established norms, with the goal of informing and motivating performance improvement. When applied to building energy use, benchmarking serves as a mechanism to measure energy performance of a single building over time, relative to other similar buildings, or to modeled simulations of a reference building built to a specific

[4] https://www.energy.gov/eere/slsc/building-energy-use-benchmarking

standard (such as an energy code). Benchmarking is a critical element of an organization's energy management strategy. Benchmarking will play a very crucial role in the jurisdiction's long term vision of outcome based codes as well.

Commercial buildings in Boulder are required to submit annual energy use data to the city under the Boulder Building Performance Ordinance[5]. For new buildings constructed under the 2020 COBECC, the city will implement a strategy to compare the actual energy use reported to the city to the predicted performance submitted for energy code compliance.

Within the first two years of building occupancy, the building owner will be required to submit an analysis of how actual building energy use diverges from proposed building energy use. This process will help the building team understand how well their building performs compared to the performance anticipated in the modeling submittal process. Projects will be encouraged to examine building use patterns and sub metered data to identify performance discrepancies or opportunities for improvement. In this first code cycle where performance follow-up is required, the focus of this effort will be educational and informational for the design community in Boulder and will help with data mining for the City. This process will set the stage for an increased focus on actual building performance in subsequent code cycles by creating performance feedback loops from design to building operation, and by beginning to leverage the value of disclosure data in driving improved building performance.

SUMMARY

The commercial code strategies identified in this document will set Boulder on a pathway to deep building sector energy savings aligned with Boulder's climate goals. These strategies will be incorporated into code language proposals for the City of Boulder to be adopted in the 2020 upgrades to the COBECC.

[5] https://bouldercolorado.gov/sustainability/boulder-building-performance-home

APPENDIX A: PLUG LOAD EQUIPMENT POWER DENSITY

Table 5 below summarizes whole building level equipment power density requirements.

Table 5: Plug Load Modeling Requirements- Whole Building

Whole Building Categories	Default Equipment Power Density (W/ft^2)
Automotive Facility	0.50
Convention Center	0.75
Courthouse	1.67
Dining: Bar Lounge/Leisure	1.32
Dining: Cafeteria/Fast Food	1.37
Dining: Family	1.26
Dormitory	1.96
Exercise Center	0.67
Fire Station	1.54
Gymnasium	0.67
Healthcare Clinic	1.22
Hospital	1.25
Hotel	1.56
Library	0.94
Manufacturing Facility	0.34
Motel	1.56
Motion Picture Theater	0.74
Multifamily	1.42
Museum	0.74
Office	1.67
Parking Garage	n.a.
Penitentiary	1.49
Performing Arts Theater	0.74
Police Station	1.54
Post Office	0.91
Religious Building	0.30
Retail	0.70
School/University	0.69
Sports Arena	0.75

Town Hall	0.75
Transportation	0.52
Warehouse	0.30
Workshop	0.43

Table 6 below summarizes space-by-space level equipment power density requirements.

Table 6: Plug Load Modeling Requirements- Space-by-Space

Space-by-Space Classifications	**Default Equipment Power Density (W/ft²)**
Audience Seating Area, Auditorium	0.75
Audience Seating Area, Convention Center	0.75
Audience Seating Area, Exercise Center	0.67
Audience Seating Area, Gymnasium	0.67
Audience Seating Area, Motion Picture Theater	0.74
Audience Seating Area, Penitentiary	0.75
Audience Seating Area, Performing Arts Theater	0.74
Audience Seating Area, Religious Building	0.73
Audience Seating Area, Sports Arena	0.74
Audience Seating Area, Transportation Facility	0.75
Audience Seating Area, Other	0.75
Atrium, Less than or equal to 40 ft	n.a.
Atrium, More than 40 ft	n.a.
Banking Activity Area,	1.72
Classroom/Lecture/Training, Penitentiary	0.59
Classroom/Lecture/Training, K-12, laboratory and shops	0.59
Classroom/Lecture/Training, Other	0.59
Conference/Meeting/Multipurpose,	0.73
Confinement Cells,	1.49
Copy/Print Room,*	UWBD
Corridor, Assisted Living	1.40
Corridor, Hospital	1.25
Corridor, Manufacturing	0.34
Corridor, Other*	UWBD
Courtroom,	1.49
Computer Room,	n.a.
Dining Area, Penitentiary	1.26

Dining Area, Assisted Living	1.32
Dining Area, Bar Lounge/Leisure	1.26
Dining Area, Cafeteria or Fast Food	1.37
Dining Area, Family Dining	1.32
Dining Area, Other	1.32
Electrical/Mechanical,*	UWBD
Emergency Vehicle Garage,	0.58
Food Preparation ,	1.32
Guest Room,	1.56
Judges Chambers,	1.49
Laboratory, Classrooms	3.34
Laboratory, Other	3.34
Laundry/Washing Area,	0.52
Loading Dock, Interior,	n.a.
Lobby, Assisted Living	1.40
Lobby, Elevator*	UWBD
Lobby, Hotel	1.56
Lobby, Motion Picture Theater	0.74
Lobby, Performing Arts Theater	0.74
Lobby, Other*	UWBD
Locker Room ,	n.a.
Lounge/Break, Healthcare	1.25
Lounge/Break, Other*	UWBD
Office, Enclosed	1.67
Office, Open Plan	1.67
Parking Area, Interior,	n.a.
Pharmacy Area,	0.55
Restrooms , Assisted Living	1.40
Restrooms , Other*	UWBD
Sales Area,	0.55
Seating Area General,*	UWBD
Stairway,*	UWBD
Storage, Hospital	1.25
Storage, >= 50 ft^2	0.31
Storage, < 50 ft^2	0.31
Vehicular Maintenance,	0.50
Workshop,	0.43
Assisted Living, Chapel	1.40
Assisted Living, Recreation Room	1.40
Convention Center, Exhibit Space	0.75

Dormitory, Living Quarters	1.96
Fire Station, Sleeping Quarters	1.54
Gymnasium/Fitness Center, Exercise Area	0.67
Gymnasium/Fitness Center, Playing Area	0.67
Healthcare, Emergency Room	1.25
Healthcare, Exam/Treatment	1.25
Healthcare, Supply Room	1.25
Healthcare, Nursery	1.25
Healthcare, Nurses' Station	1.25
Healthcare, Operating Room	1.25
Healthcare, Patient Room	1.25
Healthcare, Physical Therapy	1.25
Healthcare, Recovery Room	1.25
Library, Reading Area	0.94
Library, Stacks	0.94
Manufacturing Facility, Detailed Manufacturing	0.34
Manufacturing Facility, Equipment Room	0.34
Manufacturing Facility, Extra High Bay (>50 ft Floor to Ceiling Height)	0.34
Manufacturing Facility, High Bay (25–50 ft Floor to Ceiling Height)	0.34
Manufacturing Facility, Low Bay (<25 ft Floor to Ceiling Height)	0.34
Museum, General Exhibition	0.74
Museum, Restoration	0.43
Post Office, Sorting Area	1.67
Religious Building, Fellowship Hall	0.30
Religious Building, Worship/Pulpit/Choir	0.30
Retail, Dressing/Fitting Room	0.82
Retail, Mall Concourse	0.00
Sports Arena Playing Area, Class I	0.67
Sports Arena Playing Area, Class II	0.67
Sports Arena Playing Area, Class III	0.67
Sports Arena Playing Area, Class IV	0.67
Transportation, Baggage/Carousel Area	0.76
Transportation, Concourse	0.76
Transportation, Ticket Counter	0.76
Warehouse, Medium/Bulky Items on Pallets	0.31
Warehouse, Smaller Hand Carried Items	0.31

Note: *UWBD = Use whole building data

APPENDIX B: REQUIRED BUILDING SCHEDULES

(Attached as a separate document)

2020 Commercial Energy Code Outreach

Attendee Summary

Wednesday, February 27, 20
1:30 PM to 2:30 P

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2020 Residential Energy Code
December 20, 2018
Brenton Building

Community Engagement Feedback

- Provide permit data analysis that illustrates the 2017/18 square footage ranges for new construction to better understand and provide context for the proposed 2020 ERI targets.

- Put the energy code update in context of broader community issues and priorities, specifically affordable housing and social equity. Look for opportunities to solve these issues innovatively through zoning and planning solutions (e.g. incentivize higher density development and mixed use development, eliminate code incentives to build larger homes, re-evaluate parking requirements to address density, etc.) Recognize that energy code requirements have real first cost implications.

- Recognize the state regulation that limits PV size to 120% of the home's demonstrated usage impacts smaller homes more so than larger homes as the flat, $2,000 Design Load Analysis fee disproportionately impacts smaller homes with smaller budgets. Follow-up note from staff: Xcel will also accept the HERS/ERI analysis for the purpose of sizing the PV array. The Design Load Analysis is only necessary if the home is trying to install PV in excess of the HERS.

- The triggers and requirements for alterations need further analysis. Construction Value and Actual Value as currently defined in the 2017 code and as proposed in the 2020 code feel disconnected and inequitable. If code requirements depend on the Assessor's data rather than market value rates for home value, the Construction Value for improvements should reference the Schedule of Values rather than market value cost estimates. Additional conversation on this topic raised numerous concerns about what energy efficiency improvements should be triggered for alterations. Staff agreed to investigate alternative triggers for alterations that rely less on the Assessor's database.

- Alternative energy performance requirements for alterations were discussed that would require existing homes to establish a baseline HERS/ERI score and then make improvement on that baseline HERS/ERI score. This idea was supported by several present, and it was discussed that Denver recently adopted similar policy.

- It was requested that the IMC ventilation requirements for make-up air to prevent back-drafting be adjusted if combustion closets are required for open combustions equipment or if closed combustion equipment is installed. This could save a homeowner as much as $1,000 on a kitchen renovation.

- Regarding proposed renewable offset requirements, it was requested that unpermitted hot tubs be grandfathered in. It was suggested that staff solicit feedback from the County on this regulation.

- Regarding the proposed construction waste and demolition waste requirements, several design professionals voiced concern over their inability to control how this is tracked. Subcontractors performing the work do not adequately carry the burden of complying with these requirements. The owner and builder are held responsible when waste haulers fail to comply.

- The design professionals present suggested staff solicit feedback from homeowners directly, as the alteration requirements ultimately effect homeowners ability to make improvements to their homes.

- There was much discussion on the need for city process improvements not just related to the energy code, but with regard to the many city regulations/ordinances that design teams must demonstrate compliance with. It was suggested that the cost to assemble a permit package for the City of Boulder was up to $20,000 more than other jurisdictions. It was recommended that the city consider streamlining these requirements and rely more on the professionalism and ethics of the consultants.

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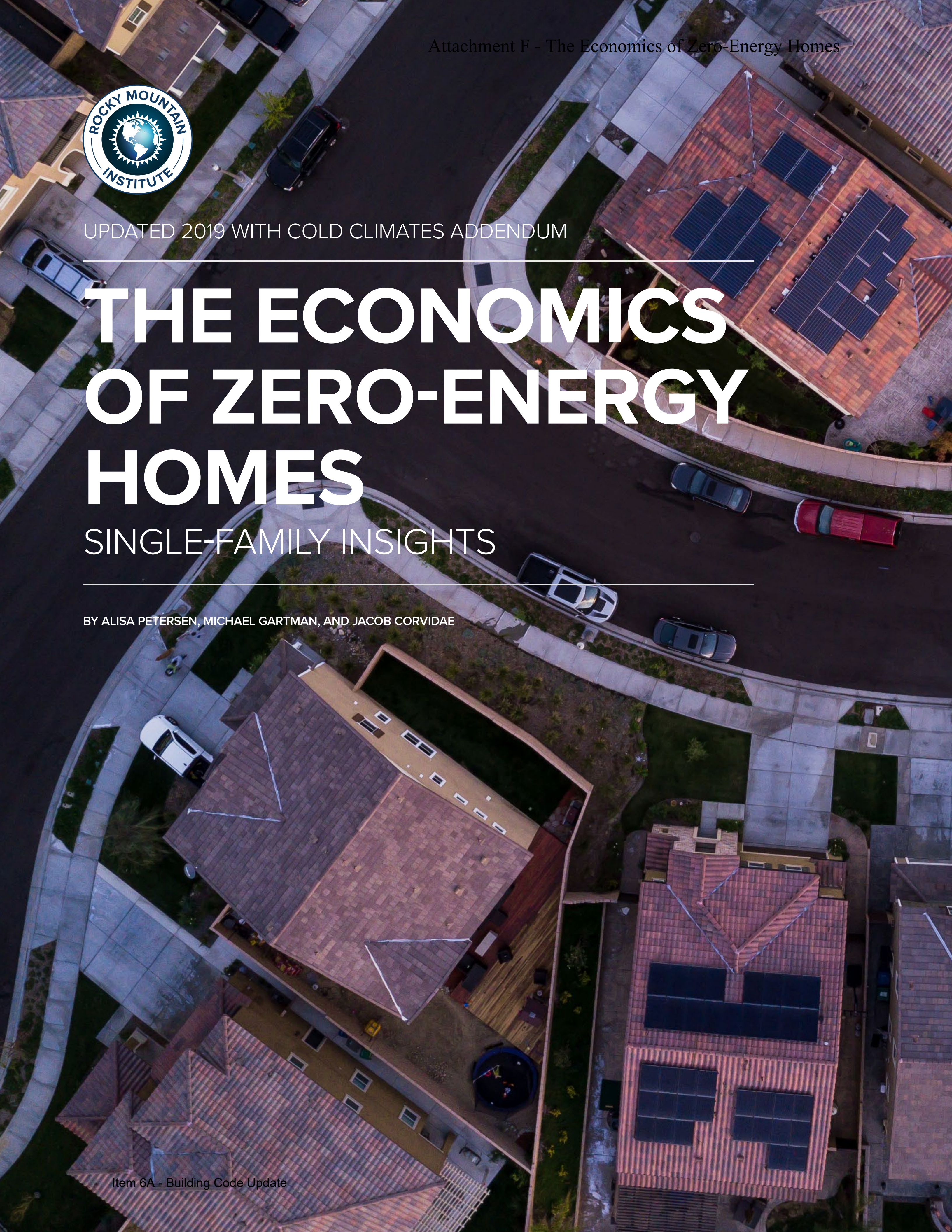

ROCKY MOUNTAIN INSTITUTE

UPDATED 2019 WITH COLD CLIMATES ADDENDUM

THE ECONOMICS OF ZERO-ENERGY HOMES

SINGLE-FAMILY INSIGHTS

BY ALISA PETERSEN, MICHAEL GARTMAN, AND JACOB CORVIDAE

AUTHORS & ACKNOWLEDGMENTS

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ABOUT US

ABOUT ROCKY MOUNTAIN INSTITUTE

Rocky Mountain Institute (RMI)—an independent nonprofit founded in 1982—transforms global energy use to create a clean, prosperous, and secure low-carbon future. It engages businesses, communities, institutions, and entrepreneurs to accelerate the adoption of market-based solutions that cost-effectively shift from fossil fuels to efficiency and renewables. RMI has offices in Basalt and Boulder, Colorado; New York City; Washington, D.C.; and Beijing.

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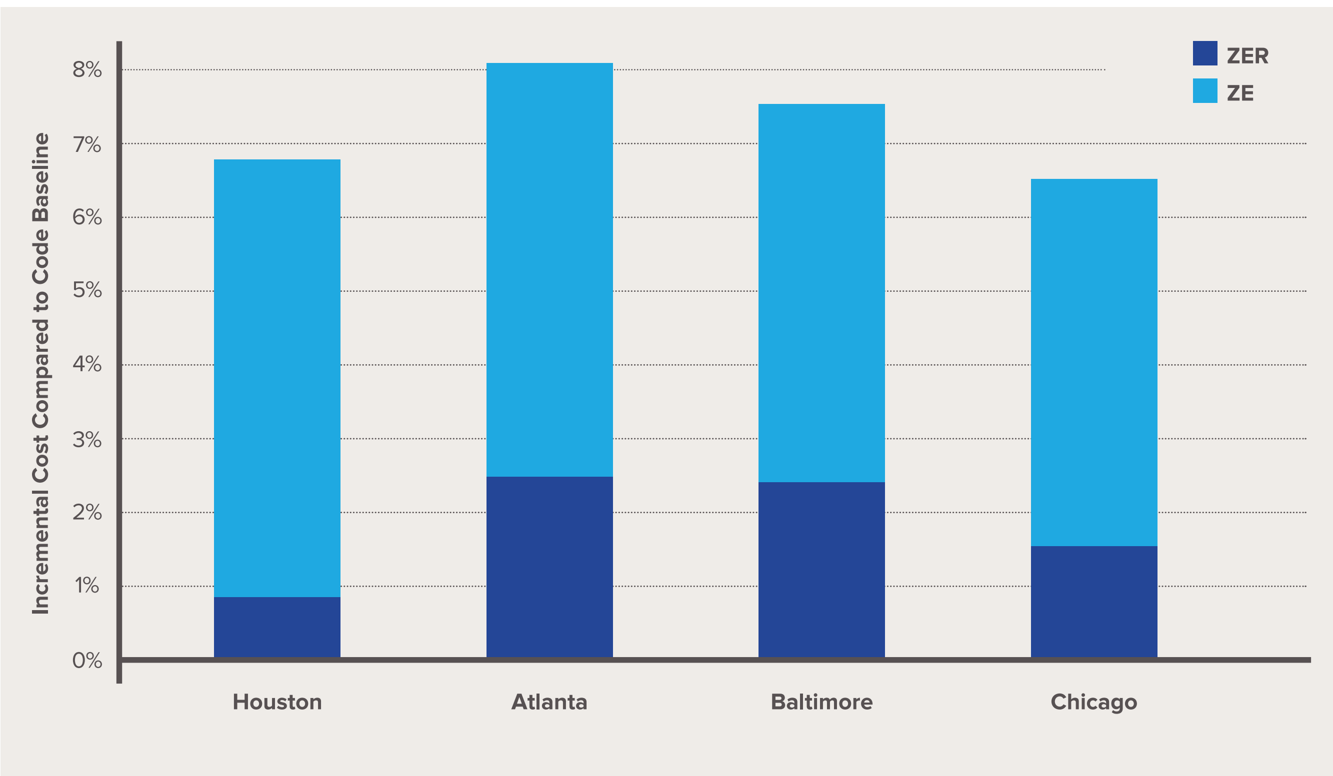
EXECUTIVE SUMMARY

EXECUTIVE SUMMARY

Building new single-family homes to zero-energy (ZE) or zero-energy ready (ZER) home standards can save consumers thousands of dollars over the home's life cycle. ZE homes produce as much renewable energy as they consume over the course of a year, and ZER homes have similar levels of efficiency without on-site solar photovoltaics (PV). In addition, increasing market penetration of ZE homes can help cities meet their aggressive greenhouse gas emission goals while building a more future-proofed and energy-secure building stock.

Despite these benefits, ZE and ZER homes make up less than 1% of the residential market, partially due to outdated perceptions of the incremental cost for these offerings. This report demonstrates that the cost increase to build a ZE or ZER home is modest (with incremental costs of 6.7%–8.1% for ZE homes and 0.9%–2.5% for ZER homes as shown in Figure 1)—far less than consumers, builders, and policymakers may realize—and highlights methods builders and policymakers can use to drive increased market penetration.

FIGURE 1: INCREMENTAL COSTS FOR ZE AND ZER HOMES



Consumer Thresholds

Rocky Mountain Institute (RMI) compared the incremental costs of building ZE and ZER homes in four US locations against four key consumer cost thresholds that reflect the metrics that both homebuyers and builders use to make investment decisions:

- **Mortgage:** The anticipated energy savings over the life of the mortgage.
- **Resale:** The anticipated energy savings over 12 years (the typical length of time homeowners stay in a home).
- **Consumer Willingness to Pay (WTP):** The 4% first cost premium customers have stated they're willing to pay, according to consumer research.
- **First Cost:** The cost to build an identical home that meets local energy code.

When the incremental costs of building ZE and ZER homes are equal to or less than the cost thresholds, decision makers are more likely to bear the cost of investment in ZE or ZER homes. In many cases, the cost thresholds have already been achieved. Figure 2 and Figure 3, respectively, summarize the results for ZER and ZE homes compared against these cost thresholds.

FIGURE 2: INCREMENTAL COSTS FOR ZER HOMES COMPARED AGAINST COST THRESHOLDS

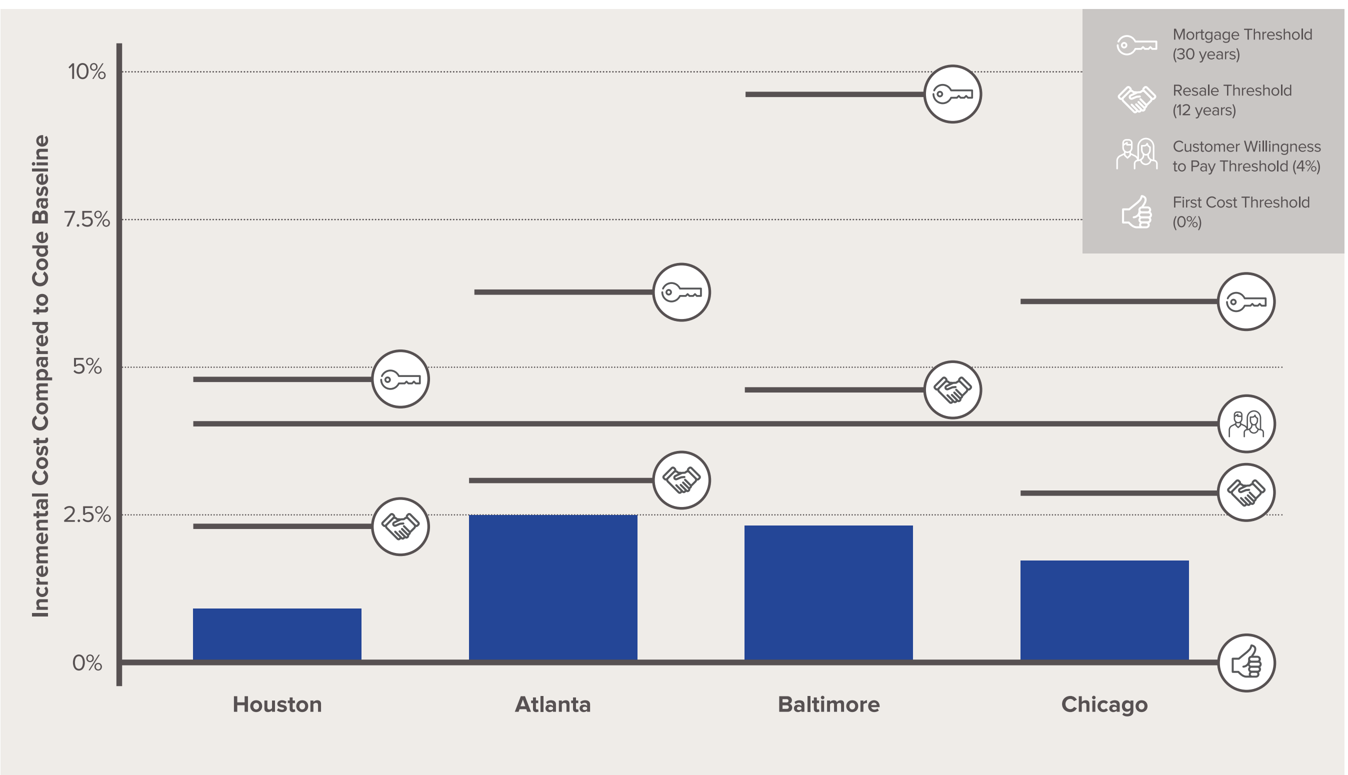
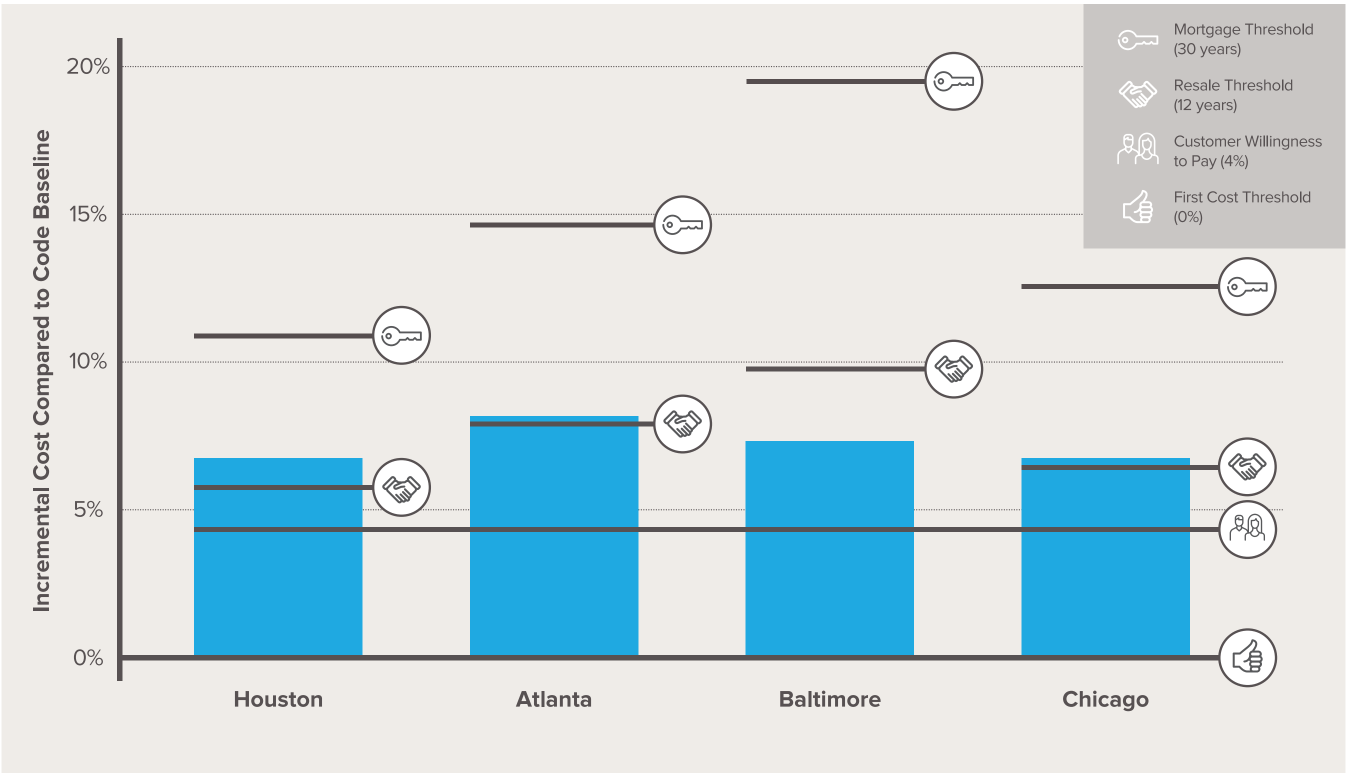


FIGURE 3: INCREMENTAL COSTS FOR ZE HOMES COMPARED AGAINST COST THRESHOLDS



Actions for Builders and Policymakers
Builders can use the recommendations provided in this report to fine-tune home designs and construction processes to minimize incremental costs. This report also outlines key actions that policymakers can take to drive increased adoption of ZE and ZER homes in their jurisdictions. Both builders and policymakers are essential to driving progress in this industry.

For the cases in which the cost thresholds are not met, it is important to remember that costs of building ZE and ZER homes continue to decline, with a projected incremental cost for ZE homes of 3%–5% by 2030. Although our analysis yielded concrete recommendations for cost-optimal ZE home designs, a variety of other solutions are available and may be specified based on local conditions or consumer priorities. This analysis also focused on all-electric solutions; we did not analyze natural gas options.

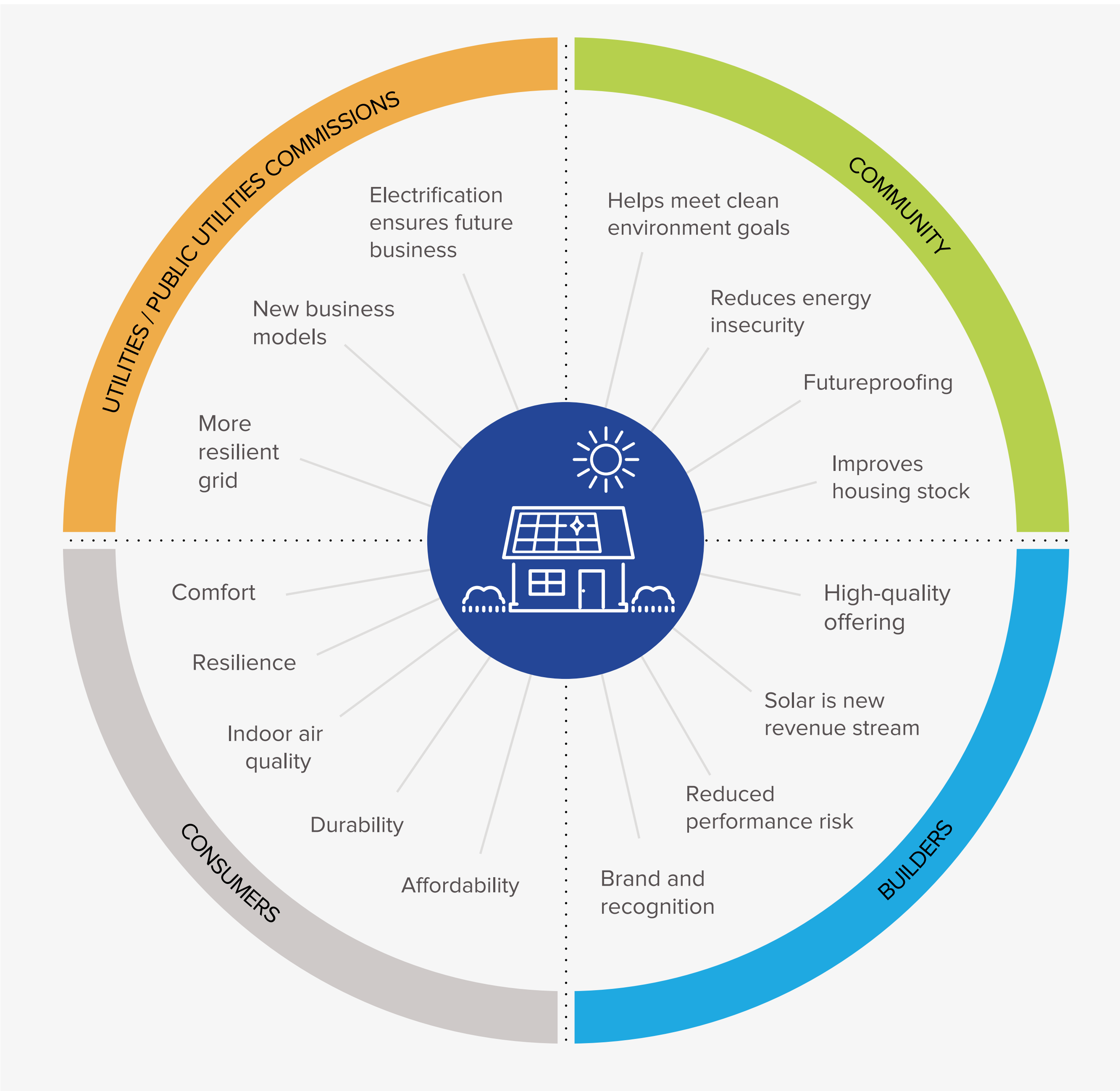
01

THE COST BARRIER FOR ZE HOMES

THE COST BARRIER FOR ZE HOMES

The energy performance of highly efficient ZE and ZER homes can provide myriad benefits to homeowners, builders, utilities, and communities at large, as documented in a growing body of evidence.[1] Figure 4 provides a summary of these benefits across key stakeholder groups.

FIGURE 4: BENEFITS OF ZE HOMES

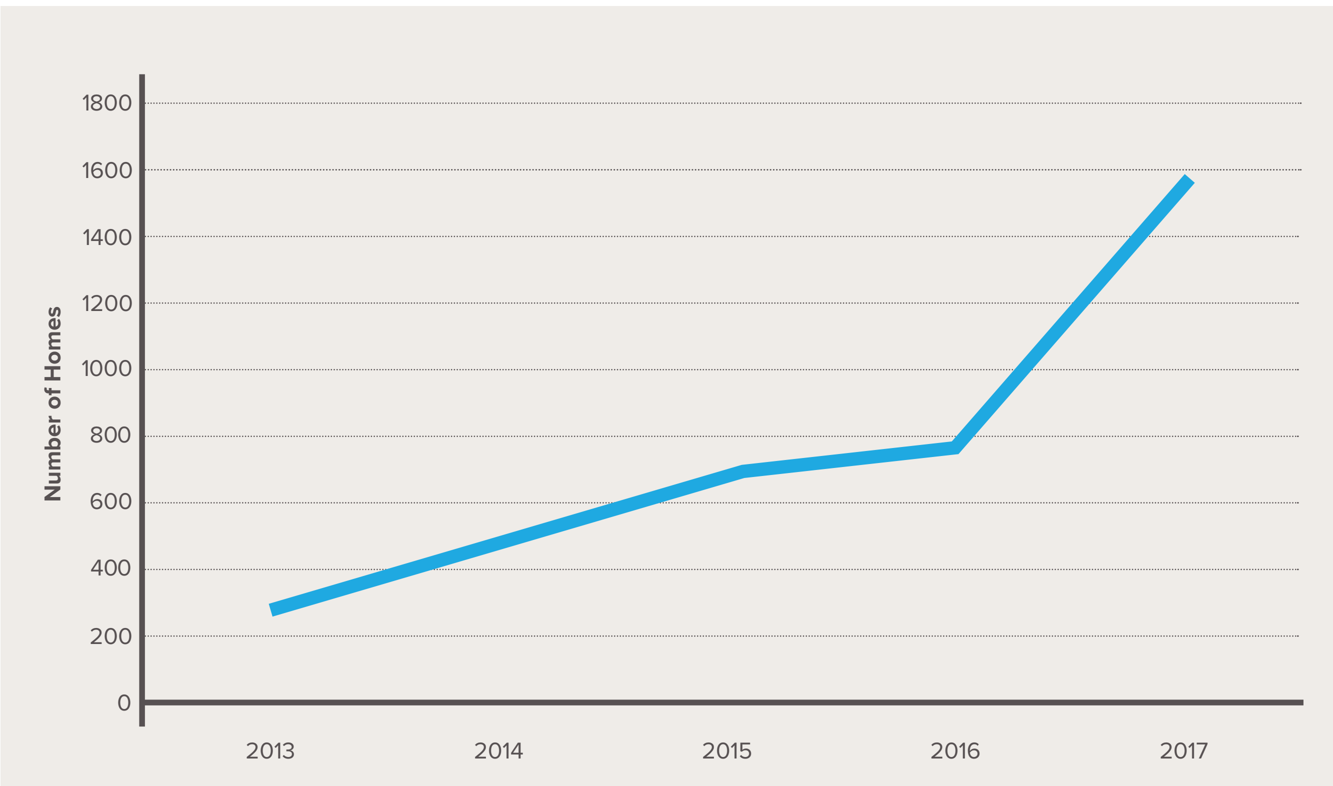


Yet, most stakeholders never consider the opportunity that ZE and ZER homes represent due to outdated perceptions of the price tag these benefits carry: A National Association of Home Builders (NAHB) 2017 survey found that 81% of single-family home builders either don't know how much more it will cost to build a green home or thought green home building would add more than 5% to the cost, while 58% think consumers are willing to pay less than a 5% premium for a green home.[2] Consumer research yields a similar result for home buyers. These perceptions are preventing or disincentivizing stakeholders from acting in their own long-term interests.

While ZE and ZER single-family homes still comprise less than 0.1% of the current US residential housing stock,[3] the market for these homes is growing rapidly: Net Zero Energy Coalition reported an astounding 60% market growth from 2016 to 2017,[4] while DOE's Zero Energy Ready Home (ZERH) program reported 104% growth in certified projects over the same time period (see Figure 5). Additionally, DOE's ZERH program has forecasted 1,150 certified homes in 2018, nearly doubling the number of certified homes for the third straight year.

This report attempts to further accelerate that growth by addressing outdated cost perceptions and showing

FIGURE 5: ZERO ENERGY READY HOMES CERTIFIED EACH YEAR[5]



that the superior long-term performance of ZE and ZER homes deserves consideration from a variety of stakeholders. The following pages identify the current incremental cost of ZE and ZER homes, describe best practices for builders to minimize costs, shed light on dropping cost trends, and provide policymakers with recommendations for how to promote growth of ZE homes in their cities.

This report is focused on single-family homes. A similar report focused on multifamily housing will be produced at a later date.

What Is Zero Energy? What Is Zero Energy Ready?

A ZE home is a highly efficient home that produces as much renewable energy as it consumes over the course of the year. This report defines a ZER home as a home that could be certified under the DOE ZERH program. DOE defines a ZER home as "a high-performance home so energy efficient all or most annual energy consumption can be offset with renewable energy." A home builder may choose to pursue ZER instead of ZE if there is excessive roof shading (e.g., trees, urban locations), unconducive roof design for solar PV (e.g., orientation, complexity), budget constraints requiring a lower up-front cost, or preference to wait until solar prices drop further before purchasing. Although not all buildings can be built to ZE standards, all buildings can be built to ZER standards. ZER helps "futureproof" homes against changing expectations and allows for other renewable energy solutions, such as community solar programs, utility renewable power purchase options, and purchase of carbon offsets. The DOE ZERH program requires independent verification to ensure that homes will perform as intended, and it offers easy-to-follow guidance for builders that are new to building ZER homes.

Although ZE homes don't need to be all electric (this is not a requirement of the DOE ZERH program), this report focuses on completely electric ZE homes. Natural gas, fuel oil, and propane in residences currently account for one-tenth of total US carbon emissions and cannot be directly offset using renewables.[6] Further, RMI's research and analysis have found that in many cases electrification of space and water heating in new construction homes reduces homeowner costs over the lifetime of the appliances when compared with fossil fuels.[7] This focus also reflects the industry trend of electrifying building components as related technology matures: most notably, 43% of new homes now use air source heat pumps (ASHPs) for heating and cooling, compared with 10% of all existing homes as of 2015.[8]

Note that a wide range of terminology exists for these super-efficient building definitions. ZE homes are commonly referred to as net-zero energy homes; ZER homes are similarly referred to as net-zero energy ready homes. Net-zero carbon homes share very similar features but may not be identical to a ZE home. This report uses the terms "zero energy" and "zero-energy ready" to align with DOE-adopted terminology.

Introducing Cost Thresholds

Many prospective homebuyers don't factor in long-term costs associated with homeownership, such as utility bills, maintenance, and future value. Although some consumers might be willing to overlook sticker price because they understand the added benefits of a ZE home, this is not typical. Therefore, to increase market penetration, ZE and ZER homes need to be financially appealing to the broader market.

RMI centered the analysis in this report upon four "cost thresholds" that reflect metrics that both homebuyers and builders use to make investment decisions. When these cost thresholds are achieved (as some already have been), these decision makers are more likely to bear the cost of investment in ZE or ZER homes. The cost thresholds considered are:

- **Mortgage Threshold:** This threshold compares the incremental cost to build a ZE and ZER home (compared with an identical home that meets local energy code efficiency standards) to the net-present value of the anticipated energy savings over the life of the mortgage (**30 years** is most common).[9] This threshold might be desirable to long-term consumers who have no intention of moving and are likely interested in owning a ZE home for more than just financial reasons. Another way of thinking about this threshold is using net monthly cash flow: if the monthly mortgage payment increase is less than or equal to the monthly energy bill savings, then the mortgage threshold has been achieved.[10]

- **Resale Threshold:** This threshold compares the incremental cost to build a ZE and ZER home (compared with an identical home that meets local energy code) with the net-present value of the anticipated energy savings over the typical length a homeowner is expected to stay in the home (which is **12 years**).[11]

- **Consumer Willingness to Pay Threshold:** This threshold compares the incremental cost to build a ZE and ZER home (compared with an identical home that meets local energy code) with the first cost premium customers have stated they're willing to pay in consumer research. According to the latest NAHB research, 42% of consumers are willing to pay a **4% premium for a green home**, and 51% of consumers are willing to pay a 4% premium for a ZE home, according to an Opinion Dynamics survey performed in California.[12] Another study by NAHB found that consumers would be willing to spend an average of $10,732 more for every $1,000 in annual energy savings, which roughly translates to a **3.9% incremental cost**.[13] Although none of these consumer WTP metrics perfectly represents how much more consumers nationally would be willing to pay for a ZE home, combined they point to a similar threshold that people would be willing to pay for a ZE home—roughly a 4% premium.

- **First Cost Threshold:** This threshold compares the incremental cost to build a ZE and ZER home with an identical home that meets local energy code. If the first cost threshold is achieved, a ZE and ZER home will **cost the same** as a code-compliant home. If this threshold is achieved, the cost barrier to ZE and ZER homes has been eliminated.

Policymakers can use these cost thresholds to inform ZE programs and determine the level of incentives or cost reduction strategies required to overcome the first cost objection. Builders can use these cost thresholds to set targets for cost reduction in their ZE and ZER homes. This can help support their net profits by reducing costs and increasing the pool of customers they can serve with ZE and ZER homes.

02

THE CURRENT COST OF ZE HOMES

THE CURRENT COST OF ZE HOMES

RMI's techno-economic analysis confirmed that ZE homes have already passed the mortgage and some resale thresholds and that ZER homes have already passed the mortgage, resale, and consumer WTP thresholds in most US markets. To determine the current state of ZER and ZE home costs, RMI analyzed a typical single-family home in four cities (Houston, Atlanta, Baltimore, and Chicago) representing International Energy Conservation Code (IECC) climate zones 2–5, where 90% of new construction homes are being built.[14] These locations collectively represent an array of utility rates, labor costs, and solar resources, providing a diverse look at ZE costs across the country. The updated version of this report now also includes an addendum covering findings for climate zones 6 and 7.

RMI used BEopt, a free software tool developed by the National Renewable Energy Laboratory (NREL) to complete this analysis. BEopt can model various energy efficiency measure packages to find the "optimal" ZE package at the lowest cost.[15] Embedded in BEopt is a measure database that is set up to easily model certain envelope, lighting, large appliance, heating and cooling equipment, and hot water energy conservation measures (ECMs). The measure database has costs associated with each ECM using the National Residential Efficiency Measures Database (NREMD); these costs were updated or verified using RSMeans data; American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) data; National Institute of Standards and Technology (NIST) data; Electric Power Research Institute (EPRI) data; manufacturer cost quotes; and other available resources. The cost resource used for each ECM can be found in Appendix A.

RMI derived the baseline home cost from RSMeans and altered cost by location using RSMeans city-specific location factors. We also created a baseline model in BEopt to determine baseline energy consumption and baseline costs associated with energy-related equipment. We then compared the cost-optimized ZE home with the baseline BEopt home cost to determine incremental cost of energy-related equipment. Each baseline model was the same 2,200-square-foot, three-bedroom, two-bathroom home with a two-car garage but envelope and HVAC properties were climate zone-specific to the levels required by IECC 2009 energy code. Because the home was modeled to mimic typical construction, passive design strategies, such as optimized window placement, were not considered. **IECC 2009 energy code was selected as the baseline code** because that is the most common code in the United States,[16] and most cities with an energy code that isn't IECC 2009 have a more aggressive code, which would result in even smaller incremental costs to achieve ZE or ZER homes. Additionally, one goal of this analysis is to be able to scale the results from the four-city analysis throughout the United States. ZE and ZER home costs vary widely based on location. Labor and material rates, climate zones, utility rates, and building energy codes all play a role in determining the incremental cost to construct a ZE and ZER home. Appendix B summarizes how these results can be used to approximate the cost of ZE and ZER homes in 50 other cities as well as a methodology to use the results to approximate the cost in additional cities. Additional details about the assumptions that went into the baseline building models can be found in Appendix A. The results from the four-city analysis are summarized in Table 1.

TABLE 1: RESULTS FROM THE BEOPT ANALYSIS

	CZ2	CZ3	CZ4	CZ5
Modeled City	Houston, TX	Atlanta, GA	Baltimore, MD	Chicago, IL
Utility Energy Rate ($/kWh)	$0.096	$0.121	$0.147	$0.122
Baseline Energy Use Intensity (kBtu/sf/yr)	22.0	23.6	26.9	33.1
Proposed Energy Use Intensity (kBtu/sf/yr)	13.0	13.3	13.8	16.0
Solar PV Size (kW)	6.5	6.2	6.8	8.4
Baseline Cost ($)	$228,479	$242,243	$253,254	$346,848
Incremental Cost for ZER Homes($)	$2,065	$6,094	$5,993	$5,368
Incremental Cost for ZER Homes (%)	0.9%	2.5%	2.4%	1.5%
Incremental Cost for ZE Homes ($)	$21,240	$25,314	$24,693	$30,736
Incremental Cost for ZE Homes (%)	9.3%	10.4%	9.8%	8.9%
Incremental Cost for ZE Homes with ITC ($)	$15,488	$19,548	$19,083	$23,125
Incremental Cost for ZE Homes with ITC (%)	6.8%	8.1%	7.5%	6.7%

ZE homes have an average 7.3% cost premium and ZER homes have an average 1.8% cost premium compared with code baseline efficiency homes, based on the techno-economic analysis performed by RMI and summarized in Table 1. This is the cost to builders and does not include the cost of land. Incremental increases for ZE homes for developers and home buyers will be a smaller percentage of the total cost.

ZER Cost Thresholds Snapshot

The maximum incremental cost to meet each cost threshold was calculated and compared with the current incremental cost to build ZER homes. Figure 6 summarizes the results. Houston has the lowest mortgage and resale thresholds because it has the lowest utility rates, as Table 1 shows. The city also has a lower incremental cost because it doesn't require significant envelope upgrades beyond IECC 2009.

FIGURE 6: SUMMARY OF ZER HOME COST THRESHOLD ACHIEVEMENT

	Houston (CZ2)	Atlanta (CZ3)	Baltimore (CZ4)	Chicago (CZ5)
ZER Incremental Cost	$2,065	$6,094	$5,993	$5,368
Mortgage Threshold (30 years)	✓ $10,980	✓ $15,563	✓ $23,305	✓ $20,619
Resale Threshold (12 years)	✓ $5,576	✓ $7,903	✓ $11,835	✓ $10,472
Customer Willingness to Pay Threshold (4%)	✓ $9,139	✓ $9,690	✓ $10,130	✓ $13,874
First Cost Threshold (0%)	✗ $0	✗ $0	✗ $0	✗ $0

ZER homes are consistently less expensive than the mortgage, resale, and consumer WTP thresholds. Surprisingly, these homes almost meet the first cost threshold; on average, they only cost 1.8% more than a code-compliant home.

ZE Cost Thresholds Snapshot

The maximum incremental cost to meet each cost threshold was calculated and compared with the current incremental cost to build ZE homes. Figure 7 summarizes the results.

ZE homes consistently passed the mortgage threshold and are close to passing the resale threshold. This analysis includes the solar Investment Tax Credit (ITC), a federal tax credit that reduces solar cost by 30% until 2019. This tax credit is in the process of being phased out; the impact of this phaseout is addressed in the "Solar PV Installed Costs" section of the report.

FIGURE 7: SUMMARY OF ZE HOME COST THRESHOLD ACHIEVEMENT

	Houston (CZ2)	Atlanta (CZ3)	Baltimore (CZ4)	Chicago (CZ5)
ZE Incremental Cost	$15,488	$19,548	$19,083	$23,125
Mortgage Threshold (30 years)	✓ $26,715	✓ $35,927	✓ $49,118	✓ $45,414
Resale Threshold (12 years)	✗ $13,567	✗ $18,245	✓ $24,945	✗ $23,063
Customer Willingness to Pay Threshold (4%)	✗ $9,139	✗ $9,690	✗ $10,130	✗ $13,874
First Cost Threshold (0%)	✗ $0	✗ $0	✗ $0	✗ $0

How Does Builder Expertise Affect Cost?

Builder expertise and experience with ZE homes play a large role in the incremental cost to build a ZE home. Builders new to ZE homes might initially see higher costs than the costs highlighted above, but new ZE builders should be able to achieve these costs or lower as they optimize technical solutions and get crews acclimated to these approaches. This learning curve will likely be much steeper for minimum code builders compared with ENERGY STAR builders, but all builders should rapidly find opportunities for cost reductions from systems integration and optimization often only gained with experience. A recent NAHB study showed that builders that build majority green homes think green homes have less than a 4% incremental cost to build, whereas builders that have only a small green building portfolio typically think it has a 10% incremental cost.[17] When builders are first starting to build ZE homes, there is a large learning curve. The typical subcontractors they work with might not be familiar with the new technology, selection of the cost-optimal package may take a few iterations, and builders need to integrate completely new processes into their design, such as the Home Energy Rating System (HERS) rater.

Could Local Incentives Help Achieve Cost Parity?

This analysis conservatively assumes no local incentives. Where efficiency incentives are available, ZER homes may already have a lower cost than standard construction. For example, in Chicago, Commonwealth Edison offers incentives for appliances, smart thermostats, mini splits, and hot water heat pumps, for a combined incentive of $1,450. These incentives bring ZER homes even closer to cost parity with only a 1.1% incremental cost compared with a code baseline home. For local incentives to help increase market penetration of ZE buildings, incentives will need to be effectively communicated to builders and easy to use.

Could a Solar PPA or Lease Help ZE Homes Achieve Cost Parity?

Although this analysis assumes outright purchasing of solar PV, financing options could offset most or all PV first costs and spread them over the life of the system. Because third-party solar providers offer power purchase agreements (PPAs) and solar leases, homeowners can use these financing vehicles to capture the Modified Accelerated Cost Recovery System (MACRS) tax credit, which is normally available only to businesses.[18] In some locations, PPA providers can offer contracts that provide homeowners with cheaper electricity rates than those available through utilities, allowing consumers to purchase ZE homes at ZER prices.[19] Policymakers can encourage businesses to offer PPAs and loans by working with utilities to offer favorable interconnection and net-metering policies and local financial incentives and by providing clarity around any legal or regulatory requirements for third-party solar ownership models.

The Added Cost of Ensuring Indoor Air Quality

ZE and ZER homes have better indoor air quality than most residential homes on the market because they require mechanical ventilation, which means that fresh air entering the home isn't dependent on occupants opening windows or high levels of infiltration. Having good indoor air quality reduces the risk of mold, asthma symptoms, moisture, radon, carbon monoxide, and toxic chemicals.[20] Better indoor air quality can reduce eye irritation, allergies, headaches, and respiratory problems. To qualify for the ZER certification, a home must also be certified under the US Environmental Protection Agency (EPA) Indoor airPLUS program, which adds an estimated $1,000 to the incremental cost.[21] This would have a minor effect on the incremental cost. For example, this would increase the ZER cost in Chicago from 1.5% to 1.8%. This added cost comes from requirements such as radon-resistant construction in EPA Radon Zone 1; supplemental dehumidification in hot/humid climates; low-formaldehyde wood products and adhesives; corrosion-proof rodent screens; low-volatile organic compound (low-VOC) interior paints, finishes, and carpets; home ventilation before occupancy; and equipment manuals. This program also improves pest management in the home, which reduces residue from pests that can trigger allergy and asthma attacks. Although Indoor airPLUS certification is required to qualify for the DOE ZERH program, this cost was not included in the cost thresholds report because a home can become ZE without being certified.

Are ZE Homes More Resilient?

ZE homes can provide an added resilience value to homeowners if the right components are in place. However, solar PV alone doesn't help with resilience currently because most grid-tied solar PV systems are designed to turn off during a power outage. One low-cost solution to this challenge is a secure power supply inverter, which allows solar PV systems to supply energy to ZE homes during grid outages at an added cost of only **$350 to $400**.[22] The technology does have some restrictions: It will only provide power when the solar PV system is producing energy, and it can only supply a set amount of power. This low-cost solution would help during a natural disaster, but it would still leave ZE homes without power at night and wouldn't support 100% of typical energy usage in the home.

An even more robust resiliency solution is to add an energy storage system, which can store energy produced by a solar PV system to be used even when the sun isn't shining. Energy storage systems provide resilience to homeowners and stability to the electricity grid and can even insulate homeowners against changes to utility rate structures (such as time of use, demand charges, or elimination of net metering). An energy storage system adds **$7,900 to $14,600** to the total ZE package before incentives[23]—but, like solar, costs are dropping rapidly. An energy storage system would allow the home to move away from zero energy and toward zero carbon and resilience.

Policymakers should include energy storage and secure power supplies in conversations about ZE policies to ensure a solution that minimizes grid costs and improves reliability. Although energy storage is rarely economical in residential applications under current conditions (due to a lack of demand charges or time-of-use rates), new utility business models often emphasize these strategies. Policymakers should work with utilities to ensure that future efforts to address grid volatility incorporate incentives and rate structures that support energy storage solutions. Builders and policymakers should also consider the Insurance Institute for Business & Home Safety FORTIFIED Home program for regionally specific design strategies to help fend against natural hazards.

Builders can also work with their local utility to help promote resilient ZE homes. Mandalay Homes, one of the largest ZE home builders in the United States, is building 3,000 ZE homes in Arizona with solar PV and energy storage and is coordinating with the local utility to set up a plan for the utility to pay homeowners to use the stored power.[24]

03

COST-OPTIMAL BUILDING PRACTICES FOR ZER

COST-OPTIMAL BUILDING PRACTICES FOR ZER

There is no “one-size-fits-all” solution for constructing a cost-optimized ZER home. A truly cost-optimized design is influenced by not only local climate but also site constraints, local labor rates, utility tariffs, and existing financial incentives. However, our analysis revealed several universal insights that can provide guidance for builders and policymakers alike.

HVAC: Heat Pumps Are an Essential Opportunity

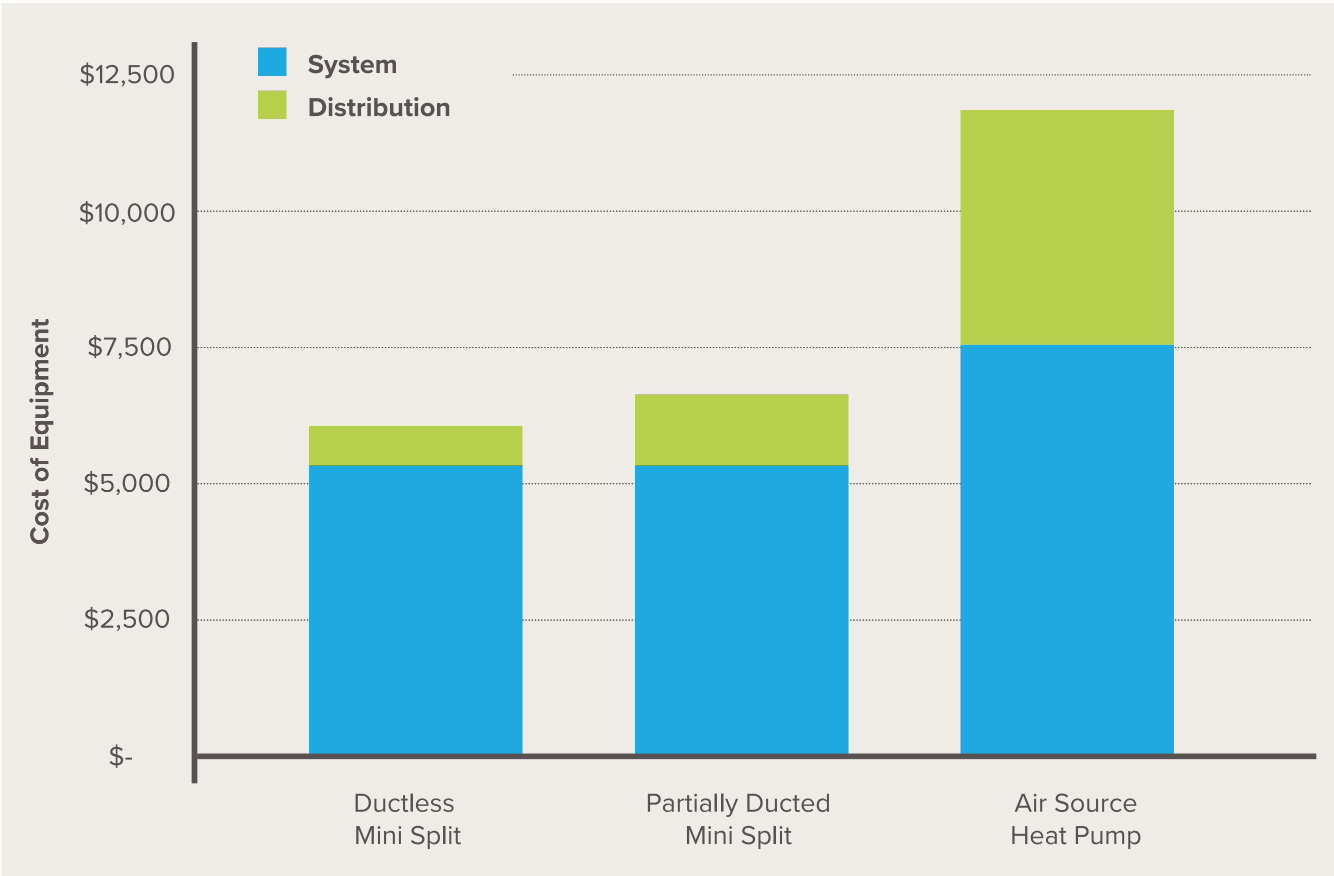
Until recently, heat pumps have primarily been relegated to the milder winter climates of the southeastern United States due to an inability to operate in subfreezing temperatures. However, technological advancements have now yielded hundreds of models that can operate efficiently in temperatures as low as 5°F, with some units performing down to -12°F,[25] allowing year-round performance even in the cold climate of Chicago.[26] These systems now represent an essential component for ZE and ZER homes.

A range of options exists for builders specifying heat pump HVAC systems:

- **Ductless Mini Splits:** Mini split systems are capable of outperforming the efficiency of best-in-class central air conditioners (ACs) by over 30%.[27] Ductless mini splits can represent the lowest-cost system option in milder climates and smaller homes where whole-house comfort can be provided with only two heads and high-transfer grilles between rooms. Using additional heads can provide occupants with a level of personalized comfort control that isn’t possible with centralized systems. Builders and policymakers must work with experienced installers or manufacturers to understand the limitations of ductless systems in their local context.
- **Partially-Ducted Mini Splits:** Builders can incorporate ductwork into mini split systems to promote whole-house comfort without the need for additional heads. They can use exposed ductwork, or tray or drop ceilings, to ensure that perimeter spaces are adequately ventilated while avoiding the energy losses introduced by situating ductwork in unconditioned attics. Targeting home layouts and mini split siting to minimize necessary distribution equipment can reduce duct costs by over 50% compared with traditional central system ductwork at a similar cost to ductless systems (see Figure 8 for a cost comparison).
- **ASHPs:** Centralized ASHP systems are typically more robust than mini split systems and do not present the same home design constraints (e.g., a need for open floor plans and careful siting of HVAC equipment). Centralized ASHPs are also capable of incorporating high-capture filtration systems,[28] a potentially significant benefit in urban environments. Progress in this industry is yielding a variety of offerings capable of competing with the cost of mini split systems.

Figure 8 provides a sampling of costs for the three heat pump HVAC systems specified for a ZER home in Baltimore. It is important to note that these costs are estimated for a single-family home layout and that cost-optimal solutions may vary for different home designs and climates.

FIGURE 8: COST OF MODELED HEAT PUMP HVAC OPTIONS FOR BALTIMORE[29]



Current-generation mini split ACs use an inverter to drastically increase efficiency by allowing the unit to ramp up or slow down to match heating or cooling loads, yielding unique commissioning and maintenance requirements that local contractor pools may not be adequately trained to handle. Policymakers can directly address this potential bottleneck by promoting training and education programs.

Ductless mini split units may not be the ideal HVAC solution for all situations. Radiant floor systems bring a measurable comfort advantage that may be appropriate in luxury applications. In mild climates, home builders may be able to avoid heating or cooling systems entirely. Like all the recommendations in the report, builders should perform their own research and consider local factors before specifying heat pump HVAC systems.

Easy Wins in Lighting, Appliances, and Water Fixtures

ENERGY STAR–certified appliances (namely refrigerators, dishwashers, and clothes washers), ENERGY STAR–certified LED lighting,[30] and EPA WaterSense–certified water fixtures were cost-optimal measures for all four locations modeled. These efficiency measures combined were able to reduce electric loads enough to downsize the necessary solar PV system by 1.5 kW–1.9 kW (a $3,000–$4,100 cost savings) at an average incremental cost of only $260.

It is important to acknowledge that some home builders and developers may be skeptical of the minimal incremental cost reported for these measures. LED lighting in particular was known as a low-value efficiency measure just a decade ago. However, costs have dropped by over 75% since 2010 and are now nearing cost parity with conventional options, while LED bulb efficiency has more than doubled over the same timeframe.[31] It may be necessary to educate builders about the rapidly changing market to ensure support for these solutions.

Heat Pump Water Heaters

Heat pump water heaters (HPWHs) use the same process as heat pump HVAC systems to provide domestic hot water (DHW) at an efficiency two to three times greater than conventional electric DHW heaters.[32] HPWH systems also cool and dehumidify the space they're in, making them ideal for hot and humid climates.[33] However, experts remain concerned about HPWHs' ability to perform in colder climates. Although the system modeled in this analysis successfully provided hot water year-round (even in Chicago), home builders and policymakers should work to verify that locally available options can provide comfort before specifying HPWH units. Specifying products that align with the Northwest Energy Efficiency Alliance Tier 3 HPWH specification may help ensure robust performance in colder climates.[34]

Beyond cold-climate performance concerns and a substantial added cost, HPWH systems also need more space than conventional systems, add complexity in commissioning and maintenance, and suffer from a reputation for being noisy. Similar to heat pump HVAC systems, there is potential for policymakers to begin addressing this issue by hosting or subsidizing training programs for this technology. If performance issues are a concern, builders could consider tankless water heaters or solar water heating.

Electrification in new developments:
For new housing developments, specifying HPWHs in conjunction with electric heating and cooking systems carries the added benefit of negating the need to install new natural gas pipelines, yielding developers additional cost-saving potential.

Envelope

The builders interviewed for this report used a wide array of framing systems to achieve their ZE designs, including structurally insulated panels (SIPs), insulated concrete forms (ICFs), and double-stud construction. Some builders used triple-pane windows. And much has been made of strategies to minimize air leakage, with builders reporting targets as low as 0.12 air changes per hour (over 50 times below IECC 2009 code).[35] However, our analysis found that even in new construction, many of the most aggressive envelope measures were not part of a cost-optimized design. Table 2 provides a summary of the envelope recommendations detailed in Appendix A.

TABLE 2: RECOMMENDATIONS FOR COST-OPTIMIZED ENVELOPE COMPONENTS

Envelope Component	Cost-Optimized Recommendations
Windows	Use high-performance windows. Specifications vary widely by climate, with an incremental cost range of $360 (climate zone 2) to $2,840 (climate zone 5).
Wall Insulation	Add R5 continuous insulation layer to wall sheathing in climate zones 3 and 4 at an added cost of $2,000–$2,100.
Roof Insulation	Use the minimum required by the DOE ZERH program (i.e., 2012/2015 IECC code levels) as a rule of thumb at an added cost of $300–$1,200.
Slab Insulation	Remain code compliant in all climates.

Although builders can typically construct ZE homes with envelopes that perform only marginally above code based on nominal specifications (such as wall R-value), ZER homes also integrate strategic enhancements (such as thermal breaks, air barrier continuity, and insulation installation quality checks) to ensure that envelopes adequately control moisture and perform to their potential.

Envelopes are far more sensitive to regional climatic conditions (including temperature, humidity, and sunlight availability) than other high-performance building components, and builders must work to ensure that they take these details into consideration when specifying envelope components. Builders should not simply use the recommendations outlined in this report, especially in climate zones outside the scope of our analysis (IECC climate zones 1, 6, 7, and 8), where envelope investments may be more prudent. Working with an energy auditor, or collaborating with other builders in the DOE ZERH program, can lead to smarter design.

For builders, there may be long-term advantages to over-engineering a super-efficient home's envelope design. Thicker walls and windows can reduce noise penetration, potentially increase a home's longevity, and improve indoor comfort in colder climates. Both SIPs and ICF wall systems bring the added benefit of increased seismic and wind resistance. Although these building methods can add thousands of dollars to the hard cost of home construction, they may result in significant cost offsets over time, including quicker construction, fewer tools, less waste, greater dimensional accuracy requiring less work, and inherently fewer defects.

Solar-Ready Roofing

Builders can employ several strategies to minimize the cost of a future PV installation in situations where immediate installation isn't preferred:[36]

- Use roof pitches of 10-30 degrees to allow for flush-mounted installation
- Use roofing that does not require roof penetrations to mount PV systems (e.g., metal stand and seam roofs)
- Minimize roof complexity: avoid wings, ells, and dormers; use gable end roof framing[37]
- Where possible, orient to maximize southern exposure
- Ensure landscaping and neighboring structures do not block solar exposure
- Minimize rooftop equipment, vents, and other obstructions
- Install mounting hardware and safety harness connection points upon roof construction

These measures have no immediate impact on a home's energy performance and may require city or state incentives to support adoption.

04

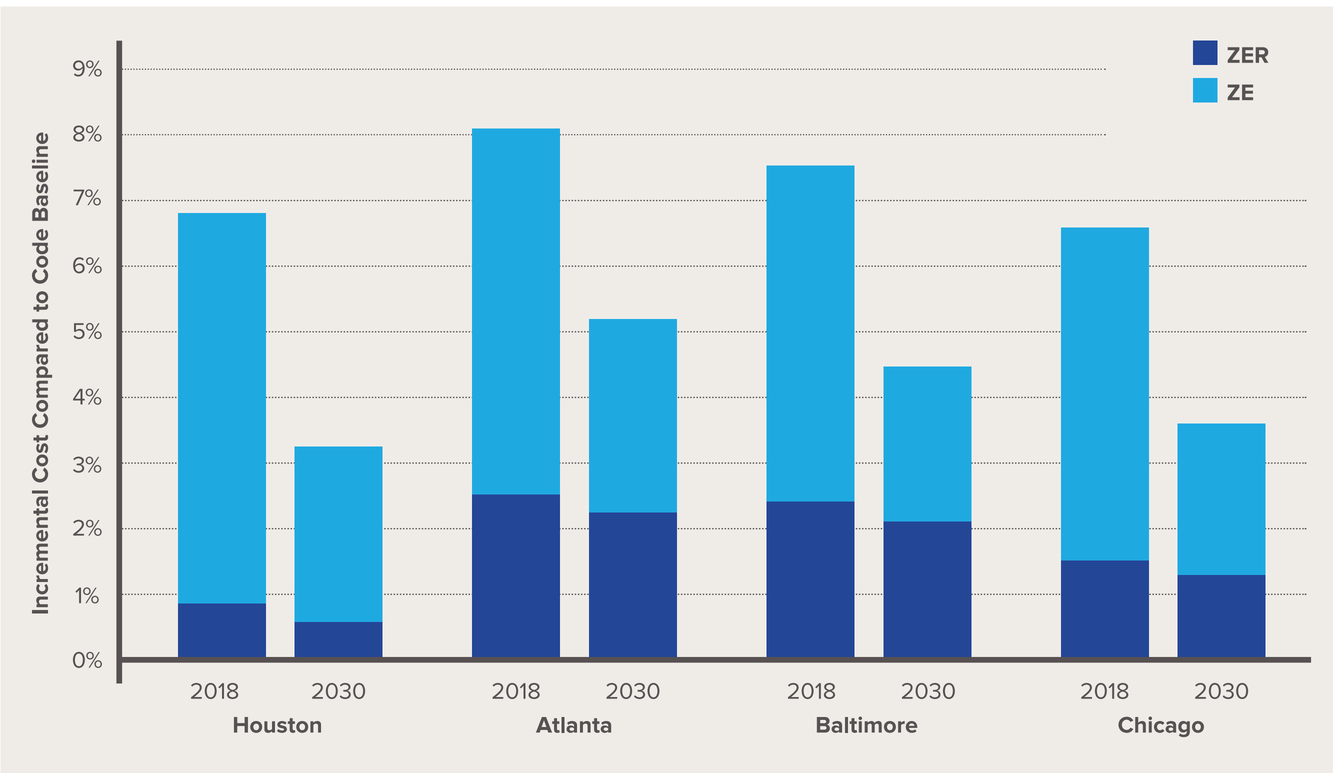
FUTURE COST PROJECTIONS

FUTURE COST PROJECTIONS

Although the results of this report show that constructing ZE homes can be economical for most homeowners in most locations today, it's important to understand how costs are expected to change in the future. Industry progress and demand for super-efficient building components are expected to drive cost savings over the next decade.

The cost factors detailed in this section significantly impact the cost for ZE homes, yielded from declining solar costs and reduced PV system size requirements (due to equipment efficient gains). These factors should bring ZE homes in the four locations modeled within a 3.1%–5.5% incremental cost by 2030, compared with a 6.7%–8.1% incremental cost today. The opportunity for cost savings in ZER homes is less significant, with incremental costs projected to drop roughly 20% by 2030 (see Figure 9).

FIGURE 9: INCREMENTAL COSTS FOR ZER AND ZE HOMES, TODAY VS. 2030

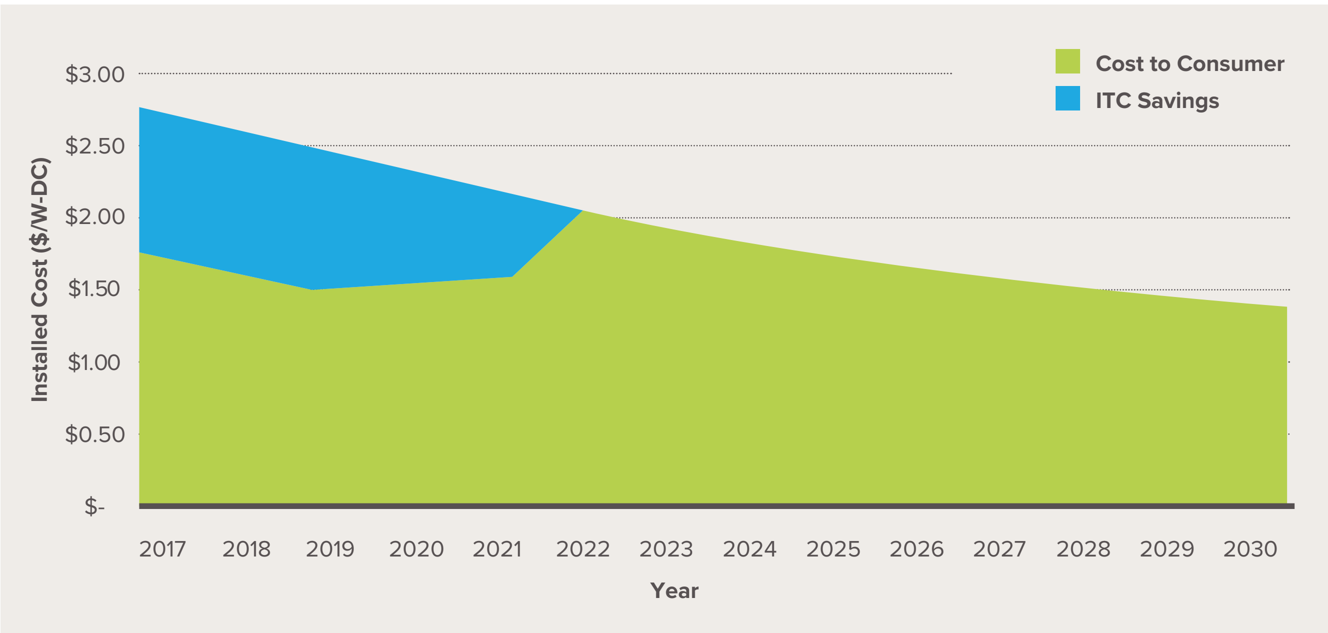


Solar PV Installed Costs

Solar PV represents both the most significant incremental cost in reaching ZE today—and the most significant opportunity for future cost savings.

However, the phasing out of the ITC could make these systems more expensive for a short time period, as Figure 10 shows.

FIGURE 10: SOLAR PV COST TO CONSUMERS WITH CURRENT ITC PHASEOUT TIMELINE[38]



However, despite a period of volatility with little accumulated savings through 2025, costs are expected to continue declining beyond 2030. NREL projects that $1.10/W rooftop solar may be available to homeowners by the end of 2030; third-party financing mechanisms allowing the capture of MACRS tax incentives could enable sub-$1.00/W PV systems in the same timeframe.

It's important to note that a majority of the cost savings potential for solar PV stems not from projected material cost savings but from soft-cost reductions, which can be accelerated through incentivizing policies.[39]

More Efficient Equipment to Reduce Solar Requirements

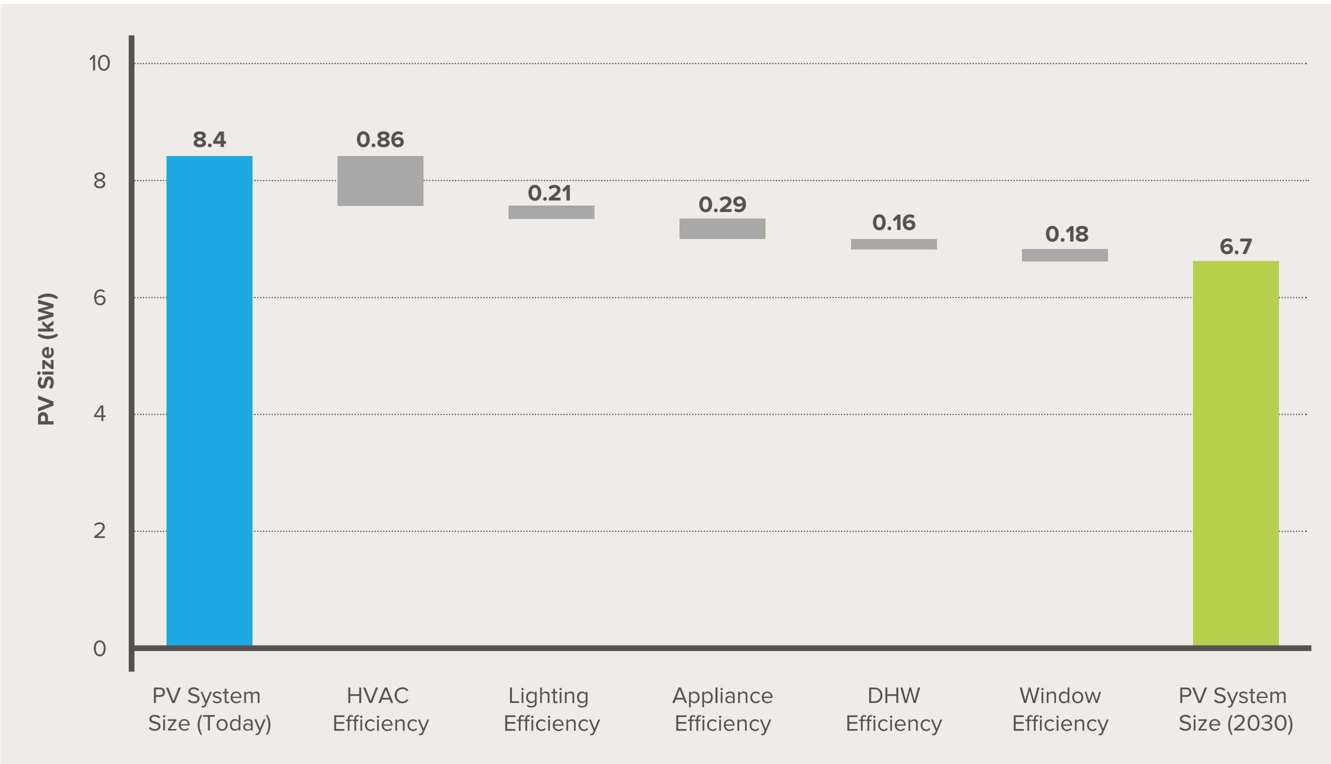
The past decade has yielded impressive progress in the efficiency of many of the building components incorporated in a cost-optimized design. Many of these trends are expected to continue through at least 2030, as summarized in Table 3.

TABLE 3: RECENT PROGRESS AND FUTURE PROJECTIONS IN RESIDENTIAL EQUIPMENT EFFICIENCY

Technology	Recent Progress	Future Projections
Heat Pump HVAC	Heat pump HVAC systems were once relegated to warmer climates but are now capable of operating below -10°F.[40] Efficiency has also drastically improved, with Carrier recently releasing a 42 SEER unit.	Global efforts are underway to commercialize a mini split AC technology that consumes 80% less electricity than the current average, or at least 50% better than current best-in-class offerings.[41]
LED Lighting	Average bulb efficacy has increased from below 50 lm/W in 2010 to roughly 130 lm/W in 2018.[42]	Bulb efficacy is expected to reach 200 lm/W by 2030, a 35% efficiency gain.[43]
ENERGY STAR Appliances	US and California appliance standards continue to drive efficiency gains, with refrigerators increasing efficiency over 40% since 2000.[44]	An additional 20% efficiency gain by 2030 has been assumed in Figure 11.
HPWH	Efficiency factors of 2–2.5 were once typical,[45] but now efficiency factor 3.0–3.5 models are common.[46]	An additional 20% efficiency gain by 2030 has been assumed in Figure 11. Forthcoming innovations may also resolve performance concerns in cold climates.
Windows	The use of thin glass in television screens has reduced material costs by over 80%, making triple-pane windows cost-effective in the coldest climates.[47]	Lawrence Berkeley National Laboratory is working with manufacturers to bring R5 to R7 windows to market at or near cost parity with existing double-pane options.[48]

This expected progress in unit efficiency will significantly reduce the internal load of a ZER home, minimizing the size of the solar PV installation necessary to achieve ZE. Expected cost savings ranged from $1,600 to $2,500 across the four locations modeled in this report.[49]

FIGURE 11: PROJECTED PV SYSTEM DOWNSIZING FROM FUTURE EFFICIENCY GAINS FOR CHICAGO



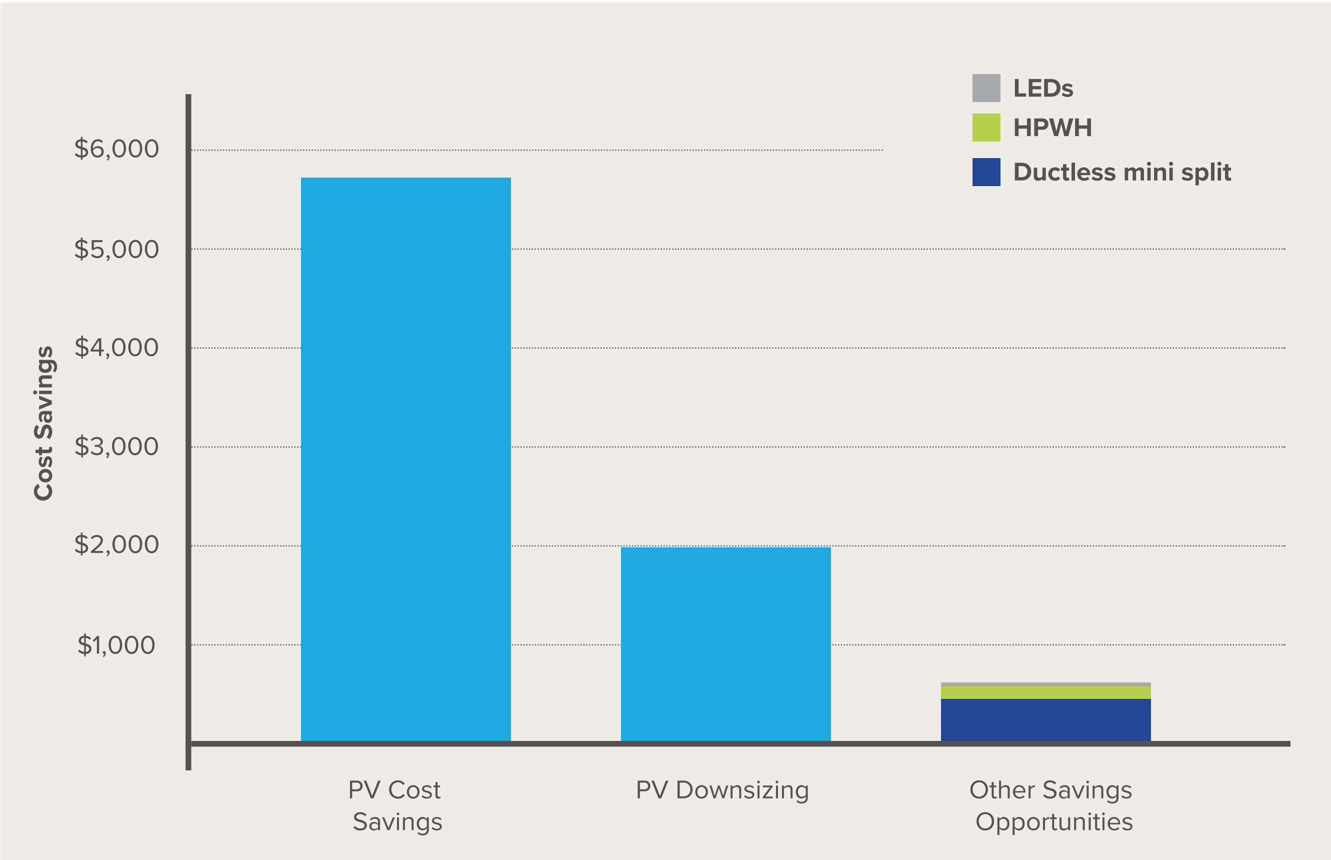
Other Component Cost Savings

Additional cost savings may occur as other super-efficient building components—particularly HPWHs and HVAC systems—enter the mainstream following consumer demand, builder leadership, and government policies. However, these savings are expected to be minimal in comparison with the solar PV savings available through declining costs and efficiency improvements (as shown in Figure 12).

"With California implementing zero requirements, manufacturers are going to have a much bigger market for their high-efficiency products. I expect that to bring costs down, even for us in Colorado."

GENE MYERS,
Owner and CEO at Thrive Home Builders

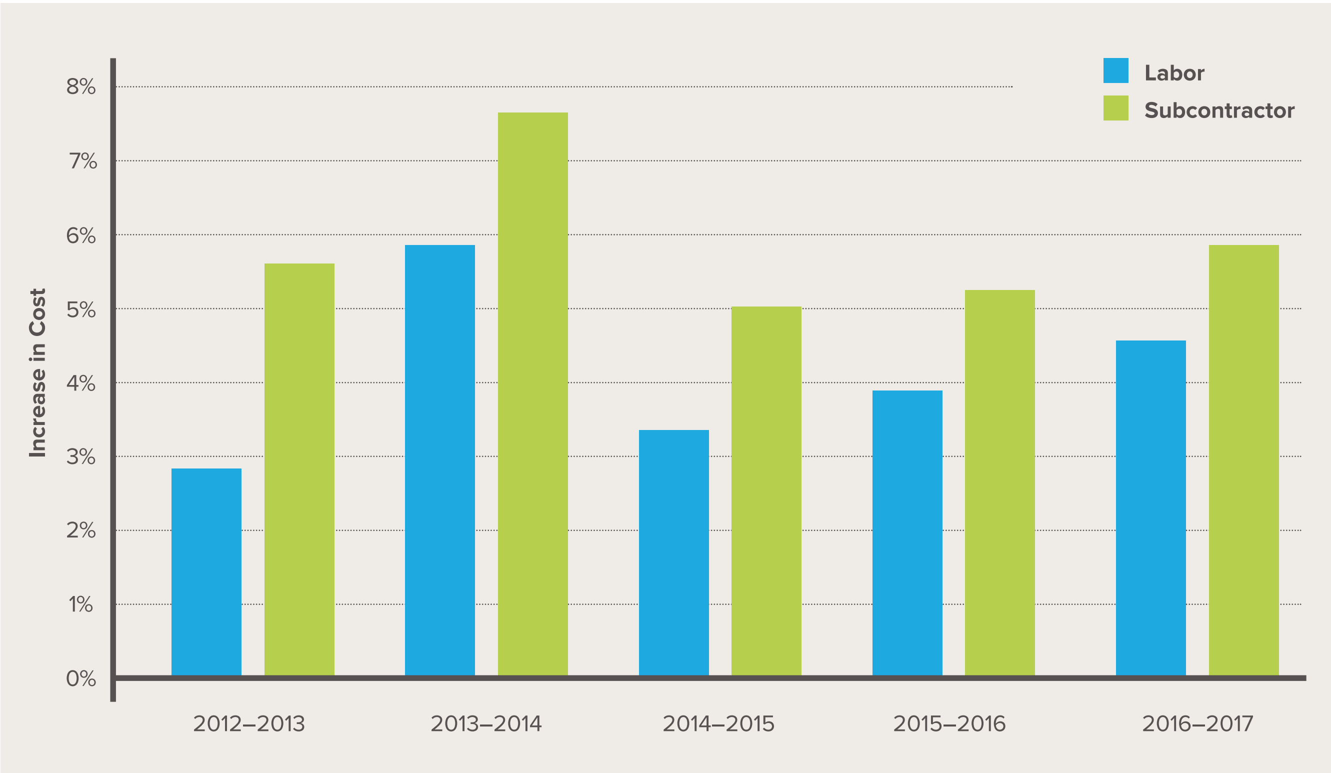
FIGURE 12: COST SAVINGS OPPORTUNITIES BY 2030, AVERAGE ACROSS FOUR LOCATIONS[50]



Labor Costs Yield Uncertainty

The cost of labor is a significant concern for conventional and super-efficient home builders alike. The cost for construction labor has steadily risen since the recession, with the trend recently rising above a 4% per annum increase as shown in Figure 13. Notably, the cost for subcontractor labor has outpaced the cost of labor overall, signifying a shortage of carpenters, electricians, HVAC technicians, and other skilled construction labor.

FIGURE 13: ANNUAL INCREASE IN HOME BUILDING COSTS, 2012–2017[51]



What this means for the incremental cost of ZE homes is unclear. Most of the home builders interviewed for this report noted that their ZE homes required more labor expenditures than code-compliant construction, a sensible conclusion given the technical complexity and lack of subcontractor familiarity with many modern building components. Modern mini split AC units, HPWHs, and air sealing barriers require more effort to properly install and commission than legacy products. However, these labor cost increases are counteracted by the fact that the cost-optimized designs covered in this report avoided advanced framing systems and heating/cooling ductwork (components that many interviewed builders still use in their designs). Whether costs are offset entirely will depend largely on local factors and will require further study.

It is important to note here that the shortage of skilled labor is an ongoing crisis for the residential construction industry—one that policymakers have the potential to influence. Providing or sponsoring training programs focused on high-performance building components represents an essential step for ensuring that the supply of ZE homes is capable of meeting demand—and for turning an industry-wide crisis into an opportunity to proliferate efficient home building practices.

“The labor market aging out is a massive issue for all home builders. This industry simply doesn’t have enough resources to meet demand. But the other side of that coin is that as new labor comes on, you can teach them new tricks.”

C.R. Herro,

Vice President of Energy Efficiency and Sustainability at Meritage Homes

Note Potential for Evolving Design:
Advancements in nascent building technologies may fundamentally change the cost-optimized design of a ZE home in the near future. This is particularly true of SIPs and energy recovery ventilators. Although these technologies were not identified as cost-optimal design components in our analysis, they bring measurable benefits, can be sensible solutions in the right situation, and may yet have a significant impact on the home building industry. Both builders and policymakers should stay apprised of these technologies and consider incentivizing them.

05

RECOMMENDATIONS FOR BUILDERS

RECOMMENDATIONS FOR BUILDERS

The following sections summarize the implications of this report for home builders and developers looking to provide ZE or ZER offerings.

Use This Report to Inform Future Construction

Both prospective and established ZE home builders can use the cost-optimized efficiency measures identified in this report as a starting point for informing or updating their home designs. Note that DOE provides additional ZERH climate-optimized efficiency packages as part of its Building America Solution Center.[52] Home builders should iterate on these recommendations to ensure that the recommendations adequately consider their local context, including existing contractor relationships and pricing, climate considerations, code requirements, and available incentives.[53]

A truly cost-optimized design is dependent on an integrated design that considers the various systems that comprise home energy use in parallel. The Building America program is helping builders navigate these issues with focused research and development on integrated solutions, and it may be a valuable supplement to the resources provided in the DOE ZERH program.[54] Builders should also work with energy modeling professionals to analyze integrated solutions that account for local climate, costs, incentives, and site constraints.

Collaborate in the DOE ZERH Program

The fact that home builders specializing in green homes report a cost premium less than half that stated by conventional home builders shows just how significantly experience itself can influence costs.[55] However, for those conventional home builders looking to break into a new market segment, the promise of reduced costs after their first, tenth, or hundredth green home is not particularly soothing. The DOE ZERH program works to address this hurdle by offering dozens of case studies,[56] encouraging collaboration between green home builders, providing training webinars on advanced building topics, and providing prescriptive guidance on the design and construction of ZER homes.

The ZER certification process also provides builders with a method of quality control by requiring that buildings undergo a HERS rating (including blower door tests and energy modeling) and use checklists for thermal and air barriers, quality HVAC installation, comprehensive indoor air quality measures, and solar-ready construction (in locations with a significant solar resource). These steps can help home builders (especially those new to super-efficient construction) ensure quality, regardless of whether they complete the other requirements for ZER certification. Although this report focuses on ZER certification, builders can pursue other certifications that also provide design guidance and credibility to a ZE home, including LEED, National Green Building Standard, and ENERGY STAR for homes.

Find the Right Subcontractors

The costs identified in this report assume that projects are bid competitively by subcontractors. Builders and developers rooted in conventional building practices may find that their preferred subcontractors have limited experience in the super-efficient technologies and building techniques incorporated in this report (e.g., commissioning the inverters on ductless mini splits) and that they thus quote prices substantially higher than those listed here to minimize their risk and uncertainty.

The costs listed in this report are derived from trusted resources based on real-world cost data (see Appendix A for details). Home builders should be able to achieve similar costs in their locations. Home builders should look for subcontractors that are amenable to taking on new technologies and techniques without introducing extreme contingency costs to learn new skills—more likely if a high-volume builder is asking. Where meeting resistance to change, home builders should look to establish and build new relationships.

Hone Your Salesmanship

There is some disagreement in the real estate community regarding the difficulty in selling green homes, with 34% reporting a sales advantage and 29% reporting a disadvantage.[57] Regardless of the current state of affairs, it's clear that there is room to improve.

Many of the first movers in this industry can share painful stories about the overly technical presentations they first used to try to sell a ZE or ZER home. These builders have learned through experience that a successful sales pitch does not focus on technical aspects. In fact, many home builders report that even highlighting the superior total cost of ownership for a super-efficient home doesn't provide the emotional pull necessary for a prospective buyer. Green home builders are quickly learning that establishing this emotional connection is essential to their success.

"We don't talk about just 'energy performance' with our homebuyers. We focus instead on how that performance impacts the pain points they encounter every day: comfort, quiet, air quality, health, and price predictability."
Parlin Meyer,
Director at BrightBuilt Home

"The last thing a customer wants is for you to tell them how the engine works under the hood."
Tom Wade,
Owner at Palo Duro Homes, Inc.

Home builders can learn more about successful marketing strategies and phrases for super-efficient homes using the Building America Building Science Translator[58] and the Building America Solution Center Sales Tool.[59]

Engage with Local Policymakers

This report includes recommendations for policymakers interested in promoting ZE or ZER new construction. Builders should share those recommendations with government officials in the cities or states where they operate to help accelerate this industry. Better, they should work with those government officials to share their perspective as a local home builder to ensure that enacted policies represent an optimal approach to accelerating adoption.

06

RECOMMENDATIONS FOR POLICYMAKERS

RECOMMENDATIONS FOR POLICYMAKERS

Policymakers have an important role in improving grid reliability, meeting community energy needs, supporting affordability, improving the housing stock, and addressing climate change. Driving ZE home construction can be an essential action in addressing all of these issues. The following sections summarize the implications of this report for policymakers interested in driving the construction of ZE and ZER single-family homes in their city, county, or state.

Clarify Goals to Inform Actions

It is essential to set clear, ambitious, and measurable goals to guide policies and actions. The content of this report can be used in concert with other available resources to inform the discussions and analysis necessary to define the goals that policies will drive toward.

RMI will be providing additional tools for policymakers to accelerate ZE construction in 2019.[60]

Use This Report to Inform and Support Policy

The cost-optimized home constructions highlighted in this report can be used to guide incentives and quantify the economic impact that these measures will have on real estate developers and home buyers. The previous pages highlight several high-value opportunities, including:

1. Prescriptive incentives, especially for heat pump HVAC systems, HPWHs, and high-performance windows (climate dependent)
2. Subsidized costs for building certifications (e.g., the DOE ZERH program); the cost of ZER certification can make up over one-quarter of the cost for a ZER home,[61] though the cost is significantly less for production homes
3. Incentives for solar-ready roofing
4. State standardization of permitting, inspection, and interconnection procedures to reduce soft costs for installing solar PV
5. State legislation enabling community solar, PPAs, or property-assessed clean energy (PACE) financing

Policy can also be used to enable a number of other benefits to incentivize first movers, including expedited permitting, density or height bonuses, and setback exceptions. Although most builders interviewed didn't consider these bonuses essential drivers of adoption, they can be provided at little to no cost to governing bodies and communities.

It's also worth highlighting the benefit of energy disclosure programs in promoting the value of high-performance homes. Particularly innovative disclosure programs are in place in Portland, Oregon; Austin, Texas; and Berkeley, California.[62] Although these policies aren't focused on new construction, they are important pieces in ensuring that the energy performance of all homes is considered and properly valued by consumers.

Support Labor Training Programs

This report highlights that an essential aspect driving adoption of ZE and ZER homes is supporting a larger and more skilled construction workforce. Labor shortages are driving up costs as the industry struggles to secure skilled specialty subcontractors. Policymakers can address this issue by supporting, promoting, or partnering with local trade schools.

Super-efficient home builders are particularly affected by skilled labor shortages due to the specialty requirements for advanced building techniques and products. Policymakers can work to address this issue by establishing or supporting training programs, especially in the following topic areas:

- Installing, commissioning, and servicing heat pump ACs with inverters
- Installing and servicing HPWHs
- Air sealing techniques and products

- Certification program compliance
- Solar-ready roofing
- Window specification

It is worth incentivizing home builders to collaborate with the DOE ZERH program, which provides both a performance and prescriptive path for ZER homes that has been vetted with hundreds of buildings on thousands of homes across the country. Moreover, the program actively encourages collaboration between builders to share experiences and proliferate lessons learned.

"The Zero Energy Ready Homes program has been a huge benefit to this industry. It helps builders to see that this isn't just possible, it is easy, and repeatable."
Ted Clifton,
founder and CEO at Clifton View Homes

Support Training for Other Influencing Parties

Home builders are not the only stakeholder group that will need to enhance skill sets to support a push toward ZE or ZER new construction. The real estate appraisal industry is critical to ensuring that efficiency and renewable energy investments are properly and transparently considered as part of the home valuation process. The Appraisal Institute, the nation's largest professional association of real estate appraisers, offers a professional development program on the valuation of sustainable buildings (among other resources), and its registry of green residential appraisers continues to grow.[63]

Real estate agents can also benefit from training to learn how to best market the largely hidden value of high-performance features to prospective home buyers. In addition, as with skilled labor in the construction industry, training and capacity building for residential solar installers—particularly in less-developed solar markets in parts of the country outside of California—can also be important as demand for ZE and ZER new construction scales nationally.

07

CONCLUSION

CONCLUSION

As this report highlights, ZE and ZER homes can be built without a significant cost burden, and current costs are already meeting consumer thresholds—and continuing to decline. With ZE and ZER incremental costs as low as they are, builders and policymakers should seriously consider providing and supporting ZE offerings. Policymakers can also use findings from this report to begin a conversation around how they can increase market penetration of ZE and ZER homes in their states, regions, and cities.

Based on the analysis in this report and extensive case studies in the DOE "Tour of Zero" project database, ZER homes routinely save tens of thousands of dollars on utility bills for consumers over the lifetime of a 30-year mortgage.[64] Where solar financing is available, solar panels can bring these homes to ZE at little or no added cost (and greater long-term value). Because first cost is no longer a significant barrier, state and city policymakers should consider how to support building ZE homes from the start and avoid developments that will suffer from obsolescence and require expensive retrofits in the future. In addition, city policymakers should think about barriers beyond the first cost that builders and consumers may be facing and provide resources such as trainings, incentives, and benefits for first movers to drive the industry forward. In the end, ZE and ZER homes are good business for communities, as the value of these homes adds up to additional housing value and tax revenue over their lifetimes.

08

COLD CLIMATES ADDENDUM

COLD CLIMATES ADDENDUM

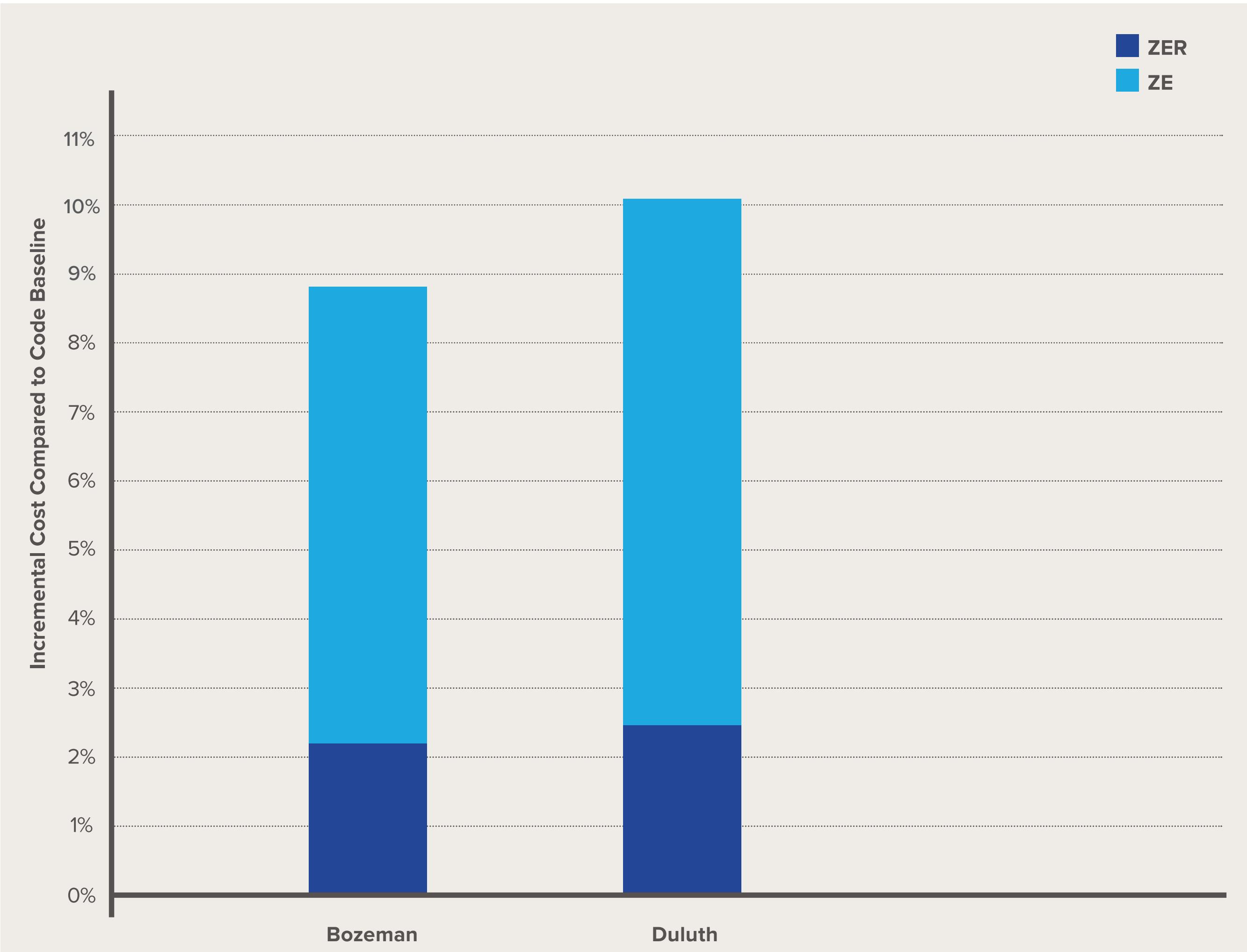
Cold climates face challenges in ZE and ZER design that aren't as present in more moderate climates, including performance concerns and higher energy consumption. This cold climate addendum is intended to add to the original report and offer additional guidance for ZE and ZER homes built in climate zones 6 and 7. The key results provided in the main body of this report for climate zones 2–5 have been replicated below for climate zones 6 and 7.

Local climates range widely even within a specific climate zone, and climatic conditions in these coldest climates can have a significant influence on optimized home construction practices. Builders and policymakers in cold climates should consider employing their own energy models to ensure that the recommendations given here can provide adequate indoor comfort in local conditions.

TABLE 4: KEY RESULTS

	CZ6	CZ7
Modeled City	Bozeman, MT	Duluth, MN
Utility Energy Rate ($/kWh)	0.101	Tiered ($0.07/kWh–$0.14/kWh)
Baseline Energy Use Intensity (kBtu/sf/yr)	57.0	80.0
Proposed Energy Use Intensity (kBtu/sf/yr)	18.0	20.0
Solar PV Size (kW)	8.6	10.9
Baseline Cost ($)	$247,435	$273,553
Incremental Cost for ZER Homes ($)	$5,358	$6,722
Incremental Cost for ZER Homes (%)	2.2%	2.5%
Incremental Cost for ZE Homes ($)	$28,750	$36,508
Incremental Cost for ZE Homes (%)	11.6%	13.3%
Incremental Cost for ZE Homes with ITC ($)	$21,733	$27,572
Incremental Cost for ZE Homes with ITC (%)	8.8%	10.1%

FIGURE 14: INCREMENTAL COSTS FOR ZE AND ZER HOMES



Surprisingly, both ZE and ZER homes in these cold climates meet similar cost thresholds to the four cities covered in the main body of this report, achieving the resale, willingness to pay, and mortgage threshold for ZER homes and the mortgage threshold for ZE homes.

FIGURE 15: SUMMARY OF ZER HOME COST THRESHOLD ACHIEVEMENT IN COLD CLIMATES

	Bozeman (CZ6)		Duluth (CZ7)	
ZER Incremental Cost	$5,358		$6,722	
Mortgage Threshold (30 years)	✔	$13,877	✔	$19,953
Resale Threshold (12 years)	✔	$7,047	✔	$10,133
Customer Willingness to Pay Threshold (4%)	✔	$9,897	✔	$10,942
First Cost Threshold (0%)	✖	$0	✖	$0

FIGURE 16: SUMMARY OF ZE HOME COST THRESHOLD ACHIEVEMENT IN COLD CLIMATES

	Bozeman (CZ6)		Duluth (CZ7)	
ZE Incremental Cost	$21,733		$27,572	
Mortgage Threshold (30 years)	✔	$36,358	✔	$46,590
Resale Threshold (12 years)	✖	$18,465	✖	$23,661
Customer Willingness to Pay Threshold (4%)	✖	$9,897	✖	$10,942
First Cost Threshold (0%)	✖	$0	✖	$0

Electrification Should Be Implemented Thoughtfully

One significant change in assumptions has taken place in performing this cost analysis for colder climates: the baseline HVAC system is assumed to be natural gas. This assumption is guided by existing industry trends: electric heating systems remain relatively uncommon in climate zones 6 and 7, representing 8% of existing homes and 12% of new construction,[65] because they can result in significantly higher annual utility costs in heating-dominated climates. See Table 5 for a summary of the costs and energy savings noted between these design alternatives. Selected baseline assumptions are highlighted.

Table 5 illustrates that while an all-electric baseline home assumption in climate zones 6 and 7 would have resulted in lower first costs (as it was for climate zones 2–5), the same assumption would have dramatically increased the estimated life-cycle value of ZER and ZE homes. Builders and policymakers in these climates should carefully consider the assumptions made in this report regarding electrified systems and adjust according to their priorities and local context.

TABLE 5: MODELED COSTS AND ENERGY SAVINGS FOR ELECTRIC AND NATURAL GAS BASELINES

		Chicago	Bozeman	Duluth
Electric Baseline	Incremental Cost of Building to ZER	**$5,369**	$4,499	$5,029
	Annual Energy Bill Savings	**$1,052**	$985	$2,934
	Payback (years)	**5.1**	4.6	1.7
Natural Gas Baseline	Incremental Cost of Building to ZER	$3,652	**$5,358**	**$6,722**
	Annual Energy Bill Savings	$921	**$708**	**$1,018**
	Payback (years)	4.0	**7.6**	**6.6**
Moving from an Electric Baseline to Natural Gas	Change in Incremental Cost for Building ZER	-$1,717	-$859	-$1,693
	Change in Payback (years)	-1.1	+3	+4.9

Note: Bold numbers indicate the baseline used for each location.

Policymakers should keep in mind that in heating-dominated climates, the electrification of heating systems will be an important (perhaps even requisite) strategy for achieving any stated climate or carbon goals due to the inability to offset GHGs from natural gas or heating fuels. This reality may support a rationale for following an all-electric baseline assumption. Furthermore, comparing the cost-benefit of building electrification with other carbon mitigation strategies may support a case for aggressively incentivizing electric heating systems to offset any increased energy cost to consumers.

Cost-Optimal Building Practices

Many of the key results from warmer climate zones still hold true: all-LED lighting, ENERGY STAR appliances, and EPA WaterSense hot water fixtures are still among the most cost-effective energy measures. More surprisingly, heat pumps are still an important technology for both space and water heating. However, the extreme cold of climate zones 6 and 7 yields some unique recommendations for ZE and ZER homes in these locations.

Maximize South-Facing Solar

Optimized energy models in climate zones 6 and 7 both maximized available south-facing rooftop area for solar PV; climate zone 7 required additional north-facing panels in order to achieve zero-energy performance. While these north-facing PV panels remained a more cost-effective measure than alternative investments in envelope insulation, they are substantially less cost-effective than their south-facing counterparts.

Homebuilders can beat the costs stated in this report for ZE and ZER homes in climate zone 7 by ensuring their home designs maximize the capacity for south-facing solar PV panels. With sufficient capacity, the production of the 10.9 kW system specified in our analysis (8.5 kW south facing and 2.4 kW north facing) could be replaced with a 10.0 kW south-facing system, reducing the first cost for a ZE home in Duluth by roughly $2,500. Added south-facing capacity could be achieved with a home design maximizing south-facing roof space, an unshaded ground-mounted system, a community solar program, or other off-site options.

Capacity for south-facing solar PV is thus a limiting factor for ZE and ZER home designs in both climate zones, and should be considered by homebuilders in the early stages of design.

Heat Pump HVAC Systems Need Help

Despite the extreme winter temperatures in these colder climates, optimized BEopt models still utilized ductless mini splits as the primary HVAC system. These heat pump units were supported by electrical resistance heating systems, which provided 4% of annual heating demand in climate zone 6 and 10% of annual heating demand in climate zone 7. These electric resistance systems can be included in an integrated ASHP system or can take the form of separate electric resistance baseboard units.

The availability of heat pump systems capable of performing in subzero temperatures is a relatively recent development. Some homebuilders, code officials, and prospective users may be skeptical of these systems' potential due to past experience; some areas may not have an established market for the purchase and installation of these systems. The Cold Climate Housing Research Center provides research that can be used by policymakers, builders, and other stakeholders to advocate for and guide the deployment of heat pump systems.[66] The Northeast Energy Efficiency Partnership offers best practice guides for both the design, installation, and operation of cold-climate heat pump systems that builders can use to ensure intended performance.[67]

Heat Pump Water Heater Considerations

Heat pump water heaters (HPWHs) are typically not capable of performing in extreme winter temperatures unless they are sited indoors. HPWHs cool the air around them and thus present an energy penalty to space heating systems when sited indoors. This may present an issue for developers and homeowners in climate zones 6 and 7 who are unwilling to relinquish conditioned square footage to mechanical systems. The NEEA Advanced Water Heater Specification should be utilized to ensure adequate long-term performance.[68]

Balance Envelope Measures with Indoor Air Quality

BEopt models specified more efficient envelope systems in climate zones 6 and 7; see Appendix A for details. The impact on the incremental costs noted in Figure 14 and Table 4 was mitigated by the more aggressive baseline building energy codes in these colder climates.

BEopt energy models initially recommended a significantly tighter envelope in climate zone 6. However, increasing the airtightness of envelope wall systems beyond code requirements reduces passive ventilation and has the potential to introduce indoor air quality (IAQ) issues not considered by energy modeling software. Mitigation can be achieved with two different strategies:

1. **Allow for a leakier envelope:** Code-compliant envelopes (3 ACH with standard exhaust systems) typically allow enough active and passive ventilation to address IAQ concerns. Heating systems will need to be sized slightly larger to accommodate for the higher air exchange. This was the most cost-effective option identified by energy models.

2. **Install an energy recovery ventilator:** An energy recovery ventilator (ERV) allows for increased ventilation without a significant thermal energy penalty by harnessing the heat from exhaust air and using it to warm intake air. ERVs were only identified as a cost-optimal measure in climate zone 7; they often aren't cost-effective in milder climates because the thermal energy saved is offset by increased fan power. This active ventilation strategy allows for increased control but increases the complexity of the building system and depends on proper occupant behavior for operation.

There is no "one size fits all" solution to envelope systems in ZE and ZER homes, and this is especially true in colder climates, where it is important to consider the added comfort and resilience benefits of a better insulated home. The need for higher levels of insulation and airtightness in these climates supports a case for considering complex envelope systems, including double-stud walls, structurally insulated panels, and insulated concrete forms. These solutions may prove more economical in certain locations given local labor rates, installer expertise, and/or site characteristics. However, the results of our BEopt energy models support the idea that more extreme insulation levels are not necessary for cost-optimized solutions for ZE and ZER home design (other benefits aside), even in the coldest climates where they are most cost-effective.

Conclusion

The recommendations in the body of this report hold true for colder climates: builders should continue to consider design alternatives, take advantage of available resources, and control quality in construction; policymakers should continue to prime the market by designing incentive programs for high-impact building components and offering workforce development programs. The results covered in this addendum also support an increased focus on two important issues:

1. **Electrification:** Policymakers in cold climates should realize that deep efficiency paired with electrification is oftentimes more cost-effective than electrification using code baseline equipment. Therefore, they should consider an increased focus on incentive programs that are less prescriptive and more integrated.
2. **Solar:** Builders in cold climates can minimize incremental costs by harnessing all available options for solar PV, including both on-site resources (e.g., south-facing roof area or ground-mounted installations) and off-site options (e.g., community solar programs). Policymakers should work to support off-site procurement with enabling legislation and incentive programs.

The results of the energy and economic analysis for this report show that ZE and ZER homes can be cost-effective even in some of the United States' coldest climates. This conclusion is supported by a growing body of evidence, including case studies and research projects sited as far north as the Arctic Circle.[69] Stakeholders should prepare now for these super-efficient homes to enter the mainstream.

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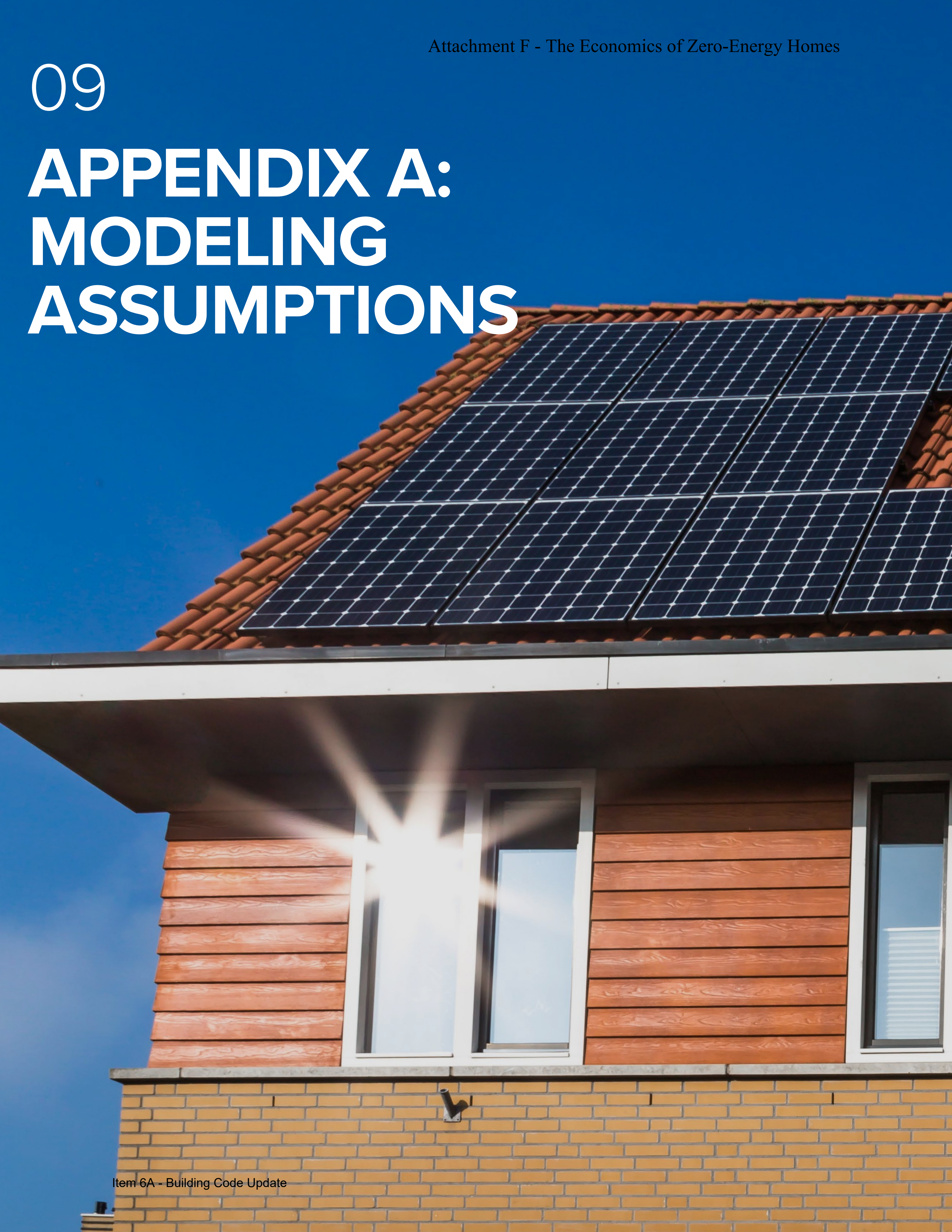
APPENDIX A: MODELING ASSUMPTIONS

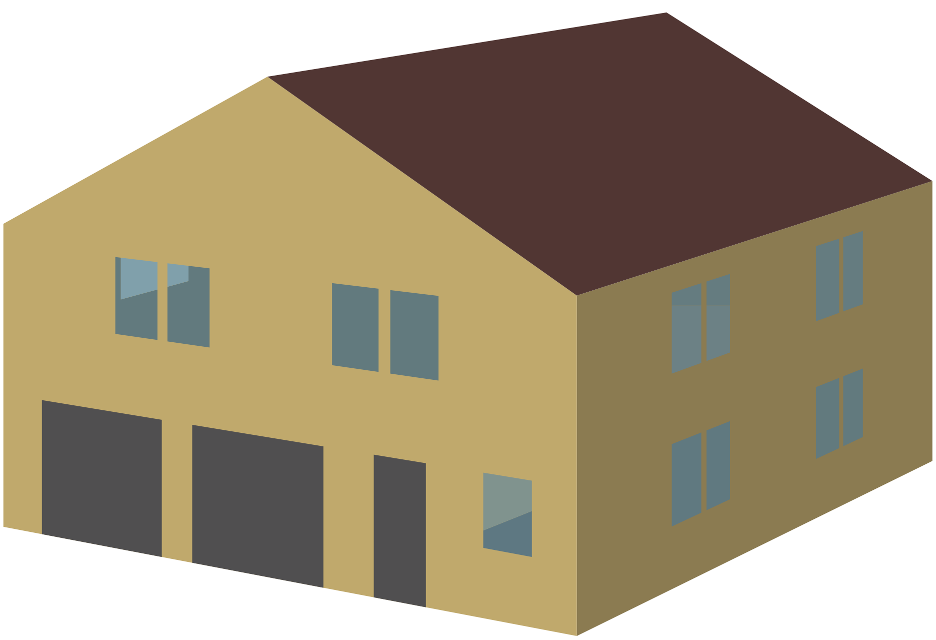


APPENDIX A: MODELING ASSUMPTIONS

Key Assumptions:

- For consistency, each house was identical across climate zones, with exception to code required climate zone differences (roof insulation, wall insulation, window properties). An image of the BEopt energy model is shown in Figure A1.
- For simplicity, this analysis used an all-electric baseline when justifiable. Although ASHPs are not very common in the existing residential market, they are the most typical HVAC system for new construction homes in climate zones 2–4.[70] In climate zone 5, natural gas is still most common for heating, so both a natural gas and electric baseline were modeled for consistency and accuracy.
- IECC 2009 code was used as the baseline code because that is the most common baseline code.[71] In addition, choosing a less aggressive code was more conservative in considering incremental cost.
- This analysis assumed a fuel escalation rate of 2% and a discount rate of 5%.
- The locations determined to represent climate zones were based on the Pacific Northwest National Library (PNNL) detailed code analysis.[72]
- Cost included certain requirements of the ZERH program including HERS rater because this quality check is crucial for high performance.

FIGURE A1: A VISUALIZATION OF THE BEOPT BUILDING ENERGY MODEL USED IN THIS REPORT



Summary of Baseline and Proposed Models:

Tables A1–A6 summarize the baseline and proposed cost-optimized building models in the four analyzed locations. A location-specific incremental cost is noted for all recommended energy upgrades.

TABLE A1: SUMMARY OF HOUSTON (CZ2) ANALYSIS

	Baseline	Proposed	Incremental Cost	Baseline Source
Geometry	Two-story, 2,200-square-foot home with 400-square-foot garage, three bedrooms, two bathrooms		$0	ZERH for size, RSMeans for geometry
Wall	Wood frame, R13 stud insulation		$0	IECC 2009 code for baseline, ZERH minimum requirements for proposed
Window	15% window-to-wall ratio U-0.65, SHGC-0.3	15% window-to-wall ratio, U-0.4, SHGC-0.25	$362	
Unfinished Attic	R30 fiberglass, vented	R38 fiberglass, vented	$287	
Slab	Uninsulated		$0	
Air Leakage	7 ACH50	2 ACH50	$469	
Mechanical Ventilation	Exhaust	Exhaust	$0	
Space Conditioning System	ASHP, SEER 14, 8 HSPF, 3.75 ton	Two mini splits, SEER 25.3, 13.4 HSPF, 1.25 ton	$1,589	ASHP is the most typical HVAC system for new construction homes in this climate zone
Distribution	Ducts in unconditioned space	Five high-flow grilles (no ducts)	($2,656)	
DHW Heater	Electric	Heat pump water heater, 3.5 EF	$727	Used electric as baselines to avoid fuel switching from baselines to proposed; 42% of homes use electric
Misc. Plug Loads	2,261 kWh/yr		$0	Used BEopt assumption
Hot Water Fixture Types	Standard flows	Low-flow fixtures	$42	IECC 2009 code
Appliances	Conventional appliances	ENERGY STAR refrigerator, clothes washer, and dishwasher	$158	
Lighting	50% CFL, 50% incandescent	100% LED	$15	
Thermostat Type	Standard	Smart thermostat	$173	
DOE ZERH Certification	N/A	Cost included, except EPA Indoor airPLUS	$900	Taken from ZERH cost analysis
Solar PV (With ITC)	N/A	6.5 kW	$13,423	N/A

TABLE A2: SUMMARY OF ATLANTA (CZ3) ANALYSIS

	Baseline	Proposed	Incremental Cost	Baseline Source
Geometry	Two-story, 2,200-square-foot home with 400-square-foot garage, three bedrooms, two bathrooms		$0	ZERH for size, RSMeans for geometry
Wall	Wood frame, R13 stud insulation	Wood frame, R13 stud insulation with R5 continuous insulation	$2,007	IECC 2009 code for baseline, ZERH minimum requirements for proposed
Window	15% window-to-wall ratio U-0.5, SHGC-0.3	15% window-to-wall ratio, U-0.3, SHGC-0.25	$2,977	
Unfinished Attic	R30 fiberglass, vented	R38 fiberglass, vented	$304	
Slab	Uninsulated		$0	
Air Leakage	7 ACH50	3 ACH50	$336	
Mechanical Ventilation	Exhaust	Exhaust	$0	
Space Conditioning System	ASHP, SEER 14, 8 HSPF, 3.75 ton	Two mini splits, SEER 25.3, 13.4 HSPF, 1.25 ton	$1,388	ASHP is the most typical HVAC system for new construction homes in this climate zone
Distribution	Ducts in unconditioned space	Five high-flow grilles (no ducts)	($2,816)	
DHW Heater	Electric	Heat pump water heater, 3.5 EF	$771	Used electric as baselines to avoid fuel switching from baselines to proposed; 42% of homes use electric
Misc. Plug Loads	2,261 kWh/yr			Used BEopt assumption
Hot Water Fixture Types	Standard flows	Low-flow fixtures	$44	IECC 2009 code
Appliances	Conventional appliances	ENERGY STAR refrigerator, clothes washer, and dishwasher	$167	
Lighting	50% CFL, 50% incandescent	100% LED	$15	
Thermostat Type	Standard	Standard	$0	
DOE ZERH Certification	N/A	Cost included, except EPA Indoor airPLUS	$900	Taken from ZERH cost analysis
Solar PV (With ITC)	N/A	6.5 kW	$13,454	N/A

TABLE A3: SUMMARY OF BALTIMORE (CZ4) ANALYSIS

	Baseline	Proposed	Incremental Cost	Baseline Source
Geometry	Two-story, 2,200-square-foot home with 400-square-foot garage, three bedrooms, two bathrooms		$0	ZERH for size, RSMeans for geometry
Wall	Wood frame, R13 stud insulation	Wood frame, R13 stud insulation with R5 continuous insulation	$2,099	IECC 2009 code for baseline, ZERH minimum requirements for proposed
Window	15% window-to-wall ratio U-0.35, SHGC-0.44	15% window-to-wall ratio, U-0.29, SHGC-0.56	$2,331	
Unfinished Attic	R38 fiberglass, vented	R49 fiberglass	$903	
Slab	2 feet R10 exterior insulation		$0	
Air Leakage	7 ACH50	2 ACH50	$520	
Mechanical Ventilation	Exhaust	Exhaust	$0	
Space Conditioning System	ASHP, SEER 14, 8 HSPF, 3.75 ton	Two mini splits, SEER 25.3, 13.4 HSPF, 1.25 ton	$949	ASHP is the most typical HVAC system for new construction homes in this climate zone
Distribution	Ducts in unconditioned space	Five high-flow grilles (no ducts)	($2,944)	
DHW Heater	Electric	Heat pump water heater, 3.5 EF	$806	Used electric as baselines to avoid fuel switching from baselines to proposed; 42% of homes use electric
Misc. Plug Loads	2,261 kWh/yr		$0	Used BEopt assumption
Hot Water Fixture Types	Standard flows	Low-flow fixtures	$46	IECC 2009 code
Appliances	Conventional appliances	ENERGY STAR refrigerator, clothes washer, and dishwasher	$176	
Lighting	50% CFL, 50% incandescent	100% LED	$16	
Thermostat Type	Standard	Smart thermostat	$191	
DOE ZERH Certification	N/A	Cost included, except EPA Indoor airPLUS	$900	Taken from ZERH cost analysis
Solar PV (With ITC)	N/A	6.8 kW	$13,090	N/A

TABLE A4: SUMMARY OF CHICAGO (CZ5) ANALYSIS

	Baseline	Proposed	Incremental Cost	Baseline Source
Geometry	Two-story, 2,200-square-foot home with 400-square-foot garage, three bedrooms, two bathrooms		$0	ZERH for size, RSMeans for geometry
Wall	Wood frame, R13 stud insulation with R5 continuous insulation		$0	IECC 2009 code for baseline, ZERH minimum requirements for proposed
Window	15% window-to-wall ratio U-0.35, SHGC-0.44	15% window-to-wall ratio, U-0.29, SHGC-0.56	$2,843	
Unfinished Attic	R38 fiberglass, vented	R49 fiberglass, vented	$1,236	
Slab	Uninsulated		$0	
Air Leakage	7 ACH50	3 ACH50	$482	
Mechanical Ventilation	Exhaust	Exhaust	$0	
Space Conditioning System	Gas furnace, SEER 13 split AC, 3 ton **OR**	Two mini splits, SEER 25.3, 13.4 HSPF, 1.25 ton	$531	Gas furnace with split AC is most common in this climate zone; for consistency across climate zones, we modeled two baselines
	ASHP, SEER 14, 8 HSPF, 3.25 ton		$2,246	
Distribution	Ducts in unconditioned space	Five high-flow grilles (no ducts)	($4,032)	
DHW Heater	Electric	Heat pump water heater, 3.5 EF	$1,104	Used electric as baselines to avoid fuel switching from baselines to proposed; 42% of homes use electric
Misc. Plug Loads	2,261 kWh/yr		$0	Used BEopt assumption
Hot Water Fixture Types	Standard flows	Low-flow fixtures	$63	IECC 2009 code
Appliances	Conventional appliances	ENERGY STAR refrigerator, clothes washer, and dishwasher	$240	
Lighting	50% CFL, 50% incandescent	100% LED	$22	
Thermostat Type	Standard	Smart thermostat	$262	
DOE ZERH Certification	N/A	Cost included, except EPA Indoor airPLUS	$900	Taken from ZERH cost analysis
Solar PV (With ITC)	N/A	8.4 kW	$17,758	N/A

TABLE A5: SUMMARY OF BOZEMAN (CZ6) ANALYSIS

	Baseline	Proposed	Incremental Cost	Baseline Source
Geometry	Two-story, 2,200-square-foot home with 400-square-foot garage, three bedrooms, two bathrooms		$0	ZERH for size, RSMeans for geometry
Wall	Wood frame, R13 stud insulation with R5 continuous insulation	Wood frame, R13 stud insulation with R10 continuous insulation	$1,088	IECC 2009 code for baseline, ZERH minimum requirements for proposed
Window	15% window-to-wall ratio U-0.35, SHGC-0.44	15% window-to-wall ratio, U-0.3, SHGC-0.4	$ 2,071	
Unfinished Attic	R49 fiberglass		$0	
Slab	4 feet R10 exterior insulation		$0	
Air Leakage	7 ACH50	3 ACH50	$344	
Mechanical Ventilation	Exhaust	Exhaust	$0	
Space Conditioning System	Gas furnace, SEER 13 split AC	Mini splits, SEER 25.3, 13.4 HSPF, electric resistance baseboards	$2,254	Gas furnace with split AC is most common in this climate zone
Distribution	Ducts in unconditioned space	Mini split minimal ducting	($2,507)	
DHW Heater	Electric	Heat pump hot water heater, 3.5 EF	$788	Used electric as baselines to avoid fuel switching from baselines to proposed; 42% of homes use electric
Misc. Plug Loads	2,261 kWh/yr		$0	Used BEopt assumption
Hot Water Fixture Types	Standard flows	Low-flow fixtures	$45	IECC 2009 code
Appliances	Conventional appliances	ENERGY STAR refrigerator, clothes washer, and dishwasher	$172	
Lighting	50% CFL, 50% incandescent	100% LED	$16	
Thermostat Type	Standard	Smart thermostat	$187	
DOE ZERH Certification	N/A	Cost included, except EPA Indoor airPLUS	$900	Taken from ZERH cost analysis
Solar PV (With ITC)	N/A	8.6 kW	$16,374	N/A

TABLE A6: SUMMARY OF DULUTH (CZ7) ANALYSIS

	Baseline	Proposed	Incremental Cost	Baseline Source
Geometry	Two-story, 2,200-square-foot home with 400-square-foot garage, three bedrooms, two bathrooms		$0	ZERH for size, RSMeans for geometry
Wall	Wood frame, R13 stud insulation with R5 continuous insulation	Wood frame, R13 stud insulation with R10 continuous insulation	$1,202	IECC 2009 code for baseline, ZERH minimum requirements for proposed
Window	15% window-to-wall ratio U-0.35, SHGC-0.44	15% window-to-wall ratio, U-0.29, SHGC-0.56	$2,566	
Unfinished Attic	R49 fiberglass		$0	
Slab	4 feet R10 exterior insulation		$0	
Air Leakage	7 ACH50	0.6 ACH50	$1,102	
Mechanical Ventilation	Exhaust	ERV 70%	$919	
Space Conditioning System	Gas furnace, SEER 13 split AC	Mini splits, SEER 25.3, 13.4 HSPF, electric resistance baseboards	$1,467	Gas furnace with split AC is most common in this climate zone
Ducts	Ducts in unconditioned space	Mini split minimal ducting	($2,772)	
DHW Heater	Electric	Heat pump hot water heater, 3.5 EF	$872	Used electric as baselines to avoid fuel switching from baselines to proposed; 42% of homes use electric
Misc. Plug Loads	2,261 kWh/yr		$0	Used BEopt assumption
Hot Water Fixture Types	Standard flows	Low-flow fixtures	$50	IECC 2009 code
Appliances	Conventional appliances	ENERGY STAR refrigerator, clothes washer, and dishwasher	$190	
Lighting	50% CFL, 50% incandescent	100% LED	$17	
Thermostat Type	Standard	Smart thermostat	$207	
DOE ZERH Certification	N/A	Cost included, except EPA Indoor airPLUS	$900	Taken from ZERH cost analysis
Solar PV (With ITC)	N/A	10.9 kW	$20,850	N/A

Table A7 and the following resource descriptions provide a summary of the sources and methods used to define the cost of each energy measure considered in this report.

TABLE A7: SUMMARY OF COST SOURCE USED FOR EACH ENERGY EFFICIENCY MEASURE

Energy Efficiency Measure	Cost Source
Wall Stud Insulation	Baseline cost came from RSMeans: Residential Costs 37th Annual Edition
Wall Sheathing	Averaged RSMeans: Residential Costs 37th Annual Edition and National Residential Efficiency Measure Database
Window Properties	Averaged RSMeans: Residential Costs 37th Annual Edition and National Residential Efficiency Measure Database
Unfinished Attic Insulation	National Residential Efficiency Measure Database
Slab Insulation	Averaged RSMeans: Residential Costs 37th Annual Edition and National Residential Efficiency Measure Database
Air Sealing	Averaged RSMeans: Residential Costs 37th Annual Edition and National Residential Efficiency Measure Database
Mechanical Ventilation System	National Residential Efficiency Measure Database
Space Conditioning System	National Residential Efficiency Measure Database
Ducts	National Residential Efficiency Measure Database
DHW Heater	National Residential Efficiency Measure Database; efficiency factor updated based on models on the market
Hot Water Fixture Types	Based on market research and interviews with builders
Appliances	National Residential Efficiency Measure Database for labor cost and market research for equipment cost
Lighting	Based on market research and interviews with builders
Thermostat Type	Based on market research and interviews with builders
High Transfer Grills	RSMeans: Residential Costs 37th Annual Edition
DOE's ZERH Certification	Based on DOE's cost estimate

Cost Sources:

- **National Residential Efficiency Measures Database**: NREMD is the backbone of measure cost estimates provided within the BEopt modeling software. It relies on a plethora of available cost studies and statistical analyses. This was the most commonly used cost resource in this analysis.

- **RSMeans:** RSMeans provides cost models and unit cost data for a variety of residential (and commercial) building types and is a well-known and trusted cost resource in the construction community. We used RSMeans' 2018 Residential Cost Data predominantly for estimating the cost of envelope and appliance measures.

- **National Institute of Standards and Technology:** NIST's 2016 report *Net-Zero Energy Residential Building Component Cost Estimates and Comparisons* uses seven data sources to estimate the incremental cost of a ZE test facility in Maryland. We used the report to inform the cost of envelope, HVAC, and water heater measures.

- **Electric Power Research Institute:** EPRI has recently published a number of reports analyzing the cost and performance of ZE homes in partnership with Meritage Homes Corporation. We used their 2016 report *Establishing Feasibility of Residential Zero Net Energy Community Development - Learnings from California's First ZNE Neighborhood* for estimating the costs of ductless mini split units.

- **American Society of Heating, Refrigerating, and Air-Conditioning Engineers:** ASHRAE's 2009 report *Economic Database in Support of ASHRAE 90.2* provides cost information specific to both single-family and multifamily constructions. Although this data is now a decade old, we used it as a rough validation measure for costs defined by other sources.

- **Expert Contractors:** We consulted with eight residential builders with ZE and ZER home building experience to validate modeled cost estimates: Anthony Aebei of Greenhill Contracting, Bill Decker of Decker Homes, Geoff Ferrell of Mandalay Homes, C.R. Herro of Meritage Homes Corporation, Parlin Meyer of BrightBuilt Home, Gene Myers of Thrive Home Builders, Ted Clifton of Clifton View Homes, and Tom Wade of Palo Duro Homes, Inc.

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APPENDIX B: HOW TO SCALE ZE COST RESULTS

APPENDIX B: HOW TO SCALE ZE COST RESULTS

General Approach: RMI modeled ZE homes in four climates (see Table B1). To scale the results to other cities, we identified a list of factors that influence cost and created a method to update the results for other cities. This approach provides a very rough approximation that can give city policymakers a sense for where costs currently stand in their cities.

TABLE B1: NATIONAL AVERAGE COSTS BY IECC CLIMATE ZONE COMPARED AGAINST IECC 2009

Climate Zone	Incremental Efficiency Cost	PV Cost	Energy Savings for ZE	Energy Savings for ZER
CZ2	$2,488	$14,887	$1,842	$757
CZ3	$6,925	$14,180	$1,968	$852
CZ4	$6,514	$16,049	$2,210	$1,049
CZ5	$4,260	$20,726	$2,459	$1,116

Factors that influence cost:

- Climate zone
- Utility rate
- Labor and material cost
- Baseline code
- Incentives
- Solar resource
- Solar cost

Climate Zone:
We modeled homes using IECC climate zones 2, 3, 4, and 5 because they account for 90.6% of single-family homes in the United States.[73] We did not model cities in climate zones 1, 6, 7, and 8; extrapolating costs from this report to these extreme climates is not recommended.

Utility Rate:
The DOE State and Local Energy Data can be used to find electric utility rates by city,[74] so policymakers will be able to look up what utility (or utilities) serve their cities to determine how their utility rates vary from the national average. The national average price of electricity was $0.1299 per kWh when this report was written.[75]

Labor and Material Cost:
RSMeans has labor and material cost factors compared with the national average for many cities.[76]

Baseline Code:
The baseline code will affect the incremental cost to build ZE as well as the estimated energy savings. This analysis used IECC 2009 as the baseline code (see Table B2), so cities with different baseline codes will need to adjust the results accordingly. Construction cost and energy bill estimates come from PNNL's cost-effectiveness analysis for IECC 2012 and IECC 2015.[77]

TABLE B2: INCREMENTAL CONSTRUCTION COST AND ANNUAL ENERGY BILL COST COMPARED WITH IECC 2009

	Climate Zone	2	3	4	5
IECC 2006	Construction Cost	($164)	($197)	($1,362)	($161)
	Energy Bill Cost	$186	$164	$143	$167
IECC 2009	Construction Cost	$0	$0	$0	$0
	Energy Bill Cost	$0	$0	$0	$0
IECC 2012	Construction Cost	$934	$4,899	$3,538	$2,717
	Energy Bill Cost	($213)	($248)	($346)	($348)
IECC 2015	Construction Cost	$934	$4,899	$3,538	$2,717
	Energy Bill Cost	($220)	($256)	($353)	($353)

Incentives:
This analysis does not include local incentives, but cities could use the Database of State Incentives for Renewables & Efficiency,[78] or work with their local utility to determine how incentives will affect up-front cost.

Solar Resource:
Solar PV electricity production is dependent on solar resources in the city, so cities with better solar resources won't need to install as much solar to achieve ZE. The average solar production of the 50 cities included in this scaling exercise was 1,481 kWh/kW, but it ranged widely from 1,103 kWh/kW to 1,790 kWh/kW. A city's solar resource can be determined using PVWatts, a free resource developed by NREL.[79]

Solar Cost:
Solar costs follow different material and location factors than energy efficiency measures. The national average solar PV cost for residential applications as of 2018 was $3.14/W. EnergySage is a good resource to determine how solar costs vary by state.[80]

Example Calculation:
This example uses New York City to demonstrate how someone can scale modeled results to a city not included in Figure B1. To apply these results to New York City, we used the following information:

- Climate Zone: 4
- Utility Rate: $0.1588/kWh
- Labor and Material Cost Multiplier: 1.4
- Residential Energy Code: IECC 2015
- Solar Resource: 1,325 kWh/kW
- Solar Cost: $3.36/W

The calculations use the following equations:

- **To calculate incremental cost of ZER:** [Incremental efficiency cost for the climate zone in Table B1] – [Additional construction cost for the climate zone and code in Table B2] * [Labor and material cost multiplier]
- **To calculate cost of solar PV:** [Solar PV cost taken from correct climate zone in Table B1] * [Ratio of solar resource compared with average] * [Ratio of solar cost compared with national average]
- **To calculate energy savings from ZE:** [Energy savings taken from climate zone in Table B1] – [Additional energy bill cost for the climate zone and code in Table B2] * [Ratio of utility cost compared with national average]
- **To calculate energy savings from ZER:** [Energy savings taken from climate zone in Table B1] – [Additional energy bill cost for the climate zone and code in Table B2] * [Ratio of utility cost compared with national average]

FIGURE B1: ZER RESULTS SCALED TO THE 50 MOST POPULOUS CITIES IN THE UNITED STATES (NOTE: MILWAUKEE, MINNEAPOLIS, AND MIAMI WERE AMONG THE TOP 50 MOST POPULOUS CITIES BUT WERE EXCLUDED BECAUSE THEY ARE OUTSIDE OF IECC CLIMATE ZONES 2–5)

City	ZER incremental Cost	Energy Savings for ZER	Mortgage Threshold?	Resale Threshold?	Consumer WTP Threshold?	First Cost Threshold
New York City, NY	$4,166	$850	✓	✓	✓	✗
Los Angeles, CA	$2,330	$701	✓	✓	✓	✗
Chicago, IL	$1,945	$746	✓	✓	✓	✗
Houston, TX	$1,290	$431	✓	✓	✓	✗
Phoenix, AZ	$1,769	$602	✓	✓	✓	✗
Philadelphia, PA	$7,621	$608	✓	✗	✓	✗
San Antonio, TX	$1,243	$444	✓	✓	✓	✗
San Diego, CA	$2,228	$393	✓	✓	✓	✗
Dallas, TX	$1,681	$513	✓	✓	✓	✗
San Jose, CA	$2,634	$607	✓	✓	✓	✗
Austin, TX	$1,228	$441	✓	✓	✓	✗
Jacksonville, FL	$1,243	$464	✓	✓	✓	✗
San Francisco, CA	$2,694	$909	✓	✓	✓	✗
Columbus, OH	$3,877	$1,094	✓	✓	✓	✗
Fort Worth, TX	$1,661	$513	✓	✓	✓	✗
Indianapolis, IN	$3,919	$889	✓	✓	✓	✗
Charlotte, NC	$6,509	$722	✓	✓	✓	✗
Washington, D.C.	$2,738	$699	✓	✓	✓	✗
Seattle, WA	$3,125	$505	✓	✓	✓	✗
Atlanta, GA	$6,094	$794	✓	✓	✓	✗
Denver, CO	$1,358	$674	✓	✓	✓	✗
Boston, MA	$1,837	$658	✓	✓	✓	✗
El Paso, TX	$1,600	$571	✓	✓	✓	✗
Detroit, MI	$1,574	$909	✓	✓	✓	✗
Nashville, TN	$5,406	$860	✓	✓	✓	✗
Memphis, TN	$5,817	$699	✓	✓	✓	✗
Portland, OR	$2,976	$573	✓	✓	✓	✗
Oklahoma City, OK	$1,641	$479	✓	✓	✓	✗
Las Vegas, NV	$2,066	$558	✓	✓	✓	✗
Louisville, KY	$5,667	$840	✓	✓	✓	✗
Baltimore, MD	$2,738	$749	✓	✓	✓	✗
Albuquerque, NM	$5,406	$998	✓	✓	✓	✗
Tucson, AZ	$1,321	$466	✓	✓	✓	✗
Fresno, CA	$2,390	$607	✓	✓	✓	✗
Sacramento, CA	$2,411	$639	✓	✓	✓	✗
Mesa, AZ	$2,140	$616	✓	✓	✓	✗
Kansas City, MO	$3,035	$711	✓	✓	✓	✗
Long Beach, CA	$2,269	$478	✓	✓	✓	✗
Omaha, NE	$3,834	$986	✓	✓	✓	✗
Raleigh, NC	$6,440	$707	✓	✓	✓	✗
Colorado Springs, CO	$3,578	$1,034	✓	✓	✓	✗
Virginia Beach, VA	$2,827	$566	✓	✓	✓	✗
Oakland, CA	$2,613	$607	✓	✓	✓	✗
Tulsa, OK	$1,661	$396	✓	✓	✓	✗
Arlington, TX	$1,702	$513	✓	✓	✓	✗
New Orleans, LA	$1,337	$418	✓	✓	✓	✗
Wichita, KS	$2,440	$703	✓	✓	✓	✗

FIGURE B2: ZE RESULTS SCALED TO THE 50 MOST POPULOUS CITIES IN THE UNITED STATES (NOTE: MILWAUKEE, MINNEAPOLIS, AND MIAMI WERE AMONG THE TOP 50 MOST POPULOUS CITIES BUT WERE EXCLUDED BECAUSE THEY ARE OUTSIDE OF IECC CLIMATE ZONES 2–5)

City	ZE incremental Cost	Energy Savings for ZE	Mortgage Threshold?	Resale Threshold?	Consumer WTP Threshold?	First Cost Threshold
New York City, NY	$19,534	$2,270	✓	✓	✗	✗
Los Angeles, CA	$18,661	$2,011	✓	✓	✗	✗
Chicago, IL	$19,702	$2,059	✓	✓	✗	✗
Houston, TX	$14,713	$1,365	✓	✗	✗	✗
Phoenix, AZ	$15,619	$1,728	✓	✓	✗	✗
Philadelphia, PA	$22,103	$1,281	✓	✗	✗	✗
San Antonio, TX	$15,298	$1,340	✓	✗	✗	✗
San Diego, CA	$17,733	$1,128	✓	✗	✗	✗
Dallas, TX	$15,195	$1,473	✓	✗	✗	✗
San Jose, CA	$18,581	$1,743	✓	✗	✗	✗
Austin, TX	$15,066	$1,331	✓	✗	✗	✗
Jacksonville, FL	$12,806	$1,390	✓	✓	✗	✗
San Francisco, CA	$17,953	$2,608	✓	✓	✗	✗
Columbus, OH	$20,095	$2,410	✓	✓	✗	✗
Fort Worth, TX	$15,291	$1,473	✓	✗	✗	✗
Indianapolis, IN	$19,903	$1,957	✓	✗	✗	✗
Charlotte, NC	$18,857	$1,668	✓	✗	✗	✗
Washington, D.C.	$17,121	$1,855	✓	✓	✗	✗
Seattle, WA	$13,815	$1,349	✓	✗	✗	✗
Atlanta, GA	$19,548	$1,833	✓	✗	✗	✗
Denver, CO	$24,248	$1,860	✓	✗	✗	✗
Boston, MA	$21,050	$1,816	✓	✗	✗	✗
El Paso, TX	$17,694	$1,639	✓	✗	✗	✗
Detroit, MI	$19,753	$2,508	✓	✓	✗	✗
Nashville, TN	$19,355	$1,812	✓	✗	✗	✗
Memphis, TN	$18,864	$1,613	✓	✗	✗	✗
Portland, OR	$15,551	$1,531	✓	✗	✗	✗
Oklahoma City, OK	$16,153	$1,374	✓	✗	✗	✗
Las Vegas, NV	$17,793	$1,589	✓	✗	✗	✗
Louisville, KY	$19,647	$1,771	✓	✗	✗	✗
Baltimore, MD	$15,828	$2,000	✓	✓	✗	✗
Albuquerque, NM	$26,654	$2,103	✓	✗	✗	✗
Tucson, AZ	$16,306	$1,396	✓	✗	✗	✗
Fresno, CA	$18,013	$1,743	✓	✗	✗	✗
Sacramento, CA	$17,915	$1,834	✓	✓	✗	✗
Mesa, AZ	$16,586	$1,499	✓	✗	✗	✗
Kansas City, MO	$19,806	$1,897	✓	✗	✗	✗
Long Beach, CA	$18,305	$1,372	✓	✗	✗	✗
Omaha, NE	$24,060	$2,171	✓	✗	✗	✗
Raleigh, NC	$18,805	$1,633	✓	✗	✗	✗
Colorado Springs, CO	$26,694	$2,277	✓	✗	✗	✗
Virginia Beach, VA	$16,773	$1,502	✓	✗	✗	✗
Oakland, CA	$17,911	$1,743	✓	✗	✗	✗
Tulsa, OK	$16,887	$1,136	✓	✗	✗	✗
Arlington, TX	$15,296	$1,473	✓	✗	✗	✗
New Orleans, LA	$16,859	$1,261	✓	✗	✗	✗
Wichita, KS	$19,162	$1,865	✓	✗	✗	✗

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ENDNOTES

ENDNOTES

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[10] The incremental resale value of the ZE home was conservatively not factored into the Mortgage Threshold or Resale Threshold because current appraisal processes do not consistently improve resale values for more energy-efficient homes.

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[14] VV Mendon, A Selvacanabady, M Zhao, and ZT Taylor, *National Cost-Effectiveness of the Residential Provisions of the 2015 IECC* (Pacific Northwest National Laboratory, June 2015.

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[16] "Status of State Energy Code Adoption," United States Department of Energy, last modified June 2018, https://www.energycodes.gov/status-state-energy-code-adoption

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[18] Bethany Speer, *Residential Solar Photovoltaics: Comparison of Financing Benefits, Innovations, and Options* (National Renewable Energy Laboratory, October 2012).

[19] Notably, Lennar (the second largest home builder in the United States) recently created a PPA program that sets the solar price 20% below utility rates for 20 years.

[20] *Step Up to Indoor airPLUS* (United States Environmental Protection Agency, August 2017).

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[26] Temperature readings reported at Chicago Midway Airport have not dropped below -10°F since January 2014.

[27] Statement derived by comparing the Lennox XC25's published seasonal energy efficiency ratio (SEER) of 26 rating to the Carrier 38MPRA's 42 SEER rating.

[28] Defined here as filters achieving a minimum efficiency reporting value (MERV) rating of 13 or greater.

[29] Modeled performance characteristics: SEER 22, 10 heating seasonal performance factor (HSPF) air source heat pump; SEER 25, 12.5 HSPF mini split.

[30] ENERGY STAR certification ensures long-term performance for selected LED products through rigorous performance standards, including lumen maintenance over time and minimum color rendering index (CRI) requirements.

[31] Owen Comstock and Kevin Jarzomski, "LED Bulb Efficiency Expected to Continue Improving as Cost Declines," United States Energy Information Administration, last modified March 19 2014, https://www.eia.gov/todayinenergy/detail.php?id=15471

[32] As defined by rated energy factor.

[33] In cooler climates, HPWHs are typically installed in a garage or other unconditioned space to avoid increasing heating loads.

[34] The specification can be found at https://neea.org/our-work/advanced-water-heater-specification

[35] Anthony Aebei interview by Michael Gartman and Alisa Petersen, February 13 2018.

[36] Detailed recommendations can be found in NREL's 2009 report *Solar Ready Buildings Planning Guide* (2009). The costs of these measures were not explicitly modeled in our analysis.

[37] These measures can reduce the cost of constructing a 2,200-square foot home by over $6,000, assuming change from hip roof framing and two avoided dormers (Source: Residential Costs, RSMeans, 2018). This value is not considered in this report.

[38] Kristen Ardani, Jeffrey Cook, Ran Fu, and Robert Margolis, *Cost-Reduction Roadmap for Residential Solar Photovoltaics* (PV), 2017–2030 (National Renewable Energy Laboratory, January 2018). Chart utilizes the average of conservative and aggressive solar PV price models.

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[48] Stephen Selkowitz, "Bringing Window Innovation to Market: Doubling the Insulating Value of US Windows," Lawrence Berkeley National Laboratory, 2017.

[49] Kristen Ardani, Jeffrey Cook, Ran Fu, and Robert Margolis, *Cost-Reduction Roadmap for Residential Solar Photovoltaics* (PV), 2017–2030 (National Renewable Energy Laboratory, January 2018). Statement assumes a 2030 cost of $1.36/W installed for solar PV.

[50] The right-most column in this graphic incorporates a 10% cost savings for installing mini split ACs and HPWHs, and LED lighting reaches cost parity with current standard technology.

[51] *Housing Market Index: Special Questions on Labor and Subcontractors' Availability* (National Association of Home Builders, July 2017).

[52] https://basc.pnnl.gov/optimized-climate-solutions

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[54] https://www.energy.gov/eere/buildings/building-america-bringing-building-innovations-market

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ATTACHMENT G – EXCERPT FROM DECEMBER 4, 2018 COUNCIL MEMO

HOME SIZE AND ENERGY

One factor to consider as average home size increases each year is the correlation between home size and energy consumption. As square footage increases, the burden on heating and cooling equipment rises, lighting requirements increase, and the likelihood that the household uses more than one refrigerator increases, as does the presence of home theaters, outdoor pools, spas, and similar high-energy-consuming features. Home energy usage is well regulated by Boulder's energy code and homes are increasingly being required to be Net Zero Energy, however, there is room for increasing these requirements as a tool to incentivize smaller homes, or to at least further mitigate the impact of larger homes. Below staff have proposed an acceleration of existing energy code requirements as well as other strategies that might be considered.

Operational Energy

Bolder has approximately 44,000 residential dwelling units that consume 15% of the city's energy annually. A key strategy in the city's roadmap for meeting our climate commitment goals is developing an increasingly stringent energy code to curb this consumption. The city currently has a robust energy code that is one of the strictest in the nation. New homes and major renovations must achieve an Energy Rating Index (ERI) score no greater than 60. An ERI score is a common energy efficiency metric defined as a numerical score from 0-100, where 100 is equivalent to the 2006 code compliant home and zero is equivalent to a Net Zero Energy (NZE) home. To mitigate the environmental impact of larger homes, a sliding scale was incorporated into the code that increased the stringency of the code for homes with larger floor area. As Figure 1Figure 1 illustrates, under the current code, all homes greater than 5,000 square feet are required to be NZE. The current long-term code strategy is to incrementally work towards NZE codes by 2031 with increasing stringency every three years, which is also illustrated in Figure 1.

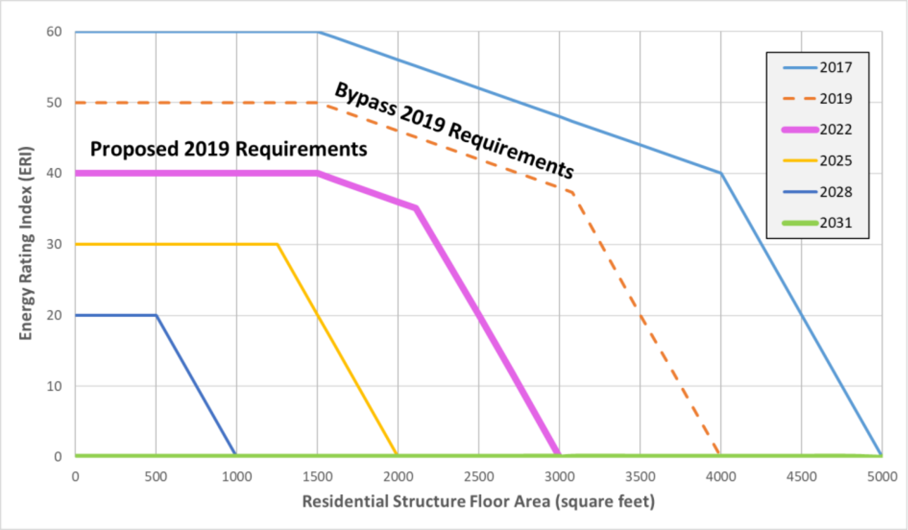


Figure 1: Residential Energy Code ERI Requirements for New Construction.

As originally planned, the 2019 update was to reduce the maximum ERI to 50 and require NZE for all new homes over 4,000 square feet. Since the implementation of the 2017 COBECC [fill in number] new homes have been built to NZE. This represents [X] percent of all new residential construction demonstrating the feasibility of achieving NZE in Boulder's market. Additionally, with the growing market and advancement in technology, achieving NZE is becoming increasingly cost effective. For this reason, staff proposes an acceleration of the ERI requirements , moving straight to the originally-planned 2022 ERI requirements (see Figure 1). This would require all new homes to have an ERI score of 40 or less and all new homes greater than 3,000 square feet to be NZE.

These increased efficiency requirements are well supported by new cost effectiveness studies suggesting the economics for building NZE homes are improving. Rocky Mountain Institute (RMI) recently released Economics of Zero-Energy Homes: Single Family Insights, which shows NZE homes are reaching cost parity with conventional construction and that, as the underlying technologies and design elements continue to improve and scale, these costs will continue to decline. In Boulder, a reduction in the price of solar, as well as technical advancement in heat pump technology and adoption is paving the way for all new homes to cost-effectively achieve NZE.

Solar and Net Zero

In the September 25, 2018 Study Session with City Council, there was discussion of requiring large homes to go beyond net zero energy and to be net positive, energy producing. Over producing electricity in Colorado has a regulated limit. The size of the solar panel system allowed on a customer's residence is determined by the customer's total electricity usage. The total output of the system must not be greater than 120% of the energy used by the customer. Therefore, grid connectivity becomes a barrier to requiring homes to be net positive. In the future net positive metering may be possible; either through a municipal electric utility or through legislative or regulatory change. Staff will continue to monitor this topic and look for ways to increase distributed solar generation through building codes.

This same 120% limit also impacts the selection of technologies for new homes subject to the NZE requirements. The 120% sizing allowance is determined explicitly by the electricity demand. While the additional 20% allowed does provide some offset for natural gas uses in the home, like cooking, it does not provide sufficient offset to cover non-electric space heating. Thus, the NZE requirement, in combination with state-level limits on solar system sizing, results in all electric new homes.

Embodied Energy

As home size increases, the energy used to build and maintain the home increases, as well. Home construction contributes significantly to resource consumption and GHG emissions. Larger homes consume more energy to construct. Electricity and fuels are consumed during the extraction, manufacture, delivery and maintenance of a home's constituent materials. Energy that is embedded in all products and processes used in constructing a building is known as embodied energy.

Boulder's energy codes currently only address operational energy. Most homes are being built tighter, with better insulation, high performance heating and ventilation systems, and high efficiency lighting and water heating equipment. As the operational energy requirements of high-performance homes drop, the embodied energy due to home construction becomes a more significant part of the life cycle building energy. Refer to Figure 2

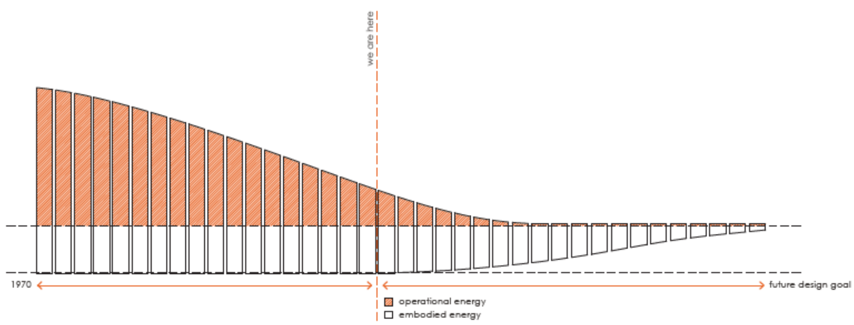
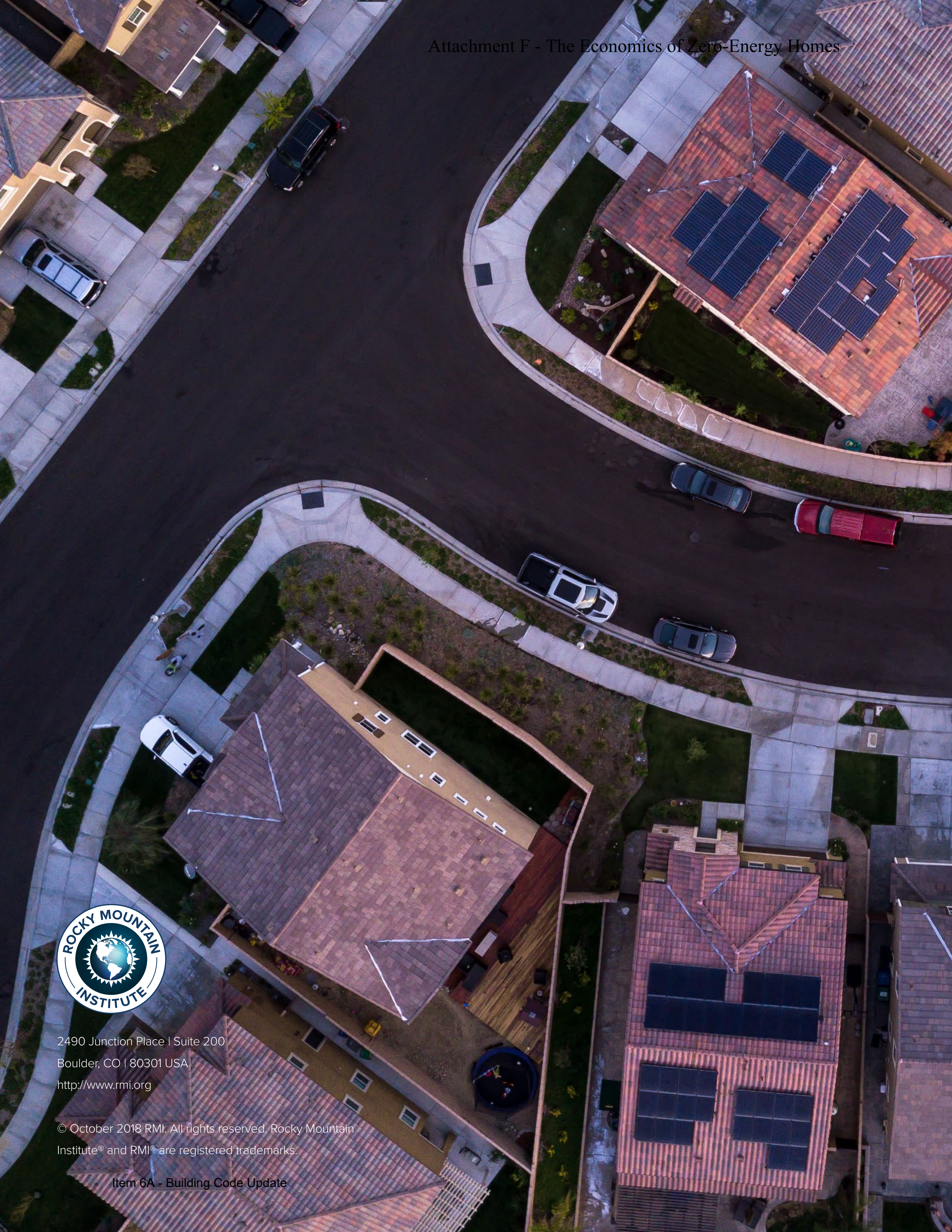


Figure 2: Building Life-cycle Energy[1]

Commented [EC1]: Hard to read the legend on this figure.

[1] Reducing the Environmental Impacts of Building Materials: Embodied Energy Analysis of a High-Performance Building, May 2017

Tracking, understanding, and curbing this consumption is challenging due to the various calculation methodologies, source data, and calculation boundaries. Nevertheless, staff is beginning to engage local design professionals to understand how the city could best encourage reduction in embodied energy. This city is also partnering with other communities to develop best practices and develop a framework for future regulation.



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