The Rent is Too D*** High! Cost-Effective Ways to Reduce Upfront and Long-Term Costs for Residential New Construction and Simplify Participation

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ABSTRACT

The Massachusetts Energy Efficiency Program Administrators (PAs) have a legislative mandate to decarbonize the building sector and therefore drop their previously fuel-neutral approach to incentivizing residential new construction (RNC). Additionally, as baselines have ramped up over time, the PAs have had to continue to think creatively about maximizing their impacts in the RNC market. This paper discusses three recent studies the PAs commissioned to help inform this work: the first two help builders reduce consumption while minimizing construction and/or energy costs while the third tests new program eligibility and savings calculation approaches to reduce participation barriers.

The first study used advanced energy optimization modeling to identify fuel-neutral combinations of measures that would cost-effectively comply with the new energy code being phased in between 2023 and 2025. The second study used similar optimization modeling to focus on building high-performance, all-electric homes. The third study shows an example of using regression modeling to develop a new approach to calculating savings for the program, resulting in a useful way to simplify the participation process for trade allies by relying on Home Energy Rating System (HERS) scores to estimate savings.

Together, these studies provided forward-looking guidance for meeting ever-higher code and program standards, setting the stage for even further innovation and market progress.

Introduction

Since 1991, the Massachusetts PAs have offered incentives to improve the energy efficiency of residential new construction (RNC). The PAs' RNC incentives help homebuilders offset the costs of these higher-efficiency homes. Modeled energy savings from program homes (all of which receive HERS ratings) compared to homes with typical construction practices provide the RNC program with a transparent metric to track energy savings. Training and educational materials for code officials, builders, and other market actors, available through the PAs' Code Compliance Support Initiative (CCSI), along with a new initiative targeting major renovation and addition projects, also contribute to the RNC program's offerings.

See Greenfield, 2022 for a full program background. Most importantly, the March 2021 Act Creating a Next Generation Roadmap for Massachusetts Climate Policy (the "Climate Act of 2021") broadened the PAs' mandate to include "strategic electrification, such as measures that are designed to result in cost-effective reductions in greenhouse gas emissions through the use of expanded electricity consumption while minimizing ratepayer costs" (Climate Act, 2021)

This also required the Secretary of the Massachusetts Executive Office of Energy and Environmental Affairs (EEA) to set a greenhouse gas reduction target for the energy efficiency program. Bolstered by their new legislative mandate and previous successes with retrofit fuel-switching programs, the PAs developed a new All-Electric New Home Incentive. The PAs simultaneously commissioned various studies to inform their incentive design (among other research efforts launched by and on behalf of the PAs), including the three studies of interest in this paper.

The first study built on the methodology of a prior study[1] (Greenfield 2022), and focused on energy optimization in support of code compliance ("EO Code Compliance Study"). It used fuel-neutral energy optimization modeling to identify minimally code measure combinations that would cost-effectively comply with the newly updated energy code (the tenth edition of the Massachusetts Building Code, based on the 2021 IECC), taking effect in 2023 and 2024. It used the National Renewable Energy Laboratory's Building Energy Optimization Tool (BEopt™) to show builders how to comply with the increasingly stringent code requirements while reducing construction costs, relying largely on measures and approaches that are prevalent and available in the market.

The second study[2] used the same optimization modeling approach, but focused only on high-performance, all-electric homes, exploring both net-zero (NZ) homes (with photovoltaics [PV]) and zero energy ready home (ZERH) styles (without PV) ("EO Electrification Study"). A home is traditionally considered NZ if on-site renewables produce at least as much energy per year as the home consumes.[3] Homes are optimized to include sufficient building shell and equipment improvements to become NZ with the addition of a cost-balanced level of photovoltaics. ZERH homes do not include any on-site energy generation.[4]

The third study was complementary but separate. It investigated the feasibility of different ways to calculate program savings and incentives, particularly, using HERS scores as the mechanism for estimating savings and/or incentives rather than actual modeled savings from energy software tools, simplifying the program in the eyes of the participants ("HERS Scores and Savings Study").

Together, we designed this package of studies to help the PAs continue to influence and achieve savings in a market where code has become increasingly stringent in recent years and that has shifted to favoring electrification in much of the state. The packages aim to make it as

[1] The first study this paper focuses on (MA21R41) was built off of a prior report, MA20R23, which is not the focus of this paper. That prior study identified combinations of mechanical equipment and building envelopes that reduced consumption and emissions while minimizing construction and/or energy costs.
[2] The first and second studies here were done independently but were technically considered Phase 1 and Phase 2 of the same numeric study; we describe them as separate studies in this paper for simplicity.
[3] In the tenth edition of the state building code the Department of Energy Resources has taken a broader perspective, where NZ is closer to what some might think of as zero energy ready homes (ZERH), i.e., high-efficiency electrified homes which would be net-zero if renewables were added, or the electric grid was 100% renewable.
[4] They are nearly compliant with DOE's Zero Energy Ready Home program version 2 requirements (DOE, 2024), but generally require additional investments in efficiency to achieve full compliance e.g., an upgrade to ENERGY STAR windows, and/or the relocation of HVAC equipment and ductwork into conditioned space.

easy as possible for market actors to participate and achieve increasingly high levels of performance without dramatically increasing the upfront or long-term operating costs.

Methodology

The following section describes the methodology used to complete the three studies discussed in this paper.

Studies 1 and 2: Energy Optimization Costs

For the EO Code Compliance Study and the EO Electrification study, the study team developed a full suite of economic and energy-related inputs to incorporate into the BEopt energy modeling tool to allow the optimization tool to identify homes that are optimized to meet various goals, whether reducing upfront or long-term costs. These two EO studies built on prior EO research done for the PAs (Greenfield 2022), [5] but for these, the study team updated costs, escalation rates, and other economic and energy-related inputs. The overarching goal was to maintain local and up-to-date labor and material costs to ensure that the research truly represented Massachusetts-specific costs whenever possible, as the specific material and labor costs built into the modeling tool dramatically affect the selection of measure options in the optimization modeling results.

Studies 1 and 2: Energy Optimization Models

The EO Code Compliance Study used the modeling tool to develop different packages that would be minimally compliant with 1) Base Code (the standard, statewide energy code in Massachusetts), 2) Stretch Code (a popular, more stringent energy code adopted at the local level that becomes **mandatory** in that municipality once adopted, and represents nearly 90% of Massachusetts), and 3) a new, Specialized Opt-In code (similar to Stretch Code, but with additional electrification-focused requirements and other energy efficiency upgrades).

For the EO Code Compliance Study to identify cost-effective, minimally code compliance measure combinations, the study team created 24 core single-family (SF) home prototypes and six multifamily (MF) building prototypes, based on common prototypes seen in recent new construction studies in Massachusetts (MA19X02, MA20R30). The team developed prototypes using different efficiency levels and measure combinations and tested a variety of mechanical system types to identify cost-effective packages that use any particular type of mechanical system. For example, for builders who prefer to use furnaces and central air conditioners, the team identified optimized packages that use those system types.

The code compliance study developed a set of optimized packages that complied with the base, stretch, and specialized codes. For each of those code versions, the team developed single-family home prototypes using air source heat pumps (ASHP), furnaces with central air conditioning, ground source heat pumps (GSHP), and ductless mini-split heat pumps (MSHP); multifamily buildings were modeled with furnace/central air and MSHP systems. For each single-family prototype (e.g., a single-family home that was base code compliant with an ASHP

[5] Other related, optimization-based research for the PAs includes the Performance Systems Development study commissioned by the Massachusetts Department of Energy Resources (DOER) which modeled scenarios to support development of the updated building code in 2020.

system), the team also developed a package using conventional single-stud wall construction, and a double-stud configuration (allowing for thicker insulation and reduced thermal bridging).

For the EO Electrification Study, the study team created 12 core single-family home prototypes and 2 multifamily building prototypes. The electrification-focused study included additional, higher-performance measure options to investigate high-performance outcomes and show builders how to continue to push beyond the code requirements specified in the EO Code Compliance Study. The electrification study developed prototypes that were NZ (with solar PV) and ZERH (without solar); for each of those categories, the team developed single-family prototypes with ASHPs, GSHPs, and MSHPs; multifamily buildings were modeled only with MSHPs. As with the code compliance study, single-family prototypes were also modeled with conventionally framed single-stud walls and with double-stud walls.

For each prototype, we used BEopt to model variations on the basic prototype with different combinations of mechanical equipment and envelope features. Each combination constitutes a "package."

For each prototype in the two EO studies, the study team isolated packages relevant to different market actors, including reference homes built to industry standard practice (but with different types of mechanical systems), and then various optimized packages, as described below, that would allow builders to select a package of measures that most aligned with their goals, such as minimizing upfront costs and reducing long-term operating costs. There is no one "optimal" home, so this tool allows market actors to find the package that best meets their needs, in the most efficient and/or economical way. Note that the different phases of the study shared some but not all of the optimizations. Optimization consisted of a multi-step filtering process, shown in Figure 1.

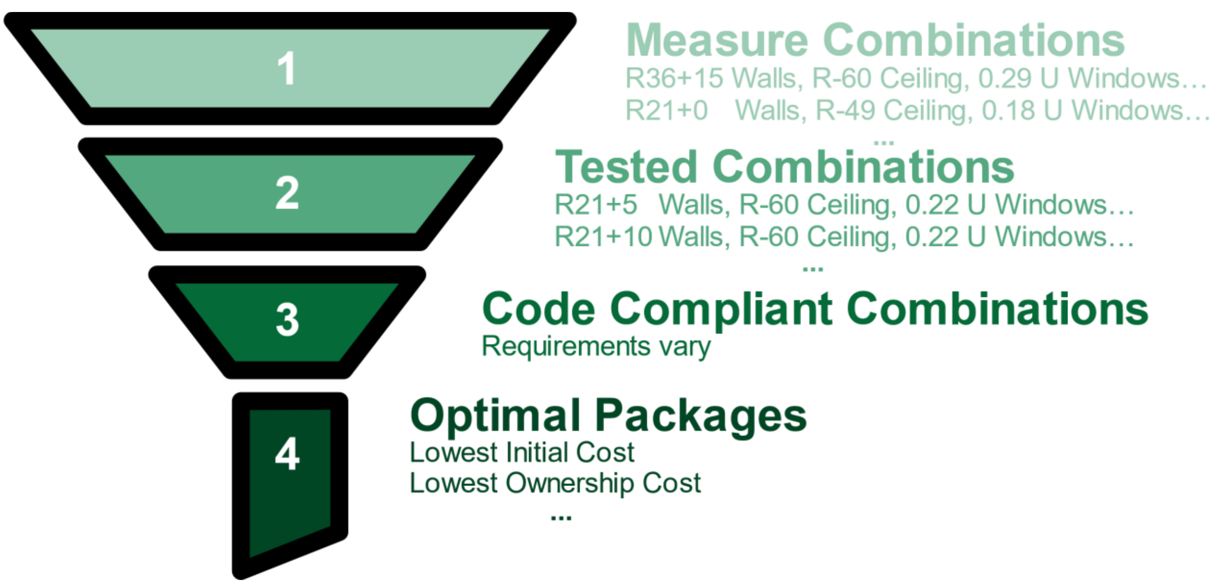

Figure 1. Package selection process

In the EO studies, the study team identified a variety of optimized package, each optimized to meet various goals, as described below:

- The **Reference package** is an unoptimized home that is approximately code compliant (with base, stretch, or specialized building codes).
- The **Construction Cost Package** has the lowest initial cost for efficiency-related measures among tested measure combinations.
- The **First-Year Cost Package** represents the lowest costs to the buyer in the first year of ownership. It has the lowest sum of the following: 20% down payment, first-year mortgage payments, first-year mortgage interest tax deduction, and first-year utility bills. As with the Construction Cost Package, the costs here are limited to energy-related features. Forces in the real estate market could dictate the overall cost of the home, which this study does not cover.
- The **Ownership Cost Package** balances upfront construction and long-term ownership costs. It includes energy efficiency upgrades and equipment replacements that exceed their initial upfront costs with utility bill savings over the life of a 30-year mortgage.
- The **Energy Savings Package** prioritizes energy savings, regardless of upfront or operational costs, and would be of most interest to the eco-minded owner. This does not represent the most savings technologically possible in a new home, just the maximum savings achievable among the tested combinations of options included in this study. (Some of the studies looked at source saving, and some looked at site savings.)

Limitations. The two EO studies included various limitations, the most significant of which include the fact that the results were based on energy modeling and prototype homes and should not be expected to perfectly predict the real-world costs of any specific home. Also, the studies focused on the energy-related costs of the home, not all costs. For example, the modeled construction costs considered cost for energy-related measures, such as framing and insulation, but not other costs, such as basement excavation or flooring, meaning that the initial costs shown do not represent full construction costs or the full selling price of a given home. Additionally, the energy modeling did not consider available energy efficiency related incentives, though those were presented as an after-the-fact bonus available to the builder or owner.

Study 2: HERS Scores and Savings

Energy savings for the RNC program have traditionally been calculated as the difference between as-built and baseline (i.e., industry standard practice) energy models. The baseline/ industry standard practice specifications are coded into the User Defined Reference Home (UDRH), the hypothetical baseline home used as the comparison point for program homes. The baseline home used by the RNC program is not simply a home that minimally complies with code – it is based on actual energy-related practices seen in new homes via on-site inspections.

The HERS Scores and Savings study tested an alternative approach for estimating savings. The study team used inputs and outputs from residential energy modeling software (software from the construction technology company Ekotrope, used to calculate HERS scores for RNC Program homes in Massachusetts) to develop and test multivariate linear regressions to predict the energy savings of RNC program participant homes using limited characteristics such as heating fuel, equipment type, and HERS score. This study used the limited inputs and outputs from the Ekotrope tool to attempt to replicate the savings values using the traditional UDRH-based modeling approach, such that the entire RNC program could potentially be redesigned around the home's HERS score. This could simplify the program's implementation. Given the nature of the BEopt modeling tool, Study 1 used ERI values, while Study 2 focused specifically on HERS scores, which are generally comparable to ERI values but generated specifically by RESNET-approved modeling tools.

Using a LASSO regression approach, ultimately, the team developed linear regressions for whole home energy savings (BTU/yr) fitted to the difference between energy models traditionally used to report savings (i.e., $UDRH_{TotalConsumption} - AsBuilt_{TotalConsumption}$).[6] Additional regressions were fitted to the proportion of whole home savings (%) attributable to each fuel (electricity, natural gas, oil, propane) and end-use (heating, cooling, hot water) combination, e.g., electric heat. Multiplying the whole home savings by a fuel-use savings proportion provides estimated BTU per year savings for that fuel and end-use (Figure 2).

$$Savings\%_{fuel\text{-}use} = \frac{UDRH_{fuel\text{-}useConsumption} - AsBuilt_{fuel\text{-}useConsumption}}{UDRH_{TotalConsumption} - AsBuilt_{TotalConsumption}}$$

Figure 2. Fuel Use Savings Calculation

The specific parameters included in each regression vary, but generally included:

- HERS rating (without renewables)
- building code (Base, Stretch, or Specialized)
- conditioned floor area
- number of bedrooms
- home type (apartment, detached, or attached)
- primary heating type (furnace, boiler, ASHP/MSHP, GSHP) and fuel
- primary water heater type (boiler, GSHP, solar, custom, unspecified) and fuel
- cooling type (CAC, ASHP/MSHP, GSHP, none)

Study Findings

Studies 1 and 2: Energy Optimization

The EO Code Compliance Study found that through the use of energy optimization modeling, in most cases, even *minimally* complying with Stretch Code offers substantial energy and dollar savings over minimal compliance with the Massachusetts Base Code. Given that the Stretch Code represents a significant savings bump over Base Code, this is a positive outcome for the owners of new homes in Stretch Code municipalities, which make up the vast majority of cities and towns in Massachusetts, because the Stretch Code greatly benefits homeowners by reducing their energy consumption substantially over Base Code homes. The savings opportunities are present regardless of the type of mechanical system the builder prefers to use, GSHPs being the one exception, given that their minimum efficiency is already so high. Figure 3 compares the range of source savings relative to an *unoptimized Base Code-compliant home*. By using optimized packages, even minimally complying with Stretch Code yields significant

[6] LASSO is robust to covariance of inputs and naturally yields regressions that require a minimal set of inputs. https://www.publichealth.columbia.edu/research/population-health-methods/least-absolute-shrinkage-and-selection-operator-lasso

savings. Interestingly, the optimization modeling showed that some optimized Stretch Code packages have *long-term ownership costs similar to or lower* than the corresponding Base Code package. This means that the energy optimization modeling approach is sufficiently useful for builders to use it to build homes to higher levels of performance without increasing long-term ownership costs (including upfront and energy-related costs). Even if the upfront costs are higher, long-term costs that take those upfront costs into account are often lower.

The EO Electrification Study shows how pushing beyond minimal compliance via optimization modeling can yield even further savings.

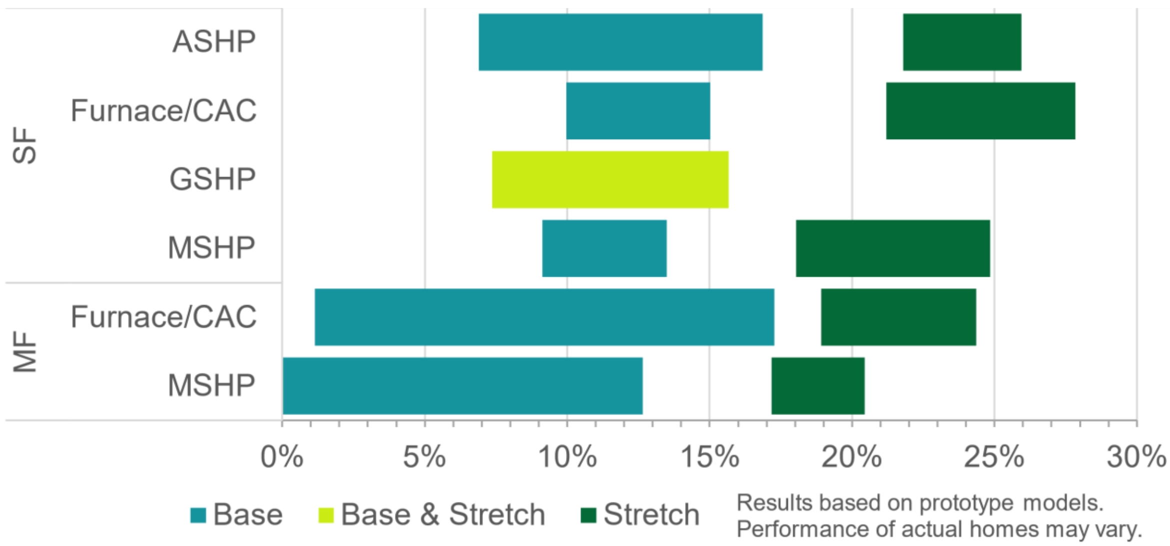

Figure 3. Range of Base Code-Relative Source Savings by Design (EO Code Compliance Study)

The EO Code Compliance Study showed that the range in performance of *optimized but still minimally code-compliant* Base and Stretch Code versions of most home designs were similar across many key metrics (utility bills, construction costs, etc.). However, there was substantial difference between optimized base and stretch code packages' energy savings and Energy Rating Index (ERI) values, showing the benefits of optimization relative to non-optimized construction practices.[7] Figure 4 compares the ERI for minimally code compliant, optimized Base and Stretch Code homes built with different mechanical systems.

[7] The permissible ERI increases by three points for all-electric homes (55 base, 45 stretch), but no packages in this phase benefit from it due to the presence of gas cooking and/or hot water.

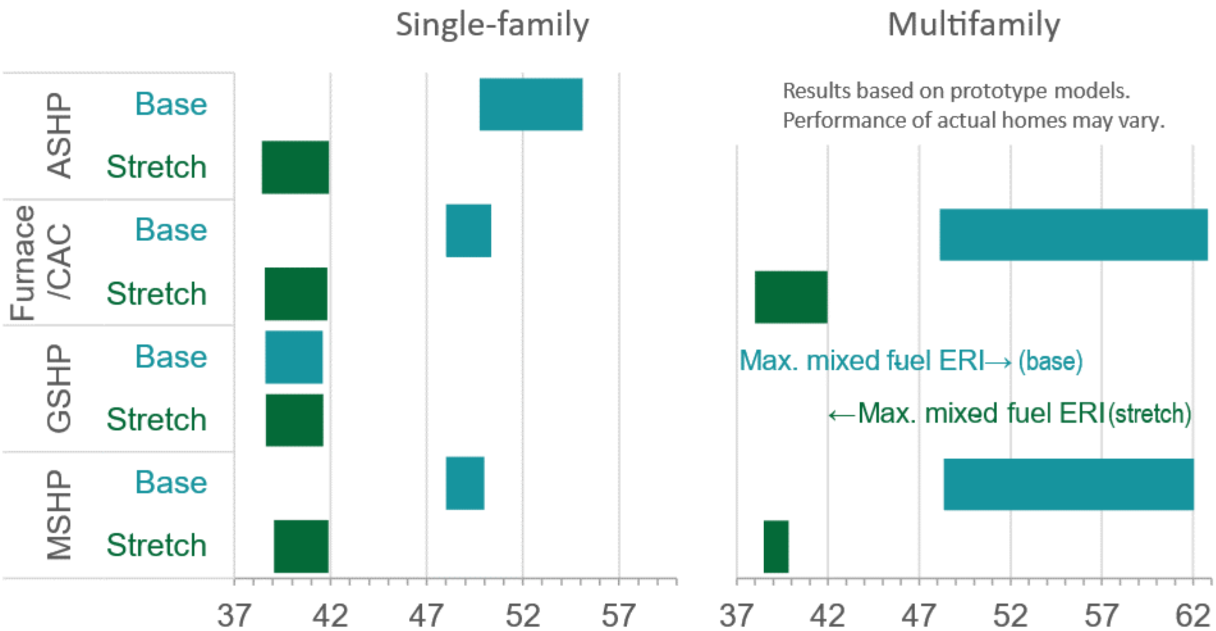

Figure 4. Range of energy rating index values for optimized packages

Another key finding from the EO Code Compliance Study was that optimized apartments and single-family homes with MSHPs were cheaper to construct than counterparts with other mechanical systems, in base and stretch code communities. Figure 5 compares the energy-related construction costs for base and stretch code-compliant homes built with different mechanical systems. Note that these represent costs associated only with energy-related features of the home – they are *not* full construction costs. The average incremental cost to move from minimally Base- to Stretch Code-compliant was lowest for MSHP homes too—approximately $5,000 for MF and $5,700 for single-family homes.

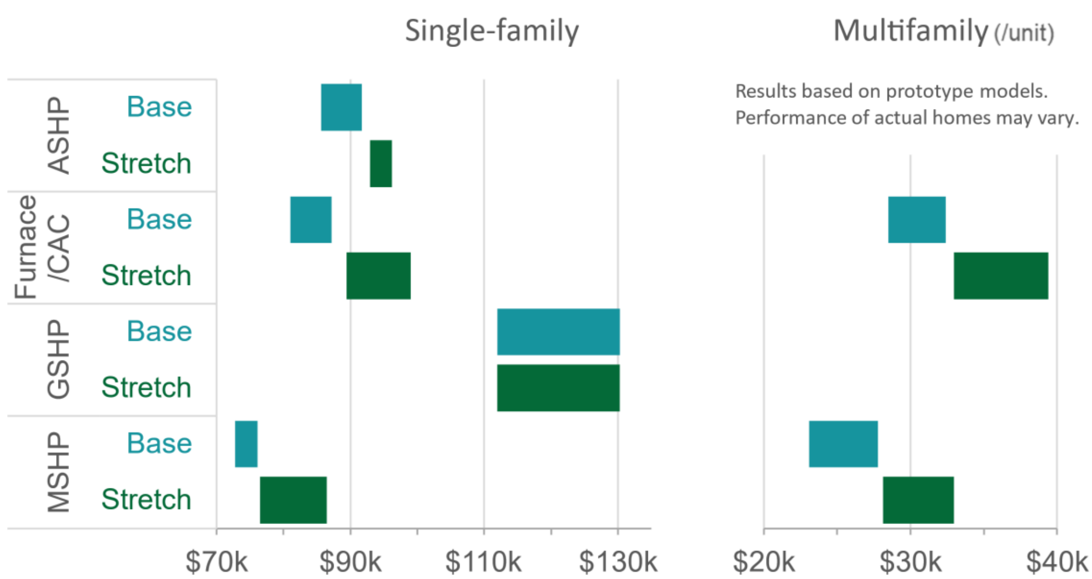

Figure 5. Range of energy-related construction costs for optimized packages

The EO Electrification Study showed builders how to optimally achieve high-levels of performance, using all-electric, market-ready approaches. It also highlighted where there is overlap between building a ZERH (no solar panels) and a NZ home (with solar panels), and perhaps more importantly, where there are tradeoffs between building a ZERH versus NZ home, despite how similar their names sound.

Overlapping measure choices between optimized ZERH and NZ homes include:

- R-49 attic insulation is sufficient to cost-effectively meet ZERH and NZ performance thresholds
- Triple-pane windows typically only make economic sense when optimizing so as to minimize long-term ownership costs or max out savings, not to reduce initial or near-term costs
- Spray foam is not necessary to cost-effectively build ZERH or NZ homes

Notable differences between optimized ZERH and NZ packages include:

- ASHP and MSHP packages differ substantially between ZERH and NZ styles, as NZ requires more efficient mechanical systems
- NZ placed more emphasis on reduced air leakage (i.e., to Passive House standards)
- NZ homes increased the level of continuous wall insulation, including double-stud wall and ceiling insulation
- NZ homes opted for higher-performance heat pumps
- All optimized NZ single-family packages and the energy-savings optimized multifamily packages upgraded to 85% from the default of 75% recovery efficiency, despite stretch code only requiring 65% sensible recovery efficiency

Study 3: HERS Scores and Savings

For the HERS Scores and Savings Study, when the team attempted to replicate UDRH-based savings approach using the regression-based approach, the HERS score-based regressions estimated savings across the program quite well. The regression approach yielded total program saving estimates extremely close to the total savings estimated via the traditional approach, but the per-home savings values could vary substantially from home to home, as shown in Table 1 below. This meant that if the program used an approach employing regression-based formulas to estimate savings, they could expect to produce a reasonably accurate estimate of program-level savings, if not for each individual participant home.

Table 1. Program home savings by approach (millions of BTU/yr)

Savings calculation approach	Minimum	Mean	Maximum	Std. Dev.	Total
Traditional/UDRH	-2.3	35.0	301.3	28.9	34,547
Regression	-6.6	35.9	181.6	26.0	34,533

Similarly, Figure 6 shows a scatterplot comparing the calculated savings for individual program homes (plotted based on their HERS score) relative to the regression's estimate of their energy savings. While individual homes vary, on average, the regression successfully predicted program savings, clearing a first hurdle in testing the feasibility of estimating the program's energy impacts with this approach.

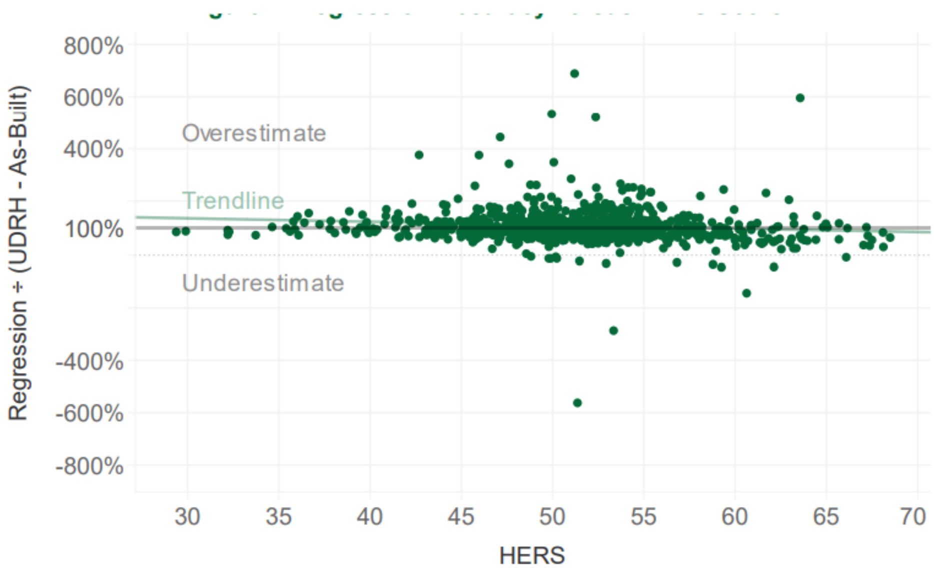

Figure 6. Regression accuracy vs. program HERS scores

The regression-based approach also worked well at predicting program-level electric savings, but in contrast, worked significantly less well at predicting savings broken down by six major fuel and end-use categories: natural gas, propane, and electric heating; natural gas and electric hot water; and electric cooling. This indicated that, while a HERS-score based approach could accurately replicate overall program savings, it was not good at actually estimating savings by fuel or end-use, limiting the ability of this approach to accurately replace model-based savings estimates. To the extent the PAs need to estimate their impacts by fuel or end-use, the regression-based approach breaks down, meaning that the direct outputs from energy models would be best suited for developing any such estimates.

Conclusions

Studies 1 and 2: Energy Optimization

Both optimization studies highlight the potential for builders, homeowners, program administrators and other emissions reduction advocates to benefit from the reduced construction cost and energy consumption of optimized designs. Realizing this potential would call for wider use of energy modeling tools that explore measure alterations to improve building plans. In turn, this would call for continued outreach to homebuilders, contractors, architects, and engineers, so they are informed early in their design process about tradeoffs involved between homes built to comply with different components of the relevant Massachusetts building code (including base and stretch, and now, specialized, adopted by many cities and towns). Program administrators and municipal bodies also learn what tradeoffs exist in the universe of energy-saving measures *before* they design programs to incentivize residential new construction, deliberate updates to building codes, and plan for a more-electrified future. They also learn how to respond to concerns from the market actor community about compliance with new, advanced building codes and program standards. Some market actors may worry that these new requirements will substantially increase construction costs – these studies show that optimized approaches can help alleviate some of those concerns.

In the first phase, optimized designs were minimally code compliant with the (2021 IECC-based) tenth edition of the Massachusetts building code. They frequently included continuous insulation, infiltration reduction, and high SRE recovery ventilation. Among optimized MF packages, half of the base code packages and every stretch code package included very low infiltration rates (0.43 ACH50). While there are approximately two dozen completed multifamily Passive House projects in Massachusetts and twice as many under construction, many employed earlier versions of the standard.[8,9] As such, knowledge of the practices necessary to achieve these low infiltration rates is not very widespread, and market actors would benefit from efforts to disperse this information. We therefore recommended to the PAs that they focus on the co-benefits of these measures in outreach materials and their code compliance program offerings.

The second study, the EO Electrification Study, narrowed the scope of model optimization to high-performance, all-electric measure packages. In so doing, it revealed measures that carried over from the first phase, such as reduced infiltration rates and high-use of continuous insulation. These measures are guidelines market actors can use to traverse the potentially difficult terrain that stands between their current practices and building homes that are high-performance and/or fully electrified. At the same time, the second study showed where design choices baked into minimally code-compliant homes could constrain their full electrification—like water heating, which is challenging to cost-effectively electrify—compared to homes that can use gas systems.

Optimization does allow for transparent, consistent analyses tailored to specific market actors—even if the modeling itself requires specialized knowledge to use effectively. The EO studies performed for the Massachusetts PAs developed an initial menu of packages that could be tailored and rolled out to market actors that best fit their expertise (e.g., building homes with ductless MSHPs vs. ground source heat pumps) and meet the preferences of their customers. Optimization can help chart a path towards further energy use reductions (e.g., meeting Passive House requirements, offsetting energy use with on-site renewable generation) that could compete on costs with industry standard practices.

Study 3: HERS Scores and Savings

The HERS Scores and Savings research found that HERS scores could replace UDRH-based savings as the metric used for calculating program incentives. Rather than requiring homes to show savings relative to a UDRH version of the home via energy modeling (a conceptually complicated task given that the inputs of the hypothetical baseline home are not readily visible in the HERS rating software), this study demonstrated that the program could set incentives simply

[8] PASSIVEhouse Massachusetts (2023). Projects. https://phmass.org/projects/ (Accessed July 2023)
[9] phius alliance (2023). Certified projected database. https://www.phius.org/certified-project-database?&status=46,25&project_type=28&building_function=27,36,93&location=Massachusetts (Accessed July 2023)

based on HERS score improvement, and still accurately predict the savings of the whole program. This could simplify program messaging, increasing the (perceived) program predictability and intuitiveness for builders since the majority must already consider the HERS ratings of their projects to establish code compliance. The study therefore encouraged the PAs to work with their implementation teams to apply this approach if they believed that it would help their trade allies more readily participate in the program and simplify the program's implementation.

While the study discussed the value of using a HERS score approach to set incentive levels, the study did not explicitly recommend the regression-based approach to *calculate program savings*. While this may be appropriate, it was not clear to the study team that the resulting decrease in accuracy resulting from shifting from reporting the savings output from the modeling tool to compare the as-built home to the UDRH baseline to a regression-based approach would be an actual improvement. Similarly, the regression approach provided low accuracy in terms of predicting savings by fuel or end-use, such that the program would need to continue to track the energy model outputs that yield UDRH-based savings estimates.

Overall

Together, these three studies illustrate the work of improving program outcomes in light of ever-increasing baselines. Policy pressures and code improvements keep applying pressure on program savings. Relatedly, the program itself continues to serve as a test bed for teaching market actors to improve their energy-related construction practices ahead of new code changes that continue to increase the performance requirements in the RNC market. By investing in research that uses energy optimization to find packages optimized to meet various goals, the PAs are helping undermine the narrative that meeting the higher performance standards of new code or the program itself can only harm market actors and the consumer. In fact, the research showed that optimization can in many cases reduce long-term costs to the consumer, if not even upfront costs for the builder. Similarly, the program's investigation of the relationship between HERS scores and savings (which is not perfectly linear, as the industry may wish), can help yield results that allow the program to be restructured so as to maximize participation and simplify the process for builders, setting the stage for continued innovation and market progress.

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