There's an Easier Way! Using Optimization Modeling to Reduce Builder Resistance to High-Performance Practices and Code Requirements

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ABSTRACT

The Massachusetts program administrators (PAs) have promoted energy-efficient residential new construction (RNC) for years, but legislation has limited them to an electric-only offering. Simultaneously, competing code variants have yielded a patchwork of codes and concerns about construction costs. This paper focuses on opportunities for builders and new construction programs to achieve continued—and attainable—improvements that contradict common narratives that new codes and all-electric programs will bankrupt builders and reduce home affordability.

In 2021, the PAs launched a series of three studies of single- and multifamily homes that used the National Renewable Energy Laboratory's BEopt^{TM} building energy optimization to assess thousands of measure combinations to identify combinations that balance energy and cost-savings. The studies considered market-ready practices that could boost savings and minimize costs using Massachusetts-based/adjusted costs data to inform the optimization modeling. The 2021 study (20R23) assessed homes with a fuel-neutral lens. The 2023 study (21R41 Phase 1) focused on minimally satisfying the new codes. The 2024 study (21R41 Phase 2) focused on high-performance, all-electric homes.

The studies identified measure combinations that reduce upfront and long-term consumption, emissions, and costs. The results supported municipalities' decisions to adopt advanced codes and showed how builders can meet new requirements and even reduce costs. This paper also compares the optimized homes described in those studies with the results of a fourth recent study (23R60) about industry standard practice among new homes in Massachusetts, showing how typical practices fare against optimized approaches. The authors of this paper were involved in all four studies.

Introduction

History

As part of its intention to promote "renewable and alternative energy and energy efficiency in the commonwealth," the Massachusetts Green Communities Act of 2008 laid the groundwork for the creation of a "Stretch Code" (MSL 2008). The Stretch Code is a more stringent code that municipalities may adopt instead of the typical "Base Code." The Massachusetts Base Code is a minimally amended IECC reference code, subject to updates every few years. When introduced as part of the eighth edition of the Massachusetts State Building Code, the Stretch Code required new homes to receive a HERS Index Score of 75 or less (BBRS 2011). The Residential Energy Services Network (RESNET) deems a home built to 2006 IECC to have a score of 100. A score of 75 represents a home that consumes 25% less energy than one with the same floorplan that just complies with 2006 IECC. The Commonwealth has amended the Stretch Code several times since 2011, lowering the permissible HERS Index Score and introducing credits to incentivize use of green technologies such as heat pumps, solar hot water, and, most recently, low-carbon construction techniques (BBRS 2018, BBRS & DOER 2024).

The current Stretch Code—based on IECC 2021 and codified in Massachusetts State Building Code tenth edition—represents a significant jump in efficiency over the previous version. A score of 55 generally met both Base and Stretch codes under the previous edition (derived from the 2018 IECC), but the new Stretch Code generally requires homes to beat that by 13 points. The new version requires homes permitted after July 1, 2024, to achieve a HERS Index Score of 42 or less without on-site power production

(BBRS & DOER 2024),[1] and introduced a requirement that mechanical ventilation systems have a minimum sensible recovery efficiency (SRE) of 65%. In accordance with the state's policies promoting electrification, the new Stretch Code also refined an earlier clean space heating credit to allow a three-point offset for all-electric homes,[2] increasing their permissible score to 45. The tenth edition also introduced a third, electrification-friendly flavor of building code that municipalities may adopt ("Specialized Code"). This code is largely equivalent to the Stretch Code but further complicates the code landscape in Massachusetts.[3]

Given the complexity of Massachusetts' energy code landscape, the PAs offer code training and technical support to help market actors better understand and comply with these various requirements.[4] In addition, the PAs have long offered incentives for builders and homeowners to incorporate energy-efficient measures into new home construction. The PAs use energy models to compare the efficiency of program participant homes to that of counterfactual versions built to baseline efficiency levels, which are typically informed by studies that describe industry standard practice. Recent legislation has resulted in a shift to an all-electric approach from a previously fuel-neutral approach to incentives.

Program Administrators' Study Goals

Understandably, the Massachusetts PAs and other state officials have anticipated (and/or heard) concerns from the builder community about these new code requirements and the program's shift to an all-electric approach. Accordingly, the PAs have engaged with the builder and HERS rater community and commissioned a variety of research studies to inform the design of their continued support of energy-efficient practices in the Massachusetts residential new construction market.

The various studies described in this paper speak to those efforts. The PAs' periodic industry standard practice (ISP) studies provide market intelligence about real-world practices in Massachusetts, and help the PAs better understand the energy-efficiency practices of builders working outside of the PAs' RNC program. They show the performance difference between program and non-program homes and help ensure the PAs continue to promote advanced practices. The three energy optimization studies discussed in this report complement the efforts of the ISP studies, showing not how builders behave outside of the program (the focus of the ISP studies), but trying to identify opportunities for them to elevate their practices without causing undue cost and hardship, particularly in light of significantly more stringent energy codes coming into effect under the tenth edition building code.

This paper describes findings from the recent ISP study (23R60) and highlights differences between those typical practices and the high-performance measures included in packages identified by the optimization studies. These findings reveal opportunities for builders to refine their practices, ensuring compliance with the newest code and program requirements while delivering value to new home buyers.

Methodology

To explore cost-effective means of constructing new homes in Massachusetts, the research team used NREL's building energy optimization software BEopt to generate and test energy models of multiple home designs including single-family and multifamily units with different construction techniques and various suites of mechanical equipment. The study team developed the sets of measure options to explore in these studies to align with real-world conditions in Massachusetts. The measure options selected for modeling were informed by the ISP established in the most recent single-family new construction baseline

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[1] This mimics the new Appendix RC Zero Net Energy Residential Building Provisions.

[2] Electric only clothes dryers, cooking, space and water heating equipment.

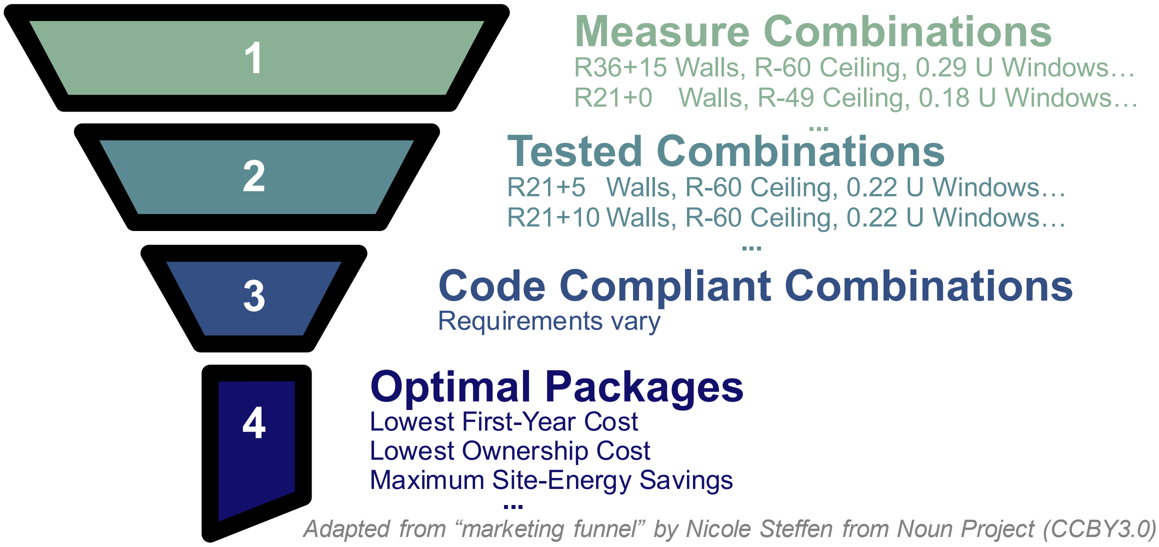
[3] An amended version of Appendix RC in the energy code.

[4] https://www.masssave.com/en/trade-partners/energy-code-training-and-technical-support

available at the time (NMR 2020), building code requirements, measures with available installation-cost data, and expert guidance. ISP informed other aspects of the energy model building designs, such as home size, described in the 2020 single-family new construction study and another related study on low-rise multifamily new construction (NMR 2022).

BEopt produces energy models for different combinations of measure options to evaluate home performance across a variety of metrics, such as energy consumption, construction cost, or long-term operating costs. The software accounts for the cost of efficiency-related measures, such as the purchase of mechanical equipment, appliances, and insulation plus their installation. BEopt also incorporates other factors like mortgage interest rate; equipment lifetime and replacement costs; utility rates, escalation rates and incentives; and tax deductions and an estimate of the average future inflation rate. Note, however, that the software omits non-energy-related aspects of the home, such as pouring the foundation, construction of partition walls, or final fit and finish such as painting and flooring.

In optimization mode, BEopt does not test all possible measure combinations (Figure 1, Step 1). Rather, it performs a gradient descent-style sequential search (Figure 1, Step 2) as it seeks to optimize the target metric—e.g., site energy consumption. However, BEopt has no sense of the building code, so code-compliant results are not guaranteed. Therefore, we directed BEopt to optimize the Energy Rating Index (ERI) and exported all of the tested combinations (grey points in Figure 2), filtering them for code compliance (Figure 1, Step 3), and finally selecting among these individual combinations with a focus on satisfying various optimization criteria (Figure 1, Step 4).[5] These criteria include lowest First-Year Cost, minimum Ownership Cost (maximum long-term economic benefit for the owner/occupant including utility bills and mortgage payments), and maximum Site Energy Savings. First-Year Costs is a composite goal seeking to maximize benefits for the builder by either minimizing construction cost or reducing energy consumption while only marginally increasing costs (less than $1,000) under the assumption that they can recoup the investment in efficiency by selling the home for a modest premium.



Adapted from "marketing funnel" by Nicole Steffen from Noun Project (CCBY3.0)

Figure 1. Optimized package selection process. Source: NMR 2024a.

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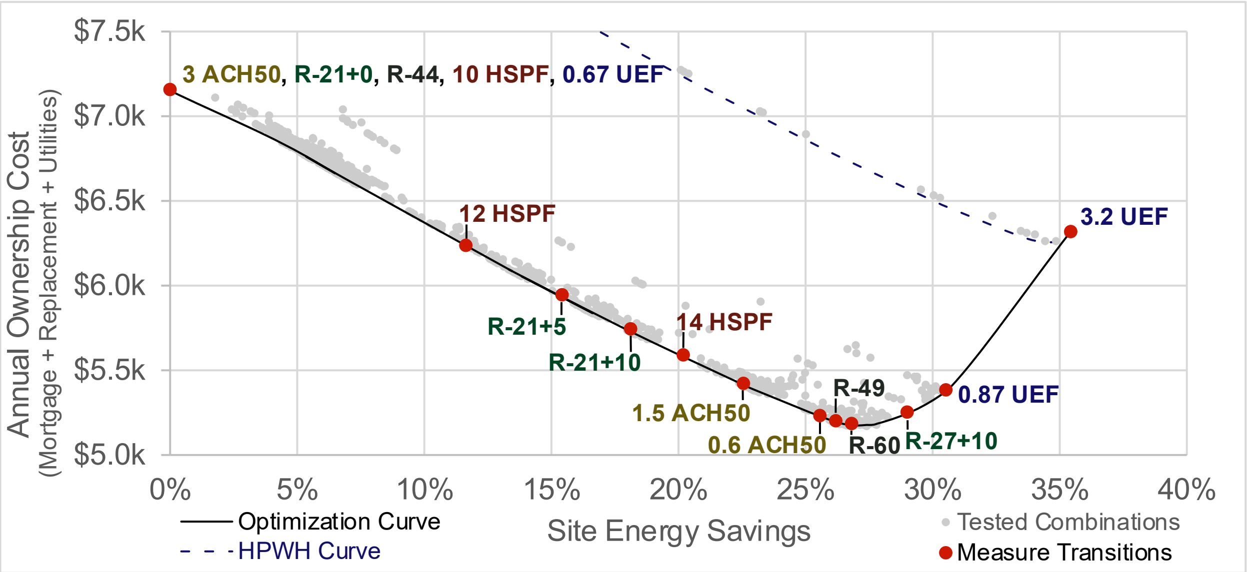
[5] ERI and HERS are closely related since the former is derived from an earlier version of RESNET's protocols for HERS. However, the latter continues to evolve independently. For example, ANSI/RESNET/ICC 301-2022 incorporates an index adjustment factor (IAF) to better account for differences between smaller and larger homes that earlier algorithms did not (RESNET & ICC 2022).

Figure 2 provides a more concrete example of the model optimization process. In the top left are the initial conditions for air leakage, nominal wall and ceiling insulation R-values, heat pump heating efficiency, and water heater efficiency. As BEopt sequentially searches the parameter space, it traces out the optimization curve of minimum long-term ownership cost for a given level of performance. As it does so, some measure options become favored over others, eventually replacing the defaults. Note that individual measures trade-off, plateauing at some value before it becomes cost-effective to invest further. In this example, the model determined that it is not worth upgrading from a 12 HSPF to 14 HSPF heat pump before upgrading the wall insulation from R-21+0 to R-21+10. The model then defers further wall insulation (R-27+10) until air leakage is reduced and ceiling insulation is increased (0.6 ACH50 and R-60 respectively).

Knowledge of these transitions is not essential to selecting a package of measures for an efficient home—nor are they even highlighted by BEopt itself—but they can be teased out of its detailed reports. We feature them here to demonstrate the types of complex and unintuitive cross-measure interactions and trade-offs that energy optimization can help to resolve. For instance, at the time (2021), it was not obvious that upgrading a home's water heater (domestic hot water, or DHW) from gas to a heat pump water heater (HPWH) would increase ownership costs by more than a thousand dollars per year. Figure 2 demonstrates that shifting from packages that fall along the primary optimization curve to packages that incorporate HPWHs (along the higher, parallel dashed curve) increases annual costs by $1.6k for 7% more energy savings; i.e., the difference between the optimization curve minimum and the 3.2 UEF transition point.



ACH50	Air changes per hour of infiltration at 50 Pascals of pressure difference with the outside
R-X+Y	Cavity plus continuous wall insulation
R-Z	Ceiling insulation
HSPF	Heating Season Performance Factor; heat pump efficiency rating
UEF	Uniform Energy Factor; water heater efficiency rating

Figure 2. Example energy optimization of a mini-split home in Massachusetts. Source: NMR 2021.

Results/Insights

Single-family comparisons: energy-efficiency features of code, ISP, and optimized homes. Table 1 (opposite) lists recent ISP averages from recent baseline studies and the applicable prescriptive energy code requirements under the ninth edition of the Massachusetts State Building Code in the left-most columns (A and B). This shows that the average home built in Stretch Code communities meets or exceeds the ninth edition code's prescriptive requirements for all of the listed measures except for duct leakage.[6] That said, only air leakage and duct leakage values are truly mandatory requirements for these homes. The other prescriptive code values listed are merely advisory, since the Massachusetts Stretch Code mandates use of the Energy Rating Index (ERI) compliance path,[7] a holistic, performance-oriented path that determines compliance based on the home's HERS Index Score.[5] The remainder of the table pertains to the current (tenth) edition of the state building code, which includes a far more stringent HERS threshold of 42, with a three-point allowance for all-electric homes.

Column D of the table represents a mixed-fuel, furnace-heated home that would minimally comply with the tenth edition code, with an ERI value (41.4) just under the 42 required for mixed-fuel homes by the new Stretch Code. The optimization modeling sought to improve upon this starting point. This Reference package mainly differs from the ISP described in the 23R60 study (HERS 51 on average, built under the previous code) through the use of more wall and ceiling insulation, reduced air leakage and total duct leakage (TDL), and exceeding the new mandatory mechanical ventilation recovery efficiency standard. These same five measures are also the primary focus of upgrades in the optimized packages, shown in the three right columns of Table 1. The First-Year optimized mixed-fuel home (column E) refines the Reference package (column D) without much change to the ERI value. Most significantly, a similar set of refinements would support full electrification (columns F and G) for a lower initial cost and reduced site energy consumption compared to similar mixed-fuel homes (like column E). The First-Year Cost optimized all-electric package (column F) has an ERI roughly five points better (40.2) than Stretch Code's threshold of 45 for all-electric homes. The Ownership Cost optimized all-electric package (column G) hits 32—far better than current ISP and 10 points better than required by code.

The construction cost row in Table 1 refers to the costs of efficiency-related measures explored by the model as described in the Methodology. They do not represent the total costs to construct a building. The listed Ownership Cost amortizes these construction costs and the end-of-life equipment replacement across the duration of a 30-year mortgage, while also incorporating forecasted annual utility bills.

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[6] In the table, insulation levels are listed as "effective R-value" (eR), the reciprocal of the assembly U-factor (1⁄U). These differ from nominal (center-of-cavity) R-values by accounting for details like framing factor. Another adjustment occurs for the duct insulation eR of some optimized packages since the IECC recommends that deeply buried ducts (those which are properly encapsulated within blown-in ceiling insulation) be treated as R-25.

[7] Section R406.2 of IECC 2015–2021 and R406.3 of IECC 2024 rely upon the building thermal envelope requirements of the prescriptive path (or UA alternative) as a backstop to ensure minimal levels of structural efficiency, making it a particularly relevant reference. However, when first introduced in IECC 2015 the ERI performance target was considerably more stringent than prescriptive path. While the IECC 2018 increased the ERI thresholds to bring the two paths closer (61 for Climate Zone 5; ICC 2016), Massachusetts kept the target index of 55. The prescriptive path in IECC 2024 (Fairey 2025) is only now approaching parity with Massachusetts' performance threshold.

Table 1. Comparison of code requirements, industry standard practice and alternate approaches in single-family homes Source: BBRS 2018, BBRS & DOER 2024, NMR 2023, NMR 2024a, NMR 2024b.

	A	B	C	D	E	F	G
Building Code	9th ed. – Stretch		10th edition – Stretch				
	(IECC 2018)		(IECC 2021)				
Source/Study	23R60	Regulation		21R41 Phase 1		21R41 Phase 2	
Optimization focus	ISP	–	–	Reference	First-Year	First-Year	Ownership
Study package label	–	–	–	DCFW.SR	DCFW.S1	DCMW.Z1	DCMW.Z2
Construction cost (Oct. 2023 $k)	–	–	–	90.0	89.8	80.8	88.6
Ownership cost, annual (Oct. 2023 $k)	–	–	–	4.4	4.4	5.0	4.9
Site energy (10^6 BTU)	–	–	–	85.6	85.9	48.5	39.8
ERI	51	55	42 gas/ 45 elec.	41.4	41.7	40.2	32.4
Air leakage (ACH_{50})	2.2	3.00	3.00	0.85	0.85	0.85	0.85
Ventilation (SRE)	<5%	–	65%	85%	85%	85%	85%
TDL ($CFM_{25}/100\ ft^2$)	5.7	*4*	*4*	4	4	–	–
Duct insulation (eR)	7.7	*8*	*8*	25[†]	25[†]	–	–
Flat ceiling (eR)	41.4	*38.5*	*41.7*	61.3	50.3	50.3	50.3
Above grade wall (eR)	20.6	*16.7*	*22.2*	28.1	33.1	28.1	33.1
Window U-factor	0.28	*0.30*	*0.30*	0.29	0.29	0.29	0.29
Window SHGC	0.29	–	*0.40*	0.35	0.35	0.35	0.35
Frame floor (eR)	31.4	*30.0*	*30.3*	32.9	32.9	32.9	32.9
Cond. bsmt. wall (eR)	19.9	*16.3*	*16.3*	16.7	16.7	16.3	16.7
Pipe insulation	1.3[º]	3	3	5	5	5	5
DHW (UEF)	0.92[‡]	0.81 / 2.04		0.95	0.95	0.98*	3.7
DHW fuel	gas	gas / elec.		gas	gas	elec.	elec.
DHW capacity (gal.)	0	0 / 66		0	0	66	83
Heating, gas (AFUE)	95.4	80		98.5	95	–	–
Heating, elec. (HSPF2)	10.7[‡]	7.0	7.5	–	–	12.4	12.4
Cooling (SEER2)	13.3[‡]	12.4[‡]	13.4	13.4	13.4	25.1	25.1

Italics mark prescriptive path requirements and are included for reference only.[7]

[†] Deeply buried ducts sandwiched in the center of floor/ceiling insulation.

* Grid-enabled electric storage water heaters have lower federal minimum efficiencies than units which are not capable of demand-response.

[º] No pipe insulation was available in the 23R60. This value is from the previous 19X02 baseline (NMR 2020).

[‡] Converted from older efficiency units.

Even though some might think of ductless mini-splits as an approach best suited for retrofit applications, the modeling effort indicated they could be highly cost-effective for new construction as well. Specifically, switching from a furnace (column E) to ductless mini-splits (columns F and G) significantly reduces the cost of electrification for both single-family (Table 1) and multifamily (Table 2) construction. This is due to a) their much higher efficiencies than either fuel-fired heating equipment or ducted air source heat pumps, and b) no need for ductwork or radiant distribution systems; see also Figure 3. Although floor mount and ceiling cassette air handlers are typically more expensive than conventional wall-mount units—offsetting some of the Ownership Cost savings—they may increase consumer acceptance of ductless technology. For instance, customers more comfortable with the form factor of steam radiators or floor duct registers may find floor-mount blower units more acceptable.

Our methodology also frequently selects packages projected to have lower (better) HERS Index Scores than the building code requires, particularly in all-electric homes.[8] The lower scores associated with these optimized packages provide builders with a larger margin for error if they cannot reach the specified Passive House-levels of air tightness (0.85 ACH50 for the modelled design) or if some other deviation impacts their project's HERS Index Score. By using the measure combinations generated in this modeling effort, builders can have increased confidence that they will meet the stringent requirements of the Stretch Code and avoid the potential for costly rework. This may be helpful since the Stretch Code has been adopted by 85% municipalities as of June 5, 2025 (GCD), leaving builders without a prescriptive compliance path fallback.

Multifamily comparisons: energy-efficiency features of code, ISP, and optimized homes. Table 2 is the multifamily analog of Table 1's single-family code and optimized package overview. It follows the same structure, though some rows are omitted for brevity (pipe insulation) or irrelevance (conditioned basement walls and duct insulation, since the design assumes all mechanical equipment is within conditioned space). An additional caveat is that the results for multifamily models in BEopt 2.8 are limited to the occupied units and do not cover common areas.[9] The modeled multifamily building was a three-story apartment building with 26 units averaging 1,270 ft^2 each.

These minor differences aside, we see that as with single-family homes, recent multifamily ISP (column A, built under the ninth edition code based on the 2018 IECC) meets or exceeds the requirements (column B) for all measures except duct leakage, although it only just satisfies the air leakage requirement. A similar set of measures (air and duct leakage, wall and ceiling insulation) are again the focus for upgrades when optimizing for the tenth edition building code (columns E through G). Interestingly, windows were not upgraded in the models designed to comply with the tenth edition code; instead, they maintained ISP-like specifications in the examples shown for both single-family and multifamily homes. In fact, only six of the study's thirty-two electrification packages include upgraded windows, all of which are single-family. However, this increases to six of sixteen when limited to Ownership Cost and Site Energy Savings packages.

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[8] This is the case even though the use of a dated national site to source energy ratio in the ERI and HERS algorithms is known to penalize all-electric homes in some markets.

[9] With an optional exception of corridor lighting, should one elect to include it within the model.

Table 2. Comparison of code requirements, industry standard practice and alternate approaches in multifamily homes Source: BBRS 2018, BBRS & DOER 2024, NMR 2023, NMR 2024a, NMR 2024b.

	A	B	C	D	E	F	G
Building Code	9th ed. – Stretch		10th edition – Stretch				
	(IECC 2018)		(IECC 2021)				
Source/Study	23R60	Regulation		21R41 Phase 1		21R41 Phase 2	
Optimization focus	ISP	–	–	Reference	First-Year	First-Year	Ownership
Study package label	–	–	–	D3FW.SR	D3FW.S1	D3MW.Z1	D3MW.Z2
Construction cost (Oct. 2023 $k)	–	–	–	902.9	902.3	697.5	714.6
Ownership cost, annual (Oct. 2023 $k)	–	–	–	68.2	68.0	67.2	66.9
Site energy (10^6 BTU)	–	–	–	924.5	937.4	656.5	648.0
ERI	49	55	42 gas/ 45 elec.	42.0	42.0	36.3	36.0
Air leakage (ACH$_{50}$)	3.0	3.00	3.00	0.43	0.43	0.43	0.43
Ventilation (SRE)	0%	–	65%	85%	85%	85%	85%
TDL (CFM$_{25}$/100 ft^2)	5.1	*4*	*4*	4	4	–	–
Vaulted ceiling (eR)†	39.9	*38.5*	*41.7*	45	45	45	45
Above grade wall (eR)	21.7	*16.7*	*22.2*	32.9	32.9	22.9	32.9
Window U-factor	0.27	*0.30*	*0.30*	0.29	0.29	0.29	0.29
Window SHGC	0.29	–	*0.40*	0.35	0.35	0.35	0.35
Frame floor (eR)	31.4	*30.0*	*30.3*	32.9	32.9	32.9	32.9
DHW (UEF)	0.91‡	0.81 / 2.04		0.95	0.95	3.7	3.7
DHW fuel	gas	gas / electricity		gas	gas	electricity	electricity
DHW capacity (gal.)	0	0 / 66		0	0	83	83
Heating, gas (AFUE)	95.5	80		95	95	–	–
Heating, elec. (HSPF2)	10.4	7.0	7.5	–	–	12.4	12.4
Cooling (SEER2)	13.3‡	12.4‡	13.4	13.4	13.4	25.1	25.1

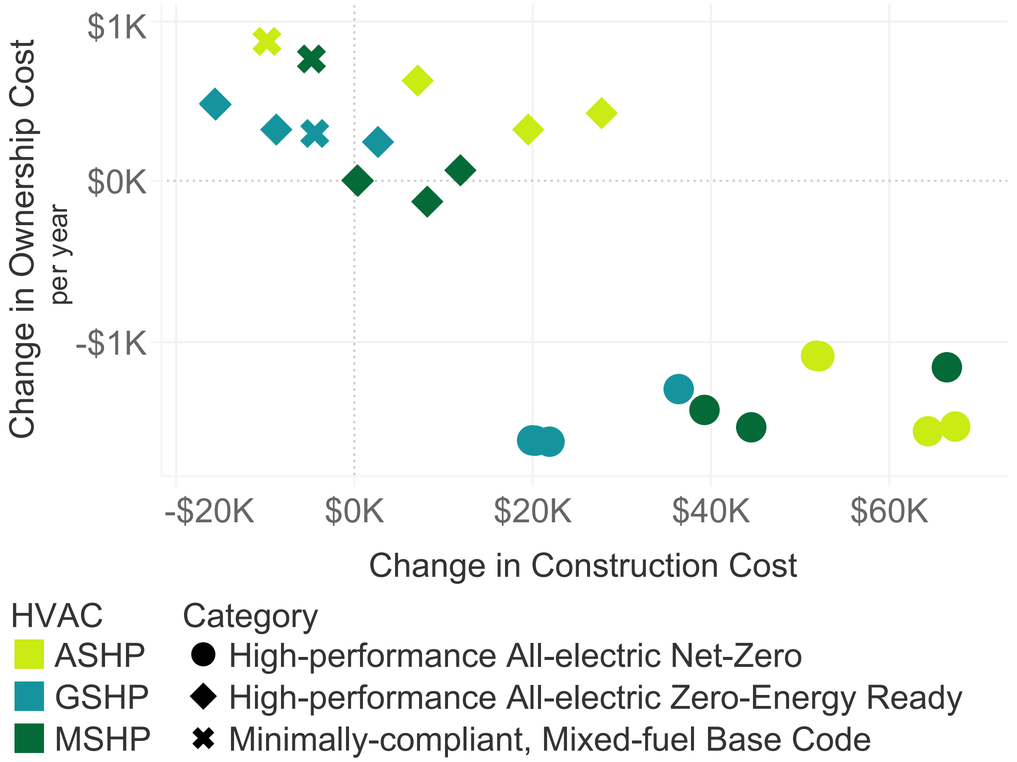
Italics mark prescriptive path requirements and are included for reference only.[7]

† Vaulted here indicates the presence of minimal air space above the insulation within the roof assembly, it does not imply a sloped or cathedral roof.

‡ Converted from older efficiency units.

Comparisons of upfront and long-term costs across code, ISP, and optimized homes. Some significant outcomes of the IECC 2021-based code studies shown above (21R41 Phases 1 & 2) are visible in Figure 3. It provides multiple simultaneous sets of comparisons between heat pump technologies (color), building codes (shapes) and optimization levels (shapes, triplet of points). The X-axis encodes change in construction cost and the Y-axis, change in annual ownership cost. The origin point ($0, $0) represents an unoptimized home that 1) minimally complies with Stretch Code, 2) is all-electric, and 3) has the same type of heating/cooling as the home under consideration. Because both axes are relative costs to different home designs, it is not possible to draw inferences about costs of mini-splits (MSHP) versus geothermal (GSHP). However, the full details of those comparisons are available in the original studies. Finally, the triplet of identically colored and shaped points for each code-HVAC combination represent, from left to right, First Year Cost, Ownership Cost and Site Savings optimized packages.

First, while minimally compliant prescriptive path, mixed-fuel homes (marked by ✕, which feature gas cooking and hot water) are cheaper to construct (farther left in the chart) than minimally code-compliant all-electric, minimally Stretch Code-compliant homes at the origin ($0, $0), the mixed-fuel homes are projected to have higher annual ownership costs (higher in the chart). This provides support for the adoption of advanced codes from the perspective of future occupants and maximizing societal benefit. Second, the incremental construction costs of optimized Zero-Energy Ready homes (ZERH, ◆) can be relatively small,[10] or *even lower* than those of unoptimized homes. Third, if one can incorporate solar panels into the design process, one can achieve Net-Zero (NZ, ●) with substantial ownership cost reductions. Finally, a fourth and subtler result is suggested when comparing the patterns of ZERH and NZ marks for each equipment type in the graph: incorporating sufficient solar capacity to achieve NZ after design and construction can result in higher total construction cost than aiming for NZ from the start. This is because the latter incorporates additional optimizations of non-solar measures with a lower marginal cost than additional panels.[11]



ASHP	Centrally ducted air-source heat pump
GSHP	Ground-source (geothermal) heat pump
MSHP	Mini/multi-split heat pump
Mixed-fuel	A non-all-electric home, typically due to gas cooking and hot water

Figure 3. Incremental cost (October 2023$) of electrification versus minimally ERI-compliant single-family homes. Source: NMR 2024a.[11]

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[10] Typically, less than 20% of the *energy-related* costs, which are already but a fraction of the total construction cost.

[11] Within each Zero-Energy Ready/Net-Zero heat pump cluster, the three marks represent from left to right the First-Year Cost, Ownership Cost and Site Energy Savings optimized packages. If the post-construction addition of solar panels to ZERH was equivalent to constructing an optimized NZ home, then we would expect the same pattern of

The team's earlier work also demonstrated the benefits of optimization even when not specifically electrifying (NMR 2021). The 2021 study presents an even clearer case of the benefits to builders (i.e., limited impact to initial cost) of these techniques given its focus on the fuel-neutral optimization of ISP-level homes. Table 3 summarizes select incremental costs and benefits of the resulting builder-friendly First-Year optimized packages versus homes built to the industry standard practice from a contemporary baseline study (NMR 2020). Notably, it shows that the most prevalent style of home—one with a gas furnace and water heater—could be constructed for lower cost than ISP while also reducing energy consumption. Some of the typical improvements in the optimized packages are 24" on center wall framing (vs. 16"), fully insulated hot water pipes (R-5 vs. "R-1", a mix of uninsulated and R-3), Grade I insulation,[12] and R-49 attics (vs. R-44).

Table 3. Costs and benefits (Dec. 2020$) of First-Year Cost optimized packages versus ISP single-family homes Source: NMR 2021.

Metric \ HVAC Type	Furnace	Geothermal	Ductless Mini-split
Study package label (20R23)	DCFW.1	DCGW.1	DCMW.1
Incremental ERI (Full ERI)	-8 (56)	-8 (43)	-4 (55)
Incremental Construction Cost	-$342	$715	$71
Incremental Annual Ownership Cost	-$336	-$716	-$118
Simple Payback (years)	–	1.0	0.6
Site Energy Savings (10^6 BTU/year)	20.9	11.4	5.0

Conclusions

Despite industry concerns about the difficulties of satisfying the requirements of the 2021 IECC-based tenth edition Massachusetts State Building Code (Bakhsh, et al. 2023), we found that in most cases, there are optimized packages that would handily meet the code requirements regardless of a builder's choice of fuel. That said, all-electric packages provide the widest margin for compliance with the new requirements. Packages optimized to reduce long-term ownership costs in particular appear to provide significant benefits, if for additional construction cost.

Given the increase in code stringency (in Massachusetts and beyond), optimized approaches may be necessary to allow builders to continue to satisfy these aggressive code targets. For example, the current Stretch Code in Massachusetts requires HERS scores no higher than 42 for gas homes – far beyond the 55 previously required. While the average non-program home in Massachusetts under the previous code performed quite a bit better than the HERS 55 requirement in effect at the time (HERS 51), shifting from 51 to the new requirement of 42 (45 for all-electric) will require a significant but achievable adjustment in builder practices, and the support of programs such as that offered by the PAs in Massachusetts. This support may be necessary to discourage communities from deciding to abandon Stretch Code and backsliding to the comparatively relaxed requirements of Base Code (HERS 52 for gas, 55 for all-electric), which did not change nearly as much relative to the previous 2018 IECC-derived codes.

This optimization work, accounting for the harsh Massachusetts climate and the state's high costs, also points to how much farther builders can improve outcomes with readily available practices and equipment. Builders could be understandably concerned, after all, that there is only so far they can go without dramatic cost increases. However, the all-electric, ownership-cost optimized package that uses MSHPs identified in the 21R41 Phase 2 study, for example, yielded an ERI of 32, 13 points better than the

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ZERH marks to appear in the NZ cluster as they are translated due to the costs and benefits of the solar panels (PV). However, since the patterns differ, we must conclude that $NZ \neq ZERH + PV$.

[12] Installed to manufacturer specifications, without gaps or compression.

current Stretch Code requirement for all-electric homes. This indicates significant room for continued performance gains, without the need for mechanical equipment that far outperforms today's systems.

Energy optimization can also be useful for code development (PSD 2020). For example, the three studies in Massachusetts validate the intuition that—at least within Climate Zone 5—introducing minimum mechanical ventilation recovery efficiency requirements reinforces the existing incentives to reduce building shell air infiltration rates. This may be particularly helpful since this measure is frequently weakened by local amendments and low compliance, even though it is generally accepted as having a significant impact on building performance.

Looking ahead, optimization may even provide insights into future IECC developments. The first residential new construction energy optimization study from 2021 (NMR) revealed the benefits of R-5 hot water insulation pipes, which aligns with new requirements in IECC 2024 (ICC 2024). Similarly, IECC 2021 (ICC 2021) introduced a prescriptive requirement for R-60 attics in Climate Zone 5, which IECC 2024 has reset to the previous R-49 in use since IECC 2012 (ICC 2012). Although R-60 attics have their place in Climate Zone 5, when optimizing home designs, we found that these attics were frequently downgraded to R-49 while investment in other measures increased.

Overall, this research underscores the importance of leveraging new approaches to support builders as they work to meet advanced code and program requirements. By leveraging these findings, PAs can continue to provide concrete guidance or additional trainings on how to cost-effectively build high-performance homes, and municipalities can feel comfortable that adopting aggressive code requirements will not put undue strain on the builder community or undue upward pressure on construction and home prices.

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