

How Low Can You (Economically) Go?

Finding the Least-Cost Path to Net Zero New Homes

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ABSTRACT

The Massachusetts Energy Efficiency Program Administrators (or, the PAs) have long offered fuel-neutral incentives to promote energy efficiency in residential new construction (RNC). Given a legislative mandate to decarbonize the building sector, the PAs are deviating from their fuel-neutral approach in launching an All-Electric New Home Incentive in 2022.

To root this paradigm shift in data-driven strategies, the PA commissioned a 2021 study to explore the financial impacts of energy efficiency and electrification on new homeowners. The analysis combined primary research that gathered local installation costs with whole-building energy optimization modeling. The modeling compared the performance of thousands of mechanical and envelope combinations in single-family and multifamily homes, using local equipment, labor, and energy costs. The research identified combinations that reduce consumption and emissions while minimizing construction and energy costs and showed how to prioritize building shell versus HVAC equipment spending.

The PAs used this research to identify requirements for the All-Electric New Homes offer and will leverage results to help builders improve performance with minimal marginal expense. This paper draws on this research and program design process to demonstrate key considerations in launching the All-Electric New Homes offer. Further, this paper discusses the tradeoffs in achieving climate and energy efficiency goals with deep understanding for the cost-impacts on homeowners. This programmatic balance of cost-efficiency and aggressive decarbonization is achievable when informed by data-driven research.

Introduction and Background

The PAs in Massachusetts have supported energy-efficient residential new construction RNC practices through incentive programs for years. The PAs' RNC program offers financial incentives to builders to offset the costs associated with building high efficiency RNC projects. The incentive program leverages the modeled energy savings from Home Energy Rating System (HERS) ratings, promoting whole-house energy efficiency. The program also offers code training and educational materials to code officials, builders, and other market actors through their Code Compliance Support Initiative (CCSI).

Massachusetts RNC programs began in 1991, with the Energy Crafted Homes (ECH) program, and transitioned to the ENERGY STAR Homes program in 1998. In 2007, the program's name was changed to the Massachusetts New Homes with ENERGY STAR program, and again to the Massachusetts Residential New Construction program in 2013.

From 2013 to 2017, the program offered two paths for participation – a tiered performance path and a prescriptive path. The tiered performance path offered four different incentive levels depending on the level of savings achieved by program participants. The prescriptive path offered incentives if specific thresholds were met by participants for mechanical equipment efficiency, air and duct leakage levels, and insulation levels.

Beginning in 2017, the program became solely performance based and now offers a blended savings approach and incentive structure based on the electric and fossil fuel savings that are achieved by program participants. The program currently requires that participants meet a minimum savings threshold (compared with baseline assumptions) to be eligible for financial incentives.

In March 2021, An 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)

and 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 programs. These legislative changes and the success of retrofit fuel-switching programs in the previous plan term catalyzed the development of an incentive offer for the construction of All-Electric New Homes. To inform the program design, the PAs commissioned the Residential New Construction Energy Optimization Cost Study to estimate overall energy cost to homeowners of a new home heated with gas compared with a new home heated with electric heat pumps.

Study Methodology

The following section describes the methodology used to complete the study, focusing on tasks that helped inform Massachusetts-specific measure-level costs and the energy modeling task. The study included a review of relevant literature to identify costs for key energy-efficiency measures, web-scraping to gather data points to inform measure-level construction costs, a web survey and interviews with HVAC/water heater installers, and energy optimization modeling.

Construction and Operation Costs

Prior to the study, the PAs had difficulty assessing the customer cost impacts of switching new homes to electric heating equipment. Thereby, much of the pre-modeling-and-analysis phase of this study focused on collecting cost information for myriad measures, with an emphasis on mechanical equipment, particularly heat pumps, since that technology continues to advance rapidly.

NREL’s National Residential Efficiency Measure’s Database (NREMDB) cost database formed the core of the cost information used in this study (NREL 2018b). However, version 3.1 of NREMDB dates to January of 2018 and provides national cost estimates, yielding cost values that were both dated and low, compared to the higher cost of living in Massachusetts. Therefore, data from the Bureau of Labor Statistics and the Federal Reserve Bank of St. Louis were used to develop local and up-to-date labor and material costs adjustment factors. Similarly, energy costs

and escalation rates were derived from Energy Information Administration data and compared to known utility rates.

The study also included a comprehensive review of available data sources to inform cost estimates for installation, operation, and maintenance for electric and fossil fuel mechanical systems. The review included 20 evaluations published between 2016 and 2019, and was supplemented by web-scraped system costs from local distributors, home improvement centers, online retailers, and online wholesalers/distributors. Overall, the web-scraping effort yielded dozens to thousands of additional cost data points per equipment category.

In addition, the study team conducted a web survey with HVAC and water heating installation contractors that operate in the new construction market in Massachusetts (n=34) to gather primary mechanical system costs for materials, labor, and maintenance. Costs were solicited for specific equipment configurations, such as 95 AFUE furnace(s) for a home with a heating load of 96 kBTUh. These configurations were informed by the findings of a recently completed residential new construction baseline study (NMR Group 2020). Follow-up interviews were conducted with eight survey respondents to verify responses and solicit additional qualitative feedback. The survey results were used to develop the specific heating, cooling and water heating options explored in this study.

Models

The study team created 48 core single-family home prototypes and eight multifamily building prototypes. Each of the combinations of home characteristics shown in Table 1 was modeled twice, once for a stud-framed home, and a second for a home built with structural insulated panels (SIPS). The single-family prototype variations covered three locations, four HVAC types, and two styles. The 30-unit multifamily prototypes included two locations and two HVAC types.

Table 1: Modeled Prototypes (Location × HVAC × Style)

Location	Air Source Heat Pump (ASHP)	Furnace/Central air	Ground Source Heat Pump (GSHP)	Ductless Mini-Split Heat Pump (MSHP)
Barnstable, MA	Colonial, Ranch	Colonial, Ranch	Colonial, Ranch	Colonial, Ranch
Boston, MA	Colonial, Ranch	Colonial, Ranch, MF	Colonial, Ranch	Colonial, Ranch, MF
Worcester, MA	Colonial, Ranch	Colonial, Ranch, MF	Colonial, Ranch	Colonial, Ranch, MF

For each prototype, we used BEopt (NREL 2018a) to model hundreds of variations on the basic prototype with different combinations of building features (i.e., packages). The software tests various combinations to find optimal packages that best meet criteria of interest. From the pool of combinations assessed for each prototype, NMR isolated four packages: a new

construction home built to industry standard practice, and three optimized packages, as described below and presented in Figure 1.¹

0. The Reference package is based on the statewide means from the 2019 Residential New Construction Baseline study.
1. The Payback Period Package provides the most energy-savings for little to no extra upfront costs. This fast payback package maximizes benefits for the builder looking to avoid additional upfront costs.
2. The Ownership Cost Package balances upfront construction and long-term ownership costs, prioritizing benefits to the homebuyer or owner who will pay the bills and mortgage for 30 years. This package uses BEopt’s annualized energy-related costs (AERC) metric, which combines the mortgage payment, tax deductions, equipment end-of-life replacement costs and utility bills, permitting a fair comparison of design-related cash flow among packages.
3. The Site Savings Package achieves the maximum site energy savings possible when choosing between the measure-level model inputs used in this study, not the most energy savings technologically possible in a new home. It prioritizes energy savings, regardless of upfront or operational costs, but only includes measure options readily available in the Massachusetts market based on the range of practices seen in the aforementioned RNC baseline study.

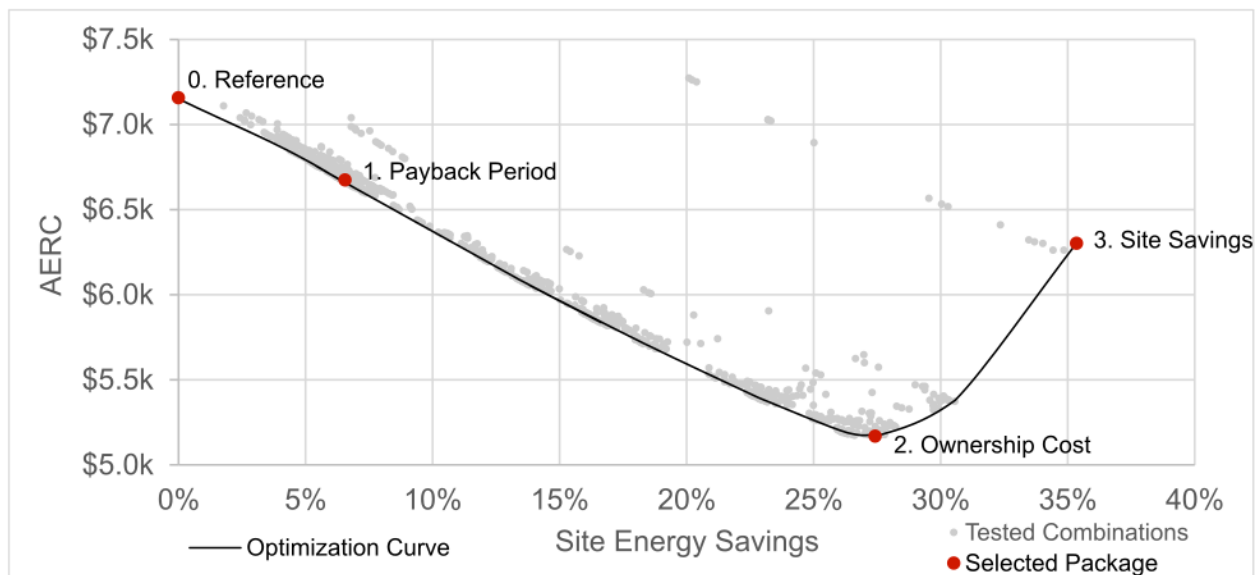


Figure 1. Example site savings versus operating costs (AERC) of modeled packages for a MSHP prototype. *Source: NMR Group 2021, p. 19.*

¹ Additional model derivatives were later explored to address specific questions that arose over the course of the study such as the implications of heat pump water heater placement or higher efficiency options for some measures. In the end, results for 355 measure packages of varying levels of optimization were compiled for 88 models.

Study Findings

Optimization yields substantial savings while maintaining flexibility of approach. As shown in Figure 2, considerable energy savings are achievable for every HVAC type and each optimization variable (payback period, ownership cost, site savings). Because Massachusetts is a heating dominated climate, these savings are primarily from reduced heating energy.²

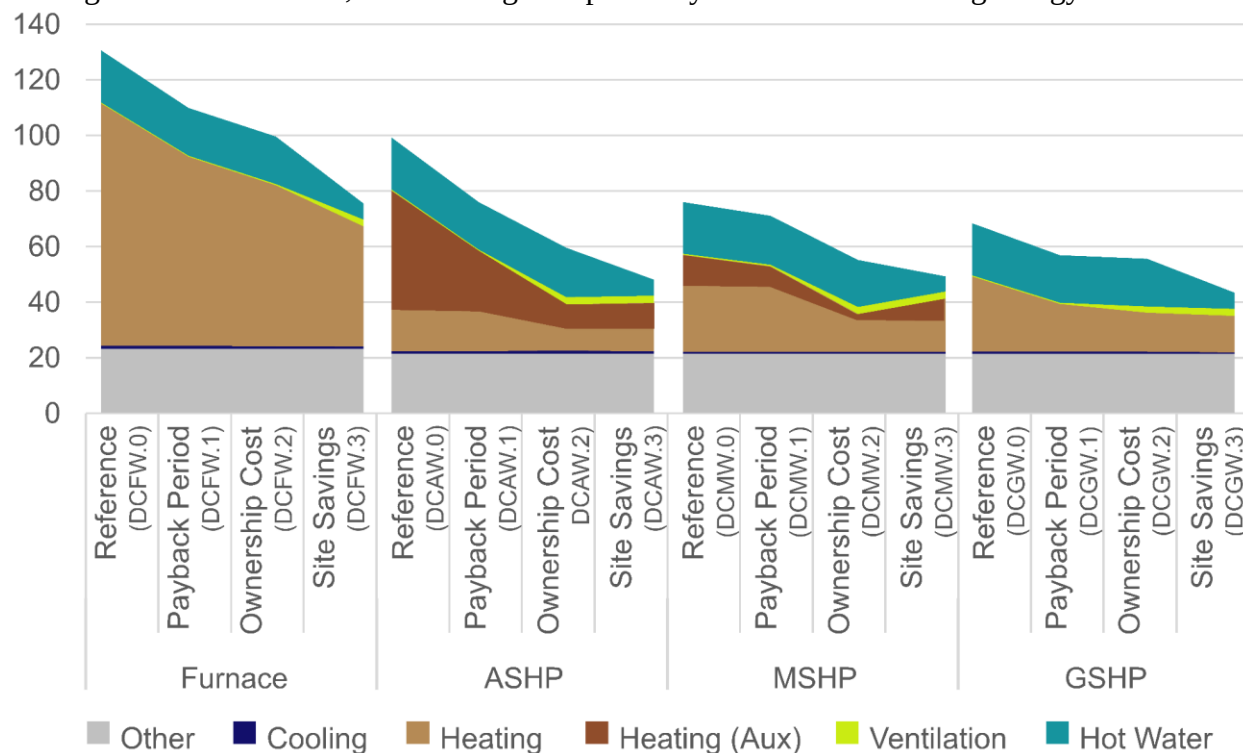


Figure 2. Site energy consumption (Millions of BTU) by end use for stud-construction colonial home packages in Worcester, MA (DCxW) Source: NMR Group 2021, p. 37.

Builders can save on their bottom line while constructing more energy-efficient homes. The study found payback period packages for 30 of the 48 prototypes could be built with lower energy-related construction costs (\$19 to \$609) but greater energy efficiency (4% to 24%) than a typical new home with the same type of HVAC equipment. Another 15 prototypes could be built 7% to 22% more efficiently with negligible additional construction costs (less than \$850). However, some energy-saving approaches included in these optimized packages may require special outreach, training or incentives. For example, moving ducts and mechanical equipment into conditioned spaces has a significant impact on system efficiency but contractors reported that not only is it easier to install systems in basements and attics, floor plans often do not leave room for them in conditioned space.

Builders also have the ability to generate utility bill savings for occupants without increasing total ownership costs. The analysis identified packages that could reduce utility bills over a typical new home for a given HVAC technology by 14–40% for single-family homes and 8–14% for multifamily buildings, using only common building practices and no onsite renewables.

² All models assume 100% LED lighting of moderate efficacy, and use the same consumer appliances.

Heat pump systems can serve optimized homes with minimal reliance on backup heat. The energy optimization process employed hourly steps with TMY3 data to fully account for summer and winter extremes. Modeling showed that cold climate heat pumps can easily satisfy the vast majority of a home's winter heating load without using backup heat. One reason for this is that heat pumps maintained a significant portion of their capacity at cold temperatures. For example, while the modeling accounted for even colder temperatures, MSHP packages retained at least 70% of their capacity at 17°F, and around 90% at 35°F, limiting the need for backup heat or dual-fuel HVAC systems. Another reason that heat pumps are able to meet the primary heating needs of optimized homes is due to lower heating loads from an improved building shell in optimized packages.

Shell Investment Pays Off

Figure 3 shows the impact of investment in shell measures for different HVAC systems of a stud-framed single-family home in Worcester, Massachusetts (IECC Climate Zone 5), although the trends are the same for single-family homes in other styles and locations.³ The graphs show the energy savings for various packages and equipment types, ranging from the reference home with no savings (leftmost point 0) to the Site Savings package (rightmost point 3), versus the relative level of investment in the building shell. The slope of the fitted line indicates which investments generally yield the best results. GSHP has the steepest slope, indicating that a far greater benefit results from investments in the shell than in the system efficiency. This is due to the substantial savings that come from reducing the size of GSHP systems. The plots for other HVAC technologies have shallower slopes that still favor prioritizing investment in the building shell, although the case for doing so with ductless mini-splits is less pronounced.



Figure 3. Shell investment ratio versus site energy savings. Source: NMR Group 2021, p.30.

The excess shell investment for packages (y-axis) was calculated using the equation in Figure 4.

$$\text{More Shell Investment}_{\text{package}} = \left(\frac{\text{Shell}_{\text{package}}}{\text{HVAC}_{\text{package}} + \text{Shell}_{\text{package}}} \right) - \left(\frac{\text{Shell}_{\text{reference}}}{\text{HVAC}_{\text{reference}} + \text{Shell}_{\text{reference}}} \right)$$

³ The large multifamily stud-framed models yielded similar results despite benefiting the square-cube law. Single-family and multifamily SIP homes with furnaces showed a flat shell investment ration across optimization levels, and a negative investment for mini-split apartments.

Figure 4. Shell investment ratio.

This analysis does not take into account the relative ease of future upgrades to mechanical equipment compared to the building shell, which further bolsters the case for building efficient structures in the first place. Furthermore, while the study does not explicitly account for recent trends in construction supply costs due to supply chain problems stemming from the COVID-19 pandemic like rising lumber prices, several key aspects of the optimized packages have zero or negative materials costs, including best practices such as:

- Using 24-inch center framing instead of 16-inch where possible, particularly in walls. This requires less lumber and reduces thermal bridging.
- Installing insulation to manufacturer specifications, rather than allowing gaps around or compression of insulation.

While this study suggests that it is generally most cost-effective to prioritize shell upgrades over mechanical systems upgrades, achieving high levels of performance does still require investment in mechanical systems. Figures 5 & 6 are example optimization curves for furnace/central air and mini-split prototypes respectively. Each point represents a specific package of efficiency options. The industry standard practice home is top left in these figures, and the other labeled points highlight when various key measures transition to higher performing options, thereby creating a more efficient overall package. Shell improvements are generally the most cost-effective investment to make, but eventually mechanical system efficiencies need to be upgraded to achieve higher energy savings against the baseline home. While major shell improvements precede equipment upgrades for the furnace/central air home, this is not true for the mini-split home where the shell and mechanical equipment measure upgrades are intermingled.

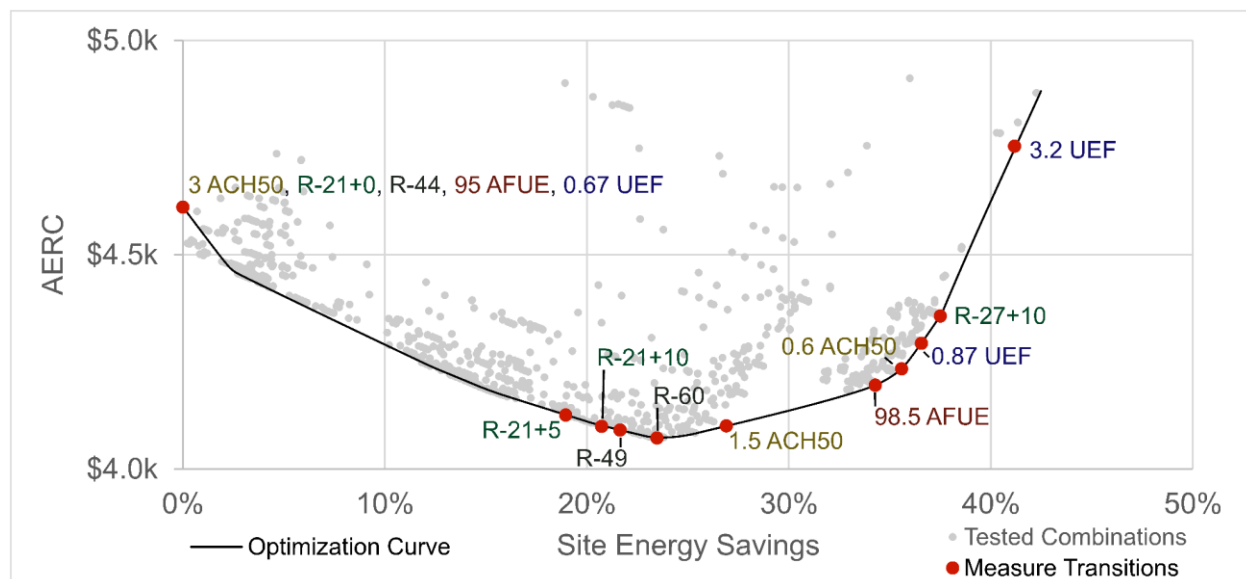


Figure 5. Sample measure option transitions for a furnace/central air home. *Source:* NMR Group 2021, p. 35.

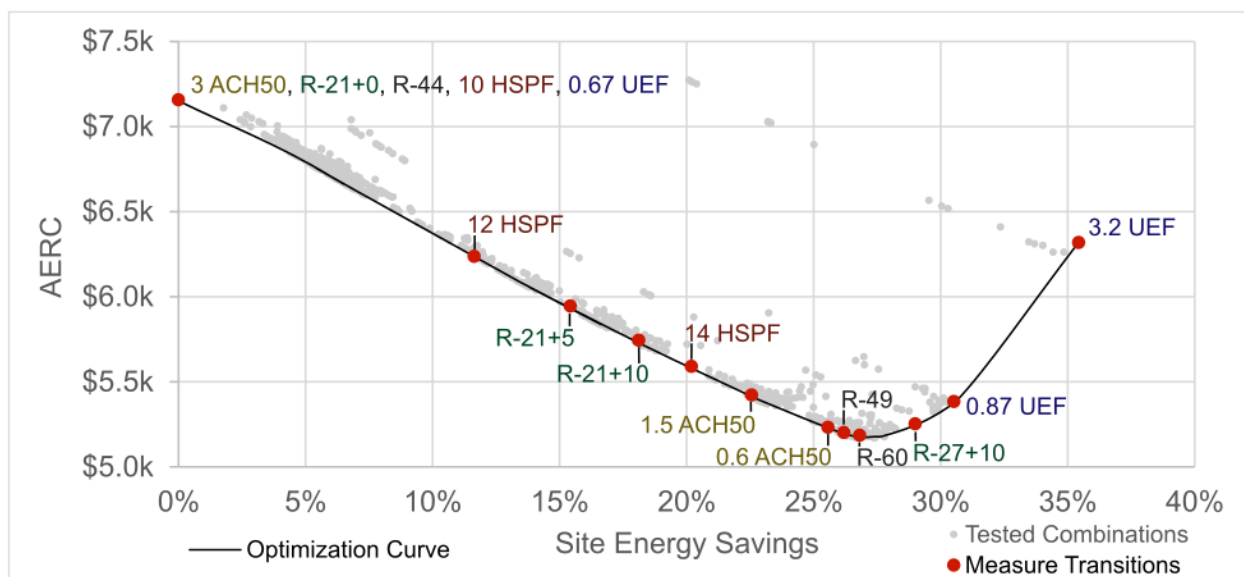


Figure 6. Sample measure option transitions for a MSHP home. *Source:* NMR Group 2021, p. 34.

It is also noteworthy that under the modeled conditions, water heater efficiency was among the last things to improve when adopting a fuel-neutral approach and not specifically optimizing for electrification. In contrast, most optimized packages (84%) include an R-5 hot water insulation upgrade, which is more stringent than the R-3 typically required by code or the uninsulated/partial insulation observed in 80% of new homes (NMR Group 2020, p. 107). This represents an example of a highly cost-effective upgrade, as it provides valuable savings at minimal incremental costs (\$220–\$380).

Electrification

Although this study did not specifically explore electrification, a task which is planned for a future study, it did yield numerous results related to the subject. For example, while the study focused on natural gas as the fuel for homes with combustion equipment and appliances, it also explored optimization for a limited range of homes that used propane instead. With few exceptions,⁴ propane home packages were similar to those for natural gas. However, as Figure 7 shows, the high cost of propane makes electrification a compelling alternative. In most cases even non-optimized ASHP and MSHP homes (large blue and lime green markers) are cheaper to operate and construct than propane-powered homes (brown markers), while optimized electrically-heated homes fare even better. Note, however, that except for the Site Savings packages—the rightmost marker for any given HVAC type in each pane of the figure—these homes still include gas hot water heater systems.

⁴ Tankless water heaters were selected as a cost-effective measure in many propane packages, and some shell improvements occurred earlier than in natural gas homes.



Figure 7. Construction versus annual utilities for propane and electrically heated packages. *Source: NMR Group 2021, p. 121.*

Another set of findings relevant for electrification comes from an exploration of the impact of heat pump water heater (HPWH) placement. BEopt permits the user to choose the location for a water heater, but the software defaults to automatic placement based on the home design. We noticed some peculiar results for the Sites Savings packages of colonial homes—which feature mixed condition basements—and modeled multiple water heater locations as well as alternate water heater technologies to investigate further. We discovered that the common practice of placing HPWH in somewhat confined conditioned spaces can result in a system with sub-optimal performance, whereas placing them in non-freezing spaces improves efficiency while reducing negative interactive effects with the home.⁵ Alternatively, ducted and split heat pump water heaters which primarily draw heat from the ambient air can offer even higher levels of performance, although these systems also have higher costs.

⁵. While HPWHs were not considered an especially complicated installation by the surveyed contractors, two of the eight interviewees said they do not install HPWHs due to their additional installation requirements, such as how they can increase the space heating load by drawing heat from the space

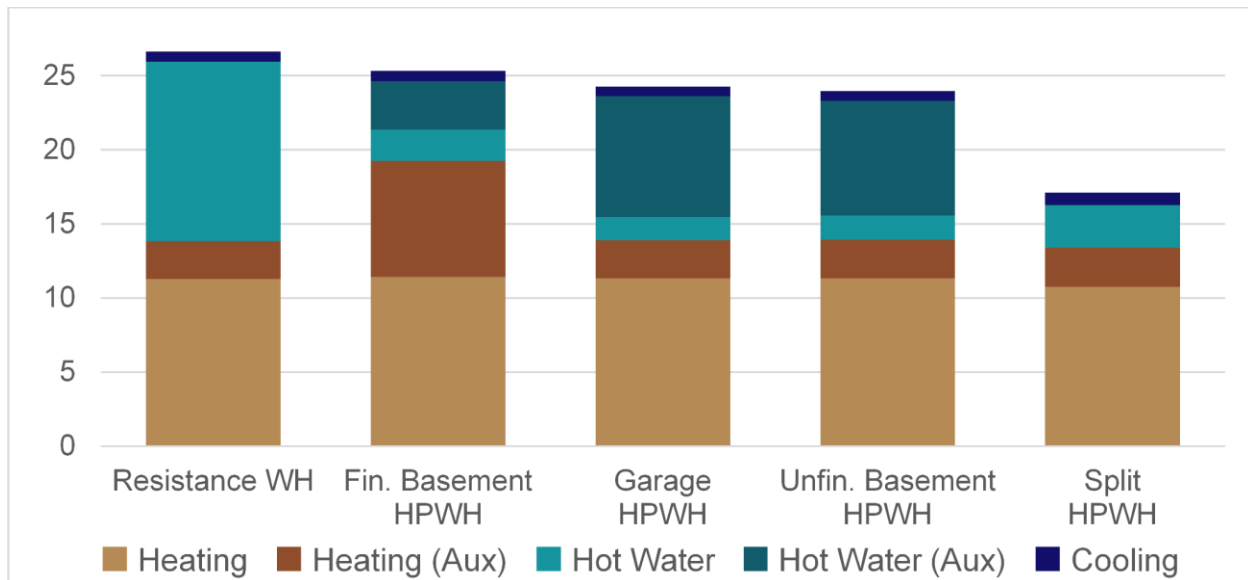


Figure 8. Electric water heater interactions of site savings colonial packages in Worcester, MA. Source: NMR Group 2021, p. 116.

The specific values plotted in Figure 8 are provided in Table 2, along with other related metrics for context. As previously seen in Figures 5 & 6, the AERC of the electric water heater options are higher than a stand-alone gas-fired storage water heater. However, all electric water heating options have lower annual site energy consumption. In addition, the construction cost for an electric resistance home is lower than that of a gas water heater, while the AERC of a split HPWH approaches that of the gas system but with a much lower Energy Rating Index (ERI) score.

Table 2: Sample water heater variation comparisons for Site Savings-optimized MSHP home

	Gas Storage	Resistance	Cond. Bsmt. HPWH	Garage HPWH	Uncond. Bsmt. HPWH	Split HPWH
UEF	0.67	0.94	3.2	3.2	3.2	3.7
Labor	\$641	\$607	\$1,111	\$1,111	\$1,111	\$1,461
Materials	\$683	\$521	\$2,125	\$2,125	\$2,125	\$4,983
Total DHW Cost	\$1,323	\$1,128	\$3,236	\$3,236	\$3,236	\$6,444
Year 1 Gas \$	\$244	\$0	\$0	\$0	\$0	\$0
Year 1 Electric \$	\$2657	\$3,569	\$3,460	\$3,334	\$3,315	\$2,898

AERC	\$5,222	\$6,300	\$6,303	\$6,098	\$6,067	\$5,652
ERI Score	38.9	41.7	41.2	38.2	38.0	33.9
Annual Energy Consumption (Million BTU/yr, Site)						
Heating	11.1	11.3	11.4	11.3	11.3	10.7
Heating, Aux.	1.9	2.6	7.8	2.6	2.6	2.6
Hot Water	17.0	12.1	2.1	1.6	1.6	2.9
Hot Water, Aux.	0.0	0.0	3.3	8.2	7.7	0.0
Cooling	0.6	0.7	0.7	0.6	0.7	0.8
Total Site Energy	30.6	26.7	25.3	24.3	23.9	17

Source: NMR Group 2021, p. 117 & Appendix E.

Conclusions

For developing the program design, the study's results on weatherization and cost tradeoffs provided clear direction. To ensure building all-electric homes reduces customer energy costs, the PAs designed the All-Electric Homes program to require stringent minimum insulation levels equivalent to a 45 HERS. For homes with efficient envelopes, NMR's research identified little marginal cost for using electric heat compared with gas heat, but substantial opportunity for energy savings. This finding enabled the PAs to confidently require participating homes to include no fossil fuel equipment. Customers, ratepayers and the environment benefit when new homes pair an efficient envelope with all-electric equipment.

Establishing incentive levels required the review of multiple cost streams. To ensure the program would be economically cost-effective for ratepayers, the PAs identified a maximum incentive rate using a utility cost test approach by estimating the benefits from past projects that would have qualified for the All-Electric Homes program. To complement that approach, the PAs performed a bottoms-up analysis of incremental costs compared with standard practice; this analysis produced the estimated capital cost burden to developers of selecting higher envelope efficiencies, all-electric equipment, and associated ventilation upgrades. These analyses converged on a \$15,000 incentive for single-family all-electric homes built to 45 HERS.

The challenges in designing this program and the value provided by NMR's research highlight a critical need in designing future efficiency programs. As decarbonization efforts complexify, there is increasing need to ensure programs holistically serve customers. No longer are single cost-effectiveness metrics sufficient to ensure efficiency programs yield sustainable value. Strategic electrification efforts need to be analyzed both as economic impacts on

ratepayers, but also as acute impacts on individual program participants. Unless electrification programs are designed to benefit those participating in them, administrators risk alienating their participants and stifling broader decarbonization efforts. Rooting program design in customer-centric and data-driven analysis yields more robust programs that benefit all parties and enable a more sustainable energy transition.

For future research, the MA PAs and NMR are launching a follow-up study that builds on the previous effort. It will provide guidance on the most cost-efficient pathways to meeting (1) the new All-Electric Homes program efficiencies and (2) the performance requirements of the newly proposed energy stretch code in Massachusetts. By continuing to inform ourselves and market actors about the multifaceted feasibility of decarbonization opportunities, the PAs are able to drive change while building trust with market actors and enabling efficient buildings practices for decades to come.

Postscript

On February 8, 2022, several months after the study described in this paper was completed, the Massachusetts Department of Energy Resources (DOER) announced its proposal for the next update to the state building code. During the presentation DOER revealed that it had independently commissioned a similar modeling effort. This alternate study also used BEopt and predates our work, but it was not made public until after the new building code proposal was issued. While the Residential Stretch Energy Code Analysis (PSD 2020) focused on different questions and used different inputs, its findings support many of the same conclusions e.g; electrification is cost-competitive in general, but especially builders should forego propane if natural gas is unavailable.

References

- An Act Creating a Next Generation Roadmap for Massachusetts Climate Policy, 2021 Mass. Acts, Chapter 8.
- Department of Public Utilities, The Commonwealth of Massachusetts. 31 January 2022. *2022-2024 Three Year Energy Efficiency Plans Order*. Docket DPU 21-120 thru 129.
- NMR Group. 2020. *2019 Residential Construction Baseline/Compliance Study (MA19X02-N-RNCBL)*. Somerville, MA: The Massachusetts Electric and Gas Program Administrators. [ma-eeac.org/wp-content/uploads/MA19X02-B-RNCBL_ResBaselineOverallReport_Final_2020.04.01_v2.pdf](https://www.ma-eeac.org/wp-content/uploads/MA19X02-B-RNCBL_ResBaselineOverallReport_Final_2020.04.01_v2.pdf)
- . 2021. *Residential New Construction Energy Optimization Cost Study (20R23)*. Somerville, MA: The Massachusetts Electric and Gas Program Administrators. [ma-eeac.org/wp-content/uploads/MA20R23-RNC-EO-Final-Report-10222021.pdf](https://www.ma-eeac.org/wp-content/uploads/MA20R23-RNC-EO-Final-Report-10222021.pdf)
- NREL [National Renewable Energy Laboratory]. January 4, 2018. *BEopt v 2.8.0.0*. www.nrel.gov/buildings/beopt.html
- NREL [National Renewable Energy Laboratory]. January 8, 2018. *National Residential Efficiency Measure Database*. remdb.nrel.gov/Performance Systems Development. October 23, 2020. (Revised September 29, 2021). *Residential Stretch Code Analysis - Task 2: Conduct Building Energy Modeling Analysis*. The Massachusetts Department of Energy Resources. www.mass.gov/doc/residential-building-energy-modeling-analysis/download
- Ungar, L. and Nadel, S. September 18, 2019. *Halfway There: Energy Efficiency Can Cut Energy Use and Greenhouse Gas Emissions in Half by 2050*. www.aceee.org/fact-sheet/halfway-there