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Predicting Cost Impact of More Energy Efficient New Single and Small-Multi Family Homes

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Focused on Massachusetts, this research investigates the cost impact of constructing residential homes at various energy efficiency levels and uses real quotes obtained from subcontractors working in the state. The study includes single-family homes and small multi-family homes (2-4 units) across different Home Energy Rating System (HERS) scenarios. These scenarios range from traditional homes (HERS 55) to more energy-efficient designs like all-electric homes with mini-split heat pumps (HERS 45), all-electric homes with central heat pumps (HERS 45), and dual-fuel homes with furnaces and ducted heat pumps (HERS 42). The findings reveal that enhancing energy efficiency increases costs, varying with housing type and targeted HERS score. Single-family homes see a cost rise between $3.77 and $8.12 per square foot (SF), while small multi-family homes face higher increases, from $7.75 to $23.78 per SF, mainly due to their smaller unit sizes. In Massachusetts, improving energy efficiency in single-family homes could add between 1.8% and 3.8% to overall costs, based on HERS scores. The incremental costs are primarily linked to insulation, air tightness, windows, HVAC systems, electrical work, and gas line. This study offers insights crucial for developing public policies to mitigate these additional costs and for making informed decisions about housing affordability.

Key Words: Energy Efficient, Building, Home Energy Rating System (HERS), HVAC Costs, Insulation

Introduction

The drive towards energy-efficient construction is a critical component in the global response to climate change. As building practices evolve to meet the challenges posed by climate change, the pursuit of energy-efficient structures becomes increasingly significant. Across various regions, efforts range from adopting higher efficiency standards to implementing Passive House principles, reshaping the residential construction landscape (Barry, 2021), (City of Boston, 2020). In terms of general construction costs, recent reports suggest an estimated increase of 0 to 10 percent, averaging around 5 percent for new construction that adopt higher energy efficiency standards (NMR Group, 2020). Despite these cost increases, the long-term benefits of energy-efficient buildings, both in terms of environmental impact and operational cost savings, are significant. Recent studies indicate that the incremental cost increase for Passive House certified multifamily buildings is comparable to other green building certifications, ranging from 1 to 8 percent (Barry, 2021). However, a lack of experience in building according to Passive House standards and the unfamiliarity of project design team with these standards significantly influence these costs. The transition to all-electric homes is another aspect of this trend. The shift from gas to electric heating and appliances requires visible changes in heating methods and household appliances. This switch has been shown to increase heating costs, especially in northern climates (Home Innovation Research Labs, 2021). In the realm of Zero Emission Buildings (ZEBs), increase in construction cost before rebates, range from 0 to 2.5 percent (City of Boston, 2020). ZEBs' efficiency heavily relies on air tightness, which significantly reduces heating loads by maintaining conditioned air inside the building. Another study by Petersen, Gartman, & Corvidae (Peterson, Gartman, & Corvidae, 2019) shows that building a zero-energy (ZE) or zero-energy ready (ZER) home increases cost by 6.7-8.1% and 0.9-2.5%, respectively, when looking at costs in selected major cities in the U.S.

While these are necessary changes to curb climate change, there are concerns arising from the incremental costs and their impact on housing affordability. Massachusetts has been facing a significant cost increase in the housing market. The median price of single-family homes in April 2021 raised by 18.1% and 32.6% compared to 2020 and 2019, respectively (Gorey, 2021). Also, it is estimated that solar photovoltaic (PV) systems in Boston cost $3.27-$4.53/Watt with a simple payback period of 11-21 years (Gunderson & Thapa, 2020). It is known that 1,468 households in Massachusetts will be priced out of the market by a $1,000 price increase (Zhao, 2022). Combining all these facts, highlights the importance of carefully crafting policies to create an equitable housing market for everyone in Massachusetts since housing is a human right.

In response to the recent updates to Massachusetts' Stretch Code of Building Energy and the introduction of a more stringent Specialized Code (Mass Department of Energy Resources, 2023), this research investigates the cost implications associated with enhancing energy efficiency in new construction, with a specific emphasis on residential buildings.

Methodology

The goal of this research was to compare the incremental construction costs of moderate size new houses including single-family and small multi-family houses (2-4 units), across four Home Energy Rating System (HERS) scenarios of (1) traditional home (HERS 55), (2) all electric, mini-split heat pumps (HERS 45), (3) all electric, central heat pump (HERS 45), and (4) dual fuel, furnace and ducted heat pumps (HERS 42) in Massachusetts. The overarching research approach was divided into the following steps:

- Reviewing the past studies of the cost premium of high-efficiency residential buildings,
- Conducting interviews with experts in different fields of AEC (architects, engineers, and contractors),
- Identifying parameters and developing model houses,
- Performing energy modeling and Manual J calculations to define specifications for the model houses,
- Developing quote sheets and quote surveys to obtain prices from trade contractors,
- Inviting subcontractors to participate in the study via interviews, completing quote sheets, and responding to surveys, and
- Analyzing the collected data and calculating the cost implications.

Following a comprehensive literature review, the research team devised and executed a semi-structured interview. The interviews engaged fourteen experts associated with single-family and small multi-family houses. These interviews aimed to evaluate the common practices and firsthand experiences related to constructing high-performance and energy-efficient homes, as well as to identify the challenges anticipated in enhancing building efficiency in Massachusetts. Each interview, on average, spanned about an hour, with the participants highlighting several key challenges frequently:

- Insufficient education for tradespeople to comply with more stringent energy code,
- Absence of flexibility in zoning and density regulations,
- Customer preferences for gas stoves and an abundance of windows, and
- Complications arising from installing exterior insulations.

The next sections explain the approach for determining the incremental cost of building at different efficiency levels on the affordability of houses.

Parameters and Specifications for Model Homes

The size of model homes for single-family and small multi-family (4-units) were determined after thorough literature review, analysis of existing and newly developed typical houses in Massachusetts, and input from the industry experts. The research team wanted to select sizes for model homes that are common on the market. Ultimately, the model houses were built based on the analyzed data and professional opinions of the team members in a way to best represent typical houses in terms of sizes, floor plans, number of floors, bedrooms, and bathrooms. Figures 1 and 2 illustrate the 3D models of the homes, while Tables 1 and 2 provide detailed parameters for both models.

Figure 1. 3D model of single-family model

Table 1

Parameters of single-family model home

Total Conditioned Area	**2,875 SF**	
Number of Floors	Basement+ 2 Floors+Attic	
Number of Bedrooms	3	
Number of Bathrooms	3.5	
Finished Basement (General Area, 1 Full Bath)	*540 SF*	*3 Windows, 18.0 SF*
Floor 1 (Kitchen, Living & Dining Rooms, 1/2 Bath)	*790 SF*	*8 Windows, 112.7 SF*
Floor 2 (3 Bedrooms, 2 Full Baths)	*1015 SF*	*12 Windows, 116.4 SF*
Finished Attic (General Area)	*530 SF*	*6 Windows, 45.8 SF*

Figure 2. 3D model of 4-unit small multi-family model home

Table 2

Parameters of 4-unit small multi-family model home

	Unit 1		***Unit 2***		***Unit 3***		***Unit 4***	
Main Floor Living Conditioned Area	1,256 SF		1,115 SF		790 SF		1,256 SF	
Upper Floor Living Conditioned Area	896 SF		1,116 SF		1,044 SF		896 SF	
Total Conditioned Area	**2,152 SF**		**2,231 SF**		**1,834 SF**		**2,152 SF**	
Number of Floors	Basement+ 2 Floors		Basement+ 2 Floors		Basement+ 2 Floors		Basement+ 2 Floors	
Number of Bedrooms	3		3		3		3	
Number of Bathrooms	3.5		3.5		3.5		3.5	
No./Area of Windows (SF): Basement	0	0	0	0	0	0	0	0
No./Area of Windows (SF): Main Floor	14	110	9	122	3	47	14	110
No./Area of Windows (SF): Upper Floor	8	133	7	83	7	83	8	133
No./Area of Windows (SF): Total	22	243	16	205	10	130	22	243

Energy Modeling

The team performed a thorough energy modeling analysis using Ekotrope (RESNET-accredited RATER software) for single-family and all 4 units of small multi-family model homes. The analysis provided detailed specifications for each scenario of both model homes. Specifications were grouped into three categories: insulation and air sealing, mechanical equipment, and lighting and appliances.

Manual J Calculations

The energy modeling resulted in identifying the necessary efficiency levels for the heating and cooling equipment under each scenario and the required load capacity needed to be estimated separately. To this end, Manual J calculations were performed room by room for single-family and all

4 units of small multi-family model homes. This allowed the team to identify the HVAC capacity and proper size for HVAC units.

Building Specs for the Model Homes

Following the Ekotrope energy modeling, Manual J calculations, and analysis of the models' outputs, the team identified the key differences in constructing houses built to four different scenarios. Table 3 depicts the specifications for the single-family model home under four selected scenarios. Similar specifications were identified for the units of the small multi-family model home.

Table 3

Specifications of single-family model home for four different scenarios

	Projected Rating Results			
	HERS 55	**HERS 45 All Electric (Ductless)**	**HERS 45 All Electric (Ducted)**	**HERS 42 Dual Fuel (Ducted)**
Insulation & Air Sealing				
Slab	Uninsulated	Uninsulated	R-10 at perimeter and under entire floor	R-10 at perimeter and under entire floor
Foundation Walls	R-10 fire rated foamboard	R-10 fire rated foamboard	R-15 fire rated foamboard	R-15 fire rated foamboard
Garage Ceiling	R-30 insulation	R-30 insulation	R-30 insulation + R-6 foamboard	R-30 insulation + R-6
Cantilevered Floor	R-30 insulation	R-30 insulation	R-30 insulation + R-6 foamboard	R-30 insulation + R-6
Blockers & Runners	R-21 insulation	R-21 insulation	R-21 insulation + R-9 sheathing	R-21 insulation + R-9 sheathing
Exterior Walls	R-21 insulation	R-20 Insulation + R-6 insulated sheathing	R-20 insulation + R-9 insulated sheathing	R-21 fiberglass batts + R-9 insulated sheathing
Flat Ceilings	R-60 loose cellulose (16" deep)	R-60 loose cellulose (16" deep)	R-60 loose cellulose (16" deep)	R-60 loose cellulose (16" deep)
Cathedral Ceilings	R-38 insulation	R-38 insulation	R-38 insulation + R-6 foamboard	R-49 spray foam
Windows & Glass Doors	U-Factor = .30	U-Factor = .28	U-Factor = .28	U-Factor = .28
Air Barrier & Air Sealing Details	Maximum blower door test of 3 ACH50	Maximum blower door test of 1.5 ACH50	Maximum blower door test of 1.5 ACH50	Maximum blower door test of 1.5 ACH50
Mechanical Equipment				
Heating Equipment	54,000 Btuh, 95% AFUE Furnace W/ ECM	32,000 Btuh, 11 HSPF ASHP	33,000 Btuh, 9.5 HSPF ASHP	31,000 Btuh, 10.5 HSPF ASHP with 97% AFUE Propane Furnace Backup

Cooling Equipment	33,500 Btuh, 13.0 SEER Central AC	30,000 Btuh, 20.0 SEER ASHP	35,000 Btuh, 16.5 SEER ASHP	33,000 Btuh, 16.5 SEER ASHP
Water Heater	.95 UEF On-Demand	3.75 UEF Heat Pump water tank	3.75 UEF Heat Pump water tank	3.75 UEF Heat Pump water tank
Ventilation System	2 Continuous Exhaust Fans	Heat Recovery Ventilator (HRV)	Heat Recovery Ventilator (HRV)	Heat Recovery Ventilator (HRV)
Lighting & Appliances				
Lighting	100% LED Bulbs	100% LED Bulbs	100% LED Bulbs	100% LED Bulbs
Refrigerator	Energy Star certified	Energy Star certified	Energy Star certified	Energy Star certified
Dishwasher	Energy Star certified	Energy Star certified	Energy Star certified	Energy Star certified
Washer	Energy Star certified	Energy Star certified	Energy Star certified	Energy Star certified
Dryer	Energy Star certified	Energy Star certified	Energy Star certified	Energy Star certified

Building Categories for Cost Deltas

To determine cost deltas among scenarios of each model home, the team identified the differing building elements between scenarios and organized them into the following categories: Insulation, Air barrier/sealing, Window, Heating/cooling system, Water heater, Ventilation system, Electrical, Gas line. These categories were used in calculating and reporting costs.

Subcontractors and Vendors Participation

To accurately calculate cost deltas among scenarios of each model home, the team involved the following trade contractors in Massachusetts to provide current and accurate market prices: (i) Insulation subcontractors for insulation and air barrier/sealing items, (ii) HVAC subcontractors for heating/cooling system, water heater, ventilation system, and (iii) Electrical subcontractors for all electrical work. The team prepared an extensive list of contractors for each of these trades and invited them via phone calls and/or emails to participate in the study in three different ways: (i) Interview with the team, (ii) Complete and return provided quote sheets, and (iii) Respond to designed surveys. To facilitate obtaining prices from trade contractors, the team developed quote sheets for each trade and both model homes using an Excel spreadsheet as well as quote surveys using Qualtrics. Since the energy modeling resulted in windows with different U-factors, the team worked with multiple vendors, suppliers, and manufacturers to obtain quotes for each model home with specific U-factor (e.g., 0.30 or 0.26 for all windows) to make the comparison reasonable. The selection of window brands was based on common brands available in the market. The gas line was a small item in both model homes. Therefore, the cost deltas resulting from this item in both model homes were calculated using RS Means.

Results

Collected Data

As mentioned earlier, the team invited insulation, HVAC, and electrical subcontractors active in Massachusetts to provide current and accurate prices for identified items in both single-family and small multi-family model homes. The team directly contacted almost 700 trade contractors via phone and/or email to invite them to participate in this study. To expand the study's reach, the team requested professional associations such as Home Builders and Remodelers Association of Massachusetts (HBRAMA), Air Conditioning Association of New England (ACA/NE), Boston Chapter of the National Electrical Contractors Association (NECA Boston), Builders and Remodelers Association of Greater Boston (BRAGB), Massachusetts Electrical Contractors Association (MECA), Plumbing, Heating, Cooling, Contractors of Massachusetts (PHCC) to contact their members/connections and encourage them to participate in the study.

The data collection campaigns collectively resulted in receiving 32 quotes for the single-family model home and 20 quotes for the small multi-family model home. Out of 32 quotes received for the single-family model home, there were 10 quotes for insulation, 8 for HVAC, and 14 for electrical. Out of 20 quotes received for the small multi-family model, there were 7 quotes for insulation, 6 for HVAC, and 7 for electrical.

Calculated Cost Implications

Before incorporating the collected data into the cost analysis, all data points were thoroughly examined to identify outliers and inconsistent data. To determine the cost deltas for scenarios for each model home, the data points were normalized with respect to the base scenario (HERS 55). Tables 4 and 5 present the results.

Table 4

Cost delta for single-family model home

	HERS 55	**HERS 45 All Electric (Ductless)**	**HERS 45 All Electric (Ducted)**	**HERS 42 Dual Fuel (Ducted)**
Insulation	$0	$3,239	$9,342	$10,348
Air Barrier/Sealing	$0	$2,902	$2,902	$2,902
Window	$0	$1,791	$1,791	$1,791
Heating/Cooling System	$0	-$434	$3,635	$6,037
Water Heater	$0	-$1,724	-$1,724	-$1,724
Ventilation System	$0	$1,956	$1,956	$1,956
Electrical	$0	$4,395	$2,567	$2,033
Gas Line	$0	-$1,281	-$1,281	$0
Total Cost Delta	**$0**	**$10,846**	**$19,188**	**$23,343**
Cost Delta Per SF	**$0**	**$3.77**	**$6.67**	**$8.12**

Table 5

Cost delta for small multi-family model home

	HERS 55	HERS 45 All Electric (Ductless)	HERS 45 All Electric (Ducted)	HERS 42 Dual Fuel (Ducted)
Insulation	$0	$21,757	$40,538	$59,842
Air Barrier/Sealing	$0	$10,550	$10,550	$10,550
Window	$0	$3,102	$3,102	$3,102
Heating/Cooling System	$0	-$14,911	$14,733	$15,515
Water Heater	$0	-$6,082	-$6,082	-$6,082
Ventilation System	$0	$9,295	$9,295	$9,295
Electrical	$0	$16,471	$16,072	$12,814
Gas Line	$0	-$5,952	-$5,952	$0
Total Cost Delta	**$0**	**$34,230**	**$82,257**	**$105,036**
Cost Delta Per SF	**$0**	**$7.75**	**$18.62**	**$23.78**

The above tables offer a comparative cost analysis related to enhancing energy efficiency in single-family and small multi-family homes, benchmarked against HERS score of 55. For single-family homes, there is an evident cost increment associated with lower HERS scores, which denotes higher efficiency levels. The most economical upgrades are observed in the HERS 45 all-electric (ductless) option, incurring an additional cost of $10,846. The HERS 42 dual fuel (ducted) option exhibits a substantial increase, totaling an additional $23,343. In small multi-family homes, the additional costs are markedly higher. The all-electric (ductless) option with a HERS 45 score is the least expensive at $34,230, while the HERS 42 dual fuel (ducted) option has the highest additional cost at $105,036. It is apparent for both housing types that dual fuel systems incur greater costs compared to all-electric systems. While insulation expenses consistently rise with higher efficiency targets in both model homes, such uniformity is not mirrored in other components. Air barrier/sealing, windows, and ventilation systems exhibit a steady cost increase, whereas water heaters and gas lines show a uniform decrease. The heating/cooling and electrical components lack a consistent pattern. Notably, the HERS 45 all-electric (ductless) option shows the highest electrical costs, offset by the lowest costs in heating/cooling systems, which can be attributed to the extensive electrical work and the omission of ductwork, respectively.

In summary, the findings reveal that enhancing energy efficiency in residential constructions leads to varying degrees of cost increments, which are influenced by the housing type and the targeted HERS score. Specifically, for single-family homes, the cost increase ranges from $3.77 to $8.12 per square foot (SF). In comparison, small multi-family homes experience a more significant cost increase, varying between $7.75 and $23.78 per SF. This notable difference is primarily due to the generally smaller unit sizes in multi-family homes compared to those in single-family homes. Considering the median new home price in Massachusetts at $606,866, it is deduced that enhancing energy efficiency in new single-family homes can lead to an overall cost increment ranging from 1.8% to 3.8%, depending on the targeted HERS score.

Conclusion

This paper investigated the cost implications of constructing energy-efficient residential buildings in Massachusetts and provided critical insights into the economic aspects of adapting to climate change through building practices and updating building codes. The study's extensive data collection and analysis revealed that pursuing lower HERS scores in both single-family and small multi-family homes results in incremental cost increases. Specifically, the most cost-efficient energy upgrades are associated with the HERS 45 all-electric (ductless) option. On the other end of the spectrum, the HERS 42 dual fuel (ducted) option incurs the highest additional cost. The incremental costs are 1.8-3.8%, which are relatively modest in comparison to the long-term benefits of reduced operational costs and environmental impact. This research contributes to the body of knowledge on sustainable construction practices and serves as a foundational framework for policymakers and stakeholders aiming to balance energy efficiency with housing affordability. These results can be utilized to support informed decision-making in the pursuit of constructing homes that are both cost-effective and environmentally responsible in the face of ongoing climate challenges.

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