RLPNC 17-14: Mini-Split Heat Pump Incremental Cost Assessment

FINAL REPORT

November 27, 2018

SUBMITTED TO:
The Massachusetts Electric and Gas Program Administrators

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Executive Summary

This study compares the initial costs (i.e., equipment and installation costs) and operating costs associated with heating, cooling, and water heating for two versions of a single-family home that meets the Massachusetts Stretch Energy Code target—an Energy Rating Index (ERI) of 55. The traditional version of the house has a gas furnace, electric Central Air Conditioning (CAC) system, and an instantaneous gas water heater, while the mini-split version of the house has a ducted mini-split heat pump and a heat pump water heater. Both versions have a first and second floor, an unfinished basement, and 2,500 square feet of living area. We modeled the houses in Wrightsoft's Right-Suite® Universal (RSU) to achieve an ERI of 55 at minimal costs given the housing configurations and HVAC and DHW equipment specifications in Table 1.

Table 1: Traditional House and Mini-Split House HVAC and DHW Equipment

Equipment	Traditional House	Ducted Mini-Split House
Heating	Gas furnace (AFUE 96)	Mini-split heat pump (HSPF 10.7)
Cooling	Electric CAC (SEER 15)	Mini-split heat pump (SEER 17.5)
Water Heating	Gas tankless (UEF 0.95)	Heat pump water heater (UEF 3.42)
Basement Configuration	Conditioned	Unconditioned
Basement Insulation	R-13 continuous wall insulation	R-30 frame floor (basement ceiling) insulation
Wall Insulation	R-21 cavity insulation	R-19 cavity + R-5 continuous insulation
Flat Attic Insulation	R-49 cellulose or fiberglass insulation	N/A
Vaulted Ceiling Insulation	N/A	R-50 foam insulation

The traditional house with gas heat has lower initial costs than the mini-split house. The HVAC equipment and installation cost for the mini-split house is $1,586 higher than for the traditional house (Table 2), driven primarily by the higher cost to purchase mini-split equipment compared to a gas furnace. The DHW equipment and installation cost for the mini-split house is $832 less than the traditional house, driven by a significantly lower cost to install a heat pump water heater than an instantaneous gas water heater. The combined initial HVAC and DHW cost for the mini-split house is 106% of the combined initial HVAC and DHW cost for the traditional house.

Table 2: Initial Cost Summary

	Traditional House	Mini-Split House	Mini-Split Delta	Mini-Split as % of Traditional House
HVAC	$9,212	$10,798	$1,586	117%
DHW	$2,512	$1,680	-$832	67%
Total	**$11,724**	**$12,478**	**$754**	**106%**

The traditional house with gas heat also has lower operating costs than the mini-split house. Even though the mini-split house requires less energy to heat, the higher cost of electricity relative to gas means that the mini-split house costs $485 more than the traditional house to heat each year (Table 3). Similarly, the mini-split house's heat pump water heater requires less energy than the traditional house's tankless gas water heater, but the higher cost of electricity relative to gas means that it costs $19 more per year more to supply hot water to the mini-split house. The mini-split house costs slightly less than the traditional house to cool ($124 compared to $132). The combined annual HVAC and DHW operating cost for the mini-split house is 133% of the combined annual HVAC and DHW operating cost for the traditional house.

Table 3: Operating Cost Summary*

	Traditional House	Mini-Split House	Mini-Split Delta	Mini-Split as % of Traditional House
Heating	$1,252	$1,737	$485	139%
Cooling	$132	$124	-$8	94%
Water Heating	$127	$146	$19	115%
Total	**$1,511**	**$2,007**	**$496**	**133%**

*Assumes $0.2063/kWh and $1.50/Therm.

Given the influence of the relative fuel prices in the operating cost analysis, we modeled a third version of the house to provide an additional comparison point. The third version is identical to the traditional house, except that it has an electric furnace rather than a gas furnace. The cost to heat the electric traditional house ($4,679) is more than double the cost to heat the mini-split house and more than triple the cost to heat the traditional house (Table 4).

Table 4: Heating Operating Cost Summary

	Traditional House	Electric Traditional House	Mini-Split House
Equipment	Gas Furnace	Electric Furnace	Heat Pump
Cost	$1,252	$4,679	$1,737

Section 1 Study Background

As part of the RLPNC 17-14 Residential New Construction (RNC) Incremental Cost Study, the evaluation team was asked to compare the equipment, installation, and operating costs associated with a standard equipment configuration found in the low-rise RNC program and a similar home with all electric heat pump technologies. Specifically, the following equipment types were compared in this effort:

- Standard Equipment Configuration
  - Gas furnace, gas tankless water heater, electric Central Air Conditioner (CAC)
- Electric Heat Pump Equipment Configuration
  - Ducted mini-split heat pumps (for heating and cooling) and a heat pump water heater

NMR contracted with Wrightsoft's production homebuilder residential HVAC design division to calculate the equipment, installation, and operating costs for the two scenarios detailed above. NMR worked with Wrightsoft and ICF, the RNC program implementation contractor, to identify the appropriate specifications for the homes considered in this assessment. The specifications used by Wrightsoft in their analysis were based on typical characteristics seen in single-family program homes.

The remainder of this report was compiled by Wrightsoft and reviewed by the evaluation team.

Section 2 Wrightsoft Report

2.1 Introduction

This study compares the equipment, installation, and operating costs associated with heating, cooling, and water heating in two versions of a single-family home located in Worcester, Massachusetts. The first version (the traditional house) has a conventional ducted gas furnace, conventional CAC system, and an instantaneous gas water heater. The second version (the mini-split house) is heated and cooled with mini-split heat pumps and has a heat pump water heater. The homes were designed to pass the Massachusetts Stretch Energy Code with a target Energy Rating Index (ERI) of 55.

We framed this study from the perspective of the production home builder, whose goal is to pass the target ERI without incurring unnecessary costs. We obtained a model floor plan from a Massachusetts home designer and modified it to meet criteria that are representative of a typical RNC program home.[1,2] We researched locally representative envelope efficiencies by reviewing publicly available building permit applications and interviewing the town building inspector of Lexington, Massachusetts. We also interviewed four New England builders who specialize in highly efficient homes heated and cooled by mini-split systems.

Our in-house HVAC engineers modeled the houses and designed the HVAC systems in Wrightsoft's Right-Suite® Universal (RSU) using ACCA Manuals (J, D, S and T). We calculated the ERI in REM/Rate. It was necessary to make changes to some characteristics of the two houses in order to pass the Stretch Code; we present these changes in Section 2.2. We obtained cost of materials and installation labor from members of the HVAC community. Finally, we calculated annual operating costs of the two prototypes in REM/Rate.

2.2 The Model Houses

The traditional house uses a Goodman gas furnace for heating, a Goodman CAC system for cooling,[3] and an AO Smith gas instantaneous water heater for water heating. The heating and cooling equipment is located in the basement. The traditional house has an independent ventilation system using a Panasonic Energy Recovery Ventilation (ERV) system.

The traditional house is insulated to the level of a typical production builder home. The constraint to pass the Stretch Code led us to condition the basement of the traditional house. This is because having the equipment in unconditioned space resulted in a rise in ERI by several points that could not be recovered without exceptional improvements to the building envelope. Conditioning the

[1] Thank you to Habitat Post and Beam, Deerfield, MA.
[2] Photos of the home that was used as the model floor plan can be found here: http://www.postandbeam.com/plan/128/. Note, the houses were modeled as wood frame construction, not as exposed post and beam construction.
[3] Goodman is common in production home building.

basement was the most economical (and therefore realistic) solution because the selected equipment had the spare capacity to cover the additional basement load and only required an additional short run of duct to mix the air.

The mini-split house uses a Mitsubishi[4] ducted "ductless" design, which gives aesthetic benefits and requires only two indoor units and one outdoor unit. The indoor unit for the first floor is located in a dropped ceiling, while the indoor unit for the second floor is located in the spray-foam sealed attic.[5] The mini-split house uses an AO Smith heat pump hybrid hot water heater. Like the traditional house, the mini-split house has an independent ventilation system using a Panasonic ERV.

In terms of performance, using the mini-splits in ducted mode incurs a reduction in SEER compared to ductless mode. We considered the alternative solution of multiple ductless indoor heads, which would require eight or nine indoor units and two outdoor units. However, we decided that the cost of an entirely ductless solution was prohibitive for a production home builder when compared to the ducted alternative. One of our builder interviewees estimated a cost of $3,000 per indoor head based on a recent project.

The change of equipment in the mini-split house caused the ERI to rise, necessitating some other changes to the mini-split house's design in order to pass the ERI target of 55. The mini-split house has some improvement to the wall insulation: R-19 cavity plus R-5 continuous in the mini-split house versus R-21 cavity insulation in the traditional house with no continuous layer. The first-floor indoor unit fits into a dropped ceiling and so the basement remains unconditioned. We considered the option of conditioning the basement to match the traditional house, but that would require the purchase of additional units to handle the extra conditioned space. We decided that a production homebuilder would be unlikely to incur the extra cost to condition an unfinished basement. Therefore, the basement ceiling was insulated and the basement walls were uninsulated. Locating the second-floor equipment in the attic necessitated encapsulating the attic with foam insulation so that unit and ducts remain inside conditioned space.

Table 5 displays the equipment types, insulation R-values, and other characteristics of the traditional house and mini-split house. It also displays MA Stretch Code requirements where applicable.

[4] Mitsubishi mini-splits are able to meet the low temperature design conditions and were preferred by our interviewees.

[5] NEEP recommends that mini-split heads be floor mounted when the customer priority is heating. Given the ducted design utilized in this study the heads were placed in a dropped ceiling. The NEEP guidance can be found here: https://neep.org/sites/default/files/Sizing%20&%20Selecting%20ASHPs%20In%20Cold%20Climates.pdf.

Table 5: Comparison of Traditional and Mini-Split Houses

Characteristic	Traditional House	Mini-Split House	MA Stretch Code
Energy rating index	55	55	55
Basement wall R-value	R-13 continuous	N/A	R-10 continuous
Floor R-value (Basement Ceiling)	n/a	R-30	R-30 (or fill framing cavity min. R-19)
Wall R-value	R-21 cavity	R-19 cavity + R-5 continuous	R-20 (or R-13 cavity + R-5 continuous)
Flat Attic R-value	R-49 cellulose or fiberglass	Not required	R-38
Vaulted Ceiling R-value	Not required	R-50 foam	R-38
Windows U-factor	0.30	0.30	0.35
Windows SHGC	0.30	0.30	NR
ACH50	3.0	3.0	3.0
Basement	Conditioned	Unconditioned	n/a
Attic	Vented	Encapsulated w/foam	n/a
Conditioned area of unfinished basement	1,349	0	n/a
Conditioned floor area	3,825	2,476	n/a
Ventilation Rate CFM	94	53	n/a
HVAC Equipment	Goodman Gas furnace: GMEC96 Electric CAC: GSX16	Mitsubishi Mini-split heat pump SEZ-KD12NA4 SEZ-KD18NA4 MXZ-4C36NAHZ	n/a
Equipment location	Conditioned basement	Conditioned ceiling & foam sealed attic	n/a
Cooling efficiency	SEER 15	SEER 17.5[6]	n/a
Heating efficiency	AFUE 96	HSPF 10.7	n/a
Hot water system	Gas tankless AO-Smith-ATI-240H-N	Heat pump hybrid 50-gal AO-Smith-HPTU-50N	n/a
HW efficiency from ahrinet.org	UEF 0.95	UEF 3.42	n/a
Ventilation	Panasonic FB-10VEC1	Panasonic FB-10VEC1	n/a
Duct leakage	3.4 CFM/100 sq. ft. @ 25 Pa	3.4 CFM/100 sq. ft. @ 25 Pa	n/a
Cooling load (sens/lat)	14,376/2,726 Btu/hr	12,624/1,863 Btu/hr	n/a
Heating load	37,597 Btu/hr	30,660 Btu/hr	n/a

[6] After reduction in SEER for use in ducted mode.

2.3 EQUIPMENT AND INSTALLATION COSTS[7]

Table 6 displays the initial costs for heating and cooling equipment, duct and ventilation systems, and installation in each house. We obtained costs for equipment and materials from local distributors and online sources. One of Wrightsoft's production home builder partners provided an estimate for HVAC installation costs.

Table 6: HVAC System Initial Costs

Cost Component	Traditional House	Mini-Split House	Mini-Split Delta
Heating and Cooling Equipment	$3,340	$5,827	$2,487
Duct System	$1,349	$948	-$401
Ventilation System	$1,173	$1,173	$0
Installation	$3,350	$2,850	-$500
Total	**$9,212**	**$10,798**	**$1,586**

Table 7 displays the initial costs for domestic hot water (DHW) equipment and installation in each house. A local plumber provided the cost to install the hot water heaters. The striking difference in installation cost between the two systems is due to the instantaneous system requiring two people to hang the system, additional time to connect the gas, and install venting to the outside.

Table 7: DHW Initial Costs

Cost Component	Traditional House	Mini-Split House	Mini-Split Delta
DHW Equipment	$912	$1,380	$468
Installation	$1,600	$300	-$1,300
Total	**$2,512**	**$1,680**	**-$832**

Table 8 displays the total initial costs for the HVAC and DHW systems in each house. HVAC and DWH equipment and installation costs are $754 more for the mini-split house than the traditional house.

Table 8: Total HVAC and DHW Initial Costs

Cost Component	Traditional House	Mini-Split House	Mini-Split Delta
HVAC	$9,212	$10,798	$1,586
DHW	$2,512	$1,680	-$832
Total	**$11,724**	**$12,478**	**$754**

[7] The costs presented in this section may differ from similar equipment and installation costs developed through other recent Massachusetts evaluations such as the RES 19, RES 23, and RES 28 studies. One reason for this could be that new construction contractors, in particular production builders, have access to lower equipment and/or installation costs due to the volume of projects that they work on. The links to the aforementioned reports can be found here:
http://ma-eeac.org/wordpress/wp-content/uploads/RES19_Assembled_Report_2018-09-27.pdf
http://ma-eeac.org/wordpress/wp-content/uploads/RES23_Task2_AC-HP_Cost_Study_Results_Memo_v3_clean.pdf
http://ma-eeac.org/wordpress/wp-content/uploads/RES28_Task4_FinalReport_v2_clean.pdf

2.4 Operating Costs

HVAC and water heating operating costs depend on several assumptions, including electricity rates, natural gas rates, and weather assumptions. The operating costs for the traditional and mini-split houses are based on the following assumptions.

Massachusetts Utility Rates:[8]

- Electricity: $0.2063/kWh
- Natural gas: $1.50/Therm

Weather and BIN City:

- Worcester, MA
- Summer ODT: 83°F
- Winter ODT: 6°F

We calculated operating costs for heating and cooling using REM/Rate after adjustments to match the load calculated by RSU. The value for infiltration load was very low in REM/Rate. We approximated the final results in our own software, Right-$, and obtained similar numbers. Table 9 displays REM/Rate's load and consumption figures for the two houses.

Table 9: REM/Rate Comparison of Annual Consumption

House	Heating Loads (MMBtu/yr)[9]	Cooling Loads (MMBtu/yr)	Hot Water Loads (MMBtu/yr)	Heating Consumption (MMBtu/yr)	Cooling Consumption (MMBtu/yr)	Hot Water Consumption (MMBtu/yr)
Traditional House	75.9	9.2	8.9	80.1	2.2	8.5
Mini-Split House	65.7	9.6	9.5	28.8	2.0	2.4

Table 10 presents the annual operating costs for heating, cooling, and water heating as calculated by REM/Rate. It costs $496 more per year to heat, cool, and supply hot water to the mini-split house compared to the traditional house.

Table 10: REM/Rate Annual Operating Costs Comparison

	Traditional House	Mini-Split House	Mini-Split Delta	Mini-Split as % of Traditional House
Heating	$1,252	$1,737	$485	139%
Cooling	$132	$124	-$8	94%
Water Heating	$127	$146	$19	115%
Total	**$1,511**	**$2,007**	**$496**	**133%**

[8] Utility rates are based on July, 2018 prices for Massachusetts as reported by the Energy Information Administration https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_5_6_a https://www.eia.gov/dnav/ng/ng_pri_sum_a_EPG0_PRS_DMcf_m.htm

[9] MMBtu = Million British Thermal Units.

The following tables are different presentations of the data in Table 10.

Table 11: Calculated Yearly Use for Cooling

	Annual Cost[10]	Source	Units	Rate	Annual Use[11]
Traditional House	$132	Electricity	kWh	0.2063	640 kWh
Mini-Split House	$124	Electricity	kWh	0.2063	601 kWh

Table 12: Calculated Yearly Use for Heating

	Annual Cost	Source	Units	Rate	Annual Use
Traditional House	$1,252	Gas	Therms	1.5	835 Therms
Mini-Split House	$1,737	Electricity	kWh	0.2063	8,420 kWh

Table 13: Calculated Yearly Use for Hot Water

	Annual Cost	Source	Units	Rate	Annual Use
Traditional House	$127	Gas	Therms	1.5	85 Therms
Mini-Split House	$146	Electricity	kWh	0.2063	708 kWh

2.5 Electric Furnace Comparison

The operating costs were strongly affected by the relative cost of energy from natural gas and electricity. For interest's sake and to give a third comparison point, we also modeled a version of the traditional home with the gas furnace replaced by an electric furnace. The new electric traditional house is identical to the traditional house, except for the heating equipment. Table 14 displays the heating equipment types and annual operating costs for the traditional house with a gas furnace, traditional house with an electric furnace, and the mini-split house. The annual heating operating cost for the traditional house with an electric furnace ($4,679) is over two times as much as the mini-split house ($1,737) and over three times as much as the traditional house with a gas furnace ($1,252).

[10] From REM/Rate.
[11] REM/Rate Cost divided by MA Rate.

Table 14: REM/Rate Annual Heating Operating Costs Including Electric Traditional House

	Traditional House	Electric Traditional House	Mini-Split House
Equipment	Goodman Gas Furnace (96 AFUE) 40,000 BTU/hr	Goodman Electric Furnace 40,000 BTU/hr	Mitsubishi Heat Pump (10.7 HSPF) 18K BTU (1st floor) 12K BTU (2nd floor)
Cost	$1,252	$4,679	$1,737

2.6 CONCLUSION

The traditional house with gas heat and electric CAC costs less to build and operate than the mini-split house. It is somewhat cheaper on initial costs ($11,724 versus $12,478), and its annual operating cost ($1,511) is 75% of the annual operating cost for the mini-split house ($2,007). The cost to heat the mini-split house is 37% of the cost to heat the traditional house with an electric furnace. Admittedly, the conditioned floor area and load are slightly lower in the mini-split house due to the design differences (see Table 1), but it is fair to say that the observed advantage of gas heating is largely due to the relative energy costs of natural gas versus electricity.

We approached this study from the perspective of the production home builder. The builders of high efficiency homes we spoke with who are using mini-splits in their projects are designing with insulation and building tightness well in excess of the Massachusetts Stretch Code. A future study might approach the problem with looser constraints on first costs, such as insulating the traditional house to the same levels required in the mini-split house regardless of cost or conditioning the basement of the mini-split house despite the need for extra equipment. A future study might also consider a system in which the independent ventilation system is used to mix air in the house (and therefore assist a smaller number of un-ducted units to meet the load over the entire house). A system like this in a well-insulated house envelope could take advantage of the potentially lower cost per million Btu provided by the un-ducted mini-splits. The feasibility of such a system would depend on the quantity and extent of airflow and the ability to vary imported outside air.

Appendix A Floor Plan

A.1 Colonial Saltbox

Home – Colonial Saltbox Drawing.pdf

Appendix B HVAC Designs

B.1 MINI-SPLIT

Home – Colonial Saltbox - RSU Draw

B.2 TRADITIONAL

Home – Colonial Saltbox - RSU Draw

Appendix C Operating Costs in Ekotrope Software

This study was designed and executed using REM/Rate software to calculate building consumption and the associated operating costs for heating, cooling, and water heating equipment. The evaluation team ran a comparison of energy consumption and cost using Ekotrope software as the Massachusetts low-rise RNC program will be using Ekotrope moving forward. The results of this analysis are presented below.

Table 15: REM/Rate vs. Ekotrope Comparison of Annual Consumption

House	Heating Consumption (MMBtu/yr)	Cooling Consumption (MMBtu/yr)	Hot Water Consumption (MMBtu/yr)
REM/Rate			
Traditional House	80.1	2.2	8.5
Mini-Split House	28.8	2.0	2.4
Ekotrope			
Traditional House	83.5	1.0	9.2
Mini-Split House	32.9	1.6	2.4

Table 16: Operating Cost Summary REM/Rate vs. Ekotrope*

	Traditional House	Mini-Split House	Mini-Split Delta	Mini-Split as % of Traditional House
REM/Rate				
Heating	$1,252	$1,737	$485	139%
Cooling	$132	$124	-$8	94%
Water Heating	$127	$146	$19	115%
Total	**$1,511**	**$2,007**	**$496**	**133%**
Ekotrope				
Heating	$1,294	$1,988	$694	154%
Cooling	$60	$98	$38	163%
Water Heating	$138	$143	$5	104%
Total	**$1,492**	**$2,229**	**$737**	**149%**

*Assumes $0.2063/kWh and $1.50/Therm.

Table 17: Calculated Yearly Use for Cooling REM/Rate vs. Ekotrope

	Annual Cost	Source	Units	Rate	Annual Use
REM/Rate					
Traditional House	$132	Electricity	kWh	0.2063	640 kWh
Mini-Split House	$124	Electricity	kWh	0.2063	601 kWh
Ekotrope					
Traditional House	$60	Electricity	kWh	0.2063	289 kWh
Mini-Split House	$98	Electricity	kWh	0.2063	476 kWh

Table 18: Calculated Yearly Use for Heating REM/Rate vs. Ekotrope

	Annual Cost	Source	Units	Rate	Annual Use
REM/Rate					
Traditional House	$1,252	Gas	Therms	1.5	835 Therms
Mini-Split House	$1,737	Electricity	kWh	0.2063	8,420 kWh
Ekotrope					
Traditional House	$1,294	Gas	Therms	1.5	826 Therms
Traditional House	$54	Electricity	kWh	.2063	263 kWh
Mini-Split House	$1,988	Electricity	kWh	0.2063	9,636 kWh

Table 19: Calculated Yearly Use for Hot Water REM/Rate vs. Ekotrope

	Annual Cost	Source	Units	Rate	Annual Use
REM/Rate					
Traditional House	$127	Gas	Therms	1.5	85 Therms
Mini-Split House	$146	Electricity	kWh	0.2063	708 kWh
Ekotrope					
Traditional House	$138	Gas	Therms	1.5	92 Therms
Mini-Split House	$143	Electricity	kWh	0.2063	692 kWh