Robinson+Cole

LETICIA C. PIMENTEL

One Financial Plaza, 14th Floor
Providence, RI 02903-2485
Main (401) 709-3300
Fax (401) 709-3378
lpimentel@rc.com
Direct (401) 709-3337

Also admitted in Massachusetts

November 17, 2023

VIA ELECTRONIC MAIL AND HAND DELIVERY

Luly E. Massaro, Clerk
Rhode Island Public Utilities Commission
89 Jefferson Boulevard
Warwick, RI 02888

Re: Docket No. 23-35-EE – 2024-2026 Three Year Energy Efficiency Plan and 2024 Annual Energy Efficiency Plan
Responses to PUC Data Requests – Set 2

Dear Ms. Massaro:

On behalf of The Narragansett Electric Company d/b/a Rhode Island Energy ("Rhode Island Energy" or the "Company"), I have enclosed the Company's responses to the Second Set of Data Requests issued by the Public Utilities Commission in the above-referenced docket.

Please contact me if you have any questions. Thank you for your attention to this matter.

Very truly yours,

Leticia Pimentel

Leticia C. Pimentel

cc: Docket 23-35-EE Service List

Certificate of Service

I hereby certify that a copy of the cover letter and any materials accompanying this certificate were electronically transmitted to the individuals listed below.

The paper copies of this filing are being hand delivered to the Rhode Island Public Utilities Commission and to the Rhode Island Division of Public Utilities and Carriers.

Leticia Pimentel
Leticia Pimentel

November 17, 2023
Date

Docket No. 23-35-EE – Rhode Island Energy's EE Plan 2024-2026 Three-Year Plan and 2024 Annual EEP
Service list updated 10/4/2023

Name /Address	E-mail Distribution List	Phone
The Narragansett Electric Company d/b/a Rhode Island Energy Andrew Marcaccio, Esq. 280 Melrose St. Providence, RI 02907	amarcaccio@pplweb.com;	401-784-4263
	cobrien@pplweb.com;	
	jhutchinson@pplweb.com;	
	jscanlon@pplweb.com;	
	dmmoreira@rienergy.com;	
	MOCrayne@rienergy.com;	
	BSFeldman@rienergy.com;	
	ACLi@rienergy.com;	
	DJTukey@rienergy.com;	
	SBriggs@pplweb.com;	
	BJPelletier@rienergy.com;	
	JOliveira@pplweb.com;	
	Teast@rienergy.com;	
	Masiegal@rienergy.com;	
Leticia C. Pimentel, Esq. Steve Boyajian, Esq. **Robinson & Cole LLP** One Financial Plaza, 14th Floor Providence, RI 02903	Cagill@rienergy.com;	
	sboyajian@rc.com;	
	LPimentel@rc.com;	
	HSeddon@rc.com;	
Division of Public Utilities & Carriers Margaret L. Hogan, Esq.	Margaret.L.Hogan@dpuc.ri.gov;	401-780-2120
	Christy.hetherington@dpuc.ri.gov;	
	john.bell@dpuc.ri.gov;	
	Joel.munoz@dpuc.ri.gov;	
	Ellen.golde@dpuc.ri.gov;	
	Machaela.Seaton@dpuc.ri.gov;	
	Paul.Roberti@dpuc.ri.gov;	

Tim Woolf Jennifer Kallay Synapse Energy Economics 22 Pearl Street Cambridge, MA 02139	twoolf@synapse-energy.com; jkallay@synapse-energy.com;	
RI EERMC Marisa Desautel, Esq. Desautel Browning Law 38 Bellevue Ave., Unit H Newport, RI 02840	marisa@desautelbrowning.com; Adrian.Caesar@nv5.com; Craig.Johnson@nv5.com; Samuel.Ross@nv5.com;	401-477-0023
Office of Energy Resources (OER) Albert Vitali, Esq. Dept. of Administration Division of Legal Services One Capitol Hill, 4th Floor Providence, RI 02908	Albert.Vitali@doa.ri.gov; Nancy.Russolino@doa.ri.gov; Christopher.Kearns@energy.ri.gov; William.Owen@energy.ri.gov; Steven.Chybowski@energy.ri.gov; Nathan.Cleveland@energy.ri.gov;	401-222-8880
Original & 9 copies file w/: Luly E. Massaro, Commission Clerk John Harrington, Commission Counsel Public Utilities Commission 89 Jefferson Blvd. Warwick, RI 02888	Luly.massaro@puc.ri.gov; John.Harrington@puc.ri.gov; Alan.nault@puc.ri.gov; Todd.bianco@puc.ri.gov ; Emma.Rodvien@puc.ri.gov;	401-780-2107
Interested Party		
Dept. of Human Services Frederick Sneesby	Frederick.sneesby@dhs.ri.gov;	
RI Infrastructure Bank Chris Vitale, Esq.,	cvitale@hvlawltd.com; SUsatine@riib.org;	
Green Energy Consumers Alliance Larry Chretien, Executive Director	Larry@massenergy.org;	
Amanda Barker	amanda@greenenergyconsumers.org;	
Acadia Center Emily Koo, Director	EKoo@acadiacenter.org;	401-276-0600 x402

PUC 2-1

Request:

In response to Division 1-1, the Company writes "the number of electrically heated homes or businesses (i.e. the penetration rate denominator) is not readily available and tracked accurately enough to provide a feasible comparison." Please explain what information the Company would need to have access to or the capabilities the Company would need to possess in order to identify the number of electrically-heated homes or businesses in its service territory. Please be specific.

Response:

In order to identify the number of electrically heated homes or businesses in its service territory, the Company would need to have confirmation from each customer of their heating system fuel type. The best way to do that would be to get the information directly from customer premises through site surveys and recording that information into the Company's billing system. Since the cost of visiting every customer premise would be prohibitive, other methods may be used which would provide an approximation of the presence of electric heat.

The presence of electric heat could be estimated from electric billing data by comparing winter season usage to shoulder season usage, but that analysis does not guarantee that a customer uses electric space heat. A follow-up survey of a sample of customers to compare their actual space heating fuel type with that predicted by the billing data analysis would add confidence to the results. The Company has performed such analyses in the past, with limited success.

Although outside sources of data that include space heating system fuel type are available, in the Company's experience, it has been difficult to match specific customer accounts to these lists, making the combined dataset incomplete.

As the Company adds advanced metering functionality (AMF) to its distribution system, there may be opportunities to better identify electric space heating customers from their annual and seasonal load profiles.

Prepared by or under the supervision of: Ann Clarke

PUC 2-2

Request:

In response to Division 1-1, the Company shows a quantity of 14,323 "heat pump quantities from 2010 to 2022" for residential customers. Then, in response to Division 1-2, the Company shows planned quantities of heat pump installations for residential customers between 2023-2026 of 11,432 (the sum of the top line of response table a). Adding those numbers together, the Company's combined responses to Division 1-1 and 1-2 suggest a total of 25,755 residential heat pump installations will have been delivered by the Company's energy efficiency plan by 2027. Regarding this estimate of heat pump deployment, please explain the following:

a. Of those 25,755 heat pumps, how many will have replaced electric resistance heating systems vs. delivered fuel systems?

b. How many residential electric customers will continue to primarily utilize electric resistance heat by 2027?

Response:

a. Please see Table 1 below for the actuals from 2010 to 2023 YTD and planned 2023 to 2026 quantities of heat pumps that will have replaced electric resistance heating systems vs. delivered fuel systems.

Table 1. Heat Pump Quantities by Type of Fuel Displacement

Type of Fuel Displacement	Actuals[1]	Planned[1,3]			
	2010-2023 YTD[2]	2023	2024	2025	2026
Electric Resistance Heating	2,297	355	868	959	1,058
Oil	521	0	0	0	0
Propane	31	0	0	0	0
Total	**2,849**	**355**	**868**	**959**	**1,058**

[1] Please note the quantities included are not counted on a per home but on a per unit basis. For instance, a home could have one outdoor unit installed plus four mini-split heat pumps, this would be counted as five units in the data.

[2] 2023 year-to-date actuals as of 11/14/2023.

[3] Planned quantities include planned installations in the Residential HVAC and EnergyWise Single Family programs in the Residential sector.

Prepared by or under the supervision of: Spencer Lawrence

b. Please refer to the Company's response in PUC 2-1.

PUC 2-3

Request:

Is the Company proposing any heat pump measures in the 2024 Annual Electric Plan or the 2024-2026 Three-Year Electric Plan that will displace existing delivered fuel heating systems?

Response:

The Company is not proposing any heat pump measures specifically for the displacement of existing delivered fuel heating systems. Beginning in 2021 the Company partnered with the Office of Energy Resources (OER) to secure RGGI funds to provide enhanced rebates for delivered fuel displacement. This program ended September 1, 2023, with the launch of OER's CleanHeatRI program, and the Company is working with OER to close-out RGGI funded enhanced incentives for customers who installed eligible heat pumps prior to the launch of CleanHeatRI.

Prepared by or under the supervision of: Spencer Lawrence

PUC 2-4

Request:

In response to Division 1-9, the Company explains that it "does not offer incentives for heat pumps as a secondary heating/cooling source because the Company wants to encourage customers to use heat pumps as their primary source for both heating and cooling." Regarding customers' reliance on heat pumps as a primary vs. secondary heating source, please explain the following:

a. Provide a definition of "primary source for both heating and cooling" and "secondary heating/cooling source" used in the above citation.

b. When a customer receives a heat pump rebate through the energy efficiency program, what (if anything) does the Company require them to do with their prior heating system? For example, does the Company require the customer to decommission their prior heating system?

c. How does the Company enforce that a customer who receives a heat pump rebate through the energy efficiency program utilizes the heat pump as their primary fuel source over the full lifetime of the heat pump? Please provide any supporting Company policies, procedures, or customer-facing materials.

d. Provide a table with the following information for each heat pump measure planned to be offered through the 2024-2026 Three-Year Plan: year in which the measure-level estimate of claimed savings included in the TRM was last evaluated and/or verified; and a copy of the most recent evaluation results.

Response:

a. The question originally posed in data request Division 1-9 was based on text that should not have been in the Company's Plan, was redacted as part of the Company's response to Division 1-9 and will be corrected in the Plan. The quoted language was the Company's best efforts to respond despite the premise of the question being inaccurate. Whether a system is primary or secondary is not material to a customer's eligibility for heat pump incentives and the Company will revise its response to Division 1-9. To clarify, the Company offers the following heat pump incentives to customers:

- Rhode Island Energy customers with an electric account can receive a standard rebate of up to $350 per ton for air source heat pump equipment as a cooling incentive.

- Rhode Island Energy customers with electric resistance heating can qualify for an enhanced incentive of $1,250 per ton for air source heat pump equipment.

b. The Company does not require the customer to do anything with their prior heating system, such as decommissioning their prior heating system.

c. The Company does not enforce that a customer who receives a heat pump rebate through the energy efficiency program utilize the heat pump as their primary fuel source over the full lifetime of the heat pump. However, there are numerous factors and reasons that would indicate that they do.

- The cost to heat a home with heat pumps is lower than the cost to heat using electric baseboard. Short of removing the existing system or rendering it inoperable the choice is to spend less money over spending more money.

- As referenced in Division 3-7, the Company (through its HVAC Lead Vendor) has conducted and will continue to conduct informal assessments to gather information and verify compliance with measures. For example, as part of a recent analysis, 12 program participants were selected to determine whether rebated heat pump systems met the home's primary heating load. Analysis included a site visit, heating load calculation, fuel bill analysis (pre- and post- installation), and an interview with residents. In all 12 surveyed homes it was determined that the heat pumps were used for primary heat. The previous systems, if still in place, were only used in rare cases for back-up heat in some of the homes during the coldest days.

- Customers are educated on the benefits of their new heat pump system and how to operate the system properly. One such example of customer (and contractor) education can be seen in Attachment PUC-2-4-1.

d. Please see Table 1 below and Attachment PUC-2-4-1 for the most recent evaluation results for the heat pump measures. Please note the measures with an asterisk (*) are calculated measures, meaning they use a calculation and do not come from an evaluation study. For the calculated Residential measures in Table 1, the Company uses historic data to estimate the savings per measure for planning. This is denoted with "Savings back calculated from 2021 Year End Report." For the Commercial & Industrial calculated measures in Table 1, the Company calculated the estimated savings for planning based on historic data and updates to the International Energy Conservation Code (IECC), as IECC 2021 adjusted the baseline used for these measures in Large C&I New Construction.

Table 1. Planned Heat Pump Measures: Year of Last Update/Verification and Source

Program	**Measure**[1]	**Year Last Updated/ Verified**	**Source**
Residential HVAC	Central Heat Pump	2021	Calculated from deemed values via RI_2022 Annual Plan Electric H&C Savings Workbook_06-14-2021.xlsx[1]
Residential HVAC	Electric Resistance to MSHP	2021	Calculated from deemed values via RI_2022 Annual Plan Electric H&C Savings Workbook_06-14-2021.xlsx[1]
Residential HVAC	MiniSplit HP	2021	Calculated from deemed values via RI_2022 Annual Plan Electric H&C Savings Workbook_06-14-2021.xlsx[1]
EnergyWise Single Family	Electric Resistance to MSHP	2021	Calculated from deemed values via RI_2022 Annual Plan Electric H&C Savings Workbook_06-14-2021.xlsx[1]
EnergyWise Multifamily	Heat Pumps*	2022	Savings back calculated from 2021 Year End Report
Income Eligible Single Family	MSHP - Electric Resistance	2021	Calculated from deemed values via RI_2022 Annual Plan Electric H&C Savings Workbook_06-14-2021.xlsx[1]
Income Eligible Multifamily	Heat Pumps*	2022	Savings back calculated from 2021 Year End Report
Large C&I New Construction	AirHP - Pkg to5.4T, 5.4-11.25T, 11.25-20T, 11.25T-20T*	2023	Based on historic savings and 2021 IECC
Large C&I New Construction	VRF HP - 5.4T-11.25T, 11.25T-20T, over 20T*	2023	Based on historic savings and 2021 IECC
Large C&I New Construction	Water Source Heat Pump*	2023	Based on historic savings and 2021 IECC

---

[1] Acronyms for Measures:
HP = Heat Pump
MSHP = Mini-Split Heat Pump
T = tons
AirHP – Pkg to 5.4T = Air Heat Pump – Package to 5.4 tons
VRF HP 11.25T-20T = Variable Refrigerant Flow Heat Pump – 11.25 tons to 20 tons
IECC Code = International Energy Conservation Code

Attachment PUC 2-4-1 is the Company's Electric H&C Savings Workbook. This workbook was most recently updated in 2021 and incorporates Deemed/Baseline value sources from the following studies, which are also included as attachments to this response:

- Attachment PUC 2-4-2: Central Air Conditioner Seasonal Energy Efficiency Rating (SEER) Values: Comprehensive TRM Review MA19R17-B-TRM_2021-04-12;

- Attachment PUC 2-4-3: Full Load Hours Values: Ductless Mini-Split Heat Pump Impact Evaluation 12-30-2016;

- Attachment PUC 2-4-4: Ductless MSHP SEER Value: Ductless Mini-Split Heat Pump Cost Study RES28 2018-10-05;

- Attachment PUC 2-4-5: Full Load Hours Values: Quick Hit Study: Ductless Mini-Split Heat Pump Survey RES 29 2018-03-30;

- Attachment PUC 2-4-6: Market Effects for Early Replacement and Replace on Failure Assumptions: Massachusetts Residential HVAC Net-to-Gross and Market Effects Study TXC34 2018-07-27.

Measure	Percent of Measure	Annual kwh Saved	Max kW Saved	Summer Coincident %	Winter Coincident %	Summer kW	Winter kW	Life (years)	Annual Benefits ($/year/unit)	One-Time Benefit ($/unit)	Incremental Cost
CAC											
ROF/New: Baseline Std (SEER 14.0) to SEER 16	60.5%	159.6	0.25	34.6%	0.0%	0.09	0.00	18.0	$4.43	$0.00	$951.22
ER: Existing to Baseline Std (SEER 14.0)	39.5%	161.0	0.26	34.6%	0.0%	0.09	0.00	6.0	$15.96	$0.00	$1,542.68
ER: Baseline Std to SEER 16		159.6	0.25	34.6%	0.0%	0.09	0.00	18.0		$0.00	
Rolled-Up SEER 16		**223.2**	**0.36**			**0.12**	**0.00**	**14.6**	**$8.98**	**$0.00**	**$1,185**
								15.0			
								3347.7			
								24%			

			Load Shape															
Measure	Percent of Measure	Annual kwh Saved	Summer Peak	Summer Off Peak	Winter Peak	Winter Off Peak	Sum Max kW	Winter Max kW	Max kW Saved	Summer Coincident %	Winter Coincident %	Summer kW Reduction	Winter kW Reduction	Life (years)	Annual Benefits ($/year/unit)	Time Benefit ($/unit)	Incremental Cost
HPs (Cooling and Heating)																	
ROF/New: Baseline Std (SEER 14, HSPF 8.2) to SEER 15, HSPF 9.0	69.5%	1,097.8	9.7%	8.6%	35.5%	46.2%	0.36	0.38	0.38	32.3%	62.0%	0.12	0.24	18.0	$4.43	$0.00	$431.00
ER: Existing to Baseline Std (SEER 14, HSPF 8.2)	31.5%	1,347.4	15.3%	13.6%	31.2%	39.9%	0.69	0.40	0.69	34.6%	35.7%	0.24	0.25	6.0	$15.96	$0.00	$1,264.26
ER: Baseline Std to SEER 15, HSPF 9.0	31.5%	1,097.8	9.7%	8.6%	35.5%	46.2%	0.36	0.38	0.38	32.3%	62.0%	0.12	0.24	18.0		$0.00	
Rolled-Up SEER 16, HSPF 8.5		**1,533.2**	**11.2%**	**10.0%**	**34.3%**	**44.4%**	**0.58**	**0.51**	**0.58**	**34.6%**	**54.7%**	**0.20**	**0.32**	**14.7**	**$8.11**	**$0.00**	**$698**
										33.2%	55.5%						

							Load Shape				Demand Savings						
Measure	SEER	EER	HSPF	Ave. Size (tons)	Annual full load hours	Annual kwh Save	Summer Peak	Summer Off Peak	Winter Peak	Winter Off Peak	Annual Max Demand Factor	Max kW Saved	Summer Coincident %	Winter Coincident Percent	Summer kW reduction	Winter kW Reduction	Life (years)
CAC Baseline Standard (effective Jan 1, 2015)	**14**	**11**	**n/a**														
Baseline Std to SEER 16 (Cooling)	16.77	13.35	n/a	2.69	419	160	47.3%	42.2%	6.6%	3.8%	0.001594	0.254	34.6%	0.0%	0.088	0.000	18
CAC ER Baseline. 13.5 SEER nameplate, with estimated age-related degradation to 12.0 SEER.	**12**	**8.5**	**n/a**														
ER of CAC 12 years old, 6 yrs remaining life (ER Baseline to Baseline Standard), Cooling				2.69	419	161	47.3%	42.2%	6.6%	3.8%	0.001594	0.257	34.6%	0.0%	0.089	0.000	6
HP Baseline Standard (effective Jan 1, 2015)	**14**	**11.7**	**8.2**														
Baseline Std to SEER 15, HSPF 9 (Cooling)	17.64	12.34	9.81	3.03	419	224.5	47.3%	42.2%	6.6%	3.8%	0.001594	0.358	34.6%	0.0%	0.124	0.000	18
Baseline Std to SEER 15, HSPF 9 (Heating)	17.64	12.34	9.81	3.03	1200	873.3	0.0%	0.0%	42.9%	57.1%	0.000438	0.382	0.0%	62.0%	0.000	0.237	18
Baseline Std to SEER 15, HSPF 9 (OVERALL)	17.64	12.34	9.81	3.03		1098	9.7%	8.6%	35.5%	46.2%		0.382	32.3%	62.0%	0.124	0.237	18
HP ER Baseline	**10**	**8.5**	**7**														
ER of HP 12 yrs old, 6 yrs remaining life (ER Baseline to Baseline Standard, Cooling)				3.03	419	435.3	47.3%	42.2%	6.6%	3.8%	0.001594	0.694	34.6%	0.0%	0.240	0.000	6
ER of HP 12 yrs old, 6 yrs remaining life (ER Baseline to Baseline Standard, Heating)				3.03	1200	912.2	0.0%	0.0%	42.9%	57.1%	0.000438	0.399	0.0%	62.0%	0.000	0.248	6
ER of HP 12 yrs old, 6 yrs remaining life (ER Baseline to Baseline Standard, OVERALL)				3.03		1347	15.3%	13.6%	31.2%	39.9%		0.694	34.6%	35.7%	0.240	0.248	6
DMSHP Baseline	**15.0**	**12.0**	**8.2**														
Baseline Std to SEER 15, HSPF 10 (Cooling)	19.7	13.3	11.2	2.33	218	96.8	43.4%	40.2%	7.4%	9.0%	0.001660	0.161	28.5%	0.0%	0.046	0.000	18
Baseline Std to SEER 15, HSPF 10 (Heating)	19.7	13.3	11.2	2.33	535	487.4	0.0%	0.0%	42.9%	57.1%	0.000438	0.213	0.0%	62.0%	0.000	0.132	18
Baseline Std to SEER 15, HSPF 10 (OVERALL)	19.7	13.3	11.2	2.33		584	7.2%	6.7%	37.0%	49.1%		0.213	21.5%	62.0%	0.046	0.132	18
CAC QIV (assuming of a First Tier SEER 16 unit) (Cooling)	16.77	13.4	n/a	2.69	419	40.3	47.3%	42.2%	6.6%	3.8%	0.001594	0.064	34.6%	0.0%	0.022	0.000	18
CAC Tune-Up (assuming of a Baseline Std unit) (Cooling)	14.0	11.0	n/a	2.69	419	48.3	47.3%	42.2%	6.6%	3.8%	0.001594	0.077	34.6%	0.0%	0.027	0.000	5
HP QIV (assuming of a "Weighted Average" unit)																	
Cooling	17.64	12.34	9.81	3.03	419	43.2	47.3%	42.2%	6.6%	3.8%	0.001594	0.069	34.6%	0.0%	0.024	0.000	18
Heating	17.64	12.34	9.81	3.03	1200	222.4	0.0%	0.0%	42.9%	57.1%	0.000438	0.097	0.0%	62.0%	0.000	0.060	18
OVERALL	17.64	12.34	9.81	3.03		265.6	7.7%	6.9%	37.0%	48.4%		0.097	24.4%	62.0%	0.024	0.060	18
HP Tune-Up (assuming of an existing, older non-EE unit)																	
Cooling	**13.0**	**11.0**	**7.7**	**3.03**	419	58.6	47.3%	42.2%	6.6%	3.8%	0.001594	0.093	34.6%	0.0%	0.032	0.000	5
Heating	13.0	11.0	7.7	3.0	1200	283.3	0.0%	0.0%	42.9%	57.1%	0.000438	0.124	0.0%	62.0%	0.000	0.077	5
OVERALL	13.0	11.0	7.7	3.0		341.9	8.1%	7.2%	36.7%	48.0%		0.124	26.0%	62.0%	0.032	0.077	5
DMSHP QIV (assuming of a "Weighted Average" Unit)																	
Cooling	19.7	13.3	11.2	2.3	218	15.5	43.4%	40.2%	7.4%	9.0%	0.001660	0.026	28.5%	0.0%	0.007	0.000	18
Heating	19.7	13.3	11.2	2.3	535	66.8	0.0%	0.0%	42.9%	57.1%	0.000438	0.029	0.0%	62.0%	0.000	0.018	18
OVERALL	19.7	13.3	11.2	2.3		82.3	8.2%	7.6%	36.2%	48.0%		0.029	25.0%	62.0%	0.007	0.018	18
Electric Resistance Heating Baseline	**15.0**	**12.0**	**3.4**														
Elec Resistance Heat to DMSHP SEER 15, HSPF 10 (Cooling)	19.2	12.6	10.4	2.43	218	92.0	43.4%	40.2%	7.4%	9.0%	0.001660	0.153	28.5%	0.0%	0.044	0.000	18
Elec Resistance Heat to DMSHP SEER 15, HSPF 10 (Heating)	19.2	12.6	10.4	2.43	1117	6457.0	0.0%	0.0%	42.9%	57.1%	0.000438	2.828	0.0%	62.0%	0.000	1.753	18
Elec Resistance Heat to DMSHP SEER 15, HSPF 10 (OVERALL)	19.2	12.6	10.4	2.43		6549.0	0.6%	0.6%	42.4%	56.4%		2.828	1.5%	62.0%	0.044	1.753	18
Duct Sealing - 100 CFM redcution in leaks 20% of flow to 10%	n/a	n/a	n/a			212	47.3%	42.2%	6.6%	3.8%		0.300	34.6%	0.0%	0.104	0.000	20
~~CoolSmart Wm Air Furnace ECM (GN Reb)~~	~~n/a~~	~~n/a~~	~~n/a~~			~~168~~	~~0.2%~~	~~0.5%~~	~~37.8%~~	~~61.5%~~		~~0.124~~	~~0.0%~~	~~16.0%~~	~~0.000~~	~~0.020~~	~~18~~
Down Size 1/2 ton	n/a	n/a	n/a			203	47.3%	42.2%	6.6%	3.8%		0.295	34.6%	0.0%	0.102	0.000	18
~~Energy Star QI~~	~~n/a~~	~~n/a~~	~~n/a~~			~~212~~	~~47.3%~~	~~42.2%~~	~~6.6%~~	~~3.8%~~		~~0.300~~	~~25.0%~~	~~0.0%~~	~~0.075~~	~~0.000~~	~~18~~
QI w/ Duct modifications	n/a	n/a	n/a			**230**	47.3%	42.2%	6.6%	3.8%		**0.180**	34.6%	0.0%	0.062	0.000	18
Circulator Pump	n/a	n/a	n/a			142	1.3%	2.0%	49.6%	47.1%		0.080	0.0%	**53.0%**	0.000	0.042	15

Inputs
Tiers Eliminated in
Changes from 2019-2021 plan to 2019 annual report
Red Text = Updated from 2020 TRM Review Study

Comprehensive TRM Review MA19R17-B-TRM

Final Report

Prepared for:

The Electric and Gas Program Administrators of Massachusetts
Part of the Residential Evaluation Program Area

Submitted by:

Guidehouse, Inc.
1375 Walnut Street
Suite 100
Boulder, CO 80302

202.973.3170
guidehouse.com

Reference No.: 209704
April 12, 2021

TABLE OF CONTENTS

EXECUTIVE SUMMARY

This review assesses the quality of assumptions and values in the Massachusetts Technical Reference Manual (TRM) to ensure that the TRM assumptions reflect the results of recent residential studies, such as the RES 1 Baseline Study.

Objectives and Methods

The TRM documents the calculations used by the state's Program Administrators (PAs) to claim savings through their energy efficiency programs. It is critical that the TRM use the best available data and that its deemed savings values are based on credible, standardized assumptions. The primary goal of this review was to ensure that relevant data from the RES 1 Baseline Study and other recent studies are incorporated into the TRM. A secondary goal was to assess the quality of the values in the residential portion of the TRM and to conduct analysis, where relevant, to improve these parameters.

Our review focused on identifying TRM parameters that were out-of-date, that were based on less relevant data sources (i.e., not Massachusetts or New England-specific), or that have a significant effect on the energy efficiency program's energy, demand, or fossil fuel savings. We designed and implemented a scoring methodology that accounted for these factors and flagged select parameters as a high priority to update. Conversely, parameters from recently published, relevant data sources or that have a low savings impact received a low priority score. The resulting priority scores helped determine which parameters are candidates for updating.

The team reviewed data collected in the RES 1 Baseline Study and other available data sources to identify newer or more robust data available for updating parameter values. Other data sources include but are not limited to federal standard updates, ENERGY STAR updates, and recent evaluation studies.

Recommended Updates

Table 1 describes the measure parameters for which the evaluation team recommends the PAs adopt updated TRM values. Table 1 is organized by measure title, with measures presented in the order in which they appear in the *2019-2021 Plan Version of the MA TRM*.

Table 1: Summary of Recommended TRM Parameter Value Updates

Measure Name	Parameter Name	Unit	Existing Value	Proposed Value
Boiler, Gas Forced Hot Water (RES-HVAC-BGFHW)	Effective Useful Life (EUL)	Years	20	23
	Baseline Efficiency, ER	AFUE	80.0% nameplate 77.4% actual	85.5% nameplate 77.4% actual
	Baseline Efficiency, ROF	AFUE	82.0% nameplate 79.3% actual	86.5% nameplate 83.7% actual
Boiler, Oil/Propane Forced Hot Water (RES-HVAC-BFHW)	Baseline Efficiency, Oil, ROF	AFUE	83.0%	Through 2020: 83.0% 2021 and on: 86.0%
	Baseline Efficiency, Propane, ROF	AFUE	82.0% nameplate 79.3% actual	86.5% nameplate 83.6% actual
Central Air Conditioning (RES-HVAC-CAC)	Baseline Efficiency, ER	SEER	10.0	13.5 nameplate 12.0 actual
	Baseline Efficiency, ROF	SEER	13.0	14.0
Central Ducted HP Fully Displacing Existing Furnace (RES-HVAC-FSHP)	Baseline Efficiency, Oil, ER	AFUE	78%	79%
Central Ducted HP Partially Displacing Existing Furnace (RES-HVAC-FSHP-P)	Baseline Efficiency, Oil, ER	AFUE	78%	79%
Clothes Dryer (RES-A-CD)	EUL, Electric	Years	12	16
	EUL, Gas	Years	12	17
Combo Condensing Boiler/Water Heater (RES-HVAC-CCBWH)	Baseline % Split of Indirect vs Storage Water Heater (WH)	%	80% Indirect, 20% Storage	24% Indirect, 76% Storage
	Baseline Efficiency, Boiler, ER	AFUE	80.0% nameplate 77.4% actual	85.5% nameplate 77.4% actual
	Baseline Efficiency, Boiler, ROF	AFUE	82.0% nameplate 79.3% actual	86.5% nameplate 83.7% actual
	Baseline Efficiency, WH, ER Blended Medium-, High-Draw	UEF	0.55	0.58
Dehumidifier (RES-PL-DH)	Capacity	Pints/Day	35	*Remove*
	Efficiency	Liters/kWh	Retirement: 1.0 Baseline: 1.5 Measure: 2.0	Retirement: 1.6 Baseline: 2.8 Measure: 3.3
	Hours of Operation	Hours/Year	Undocumented	*Remove*
	Dehumidification Load	Liters/Year	n/a	1,520
	Energy Savings	kWh/Year	New: 167.6 Retirement: 152.7	New: 82.3 Retirement: 407.1
	Demand Savings	kW	New: 0.04 Retirement: 0.04	New: 0.02 Retirement: 0.10
	EUL	Years	12	17
ECM Circulator Pump (RES-HVAC-ECMCP)	CF_{WP}	-	0.16	0.53

Measure Name	Parameter Name	Unit	Existing Value	Proposed Value
Furnace, Gas (RES-HVAC-FG)	EUL	Years	18	17
	Baseline Efficiency, ER	AFUE	78.0% nameplate 78.9% actual	85.0% nameplate 81.0% actual
	Baseline Efficiency, ROF	AFUE	85.0%	89.0% nameplate 90.1% actual
Furnace, Oil/Propane (RES-HVAC-FOP)	Baseline Efficiency, Propane, ROF	AFUE	85.0%	89.0% nameplate 90.1% actual
Heat Recovery Ventilator (RES-HVAC-HRV)	HRV Gas Savings	MMBtu	7.7	8.6
	HRV Electricity Savings	kWh	-133	-171
	HRV Demand Savings	kW	-0.10	-0.02
	ERV Gas Savings	MMBtu	-	8.8
	ERV Electricity Savings	kWh	-	-127
	ERV Demand Savings	kW	-	-0.014
Insulation (RES-BS-I)	Heating Degree-Days, Cooling Degree-Hours	HDD, CDH	Varies by City, see Table 3-19	
Low-Flow Showerhead (RES-WH-S)	EUL	Years	7	15
Low-Flow Showerhead with Thermostatic Valve (RES-WH-STV)	EUL	Years	7	15
	Electric (Single Family)	kWh	372	247
	Electric (Single Family)	kW	0.08	0.06
	Gas (Single Family)	MMBtu	1.84	1.22
	Oil (Single Family)	MMBtu	2.09	1.32
	Other (Single Family)	MMBtu	1.84	1.22
	Electric (Multi-family)	kWh	335	183
	Electric (Multi-family)	kW	0.09	0.04
	Gas (Multi-family)	MMBtu	1.66	1.41
	Oil (Multi-family)	MMBtu	1.88	1.44
	Other (Multi-family)	MMBtu	1.66	1.41
Pool Pump (RES-MAD-PP)	Operating Days per Year	Days/Year	91	122
	Pool Size	Gallons	20,000 to 23,000	22,000
	Flow Rates	gpm	Baseline: 64 2S: 66 high, 33 low VS: 50 high	Baseline: 97 2S: 97 high, 48 low VS: 77 high, 31 low
	Daily Operating Hours	Hours/day	Baseline: 8.5 2S: 2 high, 12.5 low VS: 2 high, 18 low	Baseline: 5.7 2S: 2 high, 9.5 low VS: 2 high, 15.7 low
	Energy Factor	EF	Baseline: 2.1 2S: 2.0 high, 5.2 low VS: 4.0 high, 8.8 low	Baseline: 2.0 2S: 1.9 high, 5.3 low VS: 2.9 high, 10.5 low
	Energy Savings	kWh/year	2S: 842, VS: 1,062	2S: 639, VS: 1,284
	Demand Savings	kW	2S: 0.87, VS: 1.12	2S: 0.67, VS: 1.35
	EUL	Years	10	6

Measure Name	Parameter Name	Unit	Existing Value	Proposed Value
Programmable Thermostat (RES-HVAC-PT)	EUL	Years	15	19
Quality Installation with Duct Modification (RES-HVAC-QIDM)	Energy Savings	kWh/year	513	230
	Demand Savings	kW	0.85	0.18
Room Air Cleaner (RES-PL-RAC)	Energy Savings	kWh	391	Varies; see Table 3-27
Room Air Conditioner (RES-PL-ROOMAC)	EUL	Years	8	12
Stand Alone Water Heater (RES-WH-SASWH)	Baseline Efficiency, ER	UEF	Medium Draw: 0.52 High Draw: 0.58 Blended: 0.55	Medium Draw: 0.56 High Draw: 0.60 Blended: 0.58
	EUL	Years	13	10
Thermostatic Valve (RES-WH-TV)	EUL	Years	7	15
Variable Frequency Drive (RES-MAD-VFD)	Energy Savings	kWh/HP	Varies by type; see Table 3-33	
	Demand Savings, Summer	kW/HP$_{SP}$	Varies by type; see Table 3-33	
	Demand Savings, Winter	kW/HP$_{WP}$	Varies by type; see Table 3-33	

Parameters with No Recommended Updates

The team identified several measures and parameters for which updated parameter values are not recommended. Table 2 lists these measures and the reasons why this study does not recommend updated parameter values for them.

Table 2: Measures Not Recommended for Update by this Study

Measure Names and Codes	Reason for Not Updating
• Air Source Central Heat Pumps (RES-HVAC-ASHP) • Central Air Conditioning (RES-HVAC-CAC), efficient level • Ductless Mini-Split Heat Pumps (RES-HVAC-DMHP)	The PAs use program data to update measure parameters.
• Central Ducted Heat Pump Fully Displacing Existing Furnace (RES-HVAC-FSHP) • Central Ducted Heat Pump Partially Displacing Existing Furnace, Oil (RES-HVAC-FSHP-P) • Ductless Mini-Split Heat Pump with Integrated Controls – Fully Displacing Existing Boiler (RES-HVAC-FS-DMSHP) • Ductless Mini-Split Heat Pump with Integrated Controls – Partially Displacing Existing Boiler (RES-HVAC-FS-DMSHP-P)	This study recommends revised measure lifetime values. Revised measure savings values will be informed by a new energy optimization study.
• Refrigerator/Freezer Recycling (RES-A-RFR)	Improved data is not available.
• Faucet Aerators (RES-WH-FA) • Pipe Wrap, Water Heating (RES-WH-PW) • Early Retirement Clothes Washers (RES-A-ERCW) • Clothes Dryers (RES-A-CD) • Heat Pump Quality Installation Verification (RES-HVAC-HPQIV) • Heat Pump Digital Check-up/Tune-up (RES-HVAC-HPDCU)	Measures represent a small portion of program savings.

1. INTRODUCTION

1.1 Background

The Massachusetts Technical Reference Manual (MA TRM) is foundational to the calculation of savings claimed by residential energy efficiency programs in the state. As a result, mid-plan revision of the TRM is critical to ensure that it uses the best available data and that its deemed savings values are based on credible, standardized assumptions. This revision process improves the accuracy of the savings claimed by energy efficiency programs that rely on the TRM. The primary goal of this review is to ensure that relevant data from the RES 1 Baseline Study and other recent studies are incorporated into the TRM. A secondary goal of this effort is to assess the quality of the values in the residential portion of the TRM and to conduct analysis to improve these parameters.

In early 2020, the evaluation team reviewed the existing data sources and assumptions used for residential market-rate measures in the *2019-2021 Plan Version of the MA TRM* (published October 2018). Specifically, the evaluation team reviewed 47 residential measures (listed in Table 1-1) and documented 759 parameter values or assumptions associated with these measures. These values and assumptions include any inputs that directly contribute to the calculation of energy, demand, or fossil fuel savings. In cases where the TRM specified the deemed kWh, kW, or MMBtu savings, the team also reviewed the source calculations that led to these values, even when not directly published in the TRM. Our review did not examine variables such as net-to-gross, measure costs, or in-service rates.

To select a subset of TRM parameters for detailed review, the team prioritized the collected parameters based on the impact of the parameter value on program savings and based on the data sources cited in the TRM (with older, less relevant sources designated as a high priority for review).

The evaluation team hosted a TRM workshop on March 17, 2020 to review our prioritization of different TRM parameters. During the workshop, the Program Administrators (PAs) and Energy Efficiency Advisory Council (EEAC) consultants provided feedback on the TRM parameters we proposed to update. The team sought further input from the PAs and consultants in a memo submitted on April 9, 2020, which recommended values for a subset of parameters that could be referenced with minimal effort from in-house data sources such as the RES 1 Baseline Study. Additionally, the team conducted an in-depth analysis of several high priority parameters that could not be directly referenced from prior studies.

This report contains all the recommendations that result from this TRM review study. A databook attached to this report details each individual parameter reviewed in this study with information on the data source cited for each parameter and the updated values that the team recommends.

1.2 Scope of Review

The scope of this TRM review is limited to the market-rate residential efficiency measures described in Section 1 of the *2019-2021 Plan Version of the Massachusetts TRM*. The evaluation team's review focuses on assumptions pertaining to the calculation of deemed kWh, kW, and MMBtu savings. Impact factors in the TRM, such as in-service rates, realization rates, and net-to-gross ratios, are covered by other studies and are not in scope for this review. In addition, this review excludes the following measures for the following reasons:

- **Lighting** measures, **Active Demand Reduction** measures, **New Construction** measures, and **Code Compliance** measures are evaluated under separate evaluation contracts.

- **Wi-Fi Thermostat** and **Temperature Optimization** measures are subjects of ongoing studies and should not be updated until those studies are complete.
- Measures for **Education Kits**, **Advanced Power Strips**, and **Home Energy Reports** were recently evaluated and updated by measure-specific studies.
- **Custom Multi-Family** measures and **Heat Pump High Rise** measures use savings calculated with site-specific parameters that cannot be generalized.

Table 1-1 lists the measures reviewed by the evaluation team and includes the measure category, TRM section number, and measure code for each measure.

Table 1-1: List of Measures Covered in This Review, by Measure Category

Measures listings include TRM Section, Measure Name, and Measure Code

Appliances/Plug Load

- 1.12. Clothes Dryer (RES-A-CD)
- 1.21. Dehumidifier (RES-A-DH)
- 1.28. Early Retirement Clothes Washers (RES-A-ERCW)
- 1.52. Refrigerator/Freezer Recycling (RES-A-RFR)
- 1.53. Room Air Cleaner (RES-PL-RAC)

Building Shell

- 1.3. Air Sealing (RES-BS-AS)
- 1.39. Insulation (RES-BS-I)

Hot Water

- 1.16. Condensing Water Heater (RES-WH-CWH)
- 1.30. Faucet Aerator (RES-WH-FA)
- 1.35. Heat Pump Water Heater (RES-WH-HPWH)
- 1.38. Indirect Water Heater (RES-WH-IWH)
- 1.43. Low-Flow Showerhead (RES-WH-S)
- 1.44. Low-Flow Showerhead with Thermostatic Valve (RES-WH-STV)
- 1.46. On-Demand/Tankless Water Heater (RES-WH-ODTWH)
- 1.48. Pipe Wrap (Water Heating) (RES-WH-PW)
- 1.55. Stand Alone Water Heater (RES-WH-SASWH)
- 1.57. Thermostatic Valve (RES-WH-TV)

Motors

- 1.49. Pool Pump (RES-MAD-PP)
- 1.58. Variable Frequency Drive (RES-MAD-VFD)

Refrigeration

- 1.59. Vending Miser (RES-R-VM)

HVAC

- 1.4. Air Source Central Heat Pump (RES-HVAC-ASHP)
- 1.5. Boiler Reset Control (RES-HVAC-BSC)
- 1.6. Boiler, Gas Forced Hot Water (RES-HVAC-BGFHW)
- 1.7. Boiler, Oil/Propane Forced Hot Water (RES-HVAC-BFHW)

HVAC (continued)

- 1.8. Central AC Quality Installation Verification (QIV) (RES-HVAC-CACQIV)
- 1.9. Central Air Conditioning (RES-HVAC-CAC)
- 1.10. Central Ducted Heat Pump Fully Displacing Existing Furnace (RES-HVAC-FSHP)
- 1.11. Central Ducted Heat Pump Partially Displacing Existing Furnace, Oil (RES-HVAC-FSHP-P)
- 1.14. Combo Condensing Boiler/Water Heater (RES-HVAC-CCBWH)
- 1.15. Combo Furnace/Water Heater (RES-HVAC-CFWH)
- 1.19. DMSHP with Integrated Controls Fully Displacing Existing Boiler (RES-HVAC-DMSHP)
- 1.20. DMSHP with Integrated Controls Partially Displacing Existing Boiler (RES-HVAC-FS-DMSHP-P)
- 1.22. Down-Size 1/2 Ton (RES-HVAC-DSHT)
- 1.23. Duct Insulation (RES-HVAC-DI)
- 1.24. Duct Sealing (RES-HVAC-DSAF)
- 1.25. Ductless Mini-Split Heat Pump (DMSHP) (RES-HVAC-DMHP)
- 1.26. Ductless Mini-Split Heat Pump (DMSHP) Quality Installation Verification (QIV) (RES-HVAC-MSHPQIV)
- 1.27. ECM Circulator Pump (RES-HVAC-ECMCP)
- 1.31. Furnace, Gas (RES-HVAC-FG)
- 1.32. Furnace, Oil/Propane (RES-HVAC-FOP)
- 1.33. Heat Pump Digital Check-up/Tune-up (RES-HVAC-HPDCU)
- 1.34. Heat Pump Quality Installation Verification (QIV) (RES-HVAC-HPQIV)
- 1.36. Heat Recovery Ventilator (RES-HVAC-HRV)
- 1.47. Pipe Wrap (Heating) (RES-HVAC-PW)
- 1.50. Programmable Thermostat (RES-HVAC-PT)
- 1.51. Quality Installation (QI) with Duct Modification (RES-HVAC-QIDM)
- 1.54. Room Air Conditioner (RES-PL-ROOMAC)

1.3 Report Structure

Section 2 of this report describes the evaluation team’s methodology for prioritizing parameters for review. The methodology section also describes certain analytical methods the team used to develop updated parameter values for different measures.

Section 3 describes the individual parameters in the TRM for which the evaluation team recommends updated values. Section 3 is organized by measure, with the text for each measure describing the parameters that we (the evaluation team) considered, the analysis we undertook, and the updated values we recommend.

Section 4 lists the measures and parameters that the evaluation team does not recommend updating at this time and justifies each of these decisions.

Section 5 describes the measures and parameters recommended for future evaluation planning and future Baseline Study iterations.

Appendix A details our review of parameters related to the heat recovery ventilators measure. Appendix B provides additional analysis from our review of heating degree day and cooling degree hour parameters.

2. METHODOLOGY

2.1 Methodology for Documenting and Prioritizing Parameters

Our review focused on identifying TRM parameters that were out-of-date, based on less relevant data sources (i.e., not Massachusetts or New England-specific), or had a significant effect on the measure's energy, demand, or fossil fuel savings. We designed and implemented a scoring methodology that accounted for these factors and flagged select parameters as a high priority to update. Conversely, parameters from recently published, relevant data sources or that have a low savings impact received a low priority score. The resulting priority scores helped determine which parameters are candidates for updating as part of this review.

The first step in the approach involved reviewing documentation of the in-scope TRM measures and the inputs that support each measure. The evaluation team reviewed the 2019-2021 plan version of the TRM (published in October 2018), including all sources and documentation associated with the in-scope measures. To assess the quality of the existing data sources, the team documented the inputs and assumptions of each TRM measure. These inputs included kWh or MMBtu unit savings, demand savings, baseline efficiencies, post-retrofit efficiencies, coincidence factors, measure life, and other factors that impact energy consumption (e.g., operating hours, capacities, and heating and cooling load assumptions). Net-to-gross factors, measure costs, and in-service rates were excluded from the review.

For each parameter, the team documented the variable name, variable value, units, TRM footnote number, source name, page number, source year, source link, and notes specific to each input. To ensure that recommended updates were consistent, we created an index of values used across different measures in the TRM.

After documenting each parameter's sources, the evaluation team scored the quality of the existing data—independent of whether more current data is available—and weighed source quality against the relative portfolio-level impact of each measure. The prioritization exercise helped the team evaluate parameter sources and impacts using the following criteria:

- **Existing source age**. Recently published data sources are preferable.
- **Existing source origin**. The highest preference is given to primary research, publications created by MA-specific PAs and evaluators, and government-provided publications. Undocumented/uncited sources are given the lowest ranking.
- **Impact on program savings**, as quantified in the Benefit Cost Ratio Model. The team ranked the measures by their total reported MMBtu net annual savings (first year savings) and assigned a prioritization score from 1 to 4, with a score of 4 representing measures with the highest savings.

The team overlaid a user-editable weighting for each criterion and then combined all criteria into a single priority score using the following general equation:

$$\begin{aligned}\boldsymbol{Priority\ Score}\ \% &\\ = \boldsymbol{Age\ Weight}\ \% \times \frac{\boldsymbol{Age\ Score}}{\mathbf{4}} &+ \boldsymbol{Origin\ Weight}\ \% \times \frac{\boldsymbol{Origin\ Score}}{\mathbf{4}}\\ + \boldsymbol{Impact\ Weight}\ \% \times \frac{\boldsymbol{Impact\ Score}}{\mathbf{4}} &\end{aligned}$$

As a result, each parameter received a final priority score between 0% and 100% to indicate the relative priority for updating. Higher scores indicate parameters that are a higher priority for updating.

Table 2-1 summarizes the criteria we used to prioritize parameters for updating.

Table 2-1: Summary of Parameter Prioritization Criteria

Prioritization Factor	Weight	Scoring Criteria			
		1 (Low Priority)	2	3	4 (High Priority)
Age: Existing source publication date	2	2015-2019	2010-2014	2005-2009	2004 and earlier
Origin: Existing source origin (or equivalent)	3	Primary research sponsored by the PAs and EEAC	Publications covering geographies and climates beyond MA, such as EPA and DOE sources	Publications with a limited or less applicable scope, such as data from a single vendor or other states' TRMs	Data source is not cited or is not available
Impact: Impact on program savings	4	Low impact on portfolio savings	Moderate impact on portfolio savings		High impact on portfolio savings

For most of the reviewed parameters (60%, or 458 out of 759), the team determined that the TRM’s current assumptions are up-to-date and that further study would likely not improve the accuracy of the TRM’s current assumption.

2.2 Review of RES 1 Baseline Study and Other Sources

Next, the team reviewed the RES 1 Baseline Study and other available data sources to identify newer or more robust data available for updating parameter values. Other data sources include but are not limited to federal standard updates, ENERGY STAR updates, and recent evaluation studies. The RES 1 Baseline Study has collected primary data from over 6,000 surveys and 300 onsite metered homes with subsequent follow-up surveys occurring on an annual basis. In particular, the RES 1 Baseline Study provides data related to the capacity, measure life, baseline efficiencies, and post-retrofit efficiencies of many types of HVAC equipment. The team identified RES 1 datapoints that could directly inform approximately 130 of the MA TRM’s algorithms and variable values. These datapoints do not include the demand impact model values that have already been updated in the TRM.

The RES 1 survey data that could inform estimates of replace-on-failure baseline efficiency levels for HVAC equipment has a small sample size. For example, the team identified only 17 survey records that could inform the ROF baseline efficiency levels for natural gas boilers and natural gas furnaces, and just 14 records that could inform the ROF baseline efficiency levels for central ACs. For these equipment types, the team reviewed additional data sources to inform the ROF baseline efficiency levels. A 2019 study[1], “Analysis of Residential HVAC Sales Data from HARDI Distributors (TXC65),” provides data describing distributor sales of HVAC equipment to the Massachusetts market in 2014-2017. Based on this distributor data, the team calculated an industry standard practice (ISP) efficiency level as a shipment-

---

[1] Available online at: https://ma-eeac.org/wp-content/uploads/TXC65_HARDI_Data_Memo_Final_2019.11.15.pdf

weighted average efficiency, excluding program-supported shipments and half of shipments that appear to be program-eligible but were not program-supported. The team then used RES 1 data (with low sample size) and estimated ISP levels to select an appropriate baseline level for HVAC replace-on-failure scenarios.

2.3 Recurrent Methodologies for Updating Parameters

Section 3 of this report describes the sources and methods our team used to update parameters for individual measures. To keep the Section 3 discussion of individual parameters concise, the subsections that follow describe recurrent methodologies that the team applied across multiple measures.

2.3.1 Early Retirement Baseline Efficiencies

For early retirement measures, the baseline efficiency should reflect existing, operable equipment replaced by the customer. The evaluation team used recent survey data from the RES 1 Baseline Study to characterize the stock of installed equipment in Massachusetts and to examine the baseline efficiencies of products eligible for early retirement measures.

To evaluate plausible early retirement units, existing equipment should still be within its defined expected useful life (EUL). Because of age-related degradation and less stringent code requirements in the past, the early retirement efficiency values may be lower than current code-mandated values. In most cases, EUL considerations resulted in the team considering datasets for equipment installed prior to 2010 (i.e., equipment that is at least 10 years old), as well as the subset that had installed equipment between 2000 and 2010 (between 10 and 20 years old). The team compiled a list of existing nameplate efficiency values (e.g., Annual Fuel Utilization Efficiency [AFUE] or Energy Factor [EF] values) for RES 1 households within each dataset and considered the sample size to evaluate its reliability before calculating the mean efficiency value.

To estimate age-related performance degradation, we referenced a National Renewable Energy Laboratory (NREL) study[2] that quantified *in situ* efficiency based on the type of equipment, its age, and its maintenance frequency:

$$\boldsymbol{Actual\ Efficiency = (Nameplate\ Efficiency) \times (1 - Maintenance\ Factor)^{Age}}$$

Using this equation, the team estimated the *in situ* performance of each recorded unit using an assumed maintenance factor representing professional annual maintenance, as this provides the smallest and most conservative level of degradation.[3] The team then calculated the mean degraded efficiency of type of product. The team used the mean degraded values for the age bins most representative of early retirement units, given the EUL of each measure.

2.3.2 Measure Life

In the initial measure review, we found that nearly two-thirds of the EUL assumptions for residential TRM measures cited older sources (circa 1998-2011) or cited the Massachusetts Common Assumptions.

---

[2] Building America Performance Analysis Procedures for Existing Homes. Technical Report, NREL/TP-550-38238, May 2006. https://www.nrel.gov/docs/fy06osti/38238.pdf

[3] The alternative maintenance factors listed in the NREL technical report represent “no annual maintenance”, which would have resulted in higher overall degradation.

When accounting for lifetime electricity or fossil fuel savings, an inaccurate measure life assumption can make a substantial difference in total portfolio savings estimates.

Surveys conducted during the RES 1 Baseline Study gathered information on the annual turnover of various residential appliances and HVAC equipment. Our team leveraged this information for the TRM update by estimating the EUL for end-uses with high saturations as the reciprocal of the percentage of units that were replaced in a given year.

The team considered that a minimum number of conclusive data points is required to reliably inform a change to the existing EUL values. Measures with low market penetration and low replacement rates provide fewer datapoints to analyze and, consequently, higher uncertainty around the results. In practice, all but two measures had market penetration values above 20%, and all of the changes recommended in this report were based on data from a minimum of 80 product replacement records.

The team also considered exogenous factors that influence a customer's decision to replace a product.[4] For example, utility incentive programs can encourage customers to replace equipment earlier than they would in the absence of incentive programs. This could skew an analysis based on customer activity, leading to a finding of shorter EUL values. We ignored this potential effect, since our analysis found longer EUL values than what is currently used in the TRM. It is possible that these EUL values could be even longer in the absence of program incentives but quantifying this effect would require a more extensive study of product lifetimes than was possible in the scope of this review.

Additional factors affecting measure life include longer-term market trends toward increasing or decreasing penetration. For example, oil boilers are broadly being phased out of the Massachusetts service territory as newer and more efficient technologies take over. In this case, survey results would show a bias toward a shorter calculated EUL than the real oil boiler life expectancy. Conversely, increased market-wide adoption of central air conditioners (A/Cs) would yield a longer calculated EUL, as the current equipment stock is likely to skew younger and incur lower failure rates. Where such factors are identifiable, the team has commented on potentially sources of bias and their likely impacts.

Furthermore, the RES 1 survey data only interviews customers who have inhabited their residence for the entire year. This means that replacements made upon a change of occupancy—a common time for equipment to be upgraded or changed-out—are not captured in the survey data. This has the effect of biasing survey results toward a longer EUL value than actual.

Despite the introduction of potential biases within the EUL analysis, the results are still based on real, Massachusetts-specific customer data, and are likely more appropriate than previously cited values.

2.3.3 Replace on Failure, Time of Sale, or New Installation Baseline Efficiencies

For non-early-retirement measures (referred to in this report as Replace on Failure or ROF measures), the baseline efficiency represents the typical efficiency of products installed by customers in the absence of program incentives. The team analyzed the efficiencies of all equipment installed by RES 1 survey respondents who were program nonparticipants and who installed equipment after 2010. We assumed that the mean efficiency value of products installed by nonparticipants since 2010 represents a good approximation of the equipment that customers select in the absence of program incentives. These baseline efficiency values are higher than the minimum product efficiency standards when nonparticipant customers select high efficiency products. Our analysis of survey respondents' participation status is ongoing and results depending on this participation analysis will be provided in a forthcoming addendum to this report.

---

[4] Note that EUL is defined by customer replacement for any reason, not just equipment failure.

2.3.4 Updates Based on Federal Standards, Codes, or Other Sources

In the absence of RES 1 survey data to directly characterize equipment parameters, our recommended updates were informed by a literature review of codes, federal standards, baseline studies, or other sources. In addition, even when RES 1 survey data was available, the evaluation team used these external sources to corroborate the values obtained from our analysis of survey data.

3. RECOMMENDED MEASURE PARAMETER UPDATES

This section describes the measure parameters for which the evaluation team recommends updated values. This section is organized by measure title, with measures presented in the order in which they appear in the *2019-2021 Plan Version of the MA TRM*.

3.1 Boiler, Gas Forced Hot Water (RES-HVAC-BGFHW)

Parameter: EUL.
Explanation: The team analyzed RES 1 data to determine the two-year equipment replacement rate, as outlined in Section 2. This gives Massachusetts- and program-specific values for EUL based on actual customer behavior.
Existing Source: Massachusetts common assumptions.
New Source: RES 1 baseline survey.
Methodology: The team found a 34% saturation for gas boilers. The proposed EUL value is informed by approximately 95 replacements per year (out of nearly 2,200 respondents with natural gas boilers) over a 2-year period. All replacements are considered to be standard replacements, and any early retirement considerations should be derived separately. Details are shown in Table 3-1.

Table 3-1: Natural Gas Boiler Effective Useful Life

Parameter Name	Existing EUL (Years)		Proposed EUL (Years)
	EUL	Rolled Up Measure	
EUL – Gas Boiler	20 years	19 years	23 years (not averaged with ER replacements)

Parameter: Natural Gas Hot Water Boiler Baseline Efficiency, Early Retirement.
Explanation: The team analyzed RES 1 data and applied degradation factors to estimate typical performance of boilers aged 10-20 years old.
Existing Source: Negotiated between PAs and EEAC.
New Source: RES 1 baseline survey.
Methodology: The Baseline Study data showed an average nameplate efficiency of 85.5% AFUE for a sample size of 32 respondents with boiler systems aged 10-20 years. We estimated that age-related degradation would reduce the nameplate efficiency to 80.0% AFUE using the method described in section 2.3.1.[5] Then, we applied a factor of 0. 96738 to estimate actual in situ performance of 77.4%.[6] Details are shown in Table 3-2.

Table 3-2: Gas Boiler Early Retirement Baseline Efficiency

Parameter Name	Existing AFUE	Proposed AFUE
Baseline AFUE – Gas Boiler, ER	80.0% nameplate 77.4% actual	85.5% nameplate 77.4% actual

---

[5] The team assumed a typical replacement age of 13.3 years and applied a degradation factor of 0.005, which represents “professional annual maintenance”.

[6] This *in situ* performance factor is based on Table 16 of the 2015 HEHE Impact Study, which found that baseline boilers typically underperform compared to their nameplate rating.

Parameter: Natural Gas Hot Water Boiler Baseline Efficiency, Replace on Failure.
Explanation: The team analyzed distributor data from HARDI and customer survey data from TXC52 and RES 1 to estimate typical performance of new boilers.
Existing Source: Federal minimum standard for gas boilers.
New Source: HARDI, TXC52 and RES 1.
Methodology: Customer survey data from the RES 1 Baseline Study showed an average of 88.5% AFUE for systems aged under ten years for customers that self-reported as program non-participants. However, the RES 1 data had a small sample size of n=17. Distributor data compiled from HARDI showed a shipment-weighted average of 86.6% AFUE for shipments that represent the ISP level, as described in section 2.2. However, this HARDI data represents sales across the Northeast including regions outside Massachusetts. Distributor survey data from TXC52 data showed a weighted average of 84.3% AFUE for ISP-level shipments. Based on these three data sources, the team determined that an ROF baseline nameplate efficiency of 86.5% AFUE is appropriate. We applied a factor of 0.96738 to estimate actual *in situ* performance of 83.7% AFUE.[7] Details are shown in Table 3-3.

Table 3-3: Gas Boiler Replace on Failure Baseline Efficiency

Parameter Name	Existing AFUE	Proposed AFUE
Baseline AFUE – Gas Boiler, ROF	82.0% nameplate 79.3% actual	86.5% nameplate 83.7% actual

3.2 Boiler, Oil/Propane Forced Hot Water (RES-HVAC-BFHW)

Parameter: Oil Hot Water Boiler Baseline Efficiency, Replace on Failure.
Explanation: Federal minimum standards for oil boilers increased on January 15, 2021.
Existing Source: Outdated federal minimum standard for oil boilers.
New Source: New federal minimum standard for oil boilers.
Methodology: Per 10 CFR 430.32 (e)(2)(iii)(A), the federal minimum standards for oil boilers increased to 86% AFUE, taking effect January 15, 2021. The new federal baseline level should not be applied prior to when it took effect in January 2021. Details are shown in Table 3-4.

Table 3-4: Oil Boiler Replace on Failure Baseline Efficiency

Parameter Name	Existing AFUE	Proposed AFUE
Baseline AFUE – Oil Boiler, ROF	83.0%	Through 2020: 83.0% 2021 and on: 86.0%

Parameter: Propane Hot Water Boiler Baseline Efficiency, Replace on Failure.
Explanation: Aligned with natural gas furnace efficiency values.
Existing Source: Federal minimum standard for natural gas boilers.
New Source: HARDI, TXC52 and RES 1 data for natural gas boilers.
Methodology: Due to similarities in boiler construction and overlaps in natural gas and propane boiler product lines, the team aligned assumptions of propane boiler efficiency with assumptions of natural gas boiler efficiency, described in section 3.1. Details are shown in Table 3-5.

---

[7] This *in situ* performance factor is based on Table 16 of the 2015 HEHE Impact Study, which found that baseline boilers typically underperform compared to their nameplate rating.

Table 3-5: Propane Boiler Replace on Failure Baseline Efficiency

Parameter Name	Existing AFUE	Proposed AFUE
Baseline AFUE – Propane Boiler, ROF	82.0% nameplate 79.3% actual	86.5% nameplate 83.6% actual

3.3 Central Air Conditioning (RES-HVAC-CAC)

Parameter: Central Air Conditioning Baseline Efficiency, Early Retirement.
Explanation: The team analyzed RES 1 data and applied degradation factors to estimate typical performance of central air conditioners aged 10-20 years old.
Existing Source: Uncited source.
New Source: RES 1 baseline survey.
Methodology: The Baseline Study data showed an average nameplate efficiency of 13.5 SEER for a sample size of 31 respondents with central A/C systems aged 10-20 years. We estimated that age-related degradation would reduce the nameplate efficiency to 12.0 SEER using the method described in section 2.3.1.[8] Details are shown in Table 3-5.

Table 3-6: Central Air Conditioner Early Retirement Baseline Efficiency

Parameter Name	Existing SEER	Proposed SEER
Baseline SEER – Central Air Conditioner, ER	10 SEER	13.5 SEER nameplate 12.0 SEER actual

Parameter: Central Air Conditioner Baseline Efficiency, Replace on Failure.
Explanation: The team analyzed distributor data from HARDI and customer survey data from TXC52 and RES 1 to estimate typical performance of new central A/Cs.
Existing Source: Federal minimum standard for split system central A/Cs.
New Source: HARDI, TXC52 and RES 1.
Methodology: Customer survey data from the RES 1 Baseline Study showed an average of 14.8 SEER for systems aged under ten years for customers that self-reported as program non-participants. However, the RES 1 data had a small sample size of n=14. Distributor data compiled from HARDI showed a shipment-weighted average of 13.6 SEER for shipments that represent the ISP level, as described in section 2.2. Distributor survey data from TXC52 data also showed a weighted average of 13.6 SEER for ISP-level shipments. Based on these three data sources, the team determined that an ROF baseline nameplate efficiency of 14.0 SEER is appropriate. Details are shown in Table 3-6.

Table 3-7: Central Air Conditioner Replace on Failure Baseline Efficiency

Parameter Name	Existing SEER	Proposed SEER
Baseline SEER – Central Air Conditioner, ROF	13.0 SEER	14.0 SEER

---

[8] The team assumed a typical replacement age of 12 years and applied a degradation factor of 0.01, which represents “professional annual maintenance”.

3.4 Central Ducted Heat Pump Fully Displacing Existing Furnace (RES-HVAC-FSHP)

Parameter: Oil Furnace Baseline Efficiency, Early Retirement.
Explanation: Baseline values should be internally consistent between the early retirement oil furnace measure and the ducted heat pump measure.
Existing Source: Uncited source.
New Source: 2018 Home Energy Services Impact Evaluation (RES 34).[9]
Methodology: The team reviewed RES 34 survey data to estimate the average efficiency of oil furnaces in existing Massachusetts homes. The data represents more than 20,000 oil furnaces surveyed between 2014 and 2016 including participants and nonparticipants. The team found an average efficiency of 79% AFUE for homes with oil furnaces.

Table 3-8: Oil Furnace Early Retirement Baseline Efficiency

Parameter Name	Existing	Proposed
Baseline AFUE – Oil Furnace, ER	78%	79%

Parameter: Switchover Temperature.
Explanation: The switchover temperature could be rephrased to better state that the switchover point is to electric resistance, not to fossil fuel heating.
Existing Source: 2018 Energy Optimization study.
New Source: For ease of use, the team recommends providing further clarification in the MA TRM around the switchover for measures where the newly installed system fully displaces the existing system and only one system remains. The switchover for these measures describes the switch between the heat pump's vapor compression operation and its electric resistance backup heating.

3.5 Central Ducted Heat Pump Partially Displacing Existing Furnace, Oil (RES-HVAC-FSHP-P)

See the parameter updates and explanations from Section 3.4, "Central Ducted Heat Pump Fully Displacing Existing Furnace."

3.6 Clothes Dryer (RES-A-CD)

Parameter: EUL.
Explanation: The team analyzed RES 1 data to determine the 2-year equipment replacement rate, as outlined in Section 2. This gives Massachusetts- and program-specific values for EUL based on actual customer behavior.
Existing Source: Massachusetts common assumptions.
New Source: RES 1 baseline survey.
Methodology: The team analyzed RES 1 data and found a 59% saturation of electric clothes dryers and a 23% saturation of gas clothes dryers. The proposed EUL values are informed by approximately 240 electric dryer replacements and approximately 88 gas dryer replacements (out of nearly 1,500 respondents with gas dryers) over a 2-year period. Details are shown in Table 3-8.

---

[9] http://ma-eeac.org/wordpress/wp-content/uploads/RES34_HES-Impact-Evaluation-Report-with-ES_FINAL_29AUG2018.pdf

Table 3-9: Clothes Dryer Effective Useful Life

Parameter Name	Existing EUL (Years)	Proposed EUL (Years)
EUL – Electric Clothes Dryer	12	16
EUL – Gas Clothes Dryer	12	17

3.7 Combo Condensing Boiler/Water Heater (RES-HVAC-CCBWH)

Parameter: Baseline percentage split of indirect versus storage water heaters.

Explanation: The baseline proportion of indirect versus storage water heaters is used as a weighting factor to calculate weighted average consumption for a theoretical, portfolio average baseline water heater. More up-to-date values can be sourced from RES 1 for the mix of baseline water heater equipment.

Existing Source: The existing source for the proportion of indirect versus storage water heaters is the 2015 *High Efficiency Heating Equipment Impact Evaluation* report.[10] This study cited 2013 program tracking data.

New Source: RES 1 baseline survey.

Methodology: The team compiled a list of households from the RES 1 survey that had natural gas or natural gas plus electric as their heating type, because a new combo condensing unit was unlikely to be a viable option for customers that did not already use natural gas for heating. Out of all the natural gas households surveyed, 35 households (24%) had an indirect water heater, 103 households (71%) had a storage water heater, and seven households (5%) had a tankless water heater. For a point of comparison, the evaluation team referenced NYSERDA's 2015 Residential Baseline Study for New York and found that New York shows a similar baseline split between indirect and storage water heaters.[11] See Table 3-9 for recommended updates.

Table 3-10: Water Heater Baseline Equipment Proportions

Parameter Name	Existing	Proposed
% Split of Indirect vs. Storage WH	80% Indirect 20% Storage	24% Indirect 76% Storage

Parameter: Boiler Baseline Efficiencies, Early Retirement and Replace on Failure.

Explanation: The baseline boiler efficiencies cited in the combo condensing boiler/water heater measure should be consistent with the recommendations defined for the gas boilers measure.

Existing Source: Federal minimum standard and negotiated baseline for gas boilers.

New Source HARDI, TXC52 and RES 1.

Methodology: See Section 3.1, "Boiler, Gas Forced Hot Water."

---

[10] The Cadmus Group, Inc. (2015). High Efficiency Heating Equipment Impact Evaluation

[11] The overall proportion of water heater types in New York state was: 22.7% indirect water heaters, 73.2% storage water heaters, and 3.7% tankless water heaters. https://www.nyserda.ny.gov/-/media/Files/Publications/building-stock-potential-studies/residential-baseline-study/Vol-1-Single-Family-Res-Baseline.pdf

Table 3-11: Boiler Baseline Efficiencies

Parameter Name	Existing AFUE	Proposed AFUE
Baseline AFUE – Boiler, ER	80.0% nameplate 77.4% actual	85.5% nameplate 77.4% actual
Baseline AFUE – Boiler, ROF	82.0% nameplate 79.3% actual	86.5% nameplate 83.7% actual

Parameter: Water Heater Baseline Efficiency, Early Retirement
Explanation: The baseline water heater efficiencies cited in the combo condensing boiler/water heater measure should be consistent with the recommendations defined for the standalone water heater measure.
Existing Source: Undocumented source.
New Source: RES 1 baseline survey.
Methodology: See Section 3.21, "Standalone Water Heater."

Table 3-12: Water Heater Baseline Efficiency, Early Retirement

Parameter Name	Existing ($EF_{exist,ER}$)	Proposed ($UEF_{exist,ER}$)
Baseline UEF_{exist} – Water Heater, ER	Blend of Medium- and High-Draw Products: 0.55	Blend of Medium- and High-Draw Products: 0.58

3.8 Dehumidifier (RES-PL-DH)

The dehumidifier measure in the 2019-2021 MA TRM uses a standard calculation to estimate energy savings by calculating the difference in energy consumption of the baseline and measure cases. This calculation depends on the dehumidifier capacity, the baseline and ENERGY STAR efficiency levels, and the assumed operating hours for dehumidifiers. For each of these parameters, the values in the TRM are either out-of-date or not well sourced. The dehumidifier capacity value is based on a limited set of units observed at an event in 2010; the baseline and ENERGY STAR efficiency levels are based on older standards that have been updated; and the TRM does not cite a source for the assumed operating hours.

The evaluation team considered updating each of these parameter values and maintaining the calculation approach that the TRM currently uses. However, a review of data from the RES 1 baseline study indicated that typical dehumidifier capacity has increased over time. The average capacity for units purchased between 2009 and 2014 was 52.1 pints/day, while the average capacity of units purchased between 2015 and 2019 was 67.8 pints/day.[12] Thus, a calculation-based method should not assume the same capacity for baseline and replacement dehumidifiers.

Assumptions regarding operating hours present another complication. The TRM calculation currently assumes that the same operating hours apply to baseline and high-efficiency dehumidifiers. However, the EEAC consultants pointed out that low- and high-efficiency units would likely remove a similar amount of moisture from the air, but low-efficiency units would require more operating hours to do so. Thus, a calculation-based method should not assume the same operating hours for baseline and replacement dehumidifiers.

---

[12] Based on 327 dehumidifiers identified in RES 1 belonging to both participants and nonparticipants.

These complications indicate that the current TRM calculation may not accurately represent the available energy savings from the dehumidifier measure. The evaluation team proposes a new calculation approach that uses baseline and ENERGY STAR efficiency levels, plus a new parameter for "dehumidification load" that represents the amount of moisture removed from the air each year by a typical dehumidifier user.

Parameter: Capacity.
Explanation: Capacity is the average pints of water the dehumidifier can remove per day and is a rated performance metric. The RES 1 Baseline Study has shown that dehumidifier size has grown significantly over time and the retirement case should reflect this.
Existing Source: Cape Light Compact's May 2010 event.
Recommendation: The evaluation team recommends this parameter be removed since the revised calculation method for energy savings does not require it.

Parameter: Baseline and ENERGY STAR Efficiencies.
Explanation: The measure includes three efficiency values: an early retirement baseline efficiency, a replace on failure baseline efficiency, and an ENERGY STAR efficiency for the measure's high efficiency unit.
Existing Source: The current early retirement baseline efficiency assumption comes from the 2005 federal standard.[13] The current replace on failure baseline efficiency assumption comes from the 2007 federal standard, which became effective in 2012. The current ENERGY STAR efficiency value comes from ENERGY STAR version 4.0.[14]
New Source: Each of the three existing sources has an updated version.
Methodology: Beginning with the early retirement case, the TRM states the assumption that "the baseline efficiency for recycling is a unit that is approximately eight years old, meeting the standard that was in place at the time." We propose to update the early retirement case efficiency to a level that complies with the federal standard that took effect on October 1, 2012. In the replace on failure case, the baseline efficiency is described in the TRM as a unit that meets the current federal standard. The current federal standard has an effective date of June 13, 2019 and the team proposes to update the baseline efficiency level to reflect the current federal standard. In the high efficiency measure case, we propose to update the efficiency level to align with ENERGY STAR version 5.0, the newest ENERGY STAR specification.

Parameter: Hours of Operation.
Explanation: The annual hours of operation of the unit was used as an input to the dehumidifier savings calculation in the 2019-2021 plan version of the TRM.
Existing Source: Undocumented source.
Recommendation: The evaluation team recommends this parameter be removed since the revised calculation method for energy savings does not require it.

Parameter: Dehumidification Load.
Explanation: The dehumidification load represents the amount of moisture removed from the air annually by a typical dehumidifier in Massachusetts.
Existing Source: Not applicable.
New Source: RES 1 Baseline Study meter data.
Methodology: The evaluation team estimated the annual dehumidification load using nameplate efficiency data and annual energy use measurements gathered in the RES 1 Baseline Study for 68 metered dehumidifiers. The average dehumidification load is 1,520 Liters/year.

Parameter: Energy Savings.

---

[13] https://www.ecfr.gov/cgi-bin/text-idx?rgn=div8&node=10:3.0.1.4.18.3.9.2.

[14] ENERGY STAR® Program Requirements Product Specification for Dehumidifiers, Version 4.0. Accessed at https://www.energystar.gov/sites/default/files/ENERGY%20STAR_Dehumidifiers_V4%200_Specification_Final.pdf

Explanation: The energy savings represent the difference in energy consumption between the baseline and the efficient cases. In the dehumidifier recycling case, this refers to the difference between a federally compliant unit from 8 years ago and the current federal specifications. The new dehumidifier case refers to the difference between a currently federally compliant unit and the current ENERGY STAR specifications.

Existing Source: Industry standard calculation to estimate energy savings by calculating the difference in energy consumption of the baseline and measure cases. The original unit energy savings equations are as follows.

$$\Delta \boldsymbol{kWh}_{\boldsymbol{New}} = \left[\boldsymbol{Capacity} * \left(\frac{\mathbf{0.473}}{\mathbf{24}}\right) * \left(\frac{\mathbf{1}}{\boldsymbol{Eff}_{\boldsymbol{Base}}} - \frac{\mathbf{1}}{\boldsymbol{Eff}_{\boldsymbol{EE}}}\right) * \boldsymbol{Hours}\right]$$

$$\Delta \boldsymbol{kWh}_{\boldsymbol{Recycling}} = \left[\boldsymbol{Capacity} * \left(\frac{\mathbf{0.473}}{\mathbf{24}}\right) * \left(\frac{\mathbf{1}}{\boldsymbol{Eff}_{\boldsymbol{Retire}}} - \frac{\mathbf{1}}{\boldsymbol{Eff}_{\boldsymbol{Base}}}\right) * \boldsymbol{Hours}\right]$$

Where:
Capacity = Average capacity of dehumidifier in Pints/24 Hours
Eff_{Retire} = Average efficiency of model being recycled, in Liters/kWh
Eff_{Base} = Average efficiency of model meeting the federal standard, in Liters/kWh
Eff_{EE} = Efficiency of ENERGY STAR model, in Liters/kWh
Hours = Dehumidifier annual operating hours
0.473 = Conversion factor: 0.473 Liters/Pint
24 = Conversion factor: 24 Hours/Day

New Source: Revised calculation method based on typical dehumidification loads observed for dehumidifiers in the RES 1 Baseline Study.

Methodology: The evaluation team proposes a new calculation that replaces the capacity and operating hours parameters with a single parameter for dehumidification load, as described above. The revised unit energy savings equations are as follows.

$$\Delta \boldsymbol{kWh}_{\boldsymbol{New}} = \boldsymbol{Dehumidification\_Load} * \left(\frac{\mathbf{1}}{\boldsymbol{Eff}_{\boldsymbol{Baseline}}} - \frac{\mathbf{1}}{\boldsymbol{Eff}_{\boldsymbol{EE}}}\right)$$

$$\Delta \boldsymbol{kWh}_{\boldsymbol{Recycling}} = \boldsymbol{Dehumidification\_Load} * \left(\frac{\mathbf{1}}{\boldsymbol{Eff}_{\boldsymbol{Retire}}} - \frac{\mathbf{1}}{\boldsymbol{Eff}_{\boldsymbol{Base}}}\right)$$

Where:
Dehumidification_Load = Typical annual moisture removal, in Liters/year
Eff_{Retire} = Average efficiency of model being recycled, in Liters/kWh
Eff_{Base} = Average efficiency of model meeting the federal standard, in Liters/kWh
Eff_{EE} = Efficiency of ENERGY STAR model, in Liters/kWh

Parameter: Demand Savings.

Explanation: The demand savings represents the difference in peak demand between the baseline dehumidifier and the measure dehumidifier. In the retirement case, this represents the difference between the retiring unit and the baseline unit. In the replace on failure case, this represents the difference between the baseline unit and an ENERGY STAR unit.

Existing Source: The TRM calculates demand savings by multiplying annual energy savings by the demand factor for dehumidifiers reported in the Navigant Demand Impact Model.

New Source: Navigant Demand Impact Model.

Methodology: The evaluation team recommends continuing to use the impact factors in the Navigant Demand Impact Model, but updating the calculation with the revised energy savings values reported in Table 3-12.

Parameter: EUL.

Explanation: The team analyzed RES 1 data to determine the two-year equipment replacement rate, as outlined in Section 2.3.2. This gives Massachusetts- and program-specific values for EUL based on actual customer behavior.

New Source: RES 1 baseline survey.

Methodology: The team analyzed RES 1 data and found a 40% saturation of dehumidifiers. The proposed EUL value is informed by approximately 150 replacements per year (out of more than 2,500 respondents with dehumidifiers) over a 2-year period.

Table 3-13: Dehumidifiers Updates

Parameter Name	Existing Value	Proposed Value
Dehumidification Load (Liters/year)	n/a	1,520 Liters/year
Efficiency (Liters/kWh)	Retirement: 1.0 liters/kWh* Baseline: 1.5 liters/kWh* Measure: 2.0 liters/kWh	Retirement: 1.6 liters/kWh Baseline: 2.8 liters/kWh Measure: 3.3 liters/kWh
Energy Savings (kWh/year)	New Dehumidifier: 167.6 kWh Retirement: 152.7 kWh	New Dehumidifier: 82.3 kWh Retirement: 407.1 kWh
Demand Savings	New Dehumidifier: 0.04 kW Retirement: 0.04 kW	New Dehumidifier: 0.02 kW Retirement: 0.10 kW
EUL – Dehumidifier (years)	12	17

**Existing efficiency assumptions are not documented in the TRM. The team includes these values based on federal efficiency requirements included in DOE standards effective in 2007 and 2012. (For a specified 35 pints/day capacity dehumidifier)*

3.9 ECM Circulator Pump (RES-HVAC-ECMCP)

Parameter: Summer and Winter Coincidence Factors.
Explanation: The coincidence factors should rely on the most current data available, specific to the Massachusetts PAs.
Existing Source: Energy Resources Solutions 2005 Measure Life Study (cited in the hard copy TRM) and evaluation results (cited in the eTRM, presumably referring to the 2012 Cadmus ECM Circulator Pump Impact Evaluation). The team was unable to verify the existing coincidence factors in either source.
New Source: Demand Impact Model.
Methodology: The team recommends using the Demand Impact Model On-Peak Coincidence values for boiler distribution. While the summer coincidence factor value does not change, the source should be updated in the TRM to the Demand Impact Model (2018). See Table 3-13.

Table 3-14: Recommended ECM Circulator Pump CF Update

Parameter Name	Existing Value	Proposed Value
ECM Circulator Pump CF_{SP}	0.0	0.0
ECM Circulator Pump CF_{WP}	0.16	0.53

3.10 Furnace, Gas (RES-HVAC-FG)

Parameter: EUL.
Explanation: The team analyzed RES 1 data to determine the 2-year equipment replacement rate, as outlined in Section 2.3.2. This gives Massachusetts- and program-specific values for EUL based on actual customer behavior.
New Source: RES 1 baseline survey.

Methodology: The team analyzed RES 1 data and found a 24% saturation for natural gas furnaces. The proposed EUL value is informed by approximately 92 replacements per year (out of over 1,500 respondents with natural gas furnaces) over a 2-year period. Details are shown in Table 3-14.

Table 3-15: Gas Furnace Effective Useful Life

Parameter Name	Existing EUL (years)		Proposed EUL (years), not Weighted with Early Replacement RUL
	EUL	Rolled Up Measure	
EUL – Gas Furnace	18 years	15 years	17 years (not averaged with ER replacements)

Parameter: Natural Gas Furnace Baseline Efficiency, Early Retirement.
Explanation: The team analyzed RES 1 data and applied degradation factors to estimate typical performance of gas furnaces aged 10-20 years old.
Existing Source: Negotiated between PAs and EEAC.
New Source: RES 1 baseline survey.
Methodology: The Baseline Study data showed an average nameplate efficiency of 85.0% AFUE for a sample size of 22 respondents with furnaces aged 10-20 years. We estimated that age-related degradation would reduce the nameplate efficiency to 80.0% AFUE using the method described in section 2.3.1.**[15]** Then, we applied a factor of 1.012 to estimate actual in situ performance of 81.0% AFUE.[16] Details are shown in Table 3-15.

Table 3-16: Gas Furnace Early Retirement Baseline Efficiency

Parameter Name	Existing AFUE	Proposed AFUE
Baseline AFUE – Gas Furnace, ER	78.0% nameplate 78.9% actual	85.0% nameplate 81.0% actual

Parameter: Natural Gas Furnace Baseline Efficiency, Replace on Failure.
Explanation: The team analyzed distributor data from HARDI and customer survey data from TXC52 and RES 1 to estimate typical performance of new furnaces.
Existing Source: Negotiated between PAs and EEAC.
New Source: HARDI, TXC52 and RES 1.
Methodology: Customer survey data from the RES 1 Baseline Study showed an average of 90.4% AFUE for systems aged under ten years for customers that self-reported as program non-participants. However, the RES 1 data had a small sample size of n=17. Distributor data compiled from HARDI showed a shipment-weighted average of 89.4% AFUE for shipments that represent the ISP level, as described in section 2.2. Distributor survey data from TXC52 data showed a weighted average of 87.7% AFUE for ISP-level shipments. Based on these three data sources, the team determined that an ROF baseline nameplate efficiency of 89.0% AFUE is appropriate. We applied a factor of 1.012 to estimate actual *in situ* performance of 90.1% AFUE.[17] Details are shown in Table 3-16.

---

[15] The team assumed a typical replacement age of 12 years and applied a degradation factor of 0.005, which represents “professional annual maintenance”.

[16] This *in situ* performance factor is based on Table 18 of the 2015 HEHE Impact Study, which found that baseline furnaces typically outperform their nameplate rating.

[17] This *in situ* performance factor is based on Table 18 of the 2015 HEHE Impact Study, which found that baseline furnaces typically outperform their nameplate rating.

Table 3-17: Gas Furnace Replace on Failure Baseline Efficiency

Parameter Name	Existing AFUE	Proposed AFUE
Baseline AFUE – Gas Furnace, ROF	85.0%	89.0% nameplate 90.1% actual

3.11 Furnace, Oil/Propane (RES-HVAC-FOP)

Parameter: Propane Furnace Baseline Efficiency, Replace on Failure.
Explanation: Aligned with natural gas furnace efficiency values.
Existing Source: Negotiated between PAs and EEAC.
New Source: HARDI, TXC52 and RES 1.
Methodology: Due to similarities in furnace construction and overlaps in natural gas and propane furnace product lines, the team aligned assumptions of propane furnace efficiency with assumptions of natural gas furnace efficiency, described in section 3.10. Details are shown in Table 3-17.

Table 3-18: Propane Furnace Replace on Failure Baseline Efficiency

Parameter Name	Existing AFUE	Proposed AFUE
Baseline AFUE – Propane Furnace, ROF	85.0%	89.0% nameplate 90.1% actual

3.12 Heat Recovery Ventilator (RES-HVAC-HRV)

Parameter: Unit MMBtu and Demand Savings.
Explanation: Heat Recovery Ventilators (HRVs) can help make mechanical ventilation more cost-effective by reclaiming energy from exhaust airflows.
Existing Source: Natural Gas Energy Efficiency Potential in Massachusetts, GDS Associates, 2009.
New Source: New engineering calculation.
Methodology: The existing source is based on older research. The specific calculation, inputs, baseline details, and assumptions were not included in the report and were not available for review. The team conducted a literature review of other state TRMs, state and national energy code analysis, and other publicly available published studies to determine if more recent energy savings values were available. The literature review did not identify a newer or more robust source for HRV energy savings, so the team created an engineering calculation to estimate savings, provided in conjunction with this report, based on available information. Future work to improve the savings estimation could include energy modeling or a metered study. Appendix A includes the literature review summary and a methodology supporting the recommended updates in Table 3-18.

Table 3-19: Heat Recovery Ventilator Updates

Parameter Name	Existing Value	Proposed Value
HRV Gas Savings (MMBtu)	7.7	8.6
HRV Electricity Savings (kWh)	-133	-171
HRV Demand Savings (kW)	-0.10	-0.02
ERV Gas Savings (MMBtu)	No existing value	8.8
ERV Electricity Savings (kWh)	No existing value	-127
ERV Demand Savings (kW)	No existing value	-0.014

3.13 Insulation (RES-BS-I)

Parameter: Heating Degree-Days and Cooling Degree-Hours.

Explanation: Heating degree-days and cooling degree-hours (HDD and CDH, respectively) are used across most residential envelope measures in the TRM. These values are not inherent to the individual measures but rather to the climate of a geographic region. Weather patterns are trending warmer, with the potential to impact heating and cooling loads, particularly when those loads were previously marginal or took place during shoulder seasons. Updating these could improve the accuracy of multiple measures, including air sealing and insulation.

Existing Source: Typical meteorological year (TMY3) data from the period 1991-2005.[18]

New Source: National Oceanic and Atmospheric Administration (NOAA) climate data.

Methodology: The MA TRM lists HDD and CDH values for 15 different locations, and the team has updated the HDD and CDH values for each location using Local Climatological Data from NOAA from 2005-2019.[19] This data differs from TMY3 data in that it calculates the median HDD and CDH values for the most recent 15 consecutive years of weather data. Conversely, TMY3 data builds up a typical weather year out of the months of different calendar years. With impacts of climate change increasing in severity each year, the team determined that the median of the most recent 15 years would most accurately reflect the impact of climate change within the dataset. The team calculated HDD and CDH using a 60°F base temperature for heating and a 75°F base temperature for cooling—values consistent with the TRM's current assumptions. See Appendix B for a detailed discussion of the data analysis.

As Table 3-19 shows, the proposed HDD values are generally lower than the existing HDD values (an average of 1% decrease in HDD) and the proposed CDH values are higher than the existing CDH values (an average of 31% increase in CDH).

Table 3-20: Recommended Heating Degree Day (HDD) and Cooling Degree Hour (CDH) Updates

Weather Station	Existing HDD	Proposed HDD	Difference (%)	Existing CDH	Proposed CDH	Difference (%)
Barnstable Muni Boa	4,379	4,299	–2%	1,349	2,278	+69%
Beverly Muni	5,329	4,856	–9%	3,432	4,205	+23%
Boston Logan Int'l Arpt	4,550	4,299	–6%	4,329	5,382	+24%
Chicopee Falls Westo	5,016	4,940	-2%	4,116	5,577	+35%
Lawrence Muni	4,640	4,815	+4%	3,978	6,041	+52%
Martha's Vineyard	4,312	4,385	+2%	1,345	2,080	+55%
Nantucket Memorial AP	3,988	4,250	+7%	362	518	+43%
New Bedford Rgnl.	4,434	4,604	+4%	4,232	3,938	-7%

---

[18] TMY3 data was extracted and processed by a third party as a part of the 2015 High Efficiency Heating Equipment Impact Evaluation.

[19] NOAA Local Climatological Data is available at: https://www.ncdc.noaa.gov/data-access/land-based-station-data/land-based-datasets/quality-controlled-local-climatological-data-qclcd. Ten of the 15 stations did not have data available for 2005, and therefore derived results from the most recent 14 years of data.

Weather Station	Existing HDD	Proposed HDD	Difference (%)	Existing CDH	Proposed CDH	Difference (%)
North Adams	5,234	5,724	+9%	2,524	3,318	+31%
Norwood Memorial	4,872	4,777	–2%	4,763	6,069	+27%
Otis ANGBb	4,718	4,614	–2%	2,588	2,011	–22%
Plymouth Municipal	4,559	4,600	+1%	2,138	4,087	+91%
Provincetown (AWOS)	4,368	4,268	–2%	2,195	1,616	–26%
Westfield Barnes Muni AP	5,301	5,185	–2%	3,784	6,003	+59%
Worchester Regional Arpt	5,816	5,465	–6%	1,753	2,928	+67%
Average	**4,768**	**4,739**	**–1%**	**2,859**	**3,737**	**+31%**

3.14 Low-Flow Showerhead (RES-WH-S)

Parameter: EUL.
Explanation: The team analyzed RES 1 data to determine the two-year equipment replacement rate, as outlined in Section 2.3.2. This gives Massachusetts- and program-specific values for EUL based on actual customer behavior.
Existing Source: Massachusetts common assumptions.
New Source: RES 1 baseline survey.
Methodology: The team found a near 100% saturation for showerheads. The proposed EUL value is informed by over 400 replacements (out of nearly 6,500 respondents with showerheads) over a 2-year period. Details are shown in Table 3-20. Although the recommended value is more than double the existing TRM value, the previous value was informed by Massachusetts Common Assumptions, while the new value is based on nearly 100% saturation, a stable replacement rate, and Massachusetts-specific data collection.

Table 3-21: Low Flow Showerhead Effective Useful Life

Parameter Name	Existing EUL (Years)	Proposed EUL (Years)
EUL – Low-Flow Showerhead	7	15

3.15 Low-Flow Showerhead with Thermostatic Valve (RES-WH-STV)

Parameter: EUL.
Explanation: The lifetime for the Showerhead with TSV should be consistent with our recommendation for the Low-Flow Showerhead measure.
Existing Source: Massachusetts common assumptions.
New Source: RES 1 baseline survey.
Methodology: See the EUL discussion in Section 3.14. The RES 1 surveys ask about showerhead replacements in general and do not distinguish whether a thermostatic valve was included in the showerhead replacement. However, Uniform Plumbing Code (UPC) certification under IAPMO

standard IGC 244-2007a stipulates that TSV devices must meet 10,000 cycles without failure. Assuming 1.6 showers per day,[20] a TSV rated to 10,000 cycles would exceed the showerhead lifetime of 15 years. Table 3-20 shows a recommended EUL of 15 years for showerheads with TSVs.

Table 3-22: Low Flow Showerhead with TSV Effective Useful Life

Parameter Name	Existing EUL (Years)	Proposed EUL (Years)
EUL – Low-Flow Showerhead w/ TSV	7	15

Parameter: Unit Energy Savings and Demand Savings.
Explanation: This measure combines the energy savings values from the Low-Flow Showerhead measure with the adjusted energy savings values from the Thermostatic Valve measure, accounting for differences in baseline flow rates.
Existing Source: 2014 National Grid Review of ShowerStart evolve, which also calculates savings for the Thermostatic Valve-only measure.
New Source: 2018 Home Energy Services Impact Evaluation savings data.
Methodology: The current calculation uses different, much higher savings data for the Low-Flow Showerhead portion of the savings than the TRM’s current Low-Flow Showerhead measure. The current Low-Flow Showerhead measure relies on more current metered study data for savings values, using the 2018 Home Energy Services Impact Evaluation savings data. These savings values are not currently factored into the combination measure. The updated combined savings calculation uses these recent metered savings as the basis for the Low-Flow Showerhead portion of the savings. To accurately add the thermostatic valve savings, some adjustments were needed to the original calculation. The Thermostatic Valve-only measure calculates savings using a 2.5 gpm showerhead. The updated calculation assumes the same flow rate, 1.7 gpm, as the 2018 Home Energy Services Impact Evaluation. This adjustment results in lower thermostatic valve savings when added to a low-flow showerhead. The updated savings calculations accompany this memo in a databook built on the current two measures.

Table 3-23: Low-Flow Showerhead with Thermostatic Valve Savings Values

Parameter Name	Existing Savings Value	Proposed Savings Value
Electric (Single Family)	372 kWh	247 kWh
Electric (Single Family)	0.08 kW	0.06 kW
Gas (Single Family)	1.84 MMBtu	1.22 MMBtu
Oil (Single Family)	2.09 MMBtu	1.32 MMBtu
Other (Single Family)	1.84 MMBtu	1.22 MMBtu
Electric (Multifamily)	335 kWh	183 kWh
Electric (Multifamily)	0.09 kW	0.04 kW
Gas (Multifamily)	1.66 MMBtu	1.41 MMBtu
Oil (Multifamily)	1.88 MMBtu	1.44 MMBtu
Other (Multifamily)	1.66 MMBtu	1.41 MMBtu

---

[20] Biermayer, Peter J. Potential Water and Energy Savings from Showerheads. Lawrence Berkeley National Laboratory. 2006.

3.16 Pool Pump (RES-MAD-PP)

The pool pumps measured in the TRM does not provide algorithms for the calculation of energy savings. Instead, it refers to a spreadsheet-based calculator published by the ENERGY STAR program in 2013. The TRM states that savings are based on a set of six scenarios calculated using the ENERGY STAR calculator. The evaluation team was not able to recreate the TRM's savings values using the scenario inputs specified in the TRM. Rather than calculating and averaging multiple scenarios, the evaluation team recommends calculating savings based on a single baseline condition and two efficient conditions (one for two-speed pumps and one for variable-speed pumps). The team recommends revising several key inputs to the savings calculation and specifying new savings values calculated with these revised inputs. The team also recommends calculating savings with the following simple equations rather than relying on a separate calculator tool.[21]

$$\Delta kWh = UEC_{baseline} - UEC_{efficient}$$

$$UEC = \frac{days}{1000} * \left[\left(\frac{Q_{high} * 60}{EF_{high}}\right) * hours_{high} + \left(\frac{Q_{low} * 60}{EF_{low}}\right) * hours_{low}\right]$$

Where:
$UEC_{baseline}$ = Unit Energy Consumption per year for the baseline condition (kWh)
$UEC_{efficient}$ = Unit Energy Consumption per year for the efficient condition (kWh)
UEC = Unit Energy Consumption per year (kWh)
days = Annual days of operation, 122 days
Q_{high} = Flow rate at high speed, in gallons per minute (gpm)
EF_{high} = Energy factor at high speed, in gallons/Watt-hour
$hours_{high}$ = Daily operating hours at high speed
Q_{low} = Flow rate at low speed, in gallons per minute (gpm)
EF_{low} = Energy factor at low speed, in gallons/Watt-hour
$hours_{low}$ = Daily operating hours at low speed
60 = 60 minutes per hour
1,000 = 1,000 Watt-hours per kWh

Parameter: Operating days per year.
Explanation: The annual operating days of the pool pump. The annual operating days directly affect the energy consumption calculations. The current TRM assumption is 91 operating days (i.e., 3 months) per year.
Existing Source: Uncited.
New Source: Department of Energy (DOE) Technical Support Document.
Methodology: The ENERGY STAR calculator and the technical support document for DOE's 2017 pool pumps rulemaking categorize Massachusetts in the cool climate zone. Both sources assume that states in the cool climate zone see annual pool operation of 4 months (122 days) per year. See DOE (2017) Direct Final Rule Technical Support Document, Table 7.3.11. The evaluation team recommends revising the operating days to 122 days.

Parameter: Pool size.
Explanation: The pool size describes the volume of water in the pool. Coupled with the flow rate and the number of turnovers per day, the pool size determines the daily operating hours for pool pumps.
Existing Source: Uncited.
New Source: DOE Technical Support Document.

---

[21] These equations are based on the energy consumption calculations described in DOE (2017) Direct Final Rule Technical Support Document, Section 7.3. Available at: https://www.regulations.gov/document?D=EERE-2015-BT-STD-0008-0105

Methodology: The team recommends using a single pool size value of 22,000 gallons. This is the average pool size used by the Consortium for Energy Efficiency[22] and the DOE (2017) Direct Final Rule Technical Support Document, Table 7.3.3.

Parameter: Flow rate.
Explanation: The flow rate describes the volume of water moved by the pump over time. Coupled with the pool size and the number of turnovers per day, the flow rate determines the daily operating hours for pool pumps.
Existing Source: The TRM states flow rates of 64 gpm for baseline single-speed pumps, 66 gpm for efficient two-speed pumps, and 50 gpm for efficient variable-speed pumps. The source of these values is not cited, but the evaluation team notes that these flow rates align with the default assumptions in the ENERGY STAR calculator for pumps operating on Curve A (representing plumbing with a 2" pipe diameter).
New Source: DOE Technical Support Document.
Methodology: During the 2017 DOE rulemaking for pool pumps, DOE assessed the market for pool pumps and compiled flow rate information for currently available pumps. Through discussions with pool pump manufacturers and energy efficiency advocates, DOE learned that pump Curve C (representing plumbing with a 2.5" diameter) is representative of most in-ground pool installations. The DOE test procedure and standards for pool pumps are based on measurements taken on pump Curve C. The team recommends updating the flow rate values to represent pump performance on Curve C, using the following flow rates reported in DOE (2017) Direct Final Rule Technical Support Document, Table 5.8.1:[23]

- For baseline single-speed pumps: 71 gpm
- For efficient two-speed pumps: 71 gpm at high speed and 36 gpm at low speed
- For efficient variable-speed pumps: 57 gpm at high speed and 23 gpm at low speed

Parameter: Turnovers per day.
Explanation: Describes the number of times that the pool's contents are circulated through the filtration equipment in a 24-hour period. Coupled with the pool size and pump flow rate, the number of turnovers per day determines the daily operating hours for pool pumps. The TRM currently assumes 1.5 turnovers per day.
Existing Source: Uncited.
New Source: DOE Technical Support Document.
Methodology: In the course of DOE's 2017 rulemaking on pool pumps, DOE discussed turnover rates with a working group of pool pump manufacturers and efficiency advocates. DOE determined that in a cold climate zone such as Massachusetts, most pools operate with 1 or 2 turnovers per day. See DOE (2017) Direct Final Rule Technical Support Document, Table 7.3.9. Based on DOE's observations, the evaluation team recommends maintaining the current assumption of 1.5 turnovers per day.

Parameter: Daily operating hours.
Explanation: The daily operating hours of a pool pump describe the amount of time that pumps must run to maintain water clarity. The operating hours are a function of the flow rate, the pool size, and the number of turnovers per day. Two-speed and variable-speed pumps can achieve water filtration at low pump speeds, with intermittent high-speed operation to churn the pool water. As such, separate values are reported for high speed operating hours and low-speed operating hours. The TRM states operating hours of 8.5 hours/day for baseline single-speed pumps, 2

---

[22] CEE (2013) "CEESM High Efficiency Residential Swimming Pool Initiative." p.33 https://library.cee1.org/system/files/library/9986/CEE_Res_SwimmingPoolInitiative_01Jan2013_Corrected.pdf

[23] The team recommends using flow rate values reported for efficiency level 1 (EL1) as the baseline condition, EL3 as the two-speed efficient condition, and EL6 as the variable-speed efficient condition.

hours/day at high-speed and 12.5 hours/day at low-speed for two-speed pumps, and 2 hours/day at high-speed and 18 hours/day at low-speed for variable-speed pumps.

Existing Source: Uncited.

New Source: DOE Technical Support Document.

Methodology: DOE's 2017 analysis of pool pump energy consumption calculated daily operating hours as a function of pool volume, pump flow rate, and turnovers per day, using the following equation:

$$\boldsymbol{PPOH = \frac{V * N_{turns}}{Q * 60}}$$

Where:
PPOH = daily pool pump operating hours
V = pool volume in gallons
N_{turns} = number of turnovers per day
Q = pump flow rate

Based on input from pool pump manufacturers and efficiency advocates, DOE assumed that two-speed and variable-speed pumps spend no more than two hours operating at high speed and the remainder of operating hours at low speed. The operating hours for single-speed pumps are calculated with the equation above at the high-speed flow rate. For two-speed and variable-speed pumps, the low-speed operating hours are calculated with the equation above at the low-speed flow rate, less two hours to account for time spent in high-speed operation.

Parameter: Energy factor (EF)

Explanation: The EF describes the efficiency at which a pump moves water, in terms of gallons per Watt-hour. Due to pump affinity laws, two-speed and variable-speed pumps exhibit higher efficiency when operating at low speeds. The TRM states separate efficiency values for baseline single-speed pumps and for the high- and low-speed operating states of efficient two-speed and variable-speed pumps.

Existing Source: Uncited, but aligns with the default assumptions in the ENERGY STAR calculator for pumps operating on Curve A (representing plumbing with a 2" pipe diameter).

New Source: DOE Technical Support Document.

Methodology: During the 2017 DOE rulemaking for pool pumps, DOE assessed the market for pool pumps and compiled efficiency information for currently available pumps. The team recommends updating the efficiency values to represent pump performance on Curve C, using the following values reported in DOE (2017) Direct Final Rule Technical Support Document, Table 5.8.1.[24]

- For baseline single-speed pumps: 2.0 EF
- For efficient two-speed pumps: 2.0 EF at high speed and 5.3 EF at low speed
- For efficient variable-speed pumps: 2.9 EF at high speed and 10.5 EF at low speed

Parameter: Energy savings.

Explanation: The energy savings represents the difference in energy consumption between the baseline single-speed pump and the efficient pump.

Existing Source: 2013 ENERGY STAR pool pumps calculator.

New Source: DOE Technical Support Document's savings calculation.

Methodology: While the evaluation team agrees with the methods used in the ENERGY STAR calculator, we recommend simplifying the analysis using the savings equations presented above. The application of these equations with the revised input values presented in Table 3-23 yields the revised savings values presented in Table 3-23. For reference, the calculated annual energy consumption is 2,001 kWh/year for baseline single-speed pumps, 1,166 kWh/year for efficient two-speed pumps, and 641 kWh/year for efficient variable-speed pumps.

---

[24] The team recommends using efficiency values reported for efficiency level 1 (EL1) as the baseline condition, EL3 as the two-speed efficient condition, and EL6 as the variable-speed efficient condition.

Parameter: Demand savings.
Explanation: The demand savings represents the difference in peak demand between the baseline single-speed pump and the efficient pump.
Existing Source: Navigant Demand Impact Model.
New Source: Navigant Demand Impact Model using updated inputs.
Methodology: The evaluation team recommends continuing to use the impact factors in the Navigant Demand Impact Model, but updating the calculation with the revised energy savings values reported in Table 3-23.

Parameter: EUL.
Explanation: The team analyzed RES 1 data to determine the 2-year equipment replacement rate, as outlined in Section 2. This gives Massachusetts- and program-specific values for EUL based on actual customer behavior.
New Source: RES 1 baseline survey.
Methodology: The team analyzed RES 1 data and found a 7% saturation for pool pumps. The proposed EUL value is informed by approximately 83 replacements (out of nearly 500 respondents with pool pumps) over a 2-year period. Details are shown in Table 3-23.

Table 3-24: Pool Pump Updates

Parameter Name	Existing Value	Proposed Value
Operating days per year	91 days/year	122 days/year
Pool size (gallons)	20,000 to 23,000	22,000
Flow rates (gallons per minute)	Baseline: 64 Two-speed: 66 high, 33 low Variable Speed (VS): 50 high, unspecified low	Baseline: 97 Two-speed: 97 high, 48 low VS: 77 high, 31 low
Turnovers per day	1.5 turnovers	1.5 turnovers
Daily Operating Hours	Baseline: 8.5 Two-speed: 2 high, 12.5 low VS: 2 high, 18 low	Baseline: 5.7 Two-speed: 2 high, 9.5 low VS: 2 high, 15.7 low
EF	Baseline: 2.1 EF Two-speed: 2.0 high, 5.2 low VS: 4.0 high, 8.8 low	Baseline: 2.0 EF Two-speed: 1.9 high, 5.3 low VS: 2.9 high, 10.5 low
Energy Savings (kWh)	Two-speed: 842 VS: 1,062	Two-speed: 639 VS: 1,284
Demand Savings (kW)	Two-speed: 0.87 VS: 1.12	Two-speed: 0.67 VS: 1.35
EUL – Pool Pump (years)	10	6

3.17 Programmable Thermostat (RES-HVAC-PT)

Parameter: EUL.
Explanation: The team analyzed RES 1 data to determine the 2-year equipment replacement rate, as outlined in Section 2. This gives Massachusetts- and program-specific values for EUL based on actual customer behavior.
New Source: RES 1 baseline survey.

Methodology: The team analyzed RES 1 data and found an 86% saturation for programmable thermostats. The proposed EUL value is informed by approximately 290 replacements (out of over 5,500 respondents with programmable thermostats) over a 2-year period. Details are shown in Table 3-24.

Table 3-25: Programmable Thermostat Effective Useful Life

Parameter Name	Existing	Proposed
EUL – Programmable Thermostat (years)	15	19

3.18 Quality Installation (QI) with Duct Modification (RES-HVAC-QIDM)

Parameters: Energy savings, demand savings.
Explanation: The savings values in the MA TRM do not match the values in the cited source *Market Research for the Rhode Island, Massachusetts, and Connecticut Residential HVAC Market*.
Existing Source: RLW Analytics (2002).[25]
New Source: RES 1 baseline survey.
Methodology: Neither the leakage reduction assumption nor the total savings values in the current MA TRM match the cited source, RLW (2002). The MA TRM assumes the leakage reduction is from 20% to 10% and saves 513 kWh, while the RLW report modeled energy and peak demand savings with a reduction in leakage assumption from 25% to 5% and savings of 212 kWh. The 212 kWh savings value represents a 15% savings in the predicted annual cooling energy for the average household (1,450 kWh) (RLW).

The team recommends applying a 15% savings factor to the annual cooling energy consumption for an average home with a CAC, which is 1,530 kWh according to Navigant (2018).[26] Recommended peak demand savings were calculated by dividing the electric energy savings by the cooling equivalent full load hours (EFLH) of 419 hours and multiplying by the on-peak coincidence factor of 0.346 (Navigant, 2018).[27] It is also recommended that the MA TRM update the leakage reduction assumption to align with the RLW Analytics assumption of 25% to 5%.

Table 3-26: Quality Installation (QI) with Duct Modification Parameter Updates

Parameter Name	Existing	Proposed
Electric Energy Savings (kWh)	513	230
Electric Demand Savings (kW)	0.85	0.18

3.19 Room Air Cleaner (RES-PL-RAC)

Parameters: Baseline Efficiency, High Efficiency, and Energy Savings.
Explanation: The room air cleaner energy savings should reflect the diversity of the models on the market.
Existing Source: Non-existent federal standard.
New Source: ENERGY STAR v1 Calculator baseline assumption.
Methodology: Previously, the baseline efficiency case cited a federal standard; however, there is no federal standard in place for air purifiers. The high efficiency case described an ENERGY STAR

---

[25] RLW Analytics (2002). **“**Market Research for the Rhode Island, Massachusetts, and Connecticut Residential HVAC Market.”

[26] Navigant (2018). “RES 1 Baseline Load Shape Study.”

[27] Navigant (2018). “Demand Impact Model.”

v1 qualified air cleaner with a clean air delivery rate (CADR) of 51-100. The energy savings were calculated using the 2018 EPA Savings Calculator for ENERGY STAR Qualified Appliances and only a single capacity (CADR) value of 100 was used.

The baseline and high efficiency capacity of room air cleaners are measured in CADR/Watt (Dust), as described by ENERGY STAR v1, and the savings calculator is used to convert these values to kWh. The conventional efficiency used in the calculator is 1.0 CADR/Watt (Dust), which seems to be the value used in 2020 Illinois TRM and is applicable in this case. The TRM currently uses 3.0 CADR/Watt (Dust) as the high efficiency value which is higher than the ENERGY STAR requirement of 2.0 CADR/Watt (Dust). However, the ENERGY STAR average CADR/Watt (Dust) of models available in their US market database (approximately 170 models) is approximately 3.5 CADR/Watt (Dust). Hence, 3.0 CADR/Watt (Dust) seems reasonable and is recommended in Table 3-26. Note that the ENERGY STAR specification for room air cleaners is currently under revision and is expected to come into effect in July 2020. To calculate savings, the TRM previously used a fixed 100 CADR for the units, which results in a savings of 391 kWh. The team recommends using the midpoint of 51-100 (75) which results in savings of 293 kWh. Furthermore, the team recommends using different CADR ranges and selecting the midpoint of the range, instead of using a single range of 51-100. Table 3-27 provides recommended savings values for different room air cleaner capacity ranges.

Table 3-27: Room Air Cleaner Baseline and High Efficiency

Parameter Name	Existing Value (CADR/Watt$_{Dust}$)	Proposed Value (CADR/Watt$_{Dust}$)
Room Air Cleaner, Baseline Efficiency	1.0	1.0
Room Air Cleaner, High Efficiency	3.0	3.0

Table 3-28: Room Air Cleaner Savings

CADR Range	CADR Value in Calculator	Baseline Consumption (kWh)	High Efficiency Consumption (kWh)	Energy Savings (kWh)
51-100	75	441	148	293
101-150	125	733	245	488
151-200	175	1,025	342	683
201-250	225	1,317	440	877
Over 250	300	1,755	586	1,169

Parameter: EUL.
Explanation: The EUL for room air cleaners is currently 9 years in the MA TRM. Data from the RES 1 Baseline Study (26 replacements among 1,233 customers) suggests an EUL of 47 years. This value appears to be heavily influenced by changes in market saturation, and as such, Guidehouse does not recommend changing the existing EUL value.

3.20 Room Air Conditioner (RES-PL-ROOMAC)

Parameter: EUL.
Explanation: The team analyzed RES 1 data to determine the two-year equipment replacement rate, as outlined in Section 2.3.2. This gives Massachusetts- and program-specific values for EUL based on actual customer behavior.

New Source: RES 1 baseline survey.

Methodology: The team analyzed RES 1 data and found a 57% saturation for room A/Cs. The proposed EUL value is informed by approximately 296 replacements (out of over 3,600 respondents with room A/Cs) over a 2-year period. Details are shown in Table 3-28.

Table 3-29: Room Air Conditioner Effective Useful Life

Parameter Name	Existing	Proposed
EUL – Room Air Conditioner (years)	8	12

3.21 Standalone Water Heater (RES-WH-SASWH)

Parameter: Baseline/Existing UEF, Early Retirement.

Explanation: Early retirement water heater efficiencies should reflect the actual units that customers are replacing, rather than a code-mandated value. Until 2017, water heater efficiencies were described by the EF metric. In 2017, the US DOE revised the water heater test procedure to use an efficiency metric called uniform energy factor (UEF). While the EF and UEF metrics cannot be directly compared, we compare them here using a calculator that estimates UEF ratings based on EF ratings.

Existing Source: Previously, the early retirement $UEF_{exist,ER}$ value was from an undocumented source.

New Source: RES 1 baseline survey.

Methodology: The team compiled a list of existing EF values for RES 1 households that had installed standalone gas water heaters since 2010. After applying an equipment degradation factor,[28] the group (n=70) had a mean EF of 0.58. This suggests that the older storage water heaters that are likely to be replaced by this measure (and still within the official measure lifetime of 10 years) should have an average EF of 0.58. This is higher than the value listed in the current TRM[29], but is consistent with the team's expectation that average installed baseline efficiencies should trend upward over time. The team then used two existing calculators[30] to convert EF to UEF, using the established MA portfolio weighting between medium-draw and high-draw units. See Table 3-29 for details.

Table 3-30: Standalone Water Heater Early Retirement Baseline Efficiency

Parameter Name	Existing Value ($UEF_{exist,ER}$)	Proposed Value ($UEF_{exist,ER}$)
UEF_{exist} – Early Retirement	Medium Draw: 0.52 High Draw: 0.58 Blended: 0.55	Medium Draw: 0.56 High Draw: 0.60 Blended: 0.58

Parameter: Water Heater Baseline Efficiency, Replace on Failure.

Explanation: The baseline water heater efficiency should represent the typical efficiency of standalone gas water heaters recently installed by customers in the absence of the program, as long as the determined value is not superseded by the relevant code or federal standard.

Existing Source: Uncited.

New Source: Federal standard.

---

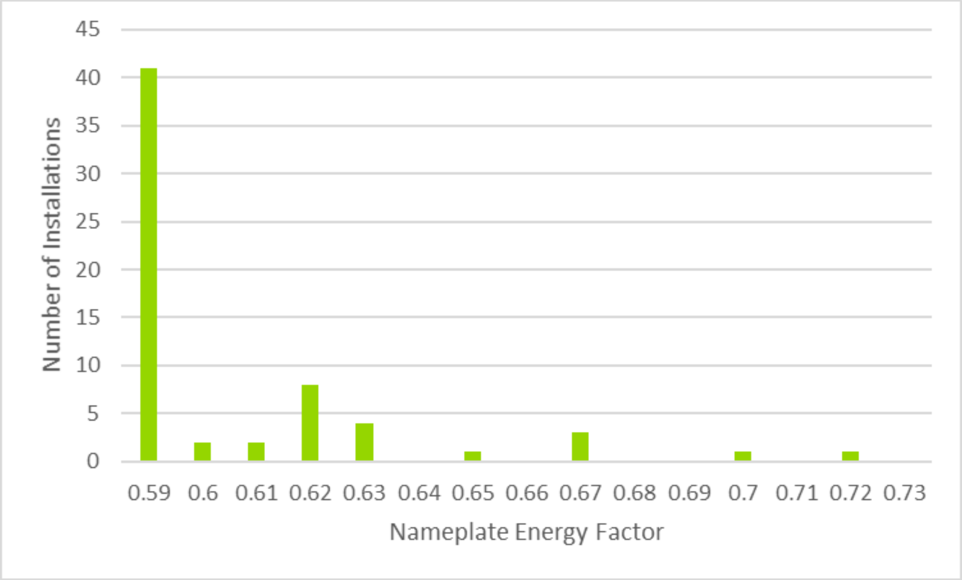
[28] The team applied a degradation factor of 0.005, which represents "professional annual maintenance".

[29] The program's prescribed early retirement baseline efficiency value of 0.55 UEF represents a blend of medium-draw products at 0.52 UEF and high-draw products at 0.58 UEF.

[30] RES19_Task7_WaterHeater_Characterization_v10.xlsx was used to convert from EF to UEF, and Water Heater UEF screening_2019-21_revised 2018.09.06.xlsx was used to weight by portfolio percentages of medium-draw vs. high-draw water heaters.

Methodology: The team analyzed the efficiencies of all standalone natural gas water heaters installed by RES 1 survey respondents and the subset of RES 1 respondents who were program nonparticipants and had installed a standalone gas water heater since 2010. Most of the sampled program nonparticipants installed units with an EF of 0.59; see Figure 3-1.

Figure 3-1: Installed Standalone Gas Water Heater EF (Non-Participants since 2010)



The mean EF for all nonparticipants who installed gas water heaters since 2010 (n=64), is 0.604. Federal standards for water heaters vary with the water heater's rated storage volume and draw pattern. The federal minimum standard is 0.58 UEF for a 40-gallon medium-draw water heater and 0.63 UEF for a 50-gallon high-draw water heater.[31] These values are consistent with the replace-on-failure efficiency values currently used by the program. The program's prescribed ROF baseline efficiency value of 0.60 UEF represents a blend of medium- and high-draw products. The team recommends no changes to these baseline values, as seen in Table 3-30.

Table 3-31: Standalone Gas Water Heater Replace on Failure Baseline Efficiency

Parameter Name	Existing UEF	Proposed UEF
Baseline EF – Replace on failure	Medium Draw: 0.58 High Draw: 0.63 Blended: 0.60	Medium Draw: 0.58 High Draw: 0.63 Blended: 0.60

Parameter: EUL.

Explanation: The team analyzed RES 1 data to determine the two-year equipment replacement rate, as outlined in Section 2.3.2. This gives Massachusetts- and program-specific values for EUL based on actual customer behavior.

New Source: RES 1 baseline survey.

Methodology: The team analyzed RES 1 data and found a 40% saturation for natural gas domestic hot water heaters. The team estimated an EUL of 10 years for standalone gas water heaters, based on observations of approximately 257 replacements per year (out of over 2,589 respondents with natural gas water heaters) over a 2-year period. Details are shown in Table 3-31.

---

[31] 10 CFR 430.32(d)

Table 3-32: Standalone Water Heater Effective Useful Life

Parameter Name	Existing		Proposed EUL
	EUL	Rolled Up Measure Life	
EUL – Standalone Water heater	13	10.2	10

3.22 Thermostatic Valve (RES-WH-TV)

Parameter: EUL.
Explanation: The lifetime for TSVs should be consistent with our recommendation for the Low-Flow Showerhead with TSV measure.
Existing Source: Massachusetts common assumptions.
New Source: RES 1 baseline survey.
Methodology: See the EUL discussion in Section 3.14. The RES 1 surveys ask about showerhead replacements in general and do not distinguish whether a thermostatic valve was included in the showerhead replacement. However, Uniform Plumbing Code (UPC) certification under IAPMO standard IGC 244-2007a stipulates that TSV devices must meet 10,000 cycles without failure. Assuming 1.6 showers per day,[32] a TSV rated to 10,000 cycles would exceed the showerhead lifetime of 15 years. Table 3-32 shows a recommended EUL of 15 years for TSVs.

Table 3-33: Thermostatic Valve Effective Useful Life

Parameter Name	Existing EUL (Years)	Proposed EUL (Years)
EUL –TSV	7	15

3.23 Variable Frequency Drive (RES-MAD-VFD)

Parameters: Energy Savings (kWh/HP), Summer Demand Savings (kW/HP_{SP}), Winter Demand Savings (kW/HP_{WP}).
Explanation: The demand savings values in the TRM did not match the values in the cited source, Cadmus (2014) *Variable Speed Drive Loadshape Project*. The energy savings values in the TRM match a different cited source, Chan (2010) *Formulation of a Prescriptive Incentive for the VFD and Motors & VFD impact tables at NSTAR,* but the source is 10 years old.
Existing Source: Energy savings are cited to Chan (2010)[33] and demand savings are cited to Cadmus (2014).[34]
New Source: Cadmus (2014).
Methodology: The team recommends using demand savings and energy savings values from the same source, Cadmus (2014), to be consistent and use the most up-to-date source. Table 3-33 summarizes the existing values in the MA TRM and the recommended values from Cadmus (2014).

---

[32] Biermayer, Peter J. Potential Water and Energy Savings from Showerheads. Lawrence Berkeley National Laboratory. 2006.
[33] Tumin Chan (2010). "Formulation of a Prescriptive Incentive for the VFD and Motors & VFD impact tables at NSTAR."
[34] Cadmus (2014). "Variable Speed Drive Loadshape Project."

Table 3-34: Variable Frequency Drive Savings Values

Parameter	Pump Type	Existing Value	Proposed Value
Energy Savings (kWh/HP)	Chilled Water Pump	1,374	1,633
	Hot Water Circulating Pump	2,400	1,548
	Return Fan	1,374	1,788
	Supply Fan	1,319	2,033
	WSHP Circulating Loop	3,713	2,562
Summer Demand Savings (kW/HP_{SP})	Chilled Water Pump	0.174	0.183
	Hot Water Circulating Pump	0.091	0.096
	Return Fan	0.287	0.302
	Supply Fan	0.274	0.288
	WSHP Circulating Loop	0.218	0.229
Winter Demand Savings (kW/HP_{WP})	Chilled Water Pump	0.184	0.194
	Hot Water Circulating Pump	0.21	0.221
	Return Fan	0.26	0.274
	Supply Fan	0.252	0.265
	WSHP Circulating Loop	0.282	0.297

4. OTHER PARAMETERS WHERE NO UPDATE IS RECOMMENDED

This section describes measures and parameters that the team considered but for which the team does not recommend updated values. The following descriptions for each measure and parameter describe the team's reasoning for not updating the existing values.

4.1 Air Source Central Heat Pump and Air Conditioning Savings Parameters

The team identified three measures for which energy efficient performance ratings ($SEER_{EE}$) are based on program participant rebate data. The updates to $SEER_{EE}$ parameter values are handled by the PAs independently of this review, so this TRM review did not consider updates to $SEER_{EE}$ values for the following measures:

- Air Source Central Heat Pumps (RES-HVAC-ASHP)
- Central AC (RES-HVAC-CAC)
- DMSHPs (RES-HVAC-DMHP)

4.2 Fuel Switching/Energy Optimization Measures

The team identified four measures that involved fuel switching and would benefit from more recent savings values derived in the Energy Optimization Model Update (MA19R16-B-EO) that concluded in March 2020. However, the PAs and the evaluation team are conducting another energy optimization study that may result in further updates to energy optimization measures. This TRM review did not include updates to energy savings values for the following measures:

- Central Ducted Heat Pump Fully Displacing Existing Furnace (RES-HVAC-FSHP)
- Central Ducted Heat Pump Partially Displacing Existing Furnace, Oil (RES-HVAC-FSHP-P)
- Ductless Mini-Split Heat Pump with Integrated Controls – Fully Displacing Existing Boiler (RES-HVAC-DMSHP)
- Ductless Mini-Split Heat Pump with Integrated Controls – Partially Displacing Existing Boiler (RES-HVAC-FS-DMSHP-P)

4.3 DMSHP and DMSHP Quality Installation Verification

Our team examined the assumptions for equipment runtime for the DMSHP and DMSHP Quality Installation Verification measures. We compared the EFLH values in the TRM with EFLH values derived in the RES 1 Baseline Study. The TRM currently uses an EFLH of 218 hours, based on the Cadmus Group's *Ductless Mini-Split Heat Pump Impact Evaluation* (2016). The RES 1 Baseline Study estimates a higher EFLH of 417 hours for ductless mini-splits. However, the sample of ductless mini-splits in the Baseline Study is much smaller than the sample in Cadmus (2016), so our team does not recommend updating this value in the TRM. We recommend that the PAs study these EFLH values further by oversampling homes with DMSHPs in future iterations of the Baseline Study.

4.4 Refrigerator and Freezer Recycling Measures

Our team examined the assumptions for electricity savings and baseline efficiency used in the Refrigerator/Freezer Recycling measure (RES-A-RFR). The RES 1 Baseline Study measures energy consumptions of secondary refrigerators and freezers for homes in the sample that use these appliances. We considered whether Baseline Study data could be used to update these assumptions. Ultimately, we assumed that data gathered from recycled appliances during implementation of these measures would provide a more accurate representation than data from the Baseline Study. We do not recommend updating the savings or baseline efficiency for the Refrigerator/Freezer Recycling measure.

4.5 Low Impact Measures

The team considered additional parameter updates for the following measures, but deprioritized them during the March 17 workshop because these measures contribute a small amount to overall program savings:

- Faucet Aerators (RES-WH-FA)
- Pipe Wrap, Water Heating (RES-WH-PW)
- Early Retirement Clothes Washers (RES-A-ERCW)
- Clothes Dryers (RES-A-CD)
- Heat Pump Quality Installation Verification (RES-HVAC-HPQIV)
- Heat Pump Digital Check-up/Tune-up (RES-HVAC-HPDCU)

5. NEXT STEPS

The evaluation team identified measures and parameters that could be updated through future studies or through additional data collection in future iterations of the Baseline Study. The team discussed potential future data collection activities with the PAs and EEAC consultants during the TRM workshop on March 17, 2020. This section incorporates the feedback received during that workshop and describes measures that could benefit from further study.

5.1 Future Evaluation Studies

The following measures would benefit from new primary data collection through dedicated evaluation studies:

- **Programmable Thermostats.** A study is underway to develop primary research-based estimates of annual programmable thermostat electric and gas savings to enhance the accuracy of the literature-review based deemed savings values currently in use.
- **Duct Sealing and Duct Insulation.** We assume participant data is collected by implementation vendors, and an evaluation study could use participant data in building simulations to estimate the impacts of these measures.
- **ECM Circulator Pumps.** Planning is in progress for an evaluation study that will examine circulator pumps.
- **Low-Flow Showerhead Energy Savings.** This TRM review recommended updates to several outdated parameter values for showerheads. A comprehensive evaluation study could provide a more holistic update for showerhead measures.

5.2 Future Baseline Study Activities

Future phases of the Baseline Study survey will gather more data that could improve baseline HVAC equipment efficiency recommendations. After the next phase of the Baseline Study survey concludes in 2021, the following parameters should be revisited.

- Boiler, Gas Forced Hot Water (RES-HVAC-BGFHW) – Baseline Efficiency, ROF and ER
- Boiler, Oil/Propane Forced Hot Water (RES-HVAC-BFHW) – Baseline Efficiency, ROF
- Central Air Conditioning (RES-HVAC-CAC) – Baseline Efficiency, ROF
- Furnace, Gas (RES-HVAC-FG) – Baseline Efficiency, ROF
- Furnace, Oil/Propane (RES-HVAC-FOP) – Baseline Efficiency for Oil and Propane, ROF

The following measure could benefit from additional data collection in future phases of the Baseline Study:

- **Room Air Cleaners** – Future phases of the Baseline Study could designate air cleaners as a “priority end use,” such that product nameplate data is gathered to inform an update to baseline efficiency assumptions.

APPENDIX A. HEAT RECOVERY VENTILATOR MEASURE REVIEW AND UPDATE

A.1 Literature Review of Potential HRV Savings Sources

The team reviewed three types of sources for residential HRV savings: Other state and regional TRMs, state and national energy code analysis, and other research publications.

A.1.1 State and Region TRMs

The review of state and regional TRMs focused on states surrounding Massachusetts summarized in Table A-1. Other than Massachusetts, only one state (Rhode Island) had a residential HRV measure. The Rhode Island TRM uses the same reported savings and GDS Associates report for its HRV measure.

Table A-1: State and Regional TRMs Reviewed for HRV Measures

State/Region	Document Type or Program	HRV Measure	Source
Rhode Island	TRM	Residential	GDS Associates (2009)
New York	TRM	No HRV measure	
Vermont	TRM	No HRV measure	
Mid Atlantic, NEEP	TRM	No HRV measure	
Minnesota	TRM	Commercial ERV Only	Calculation
Maine	TRM	No HRV measure	
Pennsylvania	TRM	No HRV measure	
New Jersey	Clean energy program	No residential HRV measure	
Pacific Northwest	RTF	No HRV measure	
Wisconsin	TRM	No HRV measure	

A.1.2 Residential Energy Codes

The literature review also investigated any state or national energy codes that require HRV to assess any comparable accompanying energy savings or cost-effectiveness analysis.

Energy codes sometimes include HRV/ERV as an optional path to meet ventilation requirements, Accordingly, energy code analysis reports did not focus on the energy savings from this equipment. The energy codes in Washington, the City of Seattle, Vermont, and Minnesota mention HRV/ERV as an option to meet ventilation requirements.

Some stretch codes or code proposals did include requirements for HRV for heat recovery purposes. NY Stretch code 2020 has a requirement for HRV in climate zones 5-7, but not required for climate zone 4. NYSERDA reviewed the cost-effectiveness of NY Stretch Energy Code in 2019 but did not report specific savings from HRV. This review stated that the energy impact was captured through energy modeling. The draft 2019 Denver Green Code has three options for residential compliance. ERV are required by the net-zero approach. Denver only recently published this code requirement and did not publish any accompanying analysis.

DOE proposed an HRV requirement for the 2018 IECC, but it was ultimately not included. The accompanying analysis for this proposal was conducted by Pacific Northwest National Laboratory (PNNL), which concluded that HRVs are cost-effective in climate zones 6-8. The PNNL study used energy modeling to quantify energy savings and reported the savings in $/year. The team followed up with PNNL to get more information on heating equipment assumptions and the complete modeling results, but PNNL was not able to share their data.

A.1.3 Other Reviewed Publications

The literature review also looked at HRV related publications by government and efficiency organizations. Some of these studies reported energy savings but these sources were either older or less relevant than the current TRM source.

- Canada implemented an ENERGY STAR specification for residential HRVs in 2010. The accompanying documents did not include energy savings estimates.
- ENERGY STAR Homes' published program requirements do not include a ventilation requirement for single family or multi-family homes.
- The Home Ventilating Institute (HVI) maintains a directory of certified HRV and ERV models. Both the PNNL study and the NYStretch Code review referenced an HVI document, *H/ERV Cost Effectiveness: Building Energy Simulations and Economic Analysis for Single Family Detached Dwelling Units*, but this document does not appear to be publicly available.
    - The team used the HVI Certified Products Directory as a source of sensible and total recovery effectiveness for the ERV and HRV energy savings calculation.
- Efficiency Nova Scotia has a residential HRV incentive but did not publicly publish an associated TRM with values for energy savings.
- DOE Building Technologies Office's Impact of Residential Mechanical Ventilation on Energy Cost (2014) found an increase in energy cost of $0-$40 from using an ERV as a ventilation source but did not provide detail on the energy analysis other than yearly cost. This study used energy modeling to compare systems.
- HRV publications by the Consortium for Advanced Residential Buildings (CARB) and Florida Solar are older than the current source. Florida Solar evaluated southern hot/humid climates. CARB was a metered study in Chicago and reports electricity and gas consumption directly but was published in 2005.
- A National Institute of Standards and Technology publication on HVAC systems in net zero energy buildings reports savings in kWh, but the home is not representative of the average Massachusetts or national home.
- Berkeley Lab's review of ventilation technologies discusses options for ventilation and lists equipment costs for HRVs but does not report energy savings.

Many sources describe HRVs as energy efficient equipment, but their energy savings in a residential application does not have robust, publicly available data. Sources that do examine their energy savings use energy modeling, but the modeling results do not separate savings by equipment or make documentation publicly available.

The HRV energy savings calculation databook's "HRV Lit Review" tab includes additional reviewed sources of information and links to these documents or websites.

A.2 Measure Update for HRV

Since the literature review did not produce a recent and representative source for energy savings, the team constructed an engineering calculation to estimate HRV and ERV energy savings, supplemental to this report. The original TRM source for the HRV measure also used an engineering calculation, but this calculation databook was not available to compare or build upon. Energy modeling may be a more robust method to estimate savings, and future updates to the TRM values should consider funding a metered study or an energy modeling analysis.

The team built an energy savings calculation for HRVs and ERVs. ERVs can recover sensible (heat) and latent (moisture) energy from the exhaust stream, while HRVs only recovery sensible energy.

The savings calculation assumed a baseline of an ASHRAE 62.2 compliant fan exhaust system with no heat recovery. The efficient case was an ERV or HRV with the same ventilation rate and heat or energy recovery capabilities. The energy savings calculation used standard engineering HVAC equations for sensible and total heat transfer, accounting for the heat recovery efficiency of HRV and ERV. The calculator includes additional details and information sources for the calculation inputs.

The calculation for ERV also included cooling season savings since the moisture transfer capability of ERV reduces the cooling load for A/C systems. Ultimately, this calculation showed that the relatively mild Massachusetts summer temperatures resulted in small cooling savings for ERV. These cooling savings were smaller in magnitude than the increase in fan energy, so the overall electricity savings for ERV was negative.

Table A-2: Heat Recovery Ventilator Updates

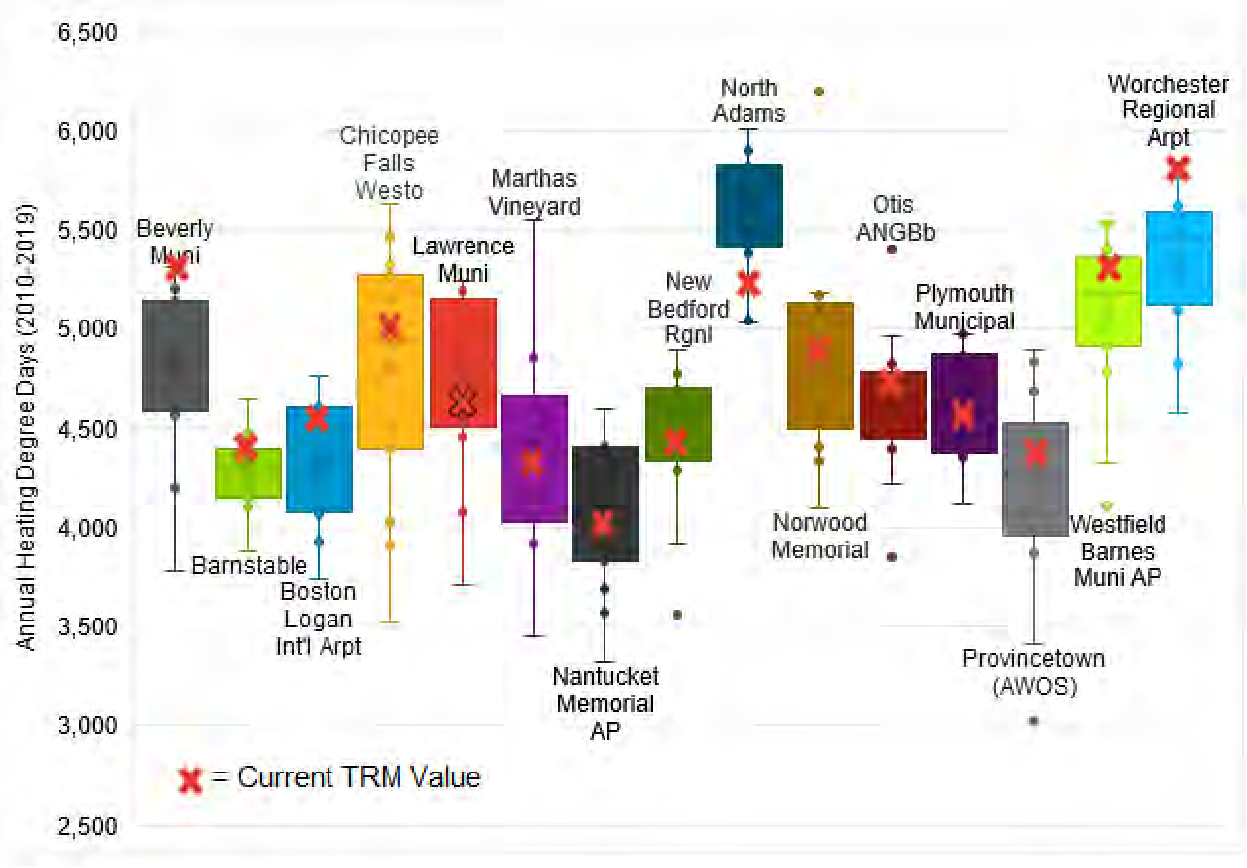
Parameter Name	Existing Value	Proposed Value
HRV Gas Savings (MMBtu)	7.7	8.6
HRV Electricity Savings (kWh)	-133	-171
HRV Demand Savings (kW)	-0.10	-0.02
ERV Gas Savings (MMBtu)	No existing value	8.8
ERV Electricity Savings (kWh)	No existing value	-127
ERV Demand Savings (kW)	No existing value	-0.014

APPENDIX B. HEATING DEGREE-DAY AND COOLING DEGREE-HOUR ANALYSIS

The weather stations cited in the MA TRM are a mix of Class 1, Class 2, and Class 3 weather stations. Class 1 stations are the most stringent in terms of distances from influential heat sources, requirements for shading, and other factors that could unduly influence temperature readings. There are five different weather station classifications, with Classes 1, 2, and 3 all providing high quality results. NOAA estimates the temperature error for each type of site (1, 2, and 3) as 1°C or lower.[35] Beyond the NOAA-estimated error bounds, the team did not evaluate additional sources of error for each weather station.

To arrive at a new representative HDD or CDH value for each site, the team examined the most recent 15 years of temperature data, as this is assumed to represent the latest actual weather conditions, given the advancing state of global climate change. Box and whisker plots of each weather station's previous 15 years can be seen in Figure B-1 and Figure B-2. Maximum and minimum values are represented by the whiskers extending from the box, which itself represents the upper and lower quartiles of the data. The median value is the dividing line within the box. The values for individual years are represented by circles and current TRM values are represented by a red **X**.

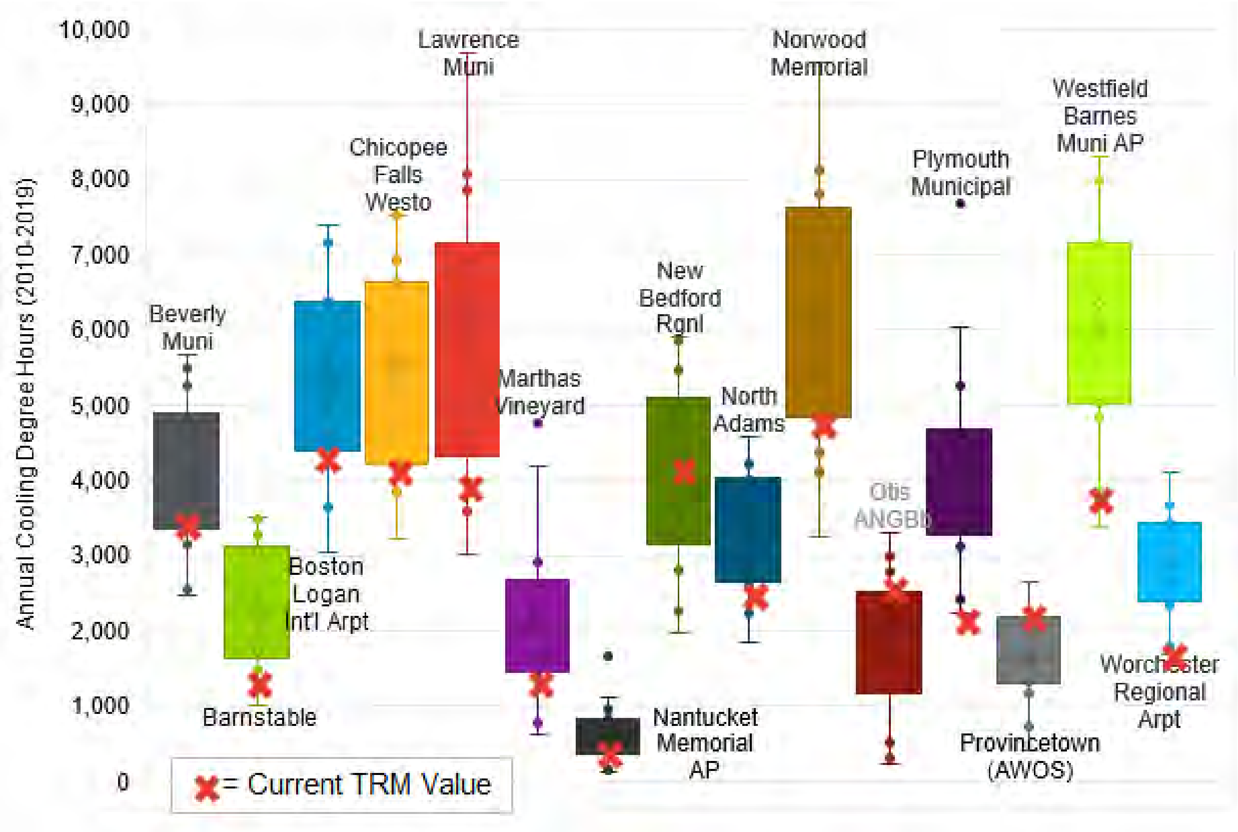
Figure B-1: Heating Degree-Days, Box and Whisker Plot, Reference Weather Stations



---

[35] NOAA (2002). "Climate Reference Network (CRN): Site Information Handbook." p.6. Available at: https://www1.ncdc.noaa.gov/pub/data/uscrn/documentation/program/X030FullDocumentD0.pdf

Figure B-2: Cooling Degree-Hours, Box and Whisker Plot, Reference Weather Stations



The team determined that the median value from each dataset would be more representative than the mean value of the 15-year period. This way, a single year of high or low values would not have a large impact upon the overall recommendation.

The team also considered the impacts of climate change moving forward. Scientific projections indicate the temperature increases are likely to continue but the exact rate of increase is not known. The team plotted the 15-year progression for each weather station to determine if significant trends exist. Aside from year-over-year variation (experienced to some degree across all weather stations), the HDD trend is too flat to be seen in Figure B-3, with some hint of a CDH increase shown in Figure B-4.

Figure B-3: Annual Heating Degree-Days, Time Series

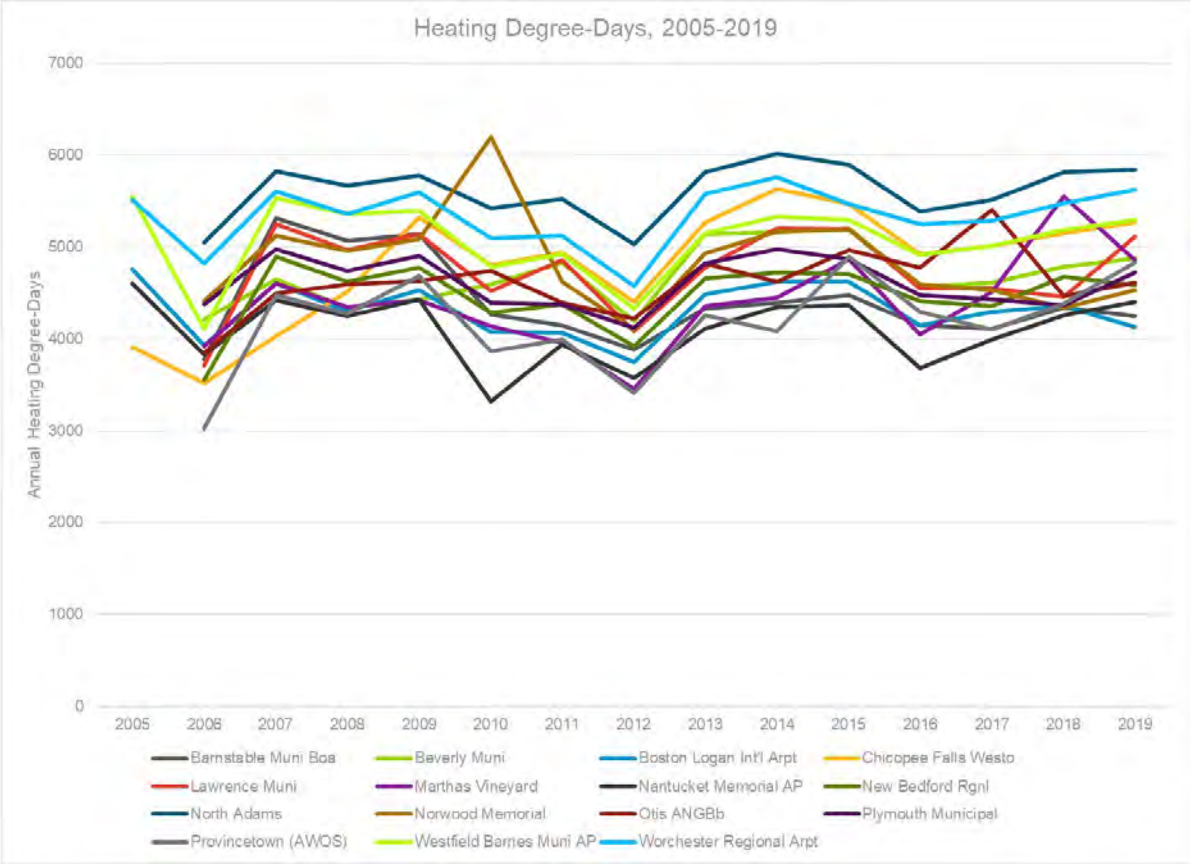
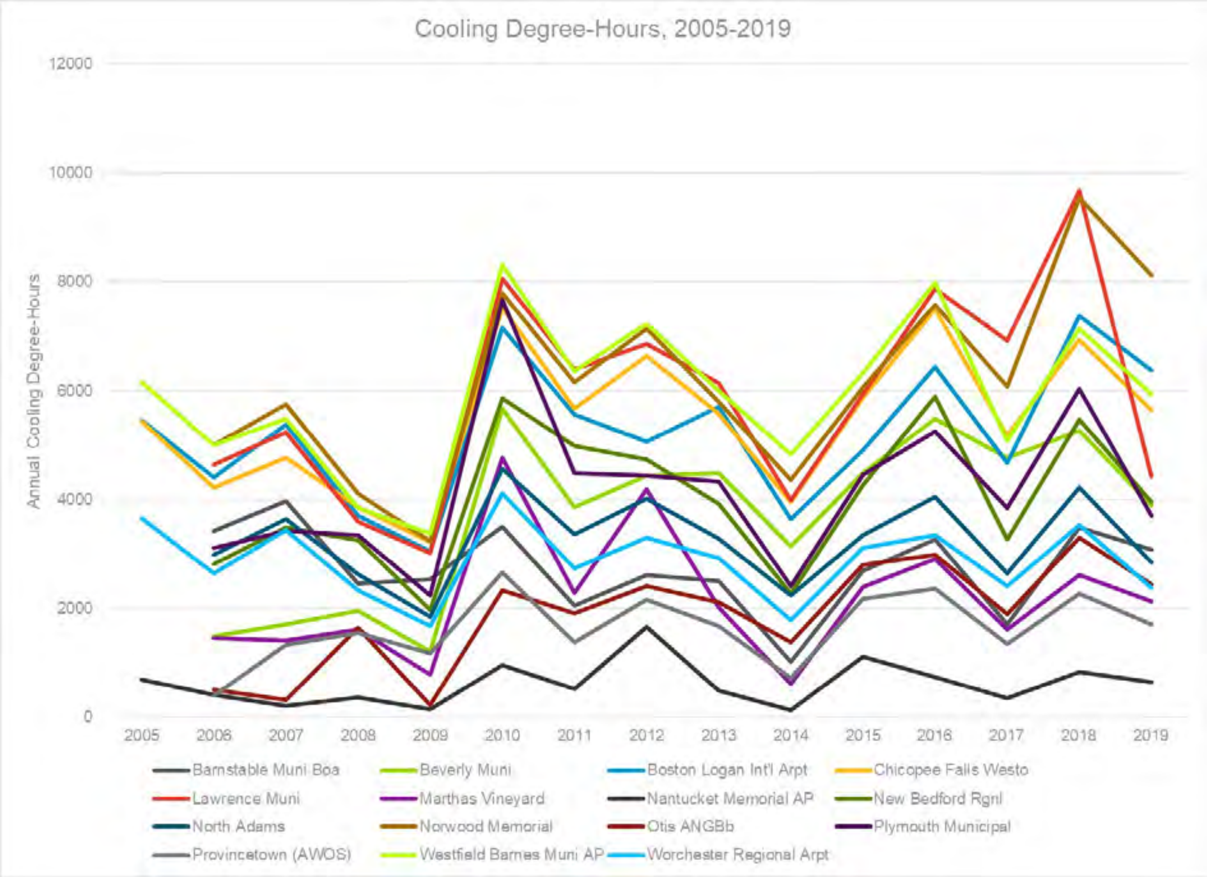


Figure B-4: Annual Cooling Degree-Hours, Time series



The weather stations appear to experience similar weather phenomena in any given year, with the normal variation expected of locations with different microclimates. Although the HDDs appear to be increasing slightly from 2005 to 2019, the aggregate values are 1% lower than the TMY3 values (not shown on the chart). For CDHs, a small increase within the 10-year period is more visible. It should be noted that the 2005 to 2019 recommended values are substantially different from the currently used TMY3 values, particularly for the CDHs. However, rather than attempting to extrapolate the rate of temperature increase into the future, it may be more prudent to simply update the numbers that populate this analysis every 10 years to maintain the most accurate representation of current weather data.

Ductless Mini-Split Heat Pump Impact Evaluation

December 30, 2016

Prepared for:

The Electric and Gas Program Administrators of Massachusetts and Rhode Island
Part of the Residential Evaluation Program Area

The Cadmus Group, Inc.
An Employee-Owned Company • www.cadmusgroup.com

This page left blank.

Prepared by:
Dave Korn, PE, CEM
John Walczyk, CEM
Ari Jackson
Andrew Machado, PE, CEM
John Kongoletos, CEM
Eric Pfann

The Cadmus Group, Inc.

This page left blank.

Table of Contents

Table of Figures

Table of Tables

Executive Summary

The Massachusetts and Rhode Island Program Administrators (PAs) commissioned Cadmus and its subcontractors, Navigant and Tetra Tech, (the evaluation team) to conduct an *in situ* evaluation of ductless mini-split heat pumps (DMSHPs). The evaluation team initially planned to study 132 Massachusetts homes that participated in the COOL SMART Program. The PAs, however, extended the scope of work to include 20 Rhode Island homes that participated in the High Efficiency Heating and Cooling Rebate Program.

Research Objectives

The evaluation sought to address many utility and consumer questions about DMSHPs, focusing on power and energy consumption, heat output, efficiency, and interactions with existing HVAC equipment. The specific research questions follow:

- How much energy is being saved with the average installation of a DMSHP through the programs?
- What are the relevant baseline equipment configurations and associated energy consumptions and load shapes?
- During each season, when are DMSHPs operating, how much energy are they consuming, and how much heating and cooling are they providing?
- How does DMSHP performance correlate with rated capacity, rated efficiency, and ambient conditions?
- How do cold-climate DMSHPs and standard unit performances compare?
- How does unit sizing affect heating performance?
- How do DMSHPs interact with central heating systems?
- What factors limit the use and performance of DMSHPs?
- Are program contractors sizing DMSHPs properly?

Sample Design

The evaluation team used the following participant parameters to stratify program populations into key groups:

- Cold-climate or non-cold-climate unit sites[1]

---

[1] DMSHP manufacturers offer units that claim high performance at very cold (below 0 °F) outdoor ambient temperatures. The evaluation team used the Efficiency Vermont Technical Reference Manual that was current during the study's planning phase to identify cold-climate units. As the report shows, units not characterized as cold climate can operate at 0 °F, although there are not the same claims of high performance at very cold temperatures.

- Single- or multi-head unit sites[2]
- Installed by the largest vendor or by all other contractors

In collaboration with evaluation stakeholders, the team identified these parameters at the study's outset, and then used them to inform sample targets during the participant recruiting process. Initially, the team designed the sampling based on Massachusetts' 2012–2013 program population, but later expanded this to include Massachusetts' 2014 program population and Rhode Island's 2013 program population. Massachusetts participants from the 2014 program year did not receive online surveys (i.e., the study added them after the surveys had been completed). In 2015, a separate Rhode Island survey examined the similarity between Massachusetts and Rhode Island populations. This sought to justify the application of the study results to the Rhode Island population. Sample sizes were determined by the PAs and the evaluation team with a target of 90/20 confidence and precision for each stratum, assuming a coefficient of variation of 0.7. Table ES-1 details these program populations, as measured by participant surveys, program tracking data, and collected evaluation data.

Table ES-1. Program Populations Strata

Sites	MA 2012–2013 Program Participant Share	MA 2014 Program Participant Share	RI 2013 Program Participant Share	Study Sample Participant Share	Study Sample Participant Planned Target	Study Sample Participant Count
Cold-climate unit sites(1)	41%	15%	22%	51%	34	78
Non-cold-climate unit sites	59%	85%	78%	49%	34	74
Single-head unit sites	48%	Unknown(2)	73%	50%	34	107
Multiple-head unit sites	52%	Unknown	27%	50%	34	45
Installed by largest (MA) vendor sites	13%	7%	0%	28%	34	43
Installed by all other vendor sites	87%	93%	100%	72%	34	109
Population Total	**3,229**	**1,055**	**507**	**n/a**	**n/a**	**n/a**
Sample Total(3)	**112**	**20**	**20**	**n/a**	**135**	**152**

(1)All cold-climate unit sites contained single-head units only.
(2)Because 2014 Massachusetts participants were not surveyed, these data were not readily available for the total program population.
(3)Many categories overlap, producing a strata total greater than the overall totals.

---

[2] A DMSHP consist of an outdoor unit that serves one or more indoor heads that deliver heating and cooling. Single-head units have one such head; multi-head units have more than one head.

Figure ES-1 shows the locations of studied homes and systems in Massachusetts and Rhode Island.

Figure ES-1. Locations of Sampled Residences

Table ES-2 shows the average nameplate attributes of DMSHPs metered at the 152 sites. Units averaged about 1.3 tons and just over 20 SEER and 10 HSPF.

During the pilot phase in summer 2014, the team initially installed metering equipment at 30 sites. The team then installed metering equipment at 102 sites during fall 2014 and at the remaining 20 Rhode Island sites in January 2015. During spring 2015, three homeowners sold their homes, and the team removed meters prior to closing. Initially, the study planned to remove all meters in fall 2015, but, as winter 2014/2015 experienced an unusually large amount snowfall that buried many outdoor units, the study sponsors decided a portion of meters should be left in for winter 2015/2016. In fall 2015, roughly 45 Massachusetts sites were removed; the remaining 85 were removed in spring 2016. At the client’s request, the team removed all meters on Rhode Island sites in late fall 2015.

Table ES-2. Average Nameplate Ratings for Outdoor Units

System Category	Sample Size	Average Rated Cooling Capacity (nominal cooling at 95°F)(1) [Btu/h]	Average Rated Heating Capacity at 47°F [Btu/h]	Average Rated Heating Capacity at 17°F [Btu/h]	Average Rated EER(2) [Btu/Wh]	Average Rated SEER(3) [Btu/Wh]	Average Rated HSPF(4) [Btu/Wh]
All	152	16,435	19,491	11,426	13.2	20.6	10.3
Cold Climate Units (CC)	78	14,680	17,985	10,409	13.8	22.3	11.0
Non CC, multi	45	20,444	23,484	13,682	12.4	17.9	9.2
Non CC single	29	14,414	17,268	10,632	12.7	20.3	10.2

(1) Capacity is measured per Air-Conditioning, Heating, and Refrigeration Institute (AHRI) guidelines for various outdoor temperatures: 95 °F, 47 °F, and 17 °F.

(2) Energy Efficiency Ratio (EER) equals the cooling heating provided (in BTUs), divided by the power consumption in watts—essentially the coefficient of performance (COP) times 3.412. It is tested at an outdoor temperature of 95°F and an indoor temperature of 80°F.

(3) Seasonal Energy Efficiency Ratio (SEER) equals the cooling heating provided (in BTUs), divided by the power consumption in watts—essentially the coefficient of performance (COP) times 3.412. It is tested at outside air temperatures ranging from 67°F to 95°F, with the lower temperatures weighted more heavily, and is meant to represent seasonal performance. The indoor temperature is set to 80°F.

(4) Heating Seasonal Performance Factor (HSPF) equals the heating provided (in BTUs), divided by the power consumption in watts—essentially the COP times 3.412. It is tested at outside air temperatures ranging from 17°F to 62°F, and represents seasonal performance. The indoor temperature is set to 70°F.

Findings

Analysis Notes

This report uses many box and whisker plot graphs. The boxes show a range of data from the 25th to the 75th percentile, otherwise known as the 1rst and 3rd quartiles. The middle line in each box is the median data point, or the 50th percentile. Half of the data lie above this line and half fall below. The lines extending above and below the boxes represent the upper 25% and lowest 25% of the data, respectively.

The evaluation team based all energy-use calculations on “site” energy, meaning the calculations did not include line losses and energy-generation losses. Compared energy costs—energy costs at the site or meter—represent the amount paid by the consumer.

In all, the study metered 152 homes. Of these, nearly all power meter files were sufficiently complete for a basic analysis. This study’s analyses were based on continual logging of BTUs and COP. To meter this effectively, meter sets had to concurrently log total power, fan amperage, supply temperature and relative humidity (RH), and return temperature and RH. If these parameters were not metered for a period, BTUs could not be calculated for that period. Consequently, sample sizes (n) shown in the graphs were lower than 152. Similarly, 85 sites metered for winter 2015/2016 resulted in sample sizes lower than 85 for the second consecutive winter. Nevertheless, as this study represents the largest DMSHP study completed to date, the net sample sizes provide a broad and detailed view of DMSHP operations.

We present results for two winters: 2015 where near historically deep snowfalls buried many units for up to 1 month and 2016 which was warmer and had little snow. Because the units were buried and not fully functional for 2015 and because this is not likely to re-occur, we recommend using the winter 2016 results. Both winter's results are shown throughout the report.

Operating Hours

Table ES-3 shows simple run-time hours for metered DMSHPs, with a unit logged as running if its power draw exceeded a threshold standby power of 60W. Looking at the nominal heating season, the average unit ran about 27% of the time (793 hours) during 2015, and about 24% of the time (703 hours) during 2016. Note that an operating hour differs from a full-load hour in that an operating hour simply means that the unit remained on at some capacity, whereas a full-load hour indicates the unit ran at full capacity.

Table ES-3. Observed Run Hours for Nominal Heating and Cooling Seasons*

Season	Example Period of Operation	Season (Days)	Season (Hours)	Mean Percent Runtime	Operation Hours
Winter 2015	December-March	121	2,904	27.3%	793
Summer 2015	June-August	92	2,208	19.4%	428
Winter 2016	December-March	121	2,904	24.2%	703

*These observed run times address periods where the unit drew more than 60W (non-standby).

Equivalent Full Load Hours

Table ES-4 shows the average equivalent full load hours (EFLH) across all units for two heating seasons and one cooling season studied, comparing these values with those prescribed in the Massachusetts and Rhode Island Technical Reference Manuals (TRMs) and the averages of the top 25% of sites in the study. Values for the two heating seasons (442 and 451) remained consistent with the value (447) presented in this study's October 12, 2015, Heating Memorandum, but differed from the current 1,200 TRM value. The summer value (218) was roughly 15% lower than the value shown in the Cooling Memorandum[3] (distributed in February 2016 and finalized (259) on May 2, 2016), and differed from the 360 TRM value. This reduction in average cooling EFLH resulted from this report's use of site-specific, typical meteorological year (TMY) data, in contrast to statewide TMY data used in the memo, as well as the evaluation team filtering out energy usage that consumed power but did not provide cooling. The right most column of Table ES-4 shows the average EFLH of the units in the top 25th percentile. These values are at or above the TRM values.

---

[3] Cadmus Group. *Ductless Mini-Split Heat Pump Draft Cooling Season Results*. January 22, 2016.

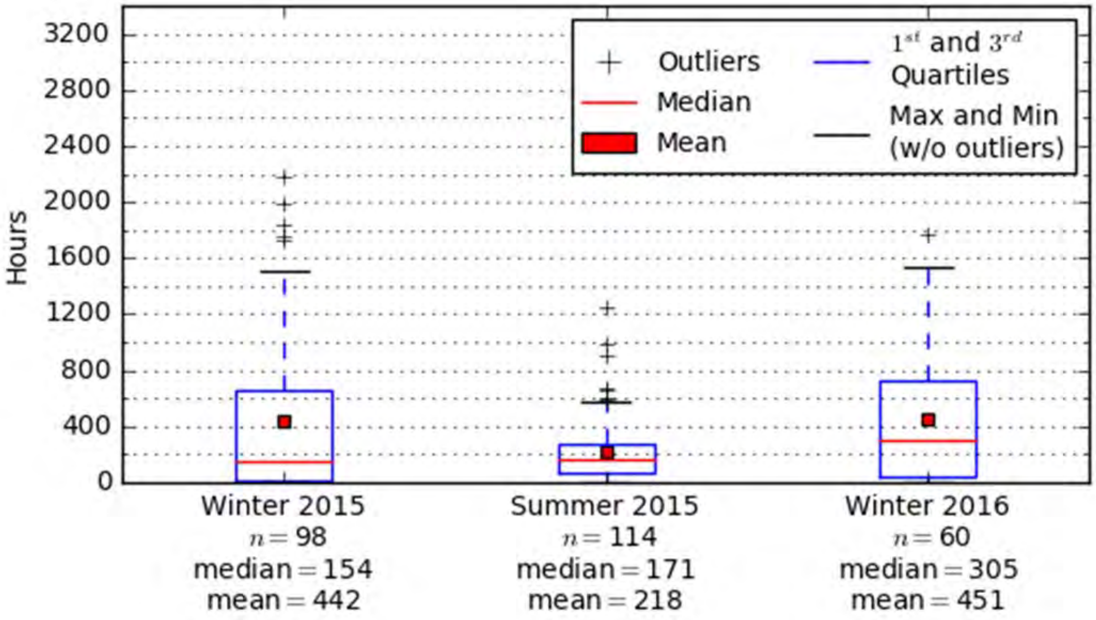
Table ES-4. Average EFLH

Season	2013–2015 MA TRM	2014 RI TRM	Average Study EFLH	Average of Top 25% of Measured EFLH
Winter 2015	1,200	1,200	442	1,275
Summer 2015	360	360	218	499
Winter 2016	1,200	1,200	451	1,117

This study produced EFLH lower than values indicated in the applicable Massachusetts and Rhode Island TRMs for conventional heating and cooling systems (e.g., gas-fired furnaces, central air conditioning). These variances occurred for the following reasons:

- Not all units were used routinely for each season. Many units were lightly used (or not used at all) for heating or cooling. Figure ES-2 illustrates this behavior, with the bottom of the box indicating the 25th percentile of the hour range at or very near zero for winter 2015.
- Many units remained off during the summer's cooler periods.
- Some units in heating mode operated coincidently with primary systems (many of which were fossil fuel-based).
- Systems were sized larger than the cooling needs of the immediate spaces they served, as discussed later in the report.
- The units operated at some level for 19% to 27% of the time for the two winter and one summer season, and were off or on standby for much of the time (Table ES-2). Comparing the EFLH to the total operating hours one can see that the units operate on average at about 56% and 64% of capacity for winter 2015 and winter 2016 and at about 51% of capacity for the summer.
- TRM sources for legacy EFLH values could be inappropriate for DMSHPs. The cooling EFLH value (360) was based on a 2009 study of central air conditioners. The heating EFLH value (1,200) was sourced from a "Massachusetts Common Assumption" also used for other types of heating equipment. Both legacy values appear high relative to this study's findings, supporting the theory that homeowners used DMSHPs differently than conventional heating or cooling equipment.
- The average ELFH of the top 25th percentile of units have values close to or above the TRM values.

Figure ES-2. DMSHP EFLH vs. Season*



> *The blue boxes delineate first and third data quartiles. The lines (whiskers) indicate upper and lower quartiles. The plus symbols represent outliers (points greater than or less than 1.5*(Inter Quartile Range), where the IQR equals the distance between the first and third quartiles).

Figure ES-3 more closely examines this variation, showing that units bought for “both heating and cooling” were used much more for heating than units where users identified their purchases as for “cooling only.” Winter 2016 was a milder than winter 2015, and units operated more efficiently during the former season, resulting in lower EFLH for users intending “both heating and cooling.” During winter 2016, units purchased for “cooling only” saw some heating usage.

Figure ES-3. DMSHP Usage vs. Purchase Intent and Season

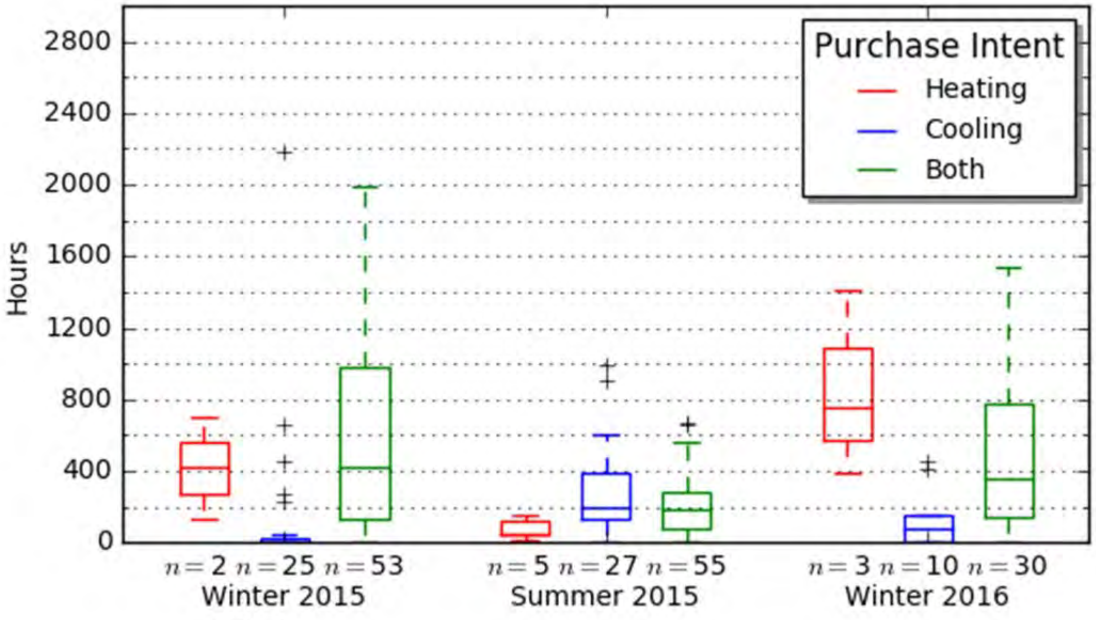


Table ES-5 shows average savings per DMSHP by season and baseline system. As the evaluation team expected, homes heated by electric resistance realized the highest savings; the lowest savings were for a DMSHP (HSPF = 8.2). Three columns present energy use and savings:

- Electricity consumed by the DMSHP
- Energy saved by heat provided by the DMSHP
- Net energy savings after subtracting DMSHP electric consumption

Credit was not taken for the reduction of energy used by a conventional furnace fan or boiler pump. This assumption is conservative because there is likely some reduction in fan and pump use, however, without a pre post study of DMSHP use it is difficult to discern the reduction. On average, a standard boiler pump uses about 120 kWh per year[4] and a fan uses about 440 kWh[5] per year for heating. Where a DMSHP can be used as the primary source of heating, this electricity use could be substantially reduced, increasing savings and decreasing DMSHP net electricity use.

Savings

For electric savings, the study used actual DMSHP performance, decrementing the baseline unit's efficiency from its nameplate rating by the same proportion that the efficient unit's performance

---

[4] Forthcoming Cadmus boiler pump study for National Grid. 2016.

[5] Air-Conditioning, Heating & Refrigeration Institute (AHRI) average = 365W/ 1,000 CFM. At 1,200 CFM and 1,000 run-time hours, this is 438 kWh.

differed from its rating. Cooling savings increased with lower efficiency baselines. Savings calculations relative to a central air conditioner baseline included a 15% duct loss,[6] decreasing the central unit's net efficiency. Table ES-6 shows demand savings.

Table ES-5. Energy Savings by Season and Baseline System

Season	Baseline System	Sample Size	Electric Usage of DMSHP [kWh]	Baseline Energy Reduction	Net Energy Savings	Precision at 90% Confidence [%]
Winter 2015	90% AFUE Furnace(1)	98	683	4.87 MMBtu	2.54 MMBtu	37
	85% AFUE Furnace(2)		683	5.16 MMBtu	2.83 MMBtu	36
	82% AFUE Boiler		683	4.54 MMBtu	2.21 MMBtu	39
	HSPF 7.7 DMSHP		683	907 kWh	224 kWh	21
	HSPF 8.2 DMSHP		683	851 kWh	168 kWh	21
	Electric Resistance		683	1,092 kWh	409 kWh	48
Summer 2015	EER 9.8 Window AC	114	159	213 kWh	54 kWh	15
	SEER 13.0 Central AC		159	288 kWh	129 kWh	14
	SEER 13.0 DMSHP		159	245 kWh	86 kWh	14
	SEER 14.5 DMSHP		159	220 kWh	61 kWh	15
Winter 2016	90% AFUE Furnace	60	763	6.9 MMBtu	4.3 MMBtu	37
	85% AFUE Furnace		763	7.31 MMBtu	4.7 MMBtu	36
	82% AFUE Boiler		763	6.44 MMBtu	3.83 MMBtu	37
	HSPF 7.7 DMSHP		763	989 kWh	226 kWh	22
	HSPF 8.2 DMSHP		763	929 kWh	166 kWh	23
	Electric Resistance		763	1,547 kWh	784 kWh	42

(1) Duct losses assumed at 15%.
(2) Baseline efficiency prescribed by relevant Massachusetts (2013-2015) and Rhode Island (2015) TRMs in force when the study began.

---

[6] *Massachusetts Technical Reference Manual*, 2013–2015 Program Years, HVAC-Duct Sealing, assumed baseline efficiency.

Table ES-6. Demand Savings by Season and Baseline System

Season	Baseline System	Sample Size	Electric Usage of DMSHP [kW]	Baseline Power Reduction [kW]	Average Peak Period Demand Savings [kW]	Precision at 90% Confidence [%]
Winter 2015	90% AFUE Furnace	98	0.21	0	-0.21	33
	85% AFUE Furnace		0.21	0	-0.21	33
	82% AFUE Boiler		0.21	0	-0.21	33
	HSPF 7.7 DMSHP		0.21	0.28	0.07	22
	HSPF 8.2 DMSHP		0.21	0.26	0.05	22
	Electric Resistance		0.21	0.33	0.12	43
Summer 2015	EER 9.8 Window AC	114	0.11	0.15	0.04	16
	SEER 13.0 Central AC		0.11	0.20	0.09	15
	SEER 13.0 DMSHP		0.11	0.05	0.06	15
	SEER 14.5 DMSHP		0.11	0.07	0.04	15
Winter 2016	90% AFUE Furnace	60	0.25	0	-0.25	34
	85% AFUE Furnace		0.25	0	-0.25	34
	82% AFUE Boiler		0.25	0	-0.25	34
	HSPF 7.7 DMSHP		0.25	0.33	0.08	24
	HSPF 8.2 DMSHP		0.25	0.31	0.06	25
	Electric Resistance		0.25	0.58	0.33	38

To examine the practical potential savings achievable by DMSHPs used more frequently, the evaluation team took sites in the top 25%, based on savings. Table ES-7 and Table ES-8 show savings for this subpopulation. Usage and savings were much higher than the mean, as one would expect mathematically. In practical terms, these were savings expected upon removing units lightly used or not used from the population.

Table ES-7. Energy Savings, Each Baseline Applied to All Sites, Top 25%

Season	Baseline System	Sample Size	Electric Usage of DMSHP [kWh]	Baseline Energy Reduction	Average Energy Savings	Precision at 90% Confidence [%]
Winter 2015	90% AFUE Furnace	25	1,414	14.7 MMBtu	9.84 MMBtu	22
	85% AFUE Furnace		1,414	15.5 MMBtu	10.70 MMBtu	22
	82% AFUE Boiler		1,414	13.1 MMBtu	8.86 MMBtu	22
	HSPF 7.7 DMSHP		1,894	2,536 kWh	642 kWh	10
	HSPF 8.2 DMSHP		1,894	2,382 kWh	488 kWh	11
	Electric Resistance		1,414	3,287 kWh	1,873 kWh	24
Summer 2015	EER 9.8 Window AC	29	358	484 kWh	126 kWh	12
	SEER 13.0 Central AC		371	663 kWh	292 kWh	11
	SEER 13.0 DMSHP		363	556 kWh	193 kWh	12
	SEER 14.5 DMSHP		332	468 kWh	136 kWh	14
Winter 2016	90% AFUE Furnace	15	1,566	18.68 MMBtu	13.34 MMBtu	30
	85% AFUE Furnace		1,566	19.78 MMBtu	14.44 MMBtu	30
	82% AFUE Boiler		1,566	17.43 MMBtu	12.09 MMBtu	31
	HSPF 7.7 DMSHP		1,862	2,433 kWh	571 kWh	13
	HSPF 8.2 DMSHP		1,761	2,184 kWh	423 kWh	15
	Electric Resistance		1,566	4,188	2,622 kWh	33

Similarly, Table ES-8 shows demand savings for the top 25% of sites.

Table ES-8. Peak Demand Savings, Baseline Applied Based on Survey Responses and Existing Systems, Top 25%

Season	Baseline System	Sample Size	Electric Usage of DMSHP [kW]	Baseline Power Reduction [kW]	Average Peak Period Demand Savings [kW]	Precision at 90% Confidence [%]
Winter 2015	90% AFUE Furnace	25	0.47	0	-0.47	18
	85% AFUE Furnace		0.47	0	-0.47	18
	82% AFUE Boiler		0.47	0	-0.47	18
	HSPF 7.7 DMSHP		0.62	0.82	0.20	13
	HSPF 8.2 DMSHP		0.56	0.70	0.14	14
	Electric Resistance		0.47	1.02	0.55	19
Summer 2015	EER 9.8 Window AC	29	0.24	0.33	0.09	13
	SEER 13.0 Central AC		0.25	0.45	0.20	11
	SEER 13.0 DMSHP		0.23	0.36	0.13	12
	SEER 14.5 DMSHP		0.22	0.31	0.09	13
Winter 2016	90% AFUE Furnace	15	0.54	0	-0.54	25
	85% AFUE Furnace		0.54	0	-0.54	25
	82% AFUE Boiler		0.54	0	-0.54	25
	HSPF 7.7 DMSHP		0.61	0.80	0.19	12
	HSPF 8.2 DMSHP		0.61	0.76	0.15	15
	Electric Resistance		0.54	1.64	1.1	26

Using baseline weighting from the previously published Baseline Memorandum, the evaluation team calculated average weighted savings for each of the three studied seasons, both for a single and specific baseline, as shown in Table ES-9. The terms “Single Baseline” and “Specific Baseline” differentiate the methodologies used in calculating savings; the former averages DMSHP usage across all participants and applies various baselines to the result, and the latter calculates savings using survey responses indicating participant specific baselines. Generally, winter 2016, with data unaffected by the large snowfalls of 2015, realized higher savings. Specific baselines showed savings similar to, or somewhat higher than, single baselines, but at poorer (higher) precisions.

Table ES-9. Weighted Average Savings, Fuel Switching

Fuel Switching					Single Baseline						Specific Baseline					
Season	Baseline System	Base Eff.	Efficiency Metric	Savings Units	n	Mean Savings	Mean Savings [kWh]	Population with Baseline [%]	Expected Baseline Savings [kWh]	Precision [%]	Sample Size	Mean Savings	Mean Savings [kWh]	Pop. with Baseline [%]	Expected Baseline Savings [kWh]	Precision [%]
Winter 2015	Furnace	0.85	AFUE	MMBtu	98	2.83	829	13%	108	36	10	1.62	475	13%	62	109
	Boiler	0.82	AFUE	MMBtu		2.21	648	35%	227	39	27	2.83	829	35%	291	68
	ER	1	COP	kWh		409	409	4%	16	48	3	398	398	4%	15	334
	DHP	7.7	HSPF	kWh		224	224	48%	108	21	37	163	163	48%	78	41
	Weighted Total							100%	458	31				100%	446	71
Summer 2015	Window AC	9.8	EER	kWh	114	54	54	17%	9	15	9	93	93	17%	16	33
	CAC	13	SEER	kWh		129	129	13%	17	14	7	95	95	13%	12	50
	DHP	13	SEER	kWh		86	86	70%	61	14	38	103	103	70%	72	26
	Weighted Total							100%	86	14				100%	100	30
Winter 2016	Furnace	0.85	AFUE	MMBtu	60	4.70	1378	16%	218	36	6	3.05	894	16%	141	103
	Boiler	0.82	AFUE	MMBtu		3.83	1123	37%	414	37	14	6.17	1808	37%	666	82
	ER	1	COP	kWh		784	784	5%	41	42	2	1778	1778	5%	94	35
	DHP	7.7	HSPF	kWh		226	226	42%	95	22	16	176	176	42%	74	55
	Weighted Total							100%	768	31				100%	975	71

Table ES-10 shows non-fuel switching savings that are lower than fuel switching savings because baseline DMSHP savings are lower than fuel heating savings.

Table ES-10. Weighted Average Savings, Non-Fuel Switching

Non Fuel Switching					Single baseline						Specific baseline					
Season	Baseline System	Base Eff.	Efficiency Metric	Savings Units	n	Mean Savings	Mean Savings [kWh]	Population with Baseline [%]	Expected Baseline Savings [kWh]	Precision [%]	Sample Size	Mean Savings	Mean Savings [kWh]	Pop. with Baseline [%]	Expected Baseline Savings [kWh]	Precision [%]
Winter 2015	ER	1	COP	kWh	98	409	409	8%	31	48	3	398	398	8%	30	334
	DHP	7.7	HSPF	kWh		224	224	93%	207	21	37	163	163	93%	150	41
	Weighted Total							100%	238	23				100%	180	63
Summer 2015	Window AC	9.8	EER	kWh	114	54	54	17%	9	15	9	93	93	17%	16	33
	CAC	13	SEER	kWh		129	129	13%	17	14	7	95	95	13%	12	50
	DHP	13	SEER	kWh		86	86	70%	61	14	38	103	103	70%	72	26
	Weighted Total							100%	86	14				100%	100	30
Winter 2016	ER	1	COP	kWh	60	784	784	11%	87	42	2	1778	1778	11%	198	35
	DHP	7.7	HSPF	kWh		226	226	89%	201	22	16	176	176	89%	156	55
	Weighted Total							100%	288	25				100%	354	53

Cold Climate Performance

DMSHP manufacturers offer units with claims of increased performance at very cold outdoor ambient temperatures in raltion to standard units. This report characterizes these as "cold-climate" units and all others as standard or "non-cold-climate" units. The evaluation team used the Efficiency Vermont TRM, current during study's planning phase, to identify cold-climate units. DMSHP manufacturers continue to offer new units with claims of increased performance at very cold outdoor ambient temperatures. Currently, various makers claim DMSHPs offer 100% capacity at 20°F or at 5°F (depending upon how they are rated) and operate down to -15°F.

Figure ES-4 and Figure ES-5 present COPs,[7] plotted for cold-climate and non-cold-climate units against outside ambient temperatures for winter 2015 and winter 2016, respectively. Each data point represents averaged performance from many units. In terms of HSPF, the rated differences were 1.55 for winter 2015 and 1.24 for winter 2016—equivalent to a COP difference of 0.43 and 0.36, respectively[8]. This difference would average across the seasons (see the keys for Figure ES-4 and Figure ES-5). Data for winter 2015—already noted for deep snowfalls that buried many units—indicated separation of efficiencies only at temperatures below 40°F. The COP separation grew to about 0.5 at 0°F. For winter 2016, without snowfall issues, separation of efficiency curves for the entire range of outdoor temperatures grew from about 0.4 at -10°F to about 1.0 at 50°F. These differences were consistent with HSPF ratings and appeared to show efficiency advantages across the temperature spectrum.

The ratings difference also was consistent with comments the evaluation team heard from engineers at a major manufacturer; they stated that cold-climate units were of higher quality and featured more of the newest technologies. As cold-climate units drew the greatest customer demand, the engineers reasoned that putting more effort and innovation into cold-climate models made sense.

Notably, observed non-cold-climate models operated at outdoor ambient temperatures below 0°F, but at lower efficiency levels than cold-climate models. It is difficult to separate improved cold-climate performance from overall, higher seasonal ratings. The 152 units metered through the study and installed prior to summer 2014 had an average 10.3 HSPF; cold-climate units had an average 11 HSPF. Today, units offer HSPFs up to 14.

---

[7] For electrical resistance heating, the COP is 1.0; for fuel heating, it is equivalent to system efficiency (0.7 to 0.9).

[8] Delta_HSPF = 10.81 – 9.57 = 1.24 Btu/Wh. Delta_COP = 1.24 Btu/Wh * 1/3.41 Wh/Btu = 0.36

Figure ES-4. Average Heating COP vs. Outdoor Air Temperature for Cold-Climate and Non-Cold-Climate Systems—Winter 2015

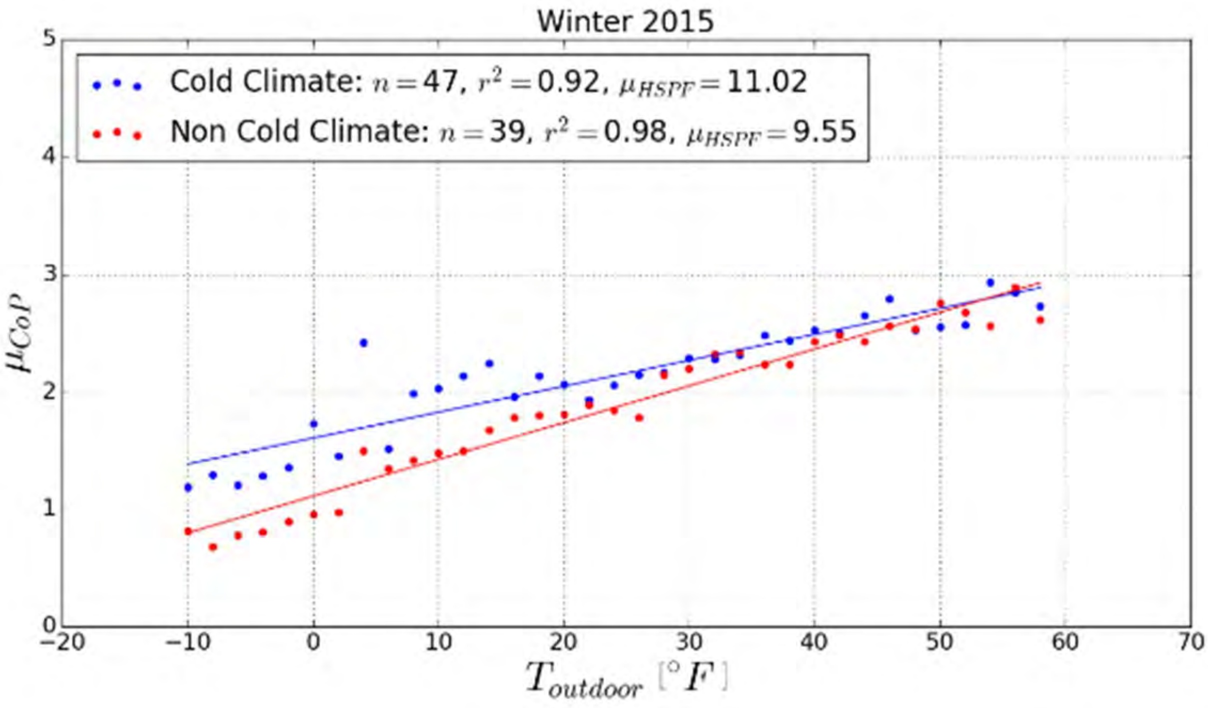


Figure ES-5. Average Heating COP vs. Outdoor Air Temperature for Cold-Climate and Non-Cold-Climate Systems—Winter 2016

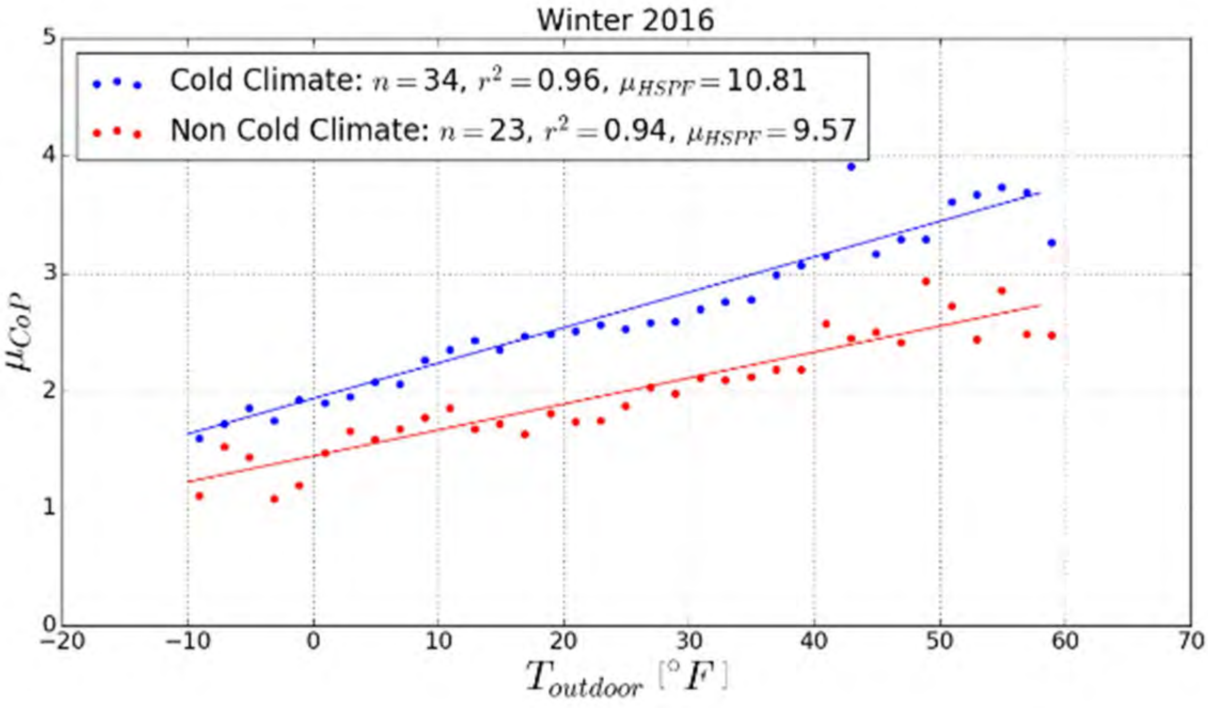


Figure ES-6 provides a two-dimensional map of electricity and fuel prices. A blue circle indicates average energy prices for winter 2016; a red triangle indicates energy pricing for winter 2015. The topographical-style lines show a third dimension: the temperature breakpoint above which a DMSHP is less expensive to operate than an alternative fuel-fired heating system. For example, if the temperature breakpoint was 30°F, above this temperature the DMSHP is more economical to operate; below this temperature, the alternate heat source proved more economical to operate. The evaluation team derived these contours from averages of measured efficiencies for all types of DMSHP systems.

The temperature dependence resulted from DMSHPs' decreasing efficiency at lower temperatures. For natural gas, the figure shows a temperature breakpoint above 70F° for either winter, meaning a DMSHP would essentially never be cost-effective, compared with an 80% efficient heating system.[9] This effectively means a DMSHP does not offer a viable direct replacement for a gas-fired system at today's energy prices.

The figure also shows a temperature balance point about 32°F for an oil-fired system in 2016 and 12°F in 2015. Both winters indicate a propane balance point of -15°F, meaning a DMSHP would always be less expensive than the propane option.

Figure ES-7 shows the same analysis, but addresses units listed as cold climate. These units operate somewhat more efficiently, and the economic balance points shift to colder temperatures, where gas balance points were at or above 58°F for both winters. Oil-fired systems' balance points were 26°F for 2016 and 8°F for 2015. These values do not account for zonal savings. For example, if a homeowner could use a DMSHP to heat 30% less of their home, that temperature balance point would drop by 20°F or more.

---

[9] Here, efficiency means system efficiency, inclusive of duct losses, and furnace fan and boiler pump energy use. It is lower than the rated or measured combustion efficiency.

Figure ES-6. Operational Break Point Temperature of Heating with DMSHP, Winter 2016, All Units

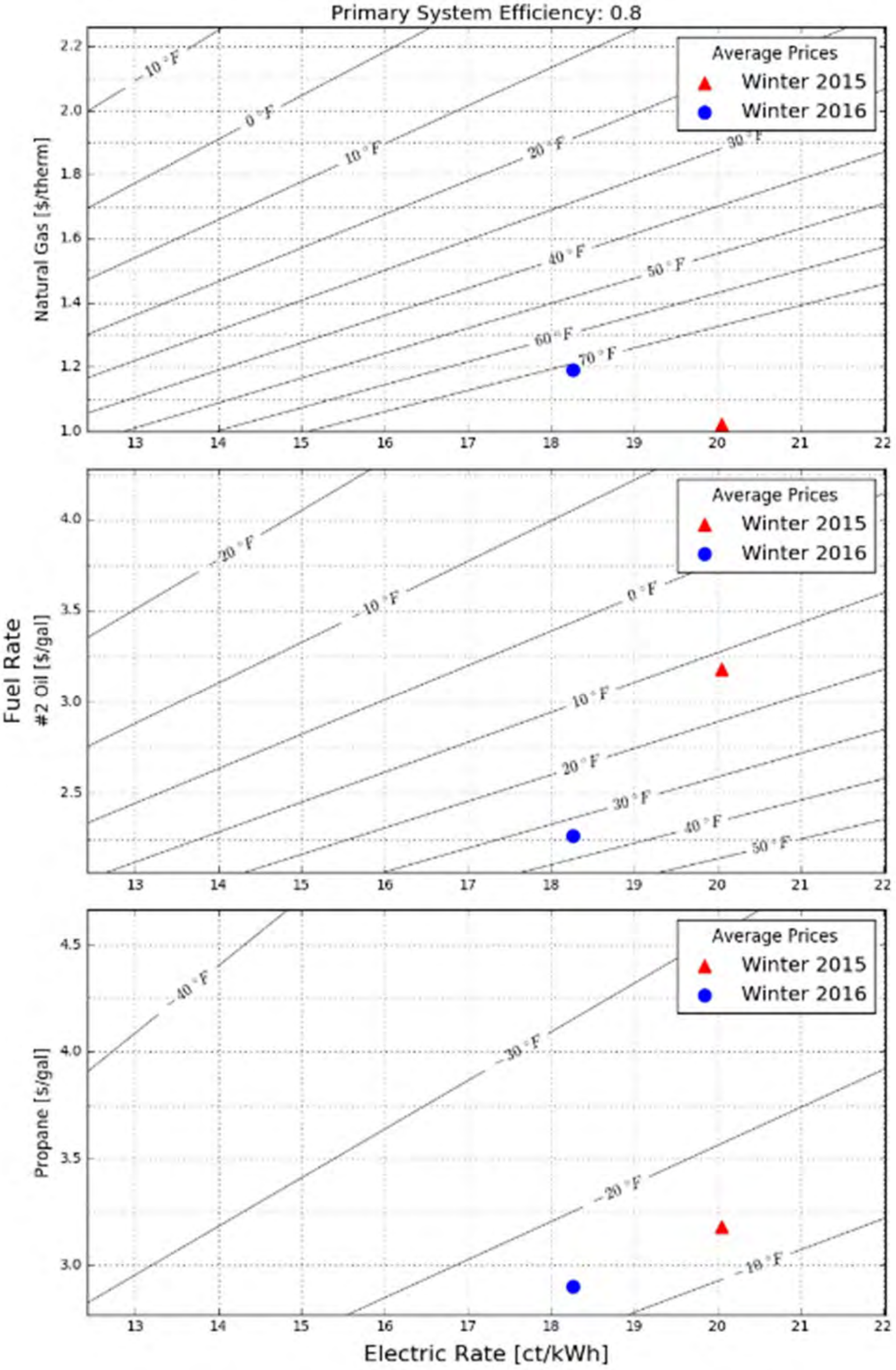
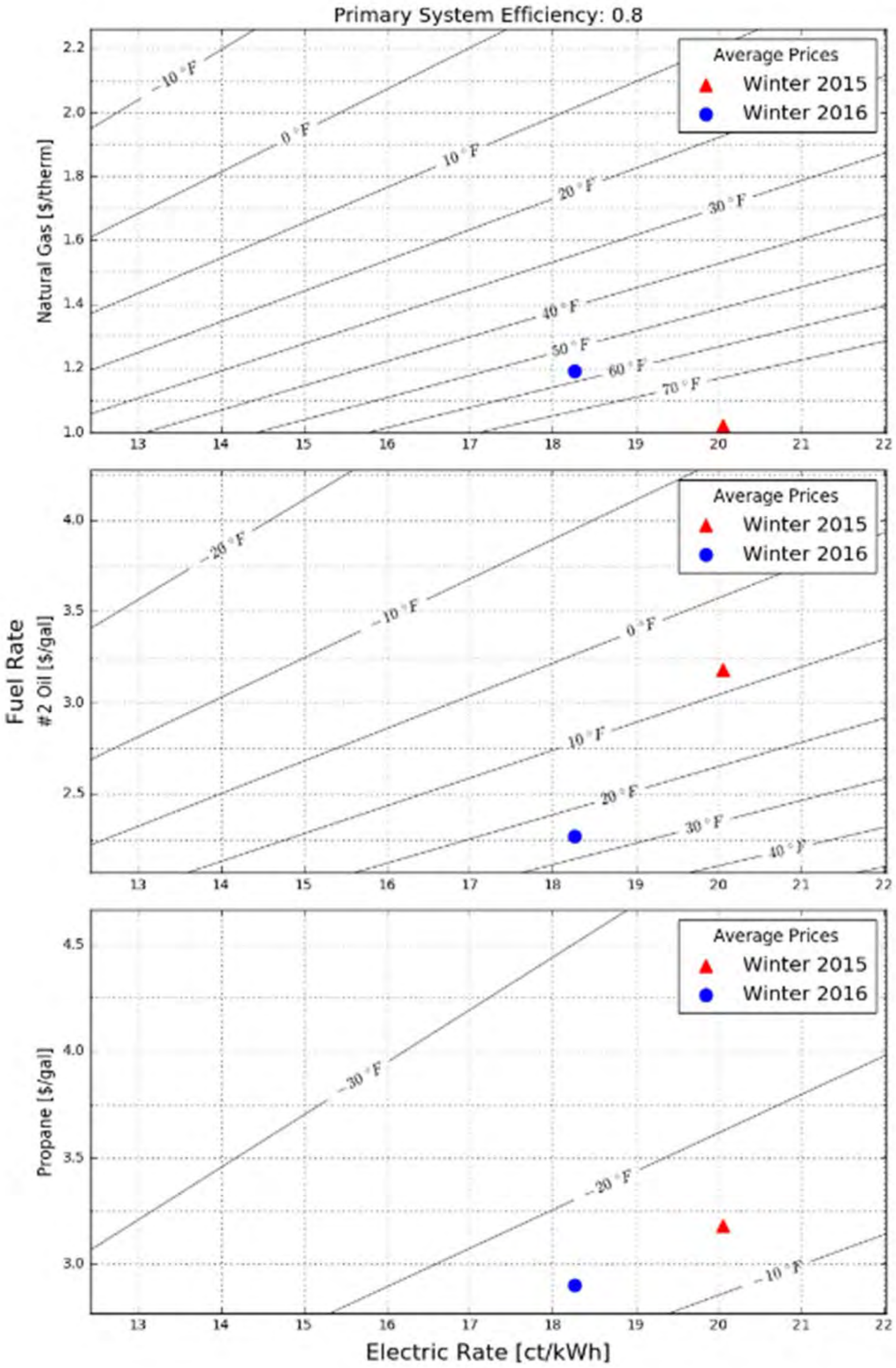


Figure ES-7. Operational Break Point Temperature of Heating with DMSHP, Winter 2016, Cold Climate Units



Discussion

In general, the evaluation team found DMSHPs operated in highly variable ways, resulting in widely varying hours of use, power use, and savings among units. Some variation resulted from variable-speed designs, but the larger factor appeared to be the way users chose to operate their equipment. The following discussion addresses results from cooling, heating, and efficiency ratings.

Cooling

The evaluation team determined an average EFLH cooling value of 218, well below the 360-hour value assumed in the Massachusetts and Rhode Island TRMs. Units often operated at low capacity or even were turned off for periods. The following elements contributed to the low EFLH:

- Units sometimes operated in dehumidifier or "dry" mode. In dry mode, the indoor unit lowers coil temperatures to induce condensation formation. The unit then operates the fan on its lowest speed setting to not excessively decrease temperature in the space.
- Some units that cooled a seldom-used space were turned on only when needed.
- As DMSHP units experienced neither duct losses nor insufficient evaporator airflow (as some central air conditioning units might), they provided the same cooling level with fewer EFLH. That is: central air conditioners can lose efficiency at the air handler due to low airflow, and then lose more energy through duct leakage as well as through heat losses and gains as ducts pass through unoccupied spaces. DMSHPs do not experience these losses.
- On average, units were sized to provide about 2.6 times the design-cooling load calculated using Manual J. This could result from contractors sizing DSMHP units to meet larger design-heating loads. Units also may be designed to cool adjacent spaces when doors to a cooled room remain open.
- TRM sources for legacy EFLH values may be inappropriate for DMSHPs: the cooling EFLH value was based on a 2009 study of central air conditioners.

Given these factors, the evaluation team found it unsurprising that the average EFLH for cooling fell below the TRM values. A low EFLH would reduce savings calculated by the TRM equation, but not necessarily mean reduced savings. For example, if a unit's size fell by 50%, the EFLH would roughly double, but the TRM equation would yield the same savings:

$$2\ (\text{EFLH}) * 0.5\ (\text{Capacity}) = \text{EFLH} * \text{Capacity}$$

The team based the above savings discussions on providing identical cooling amounts, but at varying efficiencies (i.e., an air conditioner with an effective 16 SEER could deliver cooling with 75% of the energy as an air conditioner with an effective 12 SEER).

In many cases, DMSHPs produced additional savings beyond simply providing more efficient air conditioning from a purely mechanical standpoint (i.e. zonal savings). Therefore, they may be providing higher savings than indicated by comparisons to baselines. As the report addresses, DMSHPs were installed at a rate of approximately 1 ton of capacity per 1,043 s.f. of home floor area. This value is far lower than typically observed for central air conditioners. Users frequently shut off DMSHPs due to unoccupied rooms or mild outdoor temperatures. Thereby, DMSHPs can deliver zonal savings by performing less cooling. DMSHP also can run in dehumidification modes, further reducing the need for cooling.

When considering new construction programs, DMSHPs potentially could deliver savings from zonal behaviors when homeowners fully cool only a portion of their houses. Typically, central air conditioners do not offer this option; to cool one room, homeowners must cool their entire houses. In contrast, a DMSHP can cool one room at a time.

For this study, the majority of DMSHPs served as the only cooling source. Homes cooled solely with DMSHPs used an average of 194 kWh for the cooling season, including standby power. Using the Massachusetts TRM value for a central air conditioner's EFLH (360 hours), a home would use approximately 830 kWh/season for a 2.5-ton unit, and about 1,000 kWh/ season for a 3-ton unit. This striking difference (830 – 1,000 kWh vs. 194 kWh) argues for investigating marketing and incentivizing DMSHP units as an alternative to central air conditioners in new construction.

Heating

The study found a heating EFLH value of roughly 450 hours. In nearly all cases, observed DMSHP units provided heat coincidentally with other systems. In most cases, DMSHPs served as secondary systems, either to provide heat for a single space or to provide supplemental heat in addition to a primary system.

The operational cost-effectiveness to a homeowner using a DMSHP for heating depended on alternative heating systems, energy prices for a given period, and outside air temperatures. Compared against electric resistance and propane heating, the DMSHP proved more cost-effective on average for all outdoor air temperatures typically observed during winters in Massachusetts and Rhode Island.

For oil-fired systems, the relative energy price determined the temperature above which a DMSHP became more cost-effective. Current oil prices remain low relative to historic values, but DMSHPs proved cost-effective in comparison to oil. Compared to natural gas heating systems, DMSHP rarely proved cost-effective. This generalization excludes a scenario where a DMSHP heats a single space, negating the need to turn on a whole-house heating system.

COP/SEER/HSPF

For this study, DMSHP unit efficiencies were directly metered for winter and summer seasons. Most previous studies have estimated COP using metered power alone (not a very accurate technique), or calculated COPs for brief periods and small quantities of units. The evaluation team found unit efficiencies varied widely by site and from period to period. On average, field-measured seasonal efficiencies for most units were below their rated values, although some units met or exceeded their ratings. Measured SEER values below rated values could result from the following:

- Some units were seldom used.

- Some homeowners used DMSHPs only to cool on the hottest days, with their resulting cooling efficiencies closer to rated EER values (i.e., the efficiency rating at 95°F).
- SEER and EER tests run at specific conditions might not fully represent actual operations. In the SEER test, for example, return air was 80°F—much warmer than most homes during cooling seasons.
- Units were used for functions that reduced the rated performance, including fan-only modes and dry or dehumidification modes. These modes may help displace cooling, but, for these SEER calculations, simply show up as energy use without much delivered cooling.

Measured HSPF values could fall below rated values for the following reasons:

- Some homeowners used their DMSHPs during very cold outdoor conditions, when the resulting DMSHP COP was lower than its rated value.
- HSPF tests run under specific conditions that did not fully represent actual operations.
- Units operated at very low capacities (due to low heating needs) realized low efficiencies.
- Site conditions caused units to run in defrost modes for long periods of time, decreasing efficiency. The evaluation team has completed other studies that found marked differences in the frequency of defrost cycles[10] between brands.

Although field-measured efficiencies generally fell below rated efficiencies, this does not mean that manufacturers are not being forthright. There are stipulated test procedures for cooling and heating (47°F and 17°F, respectively), and many manufacturers use third-party laboratories for much of their testing. Hence, they verify rated values. A number of units performed at their rated values, supporting the team’s contention that units can operate at rated efficiencies, and operating conditions and behaviors greatly contribute to delivered efficiencies.

The study metered units with an average nameplate SEER of 20.6 and an average nameplate HSPF of 10.3. Further, manufacturers continue to increase the efficiency ratings of systems they offer. The marketplace currently offers an upper-range SEER of 33, with many units above 25 SEER. Manufacturers offer DMSHP units with rated HSPFs up to 14, with many units above 12 HSPF. These new units would have delivered cooling and heating more efficiently than units measured for this study.

Savings Values

EFLH and savings values are based on averages, which include lightly used equipment, and on the rated efficiencies of the studied equipment (which are below that now available in the marketplace). While current EFLH and savings values are low relative to legacy TRM values, the evaluation team has observed high heating usage and EFLH in northern New England by populations that are motivated to

---

[10] Forthcoming study of DMSHP by Cadmus in Vermont and Illinois.

displace oil heat.[11] The team recommends incentivizing the highest-tier efficiency levels to increase savings, and combining incentives with contractor and consumer education. This approach could help target higher-use customers that could produce savings towards the higher end of this study's savings distributions.

Controls and Zoning

Use of preexisting heating systems presented a factor limiting DMSHPs' use for heating. Most furnaces use single-zone systems, meaning a single thermostat and a single set point control a home's temperature. In such homes, if the DMSHP heats one or even two rooms, homeowners may find it difficult to use DMSHPs as a primary heating system as this would under heat other portions of the home.

Though the challenge extends to boiler-heated homes, it might be more solvable in such circumstances because boilers often supply separate zones, served by separate thermostats controlling zone valves or separate secondary pumps. In homes with individually controlled electric strip heating, primary systems can be more readily replaced with a DMSHP.

To increase DMSHP heating use and associated savings, the zone served by the DMSHP should match the primary system zone. This can be accomplished by targeting homes with zoned (i.e., oil or propane-fired) boilers or by installing multi-head systems. The homeowner would then set the DMSHP temperature setting above the primary system thermostat's dead band (e.g., 3-4°F). For example, if the DMSHP were set to 70°F, the primary system's thermostat would be set to 67°F.

This situation could be improved if the DMSHP's thermostat and the primary system's thermostat communicate with each other. When the room was no longer occupied, set points could drop to lower temperatures. This way, the DMSHP would become the primary heating system, and additional zonal savings could be achieved by not fully heating the home's unused spaces.

Recently, products from major makers of ductless systems and wireless thermostats have made progress in developing systems that work together. The evaluation team recommends that makers of various smart thermostats and DMSHP manufacturers continue to collaborate in developing protocols that allow devices to communicate.

Recommendations

Program

Recommendation: The evaluation team recommends exploring ways to improve the PAs' existing lost opportunity program for DMSHPs, such as how best to encourage the installation of multiple DMSHP heads to better match existing zones and displace primary system operation. Although the EFLHs

---

[11] Forthcoming Cadmus DMSHP study in Vermont.

decreased from the values prescribed in the Massachusetts TRM, the study still finds that a modest level of savings are achievable by moving from a standard efficiency DMSHP to a higher efficiency DMSHP. Substantially more savings could be achieved (i.e., the top 25% of savings) if newly installed DMSHPs are operated more regularly and continuously by better matching and integrating them zonally with primary heating systems, through better configuration design and installation and contractor and customer education and training. For example, contractors would focus their design efforts on specifying the appropriate number and size of DMSHP heads to match and heat entire zone(s) rather than a single room. Customers would then be educated on how to properly set the set points for both their primary and DMSHP heating systems, which will depend on their primary fuel type and outdoor temperatures. Finally, establishing program incentives for the generally more efficient, cold climate heat pumps would lead to increased program savings.

Recommendation: The evaluation team recommends exploring methods for targeting homes with electric resistance heating for DMSHP retrofits. DMSHPs will nearly always be less expensive to operate than electric resistance heat, as shown by the COP of DMSHPs remaining above 1.0 on average for nearly all outdoor temperatures. Even at very cold temperatures where some non-cold climate units approach a COP of 1.0, the number of hours in this condition are very few. Prior to new activities, program and consumer cost-effectiveness would require review.

Recommendation: The team recommends targeting propane-heated homes for DMSHPs. As Figure ES-6 and Figure ES-7 show DMSHPs always operate less expensively than propane heating systems. Prior to new activities, program and consumer cost-effectiveness and regulatory considerations for fuel switching would require review.

Recommendation: The team recommends exploring methods for addressing oil-heated homes. To target these homes, homeowners should be educated to turn off a DMSHP during very cold outdoor conditions (below 8°F in 2015 and below 25°F in 2016), when an oil-fired system would operate less expensively (depending on energy prices and cold temperature COPs). This operating scheme, however, may not appeal to all customer types, as many may not wish to concern themselves about which heating system to operate and when. If oil prices increase against electric energy rates, the switchover temperature point for oil to DMSHP heat may move lower, allowing continual use of a DMSHP. Switchover points for all fuel comparisons will decrease as more efficient DMSHP units become available. Prior to new activities, program and consumer cost-effectiveness and regulatory considerations for fuel switching would require review.

Recommendation: Based on large energy-usage differences in DMSHP-cooled homes and central air conditioner-cooled homes, **the team recommends examining opportunities for a new construction measure to substitute DMSHPs for central air conditioners**.

Future Studies

This study provided a great deal of data describing how DMSHPs actually operate in Massachusetts and Rhode Island homes. These operations varied widely among units, with some used heavily and others used more like appliances turned on for short periods. Highest savings could be achieved by targeting homes where such units would deliver greater amounts of heating and cooling (i.e., where they can be installed to match the zoning of existing systems).

Another factor in increasing DMSHP savings will be development of controls that allow ductless systems and primary thermostats to interact and share information. The evaluation team recommends either targeting studies for new construction homes without natural gas available and where central air conditioning systems would be installed; or existing homes with electrical resistance and propane heating. These studies would help refine the best ways for DMSHP programs to achieve maximum savings.

Other future studies could explore the use of interfaces between learning thermostats and ductless systems. Future research questions include the following:

- How can utilities target homes with a high probability of using DMSHPs to displace more heating and cooling, therefore producing higher savings?
- What potential exists for new high-HSPF units to displace heating?
- What optimal zonal and control characteristics maximize use of DMSHPs?
- For new construction, how large would zonal savings have to be to avoid installations of single-zone central systems?

Introduction

Ductless mini-split heat pumps (DMSHPs) have supplied heating and cooling to homes across Europe and Asia for decades. Larger houses and colder climates partly explain the relatively slower adoption of these systems in the United States. Starting in 2008,[12] however, utility efficiency programs in the Pacific Northwest began marketing the technology to North American consumers and identifying its role in the residential HVAC market. The Massachusetts and Rhode Island Program Administrators (PAs) and Energy Efficiency Advisory Council (EEAC) consultants commissioned this study to better understand the impacts of DMSHPs installed in New England homes.

Figure 1 and Figure 2 show a typical DMSHP system installed at a residence in Massachusetts.

Figure 1. DMSHP Outdoor Unit

Figure 2. DMSHP Indoor Unit

---

[12] Northwest Energy Efficiency Alliance. "Efficient Ductless Heat Pumps (Warming up to Ductless Heat Pumps)." Last modified 2016. Accessed June 30, 2016. http://neea.org/initiatives/residential/ductless-heat-pumps

Program and Evaluation

The Massachusetts PAs COOL SMART Program and National Grid Rhode Island's High-Efficiency Heating and Cooling Program incentivized the installation of DMSHPs for their residential customers. Table 1 presents the program populations sampled as part of this study.

Table 1. Program Populations

State	Program Year	DMSHP Program Participant Count	Study Sample Participant Count
Massachusetts	2012–2013	3,229	112
Massachusetts	2014	1,055	20
Rhode Island	2013	507	20
Totals		**4,791**	**152**

The Massachusetts and Rhode Island PAs commissioned the evaluation team to conduct an *in situ* evaluation of DMSHPs. The team initially planned to study 132 Massachusetts homes that participated in the COOL SMART Program; the PAs, however, extended the scope of work to include 20 Rhode Island homes that participated in the High-Efficiency Heating and Cooling Rebate Program. Consequently, the team selected the sample population from participating customers who installed DMSHPs through the 2012–2013 or 2014 programs. Site visits began in July 2014.

Research Objectives

The evaluation sought to address many utility and consumer questions about DMSHPs, focusing on power and energy consumption, heat output, efficiency, and interactions with existing HVAC equipment. The specific research questions follow:

- How much energy is being saved with the average installation of a DMSHP through the programs?
- What are the relevant baseline equipment configurations and associated energy consumptions and load shapes?
- During each season, when are DMSHPs operating, how much energy are they consuming, and how much heating and cooling are they providing?
- How does DMSHP performance correlate with rated capacity, rated efficiency, and ambient conditions?
- How do cold-climate DMSHPs and standard unit performances compare?
- How does unit sizing affect heating performance?
- How do DMSHPs interact with central heating systems?
- What factors limit the use and performance of DMSHPs?
- Are program contractors sizing DMSHPs properly?

Existing Research

The evaluation team conducted an initial literature review to identify gaps between this report's objectives and findings presented in past research. Table 2 compares previous available research. Most of these studies collected power levels and supply air temperatures from a relatively small number of units, and used general-efficiency ratings to generate performance and savings. Only studies by Ecotope and Steven Winter Associates, Inc. (SWA) attempted to calculate actual, delivered heating or cooling; of these two, only the SWA study directly measured delivered heating and cooling.

Table 2. Comparison of Previous Research

Study Location; Date	# Sampled Units	Length of Study; Months	Parameters Metered					Airflow and BTU Balance	Reference
			Unit Total Power	Supply Air	Return Air	Room	Airflow		
Washington; 2014	60 power only, 35 power & BTU balance	14–19	Yes	Temp.	Temp.	–	Vane Anemometer	Yes	Ecotope, 2014(1)
New York; 2014	25	7	Yes	–	–	Temp.	–	No	ERS, 8/2014(2)
Maine; 2014	51	12	Yes	–	–	Temp.	–	No	EMI, 2014(3)
NH; 2014	9	8	Yes	Temp.	–	Temp.	–	No	ERS, 5/2014(4)
MA, CT, VT; 2015	7	1–2 (4 sites) & 5–7 (3 sites)	Yes	Temp. (3)	Temp. & RH	–	Indoor Head Current, point measurement	Yes	Williamson (SWA), 2015(5)
Massachusetts & RI; 2016	152	14 (67 sites) & 18 (85 sites)	Yes	Temp. (3) & RH	Temp. & RH	Temp. & RH	Indoor Head Current, point measurement	Yes	This Study

*Temp. = Temperature, RH = Relative Humidity

(1) Ecotope Inc. *Final Summary Report for the Ductless Heat Pump Impact and Process Evaluation.*

(2) Energy & Resource Solutions. *Con Edison EEPS Programs - Impact Evaluation of Residential HVAC Electric Program*. Tech. Consolidated Edison Company of New York, Aug. 2014. Web. June 30, 2016. http://www.coned.com/energyefficiency/PDF/Con_Edison_Res_HVAC_Final_Report-8-5-14.pdf

(3) EMI Consulting. Emera Maine Heat Pump Pilot Program. Tech. Emera Maine, September 2014. Web. June 30, 2016. http://www.emiconsulting.com/assets/Emera-Maine-Heat-Pump-Final-Report-2014.09.30.pdf

(4) Energy & Resource Solutions. *Emerging Technology Program Primary Research - Ductless Heat Pumps*. Tech. Regional Evaluation, Measurement & Verification Forum; Northeast Energy Efficiency Partnerships, May 2014. Web. June 30, 2016. http://www.neep.org/primary-research-ductless-mini-split-heat-pumps-0.

(5) Williamson, James, and Robb Aldrich. *Field Performance of Inverter-Driven Heat Pumps*. Tech. U.S Department of Energy, August 2015. Web. June 30, 2016. http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/inverter-driven-heat-pumps-cold.pdf

Method

In designing a research approach, the evaluation team first identified industry metrics for assessing DMSHP performance and the fundamental equations required to calculate such performance. The team determined which data points to collect, as follows:

- Solving the equations in terms of practically measured quantities
- Considering the roles of participant intentions and baseline equipment in DMSHPs' performance

The team used primary data collected at participant homes as well as derived parameters and secondary sources, such as manufacturer specifications, to answer the study's questions.

Sample Design

The evaluation team used several parameters to stratify program populations into key groups:

- Cold-climate or non-cold-climate unit sites[13]
- Single- or multi-head unit sites[14]
- Installed by the largest vendor or by all other contractors

In collaboration with the PAs and other evaluation stakeholders, the team identified these parameters at the study's outset, using them to inform sample targets during the participant recruiting process. Initially, the team designed sampling based on Massachusetts' 2012–2013 program population, but later expanded this to include Massachusetts' 2014 program population and Rhode Island's 2013 program population. Massachusetts participants from the 2014 program year did not receive an online survey due to timing considerations (i.e., they were added to the study after surveys had been completed). The team determined the sample size with a target of 90/20 confidence and precision for each stratum, assuming a coefficient of variation of 0.7. Table 3 presents details regarding these program populations, as measured by participant surveys and program tracking data. Figure 3 shows the locations of homes and systems studied in Massachusetts and Rhode Island.

---

[13] DMSHP manufacturers offer units with claimed high performance at very cold (below 0 °F) outdoor ambient temperatures. The evaluation team used the Efficiency Vermont TRM, current at the study's planning phase, to identify cold-climate units.

[14] DMSHPs consist of an outdoor unit that serves one or more indoor heads, which deliver heating and cooling. Single head units have one such head, and multi-head units have more than one head.

Table 3. Program Populations Strata

Sites	MA 2012–2013 Program Participant Share	MA 2014 Program Participant Share	RI 2013 Program Participant Share	Study Sample Participant Share	Study Sample Participant Planned Target	Study Sample Participant Count
Cold-climate unit sites	41%	15%	22%	51%	34	78
Non-cold-climate unit sites	59%	85%	78%	49%	34	74
Single-head unit sites (cold-climate units only)	48%	unknown(1)	73%	50%	34	107
Multiple-head unit sites	52%	unknown(1)	27%	50%	34	45
Installed by largest (MA) vendor sites	13%	7%	0%	28%	34	43
Installed by all other vendor sites	87%	93%	100%	72%	34	109
Population Total	**3,229**	**1,055**	**507**	**n/a**	**n/a**	**n/a**
Sample Total	**112**	**20**	**20**	**n/a**	**135**	**152**

(1) 2014 Massachusetts participants were not surveyed, so these data are not available for the total program population.

Figure 3. Locations of Sampled Residences

The team initially installed metering equipment at 30 sites during the pilot phase in summer 2014. The team then installed metering equipment at 102 sites during fall 2014, and the remaining 20 Rhode

Island sites in January 2015. During spring 2015, three homeowners sold their homes and meters were removed prior to closing. For the remaining Massachusetts sites, roughly 44 metering installations were removed in fall 2015, and the remaining 85 were removed in spring 2016. All Rhode Island sites were removed in late fall 2015.

Table 4 shows average attributes for the DMSHP metered at 152 sites. Units averaged about 1.3 tons, at just over 20 SEER and 10 HSPF.

Table 4. Average Ratings for Measured Outdoor Units

Category of System	Sample Size	Average Rated Cooling Capacity(1) (95°F) [Btu/h]	Average Rated Capacity at 47°F [Btu/h]	Average Rated Capacity at 17°F [Btu/h]	Average Rated EER(2) [Btu/Wh]	Average Rated SEER(3) [Btu/Wh]	Average Rated HSPF(4) [Btu/Wh]
All	152	16,435	19,491	11,426	13.2	20.6	10.3
Cold Climate Units (CC)	78	14,680	17,985	10,409	13.8	22.3	11.0
Non CC, multi	45	20,444	23,484	13,682	12.4	17.9	9.2
Non CC single	29	14,414	17,268	10,632	12.7	20.3	10.2

(1) The capacity is measured according to Air-Conditioning, Heating, and Refrigeration Institute (AHRI) guidelines for various outdoor temperatures: 95 °F, 47 °F, and 17 °F.

(2) The EER is the cooling provided in BTU, divided by the power consumption in watts—essentially the coefficient of performance (COP) times 3.412. It is tested at 95 °F outside and an indoor temperature of 80 °F.

(3) The seasonal energy efficiency ratio (SEER) is the cooling provided in BTU, divided by the power consumption in watts—essentially the COP times 3.412. It is tested at outside air temperatures ranging from 67 °F to 95 °F, with the lower temperatures weighted more heavily, and is meant to represent seasonal performance. The indoor temperature is set to 80 °F.

(4) The heating seasonal performance factor (HSPF) is the heating provided in BTU, divided by the power consumption in watts—essentially the COP times 3.412. It is tested at outside air temperatures ranging from 17 °F to 62 °F, and is meant to represent a seasonal performance. The indoor temperature is set to 70 °F.

Engineering Background

Some metrics used to quantify heating and cooling system performance can be measured directly, but others must be derived from related measurements. This section provides much of the background necessary to understand what these metrics are, their derivation from data collected, and assumptions made in this process.

Efficiency Metrics

Several commonly reported metrics serve to compare the performance of cooling and heating systems. Most of these metrics use point or spot measurements, evaluated at a specific set of conditions; for example, EER is calculated at 95 °F, and SEER is calculated from measured energy efficiency ratios (eer)[15] at several temperature points and compressor speeds. As these values are calculated based on specific operating conditions, they cannot be directly translated to another set of conditions.

These metrics prove useful for comparing like systems under similar conditions, but they do not fully represent actual DMSHP performance, mostly due to the way systems actually operate. Multiple metrics, evaluated over time and on site (*in situ*) incorporate real-world operating practices and can provide insights into how systems are used and how they react to various conditions. Two standard metrics are used to compare heat pumps: the coefficient of performance (COP) and the eer. When used across a range of conditions, these offer insights into the way systems actually operate.

Coefficient of Performance

A COP, defined at a given time for a given temperature, results from the following equation:

$$COP = \frac{heat\ provided\ by\ DMSHP\ \left(\frac{Btu}{h}\right)}{equivalent\ electric\ power\ input\ \left(\frac{Btu}{h}\right)} = \frac{heat\ provided\ by\ DMSHP\ \left(\frac{Btu}{h}\right)}{3.412\ \frac{\frac{Btu}{h}}{W} * \ electrical\ power\ input\ (W)}$$

While the COP can be determined for a DMSHP in both heating and cooling modes, industry practice typically uses it to define the heating mode (as reflected in the formula). The following equation defines a COP's theoretical upper bound (i.e., the Carnot Efficiency Limit) for a DMSHP operating in heating mode. Note that the equation evaluates temperatures in Rankine (an absolute temperature scale), equivalent to degrees Fahrenheit plus 459.67.

$$COP_{Carnot} = \frac{temperature\ supplied\ (Rankine)}{temperature\ supplied\ (Rankine) - outdoor\ air\ temperature\ (Rankine)}$$

An example of the theoretical maximum COP for 17 °F outside air and 120 °F discharge air is 5.62. At -10 °F, the theoretical maximum COP falls to 4.45. Actual systems never achieve these theoretical values, as they assume no losses and perfect efficiencies. Typical heat pump COP values in heating mode range from 2 to 4,[16,17] meaning a DMSHP produces two to four times more heat than the heat equivalent of the electricity it consumes. In comparison, electric resistance heating—which produces as much heat as electricity provided—maintains a 1.0 COP.

---

[15] For clarity, the evaluation team uses EER to refer to an AHRI energy efficiency ratio rating at 95 °F, and eer to refer to energy efficiency ratios in general for other conditions.

[16] Princeton University. "Appendix 2-A Definitions of Energy and Energy Efficiency." Last modified June 10, 1996. Accessed June 1, 2016. https://www.princeton.edu/~ota/disk1/1992/9204/920409.PDF

[17] Georgia State University. "Heat Pump, Air Conditioners and Heat Pumps, Coefficient of Performance, Energy Efficiency Ratio, Heat Pump Energy Flow." Last modified April 29, 2007. Accessed June 1, 2016. http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/heatpump.html

A DMSHP in heating mode also can produce a negative COP. Though infrequent, this occurs when a DMSHP in heating mode actually cools a space while defrosting an outdoor unit. Equipment only produces a negative COP when operating in the reverse of its intended purpose (e.g., heating in summer or cooling in winter). The above equation also applies for a cooling scenario, but the COP remains positive as the equation changes to reflect the heat quotient removed (or cooling provided), divided by the energy input.

Energy Efficiency Ratio

Generally defined at a given temperature, an EER metric results from the following equation:

$$EER\ \left(\frac{Btu}{Wh}\right) = \frac{heat\ removed\ by\ DMSHP\ \left(\frac{Btu}{h}\right)}{electrical\ energy\ consumed\ (W)}\ \mathrm{OR}\ \frac{cooling\ provided\ by\ DMSHP\ \left(\frac{Btu}{h}\right)}{electrical\ energy\ consumed\ (W)}$$

This equation, which quantifies efficiency for a DMSHP in cooling mode, serves as the industry standard (as defined by the Air-Conditioning, Heating, and Refrigeration Institute [AHRI]). The most common test conditions are defined as 80 °F for an inside air temperature and 95 °F for an outdoor air temperature.[18]

Though very similar to a COP, EER generally is only used for cooling mode and, unlike the dimensionless COP, is expressed in BTU per watt-hour (although industry convention drops units from the EER metric)[19,20] Typical DMSHP rated EER values range from 8 to over 12. Many DMSHPs observed for this evaluation had published rated EERs between 12.9 and 15.5 (for an average of 13.1).[21]

Seasonal Efficiency Metrics

Seasonal metrics account for natural weather variations occurring over the course of typical year that cannot be accounted for by measuring unit performance at a single point in time. Heat pump comparisons use two standard seasonal metrics: the seasonal energy efficiency ratio (SEER), and the heating seasonal performance factor (HSPF).

---

[18] Air-Conditioning, Heating, and Refrigeration Institute. *ANSI/ARI Standard 210/240 with Addenda 1 and 2: 2008 Standard for Performance Rating of Unitary Air-Conditioning and Air-Source Heat Pump Equipment.* December 2012. Available online: <http://www.ahrinet.org/App_Content/ahri/files/standards%20pdfs/ANSI%20standards%20pdfs/ANSI.AHRI%20Standard%20210.240%20with%20Addenda%201%20and%202.pdf>.

[19] Princeton University 1996.

[20] Russ Rowlett and the University of North Carolina at Chapel Hill. “How Many? A Dictionary of Units of Measurement.” Last modified December 9, 2008. Accessed June 1, 2016. <https://www.unc.edu/~rowlett/units/dictE.html>.

[21] Mitsubishi Electric Corporation. *Outdoor Unit Service Manual No. OBH543-A.* September 2010. Available online: <http://www.mitsubishipro.com/media/214712/muz-fe09-18na_service_obh543a_9-10.pdf>.

Seasonal Energy Efficiency Ratio

SEER characterizes DMSHP performance during the cooling season. Although similar to EER, SEER captures the entire season rather than a single operating point. When using SEER to rate equipment for labeling purposes, it is calculated at several specific temperature points to simulate a cooling season. For this study, the evaluation team calculated (field) SEER using heat removed from the conditioned space during the cooling season, divided by the total electrical energy consumed by the heat pump during the same time period:[22]

$$SEER\left(\frac{Btu}{Wh}\right)=\frac{total\ heat\ removed\ (Btu)}{electrical\ energy\ consumed\ (Wh)}=\frac{total\ cooling\ provided\ (Btu)}{electical\ energy\ consumed\ (Wh)}$$

Typical SEER values range from 13 to 24, with the federal minimum for DMSHPs currently set at 14 (with an average published SEER of 20.6 in units observed for this evaluation).[23] Although a unit's actual SEER depends on the climate, the standard (laboratory) rating does not account for regional climate differences in summer[24]—one reason that field SEER and tested/stated SEER values differ. Variation also occurs due to use of a system in conditions other than those simulated during testing (e.g., a homeowner might operate the unit only during hot evenings).

Heating Seasonal Performance Factor

HSPF applies to DMSHPs operating in heating mode. This uses the same units as those for SEER, but applies only to a heating scenario.[25] Typically, HSPF serves to compare air-source heat pumps (ASHP)—which include DMSHPs. The federal minimum HSPF value for an ASHP is 8.2,[26] and the U.S.

---

[22] AHRI 2012.

[23] AHRI. "Seasonal Energy Efficiency Ratio: What You Should Know about SEER." Last modified 2016. Accessed June 10, 2016 http://www.ahrinet.org/Homeowners/Save-Energy/Seasonal-Energy-Efficiency-Ratio.aspx

[24] Fairey, Philip, D. Parker, and M. Lombardi (Florida Solar Energy Center) and B. Wilcox (Berkeley Solar Group). "Climate Impacts on Heating Seasonal Performance Factor (HSPF) and Seasonal Energy Efficiency Ratio (SEER) for Air Source Heat Pumps." *ASHRAE Transactions*, American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc., Atlanta, Georgia, June 29, 2004. Available online: http://www.fsec.ucf.edu/en/publications/html/FSEC-PF-413-04/

[25] The Air-Conditioning and Refrigeration Institute (ARI 2003) describes the standard method for determining the HSPF. It describes the range of conditions to be evaluated, including six different climate zones and several building loads. However, the official published HSPF rating is from a single climate zone (IV) and building load (minimum expected for the heat pump). *https://conduitnw.org/_layouts/Conduit/FileHandler.ashx?rid=184*

[26] American Standard Heating and Air Conditioning. "2015 Federal Regional Standards for Heating and Cooling Products." eAPB1410. May 5, 2014. Available online: http://www.sgtorrice.com/files/Pages/News/2015-Regional-Standards-Cooling-Heating%20Products-rev1.pdf

Environmental Protection Agency requires an HSPF of 8.5 or more[27] to earn an ENERGY STAR rating. Rated HSPF values typically range from 7.5 to 13 (with an average published HSPF of 10.3 in units observed for this evaluation).[28] There is some concern in using the HSPF calculation for a variable speed unit such as a DMSHP. Concerns include how the unit is rated in heating mode and whether that rating affects the building load used in rating equations.

Energy

As the *Power* section outlines in greater detail, a watt-hour transducer directly measures electrical energy consumed by a DMSHP. Determining the energy output—or heating and cooling provided—requires making several indirect measurements and calculations. An energy balance, written in per-unit time, serves as the basis for this calculation:

$$\Delta\dot{E} = \dot{E}_2 - \dot{E}_1$$

In this equation, each term is a rate of energy with dimensions $\left[\frac{Btu}{min}\right]$, where the subscripts 1 and 2 correspond to the state of the system before and after contacting the indoor unit's heat exchanger (respectively), and $\Delta\dot{E}$ is the heat provided or removed from a space served by the system. In all cases, the rate of energy change is calculated as the product of the mass flow, $\dot{m}$, and enthalpy, h, which quantifies the energy held within the mass of the air-water vapor mixture (written as follows):

$$\dot{E} = \dot{m}h$$

Evaluating this across the system yields:

$$\Delta\dot{E} = \dot{m}_2 h_2 - \dot{m}_1 h_1$$

Under most situations, the mass entering the unit as an air-water vapor mixture exactly matches the mass supplied to the space served. Under certain conditions, however, cooling moist air condenses water vapor (dehumidification), and the condensed water drains from the system through a dedicated hose (as shown in Figure 4).

---

[27] ENERGY STAR. "Air-Source Heat Pumps and Central Air Conditioners Key Product Criteria." Last Modified Wednesday, July 27, 2016. Accessed Wednesday, July 27, 2016. https://www.energystar.gov/products/heating_cooling/heat_pumps_air_source/key_product_criteria

[28] "Best Heat Pump Reviews 2016." Accessed Wednesday, July 27, 2016. http://heatpumpdigest.com/

Figure 4. Indoor Unit Mass Flow

Considering this condensate's energy content versus ambient temperature to be negligible (as commonly done),[29] the mass balance simplifies to consider only entering and leaving air, as shown in the following equation:

$$\dot{m}_1 = \dot{m}_2 = \dot{m}$$

The energy balance then becomes:

$$\Delta\dot{E} = \dot{m}(h_2 - h_1)$$

Because the metered fan current supplied to the indoor head correlates with supply airflow, the evaluation team evaluated the mass of the supply air:

$$\Delta\dot{E} = \dot{m}_2(h_2 - h_1)$$

Where mass is the product of volume and density:

$$m = V\rho$$

Substitution yields:

$$\Delta\dot{E} = \dot{V}_2\rho_2(h_2 - h_1)$$

The above equation uses the following quantities and dimensions:

$\dot{V}\left[\frac{ft^3}{min}\right]$ = volumetric flow rate

$\rho\left[\frac{lbm}{ft^3}\right]$ = density

$h\left[\frac{Btu}{lbm}\right]$ = enthalpy

---

[29] Mitchell, John W. and J. E. Braun. *Principles of Heating, Ventilation, and Air Conditioning in Buildings.* March 6, 2012. Available online: http://higheredbcs.wiley.com/legacy/college/mitchell/0470624574/online_chap/ch02.doc, the latent heat of the conditioned air is however fully calculated.

All variables on the equation's right-hand side are then calculated from other measured values, relying on the additional assumptions described below.

Airflow

Calculating energy output requires continuous measurement of an indoor unit's volumetric flow rate, but devices capable of this prove ill-suited to remain in a residence for long periods, given their size and effect on a unit's operation (photos in Appendix A illustrate these limitations). Without the ability to measure airflow continuously, the evaluation team needed to meter another quantity and use those results to calculate airflow. Airflow results from operation of an indoor unit's fan, and equating the fan's electrical power with the mechanical power it supplies produces the following equation:

$$P = iv = \Delta p \dot{V}$$

Where P is power, i is current, v is voltage, Δp is differential pressure, and $\dot{V}$ is the volumetric flow rate. Substituting in the approximation[30] for the behavior of fluid passing through a resistive system element:

$$\Delta p = k\dot{V}^2$$

where k is an unknown constant, results in the following equation:

$$\dot{V} = \left(\frac{iv}{k}\right)^{\frac{1}{3}}$$

This equation says volumetric airflow is proportional to the cube of electrical power consumed. The evaluation team determined this relationship between airflow and power through measurements (i.e., empirically), as shown in Appendix A, given the constant k remains unknown, and the exponent is an approximation that varies in actual systems. Appendix A provides a complete discussion of the team's considerations in estimating airflow from current.

Data Collection

Using its understanding of measurements necessary to answer the study's essential questions, the evaluation team identified appropriate equipment, developed methods for metering these data points, and specified data to collect from on-site inspections.

Power

To measure a DMSHP system's electrical consumption, the team installed a power metering setup. This involved installing a logger and sensors inside the outdoor unit, where a circuit from residential electrical power provided power for the entire DMSHP. Figure 5 shows a sample installation.

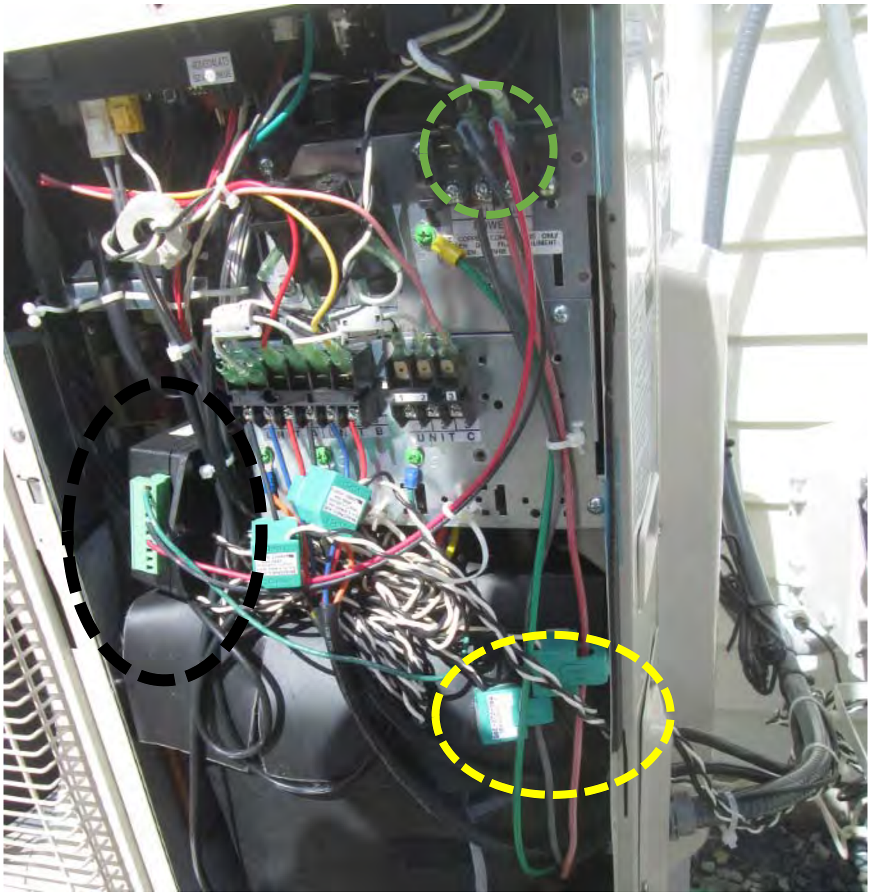
---

[30] Dr. Charles Sullivan. *Lumped Fluid Systems.* Fluid Systems Analysis, Engs 22—Systems. Summer 2004. Available online: http://www.dartmouth.edu/~sullivan/22files/Fluid_sys_anal_w_chart.pdf

The team's power metering setup included the following:

- An alternating-current watt-hour transducer (circled in black)
- Two current transformers (CTs), sized for the DMSHP's full-load operating current (circled in yellow)
- Voltage leads (circled in green)
- A data logger with a pulse adaptor (not pictured)

Figure 5. Power Metering Setup Installed on an Outdoor Unit

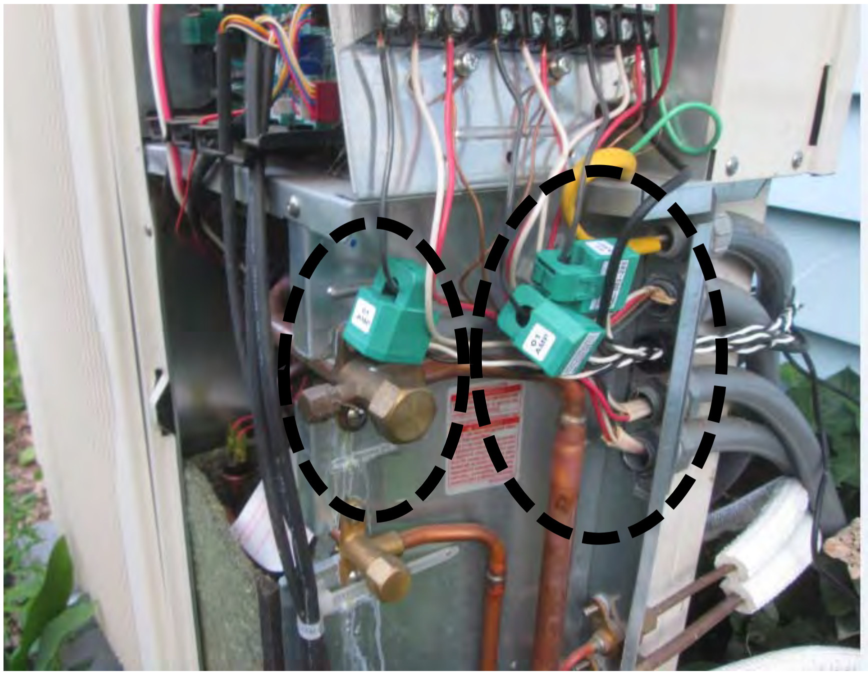


The watt-hour transducer measured voltage and current supplied to the DMSHP system and converted energy consumed during the time interval to a number of pulses. The team then used the number of pulses and the logging interval to derive average power and energy consumed over that time period.

Fan Current

For each unit studied, the evaluation team installed CTs on the wire powering the indoor head. For the study's duration, these CTs sensed the indoor unit's current (amperage) draw at one-minute intervals. The team sized CTs to capture the range of a fan's current at different fan speeds. For the airflow spot measurement process (detailed in the Airflow section), the team increased the fan current measurement frequency to read every two seconds, thus increasing the resolution and expediting the procedure. After the spot test, the team returned the sampling frequency to one-minute intervals. Figure 6 shows an installation for a DMSHP system using three indoor heads.

Figure 6. Current Transformers Installed on Fan Wires



Airflow

The evaluation team directly measured the airflow for each indoor unit while on site, using a calibrated flow hood (i.e., balometer) to capture spot measurements of delivered airflow at each corresponding fan setting. The team also used specialized frame kits for each balometer, with the instrument's geometry modified to better fit a typical DMSHP head. Figure 7 shows a typical flow hood with the specialized frame kit attached.

Figure 7. Balometer

The study population's various indoor unit models displayed great variability regarding louver settings and fan-speed options. To produce repeatable and standardized results, the team conducted airflow measurements with louvers fixed in place (i.e., not oscillating) and, wherever possible, in fan-only mode. The fan-only setting meant the mode's discharge conditions generally approximated standard conditions (i.e., 68 °F and 1 atmosphere). The issue with using other modes to measure airflow is that various units have algorithms that continuously change fan speeds as unit's approach temperature settings interfering with airflow measurement.

The team took airflow measurements at each speed setting on the indoor head's controller, while simultaneously collecting one minute of fan current readings at two-second logging intervals. This procedure collected a suitable number of current readings for each airflow reading to allow for correlating airflow and amperage. Logging began once the fan reached a steady state after ramping up or ramping down the fan motor.

Temperature and Relative Humidity

To calculate heating and cooling loads, the evaluation team measured temperature and relative humidity across different system points. Using a range of temperature and relative humidity sensors, the team measured outdoor air, leaving or supply air from the indoor unit, and entering or return air at the indoor unit. To better understand customers' operating behaviors, measurements included the indoor ambient temperature and the relative humidity.

At the outdoor unit, the team installed a temperature and relative humidity sensor, logging values at one-minute intervals. Installing this sensor on the unit's entering air side best measured the environment in which the unit absorbed or rejected heat. The team also installed a solar shield on the sensor to prevent erroneous readings from solar heating. Figure 8 shows the installation, including the solar shield.

Figure 8. Outdoor Entering Air Temperature and Relative Humidity Sensor

At the indoor unit's center, the team installed a temperature and relative humidity sensor to measure leaving air. The team also installed two additional temperature sensors far left and far right at the supply grill to gather data used to calculate the average temperature across the supply coil. Figure 9 shows installation of these sensors.

Figure 9. Leaving Air Sensors on a DMSHP Head

The team also installed a temperature and humidity sensor on top of each indoor unit to measure entering air temperatures and relative humidity. Figure 10 shows the logger and its embedded sensor zip-tied on the return grill above the indoor unit.

Figure 10. Entering Air Sensors on a DMSHP Head

Heating Systems

To measure other heating systems' operating times, the evaluation team used motor loggers, which either employ an internal AC magnetic field sensor or an external current switch. With both configurations, the team calibrated the sensors in their installed position, with the heating system metering point running and operability verified during the initial installation.

Figure 11 shows a motor logger placed on a boiler circulator pump (which also served the space served by the DMSHP). The image illustrates a similar logger on an oil burner. This same installation can be used to meter a gas valve. The team collected nameplate data from all relevant heating system equipment, and used these data for various baseline and coincident-heat calculations.

Figure 11. Boiler System Monitoring

Figure 12 shows the meter deployment for a gas-fired furnace. To monitor gas consumption, field technicians installed motor loggers with CTs on both stages of the gas valve. Technicians installed a similar logger on the blower motor's power wire. This logger provided backup data on the unit's run-time.

Figure 12. Furnace System Monitoring

Site Attributes

To analyze DMSHP performance and to determine their interactions with other cooling or heating sources, field technicians collected numerous site attributes to calculate approximate heat gain and loss using the Manual J Residential Load Calculator.

The evaluation team sketched a floor plan for each house and measured each room's wall lengths and average ceiling heights to determine room volumes. The team noted general exterior wall construction as well as space separating the conditioned area (e.g., exterior, conditioned space, ground), including space above and below each ceiling and floor (e.g., attic, exterior, conditioned space, slab, basement). Floor plan drawings indicated wall orientations as well as door and window locations. Measurements included dimensions of all windows and doors, along with notes about their construction, orientation, and amount of shading.

At each site, the team recorded a DMSHP's make, model, and configuration as well as coincident heating or cooling sources (e.g., central heating or cooling, space heating, fireplaces). The team also collected other information, including system type, fuel source, heating or cooling capacity, unit make and model, control system, and space served. Floor plans showed locations of DMSHP units, space heating or cooling equipment, and zones served by central systems. This mapping helped in determining overlap between systems.

Analysis

With data collected and a basis established for deriving further quantities from these data, the evaluation team developed additional methodologies and assumptions to conduct the analysis. Discussions of these follow.

Airflow

The Airflow section (above) described the relationship between current and airflow. The evaluation team mapped current to airflow by fitting a curve to spot measurements recorded on site, thus determining the coefficient and exponent. The team installed metering equipment at 132 sites during fall 2014, with the remaining 20 Rhode Island sites installed in January 2015. In fall 2015, the team removed roughly 65 metering installations, and removed and the remaining 85 in spring 2016. For sites removed in spring 2016, the team used two sets of spot measurements—recorded during fall 2015 and spring 2016—for these calculations. Sites removed in fall 2015 used a single set of airflow mapping data, recorded during meter removal.

This approach captured system behaviors at given times and under certain conditions, but the team also considered variables influencing airflow in addition to fan speeds, such as the amount of material present on an indoor unit's air filter, condensed water that can collect on heat exchangers during cooling, and the position of vanes used to direct conditioned air. Via testing, the team found these restrictions induced current drops proportional to the drops in volumetric airflow; metering current suitably accounted for these restrictions. Appendix A fully discusses testing methods, equipment, and results.

Weather Normalization

The evaluation team weather-normalized the study results to account for variability between weather conditions present during the study and during a typical year. The team metered air temperatures and relative humidity levels adjacent to each DMSHP outdoor unit on site. As sun, wind, snow, and other variables affected these measurements, the team also collected historical National Oceanic and Atmospheric Administration data, recorded during the study period by the nearest U.S. Weather Bureau Army Navy weather station. The team then aligned these data with each site's meter data, and calculated average values in 1-degree temperature bins.

This technique served to illustrate how, on average, participants operated their DMSHPs in various weather conditions. To normalize data to a typical year, the team gathered National Renewable Energy Laboratory (NREL) typical meteorological year (TMY3) data from the nearest U.S. Air Force weather station, binned these data by temperature, and multiplied the averages of the study's value of interest by the time spent in each bin during a typical year. Where the study found the highest or lowest temperature observed less extreme than a typical year, the team used data from the nearest observed temperature bin.

Climate During the Study

As shown in Table 5, summer 2015 experienced a larger number of cooling degree-days (CDD) than 2014. With the exception of the Norwood, Massachusetts, location, all CDD values from 2015 exceeded the 10-year average: winter 2015 was colder than the 10-year average for all stations, and winter 2016 was milder than the 10-year average for all stations.

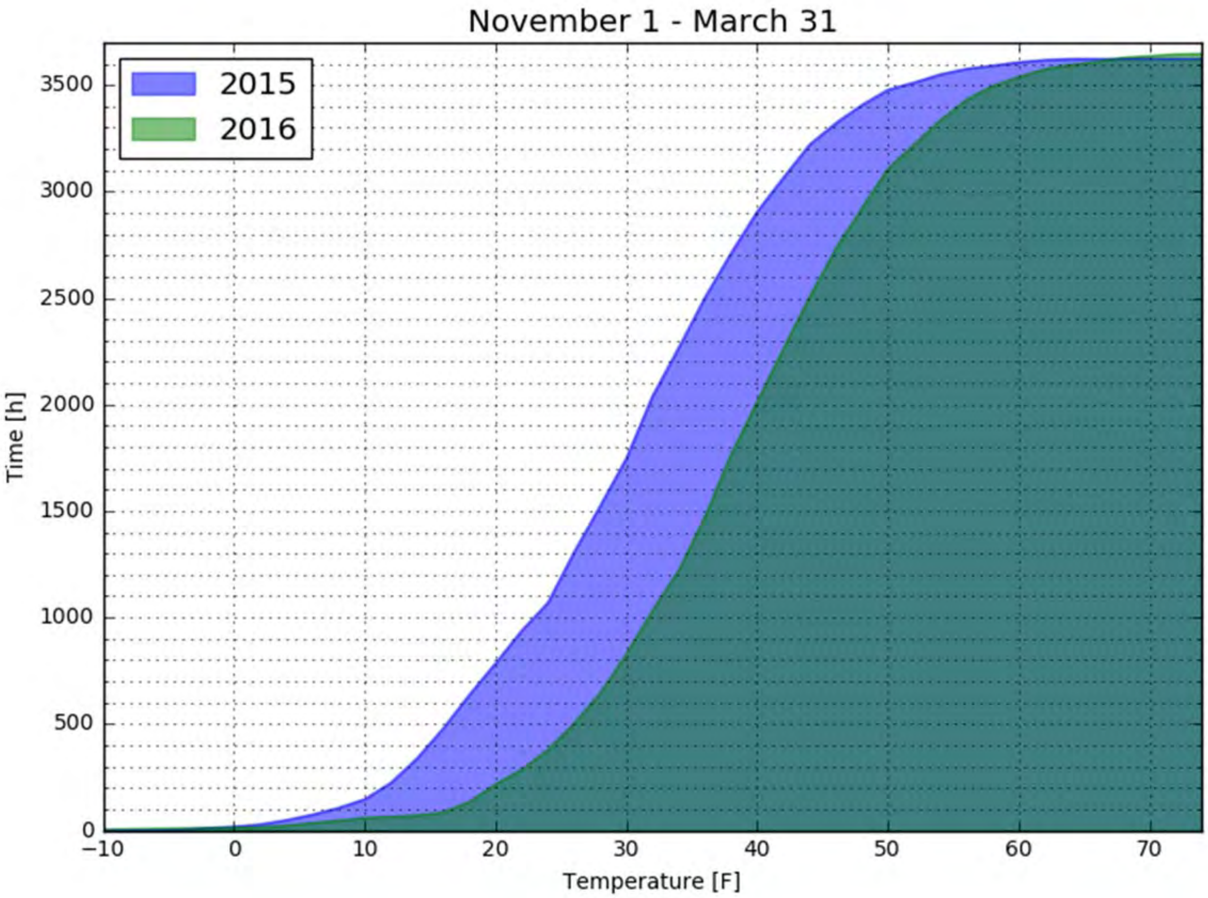
Table 5. Observed Weather During the Study

Station	10 year CDD[1] Average	2014 CDD	2015 CDD	10 year HDD Average	2014/15 HDD	2015/16 HDD
Norwood Memorial Airport (54704)	641	474	625	5,563	6,685	5,379
Worcester Regional Airport (94746)	569	412	637	6,400	7,050	5,824
Gen E L Logan International Airport (14739)	858	769	921	5,369	6,029	4,804
Lawrence Municipal Airport (94723)	765	609	839	6,462	6,661	5,264
Westover Afb/Metropolitan Airport (14703)	650	483	673	6,270	7,084	5,577
Dillant-Hopkins Airport (94721)	464	358	490	6,959	7,523	6,143
Brnsbl Muni-Bman/Pol Fd Ap (94720)	592	488	677	5,569	5,984	5,059
Marthas Vineyard Airport (94724)	528	275	554	5,547	6,208	5,052
North Central State Arpt (64710)	579	423	615	5,945	6,622	4,627
Plymouth Municipal Airport (54769)	667	481	696	5,795	6,433	5,227
Beverly Municipal Airport (54733)	606	532	702	6,068	6,663	5,378
New Bedford Rgnl Airport (94726)	643	471	706	5,671	6,227	5,034
Theodore F Green State Airport (14765)	845	699	945	5,346	6,047	4,778
Block Island State Airport (94793)	623	504	725	5,071	5,609	4,531

(1) CDDs were base 65 and based on average daily temperature.

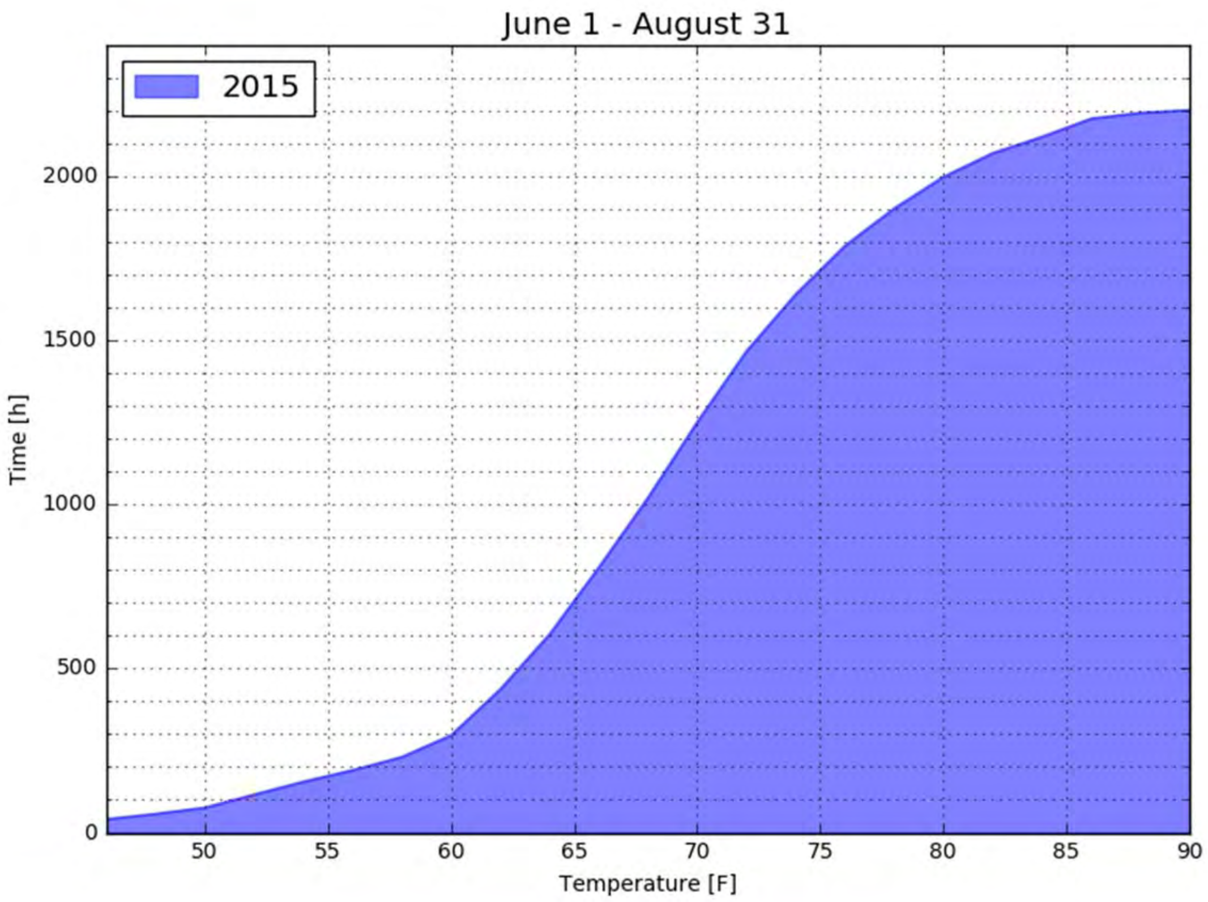
Taking a closer look at temperatures during winter 2015 and 2016, Figure 13 shows the cumulative distribution of hours spent at various temperatures for the two winters. Winter 2015 had a similarly shaped distribution of hours, but shifted left by about 8 °F. For both winters, very few hours fell below 0°F. The midpoint of distribution (i.e., half of the hours) was about 30°F during winter 2015 and about 38°F during winter 2016.

Figure 13. Cumulative Distribution of Winter Hours Versus Temperature Bin



Error! Not a valid bookmark self-reference. shows the distribution of summer hours at various temperatures, with very few hours at 90°F or greater.

Figure 14. Cumulative Distribution of Summer Hours Versus Temperature Bin



Manual J: Residential Load Calculation

The evaluation team examined how contractors sized DMSHPs and whether the units could meet the heating and cooling requirements for the spaces they served. To answer this, the team calculated thermal loads using an abridged Manual J[31] calculator, in conjunction with the *Manual J: Residential Load Calculation* textbook published by the American National Standards Institute/Air Conditioning Contractors of America (ANSI/ACCA, Version 2, Eighth Edition). These calculations estimated the highest steady state heating and cooling loads that DMSHPs would experience at design conditions.

An industry-approved method for establishing the sizing of heating and cooling systems, Manual J provides a recommended resource for contractors' use (either directly by using an abridged spreadsheet or indirectly by using the plethora of available third-party software). For this study, the team used the ANSI/ACCA Manual J's electronic spreadsheet.

Through discussions with homeowners, the team established boundaries on spaces served by DMSHP units. These boundaries, varying from large rooms to regions of a house to an entire house, proved crucial for gathering an appropriate amount of data from each house. During these discussions, the team focused on homeowners' requests to installing contractors rather than *in situ* performance to draw appropriate comparisons.

Practical limitations on data collected on site dictated the analysis detail level. For example, thicknesses and types of wall insulation often cannot be determined without opening holes in a wall. Given such limitations, the team assessed the type and quantity of insulation present in basements and attics, and consulted homeowners for further information. When the former proved difficult, the team used applicable building codes and typical construction practices.

To establish outdoor design conditions for Manual J, the team used the arithmetic mean of the geographic latitude and longitude of the entire sample population, and then selected the ACCA Manual J location closest to this point. This method provided an average condition, but gave a good indication of the unit's relative capacity to the space it served. The resulting location (i.e., Framingham, Massachusetts) had a summer 1% dry bulb temperature of 88°F and a winter 99% dry bulb temperature of 6 °F. The team used these values to calculate heat gain and heat loss in spaces served by DMSHPs.

Savings

To answer a key research question ("*How much energy is being saved with the average installation of a DMSHP through the programs?"*), the evaluation team developed a methodology to estimate savings for numerous heating and cooling baseline equipment options. Alternative equipment options for heating included the following:

---

[31] Air Conditioning Contractors of America. *ACCA Speed-Sheet for Manual J (Abridged Edition).*PowerPoint presentation and corresponding Microsoft Excel workbook. June 22, 2015. Available online: http://www.acca.org/communities/community-home/librarydocuments/viewdocument?DocumentKey=0bc73e80-6c3c-43cb-bdb2-43316a380fa4 http://www.acca.org/HigherLogic/System/DownloadDocumentFile.ashx?DocumentFileKey=b77bcc44-be9c-45d5-b23f-6774e5663ed2&forceDialog=1

- Furnace (assuming 85% and 90% AFUE, MA 2013–2015 TRM)
- Boiler (assuming 82% AFUE, MA 2013–2015 TRM)
- HSPF 7.7 DMSHP (federal minimum efficiency standard for central ASHPs prior to January 1, 2015)
- HSPF 8.2 DMSHP (current federal minimum efficiency standard for central ASHPs, effective January 1, 2016)
- Electric resistance baseboard heat or furnace (COP=1.0)

For cooling, alternative equipment options included the following:

- EER 9.8 Window AC (current federal standard)
- SEER 13.0 Central AC with duct losses of 15% (current federal minimum efficiency standard for central ACs and duct-loss estimate based on the MA 2013–2015 TRM)
- SEER 13.0 DMSHP (federal minimum efficiency standard for central ACs and for central ASHPs prior to January 1, 2015)
- SEER 14.5 DMSHP (from a team estimate from market research for lowest-cost DMSHP options available, reflecting an increase from the current federal minimum efficiency standard of SEER 14.0, effective January 1, 2016)

To develop the savings methodology, the team assumed that the DMSHP heating and cooling capacity remained constant in each baseline scenario. The numerator of SEER or HSPF value (per the Seasonal Efficiency Metrics section) represented the capacity—a metered and quantifiable parameter. To estimate savings for the most common baseline scenario (i.e., a lower-efficiency DMSHP), the team used metered energy consumption. The following equations show the savings calculation approach.

Cooling savings equation for electric baseline system:

$$\Delta kWh_{COOL} = \sum_{i=T_L}^{T_H} \left(kWh_{METERED} \times \frac{EER_{EE}}{EER_{BASE}} - kWh_{METERED} \right) \times \frac{Hours_{TMY}}{Hours_{ACTUAL}}$$

Heating savings equation for electric baseline system:

$$\Delta kWh_{HEAT} = \sum_{i=T_L}^{T_H} \left(kWh_{METERED} \times \frac{EER_{EE}}{EER_{BASE}} - kWh_{METERED} \right) \times \frac{Hours_{TMY}}{Hours_{ACTUAL}}$$

Where:

ΔkWh_$_{\text{COOL}}$ = Reduction in annual kWh cooling consumption of heat pump equipment
ΔkWh_$_{\text{HEAT}}$ = Reduction in annual kWh heating consumption of heat pump equipment
T_$_{\text{H}}$ = Highest observed outdoor dry bulb temperature with cooling during cooling season; heating during heating season from a local weather station
T_$_{\text{L}}$ = Lowest observed outdoor dry bulb temperature with cooling during cooling season; heating during heating season from a local weather station
kWh_$_{\text{METERED}}$ = Logged energy consumption
EER_$_{\text{BASE}}$ = Instantaneous efficiency of baseline equipment (varies with outdoor conditions)
EER_$_{\text{EE}}$ = Instantaneous efficiency of installed equipment (varies with outdoor conditions)
Hours_$_{\text{TMY}}$ = Total count of TMY hours in each temperature bin from a local weather station
Hours_$_{\text{ACTUAL}}$ = Total count of observed hours in each temperature bin from a local weather station

This study directly measured instantaneous efficiency to evaluate DMSHP performance. The team initially used metered efficiency and then decremented the baseline unit's efficiency by a proportional amount. This proved mathematically equivalent to the method described below.

The team reviewed manufacturers' specification data to determine baseline DMSHP performance (e.g., 13.0 or 14.5 SEER) versus temperature, and developed heating and cooling performance curves (eer versus temperature). In many cases, manufacturer-rated SEER and HSPF values differed from DMSHPs' actual seasonal operations (see Figure 50 and Figure 51). The team assumed, however, that the energy-consumption *difference* between a baseline DMSHP and efficiency DMSHP correlated to the ratio of AHRI-rated SEER and HSPF values.

In other words, if a 20.0 SEER DMSHP had an actual operating efficiency of 15.0 SEER, the team did not calculate savings relative to a 13.0- or 14.5-SEER baseline DMSHP. Rather, the team assumed the baseline DMSHP would have operated less efficiently, maintaining the following relationship as a function of temperature (T):

$$\frac{SEER_{EE}}{SEER_{base}} = \frac{\dfrac{total\ heat\ removed}{efficient\ kWh\ consumption}}{\dfrac{total\ heat\ removed}{baseline\ kWh\ consumption}} = \frac{baseline\ kWh\ consumption(T)}{efficient\ kWh\ consumption(T)}$$

To estimate savings from energy consumption, the evaluation team only used energy consumed when the DMSHP actually provided heating or cooling. This effectively removed energy consumed due to various operation types that would not generate savings (e.g., fan-only operation).

The team assumed a baseline efficiency DMSHP would have consumed energy in the same way when operating in a mode that would not provide heating or cooling. The possibility certainly exists that a baseline DMSHP could use more energy (e.g., through less efficient defrost control sequencing or less-efficient dehumidification), but the team did not have operational data of baseline DMSHPs to estimate savings. Thus, the final DMSHP savings estimates could be conservative.

The team identified heating and cooling mode operations through site-by-site review of raw meter data. Primarily, the review determined the indoor unit airflow (i.e., in some modes, indoor fans did not run) and the enthalpy differential from supply and return air sensors to identify operation for every metered interval.

To estimate savings for other system types, the team followed a similar approach, assuming that alternative equipment would have provided capacity equivalent to that provided by the DMSHP. Table 6 summarizes the savings methodologies used for the most common baseline options and describes additional adjustments to the final savings estimate for each scenario (e.g., a DMSHP that offsets heat delivered by a fossil fuel system provides positive fuel savings but negative kWh savings). Additional zonal savings could be available from only heating occupied spaces, particularly during shoulder months with low heating loads and homeowners possibly heating only with the DMSHP. This study did not directly capture such savings.

Table 6. Savings Calculation Methodology for Alternative Heating/Cooling Equipment

Baseline	Savings Methodology	Savings Adjustments
Electric Resistance	Heating savings based on total heating capacity provided by DMSHPs in winter and a difference in efficiency (1.0 COP = 3.412 HSPF)	Subtract energy use from savings estimate if use did not provide heat (e.g., defrost, standby power)
Furnace	Heating savings based on total heating capacity provided by DMSHPs in winter, converted to MMBTUs and adjusted by furnace efficiency	Subtract total electrical energy use of DMSHP from estimated fan energy use of associated furnace runtime reductions from central furnace fan
Boiler	Heating savings based on total heating capacity provided by DMSHP in winter, converted to MMBTUs and adjusted by boiler efficiency	Subtract total electrical energy use of DMSHP; assume no benefit (reduction) in boiler circulation-pump energy use.
Window AC	Same methodology used for DMSHPs (ratio of window AC AHRI EER rating to DMSHP SEER rating)	None
Central AC	Same methodology used for DMSHP (ratio of window AC AHRI EER rating to DMSHP SEER rating) with additional 15% duct losses	None

To estimate summer peak demand savings, the team determined total weather-normalized energy consumption (kWh) and savings from all meter data during the demand period and kWh by the total number of hours during the demand period. The four-hour summer demand period begins at 1:00 PM, June through August, on non-holiday weekdays. The two-hour winter demand period begins at 5:00 PM, December through January, on non-holiday weekdays. To calculate savings, the team followed the energy-savings methodology.

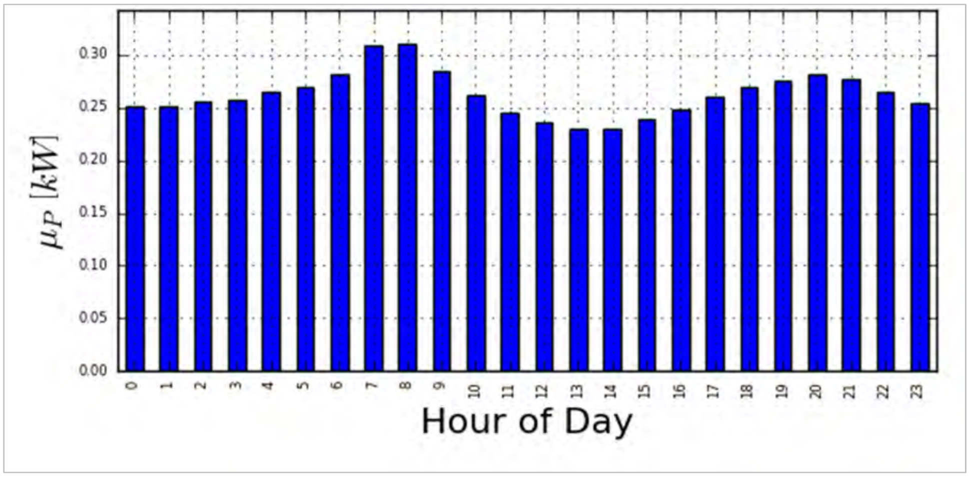
Results

This section presents the evaluation's general findings and summarizes data in the context of each research objective. The graphs and tables show results across the population of DMSHPs studied. The data underlying the graphs was derived from detailed analysis of time series of data for each system including power consumed and cooling and heating provided. Appendix D shows an example of a time series of a DMSHP.

Load Shapes

Figure 15, Figure 16, and Figure 17 show metered units' average power usage of for winter 2015,[32] summer 2015,[33] and winter 2016, respectively, by time of day. Average heating demand ranges from 150 to 300 watts, with a slight shape to the curve, a peak at 8:00 AM, and a small relative peak at 8:00 PM. The cooling curve shows much more shape and variation, with a relative minimum at 4:00 AM and a relative maximum at 4:00 PM. The cooling load shape displays a peak of approximately 160 watts.

Figure 15. Winter 2015 Average Power Consumption vs. Time of Day, N=99



---

[32] October 15 to April 15.

[33] May 15 to September 30.

Figure 16. Summer 2015 Average Power Consumption vs. Time of Day, N=115

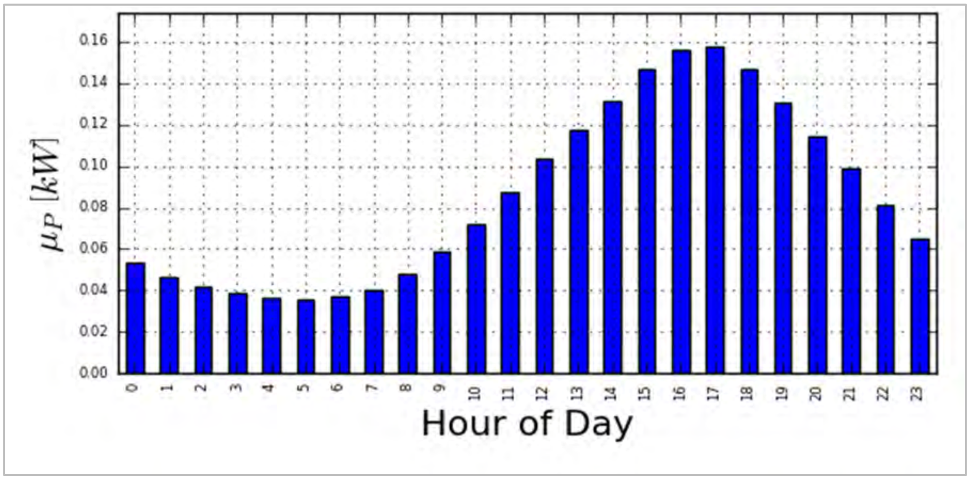


Figure 17. Winter 2016 Average Power Consumption vs. Time of Day, N=60

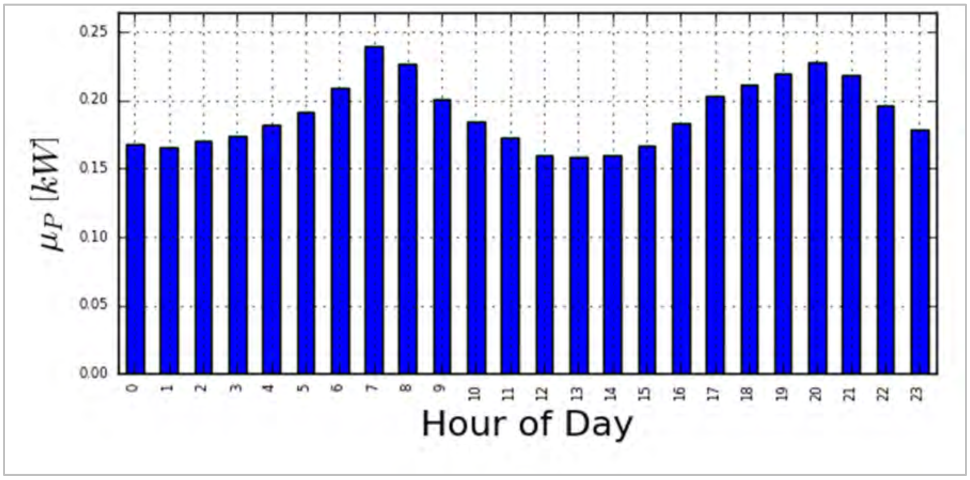


Figure 18, Figure 19, and Figure 20 present average power usage of metered units versus outdoor air temperatures for winter 2015, summer 2015, and winter 2016, respectively. This relationship proved important as efficiency (COP) and capacity of DMSHPs varied with temperatures.

Peak heating demand varied somewhat between consecutive winters. Heating demand peaked during winter 2015 at 1,500 watts, with an approximately -7 °F outside ambient temperature. The following winter, heating demand peaked at about 1,300 watts, with an approximately -5 °F outside temperature. Notably, some heating continued well below 0 °F, while some heating occurred at outdoor temperatures up to 68 °F. This behavior could result from thermal mass effects, where a house remains cool in the morning even as outdoor ambient temperatures rapidly climb.

Figure 18 and Figure 20 also show the subset of cold-climate units, which display a power-use pattern similar to the larger set of units but slightly lower for most temperature bins. This occurs for two reasons:

1. Cold climate units, with only single heads, have lower capacity, and are rated at higher efficiencies (see Table 4).
2. Cooling demand (Figure 19) increased with outside air temperatures until peaking at about 760 watts at 93 °F.

Particularly, cooling occurred down to outdoor temperatures in the 60s, which could result from thermal mass effects, where a house stays warm in the evening when outdoor temperatures rapidly drop, or from internal loads (e.g., solar).

Figure 18. Winter 2015 Average Power Consumption While Heating vs. Outdoor Air Temperature

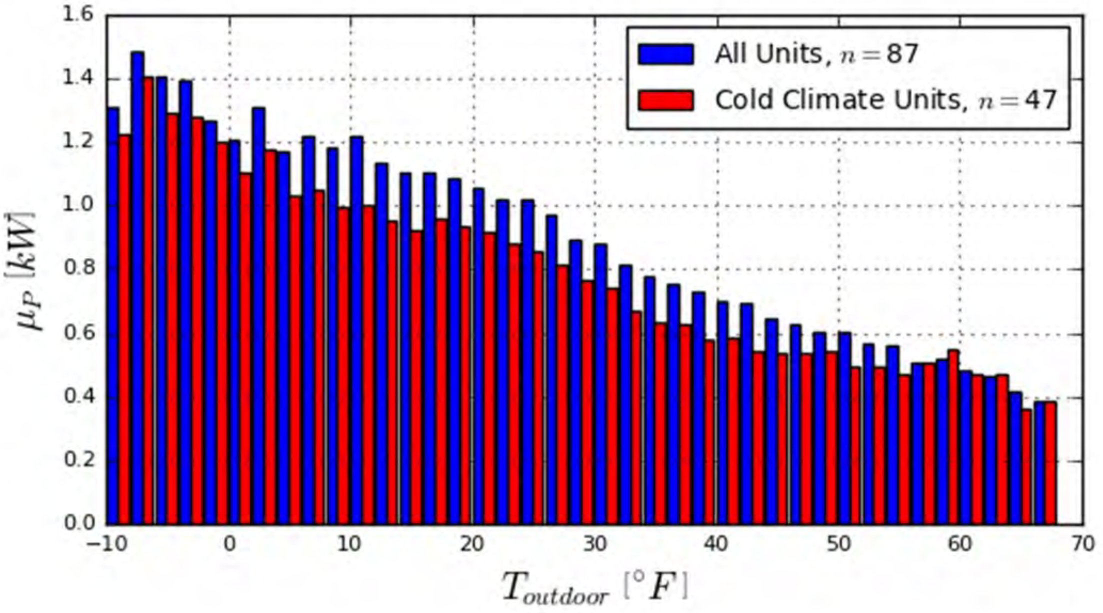


Figure 19. Summer 2015 Average Power Consumption While Cooling vs. Outdoor Air Temperature, N=114

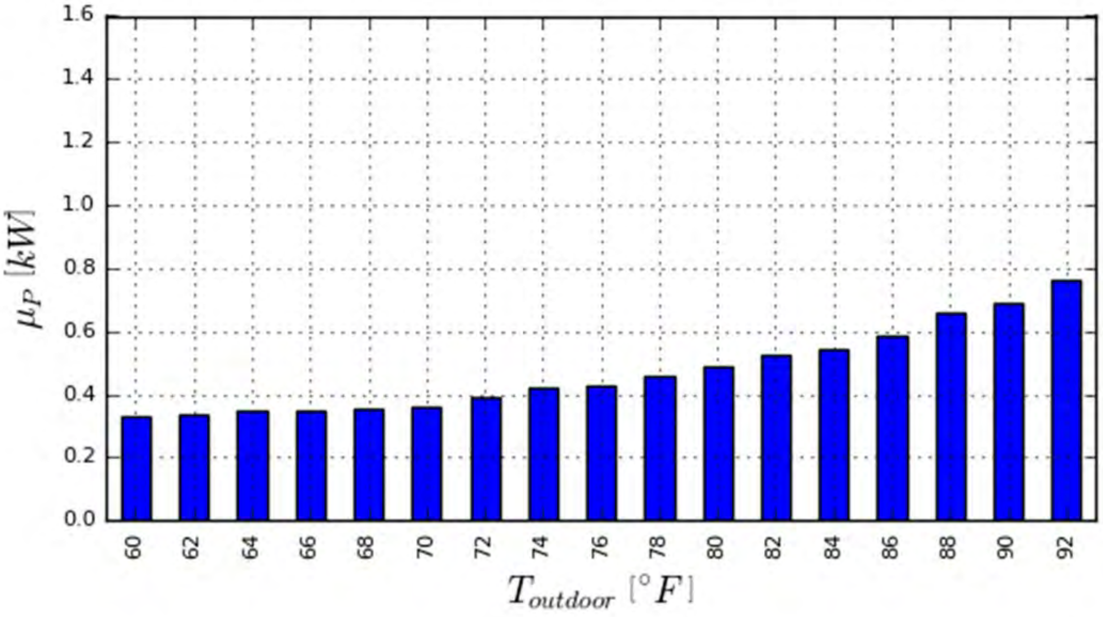


Figure 20. Winter 2016 Average Power Consumption While Heating vs. Outdoor Air Temperature, N=57

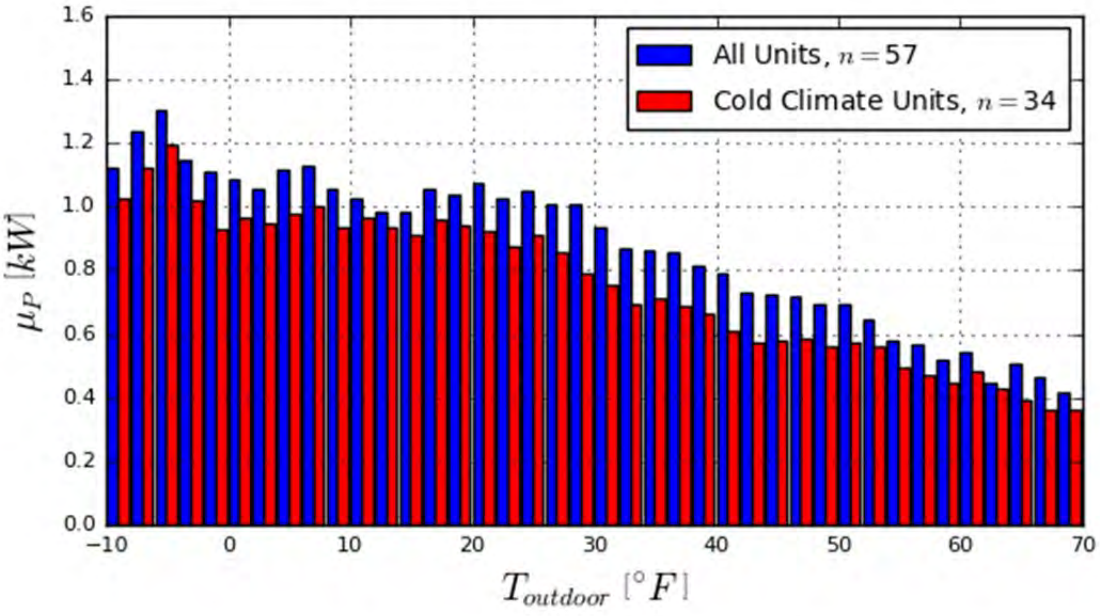


Figure 21, Figure 22, Figure 23, Figure 24, and Figure 25 show a seasonal time series of average power demand for winter 2015, summer 2015, and winter 2016 for all units and, separately, for cold climate units. Seasonal DMSHP heating use widely varies, but not nearly as much as summer usage. During summer periods with milder outdoor temperatures, DMSHP units largely remain off. The time series graphs for all units and for cold climate units produced similar results.

Figure 21. Winter 2015 Average Power Consumption vs. Time, N=99

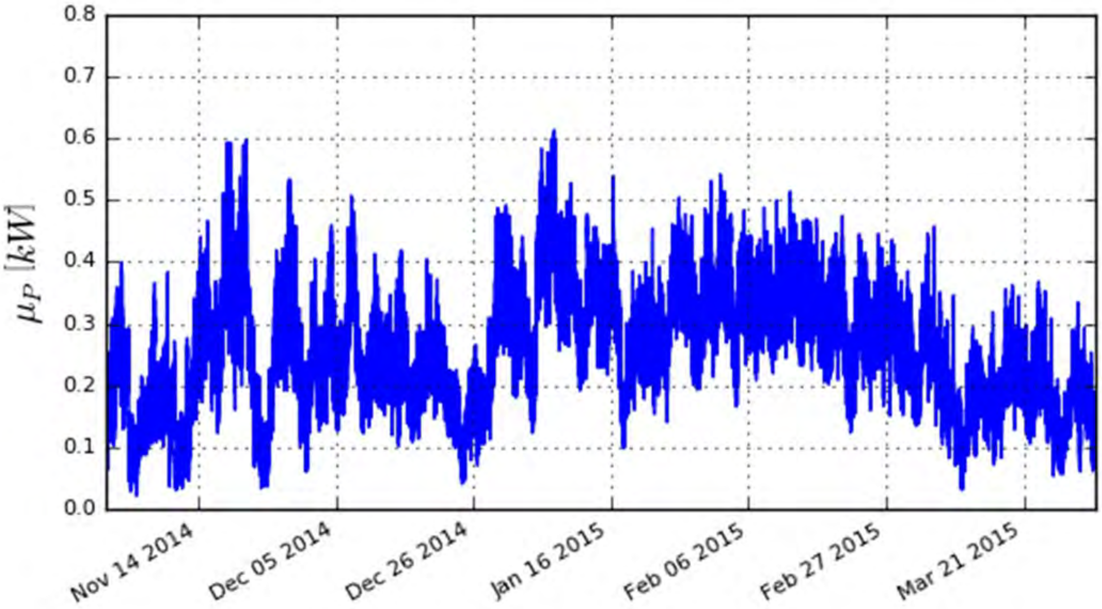


Figure 22. Winter 2015 Average Power Consumption vs. Time, N=51, Cold Climate Units

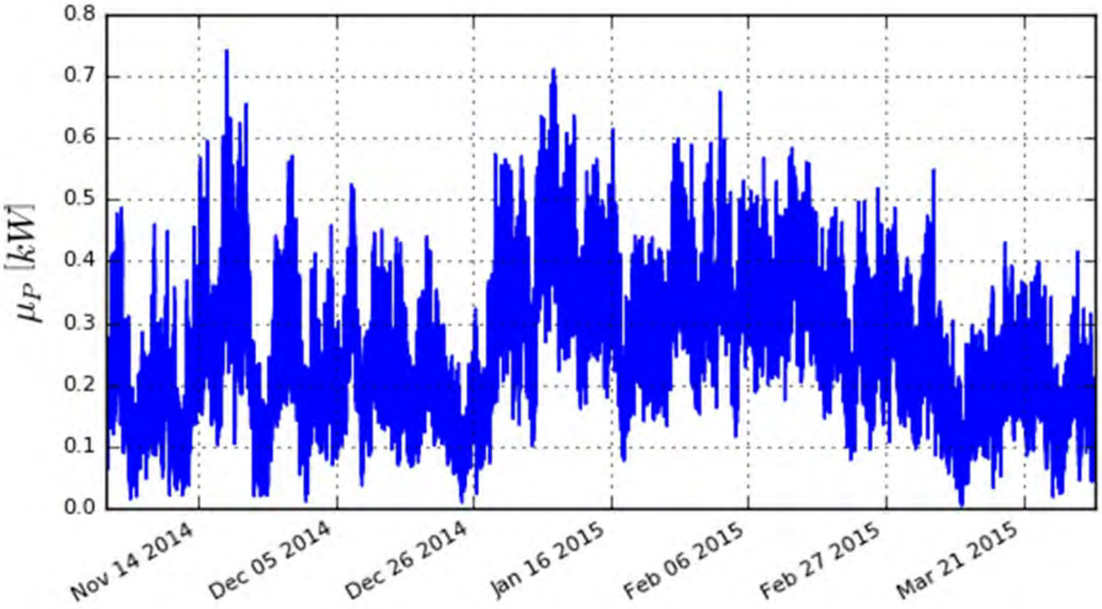


Figure 23. Summer 2015 Average Power Consumption vs. Time, N=115

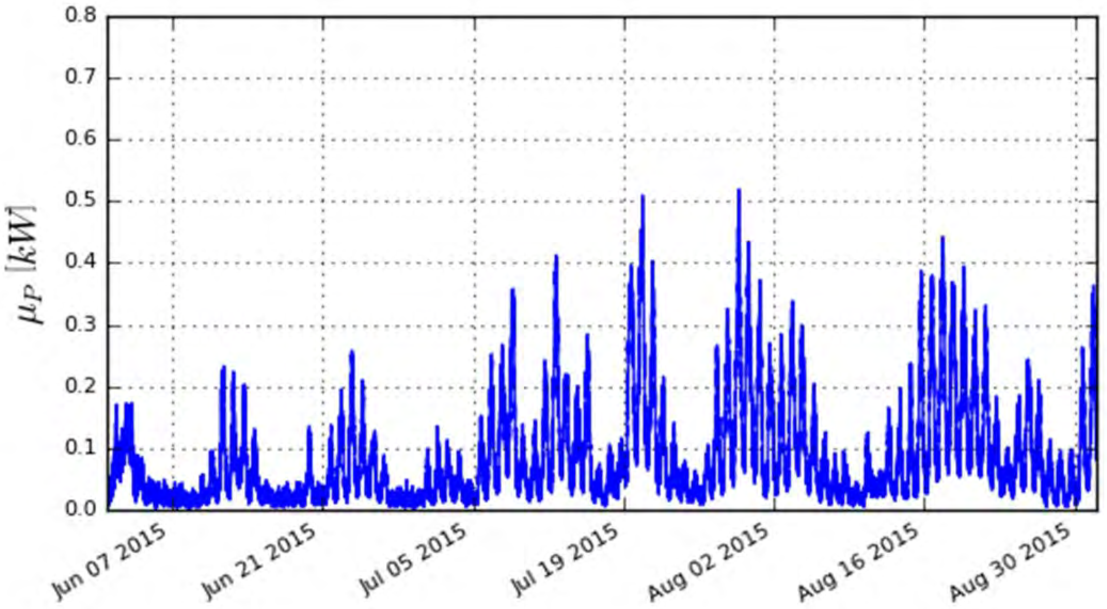


Figure 24. Winter 2016 Average Power Consumption vs. Time, N=60

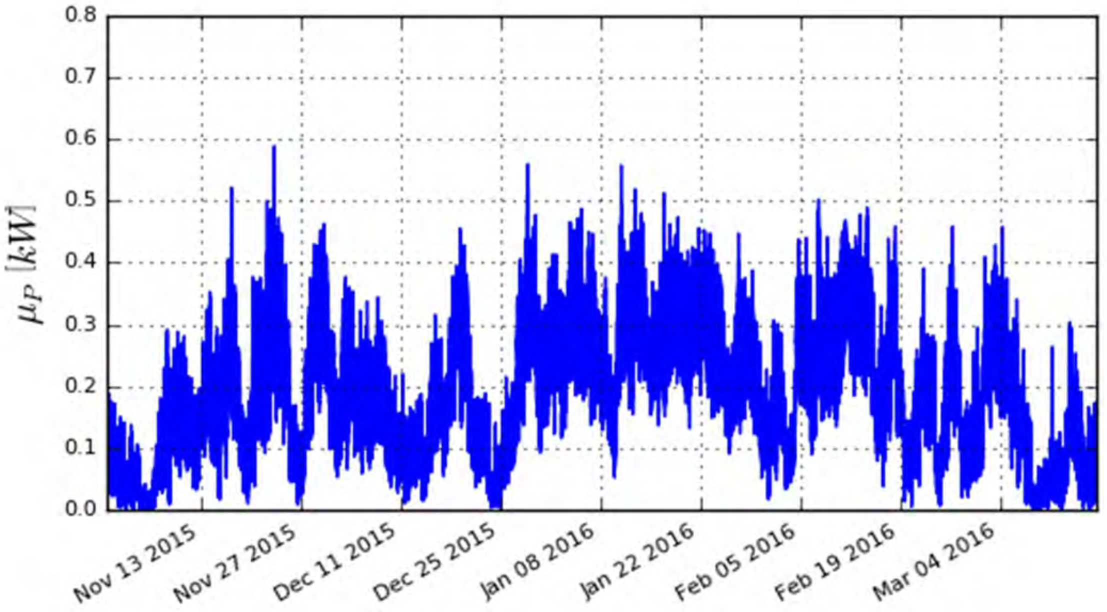


Figure 25. Winter 2016 Average Power Consumption vs. Time, N=35, Cold Climate Units

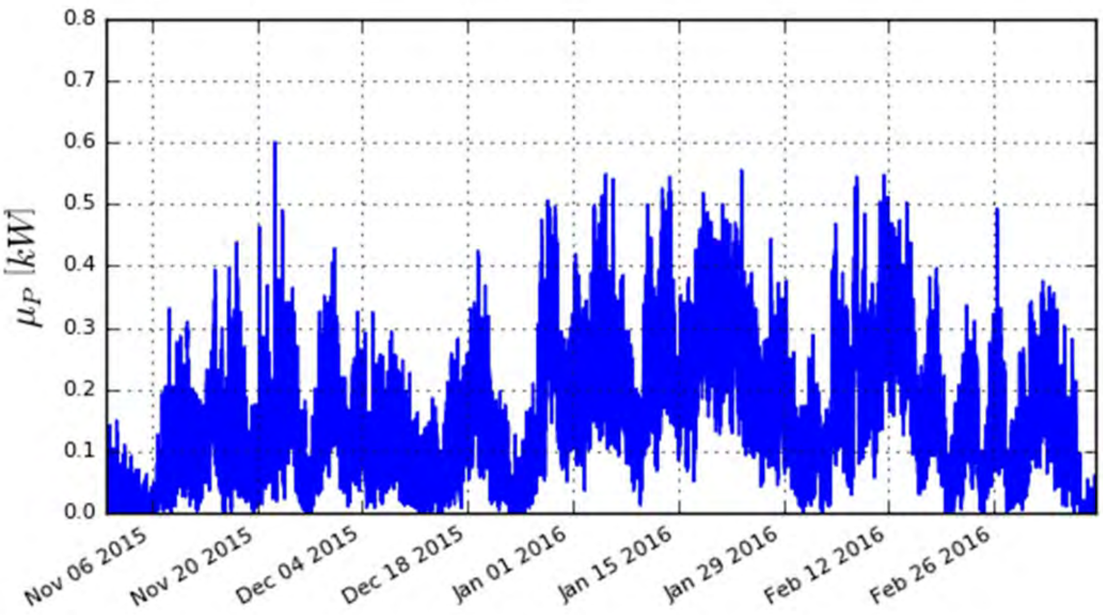


Table 7 shows units' low coincidence factors (CF) for both summer and winter peak periods, at precisions less than 1%. Essentially, many units remained off, and those running did not operate at full capacity, resulting in low CFs.

Table 7. CFs for Peak Winter and Summer Periods

Season	Mean CF	Precision [%]
Winter 2015	0.130	0.71
Summer 2015	0.181	0.99
Winter 2016	0.120	0.94

Operating Hours

Table 8 shows simple run-time hours for metered DMSHPs, with a unit logged as running if its power draw exceeded a threshold standby power of 60W. Looking at the nominal heating season, the average unit ran about 27% of the time (793 hours) during 2015, and about 24% of the time (703 hours) during 2016. Note that an operating hour differs from a full-load hour in that an operating hour simply means that the unit remained on at some capacity, whereas a full-load hour indicates the unit ran at full capacity.

Table 8. Observed Run Hours for Nominal Heating and Cooling Seasons*

Season	Example Period of Operation	Season (Days)	Season (Hours)	Mean Percent Runtime	Hours of Operation
Winter 2015	December-March	121	2,904	27.3%	793
Summer 2015	June-August	92	2,208	19.4%	428
Winter 2016	December-March	121	2,904	24.2%	703

*The observed run times were for periods where the unit drew more than 60W (non-standby) during the stated periods.

Equivalent Full Load Hours

EFLH—is a metric describing how long a piece of equipment operates at full capacity. For variable speed systems, such as DMSHPs, EFLH are usually much lower than actual operating hours because DMSHP run at less than full capacity much of the time. Calculated as the product of a DHMSHP's consumption, divided by its output capacity, times its seasonal efficiency, EFLHs are much lower than values indicated in applicable Massachusetts and Rhode Island TRMs for conventional heating and cooling systems. Several plausible reasons account for these variances:

- Not all units were used routinely or even at all for each season. Many units were lightly used or not used at all for heating or for cooling. The plots in Figure 26 illustrate this behavior, where the bottom of the box indicating the 25th percentile of the range of hours is at or very near zero for the two winters.
- Many units remain off during cooler periods in summer.
- Some units in heating mode operate coincidently with primary systems, many of which are fossil fuel-based.
- Systems were sized much larger than cooling needs of the immediate space they served (discussed later in this report).
- TRM sources for the legacy EFLH values may be inappropriate for DMSHPs. The cooling EFLH value (360) is based on a 2009 study of central air conditioners. The heating EFLH value (1,200) is sourced from a "Massachusetts Common Assumption," which is also used for other types of heating equipment. Both of these legacy values appear high relative to this study's findings, supporting the theory that DMSHPs are used in different ways than conventional heating or cooling equipment

Table 9 shows the average EFLH across all units for the two heating seasons and one cooling season investigated, and compares these values with those prescribed in the Massachusetts and Rhode Island TRMs. The two heating seasons' values (442 and 451) remain consistent with the value (447) presented in the heating memorandum from this study (October 12, 2015). The summer value (218) was roughly 15% lower than the value (259) shown in the cooling memorandum (distributed February 2016, and finalized on May 2, 2016). This reduction in the average cooling EFLH resulted from two elements:

- Use of local TMY data for this report, in contrast with statewide TMY data used in the memo
- The evaluation team removed standby power usage and off-season conditioning from this report's analysis

The right column of shows the EFLH for the top 25% of units for each seasons. These heating season values average close the TRM value and the cooling value exceeds the TRM value.

Table 9. Average EFLH

Season	2013-2015 MA TRM	2014 RI TRM	Average Study EFLH	Average of Top 25% of Measured EFLH
Winter 2015	1,200	1,200	442	1,275
Summer 2015	360	360	218	499
Winter 2016	1,200	1,200	451	1,117

Figure 26 presents DMSHP usage by season, shows a wide variation in units' EFLH, particularly for heating. Figure 27 shows a similar pattern for cold climate units.

Figure 26. DMSHP EFLH vs. Season

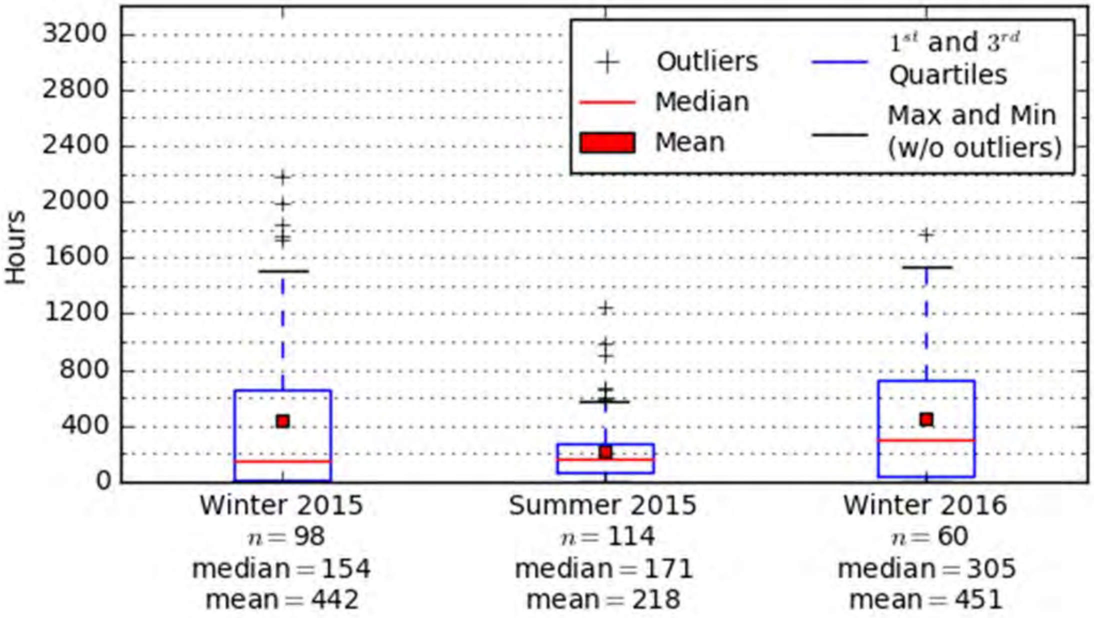


Figure 27. DMSHP EFLH vs. Season, Cold Climate Units

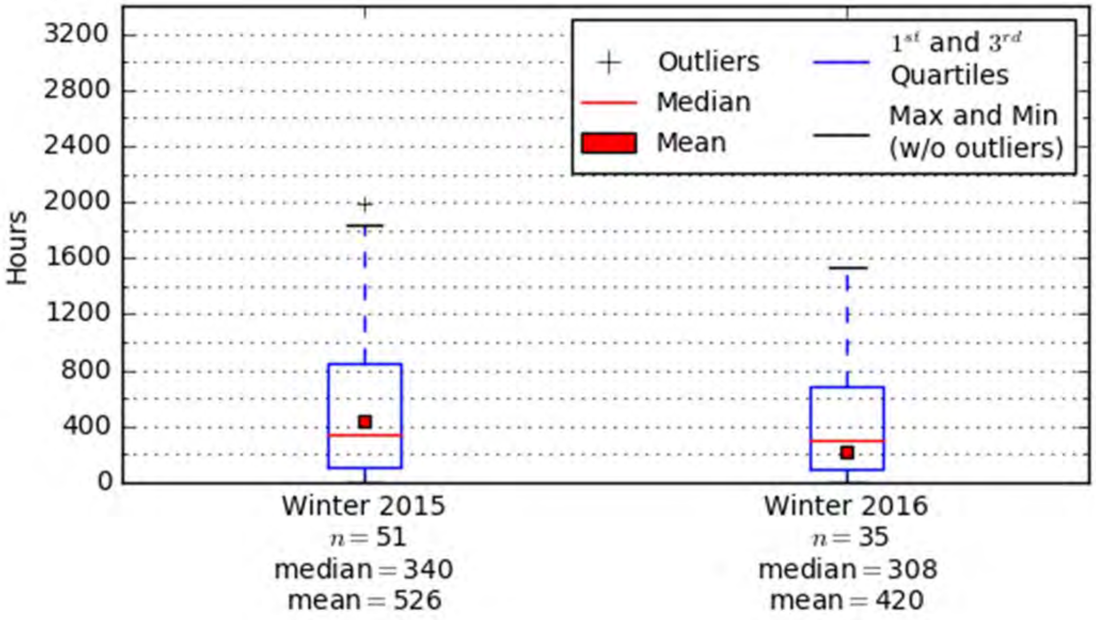


Figure 28 examines this variation more closely and shows that units purchased for “both heating and cooling” were used much more for heating than units purchased as “cooling only.” Winter 2016 was milder than winter 2015, and winter 2015 had very deep snow falls that buried units for part of the winter. Units operated more efficiently during 2016 (see Figure 52). This resulted in lower EFLH for users intending “both heating and cooling” in Winter 2016. During winter 2016, units purchased for “cooling only” saw some heating usage.

Figure 28. DMSHP EFLH vs. Purchase Intent and Season

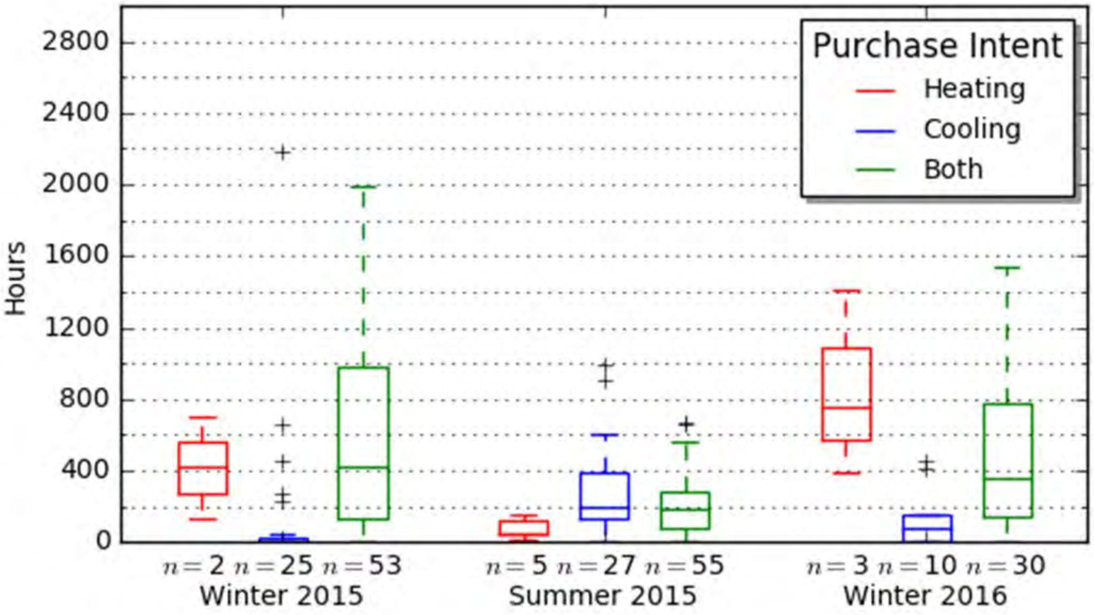
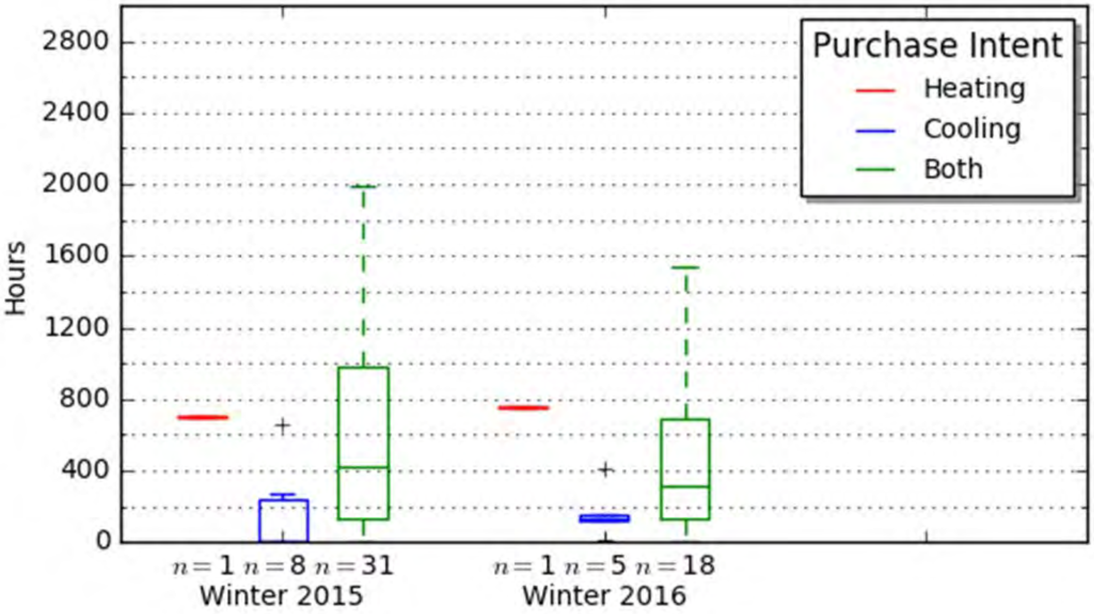


Figure 29. DMSHP EFLH vs. Purchase Intent and Season, Cold Climate Units



For electric savings, actual DMSHP performance was used, with the baseline unit's efficiency decremented from its nameplate rating by the same proportion that the efficient unit's performance differed from its rating. Cooling savings increased with lower-efficiency baselines. Calculation for savings relative to a central air conditioner baseline included a 15% duct loss, which decreases net efficiency. As discussed, these savings values were based on the baseline and on the DMSHP providing the same amount of heating (and cooling); they did not include zonal savings gained in some homes.

Table 10. Energy Savings, Each Baseline Applied to All Sites

Season	Baseline System	Sample Size	Electric Usage of DMSHP [kWh]	Baseline Energy Reduction	Net Energy Savings	Precision at 90% Confidence [%]
Winter 2015	90% AFUE Furnace⁽¹⁾	98	683	4.87 MMBtu	2.54 MMBtu	37
	85% AFUE Furnace⁽²⁾		683	5.16 MMBtu	2.83 MMBtu	36
	82% AFUE Boiler		683	4.54 MMBtu	2.21 MMBtu	39
	HSPF 7.7 DMSHP		683	907 kWh	224 kWh	21
	HSPF 8.2 DMSHP		683	851 kWh	168 kWh	21
	Electric Resistance		683	1,092 kWh	409 kWh	48
Summer 2015	EER 9.8 Window AC	114	159	213 kWh	54 kWh	15
	SEER 13.0 Central AC		159	288 kWh	129 kWh	14
	SEER 13.0 DMSHP		159	245 kWh	86 kWh	14
	SEER 14.5 DMSHP		159	220 kWh	61 kWh	15
Winter 2016	90% AFUE Furnace	60	763	6.9 MMBtu	4.3 MMBtu	37
	85% AFUE Furnace⁽²⁾		763	7.31 MMBtu	4.7 MMBtu	36
	82% AFUE Boiler		763	6.44 MMBtu	3.83 MMBtu	37
	HSPF 7.7 DMSHP		763	989 kWh	226 kWh	22
	HSPF 8.2 DMSHP		763	929 kWh	166 kWh	23
	Electric Resistance		763	1,547 kWh	784 kWh	42

(1) Duct losses were assumed as 15%.
(2) Baseline efficiency prescribed by relevant Massachusetts (2013–2015) and Rhode Island (2015) TRMs applicable when beginning this study.

Table 11 shows average winter[34] and summer[35] peak demand savings. The evaluation team calculated peak savings as follows:

- Calculating energy savings during respective summer and winter peak periods.
- Dividing savings by peak hours to yield average peak demand savings.

As with consumption savings, electrical resistance heating provided the highest savings; these declined with the baseline unit's increasing efficiency.

---

[34] The MA (2016–2018) and RI (2016) TRMs defined winter peak as 5:00 PM to 7:00 PM on non-holiday weekdays in December and January.

[35] The MA (2016–2018) and RI (2016) TRMs defined summer peak as 1:00 PM to 5:00 PM on non-holiday weekdays in June, July, and August.

Table 11. Peak Demand Savings, Each Baseline Applied to All Sites

Season	Baseline System	Sample Size	Electric Usage of DMSHP [kW]	Baseline Power Reduction [kW]	Average Peak Period Demand Savings [kW]	Precision at 90% Confidence [%]
Winter 2015	90% AFUE Furnace	98	0.21	0	-0.21	33
	85% AFUE Furnace		0.21	0	-0.21	33
	82% AFUE Boiler		0.21	0	-0.21	33
	HSPF 7.7 DMSHP		0.21	0.28	0.07	22
	HSPF 8.2 DMSHP		0.21	0.26	0.05	22
	Electric Resistance		0.21	0.33	0.12	43
Summer 2015	EER 9.8 Window AC	114	0.11	0.15	0.04	16
	SEER 13.0 Central AC		0.11	0.20	0.09	15
	SEER 13.0 DMSHP		0.11	0.05	0.06	15
	SEER 14.5 DMSHP		0.11	0.07	0.04	15
Winter 2016	90% AFUE Furnace	60	0.25	0	-0.25	34
	85% AFUE Furnace		0.25	0	-0.25	34
	82% AFUE Boiler		0.25	0	-0.25	34
	HSPF 7.7 DMSHP		0.25	0.33	0.08	24
	HSPF 8.2 DMSHP		0.25	0.31	0.06	25
	Electric Resistance		0.25	0.58	0.33	38

We did not assume electricity credit for reducing the operation of a baseline furnace fan or boiler pump. This results in a conservative assumption as some reduction in fan and pump use likely occurred. Without conducting a pre-post DMSHP study, identifying the timing and amount of that reduction proves difficult. On average, a standard boiler pump uses about 120 kWh per year,[36] and a fan uses about 440 kWh[37] per year for heating. Where a DMSHP can be used as the primary heating source, this electricity use could be substantially reduced, increasing consumption and demand savings, and decreasing DMSHP net electricity use.

As in Table 10, Table 12 shows savings for each baseline, but it applies the baseline only to homes that indicated that specific baseline, based on survey responses. Sample sizes were much smaller than those used in Table 10, and relative precisions were much larger (worse). Calculating the savings this way drew upon several stakeholder's hypotheses that users would behave differently due to different survey responses. The evaluation team suggests variability in usage is already very high, and that dividing the population into small subpopulations based on these survey responses does not yield meaningful information. Savings were generally lower, though much higher for electrical resistance heat.

---

[36] Boiler pump study

[37] AHRI average = 365W/ 1,000 CFM. At 1,200 CFM and 1,000 run time hours, this is 438 kWh.

Table 12. Energy Savings, Baseline Applied Based on Survey Responses and Existing Systems

Season	Baseline System	Sample Size	Electric Usage of DMSHP [kWh]	Baseline Energy Reduction	Average Energy Savings	Precision at 90% Confidence [%]
Winter 2015	90% AFUE Furnace	10	702	3.79 MMBtu	1.39 MMBtu	120
	85% AFUE Furnace	10	702	4.01 MMBtu	1.62 MMBtu	109
	82% AFUE Boiler	27	786	5.51 MMBtu	2.83 MMBtu	68
	HSPF 7.7 DMSHP	37	425	588 kWh	163 kWh	41
	HSPF 8.2 DMSHP	37	425	552 kWh	127 kWh	42
	Electric Resistance	3	732	1,130 kWh	398 kWh	334
Summer 2015	EER 9.8 Window AC	9	306	399 kWh	93 kWh	33
	SEER 13.0 Central AC	7	103	198 kWh	95 kWh	50
	SEER 13.0 DMSHP	38	189	292 kWh	103 kWh	26
	SEER 14.5 DMSHP	38	189	262 kWh	73 kWh	27
Winter 2016	90% AFUE Furnace	6	306	3.86 MMBtu	2.82 MMBtu	104
	85% AFUE Furnace	6	306	4.09 MMBtu	3.05 MMBtu	104
	82% AFUE Boiler	14	1,056	9.78 MMBtu	6.17 MMBtu	82
	HSPF 7.7 DMSHP	16	511	687 kWh	176 kWh	55
	HSPF 8.2 DMSHP	16	511	645 kWh	134 kWh	58
	Electric Resistance	2	1,202	2,980 kWh	1,778 kWh	35

Table 13 shows the average winter[38] and summer[39] peak demand savings for the same survey-based baseline. The demand savings generally were lower than in Table 11, but relative precision values were much higher (worse).

Table 13. Peak Demand Savings, Baseline Applied Based on Survey Responses and Existing Systems

Season	Baseline System	Sample Size	Electric Usage of DMSHP [kW]	Baseline Power Reduction [kW]	Average Peak Period Demand Savings [kW]	Precision at 90% Confidence [%]
Winter 2015	90% AFUE Furnace	10	0.28	0	-0.28	53
	85% AFUE Furnace	10	0.28	0	-0.28	53
	82% AFUE Boiler	27	0.25	0	-0.25	38
	HSPF 7.7 DMSHP	37	0.12	0.16	0.04 kW	48
	HSPF 8.2 DMSHP	37	0.12	0.15	0.03 kW	48

---

[38] The Massachusetts (2016–2018) and Rhode Island (2016) TRMs defined winter peak as 5:00 PM to 7:00 PM on non-holiday weekdays in December and January.

[39] The Massachusetts (2016–2018) and Rhode Island (2016) 2016–2018 TRMs defined summer peak as 1:00 PM to 5:00 PM on non-holiday weekdays in June, July, and August.

Season	Baseline System	Sample Size	Electric Usage of DMSHP [kW]	Baseline Power Reduction [kW]	Average Peak Period Demand Savings [kW]	Precision at 90% Confidence [%]
	Electric Resistance	3	0.16	0.31	0.15 kW	208
Summer 2015	EER 9.8 Window AC	9	0.18	0.23	0.05 kW	40
	SEER 13.0 Central AC	7	0.09	0.17	0.08 kW	58
	SEER 13.0 DMSHP	38	0.13	0.20	0.07 kW	27
	SEER 14.5 DMSHP	38	0.13	0.18	0.05 kW	28
Winter 2016	90% AFUE Furnace	6	0.16	0	-0.16	100
	85% AFUE Furnace	6	0.16	0	-0.16	100
	82% AFUE Boiler	14	0.31	0	-0.31	49
	HSPF 7.7 DMSHP	16	0.17	0.23	0.06 kW	52
	HSPF 8.2 DMSHP	16	0.17	0.21	0.04 kW	53
	Electric Resistance	2	0.46	1.13	0.67 kW	69

To examine the practical potential savings achievable by DMSHPs used more frequently, the evaluation team examined sites in the top 25%, based on savings (which in turn were correlated with higher usage). Table 14 shows savings for this subpopulation, indicating savings were much higher than the mean, as expected mathematically, but in practical terms, these savings would be expected upon removing units lightly used or not used. Relative precision rates were relatively high, given the small sample size.

Table 14. Energy Savings, Each Baseline Applied to All Sites, Top 25%

Season	Baseline System	Sample Size	Electric Usage of DMSHP [kWh]	Baseline Energy Reduction	Average Energy Savings	Precision at 90% Confidence [%]
Winter 2015	90% AFUE Furnace	25	1,414	14.7 MMBtu	9.84 MMBtu	22
	85% AFUE Furnace		1,414	15.5 MMBtu	10.70 MMBtu	22
	82% AFUE Boiler		1,414	13.1 MMBtu	8.86 MMBtu	22
	HSPF 7.7 DMSHP		1,894	2,536 kWh	642 kWh	10
	HSPF 8.2 DMSHP		1,894	2,382 kWh	488 kWh	11
	Electric Resistance		1,414	3,287 kWh	1,873 kWh	24
Summer 2015	EER 9.8 Window AC	29	358	484 kWh	126 kWh	12
	SEER 13.0 Central AC		371	663 kWh	292 kWh	11
	SEER 13.0 DMSHP		363	556 kWh	193 kWh	12
	SEER 14.5 DMSHP		332	468 kWh	136 kWh	14
Winter 2016	90% AFUE Furnace	15	1,566	18.68 MMBtu	13.34 MMBtu	30
	85% AFUE Furnace		1,566	19.78 MMBtu	14.44 MMBtu	30
	82% AFUE Boiler		1,566	17.43 MMBtu	12.09 MMBtu	31
	HSPF 7.7 DMSHP		1,862	2,433 kWh	571 kWh	13
	HSPF 8.2 DMSHP		1,761	2,184 kWh	423 kWh	15
	Electric Resistance		1,566	4,188	2,622 kWh	33

Similarly, Table 15 shows demand savings for the top 25% of sites.

Table 15. Peak Demand Savings, Each Baseline Applied to All Sites, Top 25%

Season	Baseline System	Sample Size	Electric Usage of DMSHP [kW]	Baseline Power Reduction [kW]	Average Peak Period Demand Savings [kW]	Precision at 90% Confidence [%]
Winter 2015	HSPF 7.7 DMSHP	25	0.62	0.82	0.20 kW	13
	HSPF 8.2 DMSHP		0.56	0.70	0.14 kW	14
	Electric Resistance		0.47	1.02	0.55 kW	19
Summer 2015	EER 9.8 Window AC	29	0.24	0.33	0.09 kW	13
	SEER 13.0 Central AC		0.25	0.45	0.20 kW	11
	SEER 13.0 DMSHP		0.23	0.36	0.13 kW	12
	SEER 14.5 DMSHP		0.22	0.31	0.09 kW	13
Winter 2016	HSPF 7.7 DMSHP	15	0.61	0.80	0.19 kW	12
	HSPF 8.2 DMSHP		0.61	0.76	0.15 kW	15
	Electric Resistance		0.54	1.64	1.1 kW	26

Using baselines weighted from the previously published baseline memorandum, the evaluation team calculated average weighted savings for each of the three studied seasons, calculated for a single and a weighted baseline (as shown in Table 16). In general, winter 2016, with data unaffected by 2015's large snowfalls, realized higher savings. The specific baselines show savings similar to or somewhat higher than the single baselines. Table 17 shows the non-fuel switching savings, which were far lower than fuel switching because baseline DMSHP savings are lower than those from fuel heating.

Table 16. Weighted Average Savings, Fuel Switching

Fuel Switching					Single baseline						Specific baseline					
Season	Baseline System	Base Eff.	Efficiency Metric	Savings Units	n	Mean Savings	Mean Savings [kWh]	Population with Baseline [%]	Expected Baseline Savings [kWh]	Precision [%]	Sample Size	Mean Savings	Mean Savings [kWh]	Pop. with Baseline [%]	Expected Baseline Savings [kWh]	Precision [%]
Winter 2015	Furnace	0.85	AFUE	MMBtu	98	2.83	829	13%	108	36	10	1.62	475	13%	62	109
	Boiler	0.82	AFUE	MMBtu		2.21	648	35%	227	39	27	2.83	829	35%	291	68
	ER	1	COP	kWh		409	409	4%	16	48	3	398	398	4%	15	334
	DHP	7.7	HSPF	kWh		224	224	48%	108	21	37	163	163	48%	78	41
	Weighted Total							100%	458	31				100%	446	71
Summer 2015	Window AC	9.8	EER	kWh	114	54	54	17%	9	15	9	93	93	17%	16	33
	CAC	13	SEER	kWh		129	129	13%	17	14	7	95	95	13%	12	50
	DHP	13	SEER	kWh		86	86	70%	61	14	38	103	103	70%	72	26
	Weighted Total							100%	86	14				100%	100	30
Winter 2016	Furnace	0.85	AFUE	MMBtu	60	4.70	1378	16%	218	36	6	3.05	894	16%	141	103
	Boiler	0.82	AFUE	MMBtu		3.83	1123	37%	414	37	14	6.17	1808	37%	666	82
	ER	1	COP	kWh		784	784	5%	41	42	2	1778	1778	5%	94	35
	DHP	7.7	HSPF	kWh		226	226	42%	95	22	16	176	176	42%	74	55
	Weighted Total							100%	768	31				100%	975	71

Table 17. Weighted Average Savings, Non-Fuel Switching

Non Fuel Switching					Single Baseline						Specific Baseline					
Season	Baseline System	Base Eff.	Efficiency Metric	Savings Units	n	Mean Savings	Mean Savings [kWh]	Pop. with Baseline [%]	Expected Baseline Savings [kWh]	Precision [%]	Sample Size	Mean Savings	Mean Savings [kWh]	Pop. with Baseline [%]	Expected Baseline Savings [kWh]	Precision [%]
Winter 2015	ER	1	COP	kWh	98	409	409	8%	31	48	3	398	398	8%	30	334
	DHP	7.7	HSPF	kWh		224	224	93%	207	21	37	163	163	93%	150	41
	Weighted Total							100%	238	23				100%	180	63
Summer 2015	Window AC	9.8	EER	kWh	114	54	54	17%	9	15	9	93	93	17%	16	33
	CAC	13	SEER	kWh		129	129	13%	17	14	7	95	95	13%	12	50
	DHP	13	SEER	kWh		86	86	70%	61	14	38	103	103	70%	72	26
	Weighted Total							100%	86	14				100%	100	30
Winter 2016	ER	1	COP	kWh	60	784	784	11%	87	42	2	1778	1778	11%	198	35
	DHP	7.7	HSPF	kWh		226	226	89%	201	22	16	176	176	89%	156	55
	Weighted Total							100%	288	25				100%	354	53

Performance

Figure 30 and Figure 31show measured or “field” HSPFs and SEERs for the two observed winters and one summer, for all units and for cold-climate units. The evaluation team based these values on metered heating and cooling provided, divided by power consumed. The values widely varied, but generally fell below the nameplate rating. This variation occurred for several reasons:

- In contrast to central systems, which operate throughout a season, homeowners use DMSHPs in highly variable ways, which affects efficiency. For example, if homeowner only used a DMSHP to cool on the hottest days, its cooling efficiency would be closer to its rated EER value (i.e., the efficiency rating at 95 °F outside ambient temperature) rather than its SEER value.
- SEER and EER tests run at specific conditions that may not fully represent actual operating behaviors or conditions. For example, the SEER rating test stipulates return air at 80 °F—a temperature much warmer than most homeowners would generally keep their spaces. This test’s original intent might have been to simulate heat gain in return ducts, which obviously does not apply for DMSHP units.
- Units used for other functions can reduce rated performance. These functions may include the following:
    - Fan-only mode
    - Dry or dehumidification mode—dehumidification may actually help displace cooling, but the team did not estimate savings for this mode (see Savings section)
    - Standby power
    - Defrost mode
    - Drip-pan heat use

These values could not be directly compared with the nameplate ratings of central systems (e.g., a SEER 14.0 central air conditioner) as central units would experience lower-than-rated performance for some of the reasons stated above (as well as for other reasons such as unwanted heat loss or gain through duct distribution systems). The team directly measured DMSHP efficiencies at rates lower than their ratings, and decremented the efficiencies of AC and HP systems’ baseline efficiencies a similar amount below the rating.

Figure 30. Measured Seasonal Efficiencies

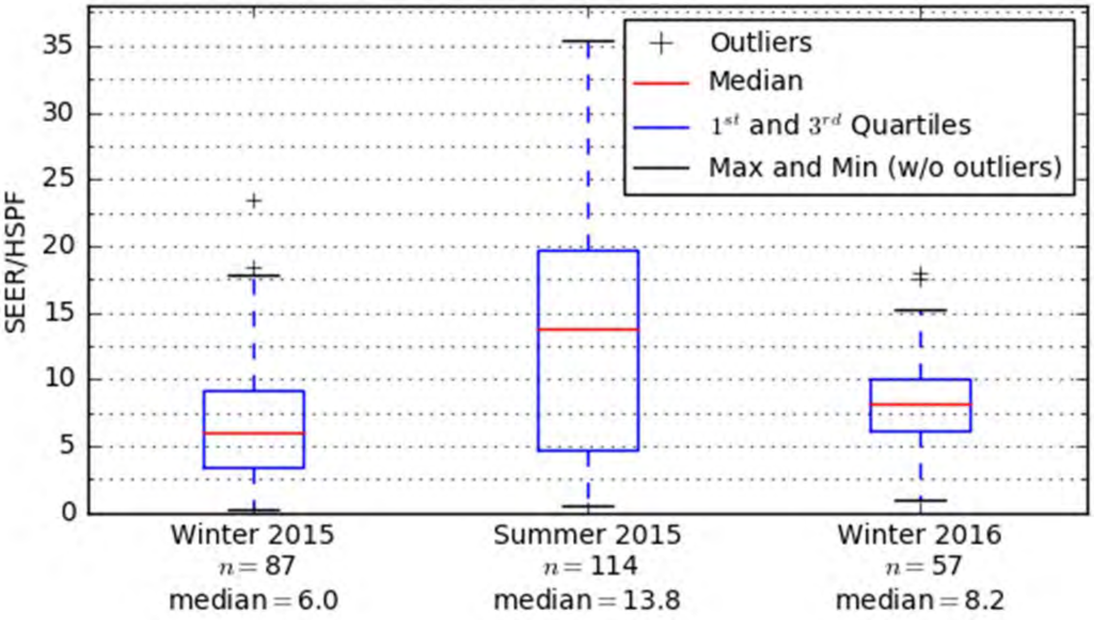


Figure 31. Measured Seasonal Efficiencies, Cold Climate Units

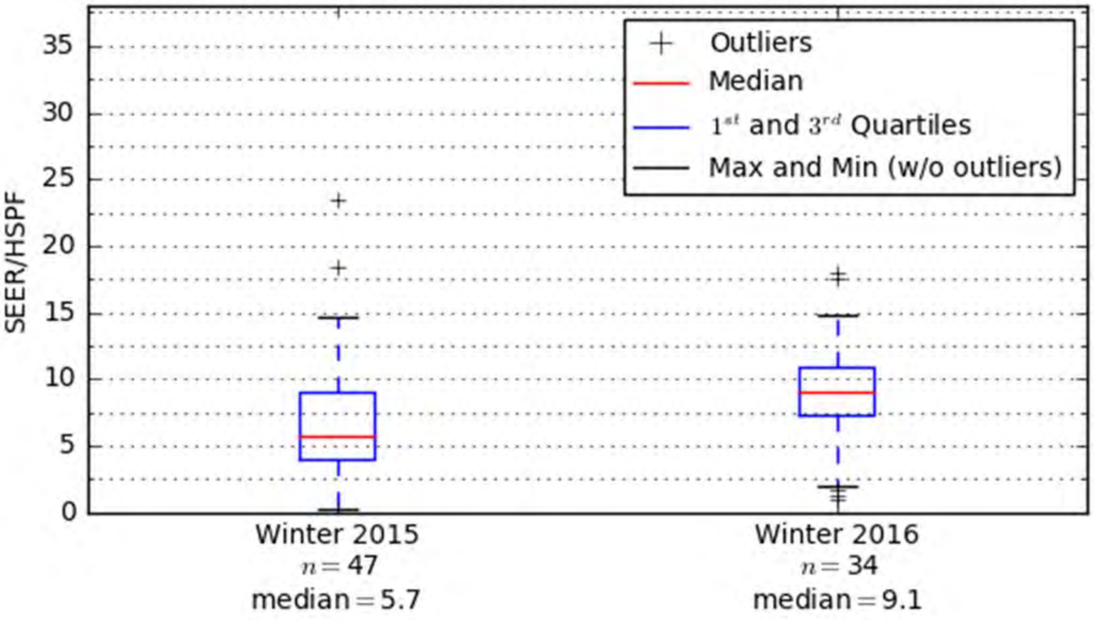


Figure 32. Winter 2015 Measured HSPF vs. EFLH, N=86

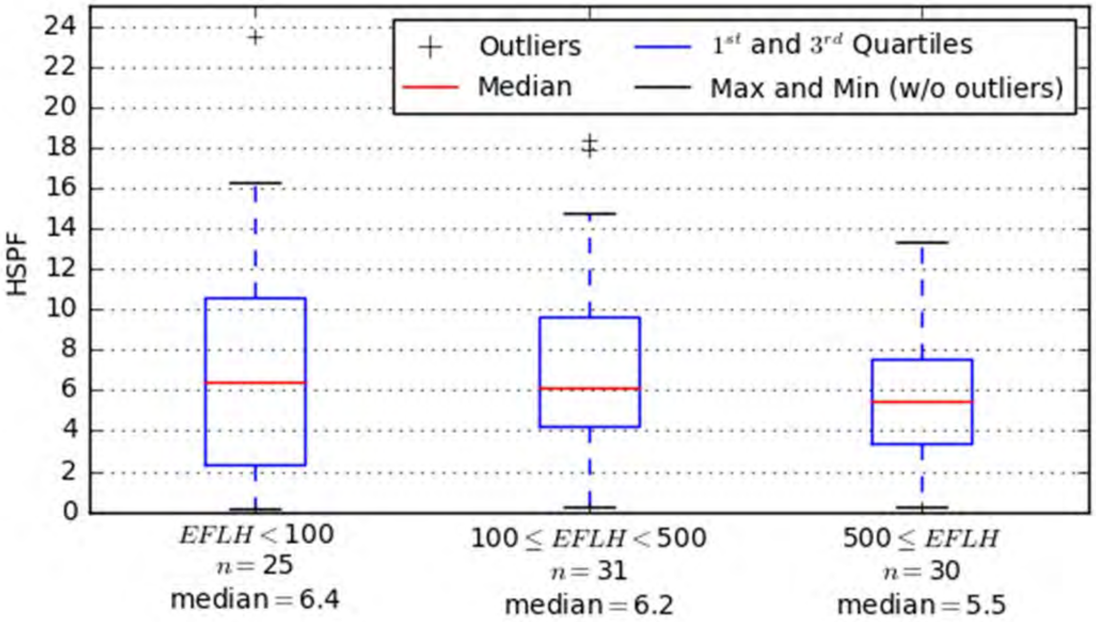


Figure 33. Summer 2015 Measured SEER vs. EFLH, N=113

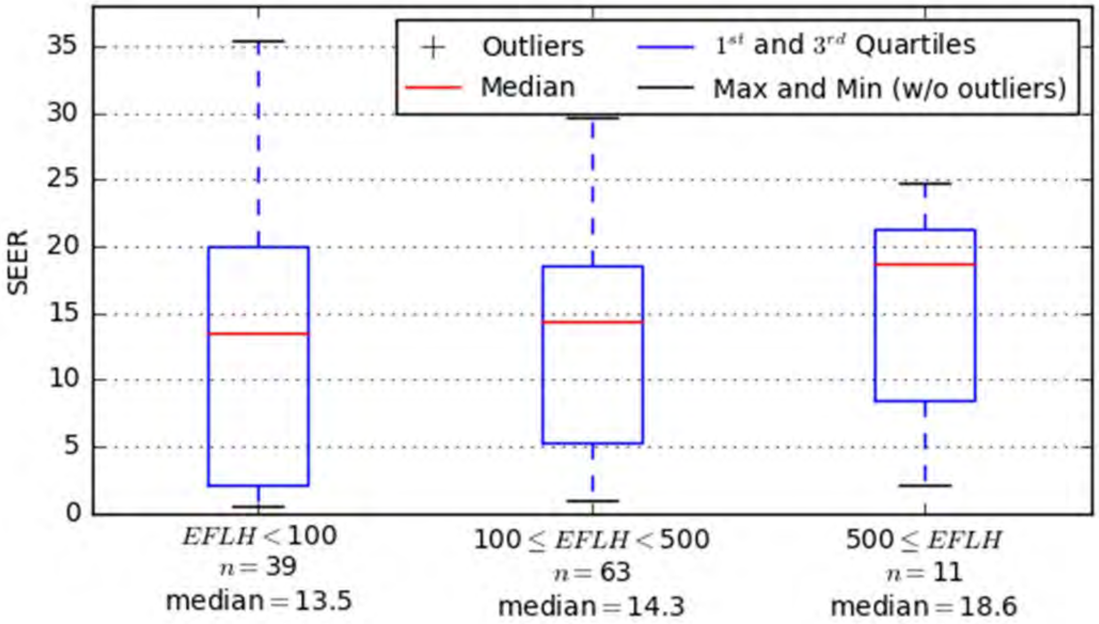


Figure 320 and Figure 341 show a substantial increase in HSPF from winter 2015 to winter 2016. This increase could result from variations in snowfall between the two winters; these can obstruct the outdoor unit's airflow. The top 25% of the units used lightly (<100 EFLH) and heavily (>500 EFLH) both approached or exceeded a 10.0 HSPF—the average rating of metered units.

Figure 34. Winter 2016 Measured HSPF vs. EFLH, N=57

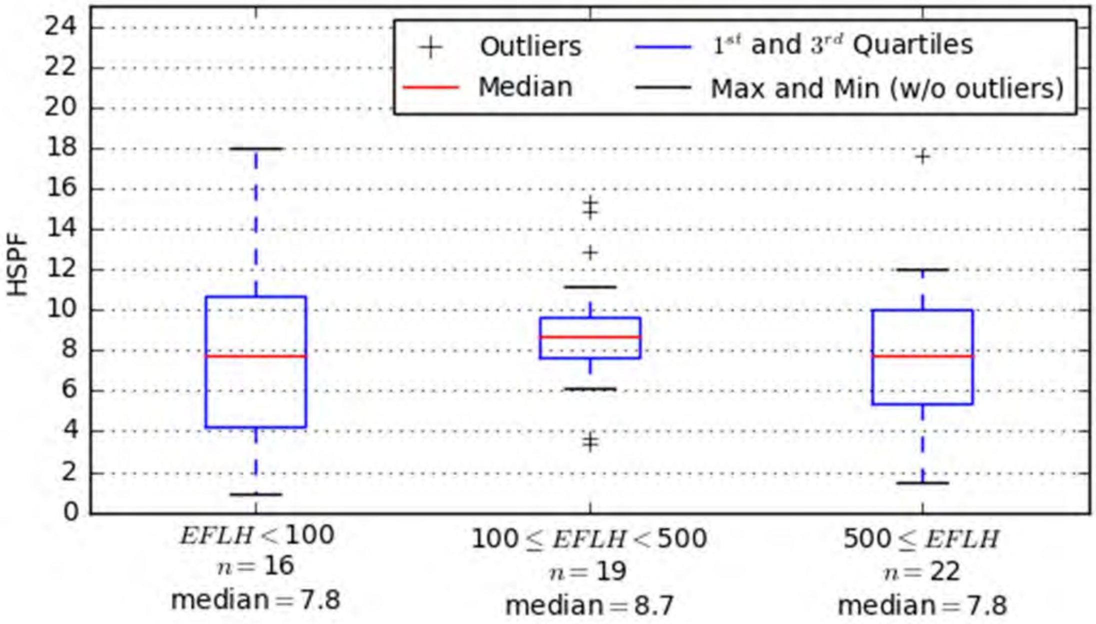


Figure 352 through Figure 40 present DMSHP efficiency plots by the number of indoor heads per outdoor unit and by EFLH. The efficiency range in these plots tightened when moving from one head to three heads, but this likely resulted from the decreasing sample size with an increasing number of heads. Efficiency appeared to decrease somewhat with an increasing number of heads, but partly resulted from the lower ratings of these multi-head systems. For single-head units, the 75th percentile of SEER (20.0) was near the average rated value. For winter 2016, the 75th percentile of HSPF was well above 10.0 for single-head units.

Figure 35. Winter 2015 HSPF vs. System Configuration, N=87

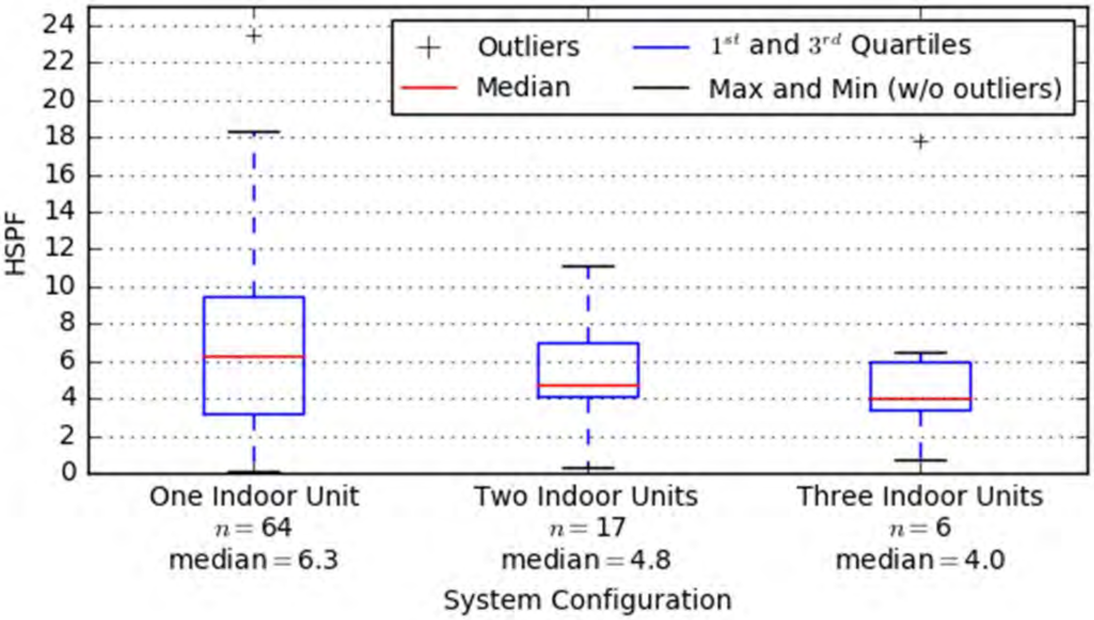


Figure 36. Summer 2015 SEER vs. System Configuration, N=114

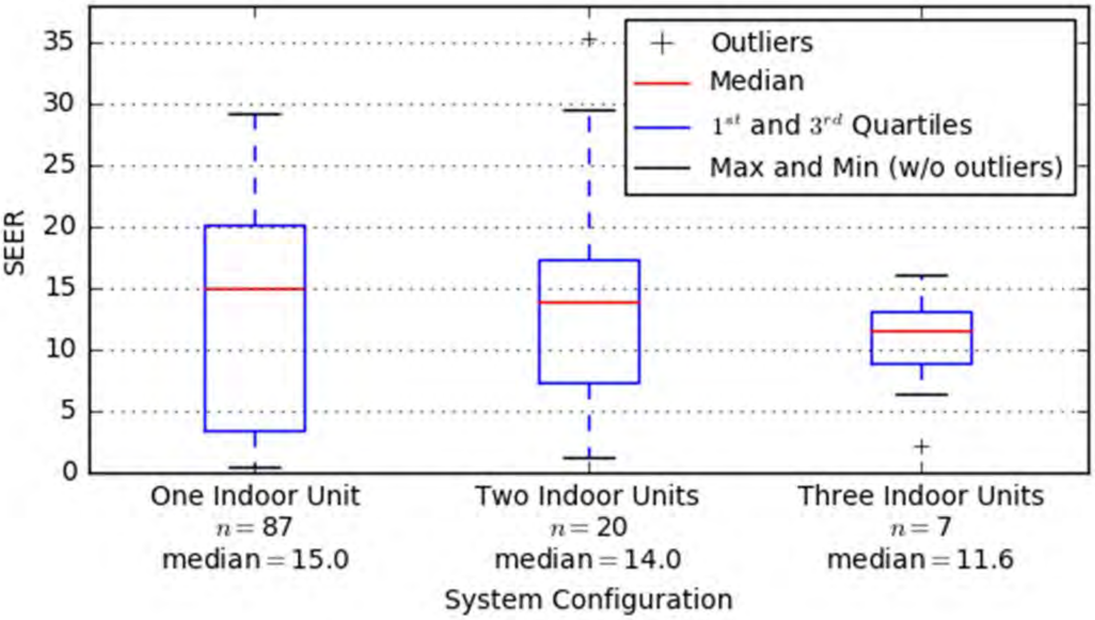


Figure 37. Winter 2016 HSPF vs. System Configuration, N=57

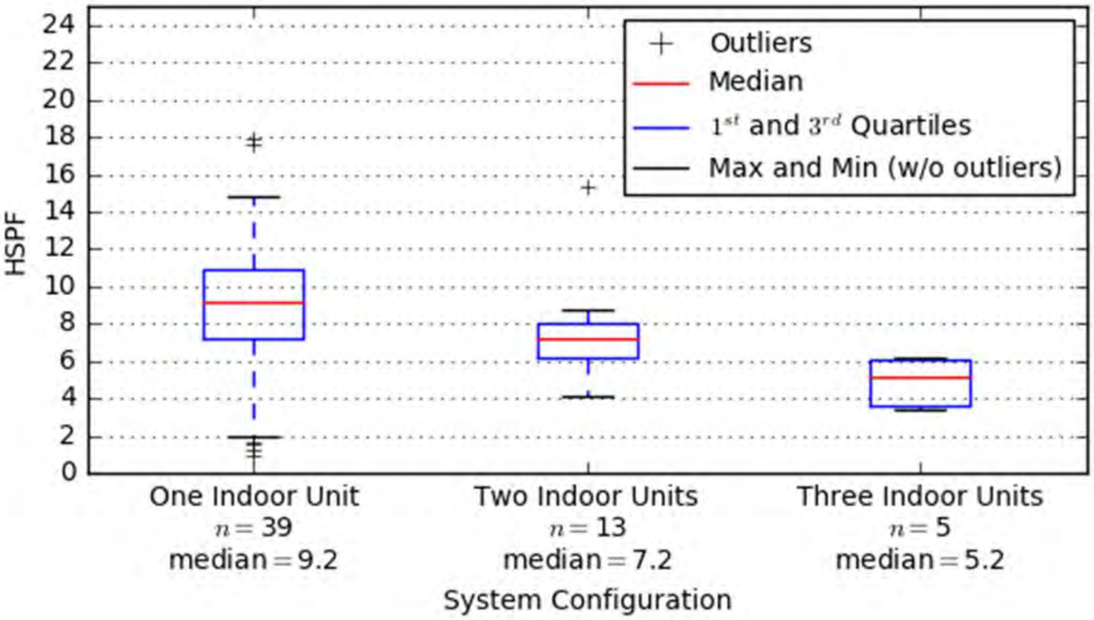


Figure 38. Winter 2015 HSPF vs. System Configuration and Usage, N=86

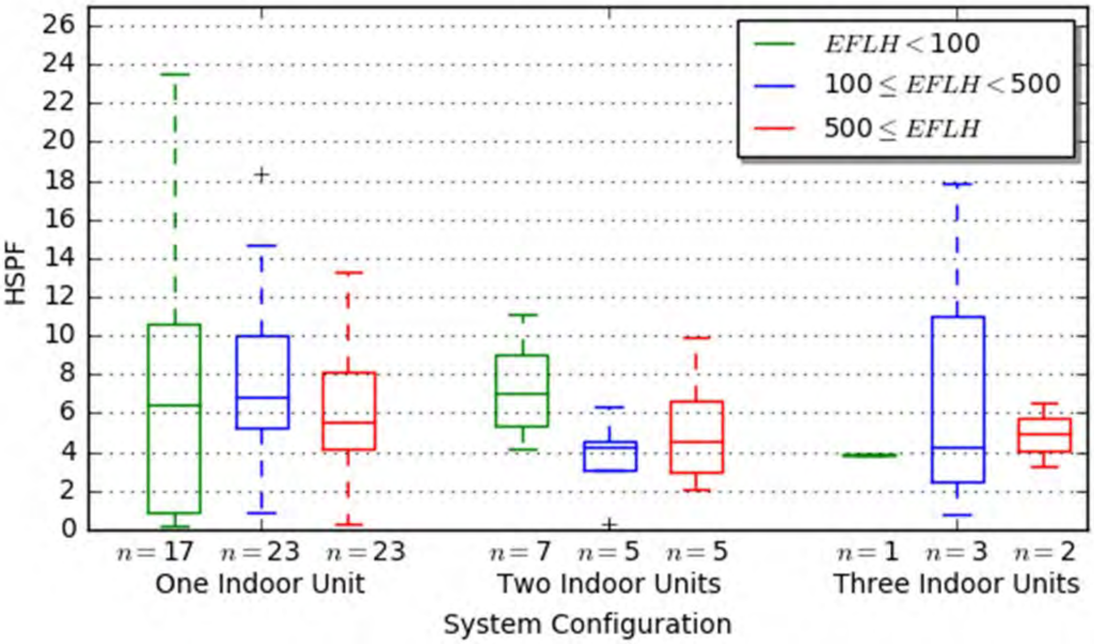


Figure 39. Summer 2015 SEER vs. System Configuration and Usage, N=113

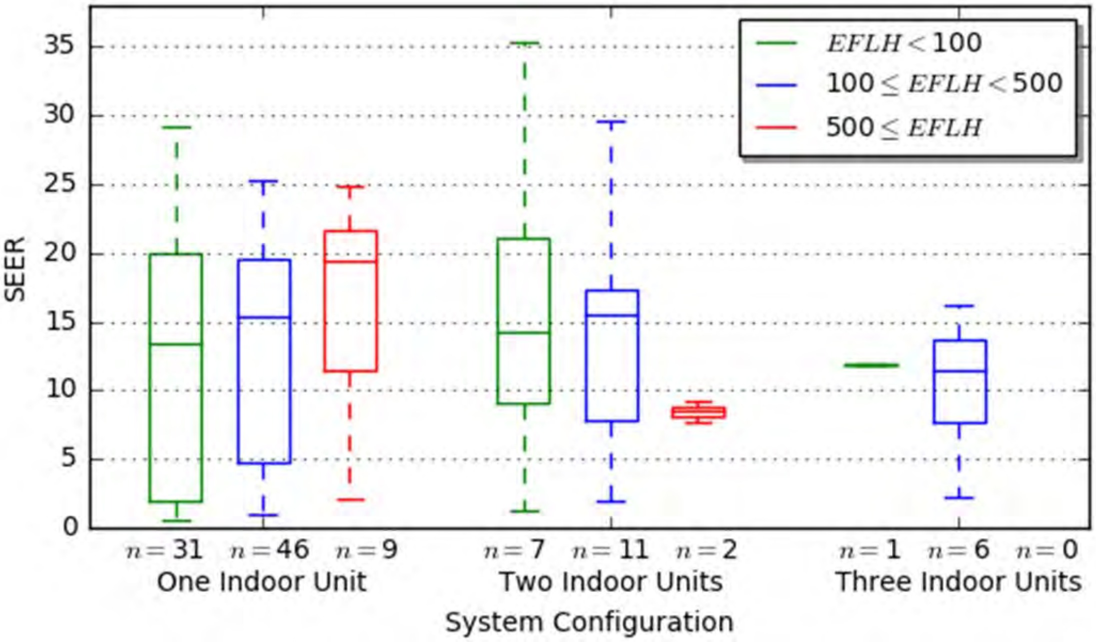
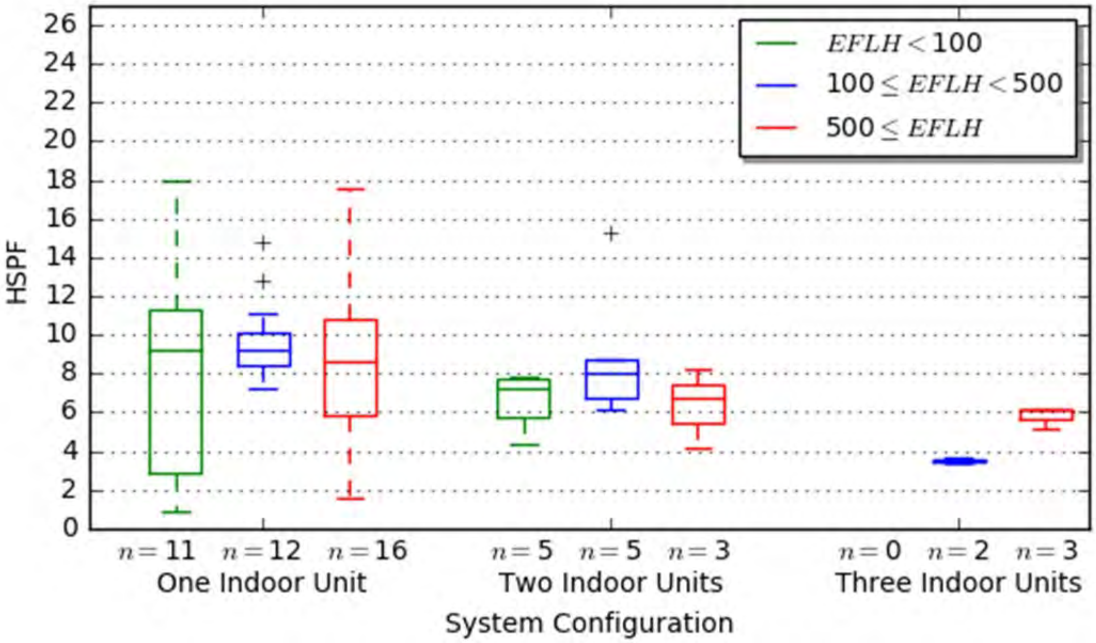


Figure 40. Winter 2016 HSPF vs. System Configuration and Usage, N=57



Units purchased for “cooling only” exhibited the highest measured SEER values, with the 75th percentile well above 20.0. A similar link did not become apparent between purchase intent and measured HSPF (see Figure 41). The same held true for cold climate units (see Figure 42).

Figure 41. Seasonal Efficiencies vs. Purchase Intent

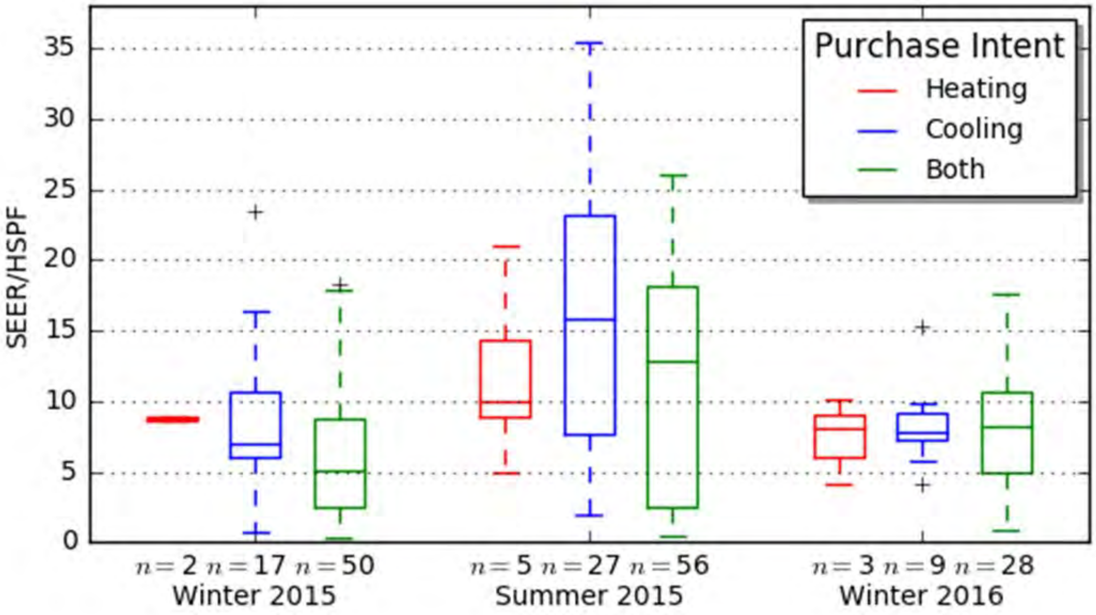


Figure 42. Seasonal Efficiencies vs. Purchase Intent, Cold Climate Units

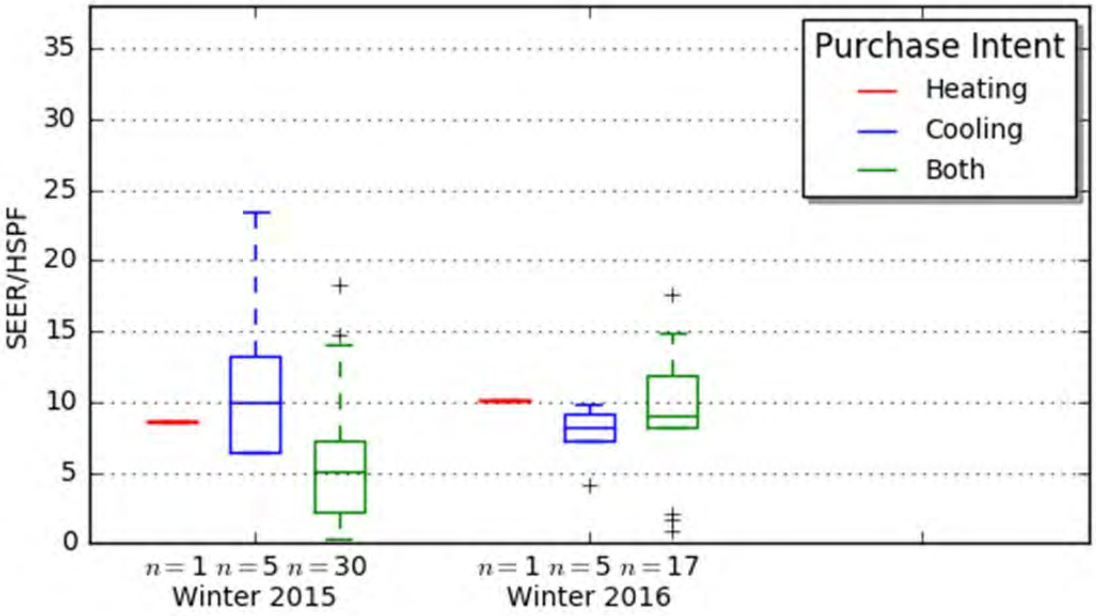


Figure 43 and Figure 45 illustrate the observed maximum capacity delivered by a unit for a season, graphed against the DMSHP's rated capacity. Each dot represents a unit for that season. The figures display a rough correlation between observed capacity and rated capacity, with the best-fit line showing observed capacity lagged rated values in winter 2015, but exceeded the rated capacity in winter 2016.

These figures show a wide range of observed maximum capacities, which, for many units, were very low. In most cases, the evaluation team considers this a product of how the units were operated, with units often used at low speed or as supplemental heat. Manufacturers use varying rating methods for heating, and units can exceed their rated heating capacity by a large amount, depending on conditions (i.e., hence many units produce much more than their rated heating capacity for short periods). During winter 2016, fewer units operated at very low capacity than they did in winter 2015. In winter 2016, most units delivered over 10,000 BTU/h at maximum, and many delivered over 20,000 BTU/h.

Figure 44 illustrates a similar, wide range of observed cooling capacities, with the best-fit line marginally higher than the rated capacity. Because the unit capacity was rated at a 95°F outside ambient temperature, one would expect units operated at cooler outdoor temperatures to exceed the rated capacity: the figure supports this expectation.

Figure 43. Winter 2015 Maximum Observed Capacity vs. Rated Capacity, N=98

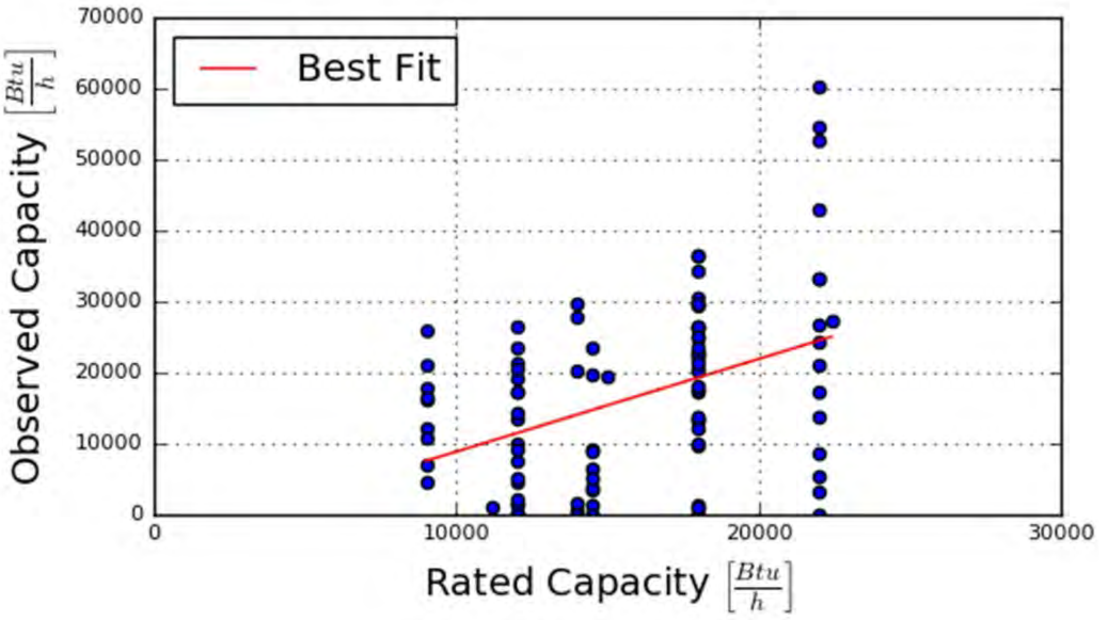


Figure 44. Summer 2015 Maximum Observed Capacity vs. Rated Capacity, N=114

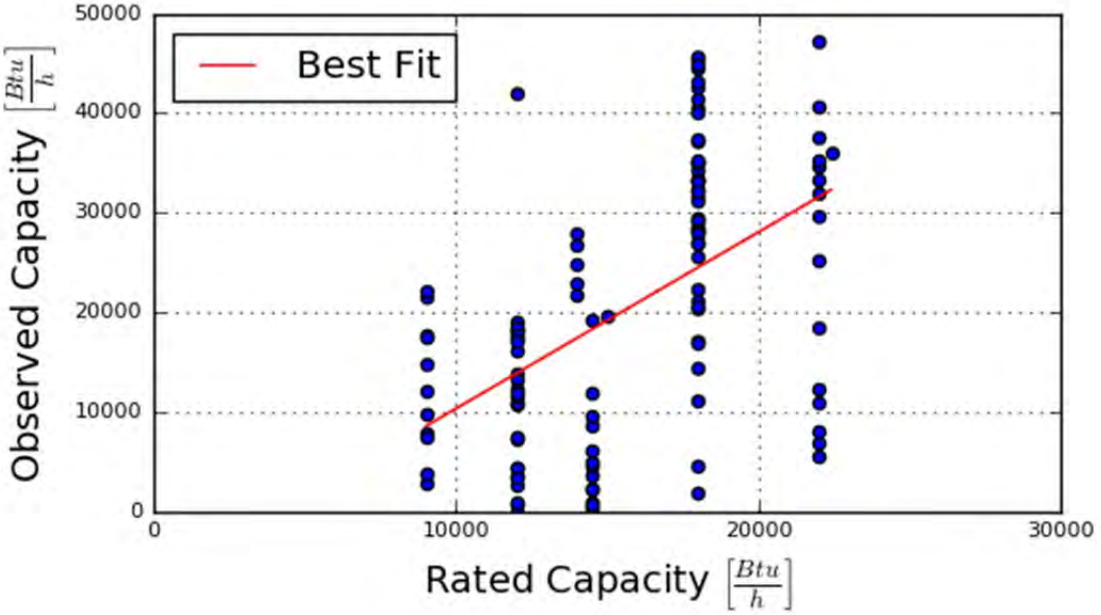


Figure 45. Winter 2016 Maximum Observed Capacity vs. Rated Capacity, N=60

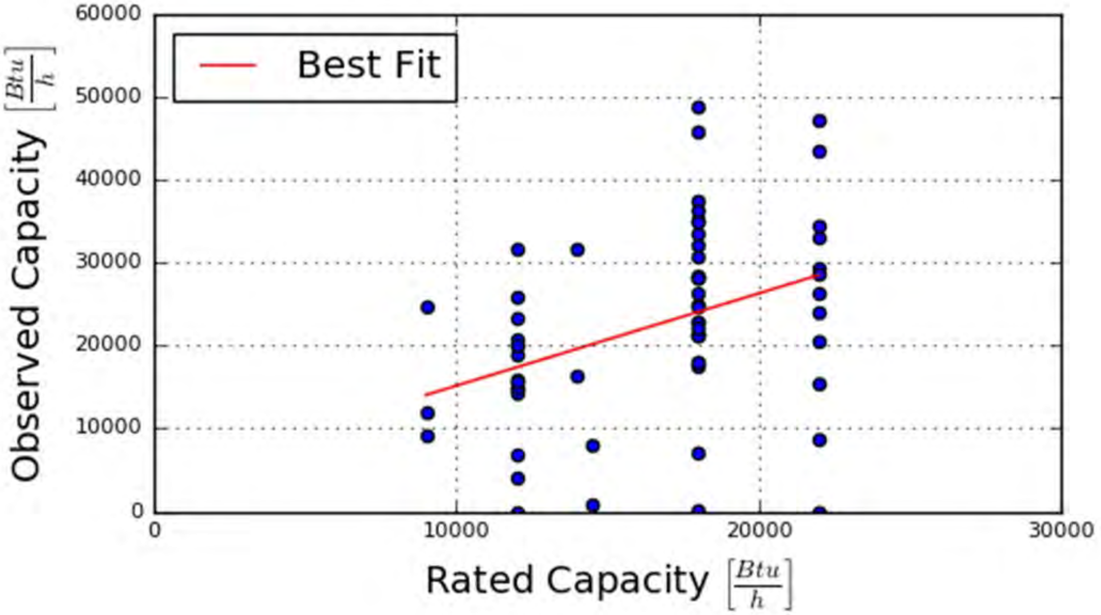


Figure 46, Figure 47, and Figure 48 present rated seasonal efficiencies against rated capacities for units metered in the study. As size increased, both a narrowing and a downward trend in rated efficiency became apparent, and the largest units (~24,000 Btu/h or ~2 Tons) had among the lowest-rated efficiencies. This should be considered an observational trend and not a strong correlation. This trend may be different today, with multiple units offered in the HSPF 14 range.

Figure 46. Winter 2015 Rated HSPF vs. Rated Capacity, N=98

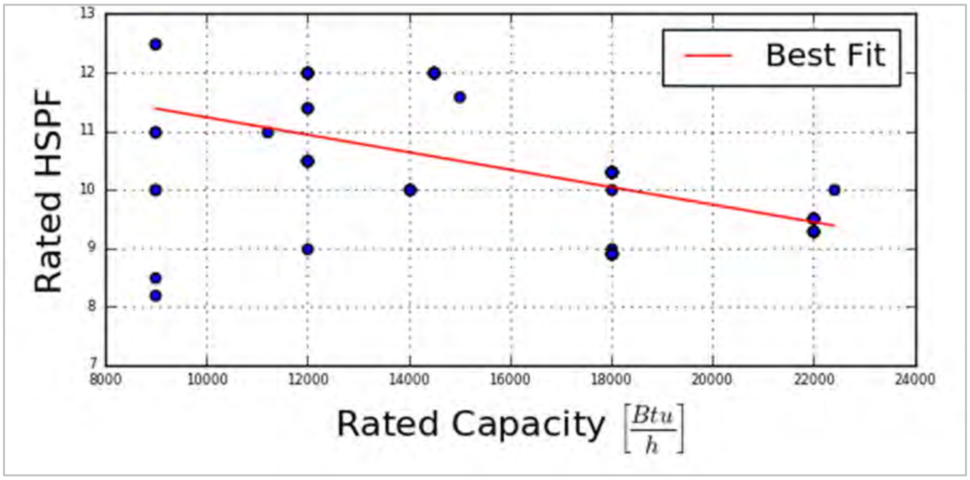


Figure 47. Summer 2015 Rated SEER vs. Rated Capacity, N=114

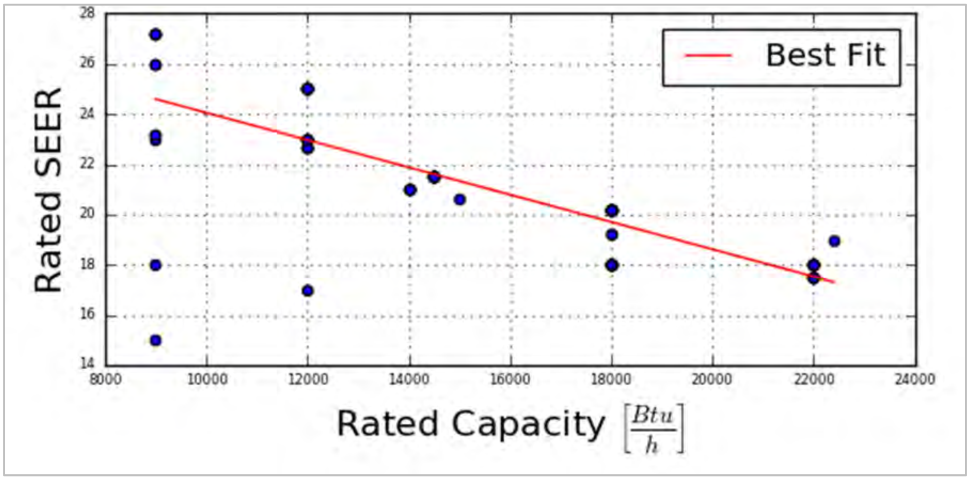


Figure 48. Winter 2016 Rated HSPF vs. Rated Capacity, N=60

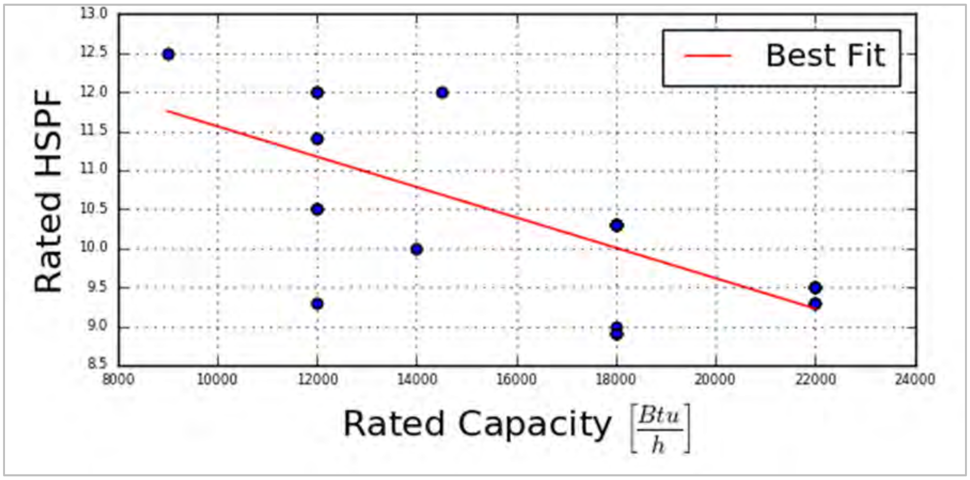


Figure 49, Figure 50, and Figure 51 present measured seasonal average efficiencies ("field" HSPFs and SEERs) for the measured units, plotted against each unit's rated efficiency. In general, this produced measured average efficiencies lower than rated, but some units performed at levels higher than rated. As previously discussed, this result was not unexpected for several reasons:

- Homeowners used DMSHPs in highly variable ways, and these behaviors affected efficiency. For example, if a DMSHP was only used to cool on the hottest days, its measured cooling seasonal efficiency would be closer to its rated EER value (i.e., the efficiency rating at 95 °F outdoor ambient) than to its rated SEER value.
- SEER and EER tests were run at specific conditions, which may not fully represent actual operating behaviors or conditions. For example, the SEER rating test stipulated the return air at 80 °F—a temperature much warmer than most homeowners would choose. The test's original intent may have been to simulate heat gain in return ducts, a factor obviously not applicable for DMSHP units.
- Units were used for other functions that could reduce rated performance, including fan-only modes and dry or dehumidification modes.

Figure 49. Winter 2015 Observed HSPF vs. Rated HSPF, N=86

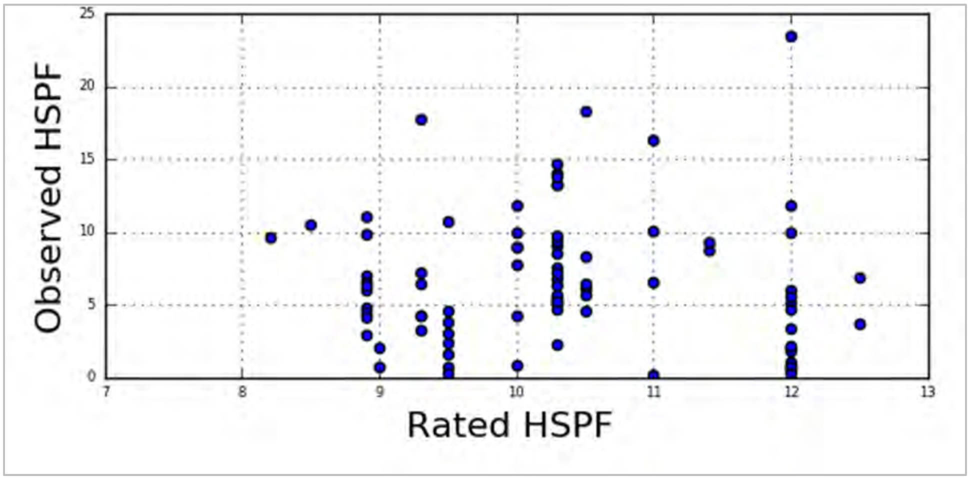


Figure 50. Summer 2015 Observed SEER vs. Rated SEER, N=113

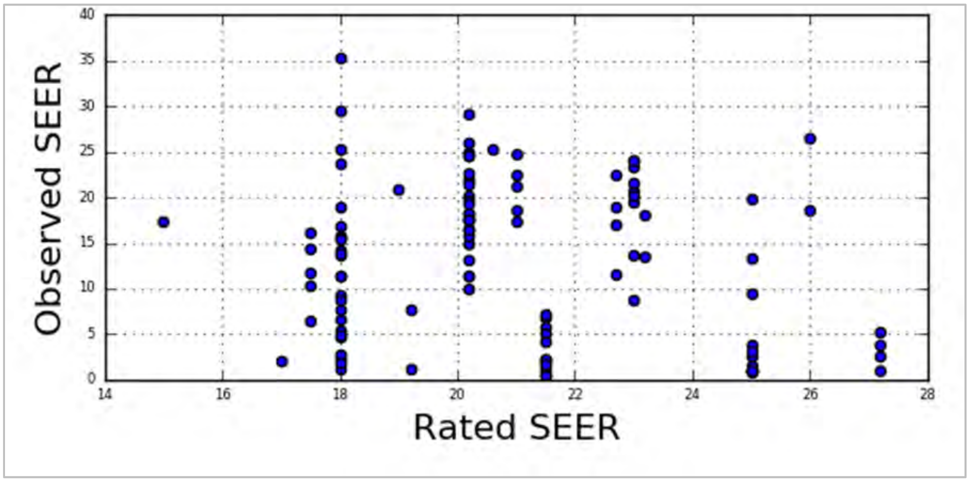
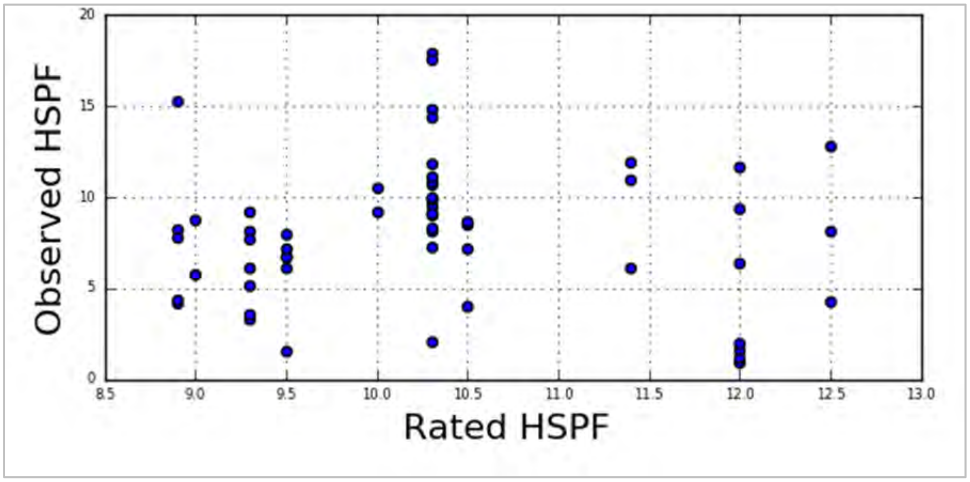


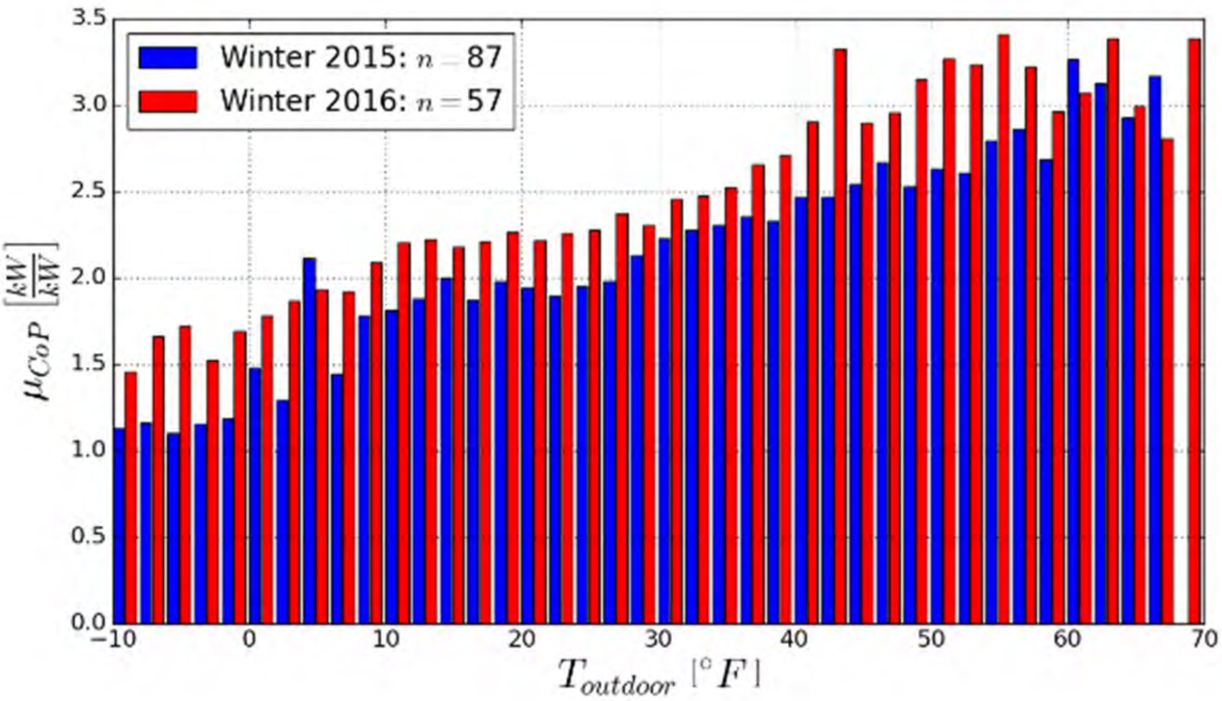
Figure 51. Winter 2015 Observed HSPF vs. Rated HSPF, N=57



Unit Efficiency COP

Figure 52 and Figure 53 provide data critical for understanding DMSHP operations, along with the average metered efficiency of units across a range of outdoor air temperatures. These measurements of field efficiency are only possible where delivered heating and cooling (i.e., BTUs) are metered. These graphs show season-long measurements for dozens of DMSHP units. Winter 2015 (Figure 52) experienced prolonged periods of deep snow and cold temperatures, and accumulated snow and ice around outdoor units can inhibit performance; so the COPs could vary greatly between this winter and the following (2016) winter. Observed units operated more efficiently the following winter (also Figure 52), with COPs averaging 1.5 at -10 to 0 °F. This is significant because it means that even for the coldest temperatures, DMSHP are far superior to electrical resistance heating, offering effective heating efficiencies 50% higher. Similar data follow for cold climate units in Figure 54 and Figure 55.

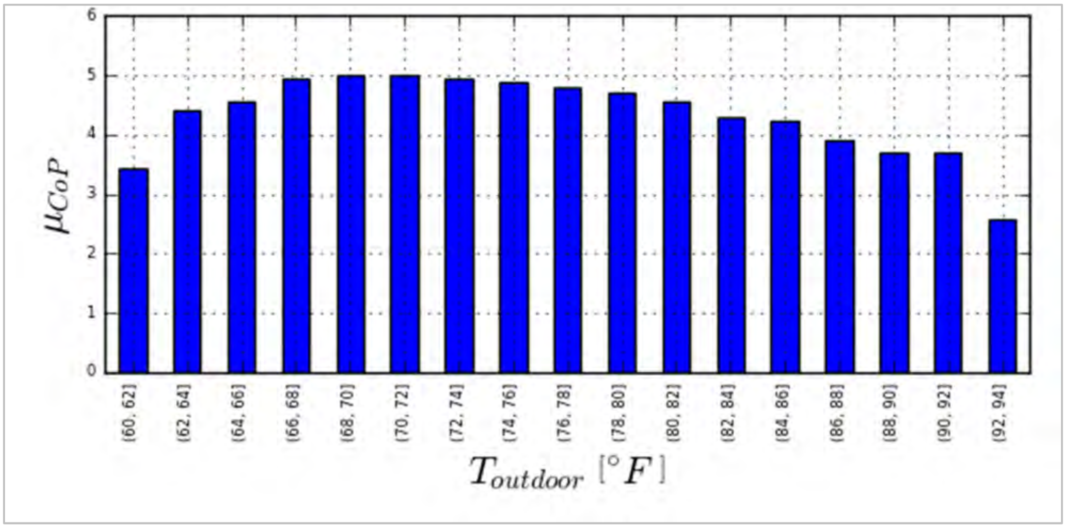
Figure 52. Winter 2015 Average COP vs. Outdoor Air Temperature, N=87



Cooling efficiency's pattern differed from heating, dropping at lower outdoor ambient temperatures (when seldom used). The average DMSHP maintained high and relatively flat efficiency at approximately a 5.0 COP from outdoor air temperatures of roughly 66 °F to about 76 °F (EER ~ 17). Average efficiency then steadily dropped with increasing temperature to an approximately 3.75 COP at 92 °F (EER ~ 13). The discontinuous efficiency drop from 92 °F to 94 °F could result from very few hours occurring in this bin and, therefore, very few hours metered, it is likely artifact of sample size and not a real trend.

Overall, the EER of 17 at milder outdoor temperatures fell below the average-rated SEER of approximately 20, but the high-temperature EER of 13 came close to the rated EER for most units.

Figure 53. Summer 2015 Average COP vs. Outdoor Air Temperature, N=114



Cold Climate Performance

DMSHP manufacturers continue to offer new units, with claims of increased performance at very cold outdoor ambient temperatures (i.e., well below 0 °F). Currently, various makers claim DMSHPs offer 100% capacity at 20 °F or at 5 °F (depending on how they are rated), and operations down to -15 °F. The evaluation team used the Efficiency Vermont TRM (current at the study's planning phase) to identify cold-climate units. Table 18 presents these DMSHP models. Manufacturers have released more capable cold-climate units in the last two years, but this evaluation drew upon installed DMSHP populations from 2012, 2013, and 2014. This report characterizes these as "cold-climate" units, with all other units are identified as standard or "non-cold-climate" units.

Table 18. Cold-Climate Unit Listing

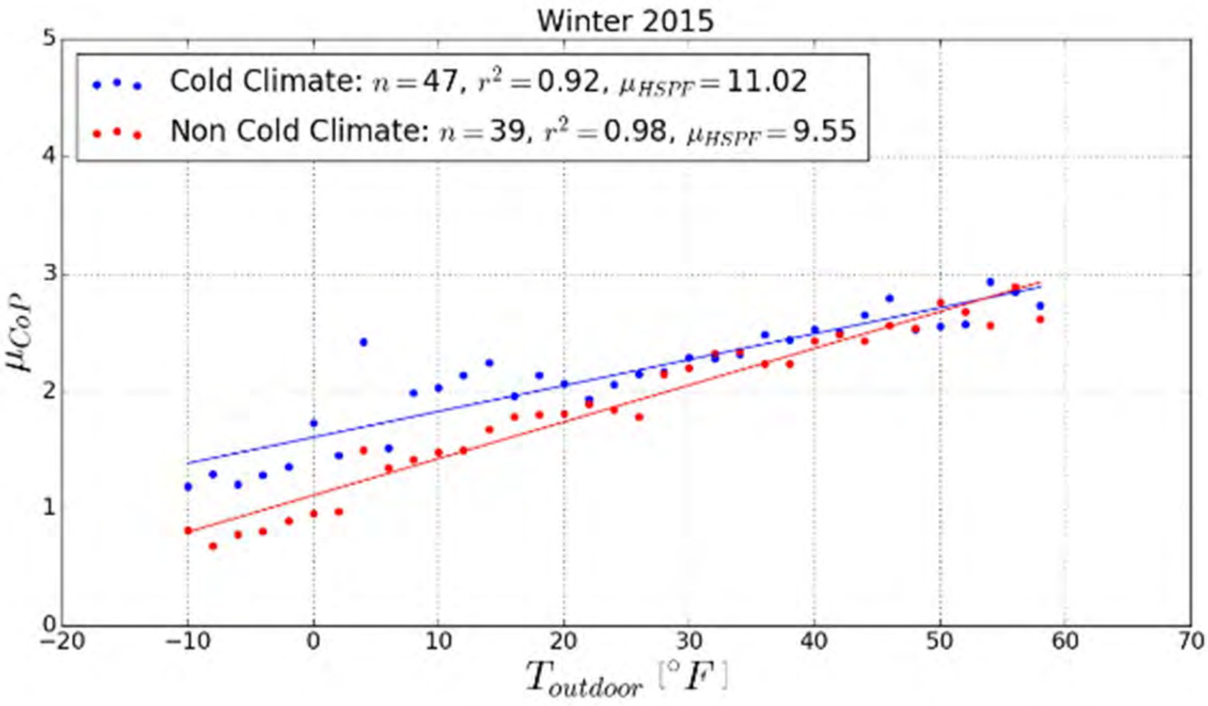
Maker & Brand	Model
Mitsubishi Mr. Slim Hyper Heat	• MUZ/MSZ-FE09NA • MUZ/MSZ-FE12NA • MUZ/MSZ-FE18NA
Fujitsu Halcyon Inverter	• AOU/ASU9RLS2 • AOU/ASU12RLS2 • AOU/ASU15RLS2 • AOU/ASU12RLS2H • AOU/ASU15RLS2H
Daikin Altherma	• ERLQ030BAVJU • ERLQ024BAVJU

Figure 54 and Figure 55 present COPs[40] plotted for cold-climate and non-cold-climate units against outside ambient temperatures for winter 2015 and winter 2016, respectively. Because data points are each performance averages from many units, they are averages and should be considered approximations. Data for winter 2015 (already noted for deep snowfalls that buried many units) showed the separation of efficiency as COP only at temperatures below 40°F. The separation in COP grows to about 0.5 moving left in the plot to 0°F.

Winter 2016, without snowfall issues, shows separation of efficiency curves for the entire range of outdoor temperatures—a curve more in keeping with the roughly 1-point difference in rated HSPF (COP difference of 0.3) between the cold climate and non-cold climate units (see the figure key).

This ratings difference is consistent with comments engineers at major manufacturers told the evaluation team, stating that cold-climate units were of higher quality and featured more of the newest technology. As cold-climate units are increasingly demanded by customers, the engineers reasoned that putting more effort and innovation into the cold-climate models made sense. Notably, observed non-cold-climate models operated at outdoor ambient temperatures below 0 °F, but at a lower efficiency than cold-climate models.

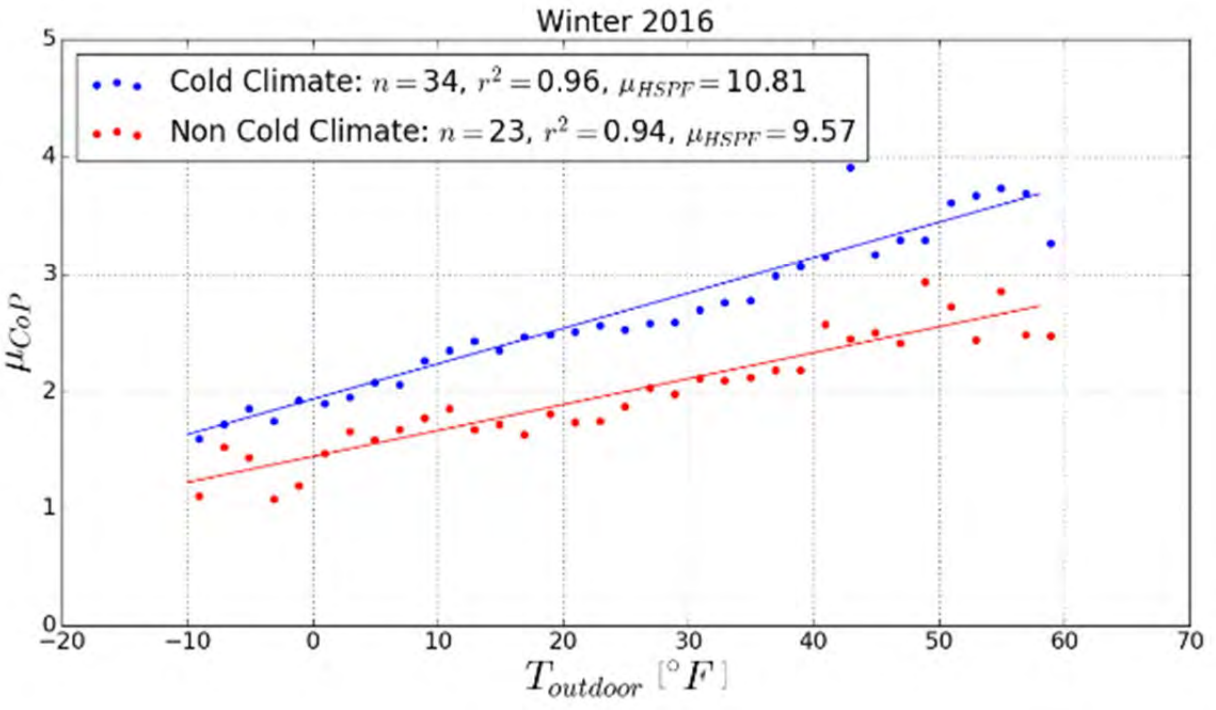
Figure 54. Average Heating COP vs. Outdoor Air Temperature for Cold-Climate and Non-Cold-Climate Systems – Winter 2015



---

[40] Electrical resistance heating has a 1.0 COP; fuel heating has a COP equivalent to system efficiency (0.7 to 0.9).

Figure 55. Average Heating COP vs. Outdoor Air Temperature for Cold-Climate and Non-Cold-Climate Systems – Winter 2016



Multi-Head Performance

DMSHP manufacturers offer different system configurations, with some systems including more than one indoor unit (or "head") for each outdoor unit. The evaluation team observed single-head systems most commonly, but many units included in the study had two, three, or even four heads.[41] System owners could choose to purchase a multi-head system for a number of reasons, but at the time of the installation of the units in this study, no cold-climate multi-head systems were available. Multi-head units are generally rated lower than single-headed systems in this study and metering data seems to follow this trend.

Figure 56 and Figure 57 show the range of efficiencies by the number of heads. Figure 56 presents COPs plotted against outdoor ambient temperatures for the heating season, and compares units with one, two, and three indoor heads per each outdoor unit. The resulting plot indicates that single-head units, in general, operated more efficiently than multi-head options. Cold-climate units were rated higher and proved more efficient than standard or non-cold-climate units (see the Cold Climate Performance section), so the trend in declining efficiency with increased head count could arise simply from ratings or from a combination of factors.

---

[41] The team observed one four-head system through the study, but excluded it from the plot due to the small sample size.

Figure 57 presents the same data as Figure 56, but for only non-cold-climate units. Though essentially identical, this plot shows (single head) non-cold-climate single-head units operating less efficiently, with a rated HSPF generally 1-point lower (equivalent to a COP difference of 0.3). The two and three head curves are identical in both figures because there are no multi-head cold climate units. The two-headed units' efficiency curve rises more steeply than the one- or three-headed units do. At this time, the technical reason for this remains unknown.

Figure 56. Average Heating COP vs. Outdoor Air Temperature for One-, Two-, and Three-Head Systems

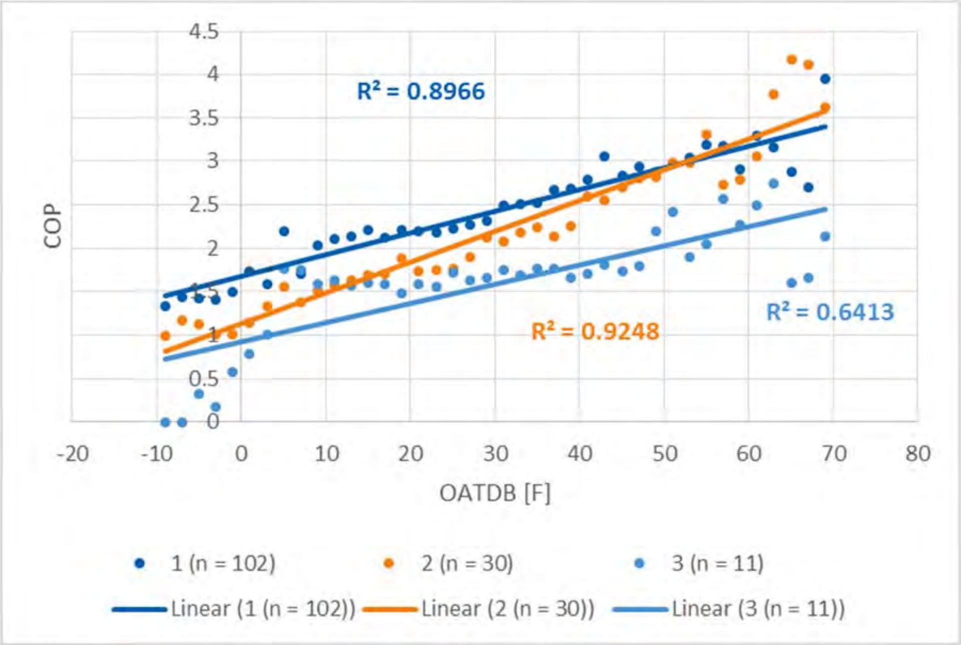
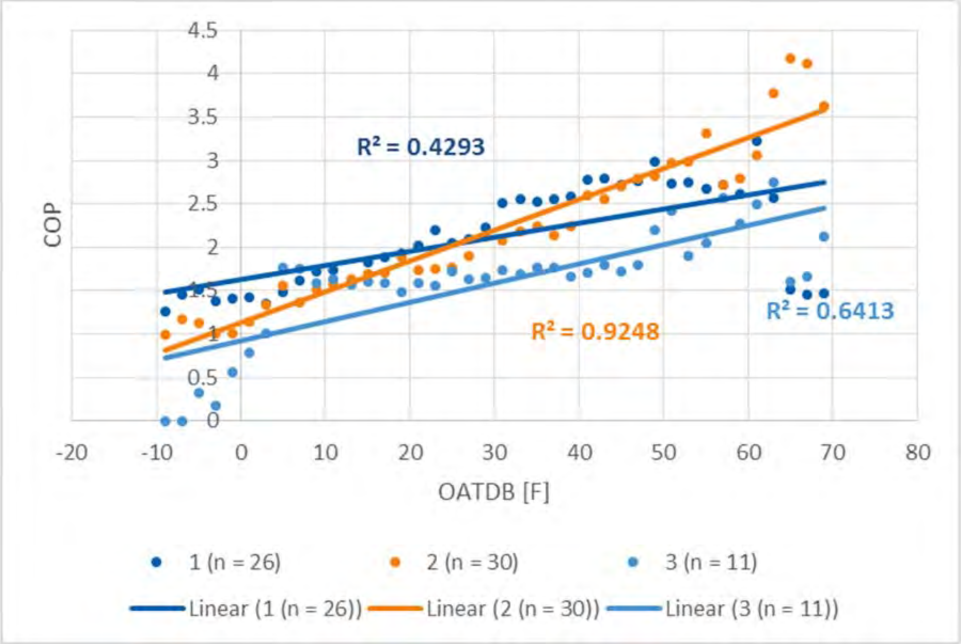


Figure 57. Average Heating COP vs. Outdoor Air Temperature for One-, Two-, and Three-Head Non-Cold-Climate Systems



Performance Related to Installing Contractors

In Massachusetts, one installer accounted for a relatively large number of installations, and several program sponsors indicated concerns about the substandard quality of their work. At multiple installations by this contractor, the evaluation team noted extra lengths of line set (up to 30 feet) coiled behind the outdoor unit. Manufacturer's installation guidance directs installers to trim line sets to minimum reasonable lengths.

To examine whether this contractor's installation practices affected efficiency, the team plotted the average COP against outside temperatures for sites installed by the contractor, along with sites installed by other contractors. Figure 58 and Figure 59 show average COP for the largest contractor and all other contractors versus outside air temperatures. The figures indicate the largest contractor's COPs were lower for all temperatures by about 0.5 COP points in winter 2015 and 1.0 for winter 2016. The average HSPF for units installed by the largest contractor was 10.3 (10.0 for both winters), while the average HSPF of units installed by others were 10.4 and 10.5. The difference of 0.1 to 0.5 points equals a rated COP difference of 0.03 to 0.15, far lower than the actual difference in the graph. Therefore, the figure differences cannot be explained by differences in rated efficiencies. This evaluation did not focus on installation quality, and any issues beyond long line sets (previously noted) would not have been directly observable. It appears however that there was an issue exists with installations by the discussed contractor.

Figure 58. Average Winter 2015 COP vs. Outdoor Air Temperature for Installing Contractor

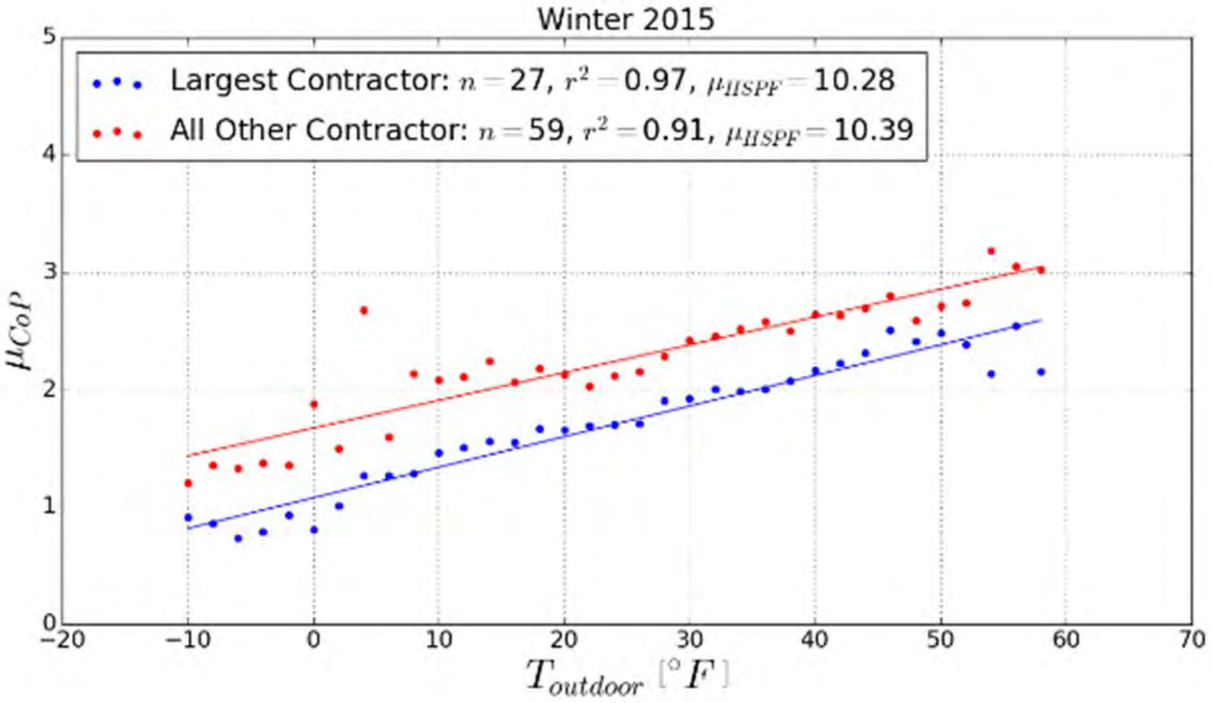
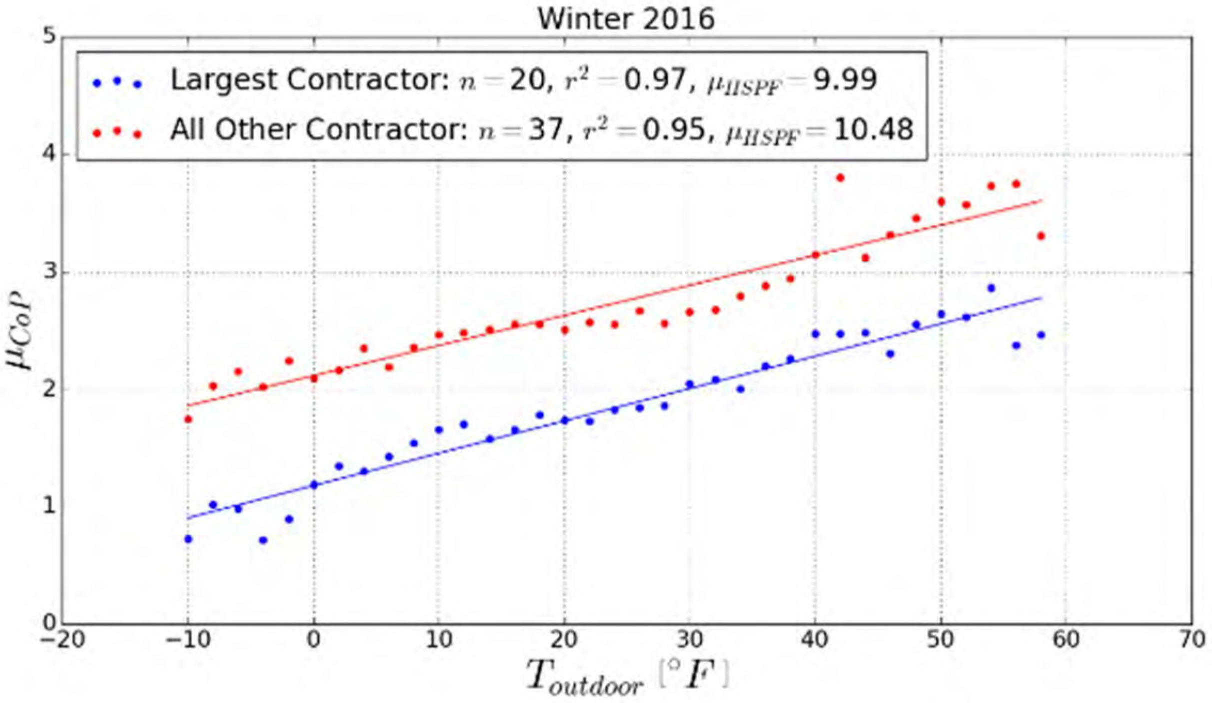


Figure 59. Average Winter 2016 COP vs. Outdoor Air Temperature for Installing Contractor

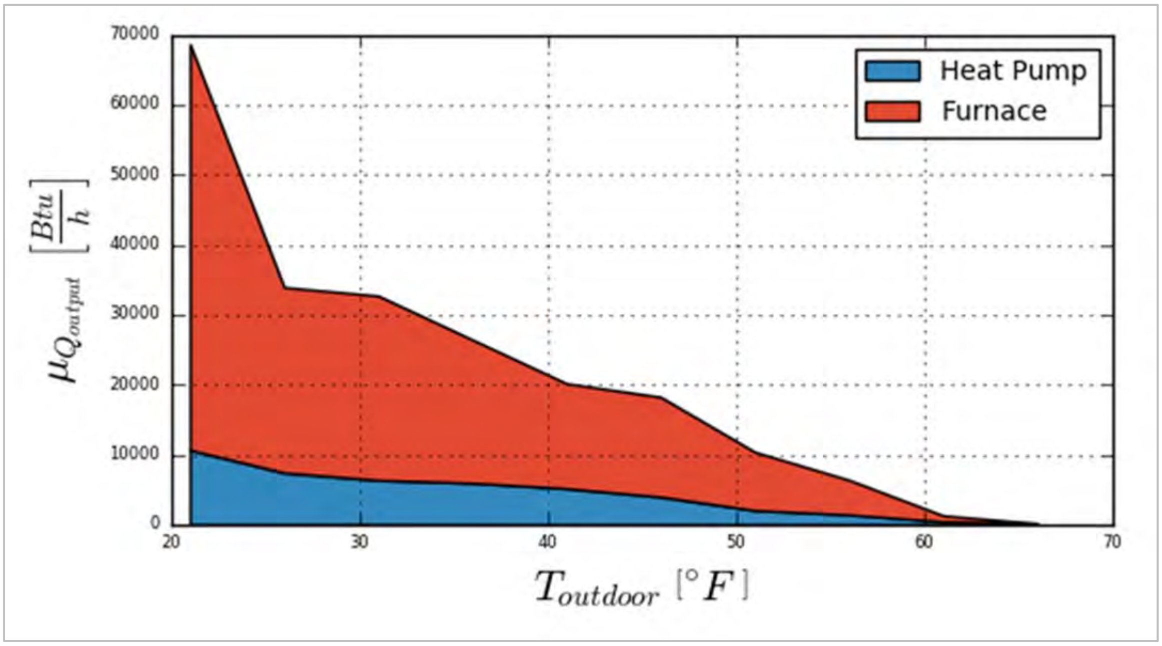


Heating System Interaction

Figure 60, Figure 61, and Figure 62 present representative heating system interactions for three homes. These stacked area charts illustrate the relative contribution of each system across a range of temperatures. The heat output rate (BTU/h) dropped to zero at the home's balance point,[42] at roughly 60 to 65 °F. The heat output rate increased in a nearly linear fashion (from right to left) as outdoor temperatures declined. The DMSHP heating rate displayed a different shape in the three sites, but, in each case, the relative contribution remained small, and the average heat output did not approach the capacity of the alternative heating unit. For Site M0193, the heat output rose to 10,000 BTU/h—the greatest value from these three sites.

The relatively small contribution of the DMSHP versus the primary system could arise from multiple reasons. Heat loss from the room could be low. At site M0193, heat provided by the DMSHP rose linearly with temperature. The amount of heat delivered (10,000 BTU/h) was relatively large, equaling the mean heat loss shown in Figure 63. The shape and magnitude of the curve may indicate it contributed most of the heat to a zone or space. In contrast, sites M0198 and M0011 exhibited a decreased DMSHP contribution as the outdoor ambient temperature dropped.

Figure 60. Site M0193, Heating System Interaction



---

[42] The balance point is defined as the outdoor ambient temperature where heat gains from internal loads equal heat losses to the outdoor environment; so heating or cooling are not needed to maintain internal conditions.

Figure 61. Site M0198, Heating System Interaction

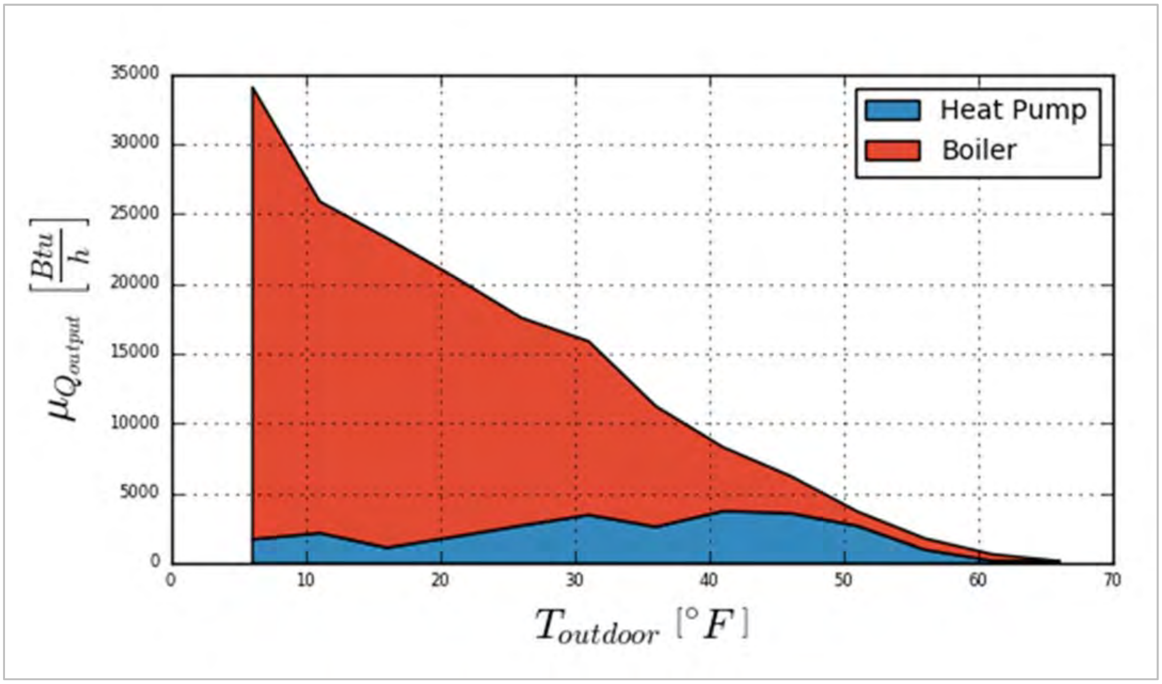
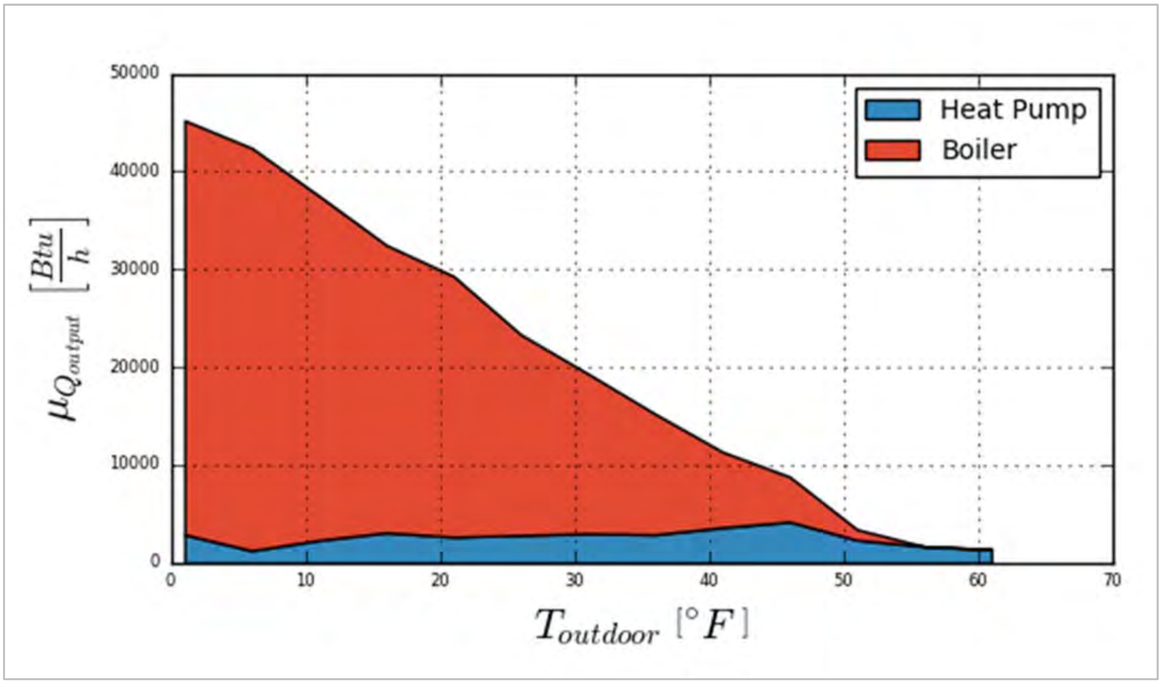


Figure 62. Site M0011, Heating System Interaction



Unit Sizing

For each indoor head, the evaluation team calculated the design's heat gain and heat loss using ANSI's *Manual J: Residential Load Calculation (Eighth Edition)*. Figure 63 shows the range of calculated heating and cooling load for each space served. In general, the calculated heat load was 5,000 to 10,000 BTU/h at 6 °F, and the median calculated cooling load was 5,000 BTU/h with a relatively tight range. Given that most DMSHP heads have rated capacities of 9,000 BTU/h and greater, these plots seem to indicate that DMSHPs were sized larger than necessary for cooling. As discussed later, this may be because they were sized to meet heating needs. Fully half of all systems have heating loads above 10,000 BTUh at 6 °F, and 25% have loads great than 13,000 BTUh. These loads will be roughly 20% higher at -5°F, assuming a balance point of 65 °F), or 12,000 and 16,000 respectively.

Figure 64 shows the ratio of rated unit capacity to calculated thermal load. This ratio was slightly above 100% for heating and just above 200% for cooling. As noted, the heating ratio probably was exaggerated as heat loss was calculated at a design temperature of 6F, while units were rated at 17°F. That is the median is likely below 100% of needs at colder temperatures as discussed below. Even at 17°F, nearly half of the units were undersized for the space's heating needs. The ratings of units' heating capacity at 5°F are not standardized, with methods varying by manufacturer and AHRI ratings limited to 17°F.

The efficiency of a unit drops as the outside temperature drops, but capacity is dependent on airflow and compressor speed. Some manufacturers report a flat capacity from 17°F to 5°F. Lacking standardized metrics at colder temperatures, to roughly estimate how much capacity might drop from 17°F to 5°F, the evaluation team took a ratio of the two ratings for fixed airflow, using manufacturer's engineering data, and found about a 20% drop. Increased compressor speeds and higher airflows could make up for this but that would be hard to determine without testing. Very roughly, if the median capacity at 17°F was 110%, and if it dropped by 20%, the capacity would be as low 88% at 5°F. Even without this drop, some 50% of units did not meet the heating load at temperatures below 17°F.

Conversely, the cooling ratio was slightly higher than indicated as the capacity was rated at 95°F, while the heat gain was calculated at 86°F. Because DMSHPs have variable speed compressors and variable speed fans, the evaluation team does not think that oversizing for cooling will appreciably affect savings or efficiency.

Figure 63. Calculated Thermal Loads of Spaces Served by DMSHPs, N=141

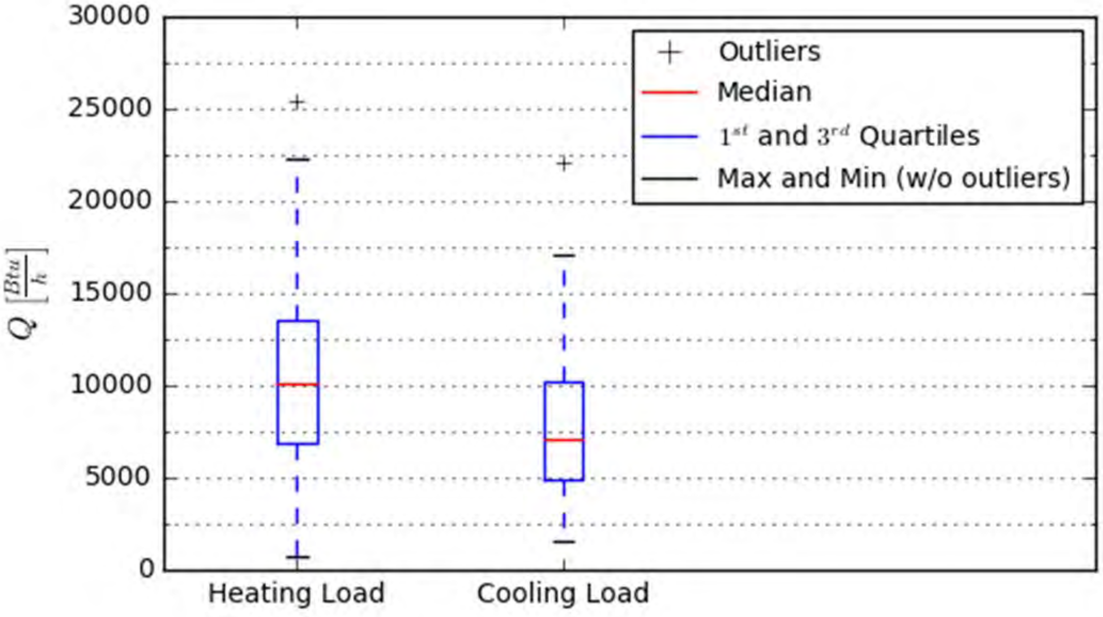


Figure 64. Ratio of DMSHP Rated Capacity to Calculated Thermal Load of Spaces Served, N=140

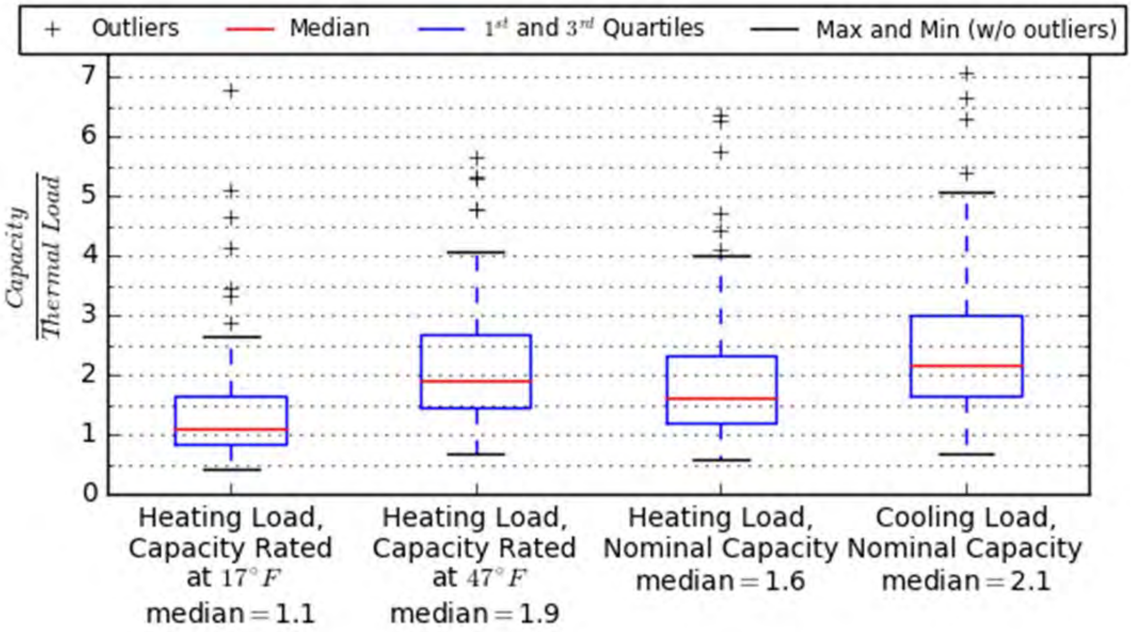


Figure 65. Ratio of DMSHP Rated Capacity to Floor Area of Spaces Served

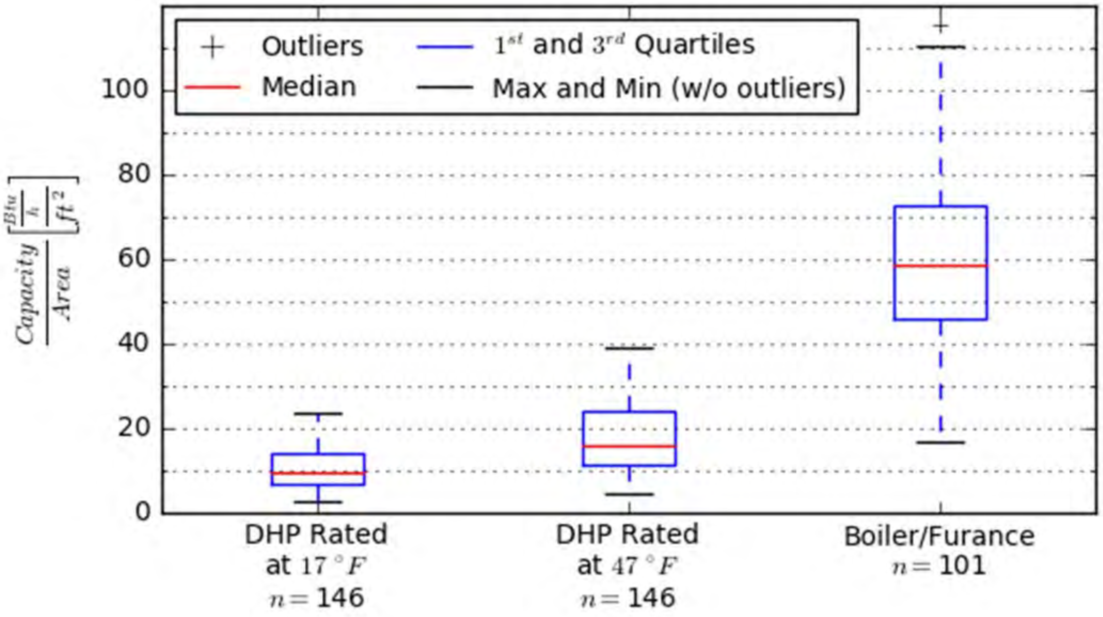


Figure 66 presents the ratio of rated unit capacity to the calculated design heat load; values greater than one indicate the unit has more capacity than the calculated load for the space served with the caveats discussed above. Table 19 summarizes these data. The team used the unit's nominal capacity for these calculations, calculating the design loads using a set of outdoor design conditions, set forth by ANSI in *Manual J.* For Framingham, Massachusetts, this calculation results in outdoor ambient conditions of 86 °F during the summer and 6 °F during the winter.

Systems that could be characterized as outliers (i.e., capacity at greater than a 4:1 ratio to heat loss or heat gain) resulted from installation of indoor units in spaces with only a small amount of area adjacent to the exterior, such as hallways. In these cases, the heating and cooling likely spilled over and served adjacent areas.

Figure 66. Heating and Cooling Rated Capacities Normalized by Calculated Design Loads

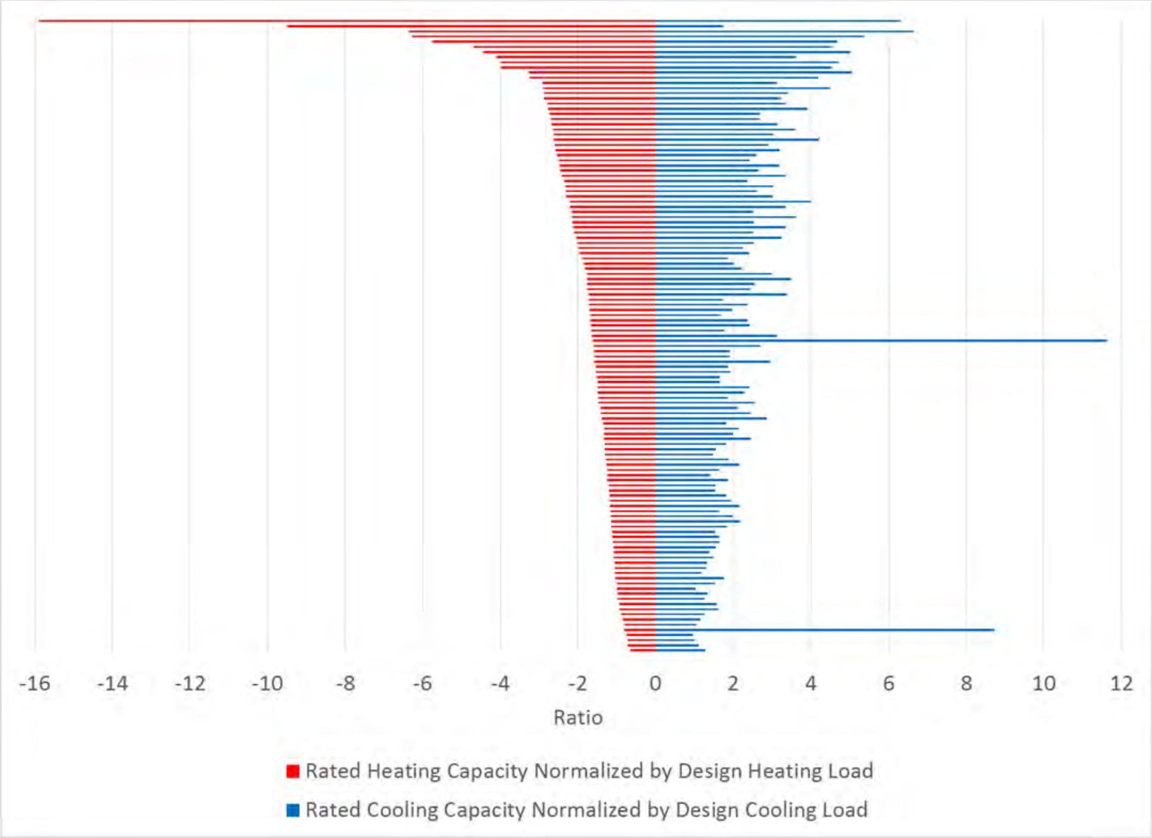


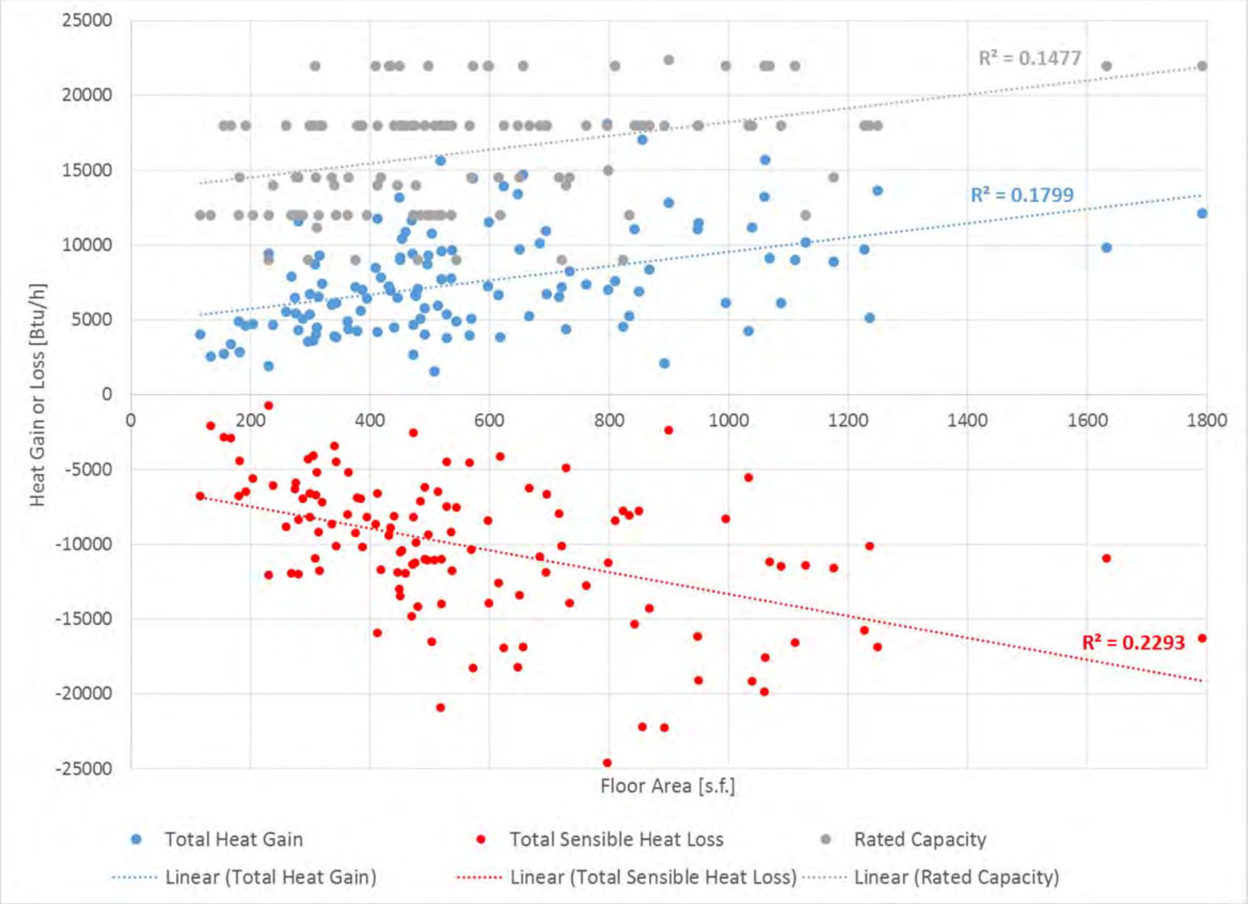
Table 19. Heating and Cooling Capacities, N=137

	Heating Capacity Ratio (Rating / Design)	Cooling Capacity Ratio (Rating / Design [86°F])	Floor Area Served / Cooling Capacity (s.f. / ton)	Heating Capacity / Floor Area Served (BTU/h per s.f.)
Minimum	64%	96%	104	11
Maximum			1,129	115
Average	See above	262%	333	36
Median	110% (17°F)	210%		

The evaluation team received only a handful of complaints from homeowners, who regarded their units as undersized to meet their cooling loads in summer; more common were complaints regarding insufficient heat during the winter. The previous discussion supports this observation.

Figure 67 presents a scatter-plot of rated capacities and calculated (*Manual J*) capacities, mapped as a function of floor area served. Based on the characteristics of homes participating in the evaluation and the resulting calculations completed via Manual J, the evaluation team considers it unlikely that contractors use *Manual J* to size DMSHP systems. Based on these data, it also remains unlikely that contractors use a “rule of thumb” to size a unit’s capacity to the floor area. As shown in Figure 67, none of the data exhibit a good trend fit or strong correlation (as the R^2 values are low relative to an ideal fit of 1.0).

Figure 67. Relationship Between Design Cooling, Design Heating, and Rated Capacities as a Function of Floor Area Served



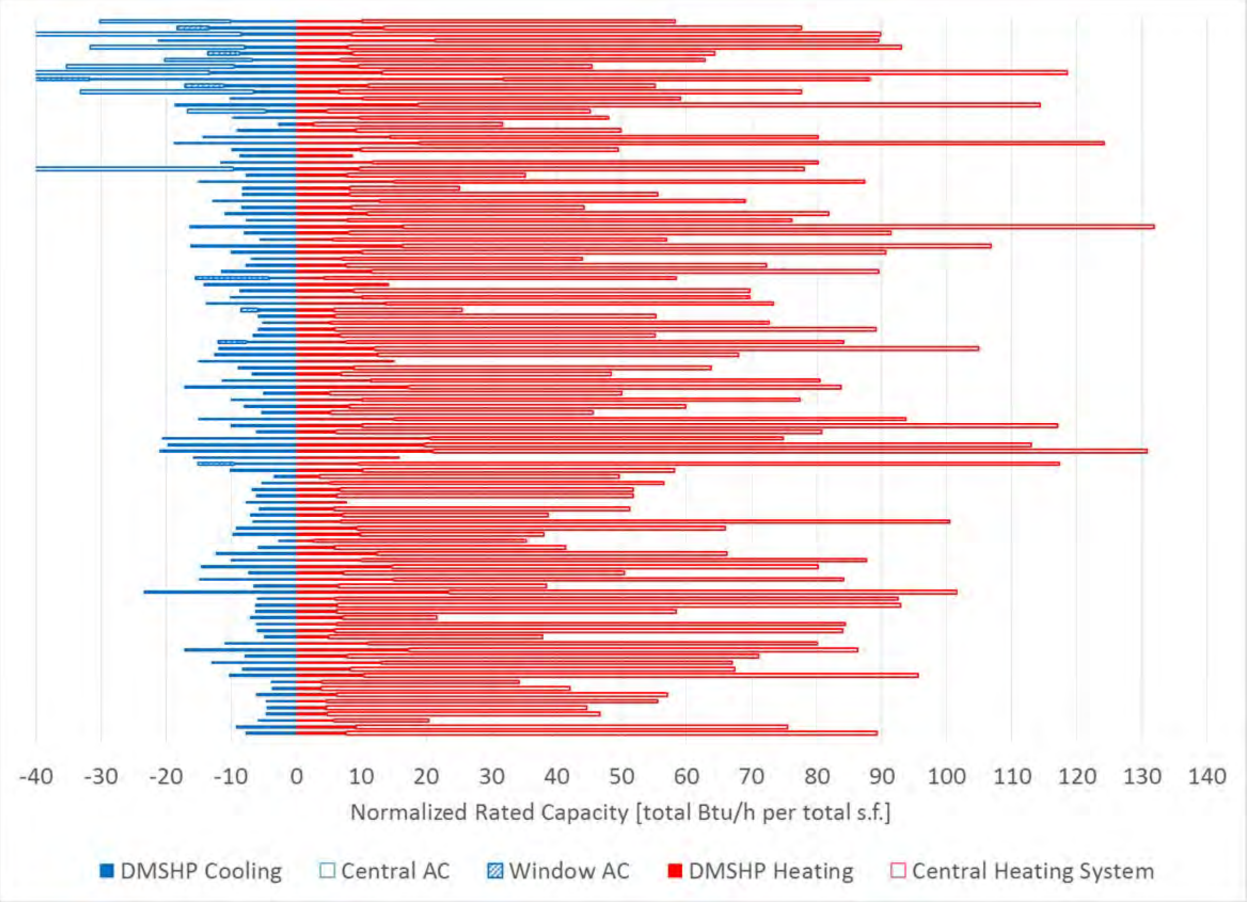
To test for use of rules-of-thumb, the evaluation team calculated the average floor area (in square feet) served per ton of capacity for cooling and the BTUh per square foot supplied for heating. The result averaged 333 sq. ft. per ton of cooling capacity, and 36 Btu/h per sq. ft. of floor area.

Finally, as shown in Figure 68, the team calculated the total rated cooling and heating capacity per total floor area of each home, which included both DMSHPs and alternative heating or cooling systems. This calculation examined the approximate portion of design capacity contributed by DMSHPs.

The figure shows the capacity of each HVAC system in the home, normalized by the home's total floor area. For most homeowners, a DMSHP system served as their only cooling source. Of homes in the study, only eight had cooling capacities greater than 20 Btu/h per total s.f. of the home (or roughly 600 s.f./ton). The average cooling capacity was about 11.5 Btu/h per total s.f. of the home (or roughly 1,043 s.f. of home/ton). This is a far lower installed capacity than most central air conditioners (CAC) that Cadmus has observed during other studies. This means that while the capacity of the DMSHP is far greater than the cooling needs of the immediate space served, the overall installed cooling capacity of DMSHP homes is far lower than homes cooled by a CAC. For heating, the average installed capacity was 67 Btu/h per s.f., where DMSHP accounted for 9.5 Btu/h per s.f. of that value.

Because DMSHP systems only accounted, on average, for about 14% of the total installed heating capacity, one can reasonably consider these units secondary or spot-heating solutions, with the bulk of home heating performed by an alternative system or systems. About 7% of homeowners in Figure 68 used their DMSHP systems in conjunction with window air conditioning units; often to meet needs in their home's represented central areas (which would otherwise require multiple window units for cooling). About 8% of homeowners used the system in conjunction with central air conditioners, presumably because the DMSHPs allowed homeowners more control over individual set points within their homes. Homeowners also indicated that DMSHPs helped to condition areas added to homes after original construction and only served partially by the existing systems.

Figure 68. Normalized HVAC System Capacities



Behavior Influence

At the beginning of winter 2016, the evaluation team distributed a postcard to a small group of study participants. All participants had existing, operational electric resistance heat in the same room as their newer DMSHP. The postcard was intended to encourage changes in operating behaviors by homeowners and to promote more efficient operations of the coincident systems. Figure 69 presents the postcard's primary content.

Figure 69. Behavior Influence Postcard

MAXIMIZE THE BENEFITS OF YOUR DUCTLESS HEAT PUMP

A ductless heat pump will deliver heating more efficiently and less expensively than electric resistance heat (your electric baseboard heaters) at all outdoor temperatures. It is up to 4 times more efficient during milder temperatures. Your goal should be to let the ductless system provide as much heat as possible. Here's how to ensure the most savings:

1 Set your ductless heat pump thermostat at your desired temperature (68°F to 70°F for most homes).

2 Set the thermostat for your electric baseboard heat (*In the room with the ductless system*), 4 to 5 degrees **below** the ductless heat pump set-point (For example set your ductless system to 68F and your main system to 64F). If your baseboard has settings like Off/Low/Medium, turn it to low or off as much as possible.

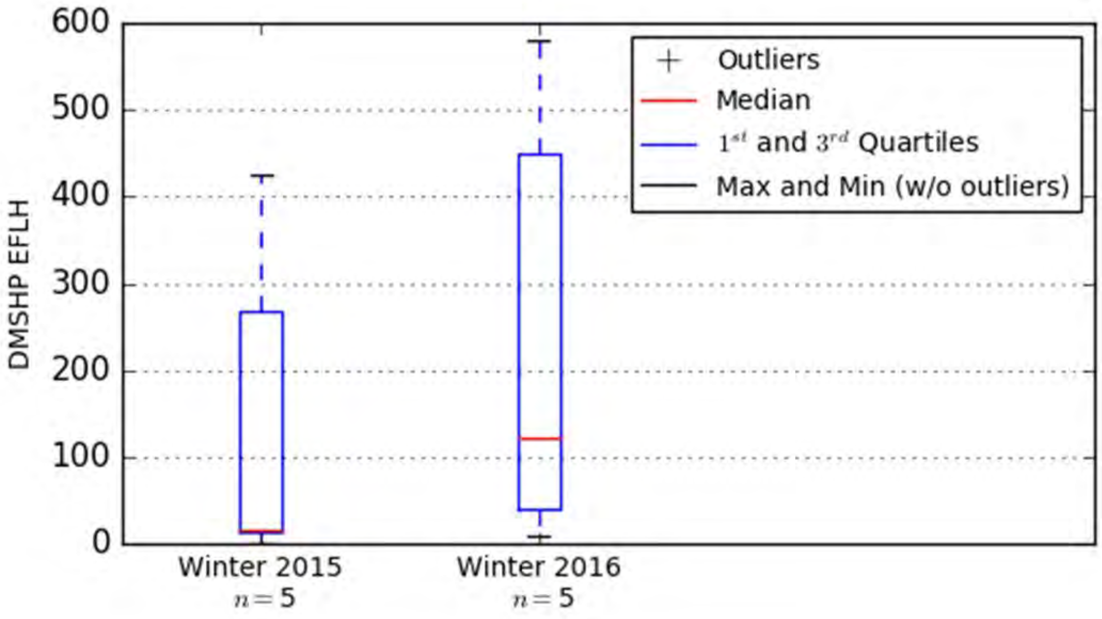
3 If you set your temperature back at night or when you are not at home make sure to keep the baseboard setting lower than the ductless system.

4 If the ductless system is not keeping your room warm enough during very cold outdoor temperatures, turn up your baseboard thermostat to heat to your desired temperature. When outdoor temperatures return to more normal temperatures, turn your baseboard back down.

5 Make sure to check your filter once per month and clean as needed. Dirty filters will reduce the efficiency of your ductless system.

Figure 70 presents compares behavior for these participants from winter 2015 to winter 2016. After normalizing for different weather conditions between the two winters, it appears this postcard mailing had the intended effect, and DMSHP usage increased among recipients. This finding indicates some potential exists for behavior-influence efforts to increase the efficiency of customer operating behaviors.

Figure 70. DMSHP Usage for Behavior Influence Postcard Recipients



Additional Findings

Throughout the study, the field team had multiple opportunities to speak with homeowners and learn about their experiences in purchasing and installing DMSHPs. The team observed a range of situations where homeowners noted diminished performance and sought guidance from field staff on improving their units' operation.

Filter Cleanliness

Staff observed the cleanliness of filters and rated them from one to three, noting whether they were clean (1), moderately dirty (2), or very dirty (3), respectively. The average filter received a rating of 1.5 to 1.6, indicating that filters typically fell between clean and moderately dirty. Dirty filters more often occurred alongside the following conditions (in descending order of influence):

- Pets in the home
- Wood or wood-pellet stoves used as a heat source
- Homeowner was unaware of the filter's presence
- Homeowner was unable to reach the filter for cleaning

As shown in Figure 71, filters can be checked for cleanliness visually. In this extreme case, dust accumulation on the filter hindered the fan's full-speed volume by 69%. Filters can be cleaned with a household vacuum or in a sink, leaving the filter to air dry before reinstalling.

The evaluation team examined filter cleanliness' impacts of on fan performance and air volumes. Under laboratory and field conditions, the team tested units under "as-is" filter conditions, without a filter, with a clean filter, and using an apparatus to simulate a dirty filter. The testing results indicated a filter's cleanliness changed the operating point along the "fan current vs. air volume" curve, but even a very dirty filter shifted the curve down by less than 10% versus a cleaned filter and by about 5% versus an average filter. Based on these data, the team concluded that no adjustments to account for filter cleanliness were necessary when processing measured data, since the measurement approach (i.e., logging indoor head current) accurately represented the unit's delivered airflow.

Figure 71. Filter Maintenance

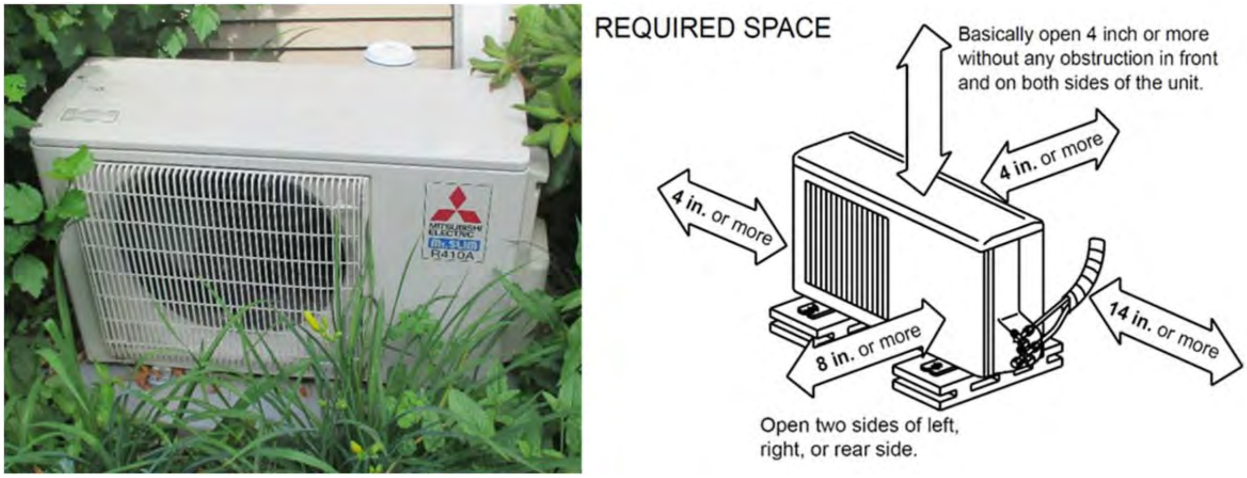
Outdoor Unit Placement

The field staff observed many DMSHP outdoor units improperly mounted or lacking appropriate clearances from roof drain water. During the winter, many units were exposed to snowmelt from a home's roof or to water collected from the defrost cycle (as melted snow and ice can build up on the unit itself). Without adequate clearance below the unit, this water could freeze and impair condenser fan operation. The team observed this scenario for at least one site, illustrated by Figure 72. The manufacturer's recommended clearance illustration[43] does not clearly define a minimum clearance value above the ground, but it implies that mounting the unit on two cement blocks would be appropriate. While the unit in the photo (left) has about one inch of clearance, the illustration (right) implies a unit should have about four inches of clearance below the unit.

---

[43] Mitsubishi Electric Corporation. *Outdoor Unit Service Manual No. OBH543 Revised Edition-A*. September 2010. Available online: http://www.mitsubishipro.com/media/214712/muz-fe09-18na_service_obh543a_9-10.pdf

Figure 72. Clearances Underneath Outdoor Units



Clearance issues do not exclusively result from installation practices. Several homeowners reported experiencing rapidly diminishing capacity over time, and field staff found outdoor units within piles of items or other debris. In one notable case, shown in Figure 73, a pile of lawn furniture encircled an outdoor unit, which was half-protected from scratches by a tarp.

Figure 73. Clearances Around Outdoor Units

The effort required to maintain a DMSHP outdoor unit's operable condition during winter presents another anecdotal finding. As this study stretched across the winter months, particularly January and February of 2015 (which experienced extended freezing temperatures and uncommonly high snowfall), several participants' DMSHP outdoor units became encased in snow and/or ice. Figure 74 shows a DMSHP unit that the evaluation team visited in February 2015. Without clearance around the outdoor unit, the DMSHP could not provide heating to the home's interior. The team removed snow from the front and rear of the unit, using only their hands to prevent damage to the exposed heat exchanger fins or the refrigerant lines.

Figure 74. Maintaining Clearances in Wintertime

The direction and presence of significant, prevailing winds also can play a role in outdoor unit performance. At an oceanfront site examined during the study, the DMSHP outdoor units were directly exposed to a strong ocean breeze. During summer, this unit placement boosted performance as the ocean breeze helped draw heat out of the unit and aid in the cooling process.

During winter, however, the DMSHP occasionally went into a defrost cycle to remove accumulated frost that can build up on the outdoor unit. During this process, the refrigeration cycle reversed, pushing heat into the outdoor unit's coils. Normally, without significant wind, the defrost cycle turns off indoor and outdoor unit fans, while the coil reaches a temperature sufficient to melt the accumulated ice. With the outdoor unit subjected to windy conditions constantly, the outdoor coil had difficulty reaching the cut-off temperature, and the cycle continued for prolonged periods. This process drew heat out of the house, which was quite frustrating to the homeowner and detrimental to the unit's energy performance. Figure 75 shows these two units, roughly 100 feet from the shoreline and exposed to ocean breezes. Relocating these units to the home's leeward side would remove issues occurring during the defrosting process.

Figure 75. DMSHPs in Windy Environment

Indoor Unit Placement

Placement of the DMSHP's indoor unit serves as a major driver for a system's overall efficacy. The DMSHP head must be placed so it can circulate air through the entire conditioned space and can provide a uniform comfort level. Properly placed indoor units include ample space above the unit; so air can be drawn from the space and through the unit, and to provide sufficient clearance for filter access and cleaning. During the study, the field staff encountered several units installed too close to the ceiling, and the resulting airflow suffered from the flow restriction. Figure 76 shows a unit that, though with the minimum clearance specified by the installation manual, did not achieve airflows as high as other metered units of the same model.

Figure 76. Vertical Clearance on Indoor Unit

Unit Controls

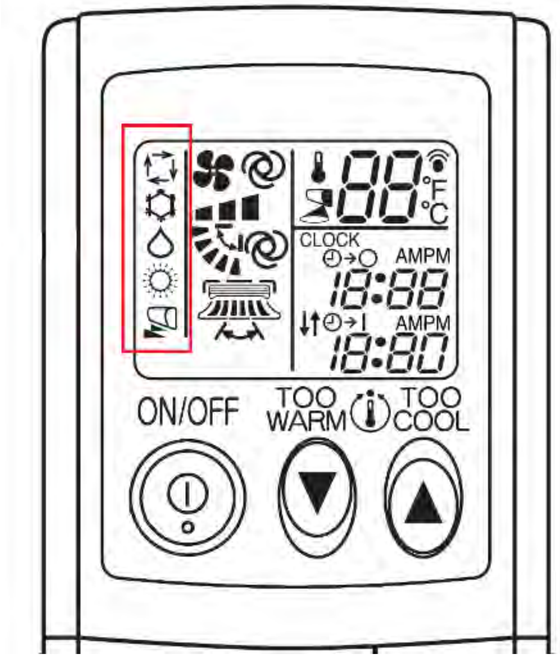
During the study, field staff continually encountered homeowners confused by the operation of the DMSHP remote. Generally, many homeowners found images on the remote too small to read and too similar to each other to understand. These homeowners reported a lack of clarity when using the remote resulted in several service calls to installers for nonoperational units that, ultimately, were resolved by adjustments of the remote settings.

As shown in Figure 77[44] (inside the red box), the symbols for cooling (symbol 2 from the top) and heating (symbol 4 from the top) look very similar, especially given the remote's actual size (one-half the size of the image shown in the figure). During a visit by the evaluation team, the homeowner sat in a 92 °F house with the DMSHP set to heat, believing it was set to cool.

---

[44] Mitsubishi Electric Corporation. *Indoor Unit Service Manual No. OBH542 Revised Edition-A*. September 2010. Available online: https://www.rfwel.com/downloads/manuals/KMO8C-User-Manual.pdf

Figure 77. Operation of DMSHP Remote Control



Staging of Alternative Heating Systems

Homeowners frequently asked the evaluation team about interactions between two or more forms of heat within a home. Specifically, homeowners wanted to know when to use each system and how to set the thermostats for each (i.e., “staging”). Based on data the team collected and subsequent analysis, the team determined that using the DMSHP proved more cost-effective at milder heating temperatures.

As the COP of DMSHP units decrease with outdoor temperatures, the price of each heat unit increases. This stands in contrast to fossil-fuel heating systems, which typically draw combustion air from a semi-conditioned space and produce the same amount of heat across a wide band of temperatures. As one system becomes more expensive to generate heat and the other stays constant, a crossover point occurs where a fossil-fuel heating system becomes the more cost-effective heating method. This crossover point depends on each heating system’s efficiency, the fuel’s cost, and the fuel’s heat content.

To illustrate this concept, the COP chart in Figure 52 can be used as a reference. On average, because DMSHP units exceeded a COP of 1.0 at all temperatures, a DMSHP proved a more efficient use of energy than an electric resistance heater.

The crossover point, defined as the point where using either source proves is equally cost-effective, is characterized by the following equation:

$$\frac{\$}{Heat\ Provided_{DMSHP}} = \frac{\$}{Heat\ Provided_{Other\ Heat\ Source}}$$

Generally, the price per unit of energy is written as follows:

$$\frac{\$}{Heat\ Provided} = (Price\ of\ Fuel\ Input)/(Efficiency)$$

Evaluating this in terms of BTUs and for the DMSHP, this becomes:

$$\frac{\$}{BTU_{DMSHP}} = \left(\frac{\$}{kWh}\right) * \left(\frac{1\ kWh}{3{,}412\ BTU}\right) * \left(\frac{1}{COP}\right)$$

Where:

COP is related to temperature through Figure 52 and Figure 53 $\frac{\$}{kWh}$ = price of one kWh of electrical energy. For an oil boiler, this equation is written as follows:

$$\frac{\$}{BTU_{Boiler}} = \left(\frac{\$}{Gallon\ of\ Oil}\right) * \left(\frac{Gallon\ of\ oil}{139{,}600\ BTU}\right) * \left(\frac{1}{Efficiency}\right)$$

Where:

$\frac{\$}{Gallon\ of\ Oil}$ = price of one gallon of #2 heating oil

$Efficiency$ = the boiler's efficiency

For a gas furnace, this equation is written as:

$$\frac{\$}{BTU_{Furnace}} = \left(\frac{\$}{therm\ of\ gas}\right) * \left(\frac{cubit\ feet\ of\ gas}{1{,}050\ BTU}\right) * \left(\frac{1}{Efficiency}\right)$$

Where:

$\frac{\$}{therm\ of\ gas}$ = price of one therm of natural gas

$Efficiency$ = the furnace's efficiency

Figure 78 shows a two-dimensional map of electric and fuels prices. The topographical style lines show a third dimension of the temperature breakpoint discussed above, where a DMSHP becomes less expensive to operate than an alternative fuel-fired heating system. The temperature dependence results from DMSHPs' drop in efficiency at lower temperatures. A round blue circle indicates average energy prices for winter 2016; a red triangle indicates energy pricing for winter 2015.

For natural gas, the figure shows a temperature breakpoint above 70°F for either winter, meaning a DMSHP only operates cost-effectively above 70°F (compared with an 80% efficient heating system).[45]

---

[45] System efficiency is inclusive of duct losses, and furnace fan and boiler pump energy use. It is, however, lower than the rated or measured combustion efficiency.

This effectively means a DMSHP does not provide a viable direct replacement for a gas-fired system at today's energy prices. This analysis does not account for zonal savings. For example, if a homeowner used a DMSHP to heat 30% less of their home, that temperature balance point would drop to 50°F.

The figure also shows a temperature balance point about 32°F for an oil-fired system in 2016 and 12°F in 2015. The balance point for propane was -15°F for both winters, meaning the DMSHP always was less expensive than the propane option.

Figure 79 shows the same analysis, but for units listed as cold climate units. These units operate somewhat more efficiently, and the economic balance points shift to colder temperatures, where gas balance points were above 58°F for both winters. Balance points were 26°F for an oil-fired system in 2016 and 8°F in 2015. These values do not account for zonal savings. For example, if a homeowner can use a DMSHP to heat 30% less of their home, the temperature balance point would drop by 20°F or more.

Figure 80 shows the same analysis, but bases it on the rating curve of a current cold-climate unit, with an HSPF of 13. A DMSHP operates more economically than propane for all temperatures; so it is not shown in this figure. The balance point for oil dropped slightly, about 15°F in 2016 and 8°F in 2015. The balance point for natural gas dropped to 40°F for 2015 and 28°F for 2016.

Figure 78. Operational Break Point Temperature of Heating with DMSHP, Winter 2016, All Units

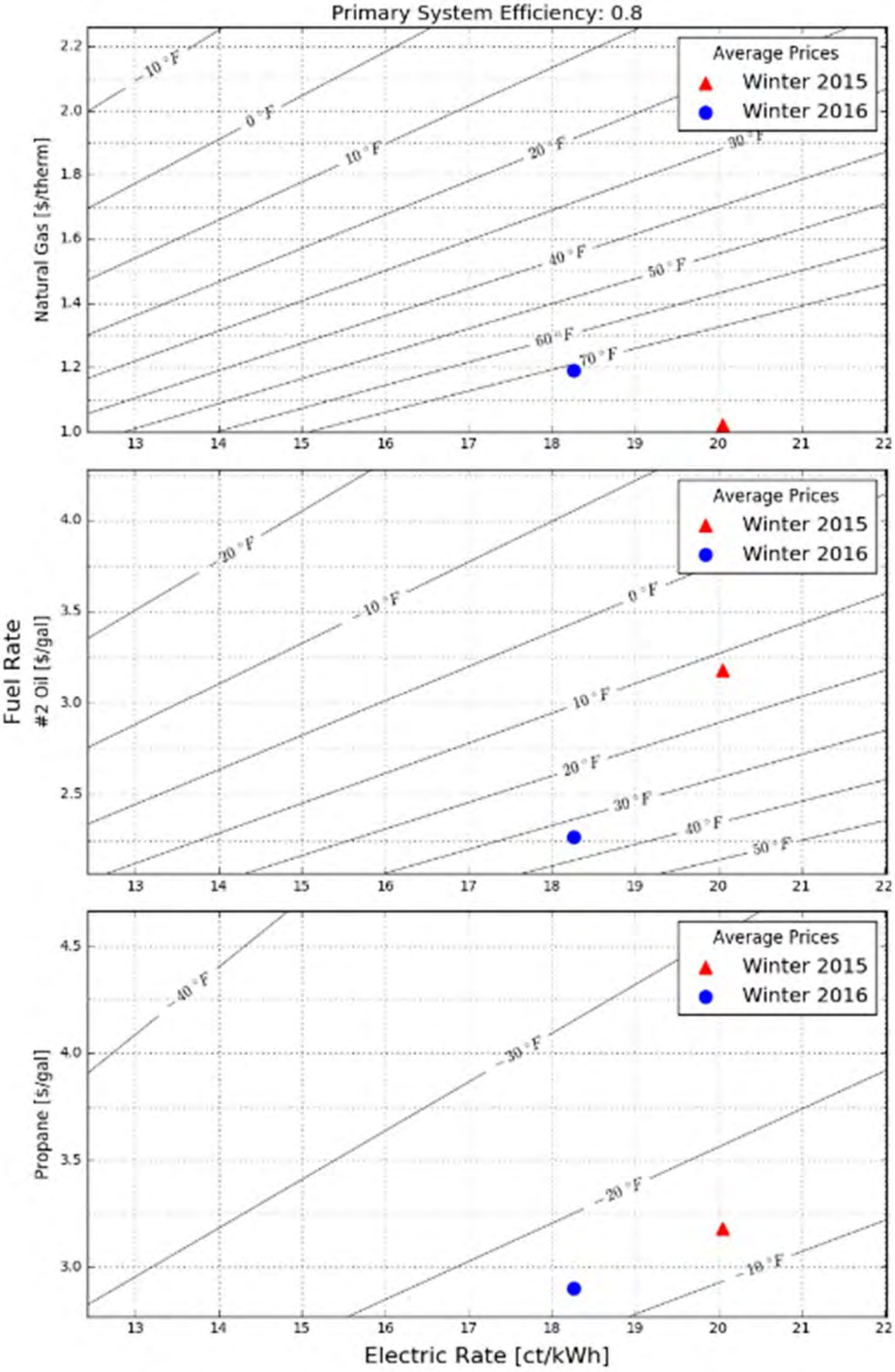


Figure 79. Operational Break Point Temperature of Heating with DMSHP, Winter 2016, Cold Climate Units

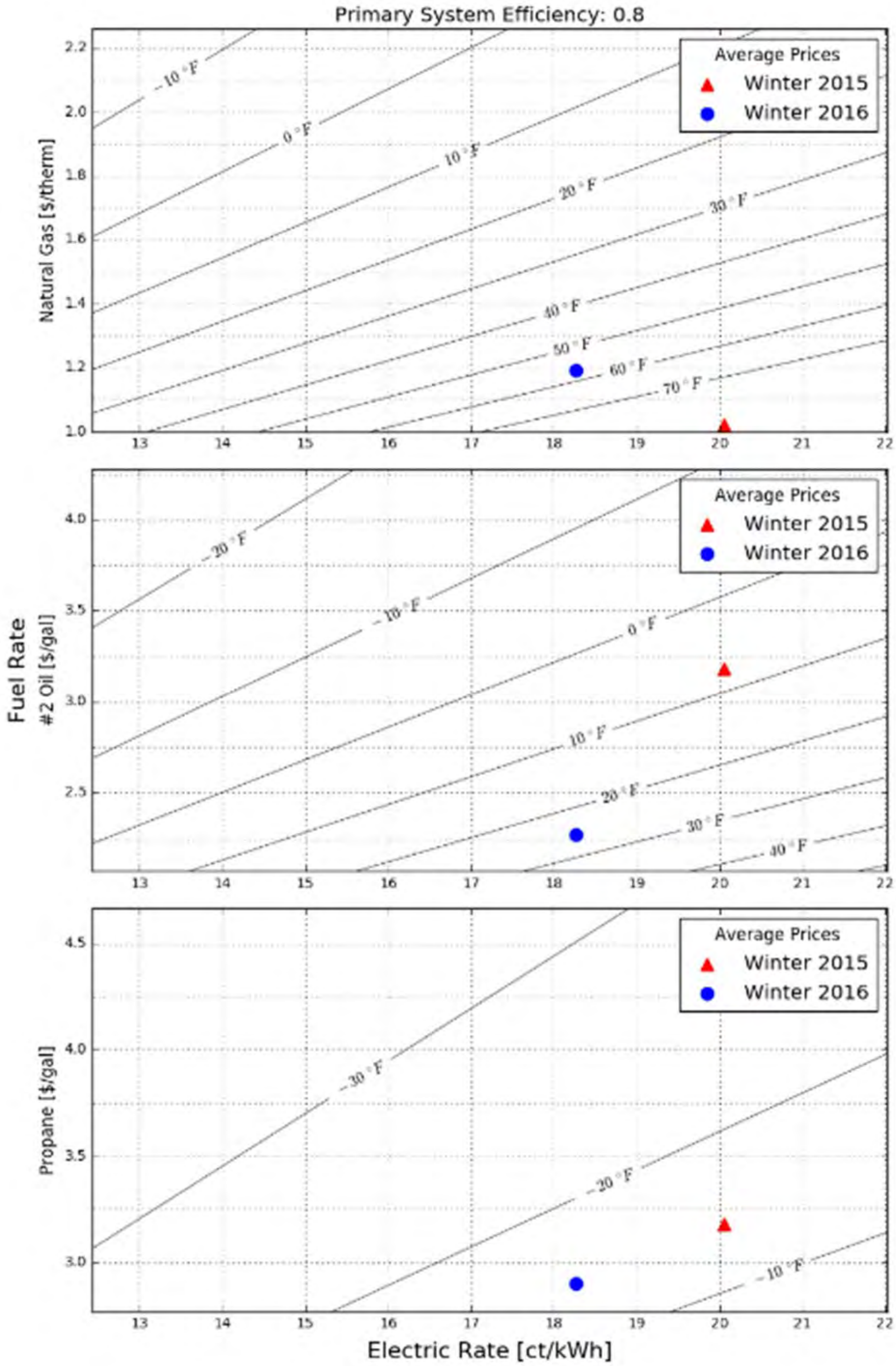
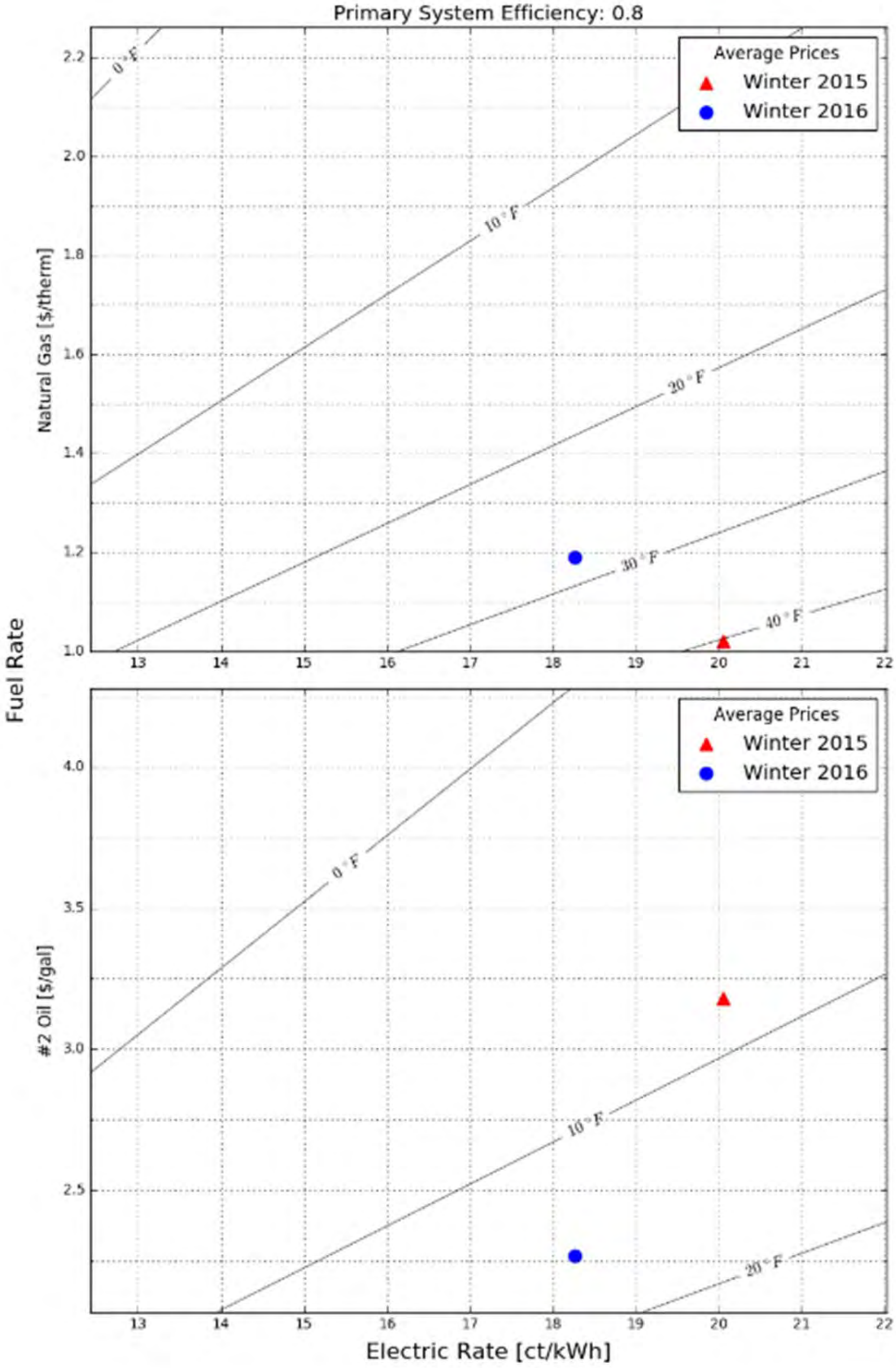


Figure 80. Operational Break Point Temperature of Heating with DMSHP, Assumed HSPF of 13



At outdoor temperatures above the crossover point and where zoning allows, the evaluation team recommends setting the DMSHP thermostat to the desired temperature and setting the boiler/furnace zone thermostat several degrees below. When the outdoor temperature drops below the crossover point, the relationship of the two systems should switch. The boiler/furnace should then be set at the desired temperature, and the DMSHP should be set several degrees below. In both cases, the system set to the lower temperature will act as a backup should the primary system not maintain the desired temperature.

When setting the DMSHP as the primary system, a risk exists: it is possible that sections of pipe for the boiler and radiators could freeze if on the outer walls of a home or if air infiltration occurs near a pipe. If possible, circulating water within the pipes can be helpful at low outdoor temperatures to avoid freezing. Alternatively, utilizing the boiler intermittently at low outdoor temperatures will help avoid frozen pipes.

Localized Heating

The field team identified another potential savings source by interviewing participants about their heating behaviors. Several participants responded that they often used the DMSHP to heat a small section of the home, while leaving central heat at a lower set point. For homes without zone control (i.e., just one central thermostat), this approach creates energy savings.

When operating the DMSHP in this way, interactions with central heating should be considered, especially at the thermostat's location. For example, if the DMSHP heats the section of a house where the thermostat controlling a central heating boiler is located, that thermostat may never call for heat as the DMSHP satisfies its requirement. In this scenario, the home outside the DMSHP area grows cold as DMSHP heat will not reach these areas, and the boiler will not provide heat as its control senses a space controlled properly above its set point.

Non-Energy Benefits

Although non-energy benefits can be difficult to quantify, they can provide insights into consumer behaviors. During the study, the evaluation team learned of many non-energy benefits that customers reported from their experiences. Largely, these benefits divided into two subgroups, based on equipment displaced by the DMSHP:

- For customers replacing window air conditioners, non-energy benefits included the following:
    - Use of operable windows for ventilation and daylighting
    - Increased control over indoor air temperatures and humidity
    - Increased uniformity in air temperatures throughout a served space
    - Increased security from locking windows
    - Increased auditory comfort from compressors isolated away from the house framing
    - Quieter operation of indoor air fans
    - Isolation of outside noises from closed windows

  - Decreased exposure to outdoor allergens
  - Additional heating available, if needed
  - Decreases in personal and property risk from installations or removals of window air conditioners
  - Increased safety from decreased indoor outlet electrical draws
- Customers who purchased DMSHPs rather than centralized cooling systems reported the following non-energy benefits:
  - Increased control of localized cooling
  - Easier installation experiences (as ductwork was not needed)
  - Heating and cooling provided by a single technology
  - Multiple units decreasing the mean time to total failure for the entire HVAC system
  - Lower installed costs if a cooling system served only a portion of the home

Discussion

In general, the evaluation found DMSHPs operated in highly variable ways, resulting in widely varying hours of use, energy consumption, and energy savings among units. Some variation results from a variable speed design, but a larger factor appears to be how users operate their equipment. A discussion follows that addresses results from cooling, heating, efficiency ratings, and airflow.

Cooling

The evaluation identified an average EFLH cooling value of 218 hours, well below the value of 360 hours assumed in the Massachusetts and Rhode Island TRMs. Units often operated at low capacity, or customers turned them off for periods. The following elements contributed to the low EFLH:

- Units sometimes operated in dehumidifier or "dry" mode, where users could not increase or decrease set temperatures. In dry mode, the indoor unit senses the indoor ambient temperature, and lowers the coil temperature a few degrees to induce condensation formation. The unit then operates the fan on the lowest speed setting to avoid decreasing the space temperature too much.
- Some units cooled seldom-used spaces and were turned on only when needed.
- As DMSHP units did not experience duct losses or suffer from insufficient evaporator airflow (as some central air conditioning units might), they provided the same cooling level with fewer EFLH. That is, a central air conditioner can lose efficiency at the air handler due to low airflow, and then lose more energy through duct leakage and heat losses/gains as ducts pass through unoccupied spaces. DMSHPs did not experience these losses.
- On average, units were sized to provide about 2.6 times the design-cooling load calculated using Manual J. This could result from contractors sizing DSMHP units to meet larger design-heating loads. Units also may be designed to cool adjacent spaces when doors to a cooled room remain open.
- TRM sources for the legacy EFLH values may be inappropriate for DMSHPs (i.e., the cooling EFLH value was based on a 2009 study of central air conditioners).
- The top 25th percentile units had EFLHs that were very close to and in some seasons, above the TRM values, showing a good portion of units were used more heavily.

Given these factors, it is not entirely surprising that the average EFLH fell below TRM values. Savings calculations in the Massachusetts and Rhode Island TRMs are a function of this EFLH parameter, but also of unit capacity. A low EFLH reduces savings in a TRM equation, but it may not mean reduced savings in in relation to a smaller unit that would have higher EFLH. For example, if a unit's size were reduced by 50%, the EFLH would roughly double, but the TRM equation would yield the same savings:

$$2\ (\text{EFLH}) * 0.5\ (\text{Capacity}) = \text{EFLH} * \text{Capacity}$$

The evaluation team based savings on the baseline and efficient systems providing identical cooling but at varying efficiencies (i.e., a 16 SEER air conditioner can deliver cooling using 75% of the energy required for a12 SEER air conditioner).

In many cases, DMSHPs provide additional savings beyond more efficient operation, and therefore may provide higher savings than indicated through comparisons with baselines. As shown later in this report, DMSHPs were installed at approximately 1 ton of capacity per 1,043 s.f. of home floor area, a value far lower than typically observed for central air conditioners. Homeowners frequently shut off DMSHPs due to unoccupied rooms or mild outdoor temperatures. Thereby, a DMSHP can deliver zonal savings by performing less cooling. DMSHP also can run in dehumidification mode, further reducing the need for cooling.

When considering new construction program, DMSHPs could potentially deliver savings from zonal behaviors where homeowners fully cools only a portion of their house, while central air conditioners typically do not offer this control—to cool one room, the homeowner must cool their entire house.

For this study, the majority of DMSHPs served as the only cooling source. Homes cooled solely with DMSHPs used an average of 194 kWh for the cooling season, including standby power. Using the Massachusetts TRM value for a central air conditioner's EFLH (360 hours), a home would use approximately 830 kWh/season for a 2.5-ton unit, and about 1,000 kWh/ season for a 3-ton unit. This striking difference (830 – 1,000 kWh vs. 194 kWh) argues for investigating marketing and incentivizing DMSHP units as an alternative to central air conditioners in new construction.

Heating

The study found an EFLH heating value of roughly 450 hours. In nearly all cases, observed DMSHP units provided heat coincidentally with other systems. In most cases, DMSHPs served as secondary systems, either to provide heat for a single space or to provide heat above a primary system's base load.

The cost-effectiveness of DMSHPs used for heating depends on alternative heating systems, energy prices for a given period, and outside air temperatures. Compared against electrical resistance and propane heating, DMSHPs proved more cost-effective for all energy prices (using the same energy source) and all outdoor air temperatures. For oil-fired systems, the relative energy price determines the temperature above which a DMSHP became more cost-effective. Given low current oil prices, relative to historic values, DMSHPs offer cost-effective heating when compared to oil but only for temperature ranges discussed in this report. A DMSHP, however, seldom proved cost-effective when compared to natural gas heating systems (excepting a scenario where a DMSHP heats single space, thus negating the need to turn on a whole house heating system).

COP/SEER/HSPF

The evaluation team directly metered efficiencies of DMSHP units during winter and summer seasons. Most previous studies have estimated COP using metered power (i.e., not very accurate), or have calculated COPs for brief periods and small unit quantities. This study found unit efficiencies varied widely by site and period to period, partly due to temperatures and partly due to set points. Field-measured seasonal efficiencies for most units fell below their rated values, on average, although some units met or exceeded their ratings. Measured SEER values below unit ratings occurred for the following reasons:

- Some seldom-used units still used some standby power.
- Some homeowners used DMSHPs only used to cool on the hottest days; so their cooling efficiency was closer to rated EER values (i.e., the efficiency rating at 95 °F) than to SEER values.
- SEER and EER tests run under specific conditions might not fully represent actual operations. For example, the SEER test uses return air is 80 °F—a temperature much higher than most homes during the cooling season.
- Units used for other functions could reduce a units rated performance (e.g., fan-only mode, dry or dehumidification mode).

Measured HSPF values could fall below rated values for the following reasons:

- Some homeowners used DMSHPs during very cold outdoor conditions, when the resulting DMSHP COP fell below its rated value.
- HSPF tests run at specific conditions may not fully represent actual operations.
- Units used for other functions could reduce rated performance (e.g., fan-only mode).
- Site conditions could cause units to run in defrost mode for long periods of time, decreasing efficiency. The evaluation team has completed other studies that discovered marked differences in the frequency of defrost cycles for different brands.

Although field-measured efficiencies generally fell below rated efficiencies, this does not mean that manufacturers have not been forthright. Others including AHRI stipulate test procedures for cooling and heating at 47°F and 17°F. Many manufacturers use third-party laboratories for testing, so values are verified. A number of units performed at their ratings, supporting the contention that operating conditions and operators' behaviors greatly contribute to delivered efficiencies.

This study metered units with a rated average 20.6 SEER and a rated average 10.3 HSPF. Manufacturers continue to increase the efficiency ratings of systems they offer, with the upper range of units currently offered at 33 SEER, with many units above 25 SEER. DMSHP manufacturers offer units with HSPF ratings up to 14, with many units above 12 HSPF. These new units would deliver cooling and heating more efficiently than units measured for the study.

Savings Values

EFLH and savings values are based on averages that included lightly used equipment as well as on equipment with rated efficiencies below that currently available in the marketplace. While current EFLH and savings values may be low relative to legacy TRM values, the evaluation team has observed high heating usage and EFLH in northern New England by populations motivated to displace oil heat.[46] As outlined in the recommendations section, the team recommends incentivizing the highest-tier efficiency levels to increase savings, and combining incentives with contractor and consumer education. This approach could target high-use customers found in this study's customer distributions.

Controls and Zoning

Use of preexisting heating systems limit DMSHP use for heating. Most furnaces are single-zone systems, meaning a single thermostat and single set point controls the home's temperature. In these homes, if a DMSHP heats only one or two rooms, homeowners find it difficult to use the DMSHP as a primary heating system because if the rely solely on the DMSHP, other portions of the house remain unconditioned. If they turn on the baseline system to heat the rest of the house, the area served by the DMSHP is also heated. A similar issue occurs with boiler-heated homes, but might be more solvable as boilers often heat separate zones, served by separate zone valves or separate secondary pumps. In homes with individually controlled electric strip heating, the primary system can be more readily replaced with a DMSHP.

To increase DMSHP heating use and associated savings, the zone served by the DMSHP needs to match a zone of the primary system. This can be accomplished by targeting homes with zoned (e.g., oil or propane-fired) boilers, room controlled electrical resistance heating, or by installing multi-head systems that combine to serve a complete zone. The DMSHP's temperature setting would then be set above the dead band of the primary system's thermostat (i.e., 3°F). For example, if the DMSHP were set to 70°F, the primary system's thermostat would be set to 67°F.

Allowing the DMSHP and the primary thermostat to communicate with each other would improve this situation. Under this scenario, set points for the primary and DMSHP would be 67°F and 70°F, respectively. When the room became unoccupied, the set points could drop to lower temperatures. This way, the DMSHP would become the primary heating system, and additional zonal savings could be achieved where unused portions of the home were not fully heated.

Achieving this communication, however, currently remains a challenge. Major ductless system manufacturers and wireless thermostats makers recently have made progress in designing systems that work together. The evaluation team recommends makers of various smart thermostats and DMSHP manufacturers continue collaborating to develop protocols that allow the devices to communicate.

Airflow

Generally, airflow measuring airflow is difficult due to its variable nature, and most methods present large associated uncertainties. Compounding this, measuring a DMSHP's airflow is even more difficult as the airflow is free discharge (i.e., not ducted) and variable, with most indoor heads capable of four or

---

[46] Unpublished Cadmus study on Vermont.

more speeds. This evaluation reviewed the most current methods for measuring DMSHP airflow (e.g., fan amperage, volumetric) spot measurements and added some notable improvements.

The evaluation team measured a large number of models and units, which decreased uncertainty. The team constructed and employed a quasi-laboratory flow nozzle to check measurements of a field-practical balometer. The testing found airflows 10% less than the units' rated values generated by independent laboratories. That these field-measured airflows are close to rated values makes sense; unlike central-ducted systems, DMSHP units installed in homes generally are similar to those installed on the wall of a test facility (i.e., no ducts or obstructions to modify airflow).

Uncertainly exists regarding these and any airflow measurements. For five test homes, the evaluation team deployed the powered, quasi-laboratory flow nozzle and the balometer. For these homes at all indoor fan speeds, the balometer measured airflow similar to but 5% to 10% higher than the flow nozzle. As no compelling evidence emerged to support one method as more accurate than another, the team used the balometer readings without adjustment. This judgment did not affect DMSHP savings estimates, as baseline system efficiencies were decremented by an equivalent amount, along with proposed DMSHP systems (see Analysis: Savings section).

Recommendations

Program

Recommendation: The evaluation team recommends exploring ways to improve the PAs' existing lost opportunity program for DMSHPs, such as how best to encourage the installation of multiple DMSHP heads to better match existing zones and displace primary system operation. Although the EFLHs decreased from the values prescribed in the Massachusetts TRM, the study still finds that a modest level of savings are achievable by moving from a standard efficiency DMSHP to a higher efficiency DMSHP. Substantially more savings could be achieved (i.e., the top 25% of savings) if newly installed DMSHPs are operated more regularly and continuously by better matching and integrating them zonally with primary heating systems, through better configuration design and installation and contractor and customer education and training. For example, contractors would focus their design efforts on specifying the appropriate number and size of DMSHP heads to match and heat entire zone(s) rather than a single room. Customers would then be educated on how to properly set the set points for both their primary and DMSHP heating systems, which will depend on their primary fuel type and outdoor temperatures. Finally, establishing program incentives for the generally more efficient, cold climate heat pumps would lead to increased program savings.

Recommendation: The evaluation team recommends exploring methods for targeting homes with electric resistance heating for DMSHP retrofits. DMSHPs will nearly always be less expensive to operate than electric resistance heat, as shown by the COP of DMSHPs remaining above 1.0 on average for nearly all outdoor temperatures. Even at very cold temperatures where some non-cold climate units approach a COP of 1.0, the number of hours in this condition are very few. Prior to new activities, program and consumer cost-effectiveness would require review.

Recommendation: The team recommends targeting propane-heated homes for DMSHPs. As Figure ES-6 and Figure ES-7 show DMSHPs always operate less expensively than propane heating systems. Prior to new activities, program and consumer cost-effectiveness and regulatory considerations for fuel switching would require review.

Recommendation: The team recommends exploring methods for addressing oil-heated homes. To target these homes, homeowners should be educated to turn off a DMSHP during very cold outdoor conditions (below 8°F in 2015 and below 25°F in 2016), when an oil-fired system would operate less expensively (depending on energy prices and cold temperature COPs). This operating scheme, however, may not appeal to all customer types, as many may not wish to concern themselves about which heating system to operate and when. If oil prices increase against electric energy rates, the switchover temperature point for oil to DMSHP heat may move lower, allowing continual use of a DMSHP. Switchover points for all fuel comparisons will decrease as more efficient DMSHP units become available. Prior to new activities, program and consumer cost-effectiveness and regulatory considerations for fuel switching would require review.

Recommendation: Based on large energy-usage differences in DMSHP-cooled homes and central air conditioner-cooled homes, **the team recommends examining opportunities for a new construction measure to substitute DMSHPs for central air conditioners**.

Future Studies

This study provided a great deal of data describing how DMSHPs actually operate in Massachusetts and Rhode Island homes. These operations varied widely among units, with some used heavily and others used more like appliances turned on for short periods. Highest savings could be achieved by targeting homes where such units would deliver greater amounts of heating and cooling (i.e., where they can be installed to match the zoning of existing systems).

Another factor in increasing DMSHP savings will be development of controls that allow ductless systems and primary thermostats to interact and share information. The evaluation team recommends either targeting studies for new construction homes without natural gas available and where central air conditioning systems would be installed; or existing homes with electrical resistance and propane heating. These studies would help refine the best ways for DMSHP programs to achieve maximum savings.

Other future studies could explore the use of interfaces between learning thermostats and ductless systems. Future research questions include the following:

- How can utilities target homes with a high probability of using DMSHPs to displace more heating and cooling, therefore producing higher savings?
- What potential exists for new high-HSPF units to displace heating?
- What optimal zonal and control characteristics maximize use of DMSHPs?
- For new construction, how large would zonal savings have to be to avoid installations of single-zone central systems?

Appendix A: Measuring Airflow in DMSHPs

Airflow

Appendix A may repeat certain report elements, but the evaluation team chose to provide additional detail on methods used for establishing DMSHP airflow. The team hopes that the following discussion will help inform future field studies regarding best practices for estimating airflow, especially for extended-duration conditions.

The evaluation team recommends the following the airflow measurement methods developed in previous published studies and refined through this study:

1. Use either a balometer or a powered flow hood for measuring volumetric airflow coincidently with measured fan amperage. For large studies, a non-powered flow hood or a powered balometer (for low flows)—such as a Flow Blaster—would be practical.
2. The team does not recommend using a flexible flow bag for airflow measurement, as applied in other studies.
3. A flow nozzle, such as the one tested in this study, can be used for small-scale, controlled, or laboratory studies, but it is not recommended for large-scale field studies. It does, however, prove useful for calibrating or adjusting the measurements of equipment recommended in #1.

Motivation and Intention

The concluding equation presented in the Method/Energy section defines energy removed or added to air as a direct function of the volumetric air flow ($\dot{V}$). To determine that volumetric air flow, the evaluation team used a combination of on-site point measurements and logged values. The team chose these methods for their ease of implementation, lack of interference with unit operations, quality of data collection, and preservation of unit integrity and housing.

Background Literature for Flow Hoods

At the project's beginning, the evaluation team reviewed publicly available literature, seeking to understand the existing body of knowledge and to check the proposed approach for measuring volumetric air flow against other methods. In November 2012, a Lawrence Berkeley National Laboratory (LBNL) publication proposed a variety of methods for taking such measurements, and presented seven methods of measuring air flow using flow hoods against a laboratory metric.[47]

Typically, flow hoods are composed of fabric stretched over a collapsible, rigid frame that guides the air flow over a velocity or pressure-sensing element. Commercially produced, these units are frequently

---

[47] J. Chris Stratton, W.J.N Turner, Craig P. Wray, Iain S. Walker. *Measuring Residential Ventilation System Airflows: Part 1 – Laboratory Evaluation of Airflow Meter Devices.* LBNL-5983E. Ernest Orlando Lawrence Berkeley National Laboratory. November 2012. Available online: <https://buildings.lbl.gov/sites/all/files/lbnl-5983e.pdf>.

used in the air-balancing industry. Flow hoods can be divided into two categories—powered or non-powered—with the 2012 LBNL study testing a representative sample of 366 and 369 hoods, respectively.

The November 2012 LBNL publication cited an earlier 2001 LBNL publication that clarified the division of flow hoods. The 2001 publication divided standard flow hoods among two examined categories (i.e., active and non-powered):[48]

- Active (or powered) flow hoods reduce the effects of back pressure on flow measurements, usually through use of an exhaust fan to draw static pressure within the flow hood to equal the ambient environment.
- Non-powered flow hoods cannot forcefully remove the buildup of static pressure. To compensate for this, these instruments typically employ a damper to evaluate the impact of static pressure on the calculated flow and to produce a revised number, factory calibrated against a standard.

Using powered/non-powered segregation, the 2012 LBNL report concluded that two of the four non-powered flow hoods tested did not produce acceptable accuracy (defined at ±5 cfm or ±10% of the measurement reading from the reference airflow). In contrast, all three powered flow hoods produced acceptable accuracy.

On the surface, this conclusion helps reinforce decades-old skepticism in the industry regarding the accuracy of flow hoods for airflow measurement. Both the 2012 LBNL report and a separate 1999 publication, however, confirmed that flow hoods realistically provide the best method for measuring airflow with adequate accuracy.[49]

Excerpted from LBNL-5983E, Figure 81 shows a test for the model used in this study. The graph shows a range of airflow, tested up to 220 CFM, or roughly the two lower speeds of the DMSHP metered in this study. The boundary of accuracy is shown in green: at ±5 CFM for low flows and at ±10% for higher flows, with y = 0 representing laboratory measurements taken as the true measurement.

---

[48] Walker, I.S., C.P. Wray, D.J. Dickerhoff, and M.H. Sherman. *Evaluation of Flow Hood Measurements for Residential Register Flows.* LBNL-47382. Lawrence Berkeley National Laboratory. September 2010. Available online: http://epb.lbl.gov/publications/pdf/lbnl-47382.pdf

[49] Ernest E. Choat, P.E. “Resolving Duct Leakage Claims.” ASHRAE Journal (March 1999). Accessed June 6, 2016. Available online: http://search.proquest.com/openview/d6c7203563370c8a9e8e050b11f0b2a9/1?pq-origsite=gscholar

Figure 81. LBNL-5983E Figure 14

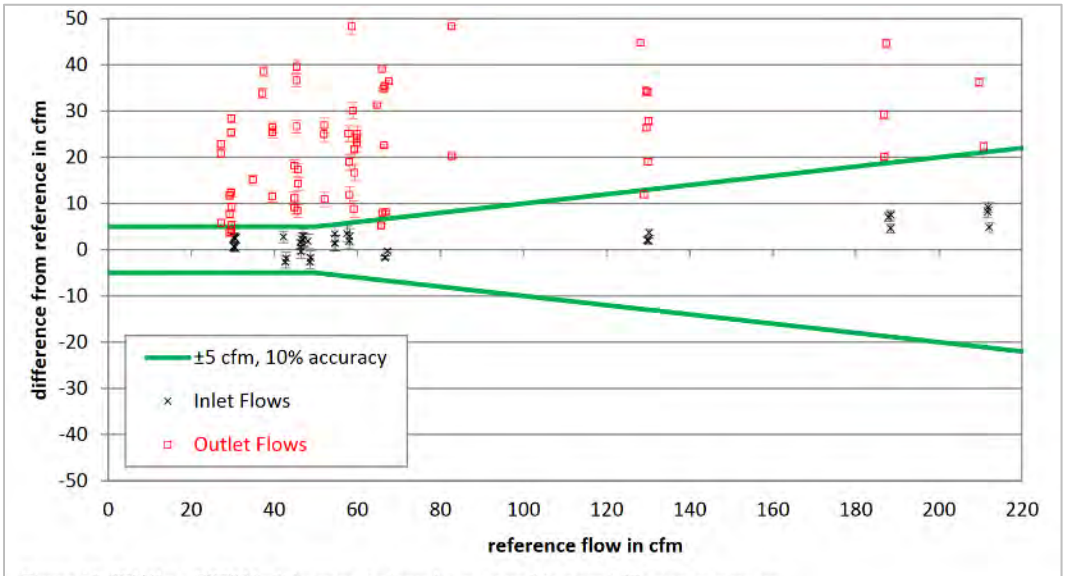


Figure 14: TSI/Alnor EBT721 - laboratory test results compared to acceptable accuracy range

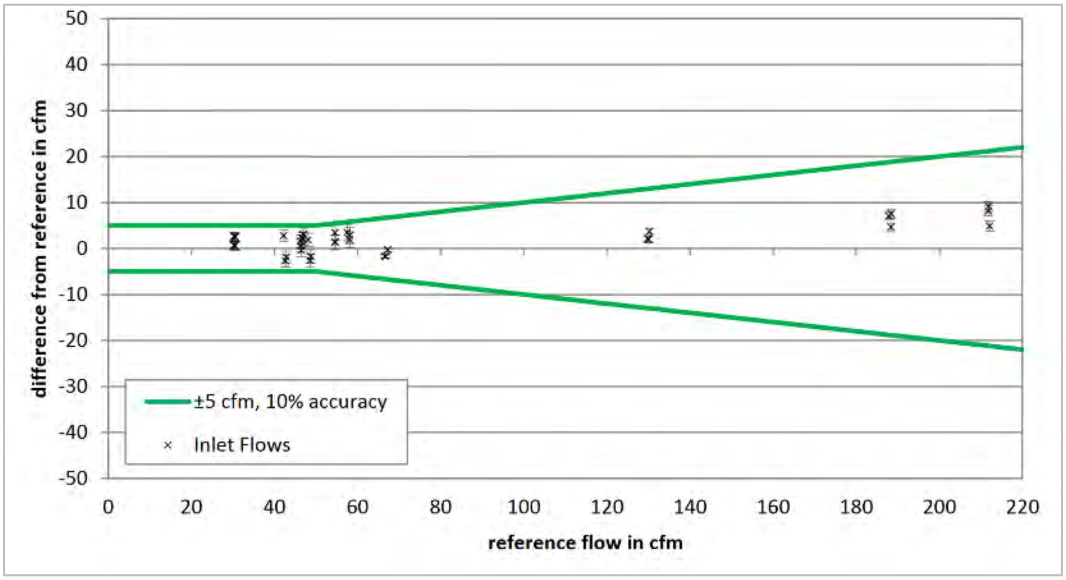
At first glance, the balometer would appear inaccurate and imprecise, with varied readings outside of the accuracy boundary. The figure presents, however, two types of data: inlet flows, which represent typical use of a balometer; and the method used in this study, where air enters a wide mouth and flows to a measurement area; and outlet flows, where the balometer is used in reverse. Filtering Figure 81 for only inlet flows (black crosses) yields Figure 82, which shows TSI/Alnor EBT721 measurements within 5% of the reference measurement above 80 CFM (few DMSHPs even have speeds below this flow rate).

As stated in the 2012 report and in personal communications with its lead author,[50] the TSI/Alnor EBT721 produces acceptable accuracy when used to measure inlet flows.

---

[50] Personal communications with Dr. Iain Walker. Response to question via e-mail regarding LBNL-5983E Publication. May 19, 2016.

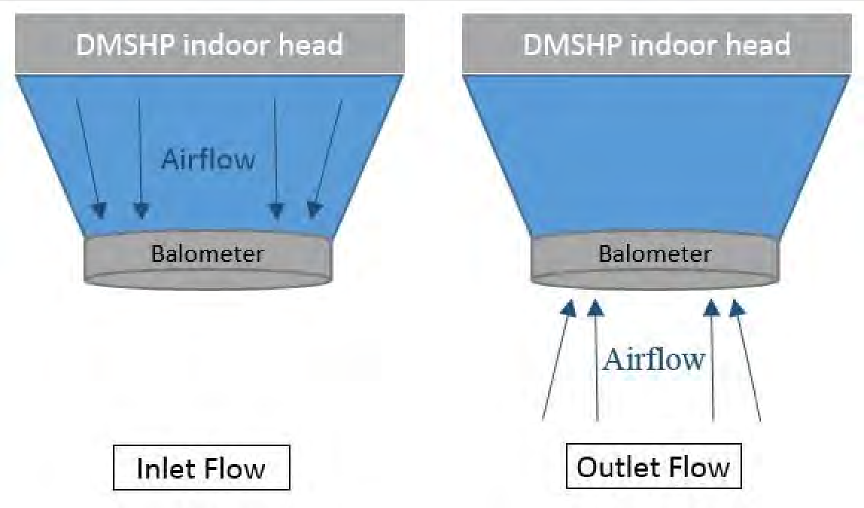
Figure 82. LBNL-5983E Figure 14, Adapted



This large difference in accuracy results from the design of the balometer itself. As shown in Figure 83, during inlet flow, the air stream is guided towards the measurement section in the fabric cone. This results in smoother (more laminar) flow. In contrast, during outlet flow, air abruptly enters the measurement section and exits into the DMSHP. This does not smooth the airflow and consequently lowers the measurement accuracy. Fortunately, this study only used balometers for the inlet mode.

Figure 83 show differences between inlet and outlet flows and assists in explaining data presented in Figure 81.

Figure 83. Inlet vs. Outlet Flow



Background Literature on Proximity Sensor Data Collection

Presented as a “Short-Term Air Flow Test,” a method[51] proposed in a NREL paper for providing long-term recording uses a proximity sensor, mounted close to a fan on an indoor unit. This arrangement used a thin, steel shim, bonded to the fan for the proximity sensor to detect each rotation, and the rotational speed would correlate to a volumetric flow determined on site. Figure 84 shows a proximity sensor, as mounted in the NREL paper.

Figure 84. Proximity Sensor Arrangement (NREL Image 18330)

*Zia Fang. National Renewable Energy Lab. August 27, 2010.
<https://images.nrel.gov/bp/#/search?q=18330&filters=%257B%257D#6309983>.

The evaluation team attempted to reproduce this method under laboratory conditions, but could not obtain consistent results from the proximity sensor, and abandoned this approach. In the process, the team broke several plastic tabs on the laboratory unit while removing the protective grille and vertical louvers that shield immediate access to the fan, indicating this approach would prove unfeasible as a general field protocol.

The team also contacted the paper’s authors to understand how short-term measurements would be logged for long-term application and deployment. The authors answered this and indicated they had abandoned the proximity sensor approach in favor of using an optical tachometer to avoid working behind the louvers.

---

[51] D. Christensen, X. Fang, J. Tomerlin, and J. Winkler (National Renewable Energy Laboratory); E. Hancock (Mountain Energy Partnership). *Field Monitoring Protocol: Mini-Split Heat Pumps*. U.S. Department of Energy Building Technologies Program. March 2011. Available online: http://www.nrel.gov/docs/fy11osti/49881.pdf

Further, the authors reported that they recently achieved success by not measuring the fan speed at all; rather, they used the fan current as a proxy for airflow—a method discussed in this appendix (see Background Literature on Current Transformer Data Collection).[52] The authors also referenced a more recent study that used fan current as a proxy for airflow.[53]

Background Literature on Optical Tachometer Data Collection

As discussed, the NREL authors also employed an optical tachometer for measuring airflow. Very similar to the proximity sensor method, this method uses a strip of reflective tape placed on the fan blades.

The evaluation team verified that this method generated values for a fan’s rotational speed, although equipment available to the team would not allow long-term concurrent readings of fan rotational speeds and air volumes supplied by the unit. In addition, the team found that, to deploy an optical sensor, the DMSHP head had to be disassembled. Due to the way some heads are constructed, this would very likely damage many units.

Lastly, the team expressed concerns that installing a sensor close to a rotating fan could cause the sensor wire to entangle the fan, in some cases leading to damage and customer dissatisfaction. Consequently, this study did not rely upon optically sensing fan rotational speeds.

Figure 85 shows spot measurements conducted on the laboratory unit. Here, the vertical louvers and protective grille were removed to ease access to the fan; these should be reinstalled to return the unit to its proper condition.

---

[52] Personal communication with Dane Christensen and Dr. Jon Winkler. Response to question via e-mail regarding field monitoring protocol MSHP. March 30, 2016.

[53] Williamson, James, and Robb Aldrich. *Field Performance of Inverter-Driven Heat Pumps*. Prepared for the U.S Department of Energy. August 2015.

Figure 85. Optical Tachometer Data Collection

Background Literature on Current Transformer Data Collection

As previous fan speed measurements faced practical issues, the evaluation team chose to log airflow using fan amperage. DOE’s latest report used fan amperage, and the team suspected the method would produce better results than alternative methods at detecting airflow differences due to wet coils and dirty filters. The team logged power going into the DMSHP indoor head as a proxy for power consumption of the indoor fan speed and volumetric airflow through the unit. In doing so, the team placed CTs on one wire providing power to the indoor head. Logging a value every minute for the study’s duration, this method provided information on how the fan functioned. As the unit’s fan speed fluctuated due to setting changes during the study, assuming a constant fan speed or volume would have been improper. Additionally, this method removed the need for direct access to the fan (difficult to achieve on most models and almost impossible on some). Figure 6, in the report’s body, shows CTs installed on a DMSHP.

Using the current transformer method offers additional benefits from any debris accumulation or airflow restrictions from the indoor unit directly representing the power draw from the fan (see Filter Cleanliness section for more discussion).

Moving from Indoor Head Current to Indoor Fan Current

Using CTs on outside units presents another complication: the measurement value is actually the total current supplied to the indoor head and not just the indoor fan current. As each DMSHP indoor head consumes a slight amount of power for the unit's circuitry and non-fan operations, this power must be estimated and removed from the measurements to arrive at the indoor fan current. The evaluation team, knowing of this impact's significance, developed a method to remove the non-fan components from the data.

First, during on-site testing, while logging the current at two-second intervals, the field staff turned the indoor unit on, letting it start blowing air, and then turning it off again. Leaving the indoor unit off for two to three minutes established more than 50 data points from which the team could evaluate the non-fan load. This load was subtracted from the raw data to establish the bound at which the fan remained non-operational. Everything above this line could be considered operational.

Field staff ran the unit in a fan-only or dehumidification mode (depending on the controls) to generate data for each fan speed. These data also were logged at two-second intervals, and the indoor fan volumetric airflow was logged concurrently with this data test. With these data available, the team could generate performance plots for each indoor fan at each fan level, drawing a regression line between available points to account for filter buildup and for operation changes.

Measuring Airflow

As described in the **Background Literature for Flow** section, flow hoods are used to measure volumetric airflow through a DMSHP's indoor unit. The evaluation team used the TSI/Alnor EBT731, a replacement model for the now-discontinued TSI/Alnor EBT721 described in the literature review. The EBT731[54] maintains the same accuracy and fundamental properties of the EBT721;[55] so additional testing was not required to justify accuracy claims beyond those provided in the literature.

The team did, however, compare the non-powered flow hood (TSI/Alnor EBT731) against a powered flow hood to evaluate the accuracy of the non-powered flow hood used. In doing so, the team designed

---

[54] Alnor Products, TSI Incorporated. "EBT BALOMETER CAPTURE HOOD MODEL EBT731 AIR VOLUME INSTRUMENTS." Last modified May 5, 2014. Accessed July 27, 2016. http://www.tsi.com/uploadedFiles/_Site_Root/Products/Literature/Spec_Sheets/EBT730-731_US_5001434.pdf

[55] Alnor Products, TSI Incorporated. "EBT Balometer Capture Hood Model EBT721." Last modified September 8, 2010. Accessed July 27, 2016. http://www.tsi.com/uploadedFiles/_Site_Root/Products/Literature/Spec_Sheets/EBT720-721_2980561_Alnor-web.pdf

a powered flow hood test using a setup very close to that used for the CARB 2015 “Filed Performance of Inverter-Driven Heat Pumps in Cold Climates” report,[56] shown in Figure 86.

Figure 86. Basis of Experimental Powered Flow Hood Setup (Figure 4 from Williamson 2015)

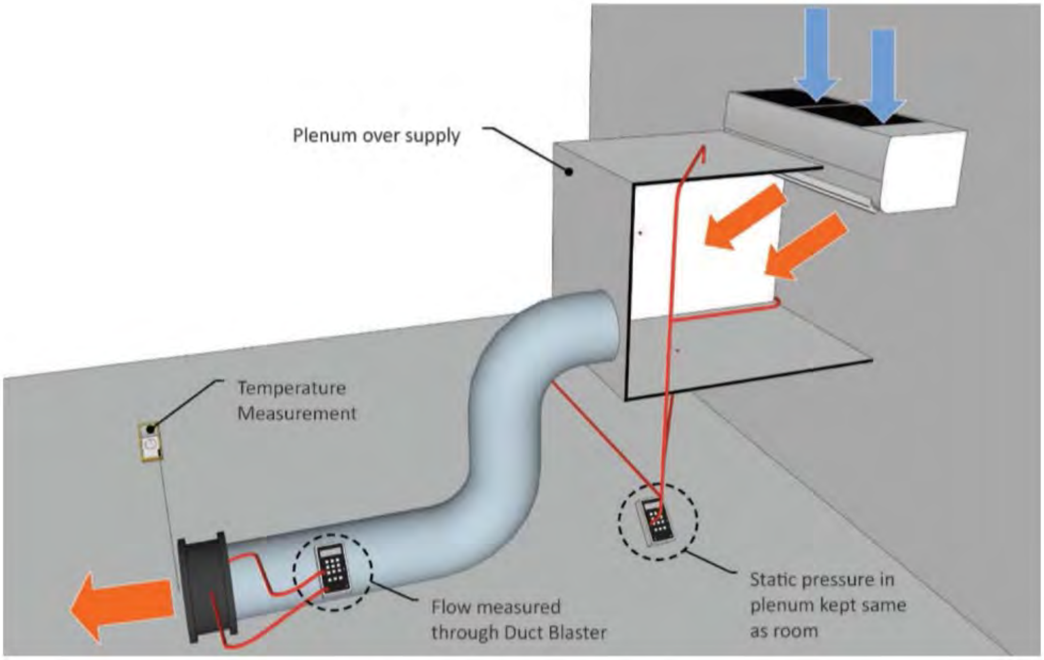


Figure 4. Diagram showing final flow testing configuration

During the experimental setup’s development, concerns arose about the rapid convergence of flow required when using the arrangement shown in Figure 86. To correct for this, the team built a convergence nozzle to adapt the shape of the DMSHP’s indoor unit to the flexible plenum of the Duct Blaster. Referencing ASHRAE 51-1999,[57] Figure 5: Transformation Piece, excerpted in Figure 87, the team built the nozzle with a 7.5° convergence angle (shown in Figure 88). Additionally, the team minimized rapid changes in flow directions by keeping the convergence nozzle and plenum in line with the flow and by maintaining the linearity of the flexible plenum.

---

[56] Williamson, James and Robb Aldrich. *Field Performance of Inverter-Drive Heat Pumps in Cold Climates.* Prepared for U.S. Department of Energy. August 2015. Available online: http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/inverter-driven-heat-pumps-cold.pdf

[57] *Laboratory Methods of Testing Fans for Aerodynamic Performance Rating*. ANSI/AMCA 210-99, ANSI/ASHRAE 51-1999. Air Movement and Control Association International, Inc. 10CFR 430 Subpart B, App. M. Available online: https://law.resource.org/pub/us/cfr/ibr/001/amca.210.1999.pdf

Figure 87. Convergence Nozzle: ASHRAE 51-1999 Figure 5 (Excerpt)

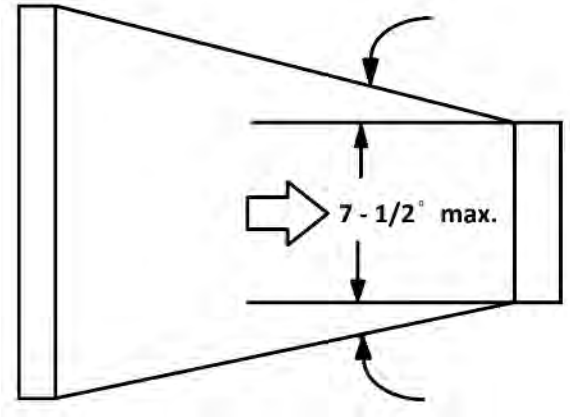


Figure 88. Powered Flow Hood Testing Setup

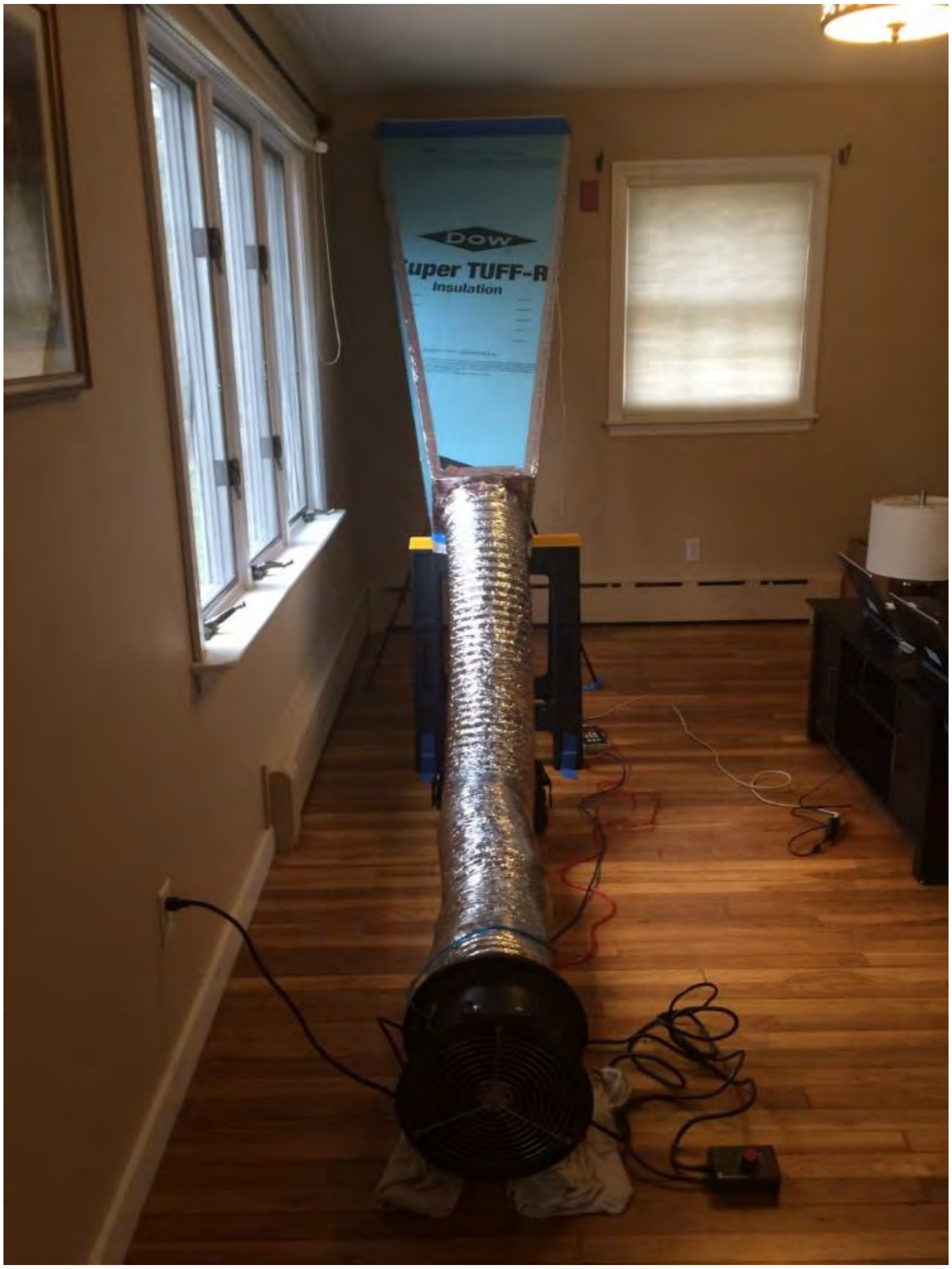
As Figure 88 shows, locking the convergence angle at 7.5° substantially extended the length of the entire setup—in this case, over 16 feet from the wall to the Duct Blaster's outlet (this did not include the necessary area at the Duct Blaster's outlet to reduce backpressure induced by constrained airflow). All testing completed for this study used at least eight feet of open space beyond the Duct Blaster's outlet.

Given the special constraints of the testing setup, applying this to a participant's homes clearly appeared neither feasible nor practical. Still, the team conducted this test at five homes, with setup time for a field team of two engineers at over an hour.

Per the CARB 2015 report setup and directions from Minneapolis Duct Blaster, the team included a flow conditioner in the setup, measuring the airflow using a single TEC DG700 Pressure and Flow Gauge, connected to a computer that logged values every second for the duration of a one-minute test. This test operated similarly as the balometer tests, with all fan speeds sampled using individualized tests. Average flow rates and currents at each fan speed could then be used to build a fan curve and subsequently compared to the TSI/Alnor EBT731 balometer tests, conducted on the same indoor unit and utilizing the same outdoor metering setup.

Figure 89 shows the testing setup with the DG700 comparing pressures from the ambient environment, plenum static probe, fan, and fan ring, configured pursuant to Minneapolis Duct Blaster directions.

Figure 89. Powered Flow Hood Testing Setup



The plenum method faced a significant issue in the space required to run the test. Most DMSHP indoor heads average 32 inches in width, requiring only the single, six-foot-long section for testing. Larger units, however, could be as wide as 46 inches, requiring the nozzle to be extended up to 11 feet. Figure 90 shows the 11-foot nozzle being installed in a participant's home. To transport the nozzle to the home and through the home to the indoor head's location required fabricating the nozzle extension separately. The setup shown required 21 feet of open space from the wall, not including the eight feet required after the Duct Blaster outlet. As noted, many homes do not have an appropriate floor plan to accommodate such a setup.

Figure 90. Extended Testing Site B: Large-Unit Powered Flow Hood

Measuring Airflow: Field Methods

Because a powered flow hood was not prove feasible for most sites, and the data alignment between the non-powered flow hood and the powered flow hood was high, the evaluation team used the non-powered Alnor/TSI EBT731 across the entire population to build up a robust airflow data sample as a function of the indoor head current.

Field staff began work by clearing an area near the DMSHP head of furniture and picture frames that could be damaged in the course of testing, as shown in Figure 91.

Figure 91. Indoor Head Prior to Testing

Field staff then set the vertical louvers to a midrange value and aligned the flow hood in the same direction as the louvers. Adopted throughout the study, this arrangement mitigated impacts from eddy currents and prevented units from swaying the louvers and introducing another analysis variable. Field staff supported the balometer in this position, taping it to the support stand. These staff decreased movement of the support stand using additional tape between the stand and the floor. Figure 92 shows the resulting positioning.

Although the balometer used an onboard battery, field staff nevertheless plugged the balometer’s charger into the nearest wall outlet to reduce any variation induced by battery voltage. The evaluation team adopted this as a precaution, given an unsuccessful search for literature that stating the results were a function of battery voltage.

Figure 92. Non-Powered Flow Hood (Balometer) Setup

After setting up the balometer positioning, the field staff sealed any visible, potential leakage routes, as shown in Figure 93. Williamson 2015 identifies a slight potential for leakage via the seam of the filter flap, leading directly to the return air space. The evaluation team did not consider this leakage pathway significant as the filter flap mated to the main housing with very little bypass space when properly closed. Williamson 2015 also tested this pathway and did not find differences in return static pressure with or without the return pathway taped, effectively stating this return pathway proved negligible within system performance.

Prior to testing, the field team confirmed the sealing was adequate, both through a visual inspection and through observations when the unit ran at full power.

The body of this report provides additional descriptions of this testing in the Data Collection: Airflow section.

Figure 93. Non-Powered Flow Hood (Balometer) Setup

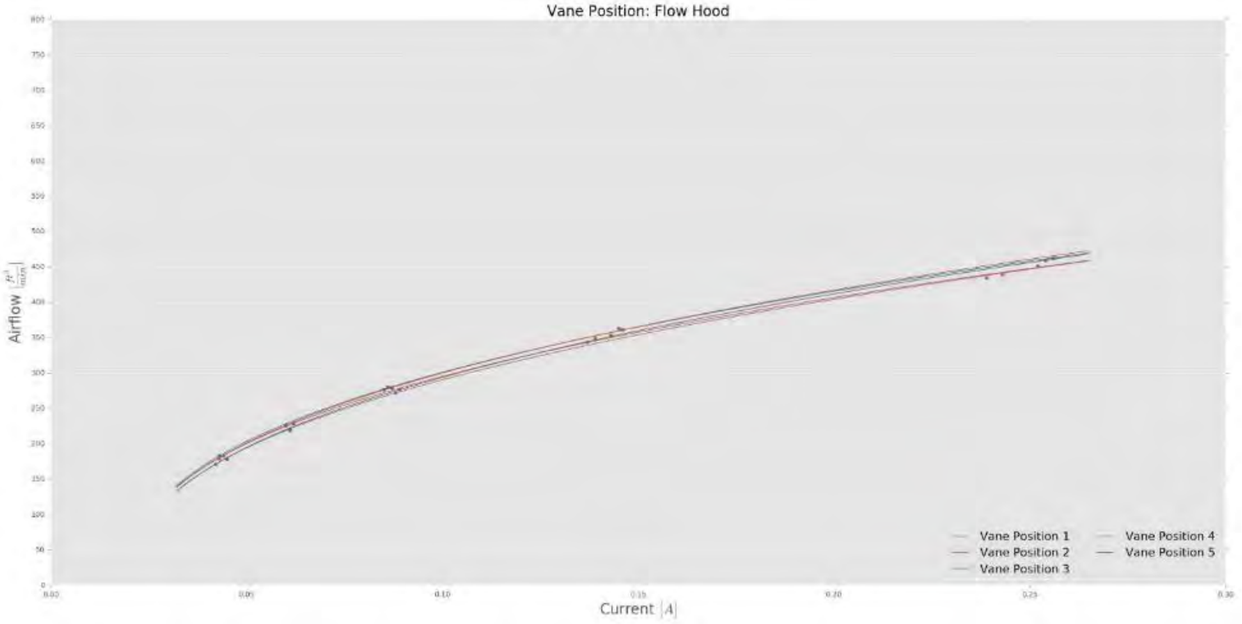
Conditional Variations

In addition to testing the sampled population for airflow as a function of the indoor head current, the evaluation team conducted isolated testing of different factors that might influence an indoor head's current. These factors included the position of louvers or vanes, accumulated condensation on the indoor head, and imposed airflow restrictions to simulate mimicked filter cleanliness.

Vane Position

During the study, the team conducted testing on the influence of vane positions to determine the elasticity of subtle variations in positioning the flow hood with respect to the reference direction. Figure 94 illustrates the influence of the vane's position on the recorded airflow volume using the powered flow hood. Per the figure, vane positions from the center to the most horizontal closely agree with one another.

Figure 94. Vane Position: Powered Flow Hood

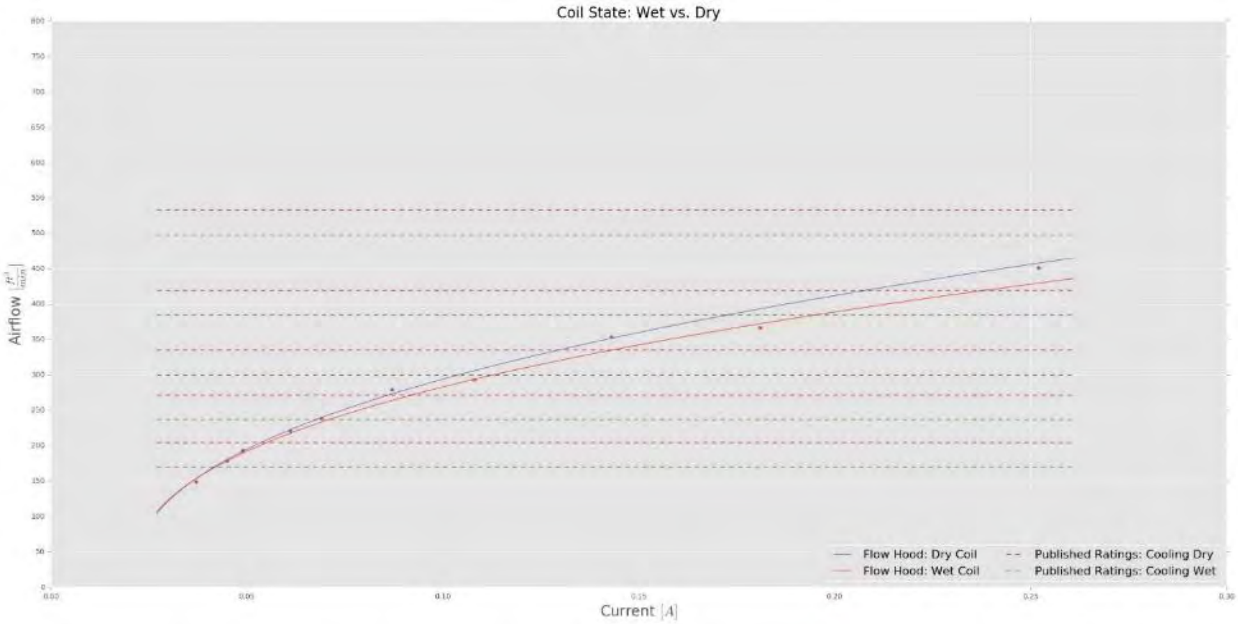


Coil Moisture

Technical submittals from DMSHP manufacturers show changes in the volumetric airflow rate when coils are wet from accumulated moisture (previously in the air). In effect, water droplets on the indoor coil restrict airflow much as restricting airflow over filters. In testing this, field staff carefully poured more than a gallon of water onto the coils of a DMSHP indoor unit. Utilizing the powered flow hood, the team ran the unit through the same tests conducted as a baseline. These tests produced wet state and dry state data points, respectively. Performing this test across the entire sample would have been impractical, given the effort required to keep control electronics dry while wetting the coil.

As shown in Figure 95, although airflow and current values differed greatly between wet and dry, data points merely serve as migrations along the fan curve as opposed to shifts to the curve itself. Consequently, data adjustments based on perceived coil wetness need not be conducted; the indoor head current serves as a good proxy for volumetric airflow.

Figure 95. Coil State: Wet vs. Dry

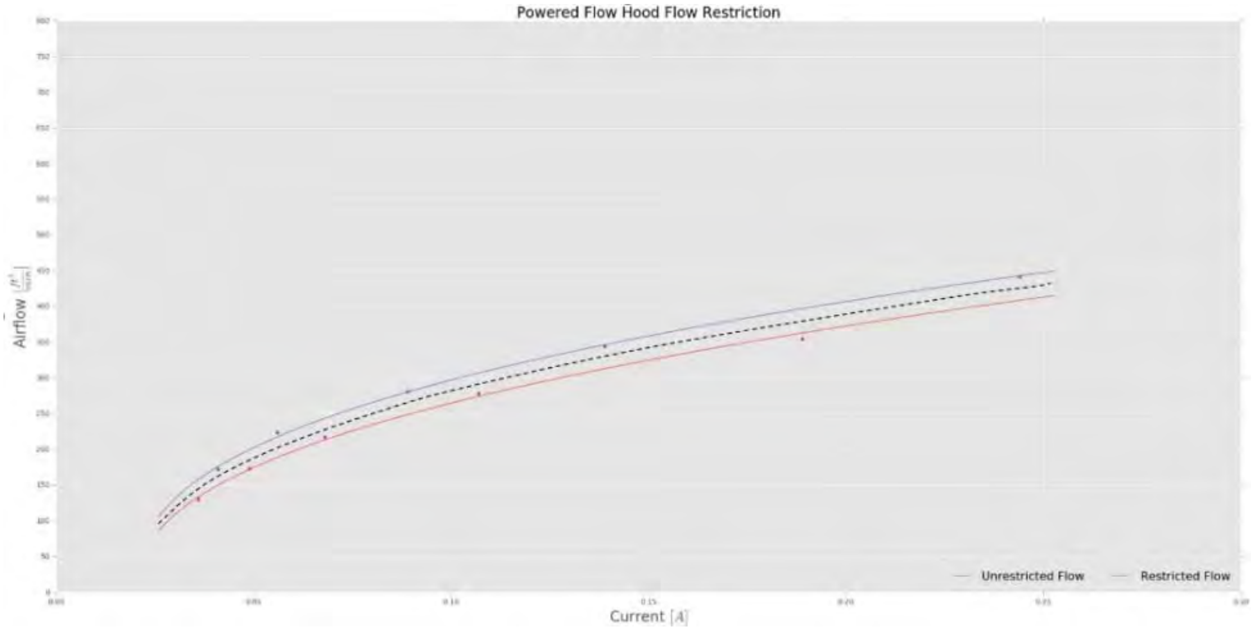


Flow Restriction (Dirty Filter)

In using an indoor unit, a filter removes dust from the air, though this accumulates if not cleaned regularly. As the filter accumulates dust and particles, the pressure drops across the filter increases, and airflow is reduced. In a test setup, the evaluation team used foam inserts to simulate dirty filters. Figure 96 shows the impact of restricting airflow to the DMSHP—the equivalent of a very dirty filter.

Similar to restrictions induced by wet and dry coils, restrictions induced by obstruction caused decreases in the airflow quantity moved through the indoor unit. And, much like wet and dry coil results, when accounting for the indoor fan current, changes were primarily migrations along the curve and not major shifts of the fan curve itself. As seen in the figure, the vertical shift at a given fan amperage from the averaged curve (dotted line) to the simulated dirty curve was less than 5%. Therefore, the team judged that no data adjustments were needed to produce an airflow number within reasonable bounds, based solely on current supplied to the fan.

Figure 96. Powered Flow Hood Flow Restriction

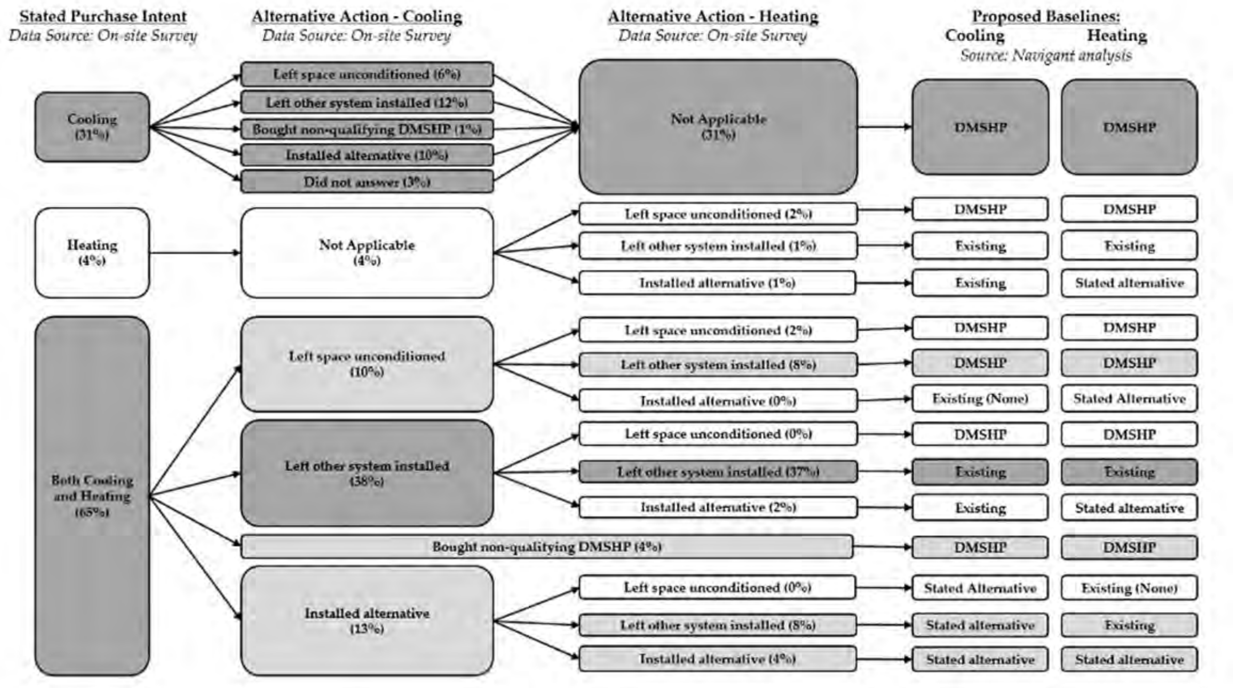


Resulting Experimental Design

Given the findings, the evaluation team chose to measure airflow using the methodology discussed in earlier sections of this report.

Appendix B: Baseline Memorandum Chart

Logic Flow Chart to Determine Baseline, with Response Percentages (n = 116)



Appendix C: TRM Memorandum, December 2, 2016

To:	Massachusetts and Rhode Island Program Administrators
From:	COOL SMART Impact Evaluation Team
Subject:	Ductless Mini-Split Heat Pump Technical Reference Manual Recommendation
Date:	December 2, 2016

This memo serves as a supplement to the forthcoming Ductless Mini-Split Heat Pump Impact Evaluation report prepared for the Massachusetts and Rhode Island Electric and Gas Program Administrators. It discusses the methods and assumptions employed by the Massachusetts Technical Reference Manual (TRM), from program years 2016-2018, for calculating energy and demand savings resulting from residential installations of ENERGY STAR® rated ductless mini-split heat pumps (DMSHPs). Provided the insights gained during the writing of the evaluation report, the basis of these TRM assumptions are reviewed, and updated inputs and methods are recommended for future use.

Measure History

The residential installation of an ENERGY STAR® rated DMSHP is categorized as a lost opportunity, HVAC measure and specifically described as "The installation of a more efficient [DMSHP] system." The significance of being "more efficient" is in reference to the assumed baseline equipment of a minimally efficient DMSHP, as determined by the Federal Register. Deemed energy and demand savings are calculated from the following sets of equations:

$$\Delta kWh_{HP} = Tons \times \frac{12\ kBtu/hr}{Ton}\left[\left(\frac{1}{SEER_{BASE}} - \frac{1}{SEER_{EE}}\right) \times Hours_C + \left(\frac{1}{HSPF_{BASE}} - \frac{1}{HSPF_{EE}}\right) \times Hours_H\right]$$

$$\Delta kW_{COOL} = Tons \times \frac{12\ kBtu/hr}{Ton} \times \left(\frac{1}{EER_{BASE}} - \frac{1}{EER_{EE}}\right)$$

$$\Delta kW_{HEAT} = Tons \times \frac{12\ kBtu/hr}{Ton} \times \left(\frac{1}{HSPF_{BASE}} - \frac{1}{HSPF_{EE}}\right)$$

With quantities:

ΔkWh_{HP}	= Reduction in annual kWh consumption of HP equipment
ΔkW_{COOL}	= Summer reduction in electric demand of HP equipment
ΔkW_{HEAT}	= Winter reduction in electric demand of HP equipment
$Tons$	= Capacity of HP equipment
$SEER_{BASE}$	= Seasonal efficiency of baseline HP equipment
$SEER_{EE}$	= Seasonal efficiency of new efficient HP equipment
EER_{BASE}	= Peak efficiency of base HP equipment

EER_{EE} = Peak efficiency of new efficient HP equipment

$HSPF_{BASE}$ = Heating efficiency of baseline HP equipment

$HSPF_{EE}$ = Heating efficiency of new HP equipment

$Hours_C$ = EFLH for cooling

$Hours_H$ = EFLH for heating

Several assumptions are involved in these calculations, including 447 equivalent full load hours (EFLH) for heating; 360 EFLH for cooling; and a baseline SEER, EER, and HSPF of 14, 10, and 8.2, respectively. A TRM table provides various cases of high efficiency SEERs, EERs, and HSPFs and their resulting energy and demand savings; these inputs and savings are replicated in for reference, drawing on past and current TRM values.

Table 1. Savings for Residential DMSHPs

Year	$SEER_{EE}$	EER_{EE}	$HSPF_{EE}$	ΔkW_{COOL}	ΔkW_{HEAT}	ΔkWh_{HP}
2013, 2014	14.5	12.0	8.2	0.250	0.119	186
2013, 2014	19	12.83	10.0	0.331	0.448	669
2013, 2014	23	13	10.6	0.346	0.533	820
2015	14.5	12.0	8.2	0.515	0.000	13
2015	19	12.83	10.0	0.596	0.329	497
2015	23	13	10.6	0.611	0.414	648
2016	20.5	13.3	9.9	0.11	0.34	286
2016	24.2	13.8	12	0.11	0.45	330

Recommendations

The assumed EFLH for cooling were greater than the same values calculated during the evaluation, as shown in Table 2. The EFLH for heating were cited from a Cadmus memo providing initial results from the DMSHP evaluation, and are in agreement with the final values reported in the study. The average of the top 25% of EFLH are also included in .

Table 2. Heating and Cooling Equivalent Full Load Hours for DMSHP

Season	MA TRM EFLH	Measured EFLH	Top 25% of Measured EFLH
Winter 2015	447	442	1,275
Summer 2015	360	218	499
Winter 2016	447	451	1,117

As part of the study, a second winter of on-site metering was included, and so two sets of measured heating EFLH values are presented above. One reason for this extension was the concern that the unusually high amount of snowfall in 2015 would prevent the outdoor unit of the DMSHP from operating at normal capacity, and result in lower EFLH. Although the measured EFLH from the two winters are within three percent of each other, the evaluation team recommends using the 2016 value as the data used in its calculation were collected under less extreme conditions. The assumed heating EFLH vary slightly from the final values reported in the evaluation; these differences resulted from refining the weather normalization method used by the evaluation team. The assumed cooling EFLH are higher than the reported values, but the added context of where this assumption was drawn from is important. The 360 EFLH for cooling were cited from an evaluation of central air conditioners, which the evaluation team expects to operate more continuously than DMSHP systems. Given these findings, it is recommended the TRM update the EFLH to 451 hours for heating and 218 hours for cooling.

The primary discrepancy between the current TRM methodology and that presented in this memo is the determination of an appropriate baseline for calculating savings. The evaluation team found homeowners frequently install DMSHP to displace existing HVAC systems or in lieu of some alternative; because of this behavior, assuming all baseline systems are minimally efficient DMSHPs will fail to accurately predict savings in many situations. Table 3 3 presents a concise set of baselines that were observed during this study.

Table 3. Recommended DMSHP Baselines

Season	Baseline Equipment	Assumed Baseline Efficiency*	Assumed Baseline Efficiency for TRM Algorithm
Cooling	Ductless Heat Pump	14 SEER, 10 EER	14 SEER, 10 EER
	Central Air Conditioner	13 SEER, 11 EER	13 SEER, 11 EER
	Window Air Conditioner	9.8 EER	14.5 SEER**, 9.8 EER
Heating	Ductless Heat Pump	8.2 HSPF	8.2 HSPF
	Boiler	0.82 AFUE	2.8 HSPF
	Furnace	0.9 AFUE	2.6 HSPF***
	Electric Resistance	1.0 COP	3.4 HSPF

*Massachusetts Technical Reference Manual for Estimating Savings from Energy Efficiency Measures. Tech. Massachusetts Electric and Gas Energy Efficiency Program Administrators, Oct. 2015. Web. Dec. 2016. < http://ma-eeac.org/wordpress/wp-content/uploads/2016-2018-Plan-1.pdf >.

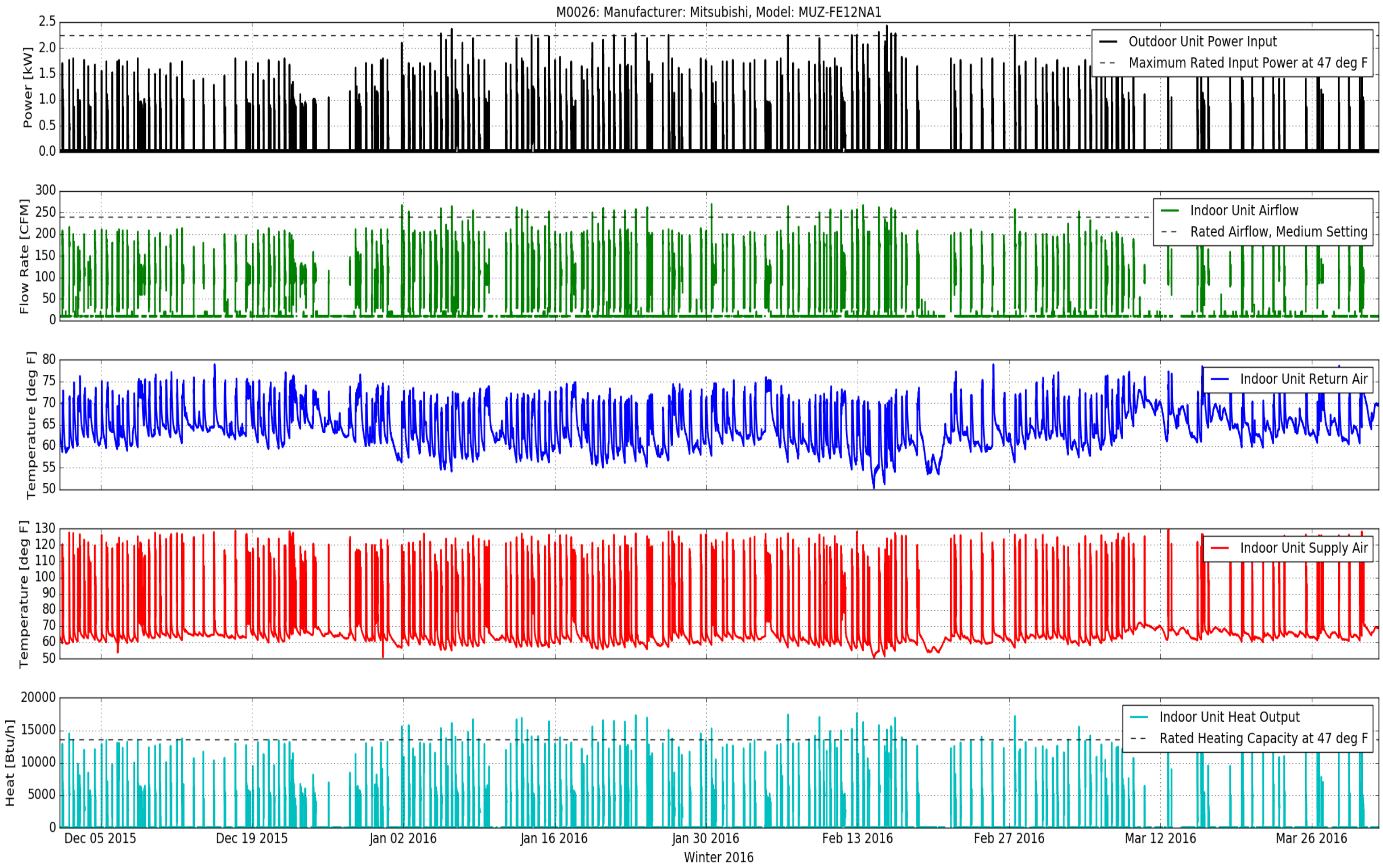
**Because manufacturers do not report seasonal efficiencies for window air conditioning units, we have applied a scalar conversion factor derived from mean ratios between DHP EERs and SEERs values reported by AHRI. Acknowledging that window air conditioners generally do not have self-regulating, variable speed motors like DHPs, which can contribute to lower seasonal efficiencies, we have averaged only DHP systems from the bottom half of the calculated ratios.

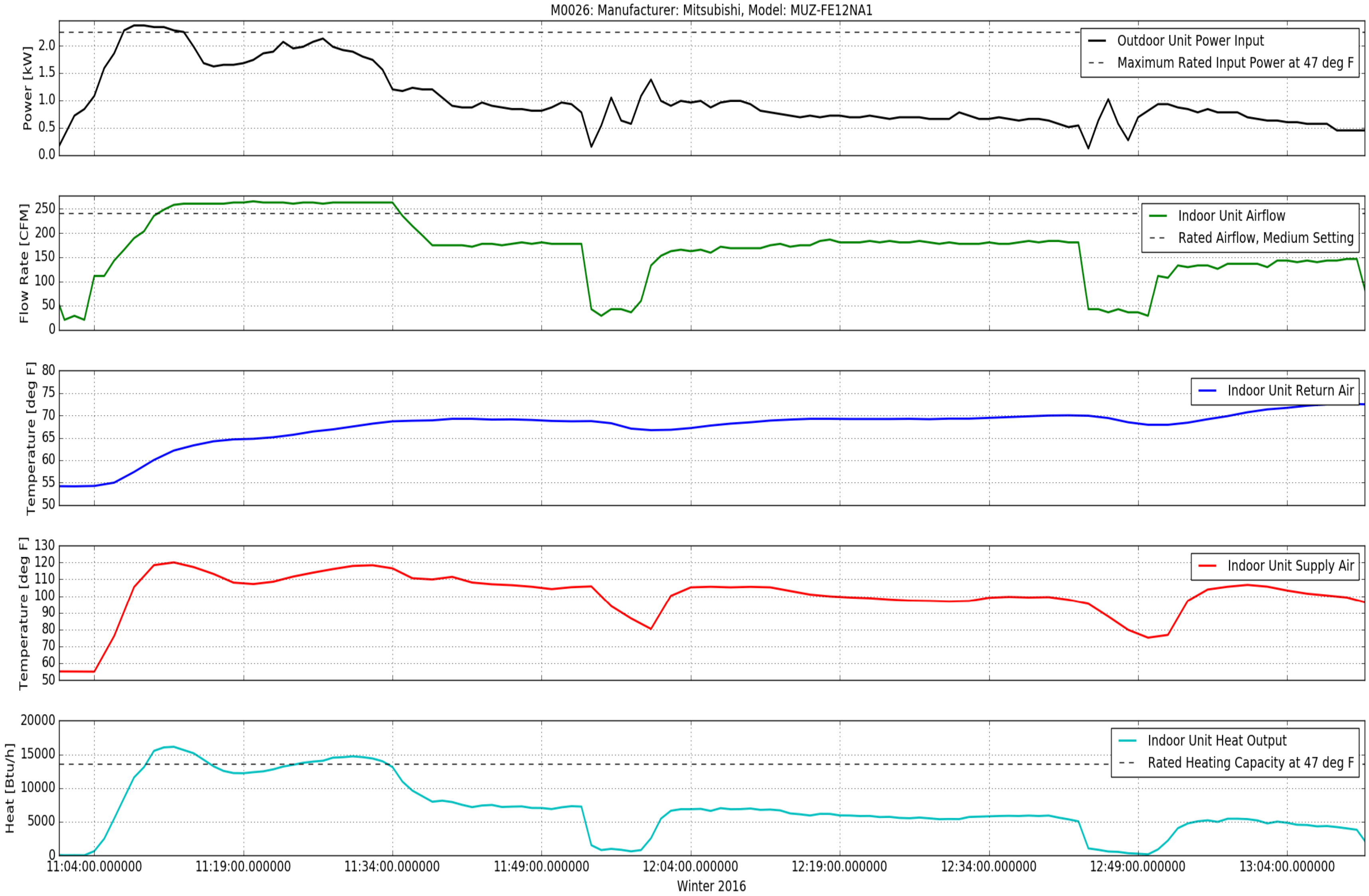
***Seasonal efficiency value includes an assumed 15% duck leakage, based on the MA PY 2016-2018 TRM duct sealing measure.

There are many nuanced arguments surrounding exactly how a DMSHP baseline should be determined, and for further discussion see the Baseline Memo, but for the purposes of a TRM algorithm the evaluation team recommends a simple approach based on the equipment present in the home, and in the absence of any coincident HVAC system, using a minimally efficient DMSHP baseline. By identifying a site specific Assumed Baseline Seasonal Efficiency from Table 3, savings can be calculated from the sets of equations currently presented in the TRM.

As a final recommendation, the evaluation team suggests that the actual SEER, EER, and HSPF ratings of the newly installed DMSHP systems reported to and tracked by the PAs are used in the high efficiency scenario of savings calculations. This change in the TRM methodology would acknowledge the wide range of ratings available to consumers and the increasing seasonal efficiencies, and provide more refined estimates of energy and demand reduction. Updating the residential, new installation DMSHP TRM algorithm with the recommendations presented in this memo will result in a more current, program specific, and data-based methodology that is informed through extended study of this measure.

Appendix D: Example DMSHP Time Series Data




M0026: Manufacturer: Mitsubishi, Model: MUZ-FE12NA1
Power [kW]
0.0
0.5
1.0
1.5
2.0
Outdoor Unit Power Input
Maximum Rated Input Power at 47 deg F
Flow Rate [CFM]
0
50
100
150
200
250
Indoor Unit Airflow
Rated Airflow, Medium Setting
Temperature [deg F]
50
55
60
65
70
75
80
Indoor Unit Return Air
Temperature [deg F]
50
60
70
80
90
100
110
120
130
Indoor Unit Supply Air
Heat [Btu/h]
0
5000
10000
15000
20000
Indoor Unit Heat Output
Rated Heating Capacity at 47 deg F
11:04:00.000000
11:19:00.000000
11:34:00.000000
11:49:00.000000
12:04:00.000000
12:19:00.000000
12:34:00.000000
12:49:00.000000
13:04:00.000000
Winter 2016

NAVIGANT

Ductless Mini-Split Heat Pump Cost Study (RES 28)

Final Report

Prepared for:

The Electric Program Administrators of Massachusetts
Part of the Residential Evaluation Program Area

Submitted by:
Navigant Consulting, Inc.
1375 Walnut Street
Suite 100
Boulder, CO 80302

303.728.2500
navigant.com

Reference No.: 183406
October 5, 2018

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The Massachusetts Residential Heating and Cooling Program offers prescriptive rebates for the installation of high-efficiency ductless mini-split heat pump (DMSHP) systems. The energy-efficiency-related costs of HVAC equipment can change rapidly. In a mature market, such as the market for conventional split-system central air conditioners and heat pumps, changes in the total installed costs are driven by changes in equipment prices as manufacturers adjust their designs in response to federal appliance regulations and fluctuating material prices. In a less mature market, such as the market for DMSHP systems, changes in the total installed cost are driven both by changes in equipment costs and changes in the cost of installation. In the recent past, DMSHPs were considered a niche product and it was difficult to find contractors who were qualified to install them. The market share of DMSHPs and the awareness of their benefits has grown rapidly in recent years, and recent market developments have likely reduced the cost of installing a baseline product. Additionally, manufacturing process improvements and reduced component costs (particularly for electronic controls) are likely to further reduce the equipment cost of higher-efficiency DMSHP systems. Taking all these factors into account, cost-efficiency curves that are several years old may not represent the current market for DMSHPs.

Evaluation Objectives & Methodology

The goal of this study was to evaluate the energy-efficiency related total and incremental costs of single family home installations of DMSHP systems currently rebated through the Residential Heating and Cooling program.

Navigant developed the Ductless Mini-Split Heat Pump Cost Study to answer the following questions:

- What are the consumer costs of purchasing and installing residential DMSHP systems in single family homes in both the retrofit and lost opportunity scenarios, and what proportion of these costs go towards equipment and labor?
- What is the relationship between cost and efficiency for DMSHP systems?
- What are the total costs and incremental costs associated with installing DMSHP systems at different efficiency levels with different configurations (i.e., single-head vs. multi-head)? Do these total and incremental costs determined from research align with the actual costs reported on invoices in collected PA program data?

Evaluation Activities

This study relies on three main data sources: 1) a survey of HVAC contractors in Massachusetts, 2) retail prices gathered by webscraping, and 3) a sample of scanned invoices for system installations that were rebated through the program. This study combines data from these three sources to construct cost-efficiency curves that describe the total installed cost of DMSHP systems across a range of different system sizes and efficiency levels.

The evaluation team first defined the representative product sizes that are typically installed in the PAs' service areas. The team then gathered cost data by surveying contractors and webscraping retail prices, and merged the data from these two sources to construct cost-efficiency curves. Finally, the team reviewed a sample of program invoices to confirm that the constructed cost-efficiency curves fall in the ranges of costs reported on program invoices. Table 1 describes the scope and rationale for each activity in this cost study.

Table 1. Cost Study Activities

Activity	Rationale
Survey of HVAC Contractors in Massachusetts	Surveys can provide accurate cost estimates for specific installation scenarios relevant to this study. Survey data was used to assess how installation costs change based on a variety of installation factors, and to assess the equipment costs at efficiency levels rebated by the program.
Webscraping of Retail DMSHP Price Data	Webscraping is inexpensive and can yield data across many brands, sizes, and efficiency levels. Webscraped data was used to fill in gaps between and above the limited efficiency levels probed in the contractor survey.
Analysis of Program Rebate Invoices	Although program invoice data is of mixed quality, many records can be gathered and processed at little cost. Program invoice data reflects the total installed costs that customers actually pay for products that meet the program's rebate thresholds. Program invoice data was used to corroborate the cost curves constructed using survey and webscraping data.

Source: Adapted from Stage 3 Evaluation Plan for Ductless Mini-Split Heat Pump Cost Study (RES 28)

Findings & Considerations

The following sections summarize the findings from the contractor survey and webscraping activities.

Installation Costs of Different DMSHP Configurations

The evaluation team used contractor survey data to assess the customer costs associated with different installation factors.

- On average, the total cost of a retrofit DMSHP installation is about $75 higher than the total cost of a replacement DMSHP installation.
- On average, installations through brick exterior walls cost about $260 more than installations through other exterior wall types (with +$200 for labor and +$60 for supplies), but this varies depending on the specifics of the installation site and the contractor's in-house capabilities.
- Relative to the base case installation where the outdoor condenser unit is located on a ground pad:
    - Mounting the outdoor unit to an exterior ground-floor wall is $70 less expensive.
    - Mounting the outdoor unit on the roof is about $400 more expensive.
    - Mounting the outdoor unit on an exterior wall above the ground floor is about $1,000 more expensive.
- Installing an indoor ceiling cassette unit that is embedded in the ceiling of the conditioned space is about $1,050 more expensive than the base case installation where the indoor unit is an exposed wall-mounted unit.

- When two DMSHP system installations are performed in the same job, customers receive a discount of about 15% on the total installed cost of the second system, compared to if the second system had been installed as a separate job.

The Cost of Efficiency in DMSHPs

Based on the contractor survey results, the evaluation team concluded that for a given capacity level, the cost of equipment changes with efficiency level, but that the cost of labor, supplies and other costs do not vary with efficiency. While the costs presented below represent the total installed cost of the system (including labor, equipment, supplies and other costs), the incremental costs between low- and high-efficiency systems are driven entirely by increases in equipment costs. The evaluation team created separate cost-efficiency curves for regular DMSHP systems and for DMSHP systems that meet the cold-climate air-source heat pump (ccASHP) specification.[1]

Table 2 presents the total installed cost for the base case and the current program rebate thresholds. Table 3 shows the incremental installed costs for the rebate thresholds compared to the base case.

Table 2. Total Installed Cost of DMSHP Systems at Common SEER-HSPF Combinations

Capacity, kBtu/h	Number of Zones	Base Case 15 SEER, 8.2 HSPF	Lower Rebate Threshold 18 SEER, 10 HSPF		Upper Rebate Threshold 20 SEER, 12 HSPF		Above Current Rebate Levels 28 SEER, 14 HSPF	
		Regular	Regular	Cold Climate	Regular	Cold Climate	Regular	Cold Climate
9 ± 1.5	1	$3,643	$3,860	$3,993	$4,212	$4,035	-*	$4,419
12 ± 1.5	1	$3,717	$3,957	$4,058	$4,407	$4,199	$4,407	$4,515
18†	1	$4,276	$4,475	$4,646	$4,956	$4,812	-‡	-‡
24 ± 3	1	$4,586	$4,811	$5,016	$5,256	$5,176	-*	-*
24 ± 3	2	$6,263	$6,679	$7,060	-*	-*	-*	-*
24 ± 3	3	$7,434	$7,852	$8,202	-*	-*	-*	-*
30 ± 3	3	$7,962	$8,024	$9,049	-*	-*	-*	-*
36 ± 3	4	$8,857	$8,857	$10,438	-*	-*	-*	-*

* The evaluation team could not identify any systems available on the market with this combination of capacity, zones, and efficiency levels.

† The evaluation team estimated the equipment costs for 18 kBtu/h using linear interpolation between the equipment costs at 12 kBtu/h and 24 kBtu/h. Based on contractor survey data, the team assumed that installation costs for 18 kBtu/h systems are the same as for 24 kBtu/h systems.

‡ Since the 18 kBtu/h data was estimated based on data for 12 and 24 kBtu/h systems, it could only be calculated for system configurations that are available at both the 12 and 24 kBtu/h capacities.

Source: Navigant Analysis

---

[1] The Cold Climate Air-Source Heat Pump Specification (ccASHP) was developed by a group of interested stakeholders facilitated by the Northeast Energy Efficiency Partnerships (NEEP). Qualifying heat pumps must meet certain performance and technology requirements, including high-efficiency performance at low ambient temperatures. For details, see section 2.3.

Table 3. Incremental Installed Cost Relative to the Base Case, and Program Rebates at Common SEER-HSPF Combinations

Capacity, kBtu/h	Number of Zones	Lower Rebate Threshold 18 SEER, 10 HSPF			Upper Rebate Threshold 20 SEER, 12 HSPF			Above Current Rebates 28 SEER, 14 HSPF	
		Regular	Cold Climate	Rebate Amount	Regular	Cold Climate	Rebate Amount	Regular	Cold Climate
9 ± 1.5	1	$217	$350	$100	$569	$392**	$300	-*	$776
12 ± 1.5	1	$239	$340	$100	$689	$481**	$300	$689	$797
18†	1	$198	$370	$100	$680	$536	$100	-‡	-‡
24 ± 3	1	$225	$430	$100	$670	$590**	$300	-*	-*
24 ± 3	2	$416	$797	$200	-*	-*	$600	-*	-*
24 ± 3	3	$418	$768	$300	-*	-*	$900	-*	-*
30 ± 3	3	$62	$1,087	$300	-*	-*	$900	-*	-*
36 ± 3	4	$0	$1,581	$400	-*	-*	$1,200	-*	-*

* The evaluation team could not identify any systems available on the market with this combination of capacity, zones, and efficiency levels.

** Cold climate units tend to cost less than regular units at high efficiencies due to a design approach that involves downsizing the compressor and overspeeding it at maximum load. For details, see section 3.3.

† The evaluation team estimated the equipment costs for 18 kBtu/h using linear interpolation between the equipment costs at 12 kBtu/h and 24 kBtu/h. Based on contractor survey data, the team assumed that installation costs for 18 kBtu/h systems are the same as for 24 kBtu/h systems.

‡ Since the 18 kBtu/h data was estimated based on data for 12 and 24 kBtu/h systems, it could only be calculated for system configurations that are available at both the 12 and 24 kBtu/h capacities.

Source: Navigant Analysis

Program Implications and Conclusions

One main finding of this study is that for a given capacity level, the cost changes associated with increasing efficiency are due entirely to changes in the cost of equipment (i.e., the installation costs do not vary with efficiency). Table 3, above, illustrates how the incremental installed costs for regular and cold-climate systems compare to the current rebate amounts for systems with different sizes and number of zones. At smaller system capacities of 24 kBtu/h and less, the incremental cost of high-efficiency systems exceeds the rebate amounts offered for those systems. However, at larger system capacities of 30 and 36 kBtu/h, the rebate amount exceeds the incremental cost of efficiency for regular (non-cold-climate) systems.

There are three strategies the Program Administrators (PAs) could pursue to improve the cost effectiveness of the DMSHP rebate offerings.

Consideration 1: To motivate the adoption of smaller capacity systems at very high-efficiencies, the PAs should consider adding a premium rebate level at 28 SEER and 14 HSPF.

> **Finding 1:** About 25% of the DMSHP rebate records in the period January 1, 2016 through July 31, 2017 were for systems within the capacity range of 9.5-13.5 kBtu/h rated below 28 SEER and 14 HSPF. There are systems in this capacity range on the market that are rated at or above 28 SEER and 14 HSPF, and these systems present a savings opportunity.

Consideration 2: At larger capacities (>30 kBtu/h) the current rebate structure incentivizes the installation of non-cold-climate systems that have little or no incremental cost above the base case. Cold-climate systems should provide additional savings at all capacity levels for a small additional cost, so the PAs should consider limiting the rebate eligibility for DMSHP systems to systems that are cold-climate qualified. This limitation may be implemented by requiring ccASHP qualification or by providing specific efficiency requirements at low outdoor temperatures.

> **Finding 2:** At larger DMSHP system capacities, such as sizes of 30 kBtu/h + 3 zones and 36 kBtu/h + 4 zones, there is little or no incremental cost to increase efficiency from the base case of 15 SEER / 8.2 HSPF to a regular (non-cold-climate) system at the lower rebate threshold of 18 SEER / 10 HSPF. On the other hand, at these sizes there are significant incremental costs for qualified *cold-climate* systems at the lower rebate threshold of 18 SEER / 10 HSPF.

Consideration 3: Since ducted DMSHP systems may comprise an increasing portion of DMSHP rebate claims, the PAs should consider an add-on task to evaluate how equipment and installation costs of ducted systems compare to the non-ducted systems examined in the current study.

> **Finding 3:** The majority of DMSHP systems rebated in 2016-2017 used wall-mounted indoor units. As such, wall-mounted units were the focus of this cost study. However, midway through this study, the evaluation team received anecdotal evidence that an increasing proportion of DMSHP installations in Massachusetts are using ducted indoor units. The evaluation team expects that ducted indoor units may offer comparable savings to non-ducted indoor units, but that ducted units could incur greater total installed costs due to the different equipment costs and the tradeoff between installing refrigerant lines versus installing ductwork.

Section 4 describes these strategies in more detail.

1. PROGRAM BACKGROUND AND STUDY OBJECTIVES

1.1 Program Background

The Massachusetts Residential Heating and Cooling Program offers prescriptive rebates for the installation of high-efficiency ductless mini-split heat pump (DMSHP) systems. The energy-efficiency-related costs of HVAC equipment can change rapidly. In a mature market, such as the market for conventional split-system central air conditioners and heat pumps, changes in the total installed costs are driven by changes in equipment prices as manufacturers adjust their designs in response to federal appliance regulations and fluctuating material prices. In a less mature market, such as the market for DMSHP systems, changes in the total installed cost are driven both by changes in equipment costs and changes in the cost of installation. In the recent past, DMSHPs were considered a niche product and it was difficult to find contractors who were qualified to install them. The market share of DMSHPs and the awareness of their benefits has grown rapidly in recent years, and recent market developments have likely reduced the cost of installing a baseline product. Additionally, manufacturing process improvements and reduced component costs (particularly for electronic controls) are likely to further reduce the equipment cost of higher-efficiency DMSHP systems. Taking all these factors into account, cost-efficiency curves that are several years old may not represent the current market for DMSHPs.

The goal of this study was to evaluate the energy-efficiency related total and incremental costs of single family home installations of DMSHP systems currently rebated through the Residential Heating and Cooling program.

1.2 Product Description

Ductless mini-split heat pumps are electrical HVAC systems capable of providing heating and cooling to one or more conditioned zones in a building. They work by transferring thermal energy between the conditioned space and the outside environment. DMSHP systems are composed of one outdoor unit and one or more indoor unit(s) connected by refrigeration tubing and electrical wiring. Generally, the units in the system are bought as a package, with matching indoor and outdoor units. The components of the system can also be bought independently, for example to replace a single unit that failed. In the analysis discussed here, all systems are assumed to be purchased as a package.

The efficiency of heat pumps is usually expressed in terms of several metrics, specified below.

a) **Coefficient of Performance (COP):** The coefficient of performance is the ratio of the useful heat added (in heating) or removed (in cooling) from the conditioned space to the energy consumed by the product. The COP is used to express performance at a specific set of testing conditions. Common COP testing conditions are an indoor temperature of 70 °F and an outdoor temperature of 47 °F for high-temperature heating, 17 °F for low-temperature heating, or 5 °F for cold-climate heating. For a given set of indoor and outdoor conditions, the larger the COP, the greater the operating efficiency. Because the COP depends on the testing conditions, the testing conditions are usually stated with the COP value. As the ratio of two energy or power quantities, the COP is a dimensionless number, though it is sometimes expressed in units of watt/watt (W/W).

b) **Energy Efficiency Ratio (EER):** Like the COP, the EER is a ratio of useful heat moved to the energy consumed by the product. The EER is generally only used to express cooling performance at a specific set of testing conditions (95 °F outdoor temperature and 80 °F indoor temperature). The EER metric is usually expressed in British thermal units per Watt-hour (Btu/W.h).

c) **Seasonal Energy Efficiency Ratio (SEER):** The SEER metric is the weighted average of EER measured across a range of cooling conditions. The standard conditions specified for the SEER metric provide an estimate of efficiency over an entire cooling season, thus providing a more representative estimate of “real-world” performance than that provided by the EER metric. The SEER metric is expressed in Btu/W.h.

d) **Heating Seasonal Performance Factor (HSPF):** The HSPF is the weighted average of the COP measured across a range of heating conditions. Analogously to the SEER metric, the HSPF is intended to provide an estimate of efficiency over an entire heating season, thus providing a more representative estimate of “real-world” performance than that provided by the COP. The HSPF metric is expressed in Btu/W.h.

DMSHPs are available in the market in a variety of capacities and efficiencies. Additionally, DMSHPs are sold with varying numbers of indoor units, which allow a single system to serve more than one conditioned zone. Generally, the cost of a DMSHP system increases with efficiency, capacity, and the number of zones supplied. The Residential Heating and Cooling program offers rebates to customers for DMSHP systems that meet certain efficiency requirements, listed in Table 4.[2] The evaluation team separately examined the costs of DMSHP systems that meet the Northeast Energy Efficiency Partnerships (NEEP) Cold Climate Air-Source Heat Pump (ccASHP) Specification, which uses the criteria presented in Table 4.[3]

Table 4. MassSave Rebate Thresholds and Cold Climate Specification Criteria.

MassSave DMSHP Rebate Criteria	NEEP Cold Climate Air Source Heat Pump Specification Criteria
Two rebate levels: • $100 per indoor unit for DMSHP systems rated at ≥18 SEER and ≥10 HSPF • $300 per indoor unit for DMSHP systems rated at ≥20 SEER and ≥12 HSPF	Systems must: • Have a variable capacity compressor • Be a matched system in the AHRI directory • Be ENERGY STAR certified • Have COP > 1.75 at 5 °F • Have HSPF ≥ 10

Source: Navigant analysis

DMSHPs may be installed in many different configurations depending on the specifics of the job site and the conditioning requirements of the home. Each configuration requires specific equipment, hardware and a certain amount of labor to install, all of which lead to varying installation costs. The evaluation team considered the following configurations in this study:

a) **Wall type:** Certain wall materials may be more difficult to drill through or may require additional hardware to ensure safe installation of the equipment. The study considered the following wall types: siding (base case), shingles, wood, and brick.

b) **Outdoor unit location:** The outdoor unit of a DMSHP system may be installed in different locations depending on the available space and the maximum distance to the indoor unit. This study considered the following outdoor installation types: on the ground (base case), mounted on

---

[2] For details, see https://www.masssave.com/en/saving/residential-rebates/electric-heating-and-cooling/.
[3] See section 2.3 for further discussion of cold-climate systems.

the wall at the ground floor level, on the roof, and mounted on the wall above the ground floor level. These installation types are shown in Figure 1.

Figure 1. Outdoor Installation Types

Image Sources: Earth Energy Innovations[4], The Home Store[5], Alpine Heat[6], McGarry and Madsen[7]

c) **Indoor unit type:** Customers may select different indoor unit types depending on the available space, the type of construction, and their aesthetic preferences. This study considered the following common indoor installation types: wall-mounted (base case) and ceiling cassette. These installation types are shown in Figure 2.

---

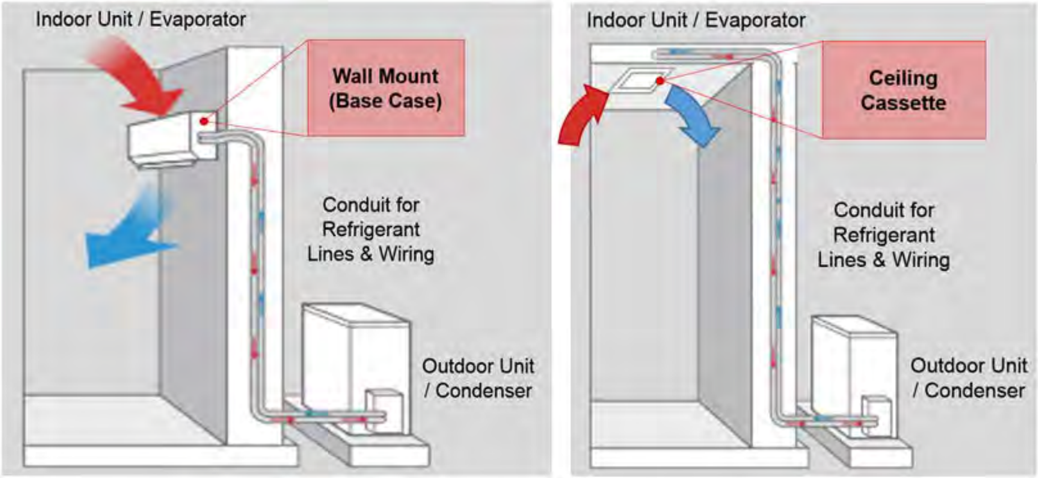
[4] Earth Energy Innovations. "Ductless Mini Split Installation - Lewistown, PA." Available at: http://www.earthenergyinnovations.com/ductless-mini-split-installations-gallery/ductless-mini-split-installation-lewistown-pa

[5] The Home Store. "Ductless Mini-Split Heating and Cooling Systems." Available at: https://www.the-homestore.com/blog/2014/10/ductless-mini-split-systems/

[6] Alpine Heat. "LG Ductless MiniSplit." Available at: http://alpineheat.com/lg-ductless-minisplit/

[7] McGarry and Madsen Home Inspection. "What is a Ductless Mini-Split Air Conditioner?" Available at: http://www.mcgarryandmadsen.com/inspection/Blog/Entries/2017/2/2_What_is_a_ductless_mini-split_air_conditioner.html

Figure 2. Indoor Installation Types



Source: ClimateRight.com[8]

d) **Number of individual systems:** Some job sites such as multi-unit buildings may require the installation of more than one DMSHP system, each with its own indoor and outdoor units. Contractors may offer discounts when consumers install more than one system at once. This study considered the additional costs of installing more than one system in a single job.

1.3 Study Objectives

This study sought to answer the following research questions:

- What are the consumer costs of purchasing and installing residential DMSHP systems in single family homes in both the retrofit and lost opportunity scenarios, and what proportion of these costs go towards equipment and labor?
- What is the relationship between cost and efficiency for DMSHP systems?
- What are the total costs and incremental costs associated with installing DMSHP systems at different efficiency levels with different configurations (i.e., single-head vs. multi-head)? Do these total and incremental costs determined from research align with the actual costs reported on invoices in collected PA program data?

1.4 Structure of this Report

The remainder of this report is organized into three sections. Section 2 contains the study methodology and describes the data collection and analysis approaches. Section 3 presents the results of the analyses. Section 4 provides considerations for program offerings and the evaluation team’s conclusions. Appendix A provides the contractor survey that was administered during this study.

---

[8] Climate Right. “Ductless Mini Split 12,000btu Air Conditioner & Heater.” Available at: https://climateright.com/mini-split-4000-12000btu-diy-quick-connect-air-conditioner-heater.html

2. METHODOLOGY

2.1 Overview and Sources of Data

This study relies on three main data sources: 1) a contractor survey conducted in Task 1 of this study, 2) retail prices gathered by webscraping in Task 2 of this study, and 3) a sample of scanned program invoices analyzed in Task 3 of this study. There are advantages and disadvantages associated with each of these data sources, as described in Table 5.

Table 5. Data Sources for DMSHP Costs and their Advantages and Disadvantages

Data Source	Advantages	Disadvantages
Contractor Survey	Surveys are an accurate source of information, since costs are provided by the companies that conduct the installation and billing.	It is expensive to gather large amounts of survey data due to the outreach efforts required and the incentive rewards for participants. The number of data points gathered by survey must be limited to avoid survey fatigue. Contractors are likely to offer estimates from memory instead of going through past invoices, so survey data is subject to recall bias.
Webscraping	Webscraping is inexpensive and can yield data across many brands, sizes, and efficiency levels.	Most customers do not purchase equipment online, and webscraped prices must be adjusted to estimate the marked-up prices that contractors charge for products. Webscraping does not provide installation costs. Webscraped data encompasses many retailers and brands, so the costs must be normalized.
Program Invoices	Program invoice data is only moderately expensive to retrieve and process.	Invoice data is of mixed quality, since only a small percentage of invoices provide line-item details distinguishing the costs of equipment, labor, and supplies separately.

Source: Navigant analysis

The methodology in this study combines data from these three sources to construct cost efficiency curves that describe the total installed cost of DMSHP systems across a range of different system sizes and efficiency levels. At a high level, this study used the following methodology. The evaluation team first defined the representative product sizes that are typically installed in the PAs' service areas. The team then gathered cost data by surveying contractors and webscraping retail prices, and merged the data from these two sources to construct cost-efficiency curves. Finally, the team reviewed a sample of program invoices to check whether the constructed cost-efficiency curves fall in the ranges of costs reported on program invoices.

The following sections describe each of these steps in detail.

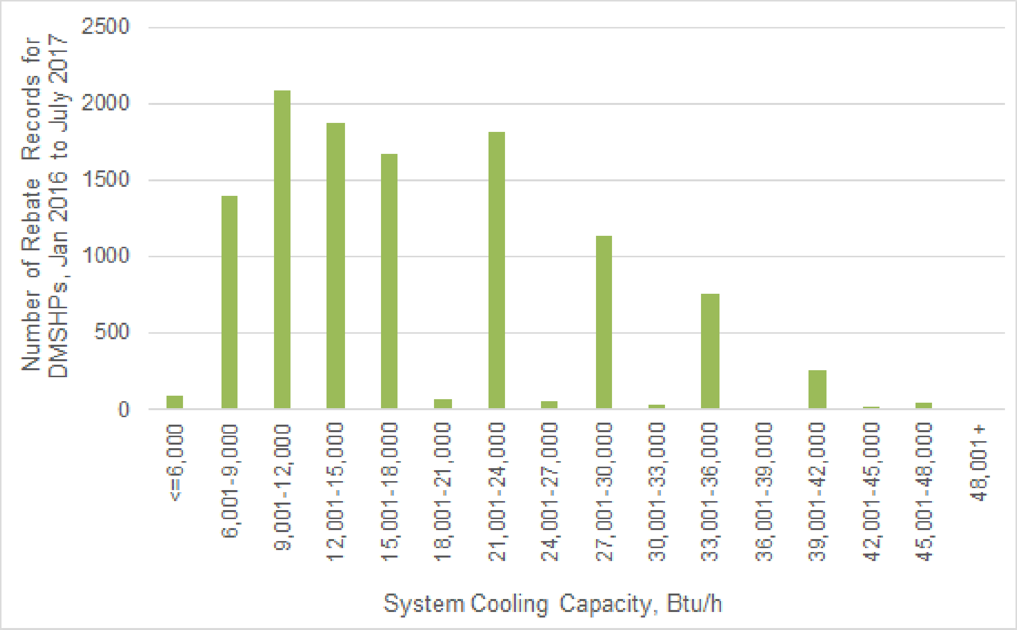
2.2 Representative Product Sizes and Number of Zones

The evaluation team identified “representative sizes” for DSMHPs that represent the DMSHP system sizes most commonly rebated in the Massachusetts PAs’ service areas. The evaluation team examined rebate data provided by the PAs to determine the number of zones that are typically served by each representative capacity.

DSMHP systems can provide cooling and heating, and most vendors market systems by their nominal cooling capacity. Consequently, the evaluation team used the nominal cooling capacity as the representative variable in its cost calculations. It should be noted that the nominal capacity may not always reflect the exact performance of the DMSHP system, especially for small systems with very high efficiency. In many cases, a DMSHP system’s maximum achievable capacity is higher than its nominal capacity, since manufacturers frequently engineer systems to achieve a higher SEER rating, and the SEER metric measures part-load operation. For the purposes of this study, the evaluation team considered this strategy to be one of the many legitimate design options that manufacturers may adopt to improve rated efficiency. The evaluation team did not adjust the data to account for differences in nominal capacity and full-load capacity. Generally, the cooling and heating capacities of any given system correlate strongly; in other words, a system that can provide twice as much cooling than another system is likely to provide twice as much heating than the other system as well.

The DMSHP market is largely clustered around a few capacity levels. These capacity levels tend to match with fractions of a cooling ton (12 kBtu/h), such as 0.75 ton (9 kBtu/h), 1 ton (12 kBtu/h) and so on. Figure 3 illustrates this clustering with a histogram of the system cooling capacities for 11,295 participant rebate records filed between 1/1/2016 and 7/31/2017.

Figure 3. Number of Massachusetts PA Rebate Records for DSMHPs in the Period from January 2016 to July 2017 as a Function of Capacity.



Source: Navigant analysis of rebate data provided by Massachusetts PAs

Given this clear clustering of the DMSHP market around certain capacity levels, the evaluation team selected a few typical capacities to represent the main clusters in the market. This allowed for a univariate analysis of cost as a function of efficiency for each capacity level, which is much simpler than creating a bivariate analysis of cost as a function of efficiency and capacity. The evaluation team selected the following capacity levels for the analysis: 9, 12, 24, 30 and 36 kBtu/h. Table 6 shows the number of zones typically offered with these capacities, as well as potential uses for them.

Table 6. Details of the Representative Cooling Capacities of DMSHP Systems

Cooling Capacity (Btu/h)	Number of Zones	Description
9,000 ± 1,500	1	These are relatively small systems that would be an appropriate, more efficient option or replacement for room or window air conditioners or packaged terminal air conditioners (PTACs). Individually, they may find application in additions, or in cold or hot spots in a building.
12,000 ± 1,500	1	Systems rated at 12,000 can condition a larger space than systems rated at 9,000 Btu/h systems. They are not large enough to condition an entire home. Thus, they make appropriate replacements for room or window air conditioners or packaged terminal air conditioners (PTACs). They may find application in garages or living rooms.
24,000 ± 3,000	1	These systems can cool large individual rooms and even small homes, if the conditioned air can be circulated through all rooms. These systems are typically used to supplement a home’s existing HVAC system or to provide heating and cooling capacity to a newly finished space.
24,000 ± 3,000	2	Due to the significant capacity (equivalent to a small residential ducted system) and the ability to provide conditioning to two zones, these systems could provide conditioning for a small home. The capacity is split between the two zones, which can be used to tailor the conditioning to the size of each zone. They could replace, for example, two room HPs or PTHPs, or even a ducted heat pump.
24,000 ± 3,000	3	These systems can provide cooling to a small home, with added flexibility compared to two-zone systems. They could replace, for example, three small room HPs or a ducted heat pump.
30,000 ± 3,000	3	With similar applications to the three-zone 24,000 Btu/h systems, these systems can provide cooling and heating to larger spaces. They could replace three room HPs or PTHPs, or a ducted heat pump.
36,000 ± 3,000	4	These systems are equivalent to a medium-sized ducted residential heat pump system and would be an appropriate replacement for them. Because four zones are available, there is flexibility in terms of conditioning when compared to the other categories analyzed. These systems can provide conditioning to small and medium-sized homes.

Source: Navigant analysis, eComfort[9], Mitsubishi Electric[10]

---

[9] eComfort.com. “Mini-split Room Sizing Guide.” Available at: https://www.ecomfort.com/stories/1185-How-to-Properly-Size-Your-Mini-Split.html

[10] Mitsubishi Electric. “What Size System Do I Need?” Available at: http://mitsubishiacdealers.com/info/what-size-system

2.3 Cold Climate Air-Source Heat Pump Specification

Due to the particularly cold climate in the Northeast, a group of interested stakeholders facilitated by the Northeast Energy Efficiency Partnerships (NEEP) developed a specification for cold climate heat pumps ("Cold Climate Air-Source Heat Pump Specification", or "ccASHP specification").[11] This specification has the following requirements:

- The system must have a variable capacity compressor.
- The indoor and outdoor units must be part of a matched system in the AHRI directory.
- The system must be ENERGY STAR certified.
- The COP of the system must be greater than 1.75 at 5 °F.
- The HSPF of the system must be greater than 10.
- The system performance data must be reported to NEEP in a specific format.

NEEP hosts a database of the systems that meet the ccASHP specification. The evaluation team utilized this database to determine which systems were cold-climate ready. Because the ccASHP specification has strict requirements, the evaluation team expected units that meet the ccASHP specification to cost more than units that do not meet this specification. Systems that meet the ccASHP specification would show significant energy savings in the Massachusetts climate and, during the planning phase of this study, several PAs showed interest in learning the costs associated with ccASHP systems. The evaluation team created separate cost-efficiency curves for systems that meet the ccASHP specification and for systems that do not meet the specification.

DMSHP systems that are cold-climate qualified have high heating efficiency (measured by COP) at low ambient temperatures. Cold-climate systems provide the greatest benefit in colder regions, since in those regions the outdoor temperature is low for much of the year and the heating load associated with low outdoor temperatures is high. When installed in colder regions, these systems often show energy savings compared to regular (non-cold-climate) systems. This difference in performance between cold-climate and non-cold-climate systems is not fully captured by the HSPF metric, however, since the HSPF metric is a weighted average of heating efficiency at several different temperatures. In fact, cold-climate-qualified systems installed in colder regions may show savings when compared to non-cold-climate systems with similar HSPF ratings.[12] Estimates of yearly energy savings using cold climate units should not be calculated based on HSPF ratings alone. Instead, the yearly energy savings may be estimated by dividing the annual heating load across the typical range of outdoor temperatures by a system's COP rating at those temperatures.

2.4 Contractor Survey

In Task 1 of this study, the evaluation team obtained data from Massachusetts contractors via a web survey. Over a period of six weeks, the evaluation team contacted a sample of 145 HVAC contractors in Massachusetts with significant experience installing DMSHP systems, as evidenced by the program rebate records. The evaluation team emailed survey invitations to 115 of the contractors in that sample, and 13 contractors completed the online survey.

---

[11] http://www.neep.org/initiatives/high-efficiency-products/emerging-technologies/ashp/cold-climate-air-source-heat-pump, accessed on December 18th, 2017.

[12] For a comparison of the performance of cold climate and regular systems at low temperatures, see figures 54 and 55 of the Ductless Mini-Split Heat Pump Impact Evaluation published by the Cadmus Group. Available at http://ma-eeac.org/wordpress/wp-content/uploads/Ductless-Mini-Split-Heat-Pump-Impact-Evaluation.pdf.

The contractor survey was designed to obtain cost information around three main cost drivers: efficiency, capacity, and installation factors. The evaluation team selected specific levels and configurations for each of these cost drivers, and requested cost data at those levels. This allowed for a structured analysis of the cost drivers, in which relatively few data points can provide a comprehensive understanding of the costs associated with each cost driver. The contractor survey is included in Appendix A of this report.

2.5 Webscraping

In Task 2 of this study, the evaluation team gathered retail prices of DMSHP systems using webscraping, then used this data to characterize the relationship between the retail product costs and system efficiency, accounting for the cost of non-efficiency-related features and the possibility of cost outliers.

For each of the representative capacities in Table 6, the evaluation team used webscraped data to develop a cost-efficiency frontier describing the retail costs across the full range of available efficiency levels. Initially, the team developed these cost-efficiency curves based on the *lowest-cost* systems available at each efficiency level. However, after reviewing the contractor survey data, the evaluation team concluded that the Massachusetts market is largely served by Mitsubishi and Fujitsu, two brands that tend to be more expensive than the average unit available online. In other words, the DMSHP systems available to customers through contractors in Massachusetts tend to be more expensive than a cost-efficiency frontier based on the lowest available prices would indicate.

Based on this fact and considering that the market shares of other brands will likely increase over time, the evaluation team revised its approach to developing cost-efficiency curves. The new approach calculates the cost-efficiency curves based on the *average cost* of systems at each efficiency level. This was done by splitting the efficiency domains (SEER and HSPF) into bins and calculating the average cost within each bin (the bin sizes were 0.5 SEER and 0.5 HSPF). This approach yields a series of average costs at each increment of 0.5-SEER or 0.5-HSPF. The evaluation team then applied a waterfall process to that series to develop cost-efficiency curves that grow monotonically with efficiency. This process is illustrated in Figure 4.

Figure 4. Process to Develop the Webscraping Cost-Efficiency Curves

The original webscraping data (a) is divided into bins, each of which is averaged independently, such as in (b) and (c). Once all bins have been averaged (d), the waterfall process is applied (e), leading to the bin-average cost-efficiency curve for retail prices (f).

Source: Navigant analysis

2.6 Cost-Efficiency Curve Construction

This section describes how the evaluation team combined contractor survey data at a limited number of efficiency levels with webscraped retail prices to estimate complete cost-efficiency curve across the full range of efficiency levels available in the market. The contractor survey covered three efficiency levels: the base case[13] (15 SEER, 8.2 HSPF), the first rebate level (18 SEER, 10 HSPF) and the second rebate level (20 SEER, 12 HSPF). The evaluation team limited the survey to three efficiency levels to avoid survey respondent fatigue that could have impacted the survey response rate. However, the DMSHP market is complex and covers a much wider and more granular range of efficiencies than the three levels covered by the contractor survey.

The team used a three-step process to adapt the webscraping data to “fill in the gaps” between and above the survey data. The team first determined how contractor equipment costs relate to online retail DMSHP prices. Understanding this relationship allows the team to estimate what contractors would charge for systems that were included in webscraping but not included in the contractor survey. The team analyzed the non-equipment installation costs from the contractor survey to determine how installation costs depend on the system capacity, efficiency, and other variables. The team then combined these findings with the webscraping data to calculate the cost-efficiency relationships for DMSHP systems at different capacities. Each step of this process is described below:

1. **Determine the relationship between retail prices and contractor equipment costs.** Survey respondents provided equipment costs for three efficiency levels, and all the survey respondents

---

[13] The evaluation team understands that the 2016 Plan-Year Report Version of the Massachusetts Technical Reference Manual reports a baseline level of 14 SEER and 8.2 HSPF for the DMSHP system measure (measure #MAE16A2a05ALL). However, the evaluation team could not identify any 14-SEER systems with cooling capacity less than 20 kBtu/h. The least efficient 12 kBtu/h systems on the market today are rated at 15 SEER and 8.2 HSPF, and this is the base case the evaluation team selected for this study.

reported that they install Fujitsu and/or Mitsubishi systems. To determine the relationship between online retail prices and typical contractor prices, the evaluation team compared the survey average equipment costs to the lowest available webscraped cost from Mitsubishi or Fujitsu at the three efficiency levels covered in the survey. The team found that contractors report equipment costs that are, on average, $875 higher than retail prices advertised online. The evaluation team observed that this cost relationship does not trend up or down with either system capacity or efficiency. In other words, contractors will typically charge an equipment cost that is $875 higher than the advertised retail cost of a system, regardless of the system capacity or efficiency.

2. **Analyze the non-equipment installation costs.** The evaluation team analyzed the contractor survey results for the non-equipment installation costs associated with labor, supplies, and other costs. The team concluded the following:
    a. The non-equipment costs are $1,751 for the installation of a single system with one wall-mounted indoor unit and one ground-mounted outdoor unit, at 15 SEER / 8.2 HSPF and 12,000 Btu/h capacity in a siding-clad home. These costs are split into categories of $1,123 for labor, $396 for supplies, and $232 for other costs.
    b. The non-equipment installation costs do not vary significantly with efficiency for DMSHP systems. In other words, for a given capacity, systems rated at 8.2 HSPF, 10 HSPF, and 12 HSPF would all have about the same costs associated with labor, supplies and other costs.
    c. Installations of systems with cooling capacity larger than 18 kBtu/h tend to cost more than systems smaller than 18 kBtu/h.[14] This cost increase is due in part to changes in the line set that connects the indoor and outdoor units of the system. On average, a system above 18 kBtu/h costs $250 more to install than a system below 18 kBtu/h.
    d. The non-equipment installation costs increase with each additional indoor head that is included in the system. This cost increase to go from a single-zone system to a two-zone system is $974, on average. For each additional zone beyond the second zone, the installation cost is slightly less, at $887 per additional head on average.
3. **Calculate the total installed costs.** The evaluation team started with the bin-average retail price cost-efficiency curves described in section 2.5 above. The team added the average contractor markup of $875 to the retail equipment prices, and then added the average installation costs (including labor, supplies and other costs) with adjustments based on capacity and number of zones as described above. The team calculated tables of total installation costs for the most common combinations of efficiency, capacity and number of zones in Massachusetts, as determined based on invoice data.

The three-step process described above yielded the tables of results that are presented in section 3.2 of this report.

2.7 Corroboration with Program Invoices

To corroborate the results of the cost-efficiency curves developed in this study, the evaluation team examined program invoice data provided by the Massachusetts PAs. The team received summary rebate data for 11,295 rebate records submitted during the period 1/1/16-7/31/17. The team selected a sample

---

[14] While the analysis did not look specifically into the costs at 18 kBtu/h, a contractor survey respondent noted that 18 kBtu/h is an important threshold in cost due to changes to the line set.

set of 305 rebate records that cover the representative capacities, efficiencies, and system configurations that are being examined in this cost study. The team segmented the rebate records by geographic region of Massachusetts, which was divided into seven regions: Greater Boston, Metro West, South of Boston, Central MA, North of Boston, Western MA, Cape Cod & Islands. The team refined the sample set to ensure the different geographic regions were well-represented

The evaluation team visually processed the records to remove records that were deemed “not useful,” and to collect DMSHP model information and cost data from the remaining records[15]. The team used the AHRI certification number and the product model number reported in the rebate application attached to each invoice to reference the capacity and efficiency of the DMSHP system from the AHRI Directory of Certified Product Performance. The team categorized the invoice records into bins based on system cooling capacity and number of indoor zones. For each capacity/zone bin that contained a sufficient number of invoice records, the team compared the installed costs reported on program invoices with the installed costs calculated for the cost-efficiency curves.

2.8 Comparison to MassCEC Rebate Records

The Massachusetts Clean Energy Center (MassCEC) operates an Air-Source Heat Pump program that provides customer rebates for installations of qualifying DMSHPs, and MassCEC published a dataset with 11,728 rebate records filed from 2014-2018.[16] These records provide the rebate date, the number of outdoor and indoor units installed, the system manufacturer and model number, and the total system installation costs, as well as other data. The evaluation team cleaned the MassCEC dataset and developed summary statistics that the team then compared with the cost-efficiency curves developed in this RES28 study. The team summarized the methodology and results of this comparison in a memo submitted to the PAs on June 21, 2018. This memo is included in Appendix B of this report.

---

[15] Individual invoice records were deemed “not useful” if the record included non-itemized services beyond the DMSHP installation (such as furnace tune-up or installation of other equipment), if the record included non-itemized installation of multiple unique systems, if the record was a duplicate of another record in the sample set, if the record was illegible or the cost information it contained was ambiguous, or if the record was not part of the sample set submitted in the initial data request.

[16] MassCEC published rebate data for the Air-Source Heat Pump Program in response to a public records request. The dataset is linked from: http://www.masscec.com/contact-masscec/public-records-requests

3. FINDINGS

In this section, the combined results of the analysis are presented and discussed. This includes the following:

- The installation costs of various installation factors, which were determined based on survey data
- The total installed costs as a function of efficiency, which were determined by combining survey and webscraping data
- The team's findings regarding cold climate units, which are based on webscraping data
- A comparison of the calculated cost-efficiency curves with costs reported on program invoices

3.1 Installation Costs of Different DMSHP Configurations

This sub-section describes the total installation costs of a base case installation and the effects that various installation factors have on the total installed cost of a DMSHP system.

3.1.1 Base Case Installation Costs

In this cost study, the base case is defined as a single DMSHP system (with one indoor wall-mounted unit and one outdoor ground-mounted unit), with efficiency ratings of 15 SEER and 8.2 HSPF and capacity of 12,000 Btu/h (1 Ton), installed in a siding-clad single family home. The contractor survey results indicated that, on average, the total installed cost for this system would be $3,875.[17] This cost is divided among the cost categories with 30% labor, 55% equipment, 10% supplies, and 5% other costs.

3.1.2 Retrofit and Replacement

The study considered the costs of installing DMSHP systems in a retrofit scenario (where a DMSHP has not previously been installed) and a replacement scenario. The contractor survey data indicated that the total cost of a retrofit installation is about $75 higher than the total cost of a replacement installation. Retrofit installations tend to have lower labor costs and higher supplies and "other" costs compared to replacement installations. It should be noted, however, that there may be significant variation in costs on a case-by-case basis.

3.1.3 Exterior Wall Types

The study considered four exterior wall types: siding (base case), shingles, wood, and brick. The contractor survey data and the comments provided by contractors indicate that brick construction is associated with the greatest installation costs, when compared to siding, shingles and wood. Some contractors need to hire a third-party to drill the exterior hole for the line set, while others may have the necessary equipment in-house. On average, installations through brick exteriors cost about $260 more than installations through other exterior wall types (with +$200 for labor and +$60 for supplies), but this varies depending on the specifics of the installation site and the contractor's in-house capabilities.

---

[17] Readers should note that the analysis adjusted this base case cost downward to $3,717 for the cost curves reported in Table 9 because the evaluation team identified DMSHP systems at efficiencies above the base case with lower costs than systems at the base case efficiency.

3.1.4 Exterior Unit Locations

This study considered the following outdoor installation types: on the ground (base case), mounted on the wall at the ground floor level, on the roof, and mounted on the wall above the ground floor level. The survey data indicates that ground and first-floor wall installations are the least expensive, only differing by the type of support material used; ground installations may require a pad and a base stand, while wall installations require a bracket. First-floor wall installations are about $70 less expensive than ground installations. Roof installation is the next highest in cost, with an additional cost of approximately $400 when compared to ground installation. The difference is due to the additional labor requirements and the need to hire a roofer. High wall installation (second floor and up) is the most expensive option for locating the outdoor unit, with an additional cost of approximately $1000 compared to ground installation. This is due to increased labor costs and to the potential need to rent a lift so that the contractor can work on the outside of the building.

3.1.5 Indoor Unit Types

This study considered two common indoor installation types: wall-mounted (base case) and ceiling cassette. Contractor survey data indicates that ceiling cassettes are costlier to install than wall-mounted indoor units. This is due to the higher labor cost (+$475, on average) and higher supplies cost (+$75, on average) involved in installing the unit in the ceiling, in addition to the higher equipment cost of ceiling cassettes (+$525, on average) compared to wall-mounted cassettes. Contractors reported lower costs in the “other” cost category (–$25) for ceiling cassette installations. In total, a single-zone DMSHP system with an indoor ceiling cassette unit costs an average $1,050 more than a comparable system with a wall-mounted indoor unit.

3.1.6 Multi-System Installations

This study considered the additional costs of installing more than one DMSHP system in a single job, each composed of an indoor and an outdoor unit. The contractor survey data indicates that when customers install a second DMSHP system in a single job, they save about 15% on the total installed costs of the second system compared to when two installations are performed separately. These savings derive from the reduced labor, supplies and other costs when bundling the installation of the second system into one job.

3.2 The Cost of Efficiency in DMSHPs

This section presents the cost-efficiency curves developed for non-cold-climate DMSHP systems at each of the representative sizes listed in Table 6. The costs presented below represent the total installed cost to the customer, including the costs associated with labor, supplies, equipment and other costs. Based on the results of the contractor survey, the evaluation team concluded that only the equipment costs change with efficiency. For a given system capacity, the labor, supplies and other costs remain constant regardless of the efficiency installed. While the costs presented below represent the total installed cost of the system, it should be noted that the incremental costs between low- and high-efficiency systems are driven entirely by increases in the cost of equipment. Table 7 shows the total installation costs at different cooling efficiency levels measured by the SEER metric. Table 8 shows the total installation costs at different heating efficiency levels measured by the HSPF metric. The evaluation team also identified six combinations of SEER and HSPF ratings that are commonly available in the market. Table 9 shows the total installed cost and Table 10 shows the incremental installed costs for these SEER-HSPF combinations compared to the base case.

Table 7. Total Installed Cost of Non-Cold-Climate DMSHP Systems, by Capacity, Zones, and SEER

Capacity, kBtu/h	Number of Zones	SEER							
		15	16	17	18	20	22	25	28
9 ± 1.5	1	$3,593	$3,593	$3,593	$3,734	$3,793	$3,793	$3,849	-
12 ± 1.5	1	$3,673	$3,673	$3,673	$3,835	$3,835	$3,961	$4,407	$4,407
18	1	$4,191	$4,191	$4,276	$4,448	$4,448	-	-	-
24 ± 3	1	$4,460	$4,460	$4,628	$4,811	$4,811	-	-	-
24 ± 3	2	$6,263	$6,263	$6,679	$6,679	$6,679	$6,949	-	-
24 ± 3	3	$7,434	$7,434	$7,852	$7,852	$7,852	$8,659	-	-
30 ± 3	3	$7,932	$7,932	$7,954	$7,954	$7,954	$8,718	-	-
36 ± 3	4	$8,857	$8,857	$8,857	$8,857	$8,857	$10,252	-	-

Source: Navigant analysis

Table 8. Total Installed Cost of Non-Cold-Climate DMSHP Systems, by Capacity, Zones, and HSPF

Capacity, kBtu/h	Number of Zones	HSPF							
		8.0	8.2	9.0	10.0	11.0	12.0	13.0	14.0
9 ± 1.5	1	$3,643	$3,643	$3,682	$3,860	$3,867	$4,212	-	-
12 ± 1.5	1	$3,717	$3,717	$3,717	$3,957	$4,053	$4,407	$4,407	$4,407
18	1	$4,276	$4,276	$4,355	$4,475	$4,523	$4,956	-	-
24 ± 3	1	$4,586	$4,586	$4,743	$4,743	$4,743	$5,256	-	-
24 ± 3	2	$6,097	$6,097	$6,097	$6,097	$7,055	$7,055	-	-
24 ± 3	3	$7,434	$7,434	$7,459	$7,459	$8,388	$8,388	-	-
30 ± 3	3	$7,962	$7,962	$8,024	$8,024	$8,425	$8,425	-	-
36 ± 3	4	$8,857	$8,857	$8,857	$8,857	$9,827	$9,827	-	-

Source: Navigant analysis

Table 9. Total Installed Cost of Non-Cold-Climate DMSHP Systems at SEER-HSPF Combinations

Capacity, kBtu/h	Number of Zones	15 SEER, 8.2 HSPF Base Case	16 SEER, 8.5 HSPF	17 SEER, 9 HSPF	18 SEER, 10 HSPF Lower Rebate Threshold	20 SEER, 12 HSPF Upper Rebate Threshold	28 SEER, 14 HSPF Above Current Rebates
9 ± 1.5	1	$3,643	$3,662	$3,682	$3,860	$4,212	-
12 ± 1.5	1	$3,717	$3,717	$3,717	$3,957	$4,407	$4,407
18	1	$4,276	$4,316	$4,355	$4,475	$4,956	-
24 ± 3	1	$4,586	$4,665	$4,743	$4,811	$5,256	-
24 ± 3	2	$6,263	$6,263	$6,679	$6,679	-	-
24 ± 3	3	$7,434	$7,446	$7,852	$7,852	-	-
30 ± 3	3	$7,962	$7,993	$8,024	$8,024	-	-
36 ± 3	4	$8,857	$8,857	$8,857	$8,857	-	-

Source: Navigant analysis

Table 10. Incremental Installed Cost of Non-Cold-Climate DMSHP Systems, and Rebate Amounts at Common Combinations of SEER and HSPF

Capacity, kBtu/h	Number of zones	16 SEER, 8.5 HSPF	17 SEER, 9 HSPF	18 SEER, 10 HSPF Lower Rebate Threshold	Lower Rebate Amount	20 SEER, 12 HSPF Upper Rebate Threshold	Upper Rebate Amount	28 SEER, 14 HSPF Above Current Rebates
9 ± 1.5	1	$20	$39	$218	$100	$569	$300	-[*]
12 ± 1.5	1	$0	$0	$239	$100	$689	$300	$689
18[†]	1	$39	$79	$198	$100	$680	$300	-[‡]
24 ± 3	1	$79	$157	$225	$100	$670	$300	-[*]
24 ± 3	2	$0	$416	$416	$200	-[*]	$600	-[*]
24 ± 3	3	$12	$418	$418	$300	-[*]	$900	-[*]
30 ± 3	3	$31	$62	$62	$300	-[*]	$900	-[*]
36 ± 3	4	$0	$0	$0	$400	-[*]	$1,200	-[*]

* There are no regular (non-cold-climate) systems available on the market with this combination of capacity, zones, and efficiency levels.

† The evaluation team estimated the equipment costs for 18 kBtu/h using linear interpolation between the equipment costs at 12 kBtu/h and 24 kBtu/h. Based on contractor survey data, the team assumed that installation costs for 18 kBtu/h systems are the same as for 24 kBtu/h systems.

‡ Since the 18 kBtu/h data was estimated based on data for 12 and 24 kBtu/h systems, it could only be calculated for system configurations that are available at both the 12 and 24 kBtu/h capacities.

Source: Navigant analysis

3.3 Cold Climate DMSHP Systems

This section presents the cost-efficiency curves developed for cold-climate DMSHP systems at each of the representative sizes listed in Table 6. Section 2.3 above describes the requirements for DMSHP systems to qualify as cold-climate systems and the method that the team used to identify systems that meet the ccASHP qualification. Based on contractor survey results, the evaluation team concluded that the installation costs (including labor, supplies, and other costs) for cold-climate DMSHP systems are the same as the installation costs for non-cold-climate DMSHP systems. Any differences between the total installed cost of cold-climate and non-cold-climate DMSHP systems are entirely due to differences in the cost of equipment. Table 11 shows the total installed cost for rebate-eligible cold-climate systems.

Table 11. Total Installed Cost of Cold-Climate DMSHP Systems, and Rebate Amounts at Common Combinations of SEER and HSPF

Capacity, kBtu/h	Number of zones	18 SEER, 10 HSPF	20 SEER, 12 HSPF	28 SEER, 14 HSPF
		Lower Rebate Threshold	Upper Rebate Threshold	Above Current Rebate Levels
9 ± 1.5	1	$3,993	$4,035	$4,419
12 ± 1.5	1	$4,058	$4,199	$4,515
18†	1	$4,646	$4,812	-‡
24 ± 3	1	$5,016	$5,176	-*
24 ± 3	2	$7,060	-*	-*
24 ± 3	3	8,202	-*	-*
30 ± 3	3	$9,049	-*	-*
36 ± 3	4	$10,438	-*	-*

* There are no cold-climate systems available on the market with this combination of capacity, zones, and efficiency levels.

† The evaluation team estimated the equipment costs for 18 kBtu/h using linear interpolation between the equipment costs at 12 kBtu/h and 24 kBtu/h. Based on contractor survey data, the team assumed that installation costs for 18 kBtu/h systems are the same as for 24 kBtu/h systems.

‡ Since the 18 kBtu/h data was estimated based on data for 12 and 24 kBtu/h systems, it could only be calculated for system configurations that are available at both the 12 and 24 kBtu/h capacities.

Source: Navigant analysis

At the lower rebate threshold of 18 SEER and 10 HSPF, the total installed cost of cold-climate systems is consistently higher than the installed cost of regular non-cold-climate systems. This is because at lower efficiency levels, cold climate systems often include components that are not present in non-cold-climate systems. Using Mitsubishi's product line as an example, Mitsubishi's 18-SEER cold-climate model (MUZ-FH12) has a defrost heater while Mitsubishi's regular non-cold climate model (Model MUZ-HM12) does not.

However, at the upper rebate threshold of 20 SEER and 12 HSPF, the total installed cost of cold-climate systems is consistently *lower* than the installed cost of regular non-cold-climate systems. At higher efficiency levels, cold-climate models do not typically include extra componentry. Continuing with the Mitsubishi example at 20 SEER, defrost heaters are included both in Mitsubishi's cold-climate model (MUZ-GL12) and in its regular model (MUFZ-KJ12). Another design difference between regular and cold-climate models at high efficiencies is that cold-climate systems typically use an undersized (less costly) compressor that is then over-speeded, compared to regular units that use a larger (costlier) compressor. For instance, at 20 SEER, Mitsubishi's cold-climate model at 12 kBtu/h uses a smaller 9 kBtu/h compressor, while their regular non-cold-climate model at 12 kBtu/h uses a larger 14 kBtu/h compressor.

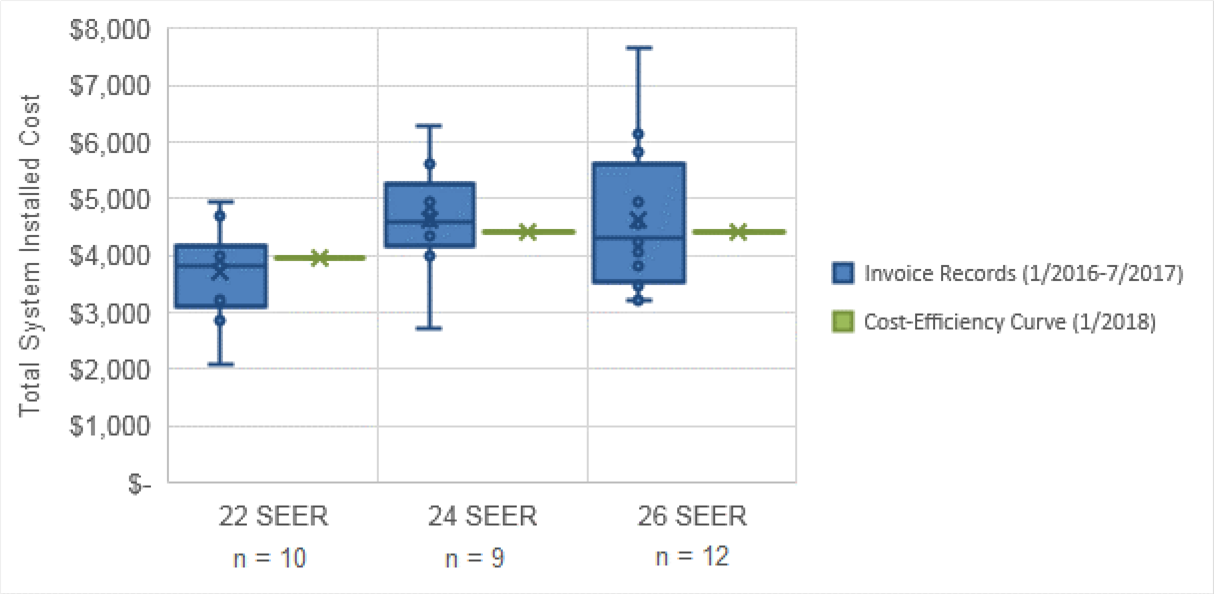
3.4 Comparison to Program Invoice Data

As described in section 2.7, the evaluation team retrieved a sample set of scanned invoices to compare the calculated cost-efficiency curves with actual cost data reported by program participants. The team removed records that were not useful from this sample set of invoice records,[18] and sorted the remaining records into bins based on the installed system's cooling capacity and number of zones.

Three of these capacity/zone bins contained more than 10 invoice records. These were the bin of 1-zone 12 kBtu/h systems, the bin of 2-zone 24 kBtu/h systems, and the bin of 3-zone 24 kBtu/h systems. In each of these bins, the team removed outlier records where the total installation cost for the record deviated markedly from other records at the same capacity and efficiency. The team then plotted the total installed cost of systems invoiced in each bin and compared the set of invoice costs at each efficiency level with the cost curves constructed in this study. Figure 5, Figure 6, and Figure 7 present box-and-whiskers plots of the total system installed costs reported on invoices at different SEER efficiency levels in these three bins. For comparison, these plots also show points from the calculated cost-efficiency curves that correspond to the SEER efficiency levels in these bins.

For the 1-zone 12 kBtu/h bin presented in Figure 5, the sample set of usable invoices did not include invoices for DMSHP systems below 22 SEER. For the efficiency levels reported in the program invoice data (22, 24, and 26 SEER), the calculated cost-efficiency curve tracks closely with the median of the total installed costs reported in the sample of program invoices.

Figure 5. Program Invoice and Cost Efficiency Curve Data for 1-Zone DMSHP Systems at 12 kBtu/h



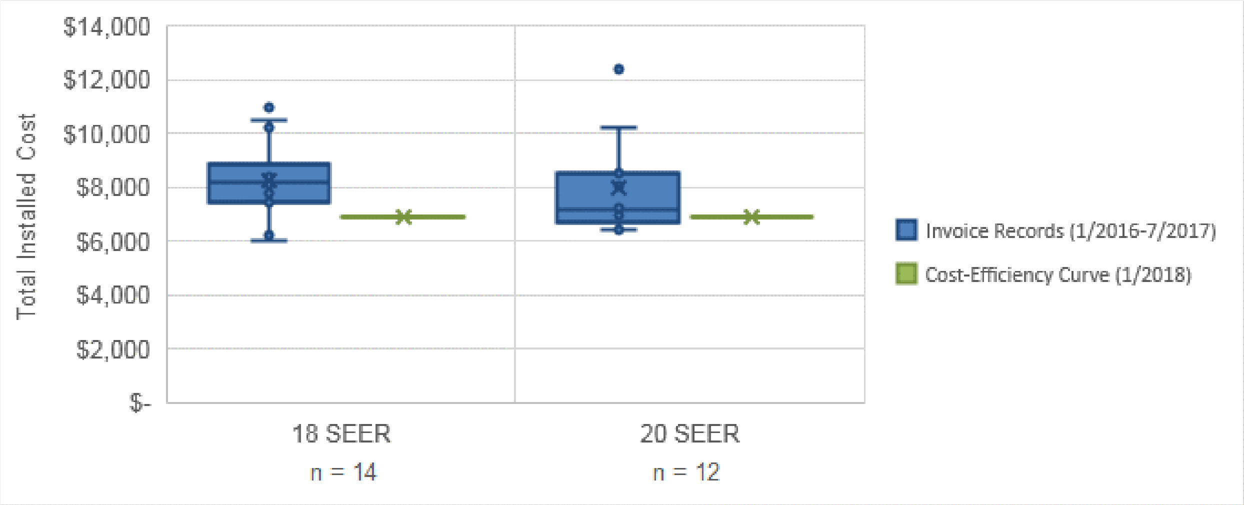
Source: Navigant analysis of scanned invoice records provided by the Massachusetts PAs

---

[18] Invoice records were deemed "not useful" if they included non-itemized services beyond the DMSHP installation (such as furnace tune-up or installation of other equipment), if they included the non-itemized installation of multiple unique systems, if the record was a duplicate of another record in the sample set (possibly because the rebate application was submitted more than one time), if the record was illegible or the cost information it contained was ambiguous, or if the record was not part of the sample set submitted in the initial data request.

For the 2-zone 24 kBtu/h bin presented in Figure 6, the sample set of usable invoices included invoices for DMSHP systems at 18 SEER and 20 SEER. At these efficiency levels, the calculated cost-efficiency curve falls within the range of total installed costs reported in the program invoice data, but below the median cost for the invoices in this bin.

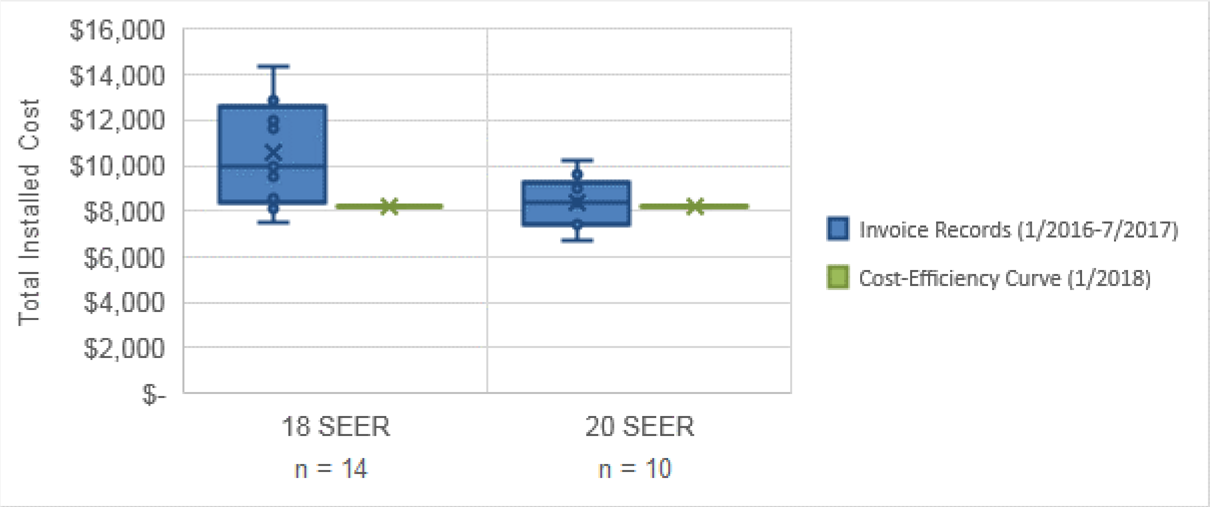
Figure 6. Program Invoice and Cost Efficiency Curve Data for 2-Zone DMSHP Systems at 24 kBtu/h



Source: Navigant analysis of scanned invoice records provided by the Massachusetts PAs

For the 3-zone 24 kBtu/h bin presented in Figure 7, the sample set of usable invoices included invoices for DMSHP systems at 18 SEER and 20 SEER. At these efficiency levels, the calculated cost-efficiency curve falls within the range of total installed costs reported in the program invoice data, but below the median cost for the invoices in this bin.

Figure 7. Program Invoice and Cost Efficiency Curve Data for 3-Zone DMSHP Systems at 24 kBtu/h



Source: Navigant analysis of scanned invoice records provided by the Massachusetts PAs

To understand why the cost curves calculated in this study estimated prices for 24 kBtu/h classes that were below the median price from the invoice records, the evaluation team identified the specific DMSHP models that were referenced in the individual invoices. The team found that all of the invoice records plotted in Figure 6 and Figure 7 represent just two DMSHP system models. The records plotted in the 18 SEER bins represent Mitsubishi model MXZ3C24NAHZ2 and the records plotted in the 20 SEER bins represent Fujitsu model AOU24RLXFZH. In contrast, the cost efficiency curves in this study are based on an average of all the systems available at each efficiency level, from brands that offer at least a 5-year warranty. The cost efficiency curves include major brands that often have lower retail system prices compared to Mitsubishi and Fujitsu, such as Daikin, Friedrich, GREE, and LG.

Another source of cost discrepancy is the related to the timing of the invoices and the contractor survey. The invoices reviewed in this task are from installations conducted between 1/1/2016 and 7/31/2017, while the contractor survey concluded on 1/29/2018. It is possible that installation costs decreased somewhet in the period between the sampled invoices and the contractor survey.

Although the cost-efficiency curves fall below the median invoice prices for 2- and 3-zone 24 kBtu/h systems, Figure 6 and Figure 7 show that the curves provide cost estimates that are within the range of costs that customers in Massachusetts may expect to pay for installations of DMSHP systems. As described in section 2.7, the evaluation team selected a sample set of program invoices that is geographically diverse, representing all the PA service areas. However, after the team removed records that were not useful, the sample set did not contain a sufficient number of invoices for the team to draw conclusions regarding how total installed costs may vary by geographic region.

The team notes that many of the invoices reported the total installed cost, but did not provide information regarding the different cost categories of equipment, labor, supplies, and other costs. This makes it difficult to use the invoices to analyze how different cost categories contribute to the total installed cost. The team believes that future cost studies would benefit if the Residential Heating and Cooling Program were to require that contractor invoices submitted with rebate forms include itemized costs.

3.5 Comparison to MassCEC Program Data

As described in section 2.8, the evaluation team compared MassCEC rebate data for DMSHP installations with the cost-efficiency results developed in this RES28 study. The team summarized the results of this comparison in a memo submitted to the PAs on June 21, 2018 (see Appendix B of this report). The results of this comparison were mixed, as illustrated in Table 13 in Appendix B. Notably, the MassCEC and RES28 are within 5% of each other at a key program level of 20 SEER/12 HSPF. Compared to the cost-efficiency curves presented above, the MassCEC data showed lower costs for small-capacity, very-high-efficiency systems and showed higher costs for large-capacity systems. However, the evaluation team could not readily rationalize these cost disparities, and the team chose not to adapt the results of this study to reflect the findings of our MassCEC data analysis. Nonetheless, there are possible yet unverifiable explanations for these cost disparities: (1) the MassCEC rebate costs may include other equipment and ancillary costs that are not reflected in the RES28 costs; and (2) the MassCEC rebate costs appear to reflect the more expensive systems offered by premium DMSHP manufacturers. To reconcile and further update the costs for DMSHP systems, the PAs could consider conducting a more comprehensive investigation of the MassCEC rebate data in 2020.

4. CONCLUSIONS AND CONSIDERATIONS

One main finding of this study is that the installation costs for DMSHP systems do not vary with efficiency, and that the cost changes with increasing efficiency are due entirely to changes in the cost of equipment. Table 3 in the Executive Summary illustrates how the incremental installed costs for regular and cold-climate systems compare to the current rebate amounts for systems with different sizes and number of zones. At smaller system capacities of 24 kBtu/h and less, the incremental cost of high-efficiency systems exceeds the rebate amounts offered for those systems. However, at larger system capacities of 30 and 36 kBtu/h, the rebate amount exceeds the incremental cost of efficiency for regular (non-cold-climate) systems.

There are three strategies the Program Administrators (PAs) could pursue to improve the cost effectiveness of the DMSHP rebate offerings.

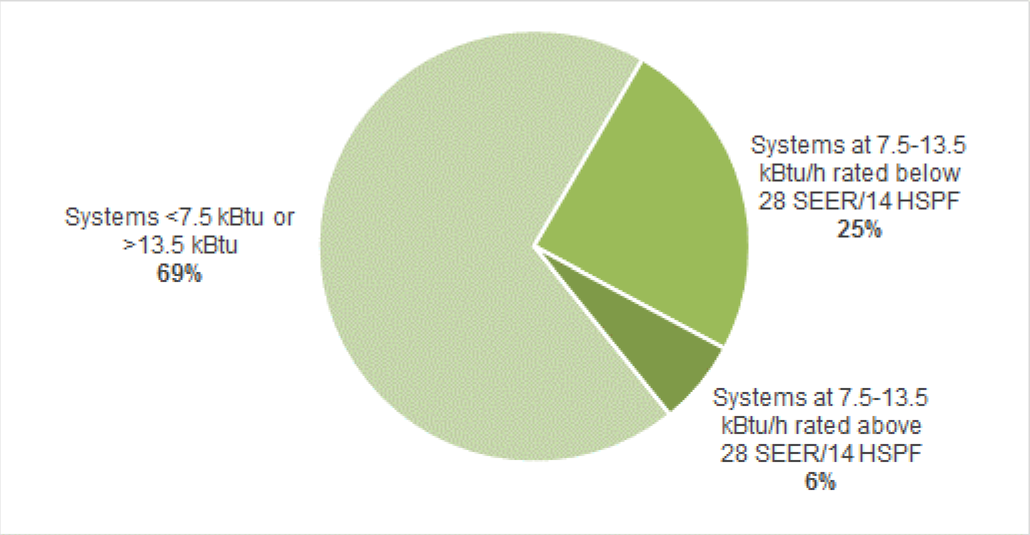
- **Consideration 1:** To motivate the adoption of smaller capacity systems at very high-efficiencies, the PAs should consider adding a premium rebate level at 28 SEER and 14 HSPF.
- **Finding 1:** About 25% of the DMSHP rebate records in the period January 1, 2016 through July 31, 2017 were for systems within the capacity range of 9.5-13.5 kBtu/h rated below 28 SEER and 14 HSPF. There are systems in this capacity range on the market that are rated at or above 28 SEER and 14 HSPF, and these systems present a savings opportunity.
- **Consideration 2:** At larger capacities (>30 kBtu/h) the current rebate structure incentivizes the installation of non-cold-climate systems that have little or no incremental cost above the base case. Cold-climate systems should provide additional savings at all capacity levels for a small additional cost, so the PAs should consider limiting the rebate eligibility for DMSHP systems to systems that are cold-climate qualified. This limitation may be implemented by requiring ccASHP qualification or by providing specific efficiency requirements at low outdoor temperatures.
- **Finding 2:** At larger DMSHP system capacities, such as sizes of 30 kBtu/h + 3 zones and 36 kBtu/h + 4 zones, there are little or no incremental cost to increase from the base case of 15 SEER / 8.2 HSPF to a regular (non-cold-climate) system at the lower rebate threshold of 18 SEER / 10 HSPF. On the other hand, at these sizes there are significant incremental costs for qualified *cold-climate* systems at the lower rebate threshold of 18 SEER / 10 HSPF.
- **Consideration 3**: Since ducted DMSHP systems may comprise an increasing portion of DMSHP rebate claims, the PAs should consider an add-on task to evaluate how equipment and installation costs of ducted systems compare to the non-ducted systems examined in the current study.
- **Finding 3:** The majority of DMSHP systems rebated in 2016-2017 used wall-mounted indoor units. As such, wall-mounted units were the focus of this cost study. However, midway through this study, the evaluation team received anecdotal evidence that an increasing proportion of DMSHP installations in Massachusetts are using ducted indoor units. The evaluation team expects that ducted indoor units may offer comparable savings to non-ducted indoor units, but that they will incur greater installation costs due to the increased equipment costs and the added task of installing ductwork.

The following sections describe these options in more detail.

4.1 Premium Rebate Levels at 28 SEER and 14 HSPF

During the period January 1, 2016 through July 31, 2017, about 11,300 rebates were filed for DMSHP systems, and about 25% of those rebates covered DMSHP systems with capacity between 9.5-13.5 kBtu/h and efficiency ratings lower than 28 SEER and 14 HSPF. Figure 8 illustrates the proportions of DMSHP rebates in this period that have capacity 7.5-13.5 kBtu/h and are rated above or below 28 SEER and 14 HSPF. Table 12 lists five unique DMSHP systems from four manufacturers that have efficiency ratings of SEER ≥ 28 and HSPF ≥ 14. These findings show there is an opportunity to incentivize the adoption of very-high-efficiency DMSHP systems at low capacity.

Figure 8. DMSHP Rebates from January 2016 to July 2017 Included a High Proportion of Low-Capacity Systems Rated below 28 SEER and 14 HSPF



Source: Navigant analysis of program rebate records provided by the Massachusetts PAs

Table 12. Very-High-Efficiency DMSHP Systems Available on the Market

Manufacturer	Outdoor Unit Model Number	Cooling Capacity (Btu/h)	SEER Rating (Btu/W.h)	HSPF Rating (Btu/W.h)	Cold Climate Qualified
Fujitsu	AOU12RLS3	12000	29.3	14	Y
Fujitsu	AOU9RLS3	9000	33	14.2	Y
Panasonic	CU-XE9SKUA	8700	30.6	14	Y
Rheem	ROSH12AHWJ	12000	29.3	14	N
Gree	SAP12HP230V1AO	12000	30.5	14	N

Source: Navigant webscrape of DMSHP systems

4.2 Cold-Climate Systems at High Capacities

This study estimated the total and incremental installed costs for regular and cold-climate DMSHP systems at different capacities and efficiencies, and compared the incremental installed costs to the Residential Heating and Cooling Program’s current rebate offerings for DMSHP systems. The study found that, for a DMSHP system at 36 kBtu/h with 4 zones, there is no incremental cost to improve from the base case of 15 SEER / 8.2 HSPF to a regular (non-cold-climate) system at the lower rebate threshold of 18 SEER / 10 HSPF. In other words, there are 4-zone 36 kBtu/h systems available at or above the lower rebate threshold that are less expensive than a baseline system at 15 SEER / 8.2 HSPF. The evaluation team investigated this phenomenon and concluded that it is the result of the selection and pricing of systems that are available on the market. At present, retailers are selling several 36-kBtu/h systems at 18 SEER / 10 HSPF at prices that are competitive with 15 SEER / 8.2 HSPF systems. If there is no incremental cost to install a high-efficiency system, then program incentives may be redesigned to motivate savings elsewhere.

For 4-zone 36 kBtu/h systems that *are* cold-climate qualified, there are significant incremental costs at the lower rebate threshold of 18 SEER / 10 HSPF. Cold-climate systems can provide significant savings in the Massachusetts climate, since they maintain a high COP efficiency even at low ambient temperatures. The comparison of incremental costs and rebate amounts in Table 3 (page v) of this report suggests that it may be more cost-effective for the program to limit rebates to DMSHP systems that are cold-climate qualified. The PAs should consider requiring cold climate qualification at all DMSHP capacity levels rather than requiring qualification at a subset of available capacities, to make the program simple for customers to understand. This may be done by requiring that systems meet NEEP’s ccASHP qualification or by providing specific efficiency requirements at low outdoor temperatures.

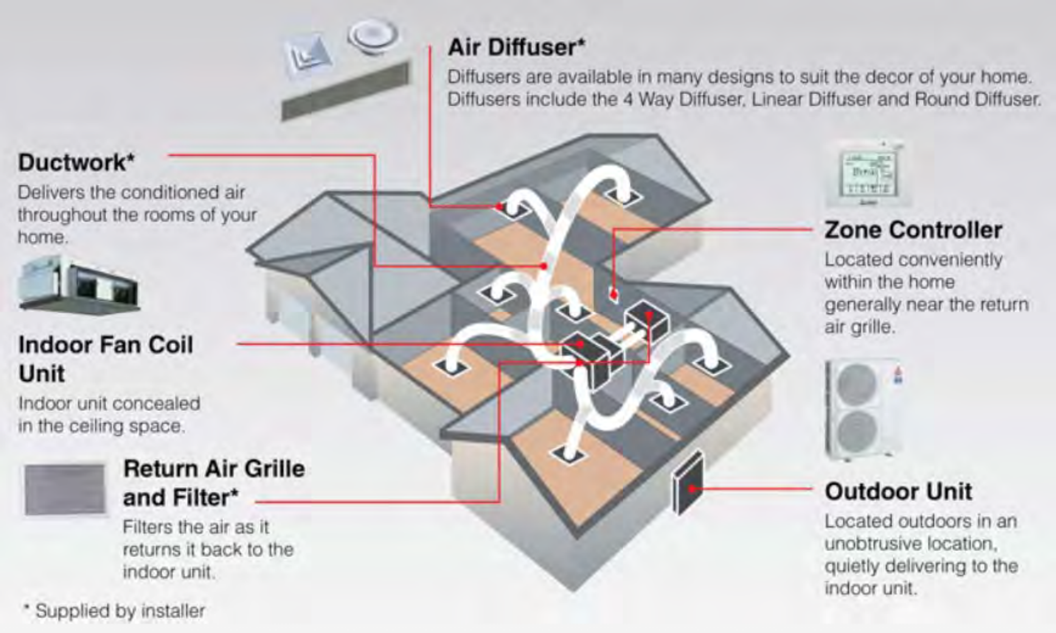
4.3 DMSHP Systems with Ducted Indoor Units

The PAs received anecdotal evidence that an increasing proportion of DMSHP installations in Massachusetts are using ducted indoor units. The evaluation team’s preliminary research on ducted indoor units yielded the following findings:

- In contrast to the ductless wall-mounted indoor units, ducted systems are located outside of the conditioned space, and they typically deliver conditioned air to more than one room of a building.
- Some DMSHP installations use a single ducted air handler to serve an entire home, as illustrated in Figure 9. These installations may take advantage of the DMSHP’s variable-speed capabilities with controllers that can control individual zones using supply dampers.
- Some DMSHP installations combine different indoor unit types with a single outdoor compressor, as illustrated in Figure 10. These installations may use non-ducted wall-mount or ceiling cassette units to serve larger living spaces, and use a single ducted unit to serve several smaller spaces (such as a bathroom and/or small bedrooms). In an installation with mixed indoor units, each zone may have an individual thermostat control.
- Ducted systems may have higher installation costs than non-ducted wall-mount systems, since equipment costs are typically higher for ducted units and there is a tradeoff between the cost of installing multiple through-wall refrigerant lines versus installing ductwork in attics or crawlspaces that may be difficult to access.

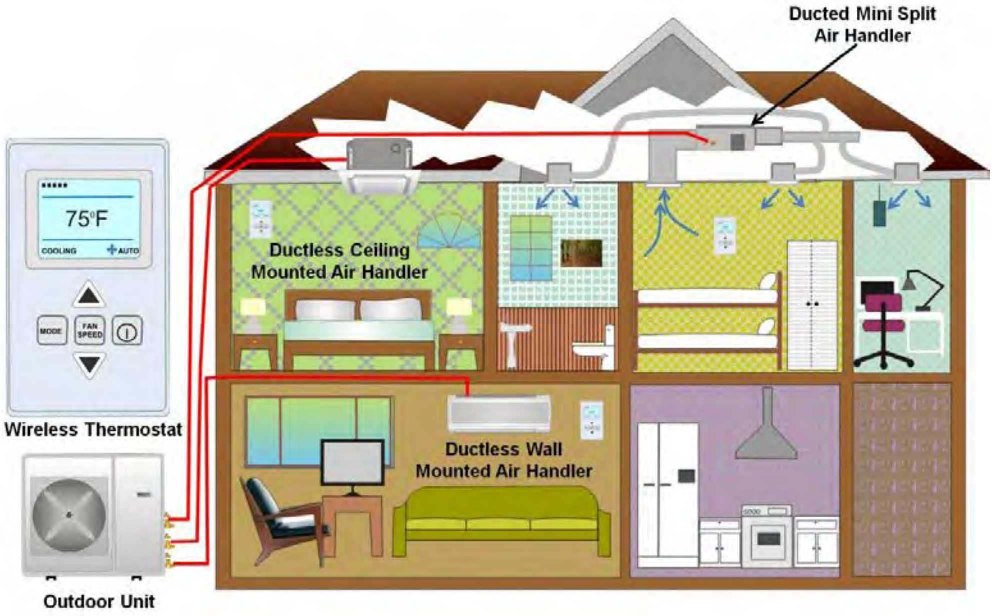
The PAs should consider completing a follow up study to assess the total installed costs associated with DMSHP systems that contain ducted indoor units. This study could also evaluate the cost of control options for multi-zone ducted indoor units and assess how multi-zone ducted indoor units are differentiated from conventional split system central heat pumps.

Figure 9. Schematic of Variable-Speed Mini-Split Heat Pump Supplying Whole-Home Conditioning with one Ducted Indoor Unit



Source: Mitsubishi Electric[19]

Figure 10. Schematic of Variable-Speed Mini-Split Heat Pump Supplying Whole-Home Conditioning with a Mix of Ducted and Non-Ducted Indoor Unit Types



Source: U.S. Department of Energy[20]

---

[19] Mitsubishi Electric (2018). “Ducted Air Conditioning.” Available at: http://www.mitsubishielectric.com.au/ducted-air-conditioning.html

[20] U.S. Dept. of Energy, Building America Solution Center (2015). “Mini-Split (Ductless) Heat Pumps.” Available at: https://basc.pnnl.gov/resource-guides/mini-split-ductless-heat-pumps#quicktabs-guides=1

APPENDIX A. CONTRACTOR SURVEY

This appendix contains a hard copy of the web-based cost survey that was delivered to a sample of HVAC contractors in Massachusetts between December 2017 and January 2018.

1. What is your name?
2. To which address should we send your gift card (provided you complete this survey)?
3. What is the best phone number to reach you at for a follow up interview (if necessary)?
4. What company do you work for?
5. Where is your company headquartered?

☐ Greater Boston
☐ Metro West
☐ North of Boston
☐ South of Boston
☐ Central MA
☐ Western MA
☐ Cape Cod & Islands
☐ Other._____________.

6. In which regions do you operate?

☐ Greater Boston
☐ Metro West
☐ North of Boston
☐ South of Boston
☐ Central MA
☐ Western MA
☐ Cape Cod & Islands
☐ Other._____________.

7. Approximately how many DMSHP installations do you do annually?
8. Do you primarily install DMSHPs for heating only, for cooling only, or for both heating and cooling?

☐ Primarily Heating
☐ Primarily Cooling
☐ Both Heating and Cooling

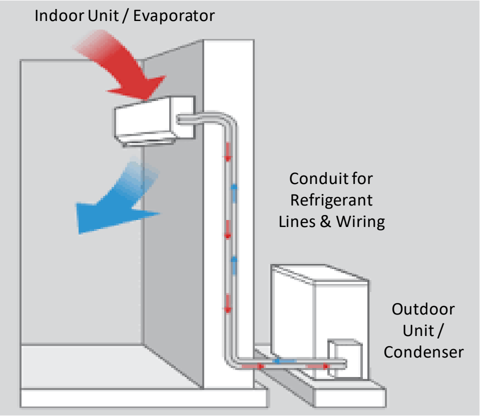
9. Which brands of DMSHPs do you typically install?

☐ Bryant
☐ Daikin
☐ Fujitsu
☐ Gree
☐ Hisense
☐ Lennox
☐ LG
☐ Midea / MDV
☐ Mitsubishi
☐ Panasonic
☐ Samsung
☐ Toshiba
☐ Trane
☐ Other(s). Please list brand name(s) ______________________________

Installation Scenarios

For the following residential installation scenarios, please provide an estimate for the labor, equipment, and other costs. The following prompts ask about the total costs for each installation described and not the incremental price differentials between different models.

Installation Scenario A: System with 1 Outdoor Unit and 1 Indoor Unit



Installation of a single system (1 air handler/indoor unit and 1 condenser/outdoor unit); 15 SEER / 8.2 HSPF (or lowest available efficiency), 12,000 Btu/h (1 Ton), ground-mounted in a single family home with aluminum, vinyl, or steel siding

10. How much would you charge for the installation scenario described above if it is a new installation where a DMSHP has not been installed previously?

New Installation

Labor costs, burdened ($) Equipment costs (indoor & outdoor units), including markup ($) Supplies costs (mounting supplies, additional lines, tools, etc.) Other costs (travel, warranty, insurance, etc.)	______ ______ ______ ______
Total	*Calculated*

Comments/Additional notes

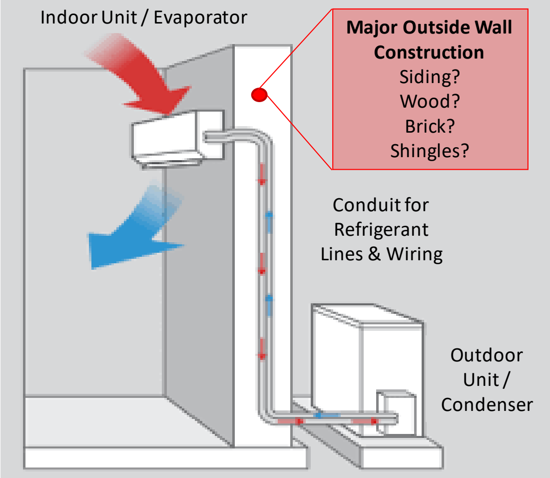
11. How much would you charge if the installation described previously involves the replacement of an existing ductless mini-split system, (including evacuation of refrigerant, disassembly, and disposal of the old system)?

Replacement Installation

Labor costs, burdened ($) Equipment costs (indoor & outdoor units), including markup ($) Supplies costs (mounting supplies, additional lines, tools, etc.) Other costs (travel, warranty, insurance, etc.)	______ ______ ______ ______
Total	Calculated

Comments/Additional notes

12. How much would you charge for the same Installation Scenario A, but in a home with **different exterior wall types**? Your previous responses for a vinyl-siding home are provided for reference.

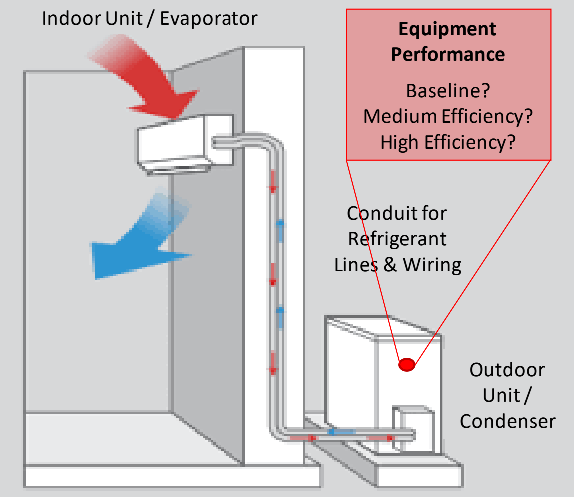


Installation of a single unit (1 air handler/indoor unit and 1 condenser/outdoor unit); 15 SEER / 8.2 HSPF (or lowest available efficiency), 12,000 Btu/h (1 Ton), ground-mounted in a single family home with the following wall types:

	Siding (aluminum, vinyl, or steel) [ANSWERS POPULATED FROM Q-10]	**Wood Exterior Wall**	**Brick**	**Shingles (composition)**
Labor costs, burdened ($)				
Equipment costs (indoor & outdoor units), including markup ($)				
Supplies costs (mounting supplies, additional lines, tools, etc.)				
Other costs (travel, warranty, insurance, etc.)				
Total	*Calculated*	*Calculated*	*Calculated*	*Calculated*

Comments/Additional notes

13. How much would you charge for the same Installation Scenario A, but with **equipment of different efficiency levels**? Your previous responses for a 15-SEER unit are provided for reference.

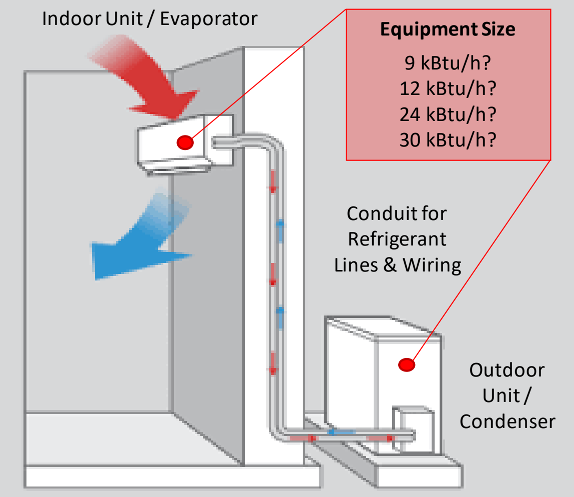


Installation of a single unit (1 air handler/indoor unit and 1 condenser/outdoor unit); 12,000 Btu/h (1 Ton), ground-mounted in a single family home with aluminum, vinyl, or steel siding and an efficiency of:

	Lowest Available Efficiency (e.g., 15 SEER, 8.2 HSPF) [ANSWERS POPULATED FROM Q-10]	**Medium Efficiency (≥18 SEER, ≥10 HSPF)**	**High Efficiency (≥20 SEER, ≥12 HSPF)**
Labor costs, burdened ($)	____________	____________	____________
Equipment costs (indoor & outdoor units), including markup ($)	____________	____________	____________
Supplies costs (mounting supplies, additional lines, tools, etc.)	____________	____________	____________
Other costs (travel, warranty, insurance, etc.)	____________	____________	____________
Total	*Calculated*	*Calculated*	*Calculated*

Comments/Additional notes

14. How much would you charge for the same Installation Scenario A, but with **different equipment sizes**? Your previous responses for a 12,000 Btu/h system are provided for reference.

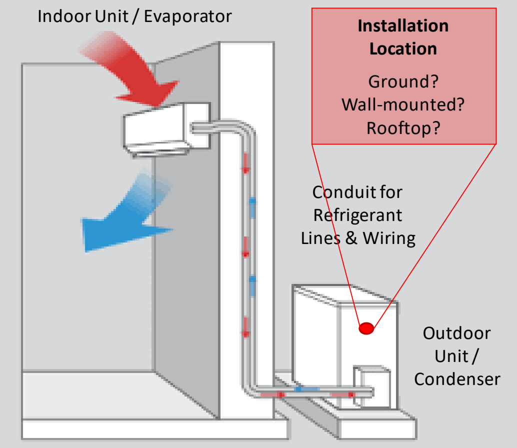


Insta**llation of a single unit (1 air handler/indoor unit and 1 condenser/outdoor unit); 15 SEER / 8.2 HSPF (or lowest available efficiency), ground-mounted in a single family home with vinyl siding and the following sizes:**

	9,000 Btu/h (0.75 Ton)	**12,000 Btu/h (1.0 Ton) [ANSWERS POPULATED FROM Q-10]**	**24,000 Btu/h (2.0 Ton)**	**30,000 Btu/h (2.5 Ton)**
Labor costs, burdened ($)	____________	____________	____________	____________
Equipment costs (indoor & outdoor units), including markup ($)	____________	____________	____________	____________
Supplies costs (mounting supplies, additional lines, tools, etc.)	____________	____________	____________	____________
Other costs (travel, warranty, insurance, etc.)	____________	____________	____________	____________
Total	*Calculated*	*Calculated*	*Calculated*	*Calculated*

Comments/Additional notes

15. How much would you charge for the same Installation Scenario A, but with **different installation locations**? Your previous responses for a ground installation are provided for reference.



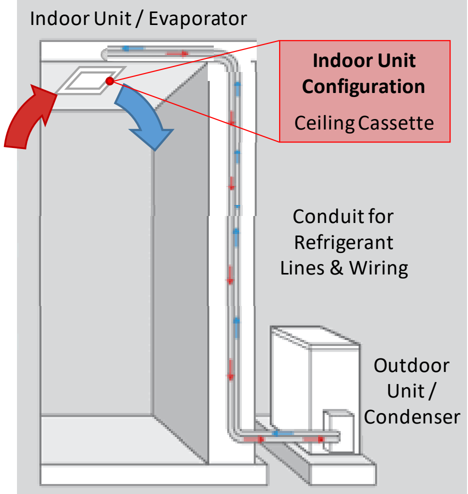
Installation of a single unit (1 air handler/indoor unit and 1 condenser/outdoor unit); 15 SEER / 8.2 HSPF (or lowest available efficiency), 12,000 Btu/h (1 Ton), in a single family home with siding in the following configurations:

			
Ground Installation	**Ground-Floor Wall Mounted**	**Roof Installation**	**Non-ground-floor Wall Mounted (e.g. wall of a 2nd-floor apartment)**

	Ground Installation [ANSWERS POPULATED FROM Q-10]	**Ground-Floor Wall Mounted**	**Roof Installation**	**Non-ground-floor Wall Mounted (e.g. outer wall of a 2nd-floor apartment)**
Labor costs, burdened ($)	________	________	________	________
Equipment costs (indoor & outdoor units), including markup ($)	________	________	________	________
Supplies costs (mounting supplies, additional lines, tools, etc.)	________	________	________	________
Other costs (travel, warranty, insurance, etc.)	________	________	________	________
Total	*Calculated*	*Calculated*	*Calculated*	*Calculated*

Comments/Additional notes

16. How much would you charge for the same Installation Scenario A, but with a **different indoor unit configuration**? Your previous responses for a wall-mounted indoor unit are provided for reference.



Installation of a single unit (1 air handler/indoor unit and 1 condenser/outdoor unit); 15 SEER / 8.2 HSPF (or lowest available efficiency), 12,000 Btu/h (1 Ton), ground-mounted in a single family home with the following indoor unit types:

Wall-Mounted Indoor Unit [ANSWERS POPULATED FROM Q-10]

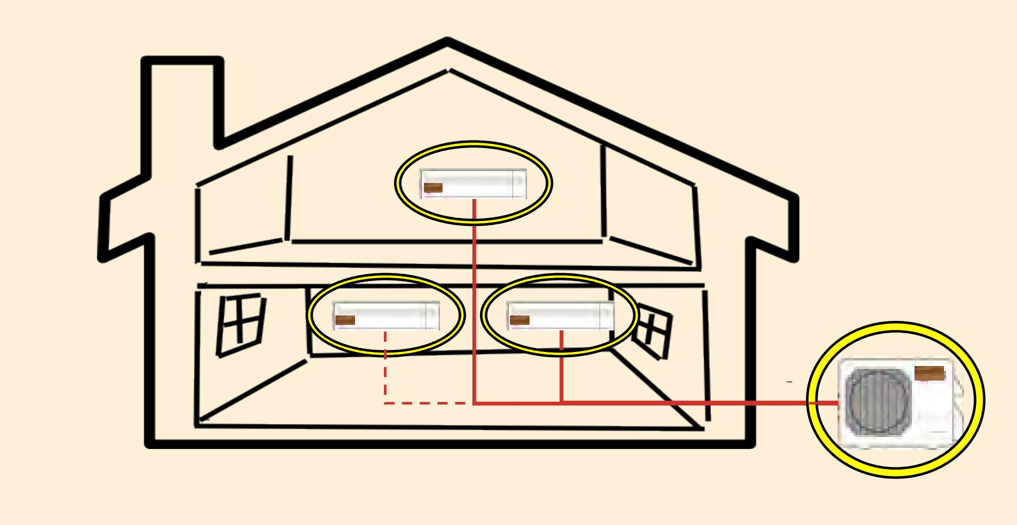
Labor costs, burdened ($) Equipment costs (indoor & outdoor units), including markup ($) Supplies costs (mounting supplies, additional lines, tools, etc.) Other costs (travel, warranty, insurance, etc.)	______ ______ ______ ______
Total	*Calculated*

Ceiling Cassette Indoor Unit

Labor costs, burdened ($) Equipment costs (indoor & outdoor units), including markup ($) Supplies costs (mounting supplies, additional lines, tools, etc.) Other costs (travel, warranty, insurance, etc.)	______ ______ ______ ______
Total	*Calculated*

Installation Scenario B: System with 1 Outdoor Unit and Multiple Indoor Units

How much would you charge for Installation Scenario B, which has one outdoor condenser unit and more than one indoor evaporator?



Installation of a multi-head unit (Multiple air handlers/indoor units and 1 condenser/outdoor unit);
15 SEER / 8.2 HSPF (or lowest available efficiency), ground-mounted in a single family home with vinyl siding

17. How much would you charge for the installation above?

Single 24,000 Btu/h (2.0 Ton) outdoor unit and 2 indoor units

Labor costs, burdened ($) Equipment costs (indoor & outdoor units), including markup ($) Supplies costs (mounting supplies, additional lines, tools, etc.) Other costs (travel, warranty, insurance, etc.)	____ ____ ____ ____
Total	*Calculated*

Single 36,000 Btu/h (3.0 Ton) outdoor unit and 3 indoor units

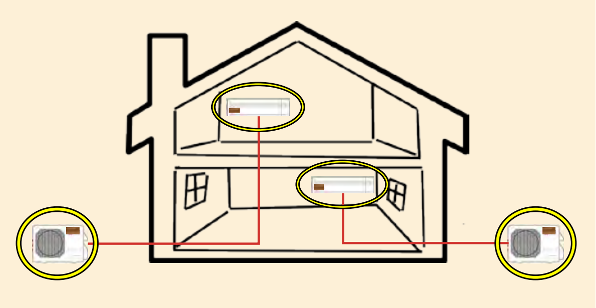
Labor costs, burdened ($) Equipment costs (indoor & outdoor units), including markup ($) Supplies costs (mounting supplies, additional lines, tools, etc.) Other costs (travel, warranty, insurance, etc.)	____ ____ ____ ____
Total	*Calculated*

Single 42,000 Btu/h (3.5 Ton) outdoor unit and 4 indoor units

Labor costs, burdened ($) Equipment costs (indoor & outdoor units), including markup ($) Supplies costs (mounting supplies, additional lines, tools, etc.) Other costs (travel, warranty, insurance, etc.)	____ ____ ____ ____
Total	*Calculated*

Installation Scenario C: Two systems with 1 outdoor and 1 indoor unit each

How much would you charge for Installation Scenario C, which has two separate ductless mini-split systems, and each system has one outdoor condenser unit and more than one indoor evaporator? Your previous responses for the installation of a single system are provided for reference.



Installation of 2 systems (2 air handlers/indoor units and 2 condensers/outdoor units); 12,000 Btu/h (1 Ton) per system, 15 SEER / 8.2 HSPF (or lowest available efficiency), ground-mounted in a single family home with vinyl siding

1 outdoor unit, 1 indoor unit (1.0 Ton) [ANSWERS POPULATED FROM Q-10]

Labor costs, burdened ($) Equipment costs (indoor & outdoor units), including markup ($) Supplies costs (mounting supplies, additional lines, tools, etc.) Other costs (travel, warranty, insurance, etc.)	________ ________ ________ ________
Total	*Calculated*

18. How much would you charge for the installation above?

2 outdoor units, 2 indoor units

Labor costs, burdened ($) Equipment costs (indoor & outdoor units), including markup ($) Supplies costs (mounting supplies, additional lines, tools, etc.) Other costs (travel, warranty, insurance, etc.)	________ ________ ________ ________
Total	*Calculated*

19. Are there any additional factors that contribute to your pricing that we did not consider?

Additional Factors

20. Were there any issues with data you entered in the survey?

Data Issues

21. Do you have any suggestions to improve the Mass Save® rebate program for ductless mini-split heat pump systems?

Suggestions

APPENDIX B. COMPARISON TO MassCEC PROGRAM RECORDS

This appendix contains a memo submitted to the PAs and EEAC on June 21, 2018 that describes an analysis the evaluation team conducted to compare the cost-efficiency results of the RES28 study with rebate record data published by the Massachusetts Clean Energy Center (MassCEC). This analysis is provided for informational purposes. The team did not use the results of the MassCEC analysis to adjust the cost results of the RES28 study.

To: Massachusetts Program Administrators and Energy Efficiency Advisory Council

From: Decker Ringo; Navigant Consulting Inc.

Date: June 21, 2018

Re: Comparison of RES28 study results to MassCEC Air-Source Heat Pump Program Records

The Ductless Mini-Split Heat Pump Cost Study (RES 28) estimated the energy-efficiency related total and incremental costs of single family home installations of DMSHP systems currently rebated through the Residential Heating and Cooling program. The study used three primary sources of data to compile these estimates: (1) a contractor survey, (2) webscraping of retail prices, and (3) a sample of invoices submitted with rebate applications to the MassSave program in 2016-2017. The study's final report (submitted on 4/2/2018) presented estimates of the total installed cost of different system sizes and configurations for DMSHP systems at common combinations of SEER and HSPF.

In an email message on May 10, 2018, Chris Chan asked the evaluation team to compare the cost results of the RES28 study to rebate record data published by the Massachusetts Clean Energy Center (MassCEC). MassCEC operates an Air-Source Heat Pump program that provides rebates for installations of qualifying DMSHPs, and MassCEC published a dataset with 11,728 rebate records filed from 2014-2018.[21] These records provide the rebate date, the number of outdoor and indoor units installed, the system manufacturer and model number, and the total system installation costs, as well as other data.

The evaluation team adapted the MassCEC dataset to enable a comparison with the RES28 conclusions. The team took the following steps:

- **Removed incomplete records.** The team discarded 12 records that omitted either the installation cost or the DMSHP model number.
- **Linked capacity and efficiency information.** The MassCEC dataset did not provide the efficiency ratings of the DMSHP records, so the team used the manufacturer and model number information from the MassCEC data to look up the cooling capacity and efficiency ratings of each record in the AHRI database of certified product performance.

---

[21] MassCEC published rebate data for the Air-Source Heat Pump Program in response to a public records request. The dataset is linked from: http://www.masscec.com/contact-masscec/public-records-requests

- **Looked up cold-climate qualification.** The MassCEC dataset did not indicate whether the rebated models in its dataset are cold-climate qualified. The team used the manufacturer and model number information to look up cold climate qualifications in a listing maintained by NEEP.[22]

- **Filtered by date.** The MassCEC dataset contains records dating from 2014. Because the market for DMSHPs is changing rapidly and costs from 2014 may not represent the current market, the team limited this comparison analysis to MassCEC rebates filed after 1/1/2016.

- **Filtered by number of outdoor units.** The RES28 study estimated costs for scenarios where just one DMSHP system is installed (i.e., where installations include only one outdoor unit). To enable a straight comparison with the RES28 results, the evaluation team filtered the MassCEC records to only include records with one outdoor unit.

After performing the steps listed above, the evaluation team binned the MassCEC records based on the cooling capacity, efficiency, and number of indoor units. The team found that nearly all of the single-system MassCEC records in the specified timeframe (since 1/1/2016) are for cold-climate-qualified systems. Table 13 compares the cold climate system costs presented in the RES28 final report with the median costs calculated for MassCEC records in each bin. The table also reports the number of MassCEC records in each bin.

For the purpose of this exercise, the team assumed that the costs reported in the MassCEC rebate records include only the cost of DMSHP system installation.

The summary findings of this exercise are as follows:

- In the specified timeframe (since 1/1/2016), MassCEC did not rebate 9 kBtu/h or 12 kBtu/h systems at the lower MassSave rebate threshold of 18 SEER and 10 HSPF.

- For systems at capacities of 9 kBtu/h and 12 kBtu/h, the MassCEC records for high-efficiency systems at 28 SEER and 14 HSPF had median installation costs that were $300-$360 lower than the MassCEC median installation cost of systems at 20 SEER and 12 HSPF. This is contrary to the RES28 finding that high-efficiency systems have higher installation costs than lower-efficiency systems.

- For systems at capacities of 9 kBtu/h and 12 kBtu/h, the MassCEC records for high-efficiency systems at 28 SEER and 14 HSPF had median installation costs that were 12%-21% lower than the costs reported in the RES28 study.

- For systems at capacities from 24 kBtu/h to 36 kBtu/h, the MassCEC records showed median installation costs that were 22%-52% higher than the costs reported in the RES28 study.

---

[22] http://www.neep.org/initiatives/high-efficiency-products/emerging-technologies/ashp/cold-climate-air-source-heat-pump

Table 13. Total Installed Cost of DMSHP Systems at Common SEER-HSPF Combinations

Capacity, kBtu/h	No. of Indoor Zones	Lower Rebate Threshold 18 SEER, 10 HSPF			Upper Rebate Threshold 20 SEER, 12 HSPF			Above Current Rebate Levels 28 SEER, 14 HSPF		
		Cold Climate			Cold Climate			Cold Climate		
		RES28	MassCEC Median	MassCEC : RES28	RES28	MassCEC Median	MassCEC : RES28	RES28	MassCEC Median	MassCEC : RES28
9 ± 1.5	1	$3,993	-	-	$4,035	$3,878 (n=22)	–4%	$4,419	$3,513 (n=140)	–21%
12 ± 1.5	1	$4,058	-	-	$4,199	$4,300 (n=707)	+2%	$4,515	$3,966 (n=148)	–12%
24 ± 3	1	$5,016	$7,616 (n=12)	+52%	$5,176	-	-	-	-	-
24 ± 3	2	$7,060	$8,583 (n=447)	+22%	-	-	-	-	-	-
24 ± 3	3	$8,202	$10,330 (n=219)	+26%	-	-	-	-	-	-
30 ± 3	3	$9,049	$11,015 (n=611)	+22%	-	-	-	-	-	-
36 ± 3	4	$10,438	$15,496 (n=257)	+48%	-	-	-	-	-	-

APPENDIX C. CONTRACTOR PRICE QUOTES (TASK 1 MEMO)

To: Massachusetts Program Administrators and Energy Efficiency Advisory Council

From: Decker Ringo and David Basak; Navigant Consulting Inc.

Date: February 5, 2018

Re: Ductless Mini-Split Heat Pump Cost Study (RES 28)
Task 1: Contractor Price Quotes

Encl: Ductless Mini-Split Survey, Final Version

This memo summarizes the evaluation team's findings from a contractor survey for ductless mini-split heat pump (DMSHP) products rebated through the Residential Heating and Cooling program. The evaluation team obtained data from Massachusetts contractors via a web survey. The web survey asked contractors to provide the cost of labor, equipment, supplies and other costs to the consumer. In the next stage of this cost study, the evaluation team will combine these survey results with other cost data to characterize the relationship between consumer costs and system efficiency. The sections below describe the sources and methodology used in this task, as well as its key findings.

Summary

Ductless mini-split heat pumps (DMSHPs) are electrical HVAC systems capable of providing heating and cooling to one or more conditioned zones in a building. They work by transferring thermal energy between the conditioned space and the outside environment. DMSHP systems are composed of one outdoor unit and one or more indoor unit(s) connected by refrigeration tubing and electrical wiring. Generally, the units in the system are bought as a package, with matching indoor and outdoor units. The components of the system can also be bought independently, for example to replace a single unit that failed. In the analysis discussed here, all systems are assumed to be purchased as a package.

DMSHPs are available in the market in a range of capacities and efficiencies. Additionally, DMSHP systems are sold with varying numbers of indoor units, which allow a single system to serve more than one conditioned zone. Generally, the cost of a DMSHP system increases with efficiency, capacity, and the number of zones supplied. The Residential Heating and Cooling program offers rebates to customers for DMSHP systems that meet certain efficiency requirements. Two rebate levels are currently available based on the efficiency metrics of Seasonal Energy Efficiency Ratio (SEER) and Heating Seasonal Performance Factor (HSPF). The rebate levels are \$100 per indoor unit for a system rated at or above 18 SEER and 10 HSPF, and \$300 per indoor unit for a system rated at or above 20 SEER and 12 HSPF.[23]

In this task, the evaluation team identified "representative sizes" for DSMHPs that represent the DMSHP system sizes most commonly rebated in the Massachusetts Program Administrators' (PAs') service areas. The evaluation team examined rebate data provided by the PAs to determine the number of zones that are typically served by each representative capacity. In this task, the evaluation team conducted a web survey with HVAC contractors to determine the consumer costs as a function

---

[23] For details, see https://www.masssave.com/en/saving/residential-rebates/electric-heating-and-cooling/.

of three main cost drivers: efficiency, capacity and the installation scenario (number of zones, number of systems, wall material, and other factors).

Over a period of six weeks, the evaluation team contacted a sample of 145 contractors in Massachusetts. The evaluation team emailed survey invitations to 115 of the contractors in that sample, and 13 contractors completed the online survey. The survey asked contractors to provide cost information for the base case, which was characterized by a single-zone DMSHP installation with a cooling capacity of 12 kBtu/h. Then, the survey asked contractors to provide cost information for other cases derived from the base case by varying the cost drivers. This allowed for the collection of data regarding the cost of efficiency, capacity, different system configurations, and various installation conditions.

Table 14 shows a summary of the results of the survey. The results are presented as the average cost for each case considering all contractors who participated in the survey. The results for each case are described in detail under the Key Findings section.

In addition to the contractor survey described in this memo, the activities in this cost study include gathering online retail prices via webscraping (Task 2) and collecting installation cost data from rebate applications (Task 3). The evaluation team will combine the data collected from these three sources to estimate the cost-efficiency relationships for ductless mini-split heat pumps.

Table 14. Results summary

Cost Driver	Installation Type	Cooling Capacity (kBtu/h)	Number of Zones	Efficiency		Exterior Wall Type	Outdoor Placement	Indoor Type	Number of Systems	Total Installed Cost	Incremental Cost, Relative to Base Case
				SEER	HSPF						
Base Case	New	12	1	15	8.2	Siding	Ground	Wall mount	1	$3,877	-
Installation Type	Replacement	12	1	15	8.2	Siding	Ground	Wall mount	1	$3,803	($75)
Capacity	New	9	1	15	8.2	Siding	Ground	Wall mount	1	$3,638	($240)
	New	24	1	15	8.2	Siding	Ground	Wall mount	1	$4,791	$913
	New	30	1	15	8.2	Siding	Ground	Wall mount	1	$5,202	$1,325
Number of Zones	New	24	2	15	8.2	Siding	Ground	Wall mount	1	$6,754	$2,877
	New	36	3	15	8.2	Siding	Ground	Wall mount	1	$8,858	$4,980
	New	42	4	15	8.2	Siding	Ground	Wall mount	1	$10,729	$6,851
Efficiency	New	12	1	18	10	Siding	Ground	Wall mount	1	$4,030	$153
	New	12	1	20	12	Siding	Ground	Wall mount	1	$4,274	$396
Exterior Wall Type	New	12	1	15	8.2	Shingles	Ground	Wall mount	1	$3,775	($102)
	New	12	1	15	8.2	Wood	Ground	Wall mount	1	$3,764	($114)
	New	12	1	15	8.2	Brick	Ground	Wall mount	1	$4,175	$298
Outdoor Unit Placement	New	12	1	15	8.2	Siding	1st floor wall	Wall mount	1	$3,806	($71)
	New	12	1	15	8.2	Siding	Roof	Wall mount	1	$4,305	$427
	New	12	1	15	8.2	Siding	2nd+ floor wall	Wall mount	1	$4,863	$986
Indoor Unit Type	New	12	1	15	8.2	Siding	Ground	Ceiling cassette	1	$4,928	$1,051
Number of Systems	New	12+12	1+1	15	8.2	Siding	Ground	Wall mount	2	$7,182	$3,304

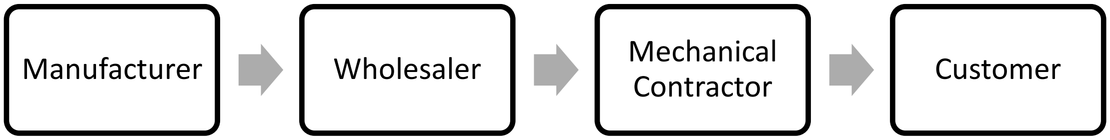
Background

Contractor Survey

The purpose of this task is to estimate the consumer cost of a complete DMSHP installation in the Massachusetts PAs' service areas. In particular, the evaluation team is interested in determining the cost of higher efficiency equipment relative to the cost of base case equipment.

When customers purchase DMSHPs to install in their home, they typically purchase them from the contractor that they hire to perform the installation, as in the distribution channel illustrated in Figure 11.[24] In this channel, the product price is marked up at three stages, by the manufacturer, the wholesaler, and the mechanical contractor. This is the most likely distribution channel that customers would use to purchase rebate-eligible products, since the MassSave® program will not provide rebate payments unless the products are installed by a licensed HVAC contractor.

Figure 11. Contractor Distribution Channel for Replacement of Residential DMSHPs.



The mechanical contractor is the last step in the supply chain, so the cost to customers is the price charged by the mechanical contractor. This price includes all equipment markups added along the supply chain, as well as the additional markups and rates charged by the contractor. For that reason, the evaluation team decided to limit the survey sample to contractors and to not survey wholesalers.

Contractor markups and labor rates vary by geographic location. Thus, national aggregate data for contractor prices or survey data from other states may not provide an accurate estimate of the consumer costs in the Massachusetts PAs' service areas. To obtain price estimates, the evaluation team developed a web survey and delivered it to contractors in the Massachusetts PAs' service areas. Details of the survey sample, design, and execution are presented in the Methodology section.

Efficiency Metrics for Ductless Mini-Split Heat Pumps

The efficiency of heat pumps in general is usually expressed in terms of several metrics, specified below.

a) Coefficient of Performance (COP): the coefficient of performance is the ratio of the useful heat added (in heating) or removed (in cooling) from the conditioned space to the energy consumed by the product. The COP is used to express performance at a specific set of testing conditions. Common COP testing conditions are an indoor temperature of 70 °F and an outdoor temperature of 47 °F for high-temperature heating, 17 °F for low-temperature heating, or 5 °F for cold-climate heating. For a given set of indoor and outdoor conditions, the larger the COP, the greater the operating efficiency. Because the COP depends on the testing conditions, the testing conditions

---

[24] Customers may also purchase equipment from online retailers, but that is less common in the context of the MassSave® program. Nonetheless, the data from online retailers can provide useful insight on the cost to consumers. For details, see the Task 2 memo.

are usually stated with the COP value. As the ratio of two energy or power quantities, the COP is a dimensionless number, though it is sometimes expressed in units of watt/watt (W/W).

b) Energy Efficiency Ratio (EER): like the COP, the EER is a ratio of useful heat moved to the energy consumed by the product. The EER is generally only used to express cooling performance at a specific set of testing conditions (95 °F outdoor temperature and 80 °F indoor temperature). The EER metric is usually expressed in British thermal units per Watt-hour (Btu/W.h).

c) Seasonal Energy Efficiency Ratio (SEER): the SEER metric is the weighted average of EER measured across a range of cooling conditions. The standard conditions specified for the SEER metric provide an estimate of efficiency over an entire cooling season, thus providing a more representative estimate of “real-world” performance than that provided by the EER metric. The SEER metric is expressed in Btu/W.h.

d) Heating Seasonal Performance Factor (HSPF): the HSPF is the weighted average of the COP measured across a range of heating conditions. Analogously to the SEER metric, the HSPF is intended to provide an estimate of efficiency over an entire heating season, thus providing a more representative estimate of “real-world” performance than that provided by the COP. The HSPF metric is expressed in Btu/W.h.

Methodology

This section describes the methodology used in developing and applying the contractor survey. The following points are described:

- The development of the contractor sample
- The survey design, including the topics covered and inputs requested from the contractors
- The survey delivery and follow-up methods

Contractor Sample

The PAs provided the evaluation team with participant rebate data assembled by Energy Federation Inc. (EFI) for the period of January 1, 2016 through July 31, 2017. Each DMSHP rebate record includes the name and contact information for the contractor who performed the installation. The evaluation team selected a survey sample from these records, selecting contractors that had significant experience with DMSHPs based on the number of rebate records they submitted for DMSHP installations. Additionally, the evaluation team considered the geographic location of the contractors so that all the PAs’ service areas were represented in the survey sample.

Table 15 presents the number of contractors contacted by the evaluation team in each region, as well as the aggregate number of DMSHP rebate records filed by those contractors. The evaluation team counted the number of contractors based on the region in which they are based, not the region(s) they serve. This was because the regions served were not available to the evaluation team prior to the survey (and, in fact, the region(s) served is one of the questions on the survey). Contractors often serve regions other than those in which they are based. For example, a contractor based in the South of Boston region may serve the Greater Boston region and parts of Cape Cod and Central Massachusetts. Thus, the number of contractors shown in Table 15 can be considered a conservative estimate of the number of contractors in the sample that serve each region.

Table 15. Number of contractors and rebate records in selected sample per region.

Region	Number of Sampled Contractors Based in the Region‡		Total Number of DMSHP Rebate Records Filed by the Sampled Contractors	
	Number	% of Sample	Number	% of Records
Cape Cod & Islands	22	15%	1118	23%
Central MA	19	13%	557	12%
Western MA	21	14%	900	19%
South of Boston	17	12%	466	10%
Metro West	52	36%	1333	28%
North of Boston	11	8%	413	9%
Greater Boston	3	2%	37	1%
TOTAL	145	100%	4824	100%

‡ Each contractor may serve regions other than the one in which they are based.

The evaluation team believes that this contractor sample is sufficient to represent the geographic distribution of contractors in Massachusetts. The sample contains at least 8 contractors for each region, except for Greater Boston. Greater Boston is the smallest region among those considered and is also the one with the costliest real estate. Thus, it is not surprising that fewer contractors have offices in that region.

Survey Design

The evaluation team designed the contractor survey to obtain cost information around three main cost drivers: efficiency, capacity, and installation factors. The evaluation team selected specific levels and configurations for each of these cost drivers and requested data at those levels. This allowed for a structured analysis of the cost drivers, in which relatively few data points can provide a comprehensive understanding of the costs associated with each cost driver.

The evaluation team selected three efficiency levels: the base case[25] (15 SEER and 8.2 HSPF) and the two efficiency levels currently rebated by the Massachusetts PAs (18 SEER and 10 HSPF, 20 SEER and 12 HSPF). For capacity, the evaluation team analyzed the current rebate data for Massachusetts and selected representative capacity levels; this process is described in detail in the Representative Sizes subsection below. For the installation scenarios, the evaluation team considered the most common configurations found in DMSHPs; these configurations are described in the Installation Scenarios subsection below. For an overall perspective on all scenarios presented in the survey, see Table 14.

The survey asked contractors to provide cost information in several billing categories: burdened labor costs, equipment costs including markups (total for indoor and outdoor units), supplies costs (mounting supplies, line sets, brazing material, etc.) and other costs (travel, warranty, insurance, overhead, etc.) for each scenario in Table 14. This allowed the evaluation team to analyze how different cost drivers impact

---

[25] The evaluation team understands that the 2016 Plan-Year Report Version of the Massachusetts Technical Reference Manual reports a baseline level of 14 SEER and 8.2 HSPF for the DMSHP system measure (measure #MAE16A2a05ALL). However, the evaluation team could not identify any 14 SEER systems with cooling capacity less than 20 kBtu/h. The least efficient 12 kBtu/h systems on the market today are rated at 15 SEER and 8.2 HSPF, and this is the base case the evaluation team selected for this study.

the different cost categories. For example, single-zone DMSHP systems with different capacities generally have different equipment costs but very similar labor and supplies costs. In contrast, DMSHP systems with the same capacity but serving a different number of zones (e.g. a 24 kBtu/h system with one zone versus two zones) generally have different equipment and labor costs. By requesting equipment costs as a single line-item cost, the evaluation team can compare the equipment costs provided by contractors with the retail costs retrieved by webscraping in Task 2 of this study.

The evaluation team designed the survey with input from the Massachusetts PAs and EEAC and with input from contractors. The PAs and EEAC reviewed an initial soft-copy draft of the survey and provided preliminary feedback. Then, after the evaluation team programmed the online survey, the PAs tested the survey and provided further comments. The evaluation team provided a digital soft copy of the survey to an initial sample set of 25 contractors. Based on the feedback and questions received from this initial contractor sample, the evaluation team updated the survey to its final form. The final form of the survey is enclosed for reference with this memo deliverable.

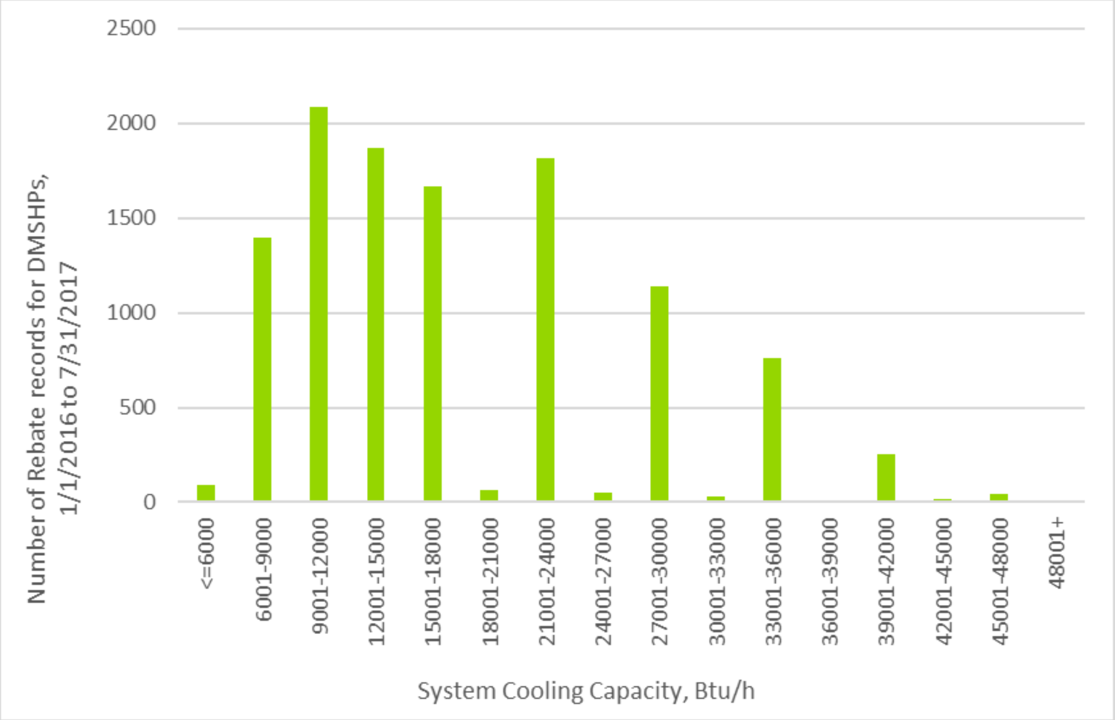
Representative Sizes and Number of Zones

The cost of a DMSHP system varies with many factors, such as the size of the system, its efficiency and its additional features (connectivity, advanced user interface, etc.). Of those factors, efficiency and capacity tend to be the main drivers of cost variations because they tend to require changes to the costliest components in the system: the heat exchangers, the electric motors, and the compressor. Thus, a cost analysis of DSMHPs must account for efficiency and capacity to yield accurate results.

DSMHP systems can provide cooling and heating, and most vendors marketed the systems by their nominal cooling capacity. Consequently, the evaluation team used the nominal cooling capacity as the representative variable in its cost calculations. It should be noted that the nominal capacity may not always reflect the exact performance of the DMSHP system, especially for small systems with very high efficiency. In many cases, a DMSHP system’s maximum achievable capacity is higher than its nominal capacity, since manufacturers frequently engineer systems to achieve a higher SEER rating, and the SEER metric measures part-load operation. For the purposes of this study, the evaluation team considered this strategy to be one of the many legitimate design options that manufacturers may adopt to improve rated efficiency. The evaluation team did not adjust the data to account for differences in nominal capacity and full-load capacity.

Generally, the cooling and heating capacities of any given system correlate strongly; in other words, a system that can provide twice as much cooling than another system is likely to provide twice as much heating than the other system as well. The DSMHP systems in the market are clustered around certain cooling capacity values (e.g. 12 kBtu/h, 24 kBtu/h, etc.). This is illustrated in Figure 12, which shows a histogram of the number of Massachusetts PA rebate records as a function of cooling capacity.

Figure 12. Number of Massachusetts PA rebate records for DSMHPs in the period from 1/1/16 to 7/31/17 as a function of capacity.



Given this clear clustering of the DMSHP market around certain capacity levels, the evaluation team selected a few typical capacities to represent the main clusters in the market. The evaluation team selected the following capacity levels for the analysis: 9, 12, 24, 30, 36 and 42 kBtu/h. Table 16 shows the number of zones typically offered with these capacities, as well as potential applications for a system at each capacity.

Table 16. Details of the capacity ranges analyzed

Cooling Capacity (Btu/h)	Number of Zones	Description
9,000	1	These are relatively small systems that would be an appropriate, more efficient option or replacement for room or window air conditioners or packaged terminal air conditioners (PTACs). Individually, they may be used in home additions, or to condition cold or hot spots in a building.
12,000	1	Systems rated at 12,000 can condition a larger space than systems rated at 9,000 Btu/h systems, but they are not large enough to condition an entire home. Thus, they make appropriate replacements for room or window air conditioners or PTACs. They may find application in garages or living rooms.
24,000	1	These systems can cool large individual rooms and even small homes, if the conditioned air can be circulated through all rooms. These systems are typically used to supplement a home's existing HVAC system or to provide heating and cooling capacity to a newly finished space.
24,000	2	Due to the significant capacity (equivalent to a small residential ducted system) and the ability to provide conditioning to two zones, these systems could provide conditioning for a small home. The capacity is split between the two zones, which can be used to tailor the conditioning to the size of each zone. They could replace, for example, two window air conditioners, or even a ducted heat pump.
30,000	1	With similar applications to the single-zone 24,000 Btu/h systems, these systems can provide cooling and heating to larger spaces.
36,000	3	These systems are equivalent to a medium-sized ducted residential heat pump system and would be an appropriate replacement for them. These systems can provide conditioning to small and medium-sized homes.
42,000	4	These systems are equivalent to a medium-sized ducted residential heat pump system and would be an appropriate replacement for them. With four zones and 42,000 Btu/h of cooling capacity, these systems could provide conditioning for small, medium and even some large homes.

Installation Scenarios

DMSHPs may be installed in many different configurations depending on the specifics of the job site and the conditioning requirements of the home. Each configuration requires specific equipment, hardware and a certain amount of work to install, all of which lead to varying installation costs. The evaluation team considered this issue and requested information about the following configurations in the contractor survey:

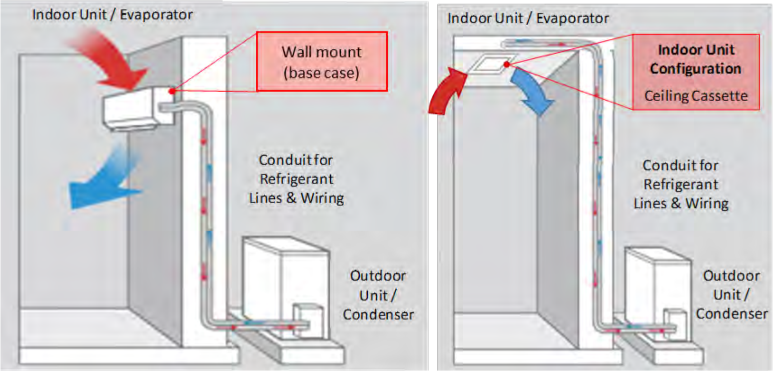
e) Wall type: certain wall materials may be more difficult to drill through or may require additional hardware to ensure safe installation of the equipment. The survey requested costs for the following wall types: siding (base case), shingles, wood, and brick.

f) Outdoor installation: the outdoor unit of a DMSHP system may be installed in different configurations depending on the available space and the maximum distance to the indoor unit. The survey requested costs for the following outdoor installation types: on the ground (base case), mounted on the wall at the ground floor level, on the roof, and mounted on the wall above the ground floor level. These installation types are shown in Figure 13.

Figure 13. Outdoor installation types

g) Indoor installation: customers may select different indoor unit types depending on the available space, the type of construction, and their aesthetic preferences. The survey requested costs for the following indoor installation types: wall-mounted (base case) and ceiling cassette. These installation types are shown in Figure 14.

Figure 14. Indoor installation types



h) Number of individual systems: some job sites such as multi-unit buildings may require the installation of more than one DMSHP system, each with its own indoor and outdoor units. Contractors may offer discounts when consumers install more than one system at once. To capture this, the survey requested data for one-system installations and for two-system installations, where each system has a single zone and a cooling capacity of 12 kBtu/h.

Survey Execution

The evaluation team conducted the survey over a six-week period from December 14, 2017 to January 25, 2018. The evaluation team first contacted all the contractors in the survey sample by telephone to request an email address for a point of contact who would be qualified to answer questions regarding DMSHP installation costs. During these initial phone calls, the team offered an incentive in the form of a $250 gift card in exchange for completing the survey. Of the 145 contractors sampled, 23 contractors indicated that they did not want to participate and 10 contractors did not respond to phone calls to provide a valid email address. The evaluation team sent an email invitation to the remaining 112 contractors with a link to participate in the online survey. The online survey allowed respondents to submit their answers via a web browser. The evaluation team followed the responses to the survey and sent follow-up emails to again ask the contractors to fill out the survey.

The evaluation team made several efforts to improve the response rate of the survey. The team conducted pre-screening calls as mentioned above, and the team sent follow-up reminder emails one week after contractors received the survey invitations. Despite these efforts, the survey had a low response rate. Out of 145 contractors sampled, only 13 provided complete survey responses. The evaluation team identified the following obstacles to obtaining a higher response rate:

- The survey was released during the holiday season, when many contractors take time off.
- The survey release coincided with a long cold spell, when many contractors were busy handling emergency calls from their customers.
- A particularly large winter storm hit Massachusetts around the same time, leading to work disruptions and power outages. Many contractors were affected and did not have the time or the means to participate.
- The survey collects sensitive data, which may be a concern to certain contractors.

To improve the response rate in future surveys, the evaluation team recommends releasing the survey at times when contractors are less busy with customer calls, such as in the spring or autumn.

Key Findings

This section presents the key findings from the contractor survey for DMSHPs. Each of the cost drivers analyzed by the team is presented in a separate subsection below. All values are presented in U.S. dollars and represent an average of the values provided by the contractors. Consequently, the values provided by any single contractor cannot be derived from the results presented here.

Each cost driver is presented in a separate subsection, and costs are presented in categories of labor, equipment, supplies and other costs. Each subsection includes a chart and table showing how costs change relative to the base case, depending on the cost driver.

In their comments on the survey, more than one contractor noted that the electrical installation is an important cost factor. Some contractors stated that they included this cost in their estimates, some contractors stated they did not include electrical costs, and other contractors did not mention this issue at all. Some contractors may have electricians on staff, which would reduce the costs associated with this issue, while others may have to hire a third-party company. We assume that each contractor’s response was internally consistent regarding whether or not they reported electrical costs. In other words, we assume contractors did not report electrical costs in their response to one question and then omit them on a different question.

Another concern mentioned by the contractors is that any unexpected difficulty in installing the line set can add a significant cost to the project (by one estimate, this can add about $500).

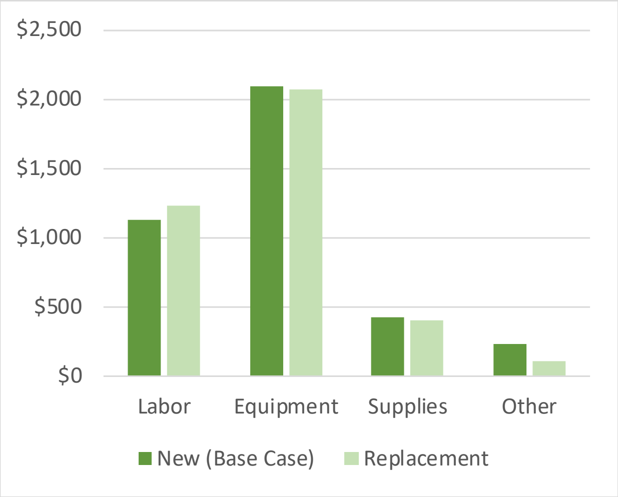
Brands Installed by Contractors

The survey respondents mentioned a total of four DMSHP brands: Daikin, Fujitsu, Lennox and Mitsubishi. Of those brands, Fujitsu and Mitsubishi were most often mentioned (eight different contractors), while Daikin and Lennox were each mentioned by two different contractors. The evaluation team reviewed DMSHP rebate records for the period 1/1/16 to 7/31/17 and found that 92.5% of the records were for systems from Fujitsu and Mitsubishi.

Base Case

In the survey delivered to contractors, the first question on costs regard a base case installation, which is defined as a single-zone DMSHP system with cooling capacity of 12 kBtu/h and efficiency of 15 SEER and 8.2 HSPF, installed as a new (i.e., not replacement) system in a home with exterior siding, with a wall-mounted indoor unit and a ground-mounted outdoor unit. All of the subsequent scenarios presented in the survey were treated as variations on this base case scenario, and each cost question in the survey reminded respondents of the costs their provided for this base case scenario. Figure 15 compares the cost of a base case (i.e., new) installation to the cost of installing a replacement system to take the place of an existing DMSHP system.

Figure 15. Base case costs, new installation compared to replacement



Average Costs by Category in 2017$		
	Installation Type	
	New System	**Replacement**
Labor	1,132	1,230
Equip.	2,088	2,066
Supplies	426	402
Other	232	105
Total	**3,877**	**3,803**

Geographic Variation

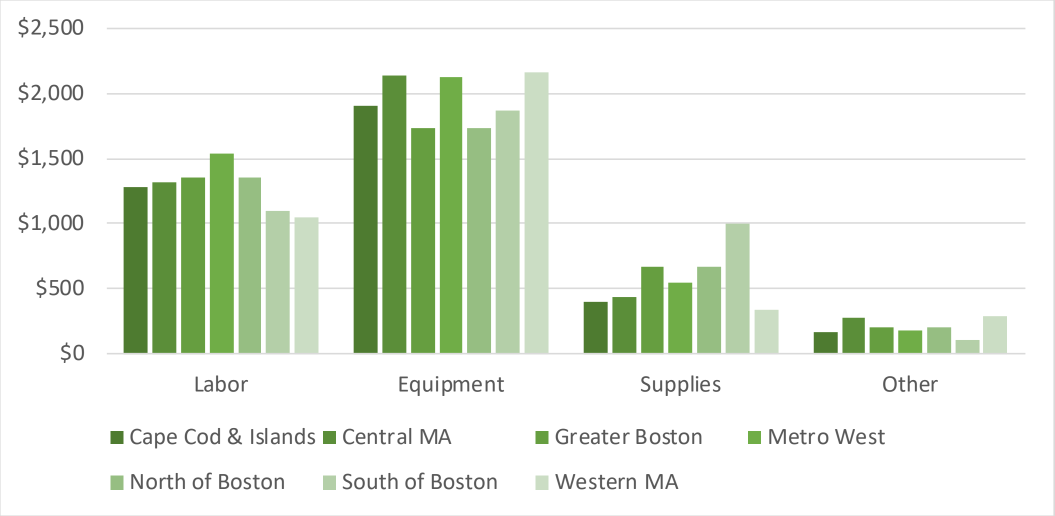
The number of responses per region served is shown in Table 17 below. The number of responses in Table 17 is greater than the number of survey respondents who took the survey because some contractors serve more than one region. Figure 16 shows the average costs for the base case scenario in different cost categories for each region.

One goal of this study is to assess how installation costs vary across different service areas in Massachusetts. However, the evaluation team observed high variability in costs *within each given region*. This is particularly true regarding the labor rates, which can vary by more than 100% from contractor to contractor. This variability and the low rate of responses to this survey make it impossible to draw strong conclusions regarding the relationship between cost and geographic region. Instead, the evaluation team focused its efforts on an analysis of Massachusetts as a whole.

Table 17. Number of survey responses per region

Region	Number of Survey Responses	Average Costs for Base Case Installation (2017$)				
		Labor	Equip-ment	Supplies	Other	Total
Cape Cod & Islands	2	1,275	1,904	393	171	3,743
Central MA	3	1,311	2,134	439	276	4,160
Greater Boston	2	1,350	1,736	668	207	3,961
Metro West	2	1,540	2,121	543	179	4,383
North of Boston	2	1,350	1,736	668	207	3,961
South of Boston	3	1,100	1,871	1,000	100	4,071
Western MA	5	1,046	2,163	336	290	3,835
Average across survey respondents:		1,132	2,088	426	232	3,877

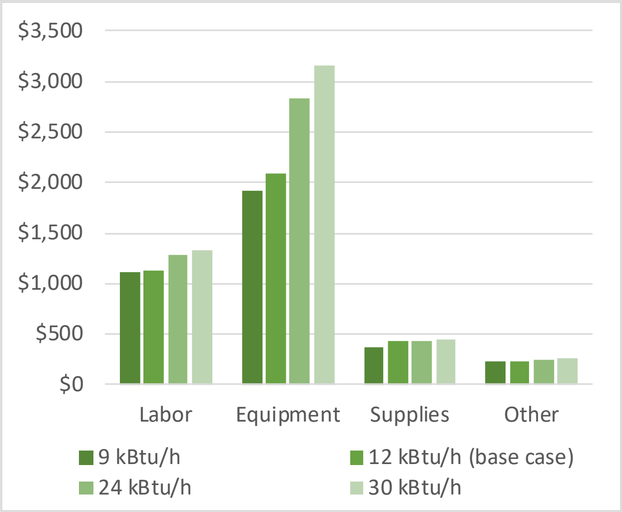
Figure 16. Average base case scenario costs per region served



Capacity and Number of Zones

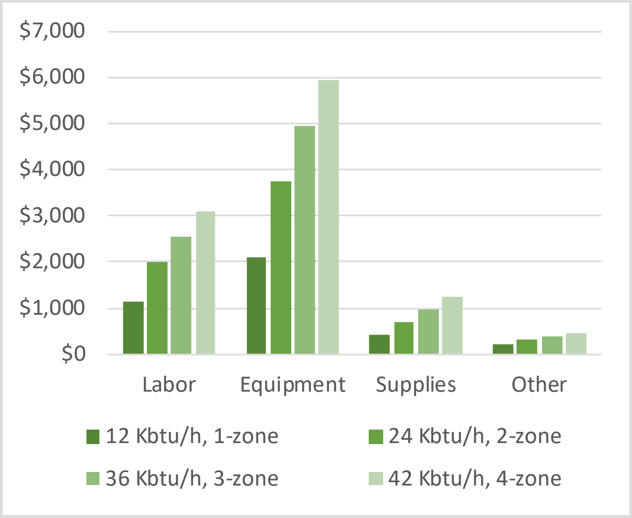
Figure 17 reports installation costs for single-zone DMSHP systems and Figure 18 reports installation costs for single- and multi-zone DMSHP systems. Both figures report costs for systems with efficiency of 15 SEER and 8.2 HSPF installed in homes with exterior siding, with a wall-mounted indoor unit and a ground-mounted outdoor unit.

Figure 17. Costs as a function of capacity for single-zone systems



Average Costs by Category in 2017$				
	Single-Zone System Capacity			
	9 kBtu/h	**12 kBtu/h**	**24 kBtu/h**	**30 kBtu/h**
Labor	1,114	1,132	1,283	1,337
Equip.	1,926	2,088	2,830	3,162
Supplies	366	426	431	446
Other	232	232	247	257
Total	**3,638**	**3,877**	**4,791**	**5,202**

Figure 18. Costs as a function of capacity and the number of conditioned zones



Average Costs by Category in 2017$				
	Multi-Zone System Capacity			
	12 kBtu 1-zone	**24 kBtu 2-zone**	**36 kBtu 3-zone**	**42 kBtu 4-zone**
Labor	1,132	1,996	2,533	3,083
Equip.	2,088	3,741	4,956	5,941
Supplies	426	704	983	1,238
Other	232	313	385	466
Total	**3,877**	**6,754**	**8,858**	**10,729**

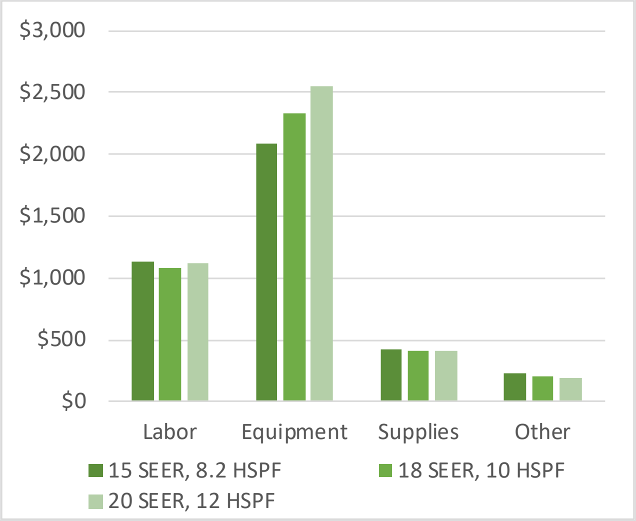
Findings related system capacity and number of zones:

- Two contractors mentioned that the installation costs are the same for all capacities of single-zone systems; according to them, only the equipment costs (including markup) change with capacity. One respondent noted that there may be a slight increase in the cost of the line set for capacities greater than 18,000 Btu/h.
- On average, each additional zone adds about $2,285 per zone, broken into $650 for labor, $1,285 for equipment, $270 for supplies, and $80 for other costs.

System Efficiency

Figure 19 reports installation costs for single-zone DMSHP systems with cooling capacity of 12 kBtu/h installed in homes with exterior siding, with a wall-mounted indoor unit and a ground-mounted outdoor unit.

Figure 19. Costs as a function of system efficiency.



Average Costs by Category in 2017$			
	System Efficiency		
	15 SEER/ 8.2 HSPF	18 SEER/ 10 HSPF	20 SEER/ 12 HSPF
Labor	1,132	1,083	1,118
Equip.	2,088	2,337	2,554
Supplies	426	412	407
Other	232	198	194
Total	**3,877**	**4,030**	**4,274**

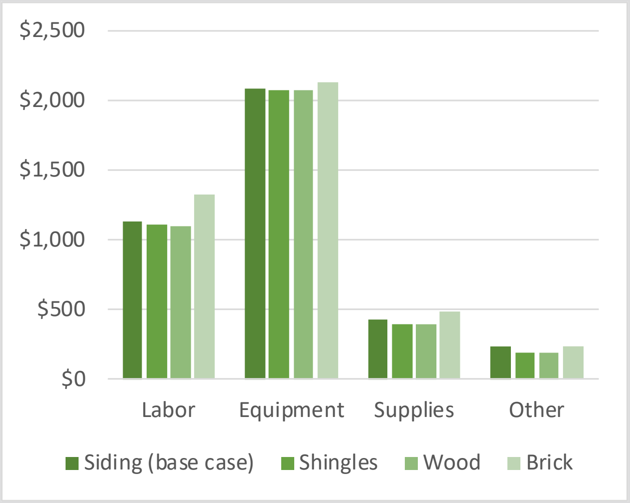
Findings related to system efficiency:

- The average cost of increasing from 15 SEER to 18 SEER is about $150.
- The average cost of increasing from 15 SEER to 20 SEER is about $400.
- Two respondents commented that the equipment cost (including markup) is the only cost category that changes with efficiency.
- One respondent commented that the change in profit margin is small with efficiency.

Exterior Wall Type

Figure 20 reports installation costs for single-zone DMSHP systems with cooling capacity of 12 kBtu/h and efficiency of 15 SEER and 8.2 HSPF, with a wall-mounted indoor unit and a ground-mounted outdoor unit.

Figure 20. Costs as a function of the exterior wall type



Average Costs by Category in 2017$				
	Exterior Wall Type			
	Siding	Shingles	Wood	Brick
Labor	1,132	1,111	1,099	1,322
Equip.	2,088	2,073	2,073	2,127
Supplies	426	400	396	492
Other	232	192	196	234
Total	**3,877**	**3,775**	**3,764**	**4,175**

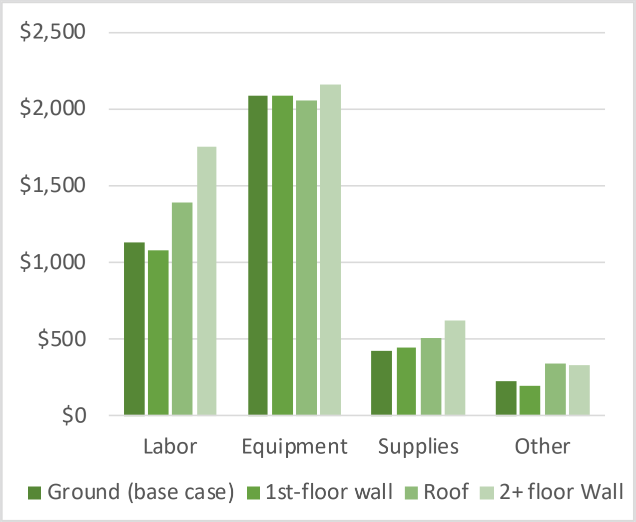
Findings related to exterior wall type:

- A common remark from the contractors was that brick and concrete constructions are the most complex installation setup. In those cases, contractors often must hire a third-party core drilling company to drill into the wall. According to one contractor, this adds an average of $400 to the cost of the project.
- In all survey responses, the labor cost associated with brick construction was greater or equal to the labor cost of other types of construction. Some contractors may have the necessary machinery in-house, which would explain the cases in which the labor cost is equal for brick and for the other materials.

Outdoor Unit Placement

Figure 21 reports installation costs for single-zone DMSHP systems with cooling capacity of 12 kBtu/h and efficiency of 15 SEER and 8.2 HSPF, installed in homes with exterior siding, with a wall-mounted indoor unit.

Figure 21. Costs as a function of the outdoor installation type



Average Costs by Category in 2017$				
	Outdoor Unit Placement			
	Ground	**Wall, 1st floor**	**Roof**	**Wall, 2+ floor**
Labor	1,132	1,083	1,392	1,755
Equip.	2,088	2,085	2,059	2,156
Supplies	426	446	508	620
Other	232	192	346	333
Total	**3,877**	**3,806**	**4,305**	**4,863**

Findings related to outdoor unit placement:

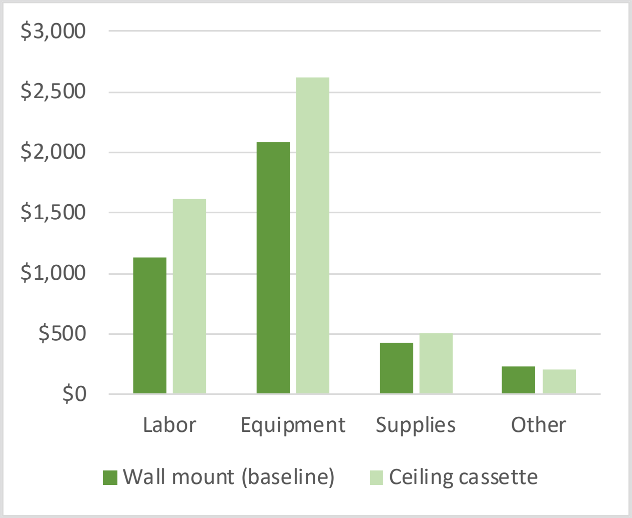
- Some contractors do not provide installation on walls above the ground floor or on the roof. One contractor attributed this choice to the difficulty in providing system maintenance.
- One respondent commented that the change in cost between an on-the-ground installation and a ground-floor-wall installation is only from the cost of the bracket.
- Responses said that roof installations and installations above the ground floor require additional labor. One contractor noted that installation above the ground floor may require the use of a lift, which leads to an increase in costs.

In sum, installations on the ground or on the ground floor wall tend to be less expensive than roof or high wall installations, and this difference is mostly due to labor costs.

Indoor Unit Type

Figure 22 reports installation costs for single-zone DMSHP systems with cooling capacity of 12 kBtu/h and efficiency of 15 SEER and 8.2 HSPF, installed in homes with exterior siding, with a ground-mounted outdoor unit.

Figure 22. Costs as a function of the indoor installation type



Average Costs by Category in 2017$		
	Indoor Unit Type	
	Wall-Mount	**Ceiling Cassette**
Labor	1,132	1,609
Equip.	2,088	2,618
Supplies	426	500
Other	232	201
Total	**3,877**	**4,928**

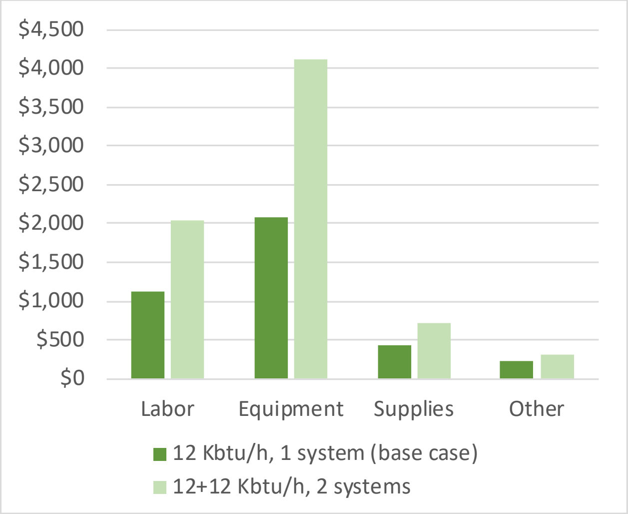
Findings related to indoor unit type:

- Responses indicated that the installation of ceiling cassettes is about $1,050 more per DMSHP system compared to wall-mounted units.
- The cost increase is split between the increased equipment cost of indoor ceiling cassette units compared to wall-mounted units and the additional labor required to cut knockout holes and run refrigerant lines through ceiling.

Number of Systems

Figure 23 reports installation costs for the installation of one system or two systems at a single address. In this case, each system is a single-zone DMSHP system with cooling capacity of 12 kBtu/h and efficiency of 15 SEER and 8.2 HSPF, in a home with exterior siding, with a wall-mounted indoor unit and a ground-mounted outdoor unit.

Figure 23. Costs as a function of the number of systems



Average Costs by Category in 2017$		
	Number of Complete Systems	
	One System	Two Systems
Labor	1,132	2,036
Equip.	2,088	4,125
Supplies	426	719
Other	232	302
Total	**3,877**	**7,182**

Findings related to number of complete systems:

- Responses indicate that doubling the number of systems in an installation does not necessarily double the cost.
- There appear to be some slight equipment and supplies discounts in two-system installations, since doubling the number of systems installed increases total equipment and supply costs by about 93%.
- There appear to be labor economies of scale with a two-system installation, since doubling the number of systems increases labor costs by 80%. This is likely due to savings in travel and setup time.

APPENDIX D. DETERMINE COST-EFFICIENCY RELATIONSHIP (TASK 2 MEMO)

To:	Massachusetts Program Administrators and Energy Efficiency Advisory Council
From:	Decker Ringo and David Basak; Navigant Consulting Inc.
Date:	February 19, 2018
Re:	Ductless Mini-Split Heat Pump Cost Study (RES 28) Task 2: Determine Cost-Efficiency Relationship

This memo summarizes the evaluation team's findings from a comprehensive webscrape of prices and performance ratings for ductless mini-split heat pump (DMSHP) products incentivized through the Residential Heating and Cooling program. The evaluation team gathered DMSHP prices using webscraping, then used this pricing data to characterize the relationship between the retail product cost and system efficiency, accounting for the cost of non-efficiency-related features and the possibility of cost outliers. The sections below describe the sources and methodology used in this task, as well as its key findings.

Summary

Ductless mini-split heat pumps (DMSHPs) are electrical HVAC systems capable of providing heating and cooling to one or more conditioned zones in a building. They work by transferring thermal energy between the conditioned space and the outside environment. DMSHP systems are composed of one outdoor unit and one or more indoor unit(s) connected by refrigeration tubing and electrical wiring. Generally, the units in the system are bought as a package, with matching indoor and outdoor units. The components of the system can also be bought independently, for example to replace a single unit that failed. In the analysis discussed here, all systems are assumed to be purchased as a package.

DMSHPs are available in the market in a range of capacities and efficiencies. Additionally, DMSHPs are sold with varying numbers of indoor units, which allow a single system to serve more than one conditioned zone. Generally, the cost of a DMSHP system increases with efficiency, capacity, and the number of zones supplied. The Residential Heating and Cooling program offers rebates to customers for DMSHP systems that meet certain efficiency requirements, listed in Table 18.[26] The evaluation team examined the costs of DMSHP systems that meet the Northeast Energy Efficiency Partnerships (NEEP) Cold Climate Air-Source Heat Pump (ccASHP) Specification, which uses the criteria presented in Table 18.[27]

---

[26] For details, see https://www.masssave.com/en/saving/residential-rebates/electric-heating-and-cooling/.

[27] See the Cold Climate Air-Source Heat Pump Specification section for details.

Table 18. MassSave Rebate Thresholds and Cold Climate Specification Criteria

MassSave DMSHP Rebate Criteria for Two Rebate Levels	NEEP Cold Climate Air Source Heat Pump Specification Criteria
A rebate of $100 per indoor unit for DMSHP systems rated at ≥18 SEER and ≥10 HSPF	Systems must: • Have a variable capacity compressor • Be a matched system in the AHRI directory • Be ENERGY STAR certified • Have COP > 1.75 at 5 °F • Have ≥10 HSPF
A rebate of $300 per indoor unit for DMSHP systems rated at ≥20 SEER and ≥12 HSPF	

Previously in this cost study, the evaluation team identified “representative sizes” for DSMHPs that represent the DMSHP system sizes most commonly rebated in the Massachusetts Program Administrators (PAs) service areas. The evaluation team examined rebate data provided by the PAs to determine the number of zones that are typically served by each representative capacity. In this task, the evaluation team used webscraping to gather online retail prices for representatively sized systems across the full range of available efficiencies for each of the system configurations considered in this study.

The team organized the webscraped data to determine the lowest-cost models available at each efficiency level from the lowest efficiency to the highest efficiency available in the market. The lowest-cost path from low efficiency to high efficiency is termed the “cost-efficiency frontier.” The team examined the feature sets of models on the cost-efficiency frontier to determine whether the higher efficiency models include any non-efficiency-related features that may affect the retail cost of the product. Some examples of non-efficiency-related features include anti-corrosion coatings, “night mode” controls, and air ionizers. The team estimated the cost of these features and subtracted that cost from the price of the affected models.

In short, the evaluation team performed Task 2 using the following steps: select the representative capacities; identify viable data sources for webscraping; use webscraping to obtain a large cost-efficiency data set; determine the typical system configurations (for example, the usual number of indoor units per outdoor unit); determine the cost-efficiency frontiers for each capacity and configuration; process the data points in the cost-efficiency frontier considering any price markups, non-efficiency-related features and cost-efficiency data outliers.

Figure 24. Simplified workflow, Task 2

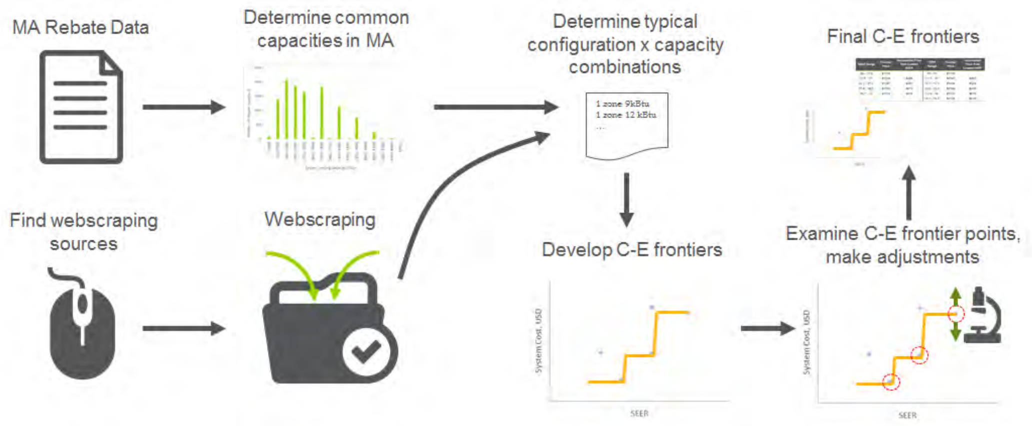


Table 19 shows a summary of the results at the efficiency levels rebated by the MassSave program. The results are provided for regular DMSHP systems and for systems that meet NEEP's Cold Climate Air-Source Heat Pump (ccASHP) Specification.[28] The results for each type and representative capacity of mini-split heat pump are described in detail under the Key Findings section. Readers should note that the tables in the Key Findings section show the individual curves for SEER (regardless of HSPF) and for HSPF (regardless of SEER). The table below shows the costs at or above the rebated combinations of SEER and HSPF ratings. Where the costs in the Key Findings tables do not match the costs in the Summary table, it is because the Key Findings tables show systems that meet only one of the SEER and HSPF criteria.

Table 19. Results summary

Nominal Capacity (kBtu/h)	Number of Zones	Online Retail Price					
		<16 SEER, <9 HSPF*		18 SEER, 10 HSPF		20 SEER, 12 HSPF	
		Regular	Cold Climate	Regular	Cold Climate	Regular	Cold Climate
9.0 ± 1.5	1	$909	There are no cold climate units in this range	$1,113	$1,219	$1,586	$1,397
12 ± 1.5[†]	1	$969		$1,176	$1,329	$1,780	$1,528
24 ± 3.0	1	$1,529		$1,638	$1,509	$2,341	$2,129
24 ± 3.0	2	$1,974		$2,180	$2,870	N/A**	N/A[‡]
24 ± 3.0	3	$2,697		$2,721	$3,330	N/A**	N/A[‡]
30 ± 3.0	3	$2,908		$2,908	$3,410	N/A**	N/A[‡]
36 ± 3.0	4	$3,233		$3,233	$4,380	N/A**	N/A[‡]

* The evaluation team understands that the 2016 Plan-Year Report Version of the Massachusetts Technical Reference Manual reports a baseline level of 14 SEER and 8.2 HSPF for the DMSHP system measure (measure #MAE16A2a05ALL). However, the evaluation team could not identify any 14 SEER systems with cooling capacity less than 20 kBtu/h. The least efficient 12 kBtu/h systems on the market today are rated at 15 SEER and 8.2 HSPF, and this is the base case the evaluation team selected for this study.

[†] This is the most popular configuration in Massachusetts based on rebate data from 1/1/16-7/31/17.

** There are no multi-split systems with this combination of capacity and efficiency in the AHRI Database of Certified Product Performance.

[‡] The NEEP database of ccASHP certified systems does not list any ductless, multi-zone systems at this capacity that meet the specified rebate level.

In addition to the analysis of webscraping data in Task 2, RES 28 also includes the analysis of contractor price quotes via a web survey (Task 1) and the analysis of invoice data provided by the program PAs (Task 3). The data from each of these analyses is focused on a specific domain and has limitations inherent to the data sources; by combining the results from each analysis, the evaluation team will be able to estimate the cost-efficiency relationships for ductless mini-split heat pumps with great confidence.

---

[28] See the Cold Climate Air-Source Heat Pump Specification section for details.

Background

Initially, the evaluation team reviewed the incremental cost study that Cadmus conducted for Ameren and Commonwealth Edison in Illinois, which the team expected to use as the main source for the cost-efficiency analysis in Task 2 of RES 28. However, the team determined that the Cadmus study would not be an ideal source for this task for the following reasons: a) the study did not assign costs to cold-climate systems; b) the study did not assign costs to connected product capabilities; c) the study is 6 months old, and prices in the DMSHP market have been changing very rapidly; and d) the results from the study showed occasional drops in cost with increases in efficiency, which did not align with market observations. As a result, on November 10, 2017 the team requested permission from the PAs and Energy Efficiency Advisory Council (EEAC) to adjust the approach of this task and determine the cost-efficiency relationship using webscraping instead. The PAs and EEAC approved of this change in approach.

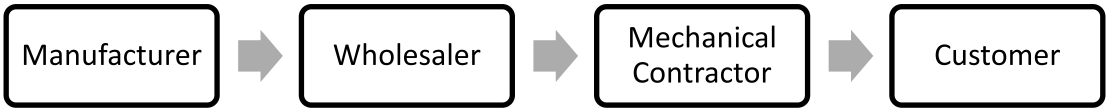
Webscraping consists of obtaining data (in the present case, price) from online sources in an automated fashion. By applying webscraping, the evaluation team obtained a large price data set in a much shorter time than would be possible through manual data acquisition. This allows for a more comprehensive understanding of the market and the costs associated with different efficiency levels.

The evaluation team used the processed webscraping data to develop a cost-efficiency analysis of DSMHPs. The webscraping data yielded a collection of cost-efficiency points. By analyzing those points, the evaluation team identified the cost-efficiency frontier, i.e. the lowest cost required to achieve a given efficiency level. This process is explained in greater detail in the methodology section.

Cost Assumptions

When customers purchase DMSHPs to install in their home, they typically purchase them from the contractor that they hire to perform the installation, as in the distribution channel illustrated in Figure 25. In this channel, the product price is marked up at three stages, by the manufacturer, the wholesaler, and the mechanical contractor. This is the most likely distribution channel that customers would use to purchase rebate-eligible products, since the MassSave® program will not provide rebate payments unless the products are installed by a licensed HVAC contractor.

Figure 25. Contractor Distribution Channel for Replacement of Residential DMSHPs



The prices and cost curves presented in this memo represent the retail cost of heating products purchased through online vendors, and the distribution channel for this mode of sale is illustrated in Figure 26. In this channel, the product price is marked up at just two stages, by the manufacturer and the online retailer.

Figure 26. Online Distribution Channel for Replacements of Residential DMSHPs

For other types of products, such as gas furnaces and central A/C systems, there is a limited selection of brands available through online vendors because manufacturers of these other products maintain tight control of their supply chain and they discourage the sale of uninstalled products. The evaluation team observed that manufacturers of DMSHP products do not exert the same controls, and there is ample pricing data available for a wide variety of mainstream brands and models. This webscraping analysis includes hundreds of system prices for Fujitsu and Mitsubishi (the most commonly rebated brands in Massachusetts), as well as for Daikin, Gree, LG, Midea, Panasonic, and other mainstream brands.

The evaluation team recognizes that a small percentage of customers purchase DMSHPs online. This memo does not claim that customers would pay the same price to purchase products through contractors as they would pay to purchase products online. The prices presented in this memo should not be interpreted as the final product prices that customers will pay for contractor-installed equipment. The online price data gathered in this task serves as one of several inputs that the evaluation team will consider when estimating the cost of installing products at different efficiency levels. Online price data is useful because it indicates the proportional price difference between low- and high-efficiency products.

Efficiency Metrics for Ductless Mini-Split Heat Pumps

The efficiency of heat pumps in general is usually expressed in terms of several metrics, specified below.

e) Coefficient of Performance (COP): the coefficient of performance is the ratio of the useful heat added (in heating) or removed (in cooling) from the conditioned space to the energy consumed by the product. The COP is used to express performance at a specific set of testing conditions. Common COP testing conditions are 70 °F indoor temperature and outdoor temperature of 47 °F for high-temperature heating, 17 °F for low-temperature heating, or 5 °F for cold climate heating. For a given set of indoor and outdoor conditions, the larger the COP, the greater the operating efficiency. Because the COP depends on the testing conditions, the testing conditions are usually stated with the COP value. As the ratio of two energy or power quantities, the COP is expressed in units of watt/watt (W/W), a dimensionless number.

f) Energy Efficiency Ratio (EER): like the COP, the EER is a ratio of useful heat moved to the energy consumed by the product. The EER is generally only used to express cooling performance at a specific set of testing conditions (95 °F outdoor temperature and 80 °F indoor temperature). Furthermore, it is usually expressed in British thermal units per Watt-hour (Btu/W.h).

g) Seasonal Energy Efficiency Ratio (SEER): the SEER metric is the weighted average of EER measured across a range of cooling conditions. These conditions were selected to provide an estimate of efficiency over an entire cooling season, thus providing a more representative estimate of “real-world” performance than that provided by the EER metric. The SEER metric is expressed in Btu/W.h.

h) Heating Seasonal Performance Factor (HSPF): the HSPF is the weighted average of the COP measured across a range of heating conditions. Analogously to the SEER metric, the HSPF is intended to provide an estimate of efficiency over an entire heating season, thus providing a more representative estimate of “real-world” performance than that provided by the COP. The HSPF metric is expressed in Btu/W.h.

Data Sources

The evaluation team used the following publicly-available data sources throughout the analyses conducted for this task.

- **AHRI Directory of Certified Product Performance**
  Link: https://www.ahridirectory.org/
  The AHRI Directory contains product performance data submitted by manufacturers to certify that their products conform to industry standards. Manufacturers typically contract 3rd-party laboratories to conduct performance testing for ductless mini-split heat pumps. The evaluation team used the AHRI database to study the population of certified products, to select the baseline efficiency levels, and to select representative models for cost analysis.
- **Northeast Energy Efficiency Partnerships (NEEP) Cold Climate Air-Source Heat Pump (ccASHP) Specification and Product Listing**
  Link: http://www.neep.org/initiatives/high-efficiency-products/emerging-technologies/ashp/cold-climate-air-source-heat-pump
  The Northeast Energy Efficiency Partnerships (NEEP) define cold climate air-source heat pumps as products with HSPF ≥ 10 and COP @ 5°F ≥ 1.75. NEEP maintains a list of cold-climate qualified DMSHP products.
- **Retail Merchant Websites**
  Many retailers advertise the prices of ductless mini-split heat pumps online. The evaluation team conducted targeted webscraping to retrieve pricing data from different online retailers. The prices used in this analysis were sourced from ACWholesalers.com, AlpineHomeAir.com, AppliancesConnection.com, SupplyHouse.com, Ingrams.com, TotalHomeSupply.com, ComfortUp.com, CasteelQuote.com, CoolRunningHS.com and Ecomfort.com. The evaluation team used these retail sites to estimate the purchase cost of ductless mini-split heat pumps at different efficiency levels.

Methodology

This section describes the methodology used to develop the cost-efficiency frontiers for different product capacities.

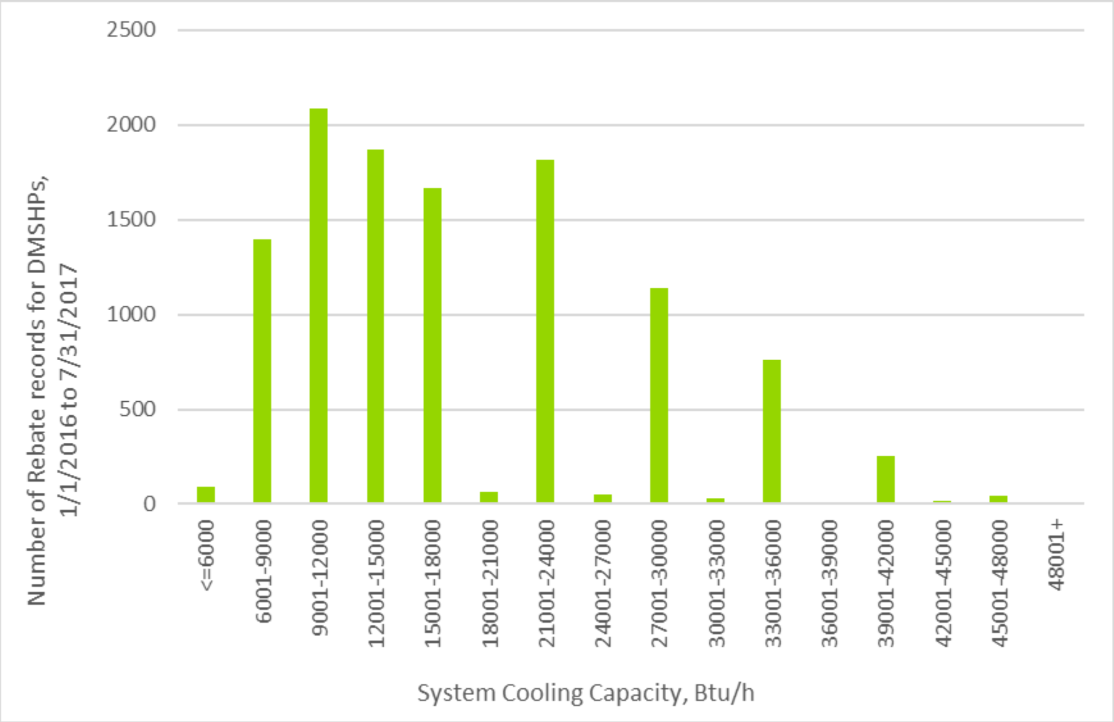
Representative Sizes and Number of Zones

The cost of a DMSHP system varies with many factors, such as the size of the system, number of zones, its efficiency, and its additional features (connectivity, advanced user interface, etc.). Of those factors, efficiency and capacity tend to be the main drivers of cost variations because they tend to require changes to the costliest components in the system: the heat exchangers, the electric motors and the compressor. Thus, a cost analysis of DSMHPs must account for efficiency, number of zones, and capacity to yield accurate results.

DSMHP systems can provide cooling and heating, and most vendors market systems by their nominal cooling capacity. Consequently, the evaluation team used the nominal cooling capacity as the representative variable in its cost calculations. It should be noted that the nominal capacity may not always reflect the exact performance of the DMSHP system, especially for small systems with very high efficiency. In many cases, a DMSHP system’s maximum achievable capacity is higher than its nominal capacity, since manufacturers frequently engineer systems to achieve a higher SEER rating, and the SEER metric measures part-load operation. For the purposes of this study, the evaluation team considered this strategy to be one of the many legitimate design options that manufacturers may adopt to improve rated efficiency. The evaluation team did not adjust the data to account for differences in nominal capacity and full-load capacity. Generally, the cooling and heating capacities of any given system correlate strongly; in other words, a system that can provide twice as much cooling than another system is likely to provide twice as much heating than the other system as well.

DSMHP systems in the market are clustered around certain cooling capacity values (e.g. 12 kBtu/h, 24 kBtu/h, etc.). This is clearly seen in the figure below, which shows a histogram of the number of Massachusetts PA rebate records as a function of cooling capacity.

Figure 27. Number of Massachusetts PA rebate records for DSMHPs in the period from 1/1/16 to 7/31/17 as a function of capacity.



Given this clear clustering of the DMSHP market around certain capacity levels, the evaluation team selected a few typical capacities to represent the main clusters in the market. This allowed for a univariate analysis of cost as a function of efficiency for each capacity level, which is much simpler than creating a bivariate analysis of cost as a function of efficiency and capacity. The evaluation team selected the following capacity levels for the analysis: 9, 12, 24, 30 and 36 kBtu/h. Table 20 shows the number of zones typically offered with these capacities, as well as potential uses for them.

Table 20. Details of the capacity ranges analyzed

Cooling Capacity (Btu/h)	Number of Zones	Description
9,000 ± 1,500	1	These are relatively small systems that would be an appropriate, more efficient option or replacement for room or window air conditioners or packaged terminal air conditioners (PTACs). Individually, they may find application in additions, or in cold or hot spots in a building.
12,000 ± 1,500	1	Systems rated at 12,000 can condition a larger space than systems rated at 9,000 Btu/h systems. They are not large enough to condition an entire home. Thus, they make appropriate replacements for room or window air conditioners or packaged terminal air conditioners (PTACs). They may find application in garages or living rooms.
24,000 ± 3,000	1	These systems can cool large individual rooms and even small homes, if the conditioned air can be circulated through all rooms. These systems are typically used to supplement a home's existing HVAC system or to provide heating and cooling capacity to a newly finished space.
24,000 ± 3,000	2	Due to the significant capacity (equivalent to a small residential ducted system) and the ability to provide conditioning to two zones, these systems could provide conditioning for a small home. The capacity is split between the two zones, which can be used to tailor the conditioning to the size of each zone. They could replace, for example, two room HPs or PTHPs, or even a ducted heat pump.
24,000 ± 3,000	3	These systems can provide cooling to a small home, with added flexibility compared to two-zone systems. They could replace, for example, three small room HPs or a ducted heat pump.
30,000 ± 3,000	3	With similar applications to the three-zone 24,000 Btu/h systems, these systems can provide cooling and heating to larger spaces. They could replace three room HPs or PTHPs, or a ducted heat pump.
36,000 ± 3,000	4	These systems are equivalent to a medium-sized ducted residential heat pump system and would be an appropriate replacement for them. Because four zones are available, there is flexibility in terms of conditioning when compared to the other categories analyzed. These systems can provide conditioning to small and medium-sized homes.

Cold Climate Air-Source Heat Pump Specification

Due to the particularly cold climate in the Northeast, a group of interested stakeholders facilitated by the Northeast Energy Efficiency Partnerships (NEEP) developed a specification for cold climate heat pumps (“Cold Climate Air-Source Heat Pump Specification”, or “ccASHP specification”).[29] This specification has the following requirements:

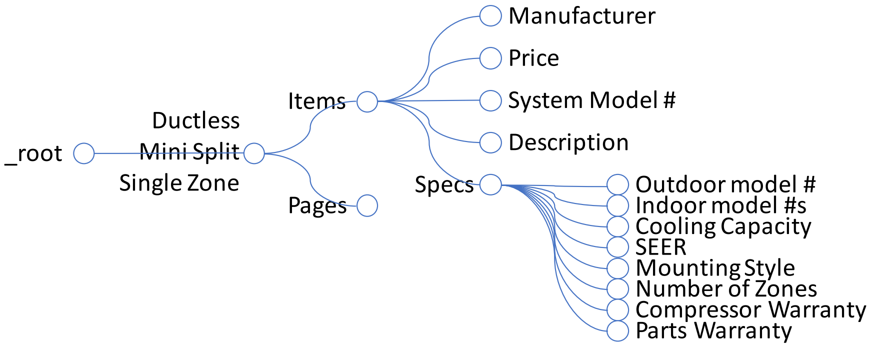
- The system must have a variable capacity compressor.
- The indoor and outdoor units must be part of a matched system in the AHRI directory.
- The system must be ENERGY STAR certified.
- The COP of the system must be greater than 1.75 at 5 °F.
- The HSPF of the system must be greater than 10.
- The system performance data must be reported to NEEP in a specific format.

NEEP hosts a database of the systems that meet the ccASHP specification. The evaluation team utilized this database to determine which systems were cold-climate ready. Because the ccASHP specification has strict requirements, the evaluation team expected units that meet the ccASHP specification to cost more than units that do not meet this specification. Systems that meet the ccASHP specification would show significant energy savings in the Massachusetts climate and, during the planning phase of this study, several PAs showed interest in learning the costs associated with ccASHP systems. The evaluation team created separate cost-efficiency curves systems that meet the ccASHP specification and for systems that do not meet the specification.

Webscraping Activities

The evaluation team conducted webscraping to obtain price and performance data for DMSHPs. We began by coding WebHarvey, an automated webscraping tool, to capture the website page-architectures for each of the online vendors. We then programmed a secondary webscraping tool, *webscraper.io*, to pull data from each of the individual product pages. Programming the *webscraper.io* tool involves developing a model of a website’s content (*i.e.*, a sitemap) with specific tags corresponding to data points of interest to our analysis. Figure 28 provides a visual representation of a sitemap to scrape single-zone DMSHP listings from the ACWholesalers.com website. Figure 29 shows a sample webpage where data has been tagged for webscraping.

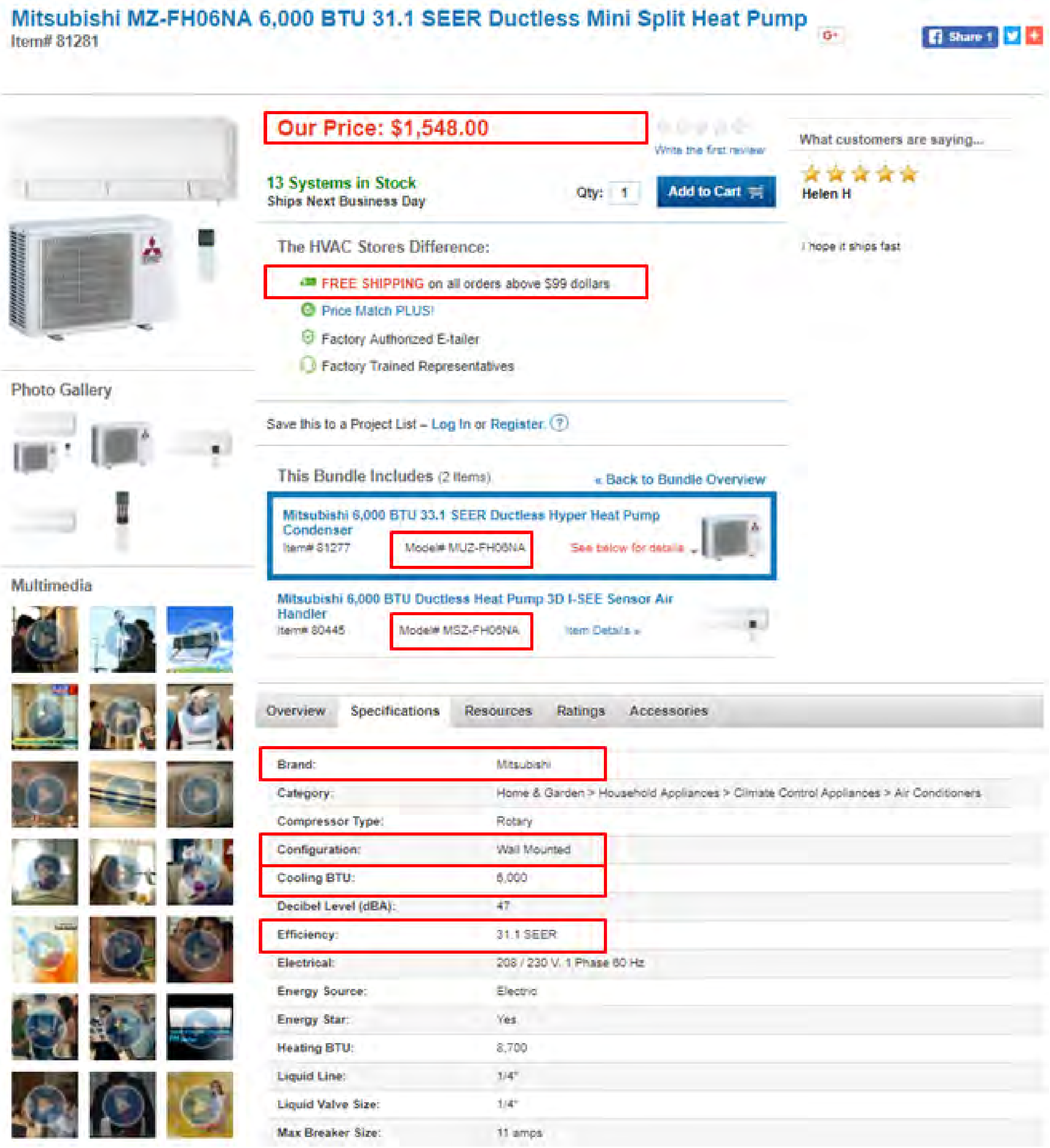
Figure 28. Sample Website Page Architecture for DMSHP Webscraping



---

[29] http://www.neep.org/initiatives/high-efficiency-products/emerging-technologies/ashp/cold-climate-air-source-heat-pump, accessed on December 18th, 2017.

Figure 29. Sample Website Content Model, with Data Tags Indicated by Red Boxes



Mitsubishi MZ-FH06NA 6,000 BTU 31.1 SEER Ductless Mini Split Heat Pump
Item# 81281

Our Price: $1,548.00

Write the first review

13 Systems in Stock
Ships Next Business Day

Qty: 1

What customers are saying...

Helen H

I hope it ships fast

The HVAC Stores Difference:

FREE SHIPPING on all orders above $99 dollars
Price Match PLUS!
Factory Authorized E-tailer
Factory Trained Representatives

Save this to a Project List – Log In or Register.

This Bundle Includes (2 items)

« Back to Bundle Overview

Mitsubishi 6,000 BTU 33.1 SEER Ductless Hyper Heat Pump Condenser
Item# 81277 Model# MUZ-FH06NA See below for details

Mitsubishi 6,000 BTU Ductless Heat Pump 3D I-SEE Sensor Air Handler
Item# 80445 Model# MSZ-FH06NA Item Details »

Brand:	Mitsubishi
Category:	Home & Garden > Household Appliances > Climate Control Appliances > Air Conditioners
Compressor Type:	Rotary
Configuration:	Wall Mounted
Cooling BTU:	6,000
Decibel Level (dBA):	47
Efficiency:	31.1 SEER
Electrical:	208 / 230 V, 1 Phase 60 Hz
Energy Source:	Electric
Energy Star:	Yes
Heating BTU:	8,700
Liquid Line:	1/4"
Liquid Valve Size:	1/4"
Max Breaker Size:	11 amps

The evaluation team gathered data from seven retailer websites and organized it into a table, with each system occupying one entry in the table. The team gathered the following variables:

- brand
- model numbers of the system, the outdoor units and the indoor unit(s)
- number of zones served by the system
- cooling capacity

- mounting style of the indoor unit(s)
- SEER rating
- Price (including shipping costs, if applicable)
- connected capability

The evaluation team linked the data from webscraping to the AHRI Directory of Certified Product Performance to obtain the AHRI certification number and the HSPF rating for each system in the dataset.[30] Additionally, the evaluation team utilized the NEEP Cold Climate Air Source Heat Pump database to identify the cold climate systems in the dataset.

Non-Efficiency-Related Features

The features included in DMSHPs can be classified into two broad groups:

a) Efficiency-related features are those that provide an improvement in the operating efficiency of the DMSHP system. Since this analysis is based on cost as a function of SEER and HSPF, the evaluation team based its classification on whether the feature improves SEER or HSPF. Common strategies for improving DSMHP efficiency are: high efficiency compressors, high efficiency fan motors and increased heat exchanger size.

b) Non-efficiency-related features are any features that do not improve SEER or HSPF. Some features classified as non-efficiency-related may have a tangible effect on energy consumption, but not on SEER or HSPF (as measured by the DOE test procedure that is used to rate DMSHP systems). Examples of non-efficiency-related features are: specific control strategies (night mode, defrost, auto-changeover), features that improve consumer comfort and safety (auto-restart, timers, rapid cooling/heating), product warranties that reduce the cost of near-term equipment failures, and features that improve durability (anti-corrosive coating).

The purpose of this cost study is to determine the cost of increasing the operating efficiency relative to a base case system at 15 SEER and 8.2 HSPF.[31] However, the retail prices gathered by webscraping also include the cost of any non-efficiency-related features that may be bundled with DMSHP systems. That means that the difference in price between two DMSHP systems is given in part by the different non-efficiency-related features each system has. Consequently, to obtain an accurate measure of the cost of efficiency, it is necessary to correct for price variations that are due to non-efficiency-related features.

The evaluation team took a careful approach to limit the effect of non-efficiency-related features on the incremental cost of efficiency. Basing the analysis on the lowest-cost systems at each efficiency level (as opposed to the average-cost system at each level) is a way to mitigate this issue. The lowest-priced systems tend to be the simplest and least costly to manufacture, so they are less likely to include non-efficiency-related features.

---

[30] https://www.ahridirectory.org/ahridirectory/pages/home.aspx, updated on September 11th, 2017.

[31] The evaluation team understands that the 2016 Plan-Year Report Version of the Massachusetts Technical Reference Manual reports a baseline level of 14 SEER and 8.2 HSPF for the DMSHP system measure (measure #MAE16A2a05ALL). However, the evaluation team could not identify any 14 SEER systems with cooling capacity less than 20 kBtu/h. The least efficient 12 kBtu/h systems on the market today are rated at 15 SEER and 8.2 HSPF, and this is the base case the evaluation team selected for this study.

Nevertheless, manufacturers may include advanced non-efficiency-related features even in their least expensive high-efficiency units, thus providing consumer value beyond the efficiency gains. Also, some manufacturers may include non-efficiency-related features that other manufacturers choose not to include. These variations in the market could mask the actual cost of improved efficiency in the webscraped data even with the lowest-cost approach described above.

To mitigate this issue, the evaluation team manually reviewed the marketing materials and catalogued the features that are included in DMSHP systems that define the cost-efficiency frontier in each product configuration. Where the team identified non-efficiency-related features, the team estimated the consumer cost associated with these features and subtracted it from the retail price of the system. The methodology for this cost estimation is described below. If a non-efficiency-related feature was present in the least efficient system on the cost-efficiency frontier, the team considered it to be a baseline feature and did not subtract its cost from the cost of the systems.

Through this process, the evaluation team deemed the following features to be baseline features since they are common in both low- and high-efficiency units across different manufacturers' product lines:

- Efficiency-related:
    - Inverter-driven compressor, which are usually used with variable-speed controls but may be driven at a single speed in rare, lower-efficiency cases
    - Brushless fan motors, which are more efficient than the cheaper permanent split capacitor motors
- Non-efficiency-related:
    - Rapid cooling and heating function, which ramps up the compressor to bring the room quickly to the set temperature
    - Energy-saving night mode
    - Anti-corrosive coating on the outdoor fins
    - Auto-restart after a power outage
    - Auto changeover (from cooling to heating or vice-versa, as the set temperature and room temperature require)
    - 24-hour timer
    - Defrost control (auto defrost of the outdoor coil)

Since these non-efficiency-related features are available across the efficiency range, the evaluation team did not include cost correction factors to compensate for them.

The evaluation team also found that the manufacturers tend to advertise features that are required for proper system operation (such as compressor heaters, base pan heaters or electronic expansion valves), and features that add negligible cost to the system (such as specialized air louver control methods). The evaluation team did not adjust the costs of the systems to account for these features.

Five non-efficiency-related features stood out as potential cost drivers: occupancy sensors, air ionizers, the ambient temperature range, the connected capabilities, and the manufacturer warranty. These features are discussed in detail below. To develop cost estimates for the occupancy sensors and the air ionizers, the evaluation team referenced Navigant Consulting's database of appliance component costs. Navigant maintains a database of appliance component costs aggregated from a variety of sources, including wholesale price quotes, manufacturer interviews, and independent cost modeling. The database contains over 8,000 appliance components, and database costs are updated on a monthly basis.

Occupancy Sensors

DMSHP systems from one manufacturer include occupancy sensors to detect whether conditioned space is occupied and to decrease the conditioning action when the space is not occupied. The marketing materials for these systems claim the occupancy sensor reduces the system's energy consumption. However, this reduction would not be captured in the SEER or HSPF measurements, so this feature was considered non-efficiency-related for the purposes of this analysis.

The evaluation team estimated the manufacturing cost per unit to include an occupancy sensor, then applied a markup to determine the price to the consumer. This estimated price was subtracted from the systems with occupancy sensors on the cost-efficiency frontier. Using Navigant's appliance component cost database, the evaluation team estimated the retail price effect of adding an occupancy sensor to be $7.88 per indoor unit, including the sensor component itself and necessary wiring, connectors and electronic components.

Air Ionizers

The evaluation team found a few systems that used air ionizers to assist in cleaning the air as it goes through the indoor unit. This technology may have some effect on customer comfort, but it does not affect the system efficiency. Therefore, the evaluation team evaluated the consumer price of a simple air ionizer implementation and subtracted that price from the price of units with this feature on the cost-efficiency frontier. Using Navigant's appliance component cost database, the evaluation team estimated the retail price effect of adding an air ionizer to be $4.99 per indoor unit, including the component itself and necessary wiring, connectors and electronic components.

Ambient Temperature Range

In reviewing the data at the cost-efficiency frontier, the evaluation team identified many units that are advertised as being able to operate at even lower temperatures than the 5 °F required by the ccASHP specification, but that are not listed on the ccASHP database. This could mean that these units cannot meet the efficiency requirements of the ccASHP specification, or that the manufacturers simply did not submit the performance data to NEEP. In either case, without the ccASHP approval the evaluation team could not determine if these units would perform appropriately under low temperatures, so they were treated as regular units in the analysis.

The evaluation team investigated the units rated for very low temperatures and found that their cost did not vary significantly from their warmer temperature counterparts. This indicates that the low temperature operation is achieved through inexpensive design options, such as specific control strategies. Generally, these design options are not clearly stated by manufacturers. Considering the lack of information and the minimal cost differences involved, the evaluation team decided not to apply a correction factor based on the stated temperature of operation of each system.

Connected Product Capabilities

Connected products give the consumer (or a third party, if user-approved) the ability to control the product remotely via the Internet. This allows the consumer to, for example, change the temperature setting of an indoor unit while they are away from the home. From a utility's perspective, it allows for the application of demand response programs (that is, utility-consumer agreements in which the system can be controlled by the utility in such a way as to reduce peaks in demand).

The evaluation team found no mention of demand response in manufacturer marketing materials, likely because marketing is usually focused on the consumer-facing aspects of connectivity (i.e. the ability to control one's own system remotely). Thus, it is not possible to determine if demand response capabilities are available in the market within the scope of this webscraping activity.

Still, the technology required in the HVAC system is essentially the same in both cases, the difference being mainly in terms of where the commands come from (a consumer's account or a third party's account). Thus, it is safe to assume that the systems that already have consumer-facing connected capabilities would only require minor changes to enable utility-facing connected capabilities, such that the difference in product price, if any, would be marginal.

There are currently two main forms of implementation of connected capabilities: a) using an add-on module, which the consumer can purchase separately and install on each indoor unit to be controlled; and b) using built-in technology that is hard-wired into the indoor unit. The evaluation team estimated the costs of each case independently and treated the systems in each case differently.

The evaluation team utilized the webscraping data to estimate the cost incremental of built-in modules. This was done by comparing the costs of nearly identical units, comparing one unit that which features connected capabilities with another unit that does not. The evaluation team found three cases that were suitable for this sort of comparison, and ignored one such case because the same price was listed with and without connected capabilities. The other two cases were averaged to obtain the estimated cost. For the add-on modules, the evaluation team obtained 24 online prices for modules from five HVAC manufacturers; those quotes were averaged to obtain an estimated cost.[32] The costs of each type of implementation are shown in Table 21.

Table 21. Average cost of implementation of connected capabilities per indoor unit based on webscraping data

Implementation Method	Average Cost (per indoor unit)
Add-on Module	$153.92
Built-in	$58.92

The average cost of an add-on module is nearly three times that of a built-in module. This is consistent with the evaluation team's expectations; while built-in modules are installed at the factory and sold as part of the unit, add-on modules must be manufactured, shipped, marketed and sold as a separate product, thus accumulating additional costs throughout the supply chain. Thus, built-in solutions are generally less expensive to purchase.

The evaluation team notes, however, that connected capabilities do not affect the operating efficiency of an HVAC system. Rather, they allow for more efficient use of the system itself.

---

[32] In developing the cost-efficiency frontiers, the evaluation team determined the least expensive means of increasing efficiency by focusing on the lowest-cost systems available in the market. In the case of add-on control features, consumers do not have a choice of which module or built-in device to purchase, because modules generally have proprietary manufacturer technology. Thus, the team believes an average-cost approach is a more accurate estimate of what the consumer will pay for the additional connected capability feature.

Consequently, in determining the cost-efficiency frontiers for DMSHPs, the evaluation team removed the cost of implementation of connected capabilities. This is only necessary in the built-in case, where the cost of the hardware must be bundled with the cost of the DMSHP system. The evaluation team subtracted the cost of the built-in connectivity hardware ($58.92 times the number of zones) from the cost of all systems that offer that feature.

Manufacturer Warranty

The evaluation team found that the least expensive DMSHP systems are marketed with brands that offer standard warranties of 2 years or less, such as Blueridge, EMI, Mirage, and OLMO. The team found that rebates for systems from these short-warranty brands comprise less than 2% of the rebate records filed through MassSave for the period 1/1/16-7/31/17. The team omitted those short-warranty brands from our analysis as outliers because we found that a short warranty has a strong effect on system cost, and because systems with short warranties do not represent typical warranties in the PAs' service areas.

For the ductless mini-split systems that were included in our analysis, we observed that a 5-year parts/7-year compressor warranty was standard across the range of prices and brands (including the most frequently rebated brands, Mitsubishi and Fujitsu). The exception is Daikin, which offers 10-year warranties on many of its systems. By removing the short-warranty models from the analysis, the evaluation team controlled for the cost effects of manufacturer warranty options.

Mandatory Additional Equipment

In addition to the DSMHP system itself, customers must often purchase additional equipment to complete the installation. DMSHP systems that are intended for installation by contractors do not ship with refrigerant line sets or electrical connecting wires.[33] These supplies must be purchased according to the length required for a given installation. Additionally, one manufacturer requires the purchase of a refrigerant distribution box for their multi-zone units. The evaluation team investigated the cost of this mandatory additional equipment and added that cost to the webscraped system cost, as applicable. The additional costs used are shown in Table 22.

Table 22. Estimated average cost of mandatory equipment

Mandatory Equipment	Cost
Line Sets (all systems)	$129.50 per zone
Refrigerant Distribution Box (only applicable to certain manufacturers)	$307.95 for two zones
	$313.95 for three zones
	$397.95 for four zones

---

[33] There are several brands of DMSHP kits on the market that ship with line sets, wires, and all the hardware necessary to install the system. These kits are marketed for installation by DIY homeowners. These kits are omitted from this analysis because homeowner-installed systems are not eligible for rebates.

Identifying and Removing Cost Outliers

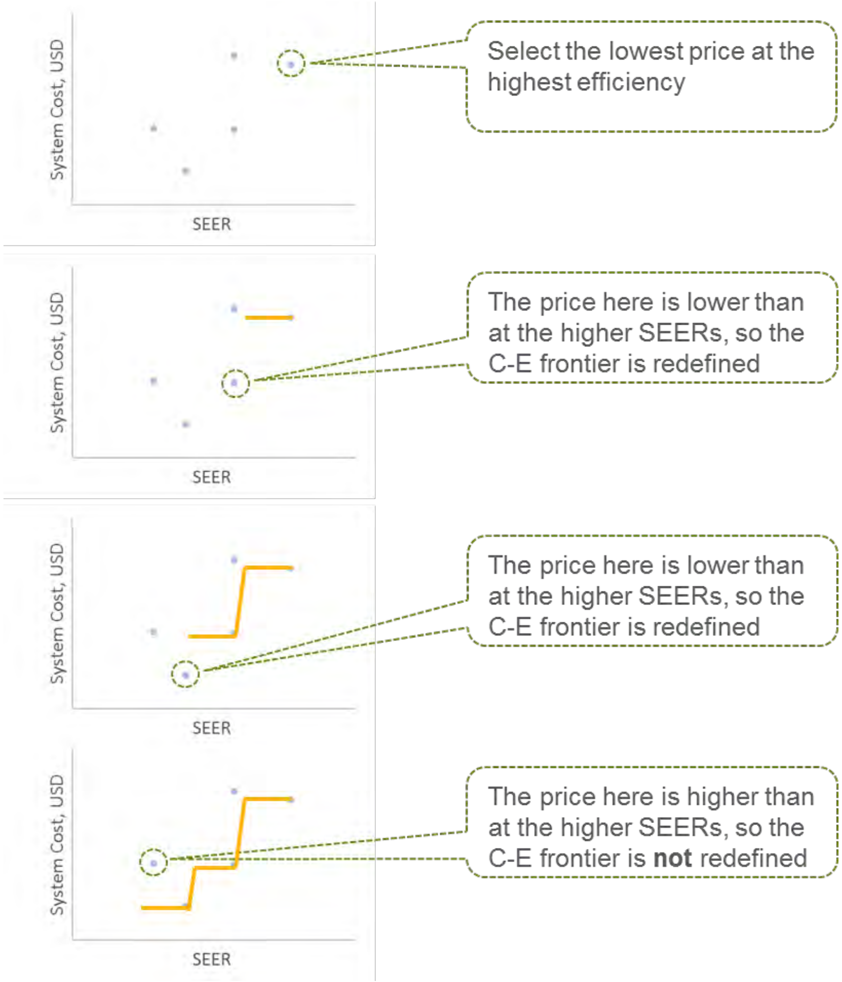
Webscraped data typically contains outlier data points due to the variability in suppliers, manufacturers, price markups and markdowns, etc. The evaluation team focused its efforts in removing outliers whose price was too low for a given efficiency. This was done by investigating the systems at the cost-efficiency frontier and evaluating whether their price is consistent with the features provided. In particular, the team considered whether the stated SEER rating was reasonable relative to the price of the system. The evaluation team considered the price of the system relative to similar systems to determine if the system was an outlier or not.

The team removed outlier systems from the analysis and the outliers did not play a role in setting the cost-efficiency frontiers. In total, the team identified 17 systems as outliers and removed them from the analysis. The plots presented in the Key Findings section distinguish these outliers from other data points.

Plotting the Cost-Efficiency Frontier

The evaluation team determined the cost to achieve a certain efficiency based on the concept of a cost-efficiency frontier. The cost-efficiency frontier is the minimum incremental price required to achieve a given efficiency. To determine the cost-efficiency frontier, the team used a “waterfall” approach: a) the highest efficiency available is determined; b) the least expensive system at the highest efficiency is selected as the cost-efficiency frontier at that efficiency; c) then, for each efficiency lower than the maximum, the cost-efficiency frontier is defined as the lowest price available at that efficiency for the next efficiency level above. With this definition, the cost-efficiency frontier cannot decrease as the efficiency goes up. In other words, the cost-efficiency frontier either remains constant or goes up as the efficiency goes up. The process is illustrated in Figure 30.

Figure 30. "Waterfall" process to determine the cost-efficiency frontier



The evaluation team created separate cost-efficiency frontiers for SEER and HSPF.

Key Findings

This section presents the key findings from the evaluation team's webscraping of retail DMSHP system prices. Each of the system types we analyzed is presented in a sub-section below. For each system type, we present the following information:

- Charts that show the cost-efficiency data and the cost-efficiency frontier. Separate charts are provided for SEER and HSPF, and for regular and cold climate systems, with a total of four charts per subsection. The outliers, which were ignored in the analysis, are shown in different format so they are clearly identifiable.
- Two tables (regular and cold climate) showing the cost-efficiency frontier in absolute terms and in terms of incremental cost. Each table shows the SEER frontier and the HSPF frontier for that product type.

The findings begin on the following page.

Wall-mount, 9.0 ± 1.5 kBtu/h, 1 zone

Figure 31. Cost and cost-efficiency frontier for 9 kBtu/h single-zone wall-mounted systems

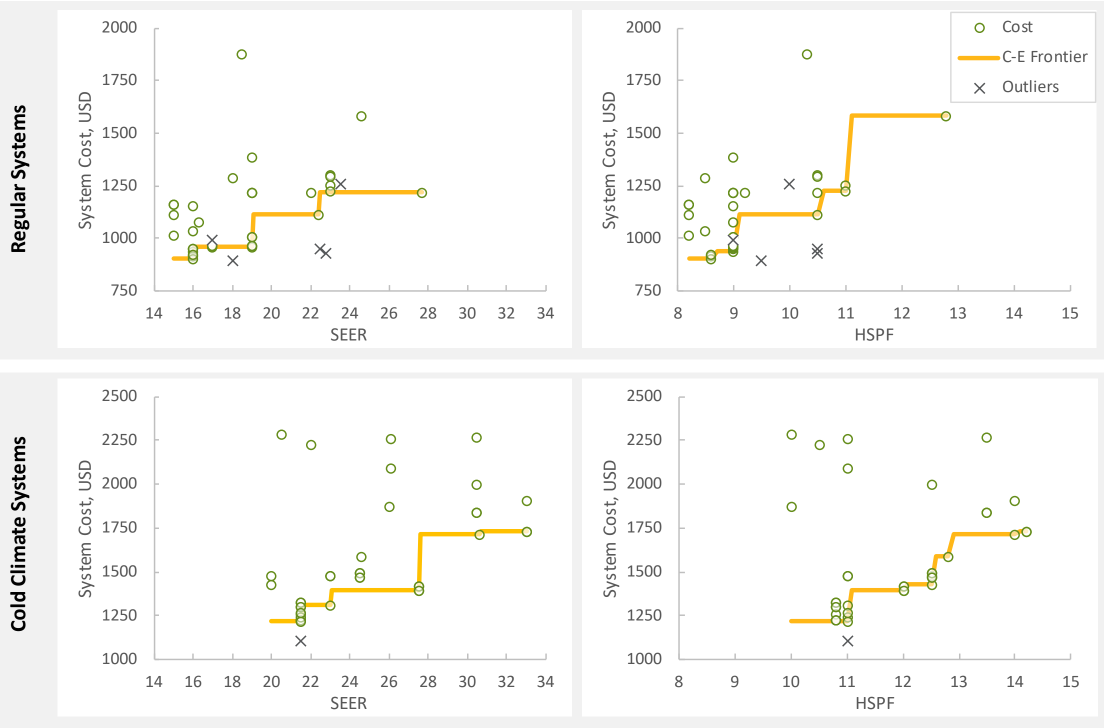


Table 23. Cost-efficiency frontier for regular systems, 9 kBtu/h

SEER Range	Frontier Price	Incremental Price from Lowest SEER	HSPF Range	Frontier Price	Incremental Price from Lowest HSPF
15 – 16	$909	-	8.2 – 8.6	$909	-
16.1 – 19	$959	$50	8.7 – 9	$943	$34
19.1 – 22.4	$1,113	$205	9.1 – 10.5	$1,113	$205
22.5 – 27.7	$1,222	$314	10.6 – 11	$1,229	$320
			11.1 – 12.8	$1,586	$677

Table 24. Cost-efficiency frontier for cold climate systems, 9 kBtu/h

SEER Range	Frontier Price	Incremental Price from Lowest SEER	HSPF Range	Frontier Price	Incremental Price from Lowest HSPF
20 – 21.5	$1,219	-	10 – 11	$1,219	-
21.6 – 23	$1,314	$95	11.1 – 12	$1,397	$178
23.1 – 27.5	$1,397	$178	12.1 – 12.5	$1,434	$215
27.6 – 30.6	$1,717	$498	12.6 – 12.8	$1,586	$367
30.7 – 33	$1,728	$510	12.9 – 14	$1,717	$498
			14.1 – 14.2	$1,728	$510

Wall-mount, 12.0 ± 1.5 kBtu/h, 1 zone

Figure 32. Cost and cost-efficiency frontier for 12 kBtu/h single-zone wall-mounted systems

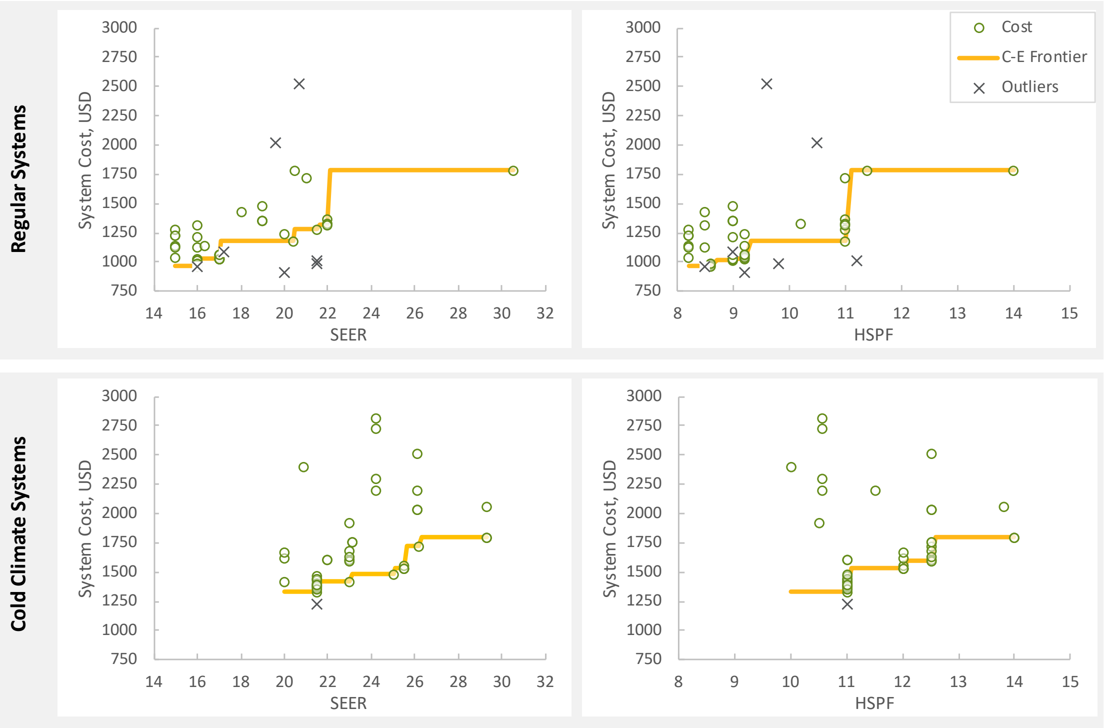


Table 25. Cost-efficiency frontier for regular systems, 12 kBtu/h

SEER Range	Frontier Price	Incremental Price from Lowest SEER	HSPF Range	Frontier Price	Incremental Price from Lowest HSPF
15 – 16	$969	-	8.2 – 8.6	$969	-
16.1 – 17	$1,027	$58	8.7 – 9	$1,021	$52
17.1 – 20.4	$1,176	$208	9.1 – 9.2	$1,029	$60
20.5 – 21.5	$1,281	$313	9.3 – 11	$1,176	$208
21.6 – 22	$1,317	$348	11.1 – 14	$1,780	$812
22.1 – 30.5	$1,780	$812			

Table 26. Cost-efficiency frontier for cold climate systems, 12 kBtu/h

SEER Range	Frontier Price	Incremental Price from Lowest SEER	HSPF Range	Frontier Price	Incremental Price from Lowest HSPF
20 – 21.5	$1,329	-	10 – 11	$1,329	-
21.6 – 23	$1,421	$92	11.1 – 12	$1,528	$199
23.1 – 25	$1,479	$150	12.1 – 12.5	$1,603	$274
25.1 – 25.5	$1,528	$199	12.6 – 14	$1,797	$469
25.6 – 26.2	$1,722	$393			
26.3 – 29.3	$1,797	$469			

Wall-mount, 24.0 ± 3.0 kBtu/h, 1 zone

Figure 33. Cost and cost-efficiency frontier for 24 kBtu/h single-zone wall-mounted systems

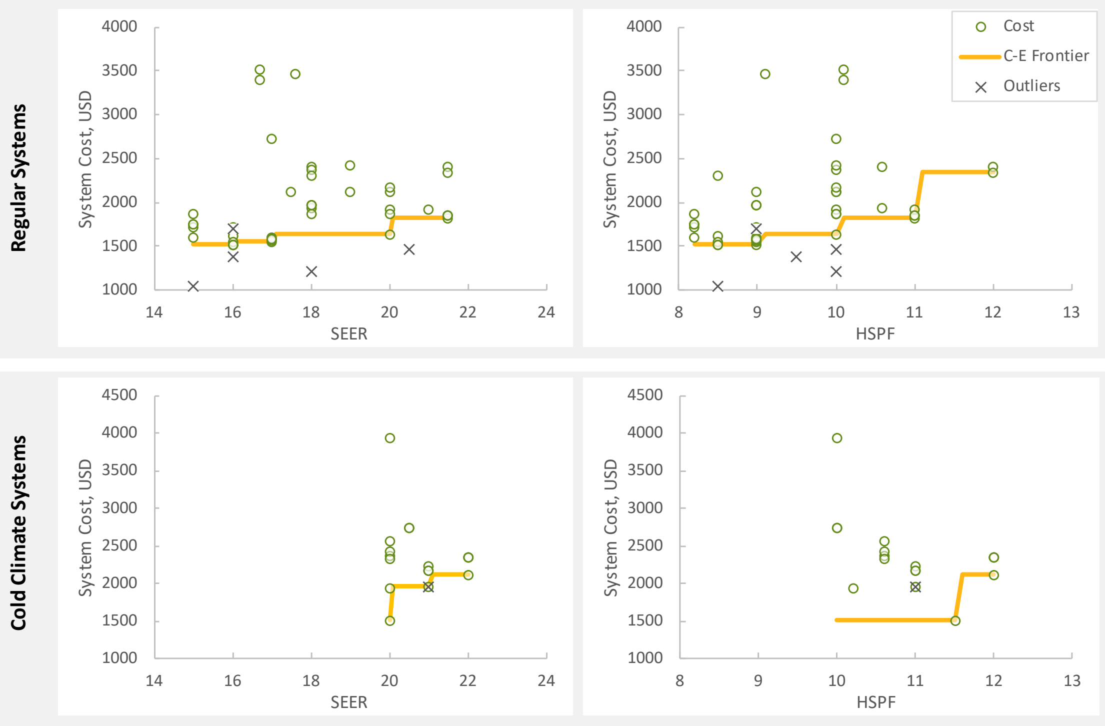


Table 27. Cost-efficiency frontier for regular systems, 24 kBtu/h, 1 zone

SEER Range	Frontier Price	Incremental Price from Lowest SEER	HSPF Range	Frontier Price	Incremental Price from Lowest HSPF
15 – 16	$1,529	-	8.2 – 8.5	$1,529	-
16.1 – 17	$1,559	$30	8.6 – 9	$1,532	$3
17.1 – 20	$1,638	$110	9.1 – 10	$1,638	$110
20.1 – 21.5	$1,820	$291	10.1 – 11	$1,820	$291
			11.1 – 12	$2,341	$812

Table 28. Cost-efficiency frontier for cold climate systems, 24 kBtu/h, 1 zone

SEER Range	Frontier Price	Incremental Price from Lowest SEER	HSPF Range	Frontier Price	Incremental Price from Lowest HSPF
20	$1,509	-	10 – 11.5	$1,509	-
20.1 – 21	$1,970	$460	11.6 – 12	$2,129	$619
21.1 – 22	$2,129	$619			

Wall-mount, 24.0 ± 3.0 kBtu/h, 2 zones

Figure 34. Cost and cost-efficiency frontier for 24 kBtu/h two-zone wall-mounted systems

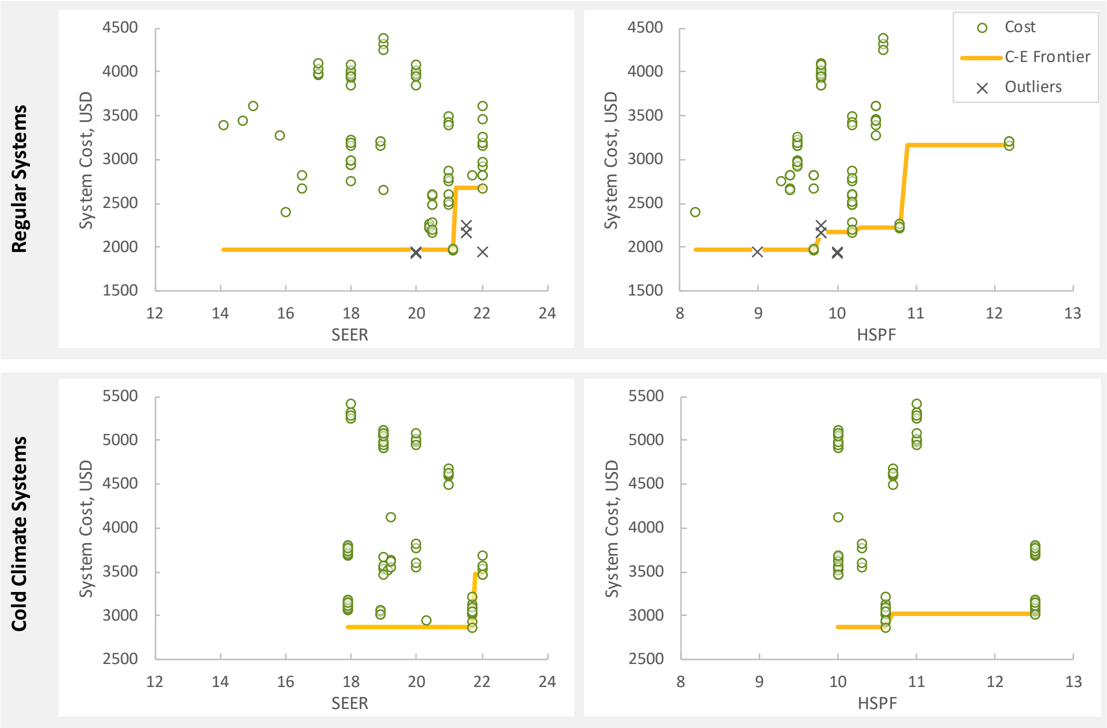


Table 29. Cost-efficiency frontier for regular systems, 24 kBtu/h, 2 zones

SEER Range	Frontier Price	Incremental Price from Lowest SEER	HSPF Range	Frontier Price	Incremental Price from Lowest HSPF
14.1 – 21.1	$1,974	-	8.2 – 9.7	$1,974	-
21.2 – 22	$2,680	$706	9.8 – 10.2	$2,180	$206
			10.3 – 10.8	$2,228	$254
			10.9 – 12.2	$3,170	$1,196

Table 30. Cost-efficiency frontier for cold climate systems, 24 kBtu/h, 2 zones

SEER Range	Frontier Price	Incremental Price from Lowest SEER	HSPF Range	Frontier Price	Incremental Price from Lowest HSPF
17.9 – 21.7	$2,870	-	10 – 10.6	$2,870	-
21.8 – 22	$3,473	$603	10.7 – 12.5	$3,025	$155

Wall-mount, 24.0 ± 3.0 kBtu/h, 3 zones

Figure 35. Cost and cost-efficiency frontier for 24 kBtu/h three-zone wall-mounted systems

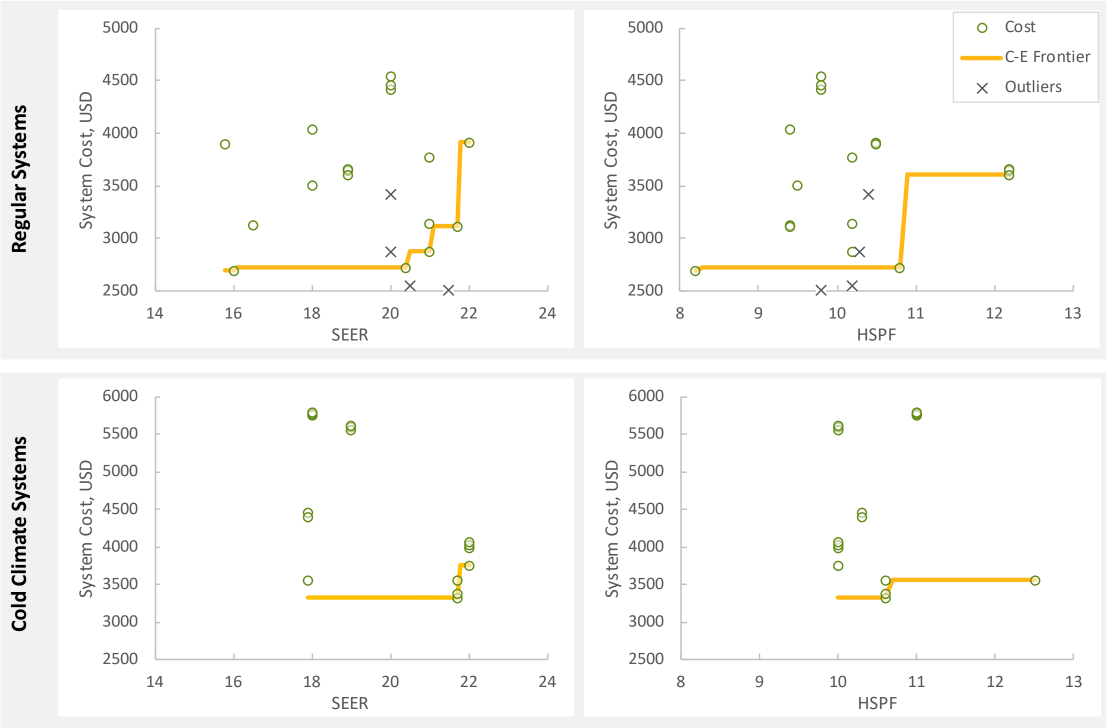


Table 31. Cost-efficiency frontier for regular systems, 24 kBtu/h, 3 zones

SEER Range	Frontier Price	Incremental Price from Lowest SEER	HSPF Range	Frontier Price	Incremental Price from Lowest HSPF
15.8 – 16	$2,697	-	8.2	$2,697	-
16.1 – 20.4	$2,721	$25	8.3 – 10.8	$2,721	$25
20.5 – 21	$2,877	$180	10.9 – 12.2	$3,610	$913
21.1 – 21.7	$3,115	$418			
21.8 – 22	$3,922	$1,225			

Table 32. Cost-efficiency frontier for cold climate systems, 24 kBtu/h, 3 zones

SEER Range	Frontier Price	Incremental Price from Lowest SEER	HSPF Range	Frontier Price	Incremental Price from Lowest HSPF
17.9 – 21.7	$3,330	-	10 – 10.6	$3,330	-
21.8 – 22	$3,761	$431	10.7 – 12.5	$3,556	$226

Wall-mount, 30.0 ± 3.0 kBtu/h, 3 zones

Figure 36. Cost and cost-efficiency frontier for 30 kBtu/h three-zone wall-mounted systems

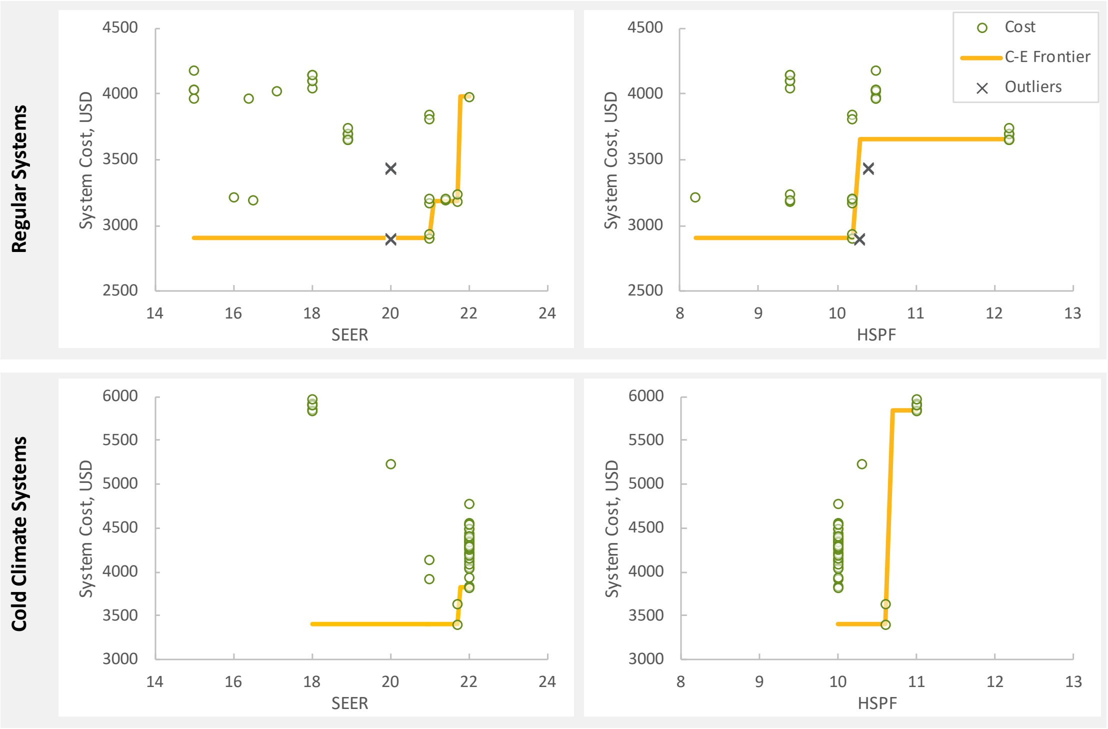


Table 33. Cost-efficiency frontier for regular systems, 30 kBtu/h, 3 zones

SEER Range	Frontier Price	Incremental Price from Lowest SEER	HSPF Range	Frontier Price	Incremental Price from Lowest HSPF
15 – 21	$2,908	-	8.2 – 10.2	$2,908	-
21.1 – 21.7	$3,188	$280	10.3 – 12.2	$3,658	$750
21.8 – 22	$3,981	$1,073			

Table 34. Cost-efficiency frontier for cold climate systems, 30 kBtu/h, 3 zones

SEER Range	Frontier Price	Incremental Price from Lowest SEER	HSPF Range	Frontier Price	Incremental Price from Lowest HSPF
18 – 21.7	$3,410	-	10 – 10.6	$3,410	-
21.8 – 22	$3,821	$411	10.7 – 11	$5,845	$2,435

Wall-mount, 36.0 ± 3.0 kBtu/h, 4 zones

Figure 37. Cost and cost-efficiency frontier for 36 kBtu/h four-zone wall-mounted systems

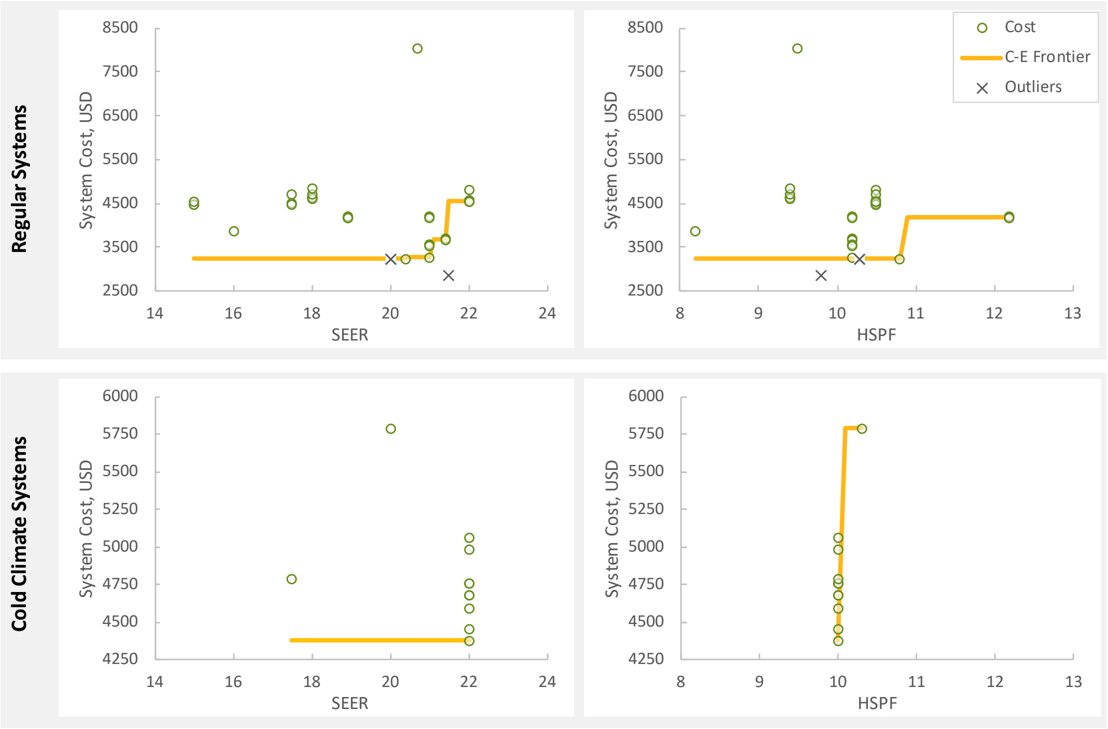


Table 35. Cost-efficiency frontier for regular systems, 36 kBtu/h, 4 zones

SEER Range	Frontier Price	Incremental Price from Lowest SEER	HSPF Range	Frontier Price	Incremental Price from Lowest HSPF
15 – 20.4	$3,233	-	8.2 – 10.8	$3,233	-
20.5 – 21	$3,287	$54	10.9 – 12.2	$4,189	$956
21.1 – 21.4	$3,688	$455			
21.5 – 22	$4,542	$1,309			

Table 36. Cost-efficiency frontier for cold climate systems, 36 kBtu/h, 4 zones

SEER Range	Frontier Price	Incremental Price from Lowest SEER	HSPF Range	Frontier Price	Incremental Price from Lowest HSPF
17.5 – 22	$4,380	-	10	$4,380	-
			10.1 - 10.3	$5,790	$1,410

NAVIGANT

Memorandum

To: Massachusetts Program Administrators and Energy Efficiency Advisory Council

From: Danielle Vitoff, Terese Decker, and Justin Spencer, Navigant

Date: March 30, 2018

Re: Quick Hit Study: Ductless Mini-Split Heat Pump Survey (RES 29)

Study Background

Through the Mass Save® Heating and Cooling program, Massachusetts residential customers are offered prescriptive rebates for the installation of qualifying ductless mini-split heat pump (DMSHP) systems. The 2016 program qualifications for DMSHP systems are presented in Table 1.

Table 1. 2016 Mass Save DMSHP Qualifications

Qualifying Products	SEER	EER	HSPF	Rebate Amount (per indoor unit)
Mini-Split Heat Pump	≥18	N/A	≥10	$100
Mini-Split Heat Pump	≥20	N/A	≥12	$300

Source: Mass Save: https://www.masssave.com/en/saving/residential-rebates/electric-heating-and-cooling/#title4

In 2014, a Navigant evaluation team conducted a web survey of participants who had received incentives for installing DMSHPs.[1] The purpose of the previous survey was to understand participant motivations for participating in the program and how the DMSHP equipment was being used. From the survey results, the evaluation team was planning to determine the appropriate baseline for program incentivized DMSHPs. The web survey, which included responses from 430 participants, determined that 74% of participants installed their DMSHPs for both heating and cooling, while 24% of participants installed their DMSHPs for cooling only and only 1% installed their DMSHPs for heating only.

To further investigate the energy savings associated with the installation of DMSHPs, the Massachusetts Program Administrators (PAs) and the Energy Efficiency Advisory Council (EEAC)

---

[1] While much the same population, in 2014 DMSHP rebates were distributed under the COOL SMART program (which has been renamed the Heating and Cooling Program) and rebate qualifying specifications were different. The results of the web survey are reported in the *Ductless Mini-Split Heat Pump Customer Survey Results* report dated September 2014 and available here: http://ma-eeac.org/wordpress/wp-content/uploads/Ductless-Min-Split-Heat-Pump-Customer-Survey-Results1.pdf

directed a Cadmus evaluation team to complete a metering study of DMSHP program participants. Many of the inputs currently used to calculate the energy savings associated with rebated DMSHPs, in other words the EFLH value of 451, are derived from the *Ductless Mini-Split Heat Pump Impact Evaluation* completed in 2016.[2] Among other findings, the Cadmus study found a heating Equivalent Full Load Hour (EFLH) value for DMSHPs that was consistent with the Massachusetts TRM, but was lower than expected by program managers and the evaluation team. The heating EFLH values resulting from the 2016 Cadmus study are presented in Table 2.

Table 2. DMSHP Heating EFLHs

Population Description	EFLHs
MA TRM	447
Population average from winter 2016 metering	451
Population top 25% from winter 2016 metering	1,117

Source: Ductless Mini-Split Heat Pump Impact Evaluation, December 30, 2016, pg 144

Heating & Cooling Program Changes

Using DMSHPs more regularly as a primary source of home heating was determined to be beneficial to the customer and the Commonwealth. As a result, in 2017, the Heating and Cooling program began adopting changes to encourage greater use of the rebated DMSHPs for heating and support a higher EFLH value. The enacted program changes include:

- Changing the rebate structure so it is based on the number of indoor heads, instead of outdoor condensers, with no maximum number of heads rebated per home. This change was meant to encourage multi-head and whole-house heating.
- Increasing the HSPF from 9 to 11 to 10 and 12 to encourage cold climate systems.
- Adding consumer education information to the rebate form, including information around their heating function.
- Revising the program website (https://www.masssave.com/en/saving/residential-rebates/electric-heating-and-cooling/) to highlight that DMSHPs can be used to heat the whole home and how to best use DMSHPs, e.g. what temperature to switch to a backup system and not to use setbacks.
- Developing co-branded marketing materials with MassCEC and adding a link to MassCEC mini-split rebates on www.masssave.com.
- Emphasizing DMSHP whole-house heating solutions during contractor trainings

Together, the changes adopted by the Heating and Cooling program were expected to result in higher heating use for rebated DMSHP systems. This study, referred to as RES 29, was designed to test this hypothesis.

Research Approach

The primary research question explored by the RES 29 study was as follows: Have any recent changes to the DMSHP program resulted in changes to how participants use their installed DMSHP equipment, specifically whether they are using their DMSHPs more for heating? This question was assessed through a participation survey, which mirrored the participant survey (and in many cases replicated questions from the survey) completed in 2014. The evaluation team planned to compare

---

[2] http://ma-eeac.org/wordpress/wp-content/uploads/Ductless-Mini-Split-Heat-Pump-Impact-Evaluation.pdf

results between the two surveys to understand differences in participant activities resulting from program changes.

Because the evaluation team was already going through the effort of developing and fielding a participant survey, it was decided to collect data on a series of secondary research questions, all of which had been addressed in the previous survey effort:

- Why do participants buy DMSHPs?
- Do DMSHP incentives induce replacement or displacement of existing heating and/or cooling equipment?
- What types of equipment do DMSHPs primarily replace/displace?
- What other types of heating and cooling equipment do customers use in addition to DMSHPs?
- What motivates the purchase of the make/model of equipment ultimately installed in a participant's home?
- How do participant use patterns vary, per their primary motivation for purchasing units (e.g., adding cooling to increase occupant comfort, adding heating to increase occupant comfort, displacing other cooling sources to improve convenience and/or reduce cooling costs, displacing other heat sources to reduce heating costs)?
- What information about using their system did the owners receive from their contractors, and how did that information affect their use of their system?

Comparing the answers to the secondary research questions between the two survey populations also provided the evaluation team a more complete picture of the survey respondents allowing for a more thorough understanding of the reason for any changes in the program populations. Note that the secondary research question findings are not discussed in detail within this memorandum, as no differences from the 2014 survey results were identified. The complete results from all survey questions are included as an appendix.

Methodology

The evaluation team surveyed program participants via a web survey that very closely resembled the web based survey fielded in 2014. The population frame included 4,667 participants, all of whom had received rebates for DMSHPs in 2017. Emails were sent to a sample of 1,976 participants drawn from this population frame. In the email invite, participants were offered a $10 Amazon gift card for completion of the online survey. Of the sample that received email invites, 131 invites (6% of the sample) bounced-back, 1,291 invitees did not respond or complete the survey, and 554 participants (28% of the sample) completed the survey and received an incentive. The overall response rate for participants with valid emails was 30%.

Findings

The 2014 and 2017 customer surveys show almost identical results between the two participant populations for comparable questions, except for a few key differences highlighted in this report. In most cases the population distributions by category are within two percentage points for each of the categorical responses. Key demographical differences between the two survey populations are reported in Table 3

Table 3. Key Differences between 2014 and 2017 Survey Results

Category	Detailed Metric	2014 Study Result	2017 Study Result
Demographics	Single family homes	90%	92%
	Installation in primary residence *[For the 8% who indicated that the DMSHP was installed in a secondary residence, they also report spending more time in the secondary home than the previous survey.]*	89%	92%
Purchase Intent	In the absence of rebates or financing, respondent would have purchased a less expensive, less energy efficient DMSHP	7%	13%
Fuel Replaced	Heating for space had been served by natural gas	27%	34%
	Heating for space had been served by electric	11%	16%
	Heating for space had been served by oil *[NOTE: There was almost an exact match between the two surveys as to the distribution of rooms served and whether the space was heating or cooled before the DMSHP installation]*	46%	39%

Source: Navigant analysis of 2014 and 2017 DMSHP survey responses

By far, the most significant difference between the 2014 and 2017 survey responses is around how participants report using the DMSHPs (Table 4). In the 2014 survey, 75% of respondents indicated that they used their DMSHP for heating (either both heating and cooling or just heating). In the 2017 survey, 89% of survey respondents indicated that they used their DMSHP for heating, a 14% increase in heating use. This is directly related to a 14% decrease in cooling only use, from 25% in the 2014 survey to 11% in the 2017 survey.

Table 4. Is the DMSHP Used for Heating, Cooling, or Both

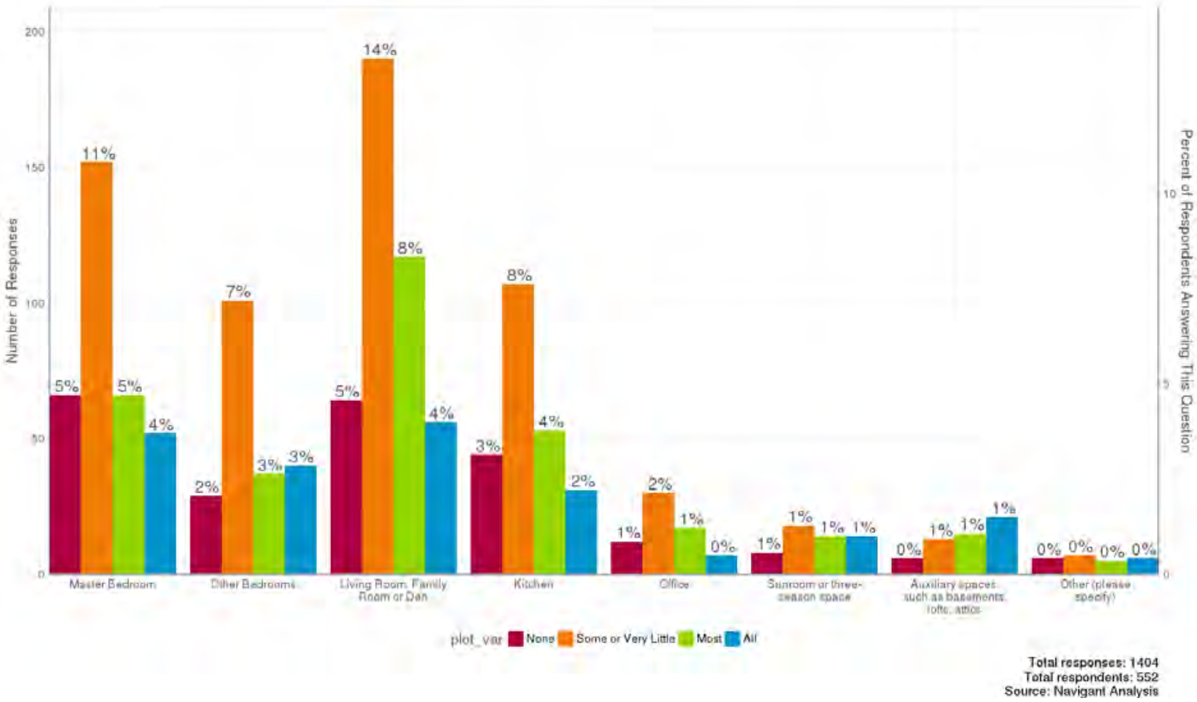
DMSHP Use	2014 Study Result	2017 Study Result
Both: Heating & Cooling	74%	88%
Cooling	25%	11%
Heating	1%	1%

Source: Navigant analysis of 2014 and 2017 DMSHP survey responses

The 2017 survey asked participants how much of their heating was provided by the DMSHP: all, most, some or very little, or no heating. The responses to this question, are reported by space type in Figure 1. Overall, only 38% of survey respondents indicated that they use their DMSHP for all or most of the heat in their space. As a corollary, over half of the survey respondents indicated that the DMSHP is used for some heating or less; in other words, most respondents are still using their DMSHP to supplement an existing primary heating system. It is important to note that the 2014 survey did not ask a similar question about the amount of heating supplied by the DMSHP.

The finding that DMSHPs are used as supplementary heating sources is supported by the fact that 94% of respondents indicated that they did not remove the previous system when the DMSHP was installed, which is the same as what was found in the 2014 survey. All together these results indicate a greater number of program participants in the 2017 population are using their rebated DMSHPs for heating, even if the DMSHPs may not be the primary heating sources.

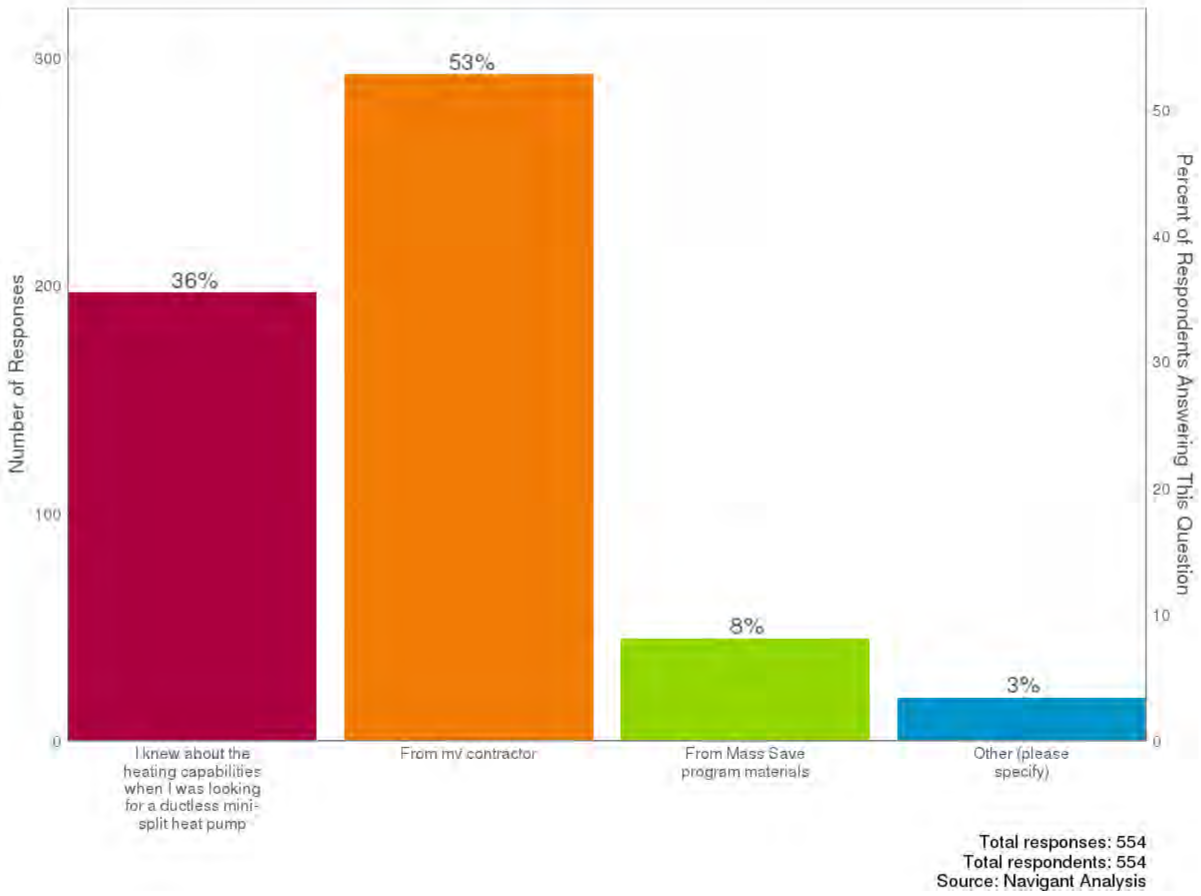
Figure 1. How Much Heating is Provided by the DMSHP, by Space



Source: Navigant analysis of 2017 DMSHP survey responses

The 2017 survey asked participants how they learned about the heating capabilities of the DMSHP system to understand if the program changes were working as designed. The majority of survey respondents (61%) indicated that they learned about the heating capabilities of the DMSHP from their contractor or Mass Save program materials, as illustrated in Figure 2. This result indicates that program design changes are resulting in more participants understanding the heating capabilities of the DMSHP systems, even if they may not be using the rebated systems as their primary heat source.

Figure 2. How Did Participants Learn About the Heating Capabilities of the DMSHP



Total responses: 554
Total respondents: 554
Source: Navigant Analysis

Source: Navigant analysis of 2017 DMSHP survey responses

Conclusions

The primary finding from this survey is that a larger percentage (89%) of 2017 program participants are using the DMSHPs rebated through the Mass Save Heating & Cooling Program for heating than 2014 program participants (75%). The survey results also indicate that the enacted program changes are resulting in a significant number of program participants learning about the heating capabilities of their DMSHPs through contractors and program materials.

Finding 1: Fifteen percent more program participants report using their DMSHPs for heating through the 2017 participant survey as compared to the 2014 survey.

Recommendation 1: The program should adjust the heating EFLH value used for calculating savings from DMSHPs as shown in Equation 1.

Equation 1. Heating EFLH Derivation

$$535 \text{ EFHL} = \{1+[(0.89-0.75)/0.75]\} \times 451$$

The evaluation team therefore recommends that the program use 535 EFLHs as the basis for estimating heating savings for DMSHPs, which is higher than the average (451 EFLH) derived from the 2016 metering study and currently being used by the PAs.

Finding 2: Sixty-one percent of survey respondents indicated that they learned about the heating capabilities of their DMSHP from their contractor or the Mass Save program.

Recommendation 2: The Mass Save Heating & Cooling program should continue enforcing the program changes enacted in 2016, as these program changes are resulting in higher heating usage of rebated DMSHPs.

Ductless Mini-Split Heat Pump Survey (RES 29)

mass save®

February 21, 2018

Prepared for:

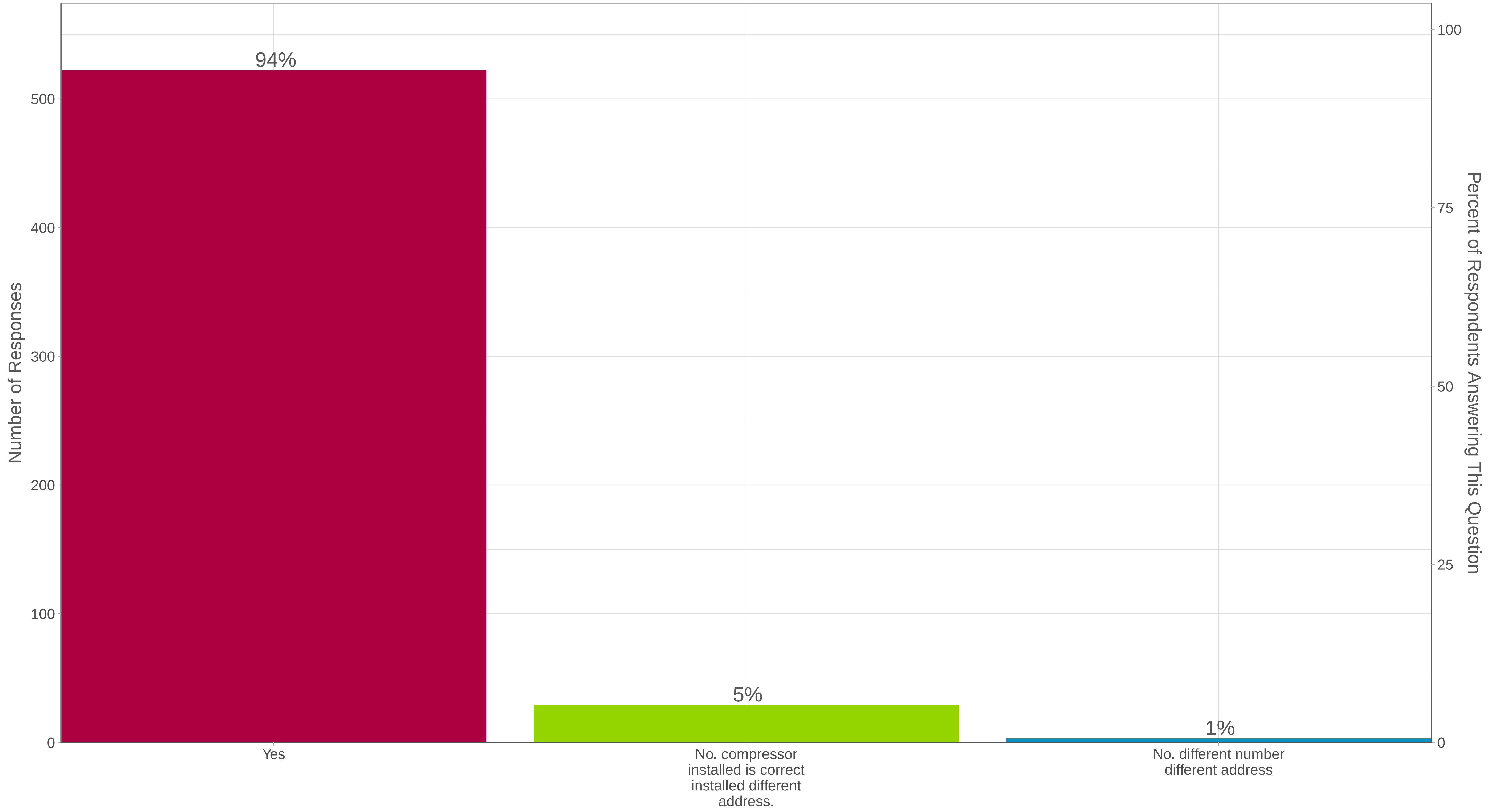
BERKSHIRE GAS
BLACKSTONE GAS COMPANY
Cape Light Compact
Columbia Gas of Massachusetts
A NiSource Company
EVERSOURCE
Liberty Utilities
nationalgrid
HERE WITH YOU. HERE FOR YOU.
Unitil
energy for life

Prepared by:
NAVIGANT

Contents

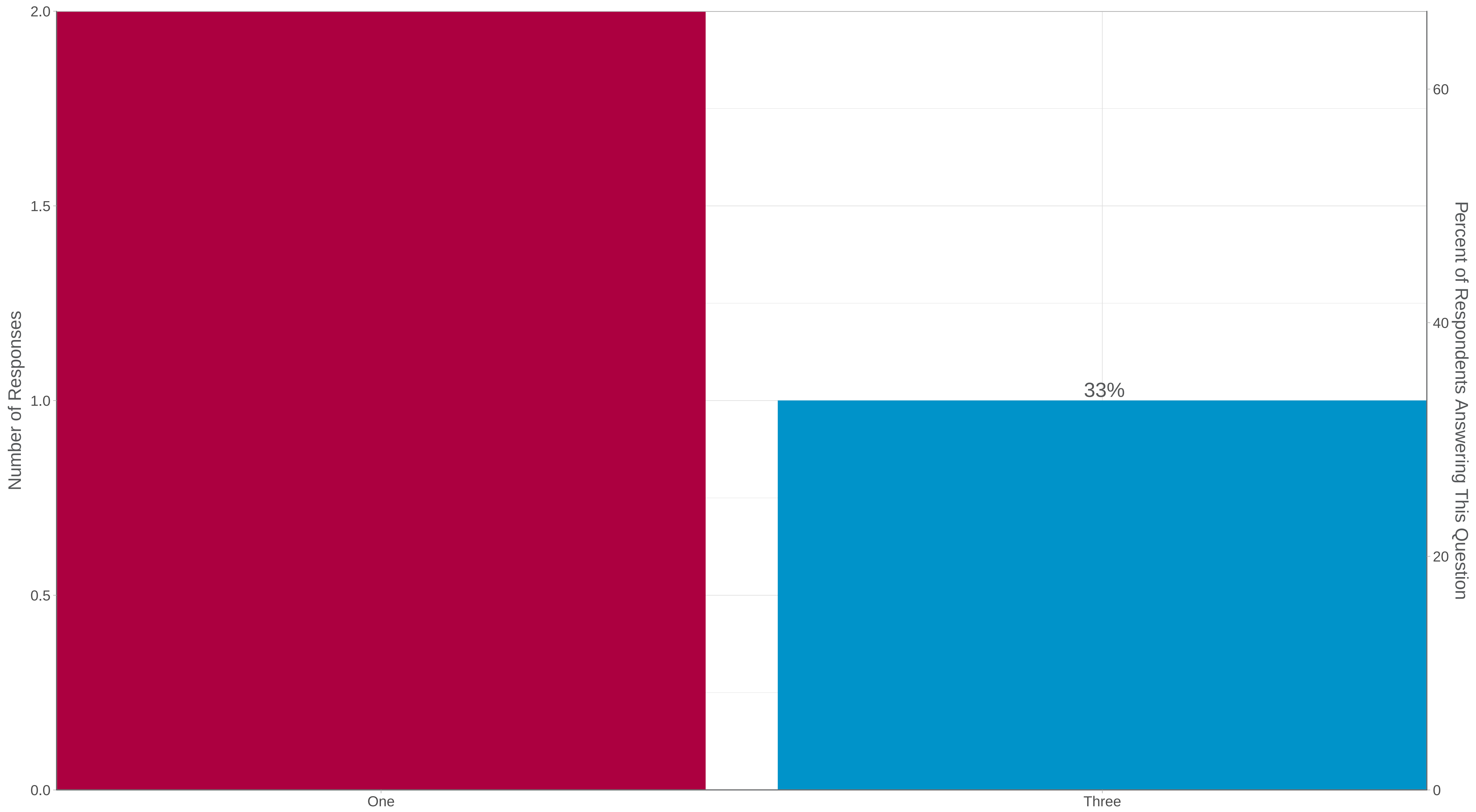
1 Survey Results

1.1 Question QI1a: Our records show that you received a rebate for installing ductless mini-split heat pump(s). Is this correct?



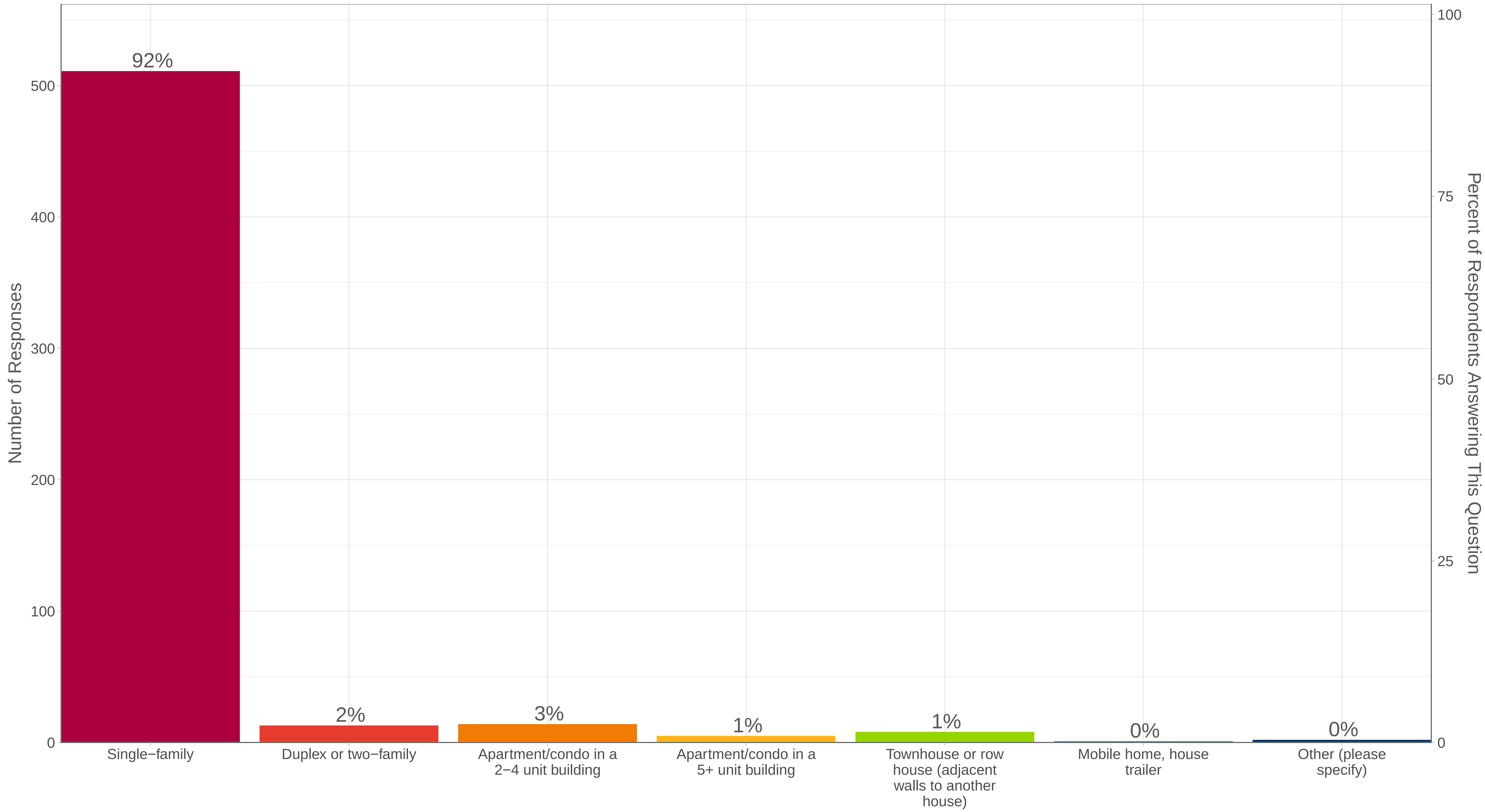
Total responses: 554
Total respondents: 554
Source: Navigant Analysis

1.2 Question Qlb: Can you please tell us for how many ductless mini-split heat pump outdoor compressor units you received a rebate at this address?



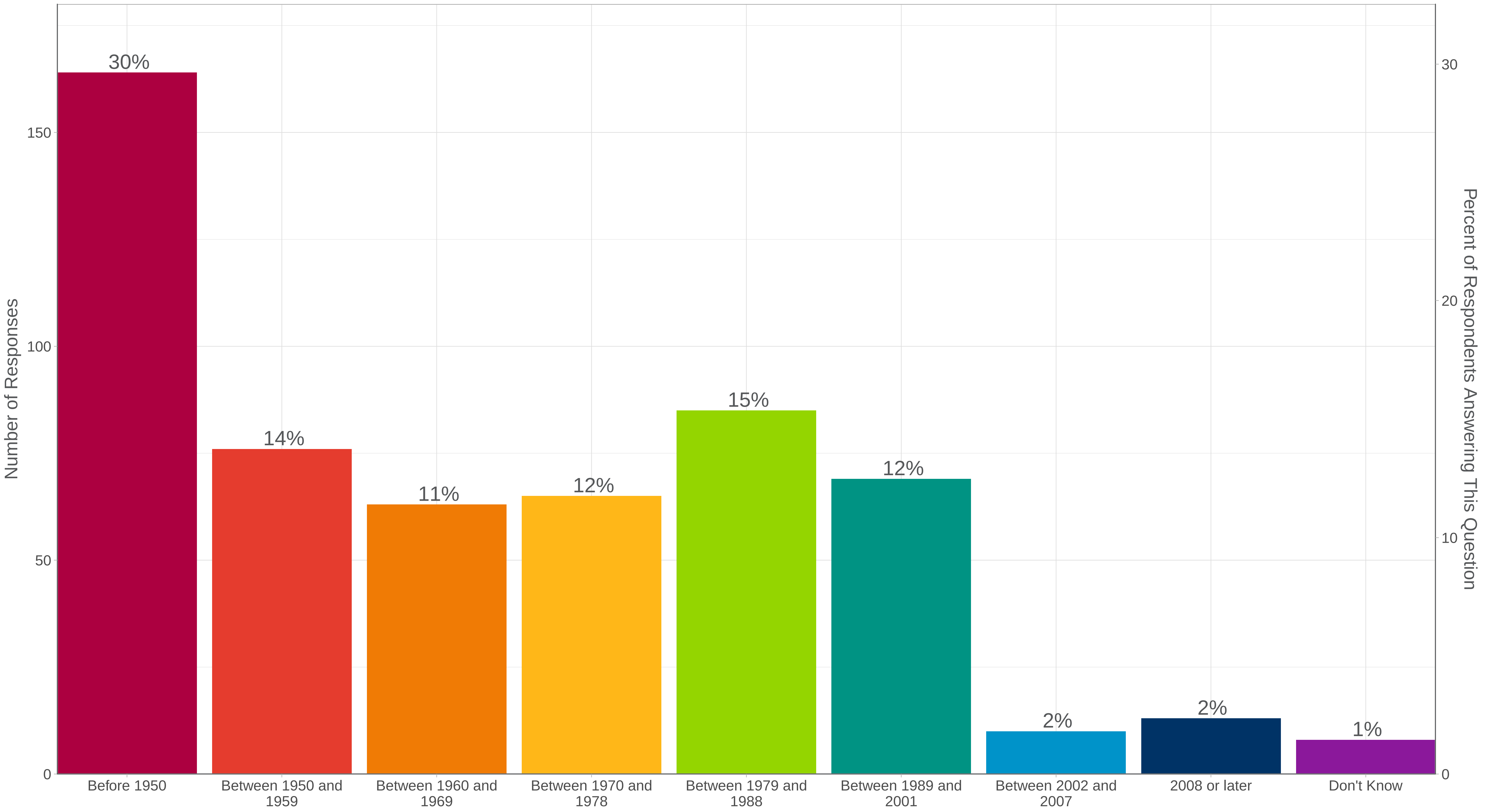
Total responses: 3
Total respondents: 3
Source: Navigant Analysis

1.3 Question QI2: What type of residence is this?



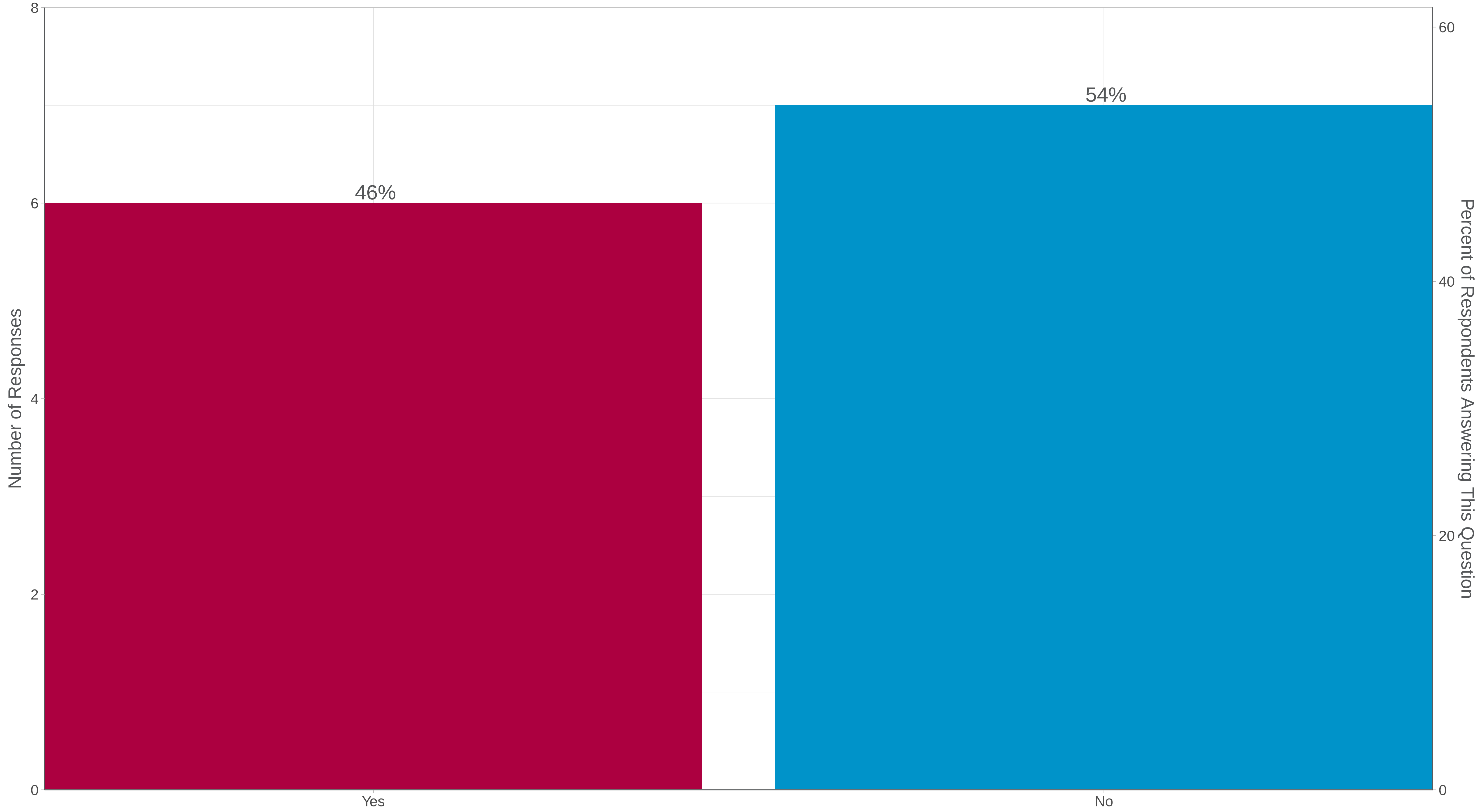
Total responses: 554
Total respondents: 554
Source: Navigant Analysis

1.4 Question QI3a: Approximately, when was this residence first built?



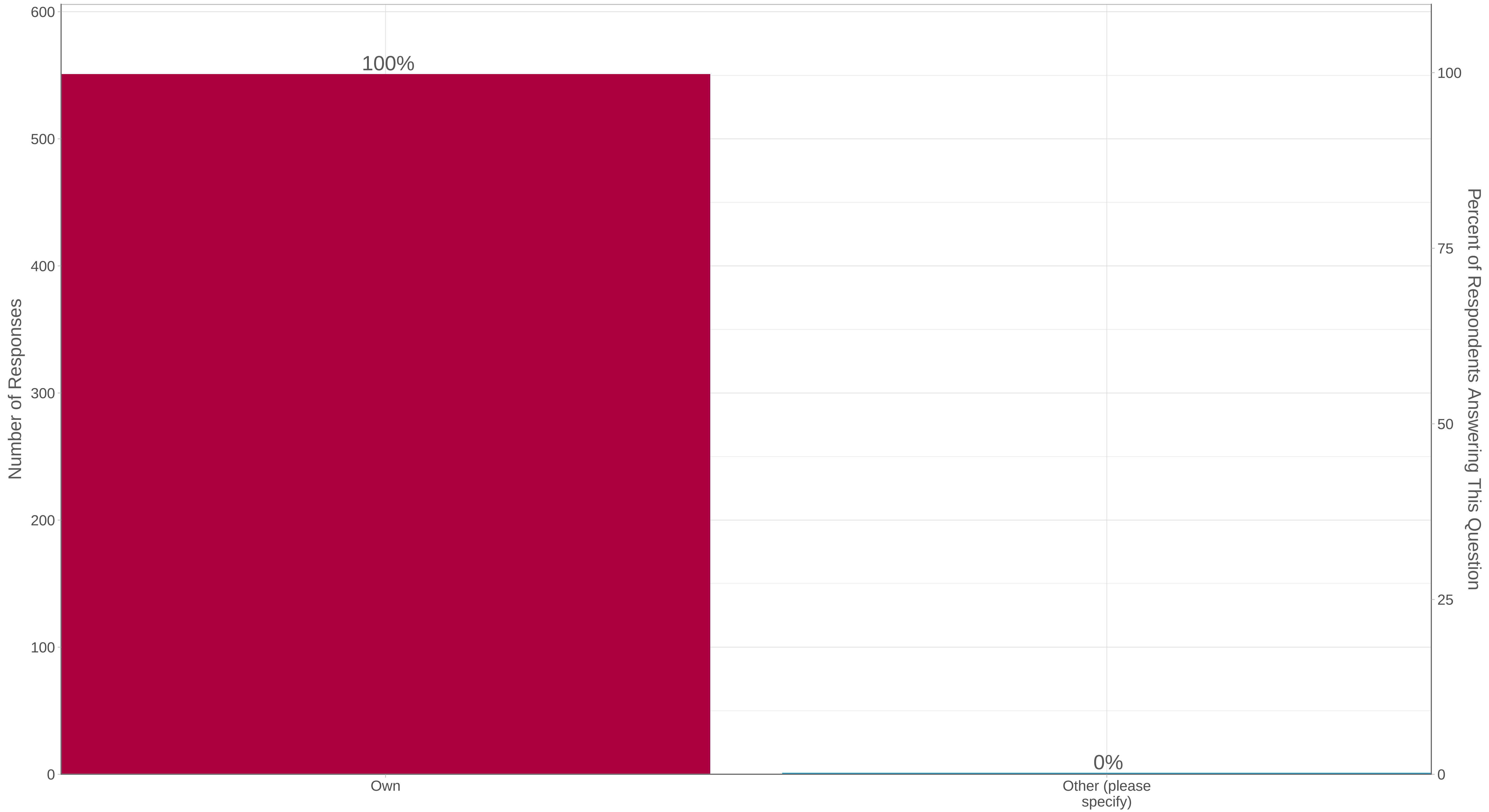
Total responses: 553
Total respondents: 553
Source: Navigant Analysis

1.5 Question QI3b: Was this ductless mini-split heat pump system installed during the course of a new construction or major renovation project?



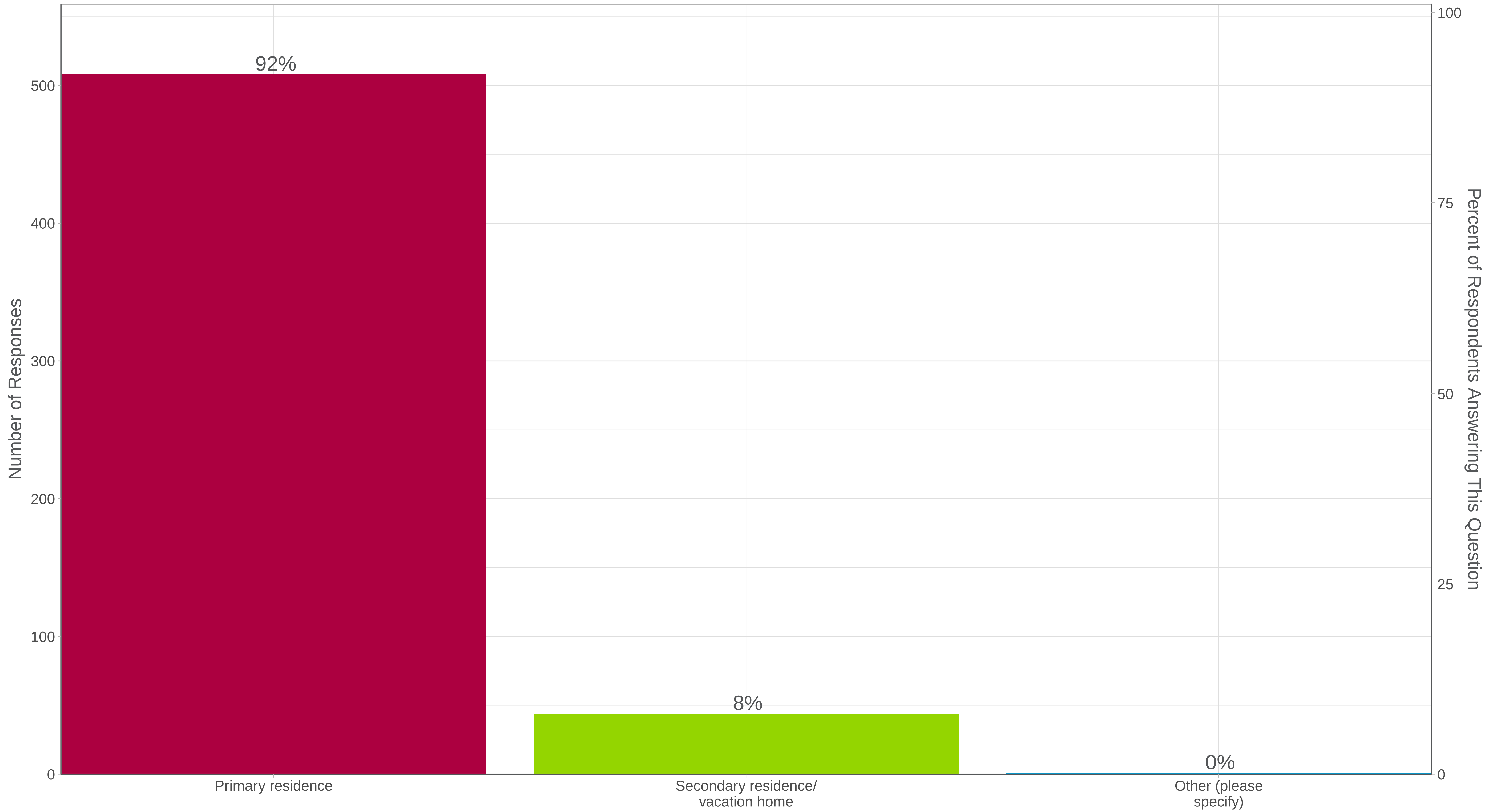
Total responses: 13
Total respondents: 13
Source: Navigant Analysis

1.6 Question QI4a: Do you own or rent this residence?



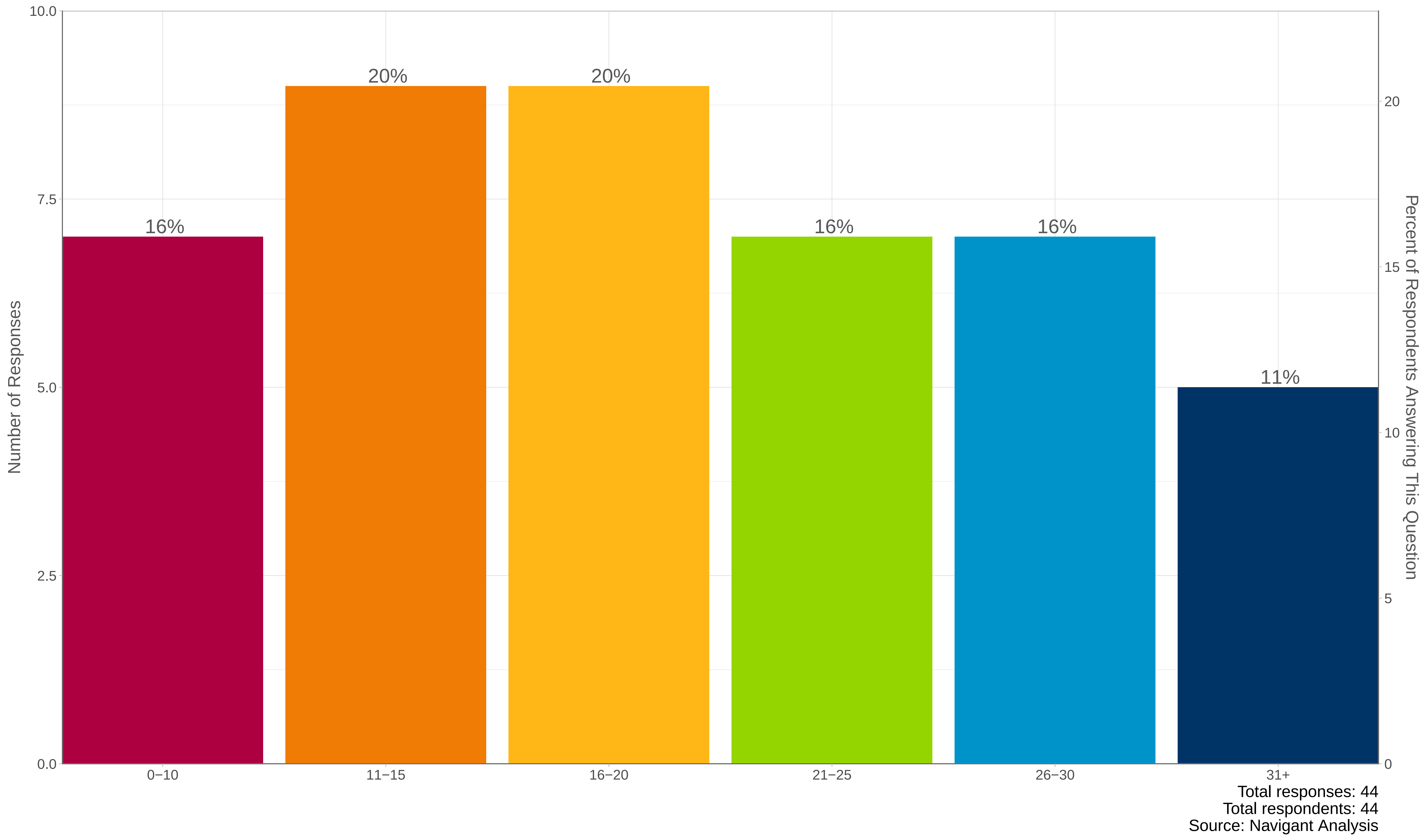
Total responses: 552
Total respondents: 552
Source: Navigant Analysis

1.7 Question QI4b: Is this your primary residence or a secondary residence/vacation home?



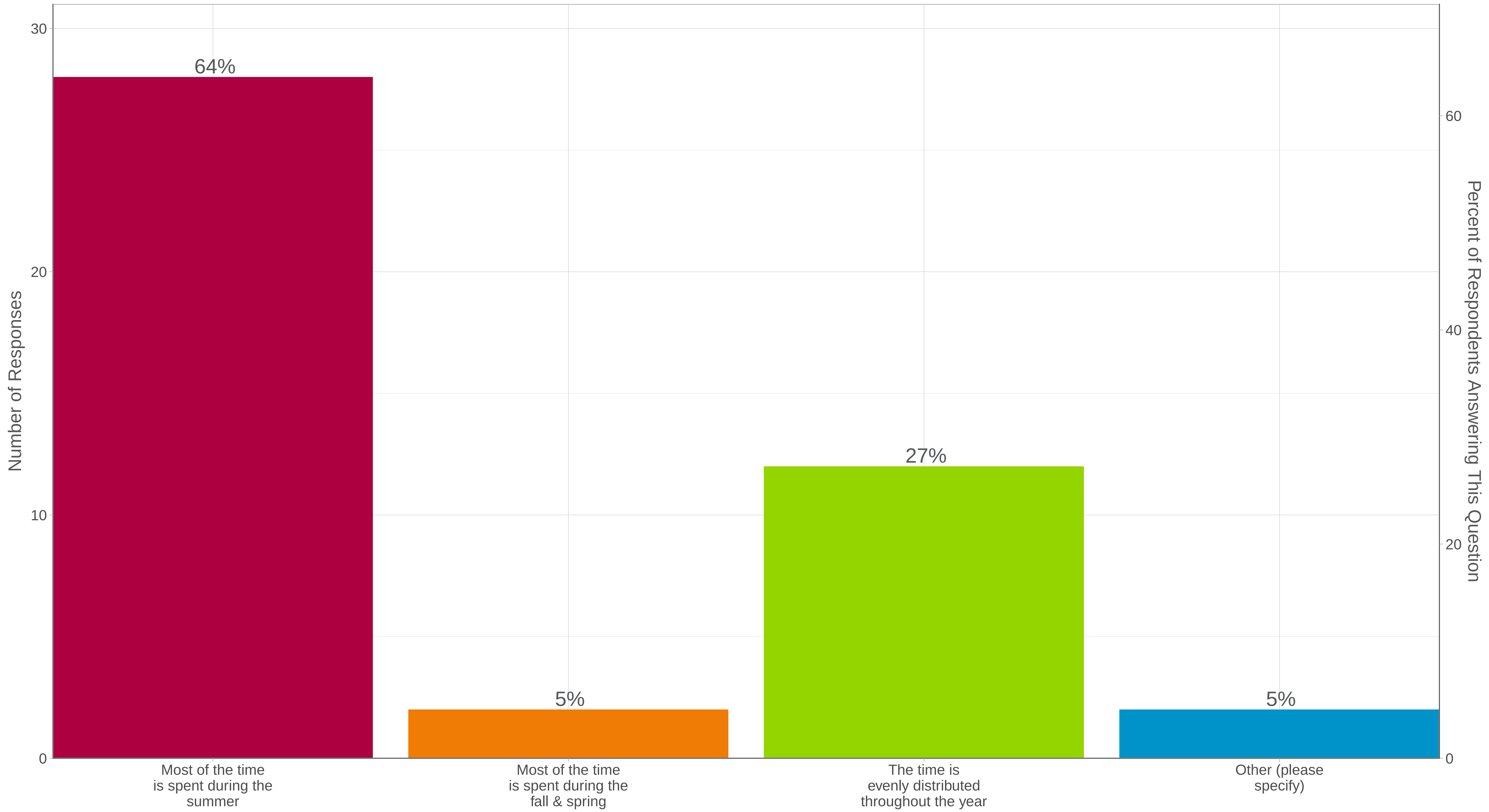
Total responses: 553
Total respondents: 553
Source: Navigant Analysis

1.8 Question QI4c: How much time, in weeks, do you spend in this secondary residence/vacation home per year? (weeks per year 0-52)



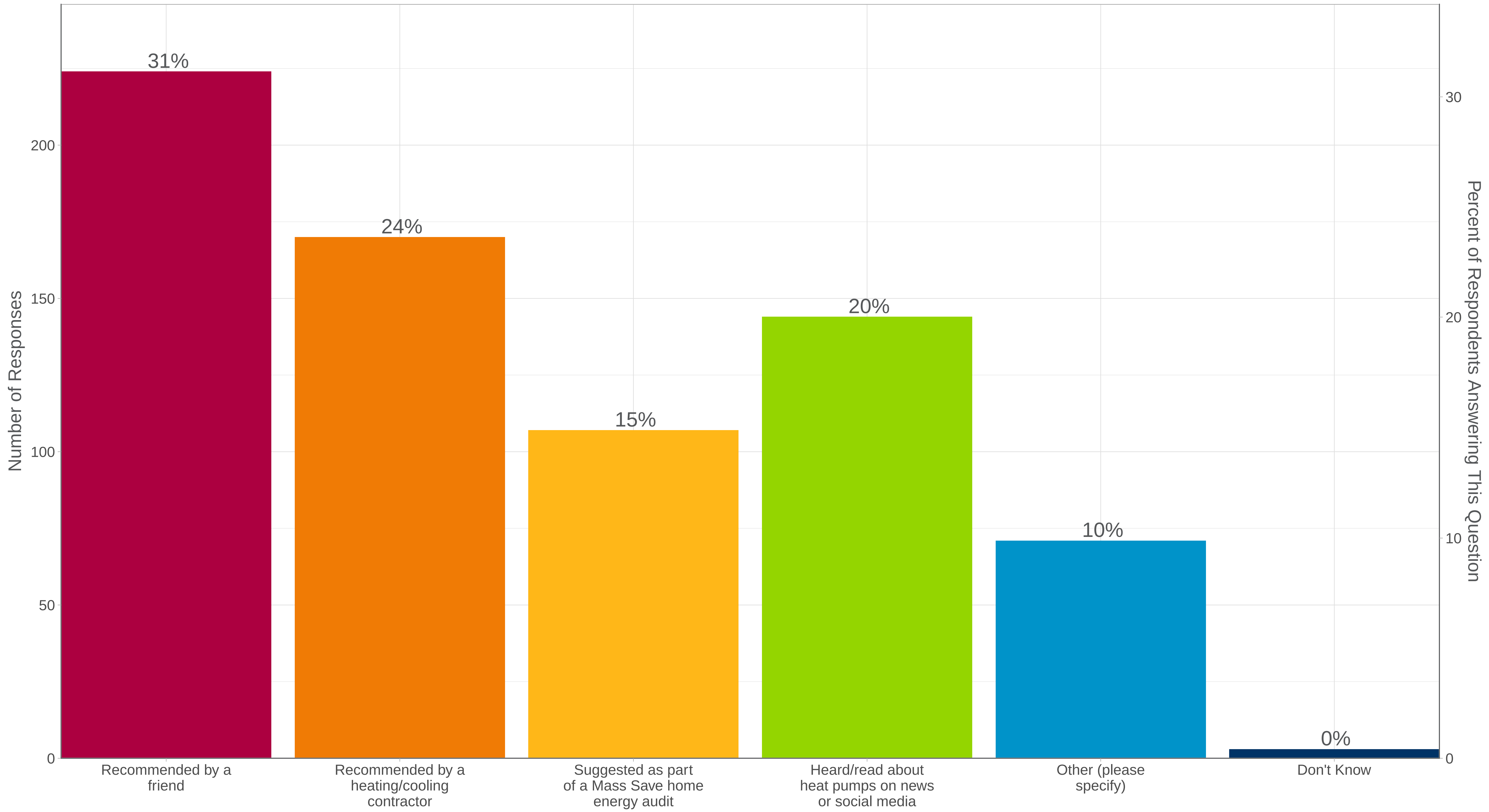
Total responses: 44
Total respondents: 44
Source: Navigant Analysis

1.9 Question QI4d: When do you spend this time in the secondary residence/vacation home?



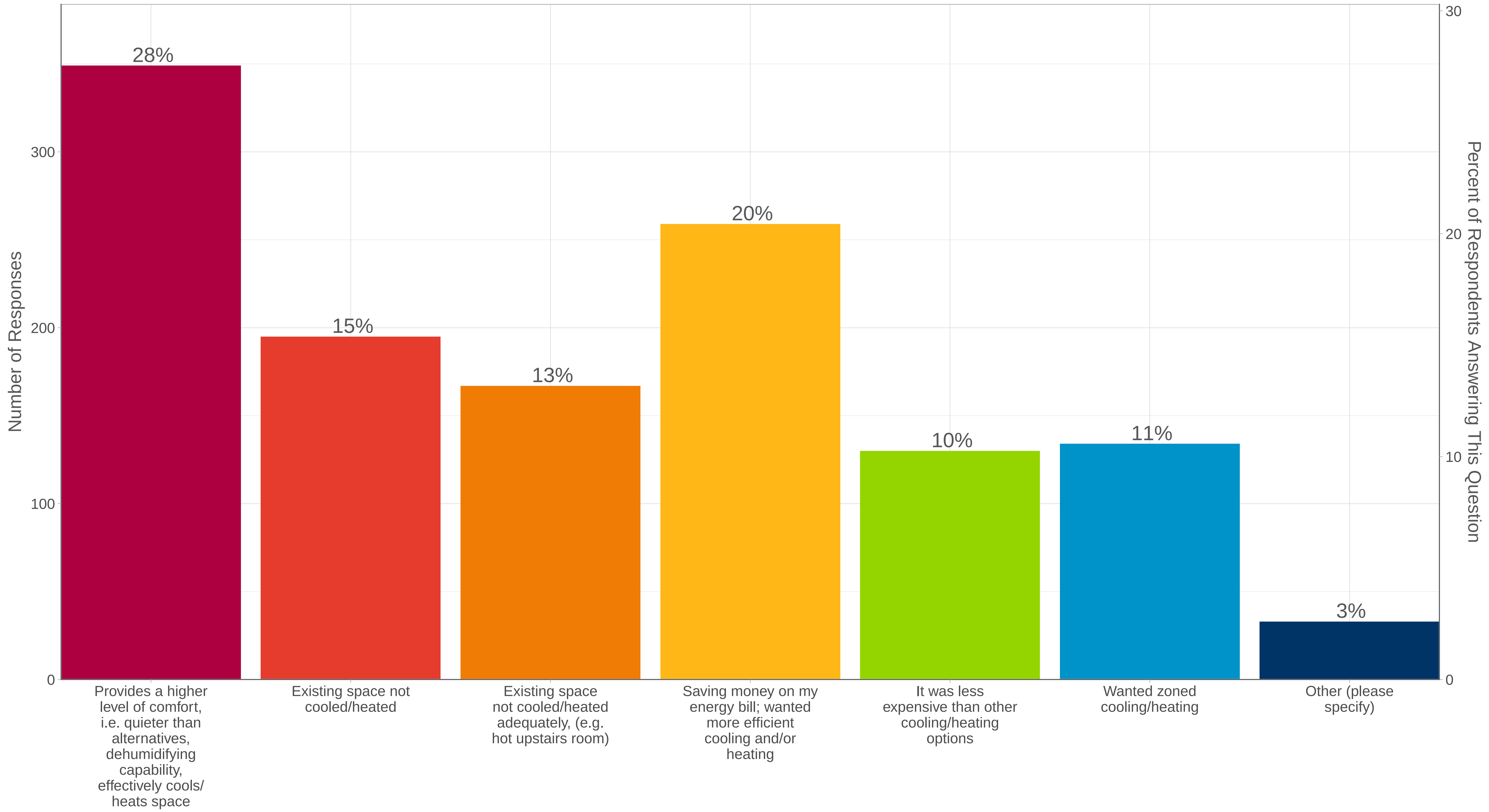
Total responses: 44
Total respondents: 44
Source: Navigant Analysis

1.10 Question QD1: How did you get the idea to install a ductless mini-split heat pump in this space? (Select all that apply)



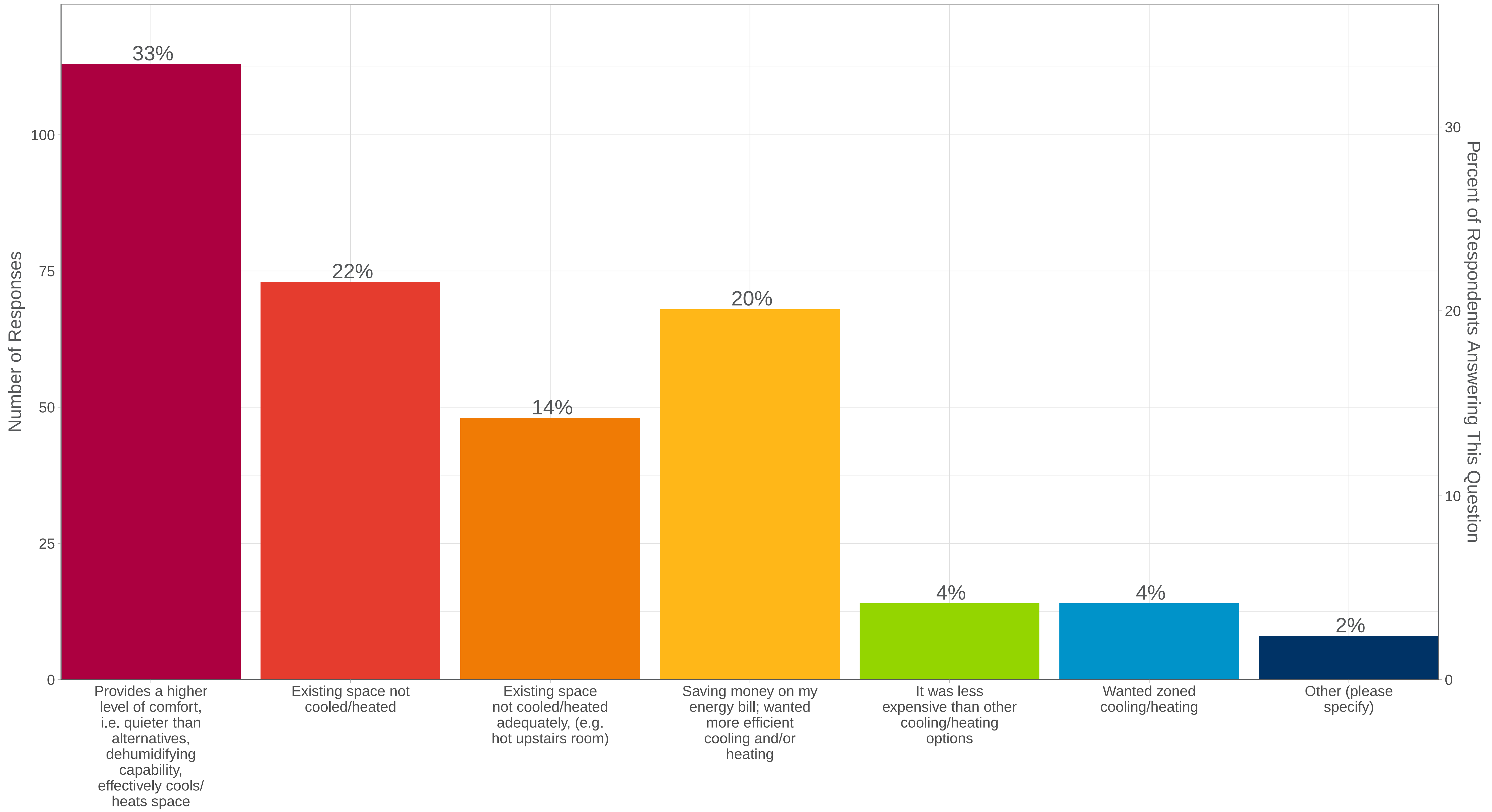
Total responses: 719
Total respondents: 554
Source: Navigant Analysis

1.11 Question QD2a: What were your reasons for purchasing a ductless mini-split heat pump? (Select all that apply)



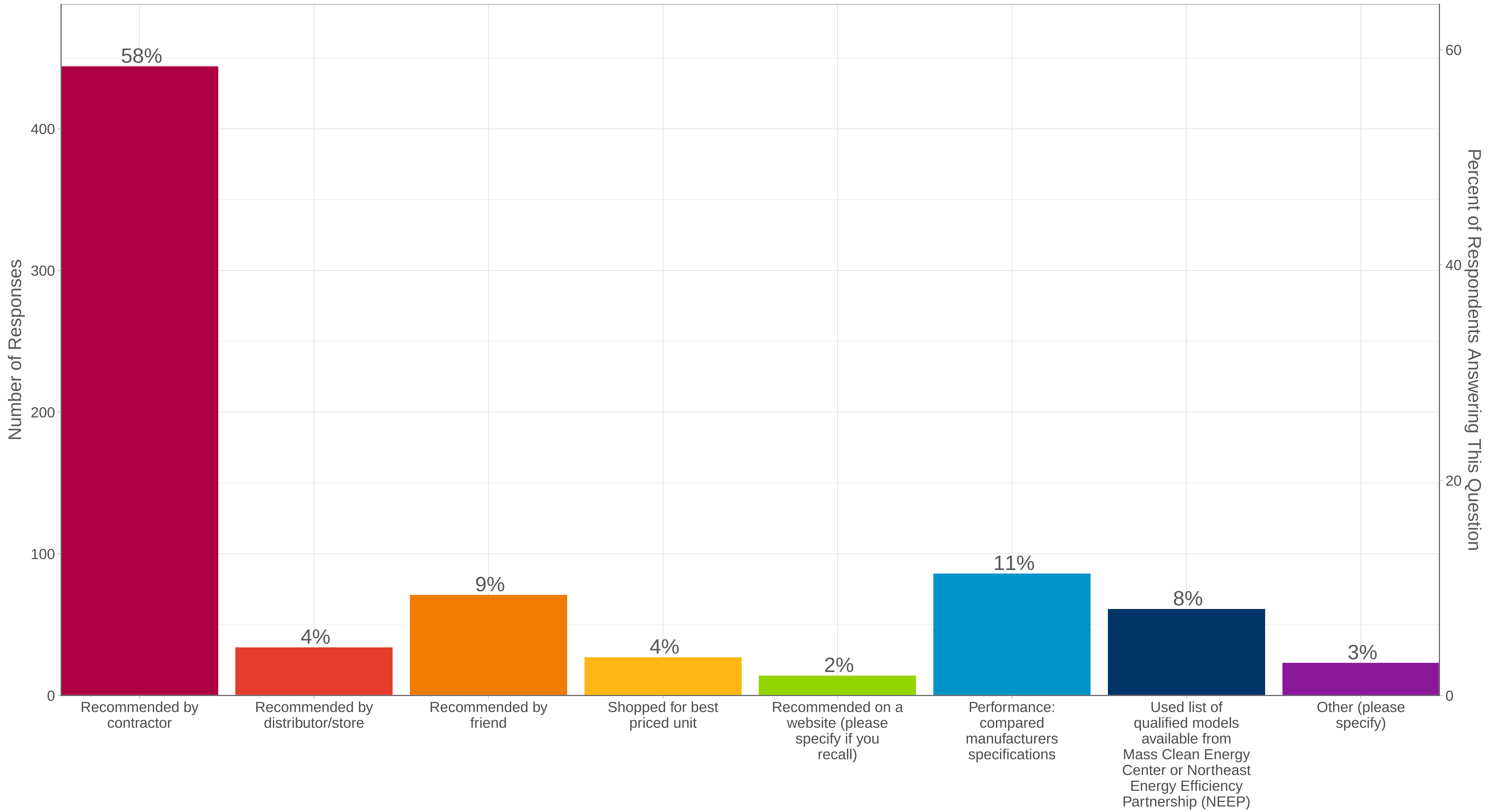
Total responses: 1267
Total respondents: 553
Source: Navigant Analysis

1.12 Question QD2b: From the reasons you just provided, what was your primary reason for purchasing a ductless mini-split heat pump?



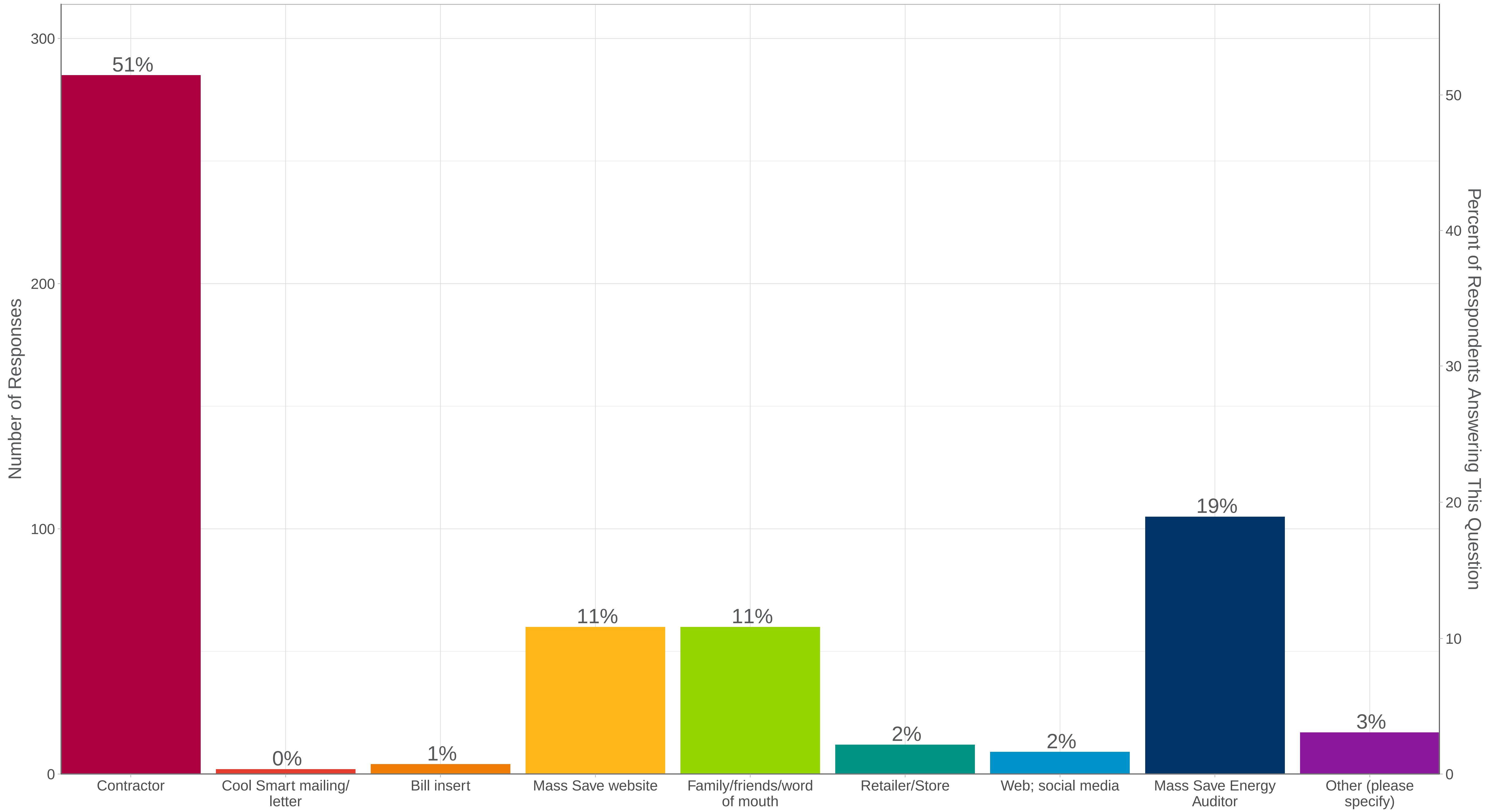
Total responses: 338
Total respondents: 338
Source: Navigant Analysis

1.13 Question QD3: How did you determine which specific make and model of ductless mini-split heat pump(s) to install?



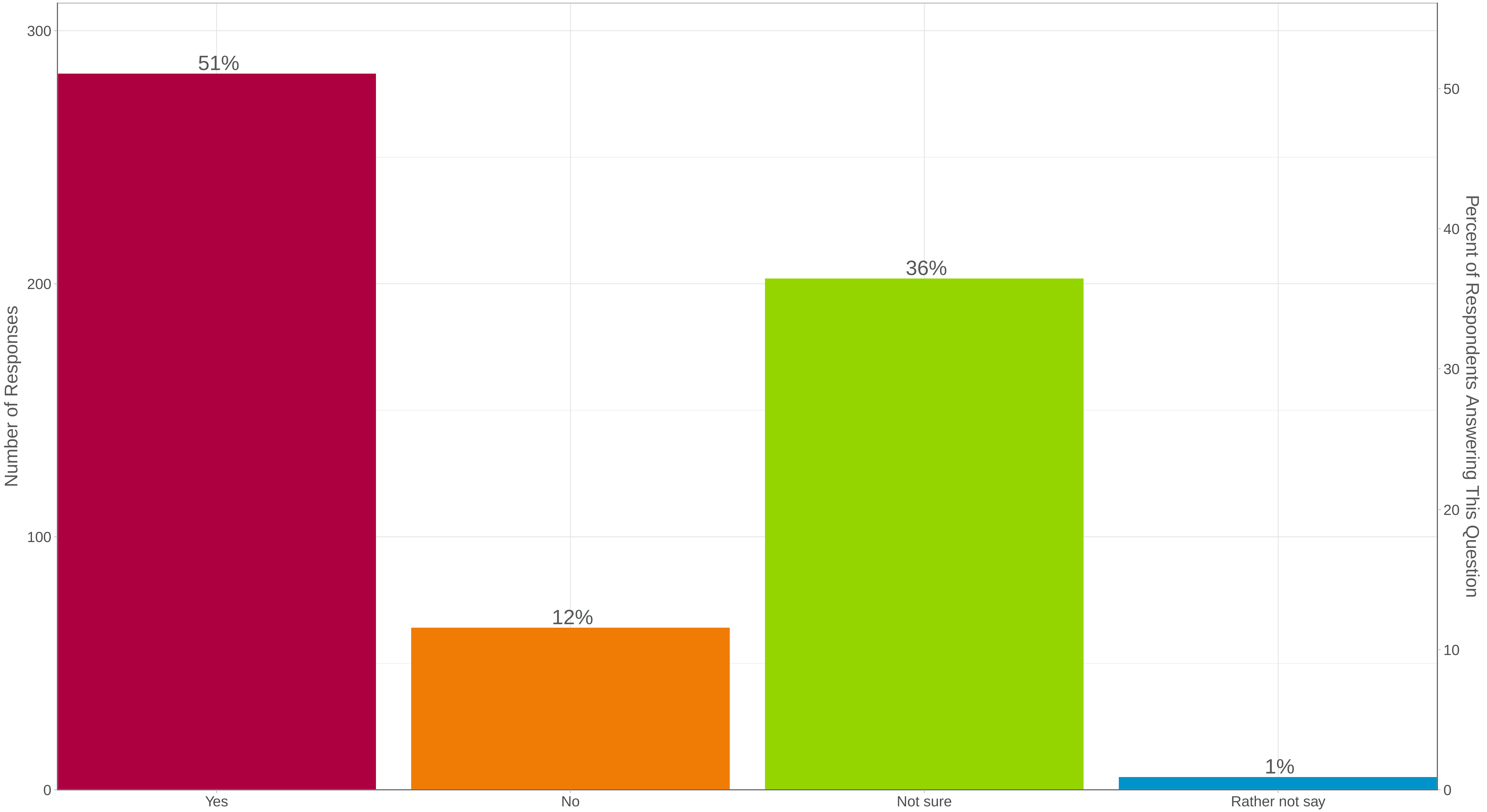
Total responses: 760
Total respondents: 554
Source: Navigant Analysis

1.14 Question QD4: Where did you first learn about the Mass Save Cool Smart Program, from which you received the rebate for the ductless mini-split heat pump?



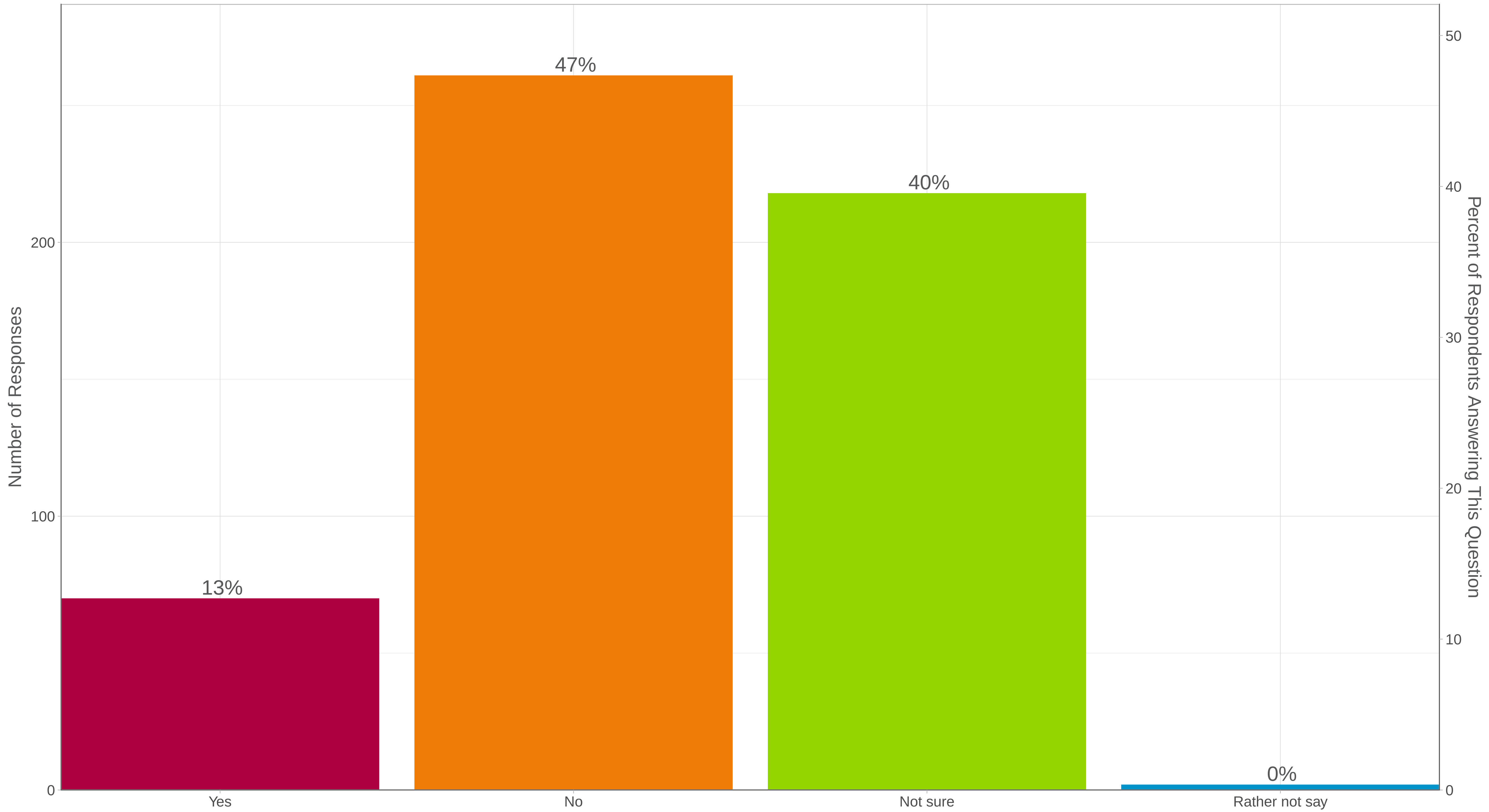
Total responses: 554
Total respondents: 554
Source: Navigant Analysis

1.15 Question QD5: Would you have still purchased a ductless mini-split heat pump in the absence of available rebates or financing? As a reminder, based on the efficiency of the unit you installed, you should have received $100 or $300 per eligible indoor unit through the Mass Save program.



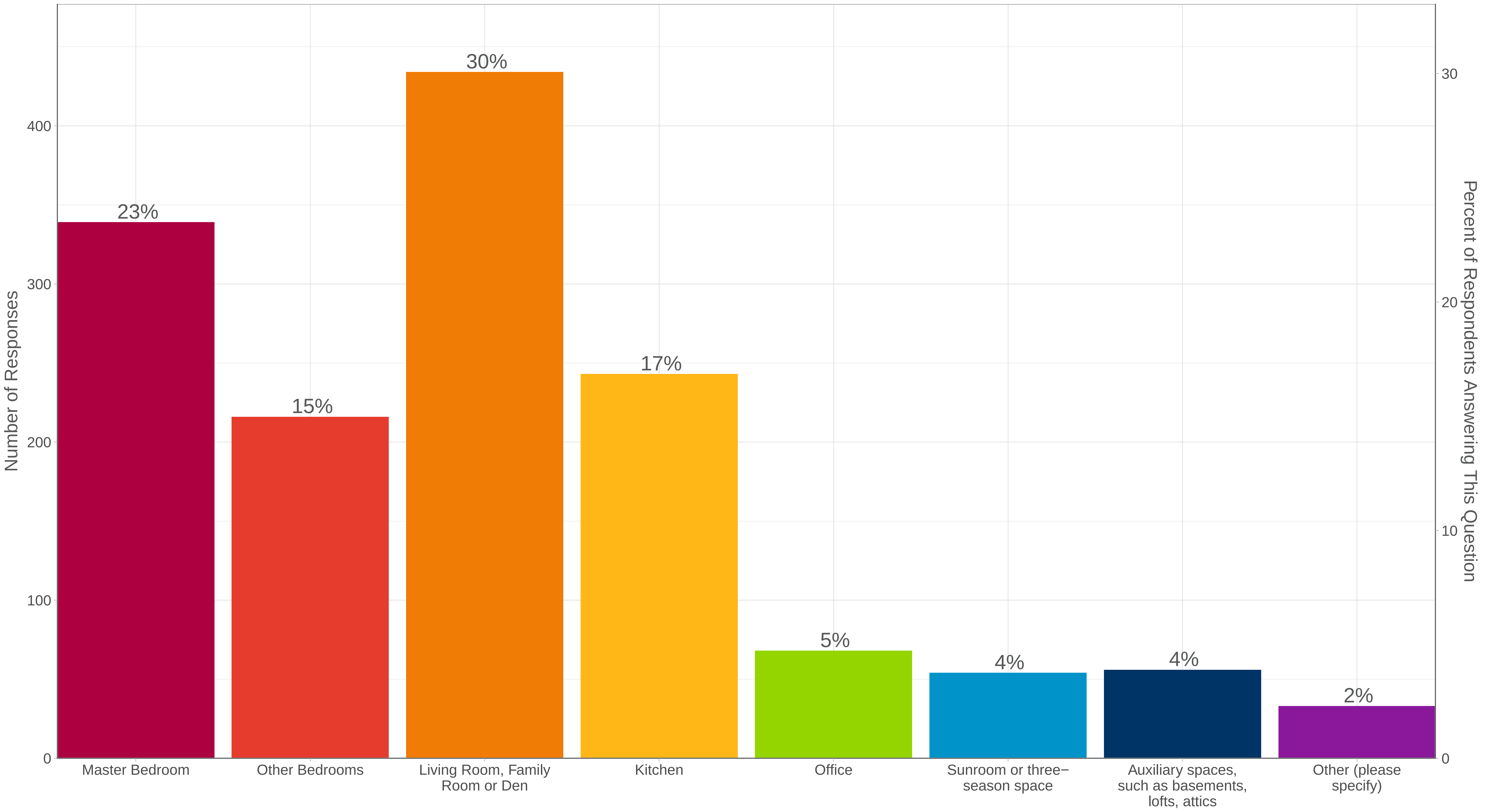
Total responses: 554
Total respondents: 554
Source: Navigant Analysis

1.16 Question QD6: If rebates or financing had been unavailable, would you have purchased a less expensive, less energy efficient, ductless mini-split heat pump(s)?



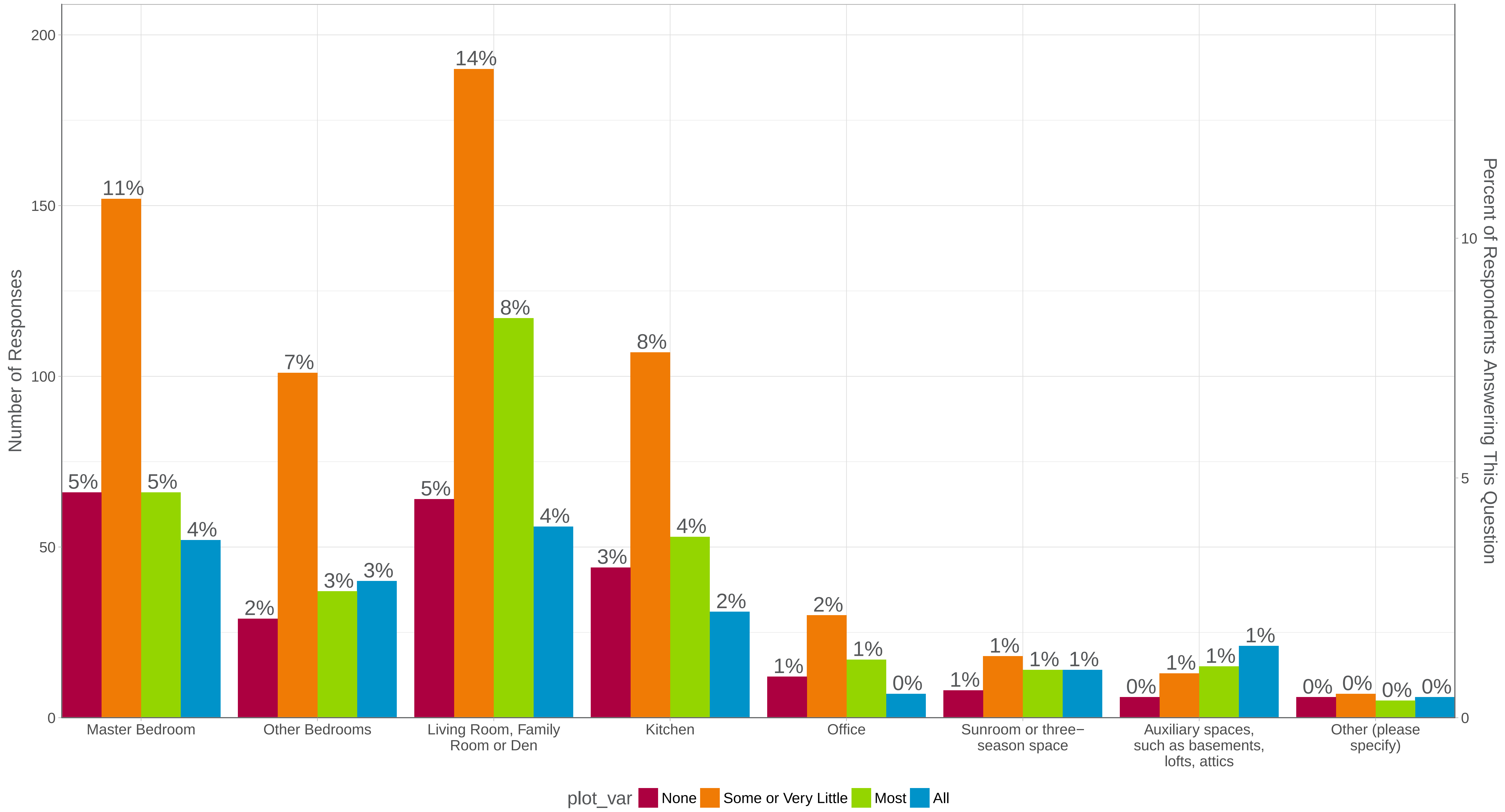
Total responses: 551
Total respondents: 551
Source: Navigant Analysis

1.17 Question QF0a: What space(s) does/do your ductless mini-split heat pump system(s) serve? (Select all that apply)



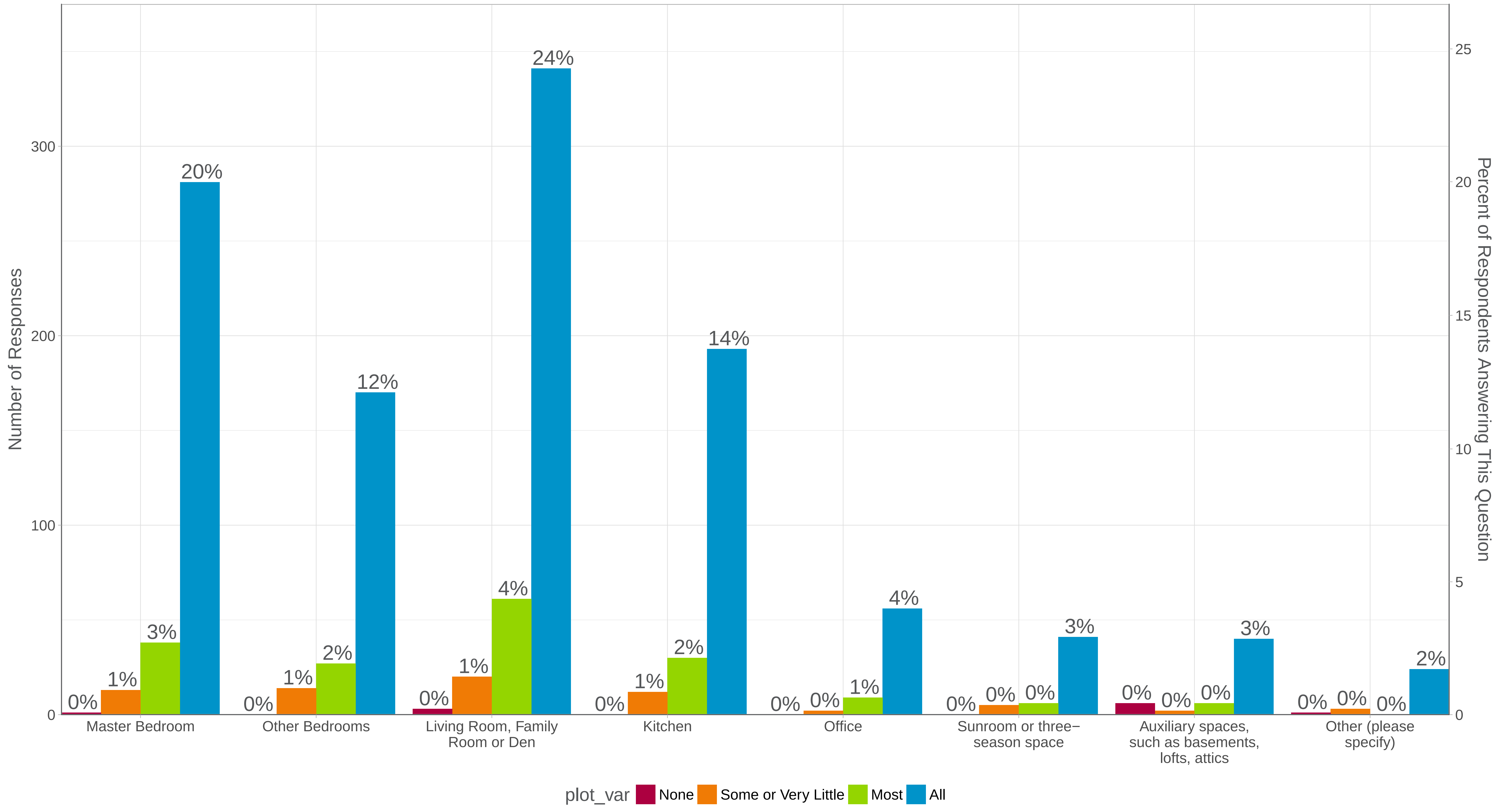
Total responses: 1443
Total respondents: 554
Source: Navigant Analysis

1.18 Question QF1a: How much of the heating that you typically need for each of the selected spaces is being provided by the ductless mini-split heat pump?



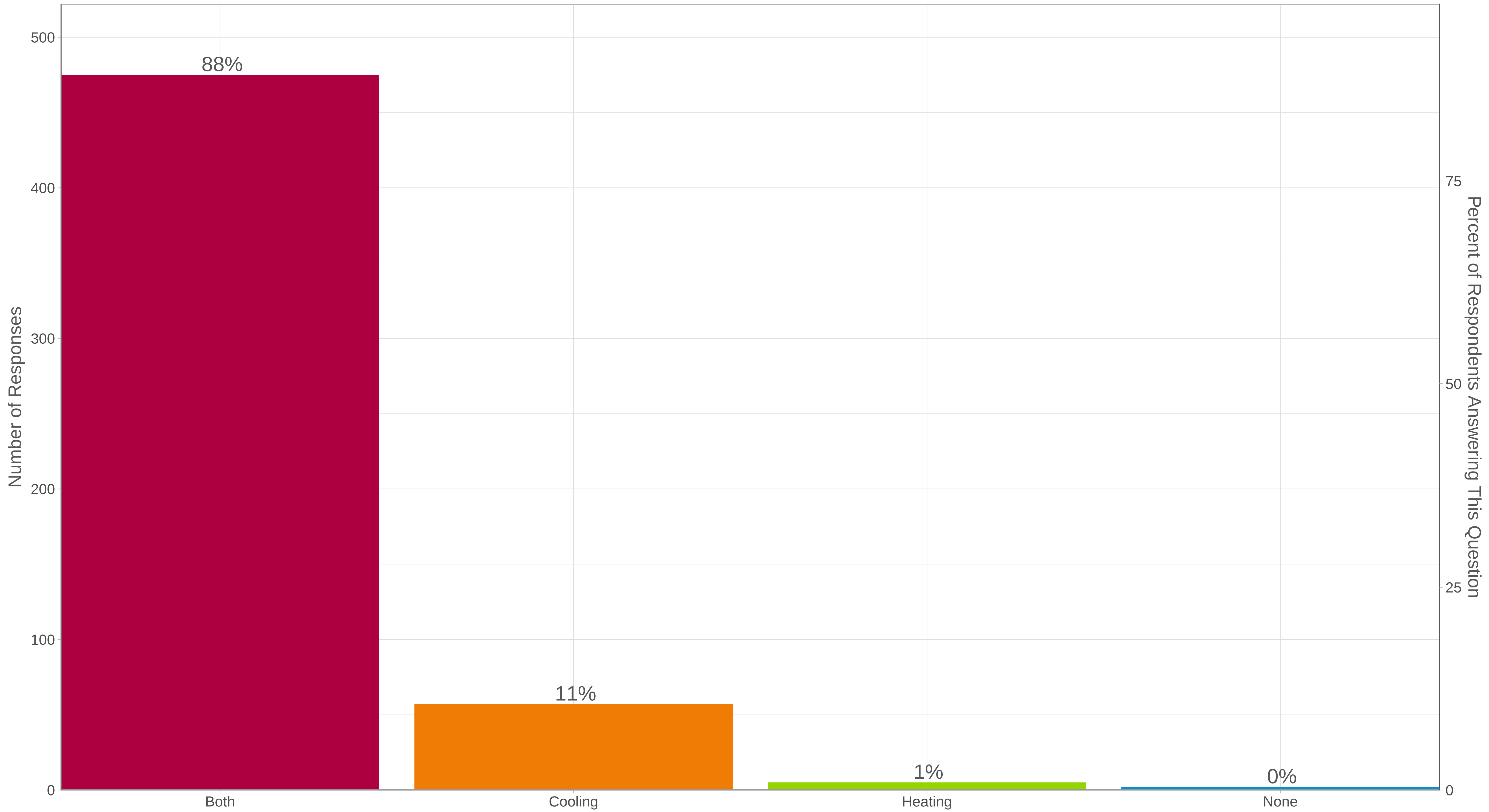
Total responses: 1404
Total respondents: 552
Source: Navigant Analysis

1.19 Question QF1b: How much of the cooling that you typically need for each of the selected spaces is being provided by the ductless mini-split heat pump?



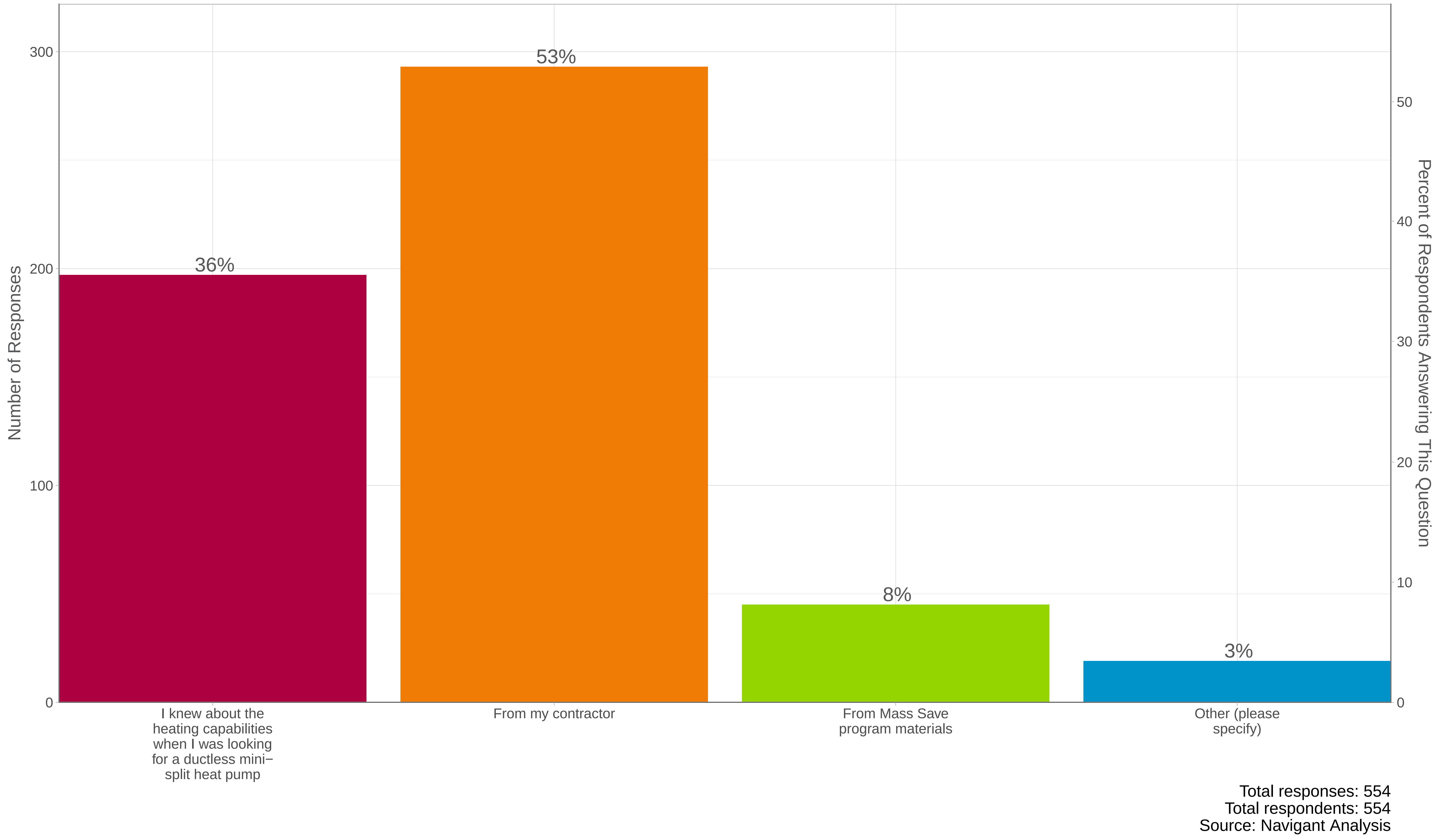
Total responses: 1405
Total respondents: 541
Source: Navigant Analysis

1.20 Question QF1: System Use

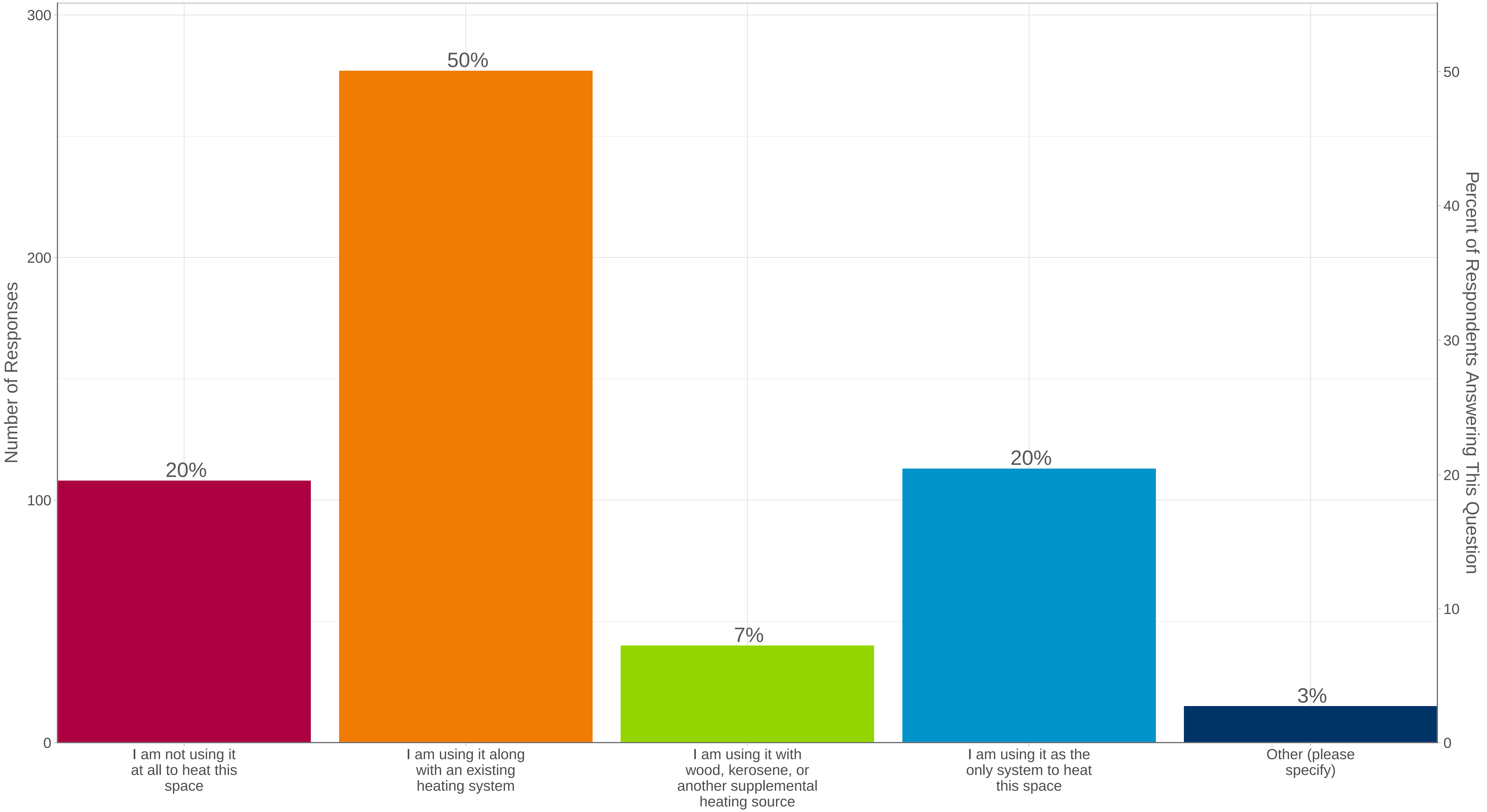


Total responses: 539
Total respondents: 539
Source: Navigant Analysis

1.21 Question QF2: How did you learn about the heating capabilities of the ductless mini-split heat pump system?

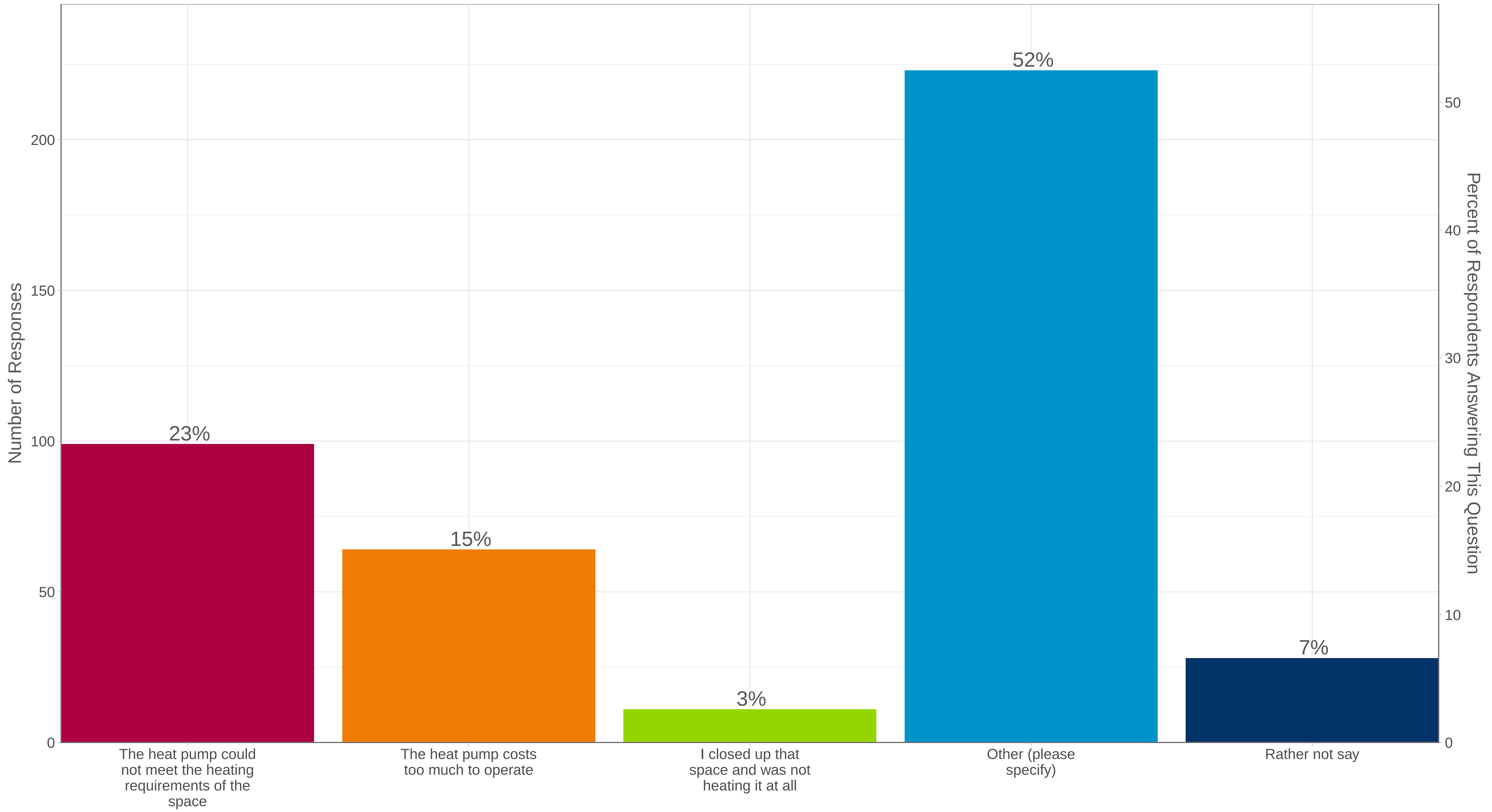


1.22 Question QF3a: This winter season, how are you using your ductless mini-split heat pump to heat the designated space?



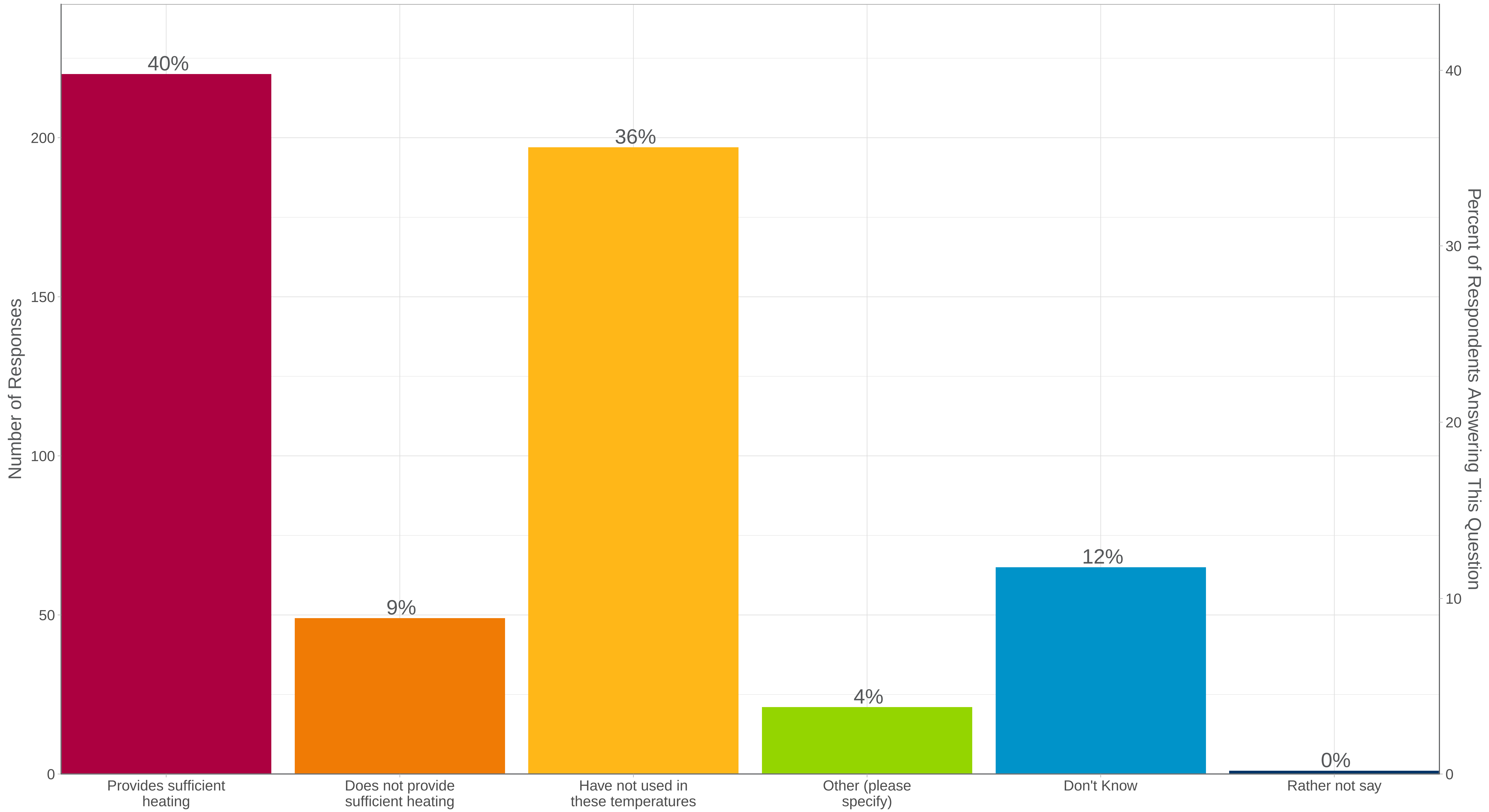
Total responses: 553
Total respondents: 553
Source: Navigant Analysis

1.23 Question QF3b: What is the reason that you did not rely solely on the ductless mini-split heat pump to heat this space?



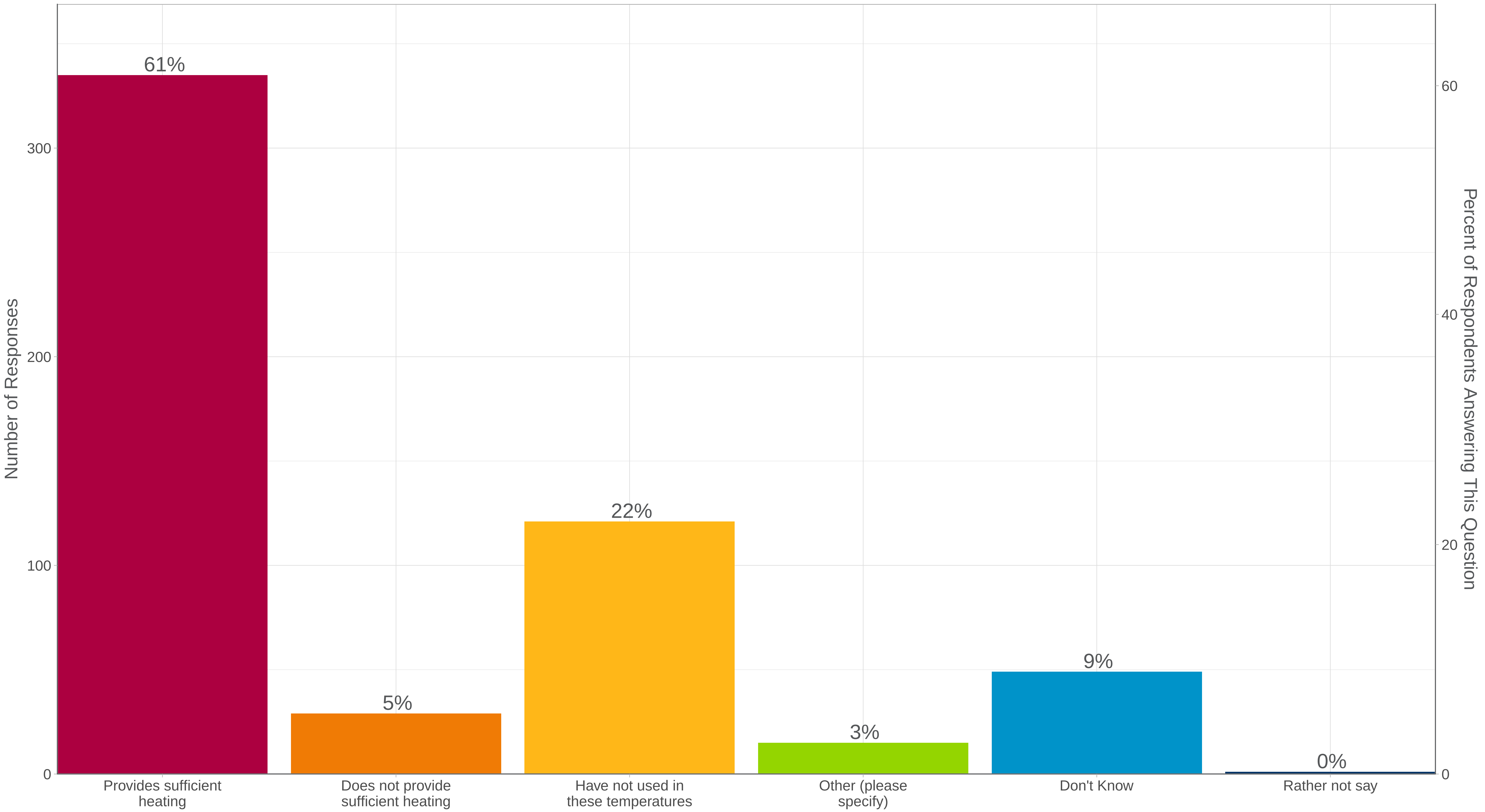
Total responses: 425
Total respondents: 425
Source: Navigant Analysis

1.24 Question QF4a: How has the ductless mini-split heat pump system performed in terms of heating during extremely cold temperatures below 15°F?



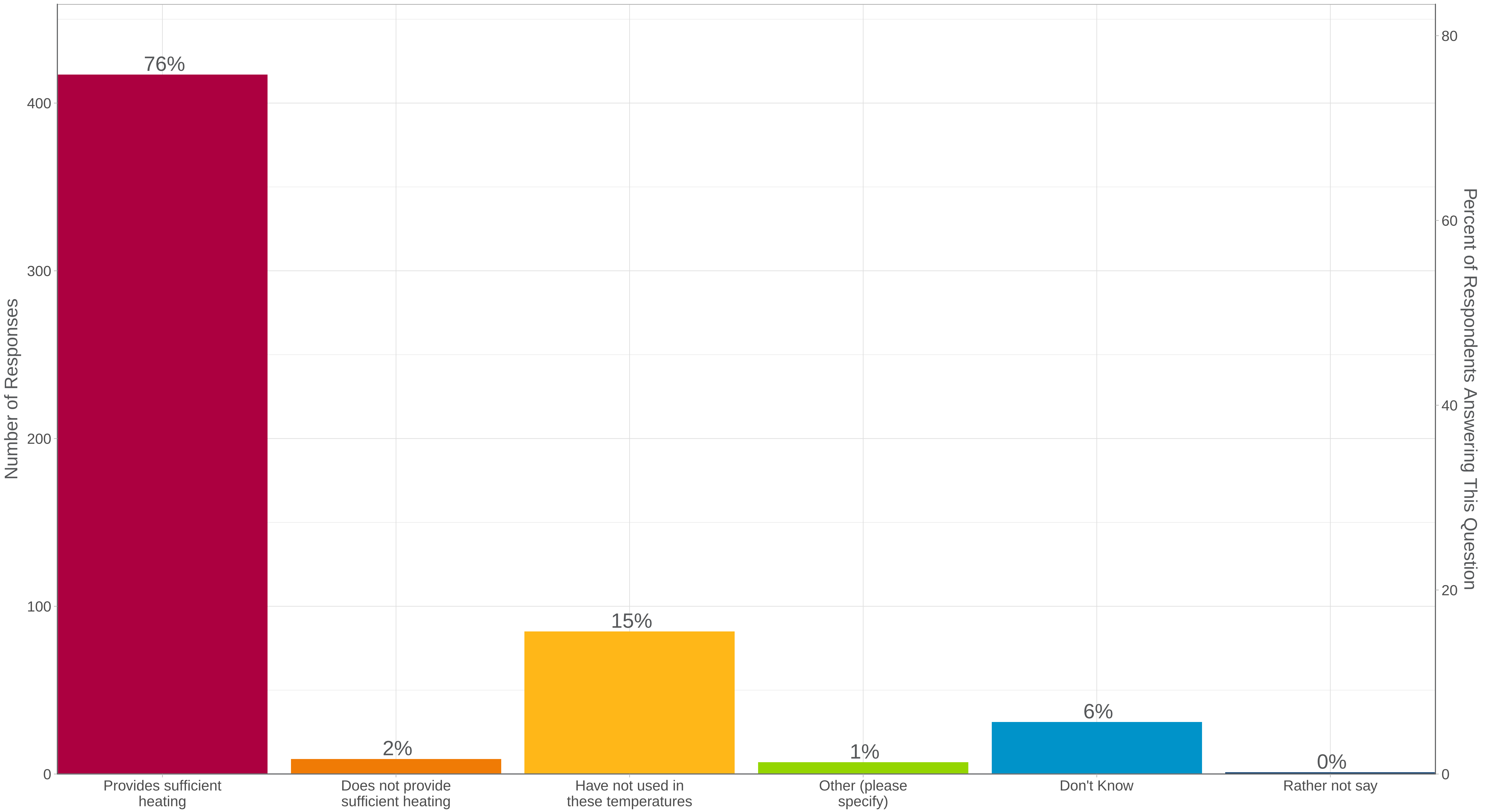
Total responses: 553
Total respondents: 553
Source: Navigant Analysis

1.25 Question QF4b: How has the ductless mini-split heat pump system performed in terms of heating during cold temperatures between 15°F and 30°F?



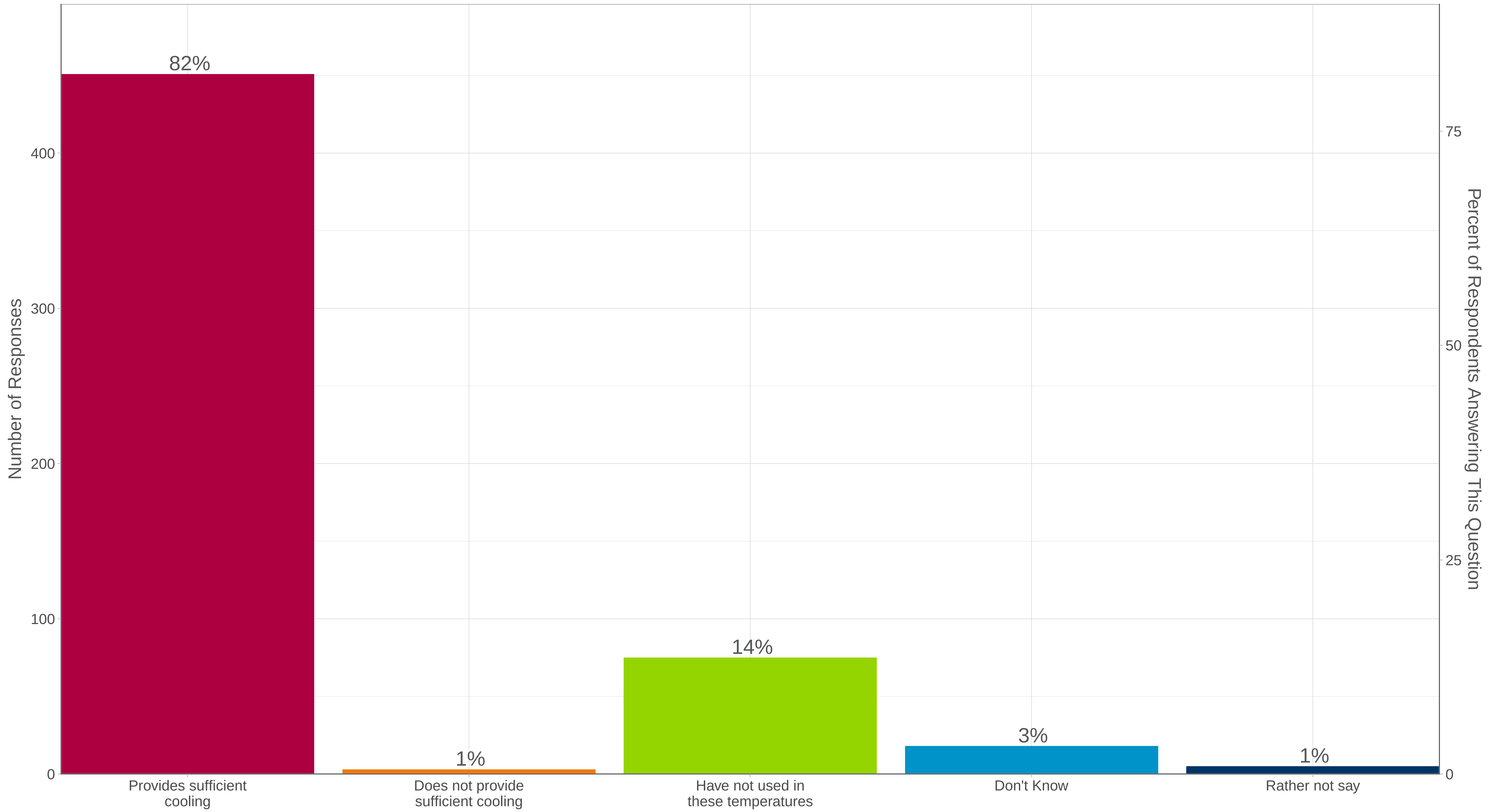
Total responses: 550
Total respondents: 550
Source: Navigant Analysis

1.26 Question QF4c: How has the ductless mini-split heat pump system performed in terms of heating during cool temperatures between 30°F and 50°F?



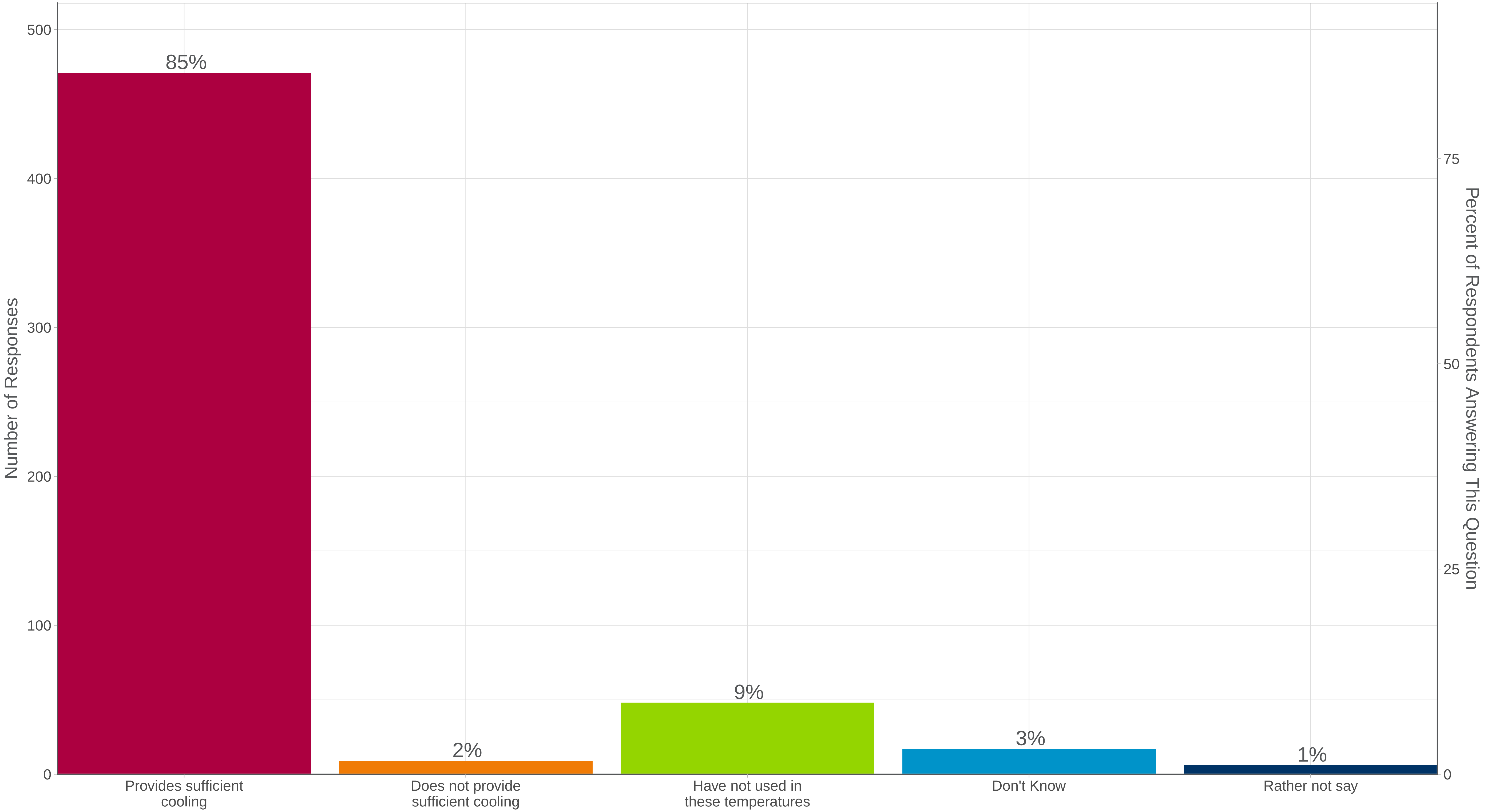
Total responses: 550
Total respondents: 550
Source: Navigant Analysis

1.27 Question QF4d: How has the ductless mini-split heat pump system performed in terms of cooling during warm temperatures between 70°F and 80°F?



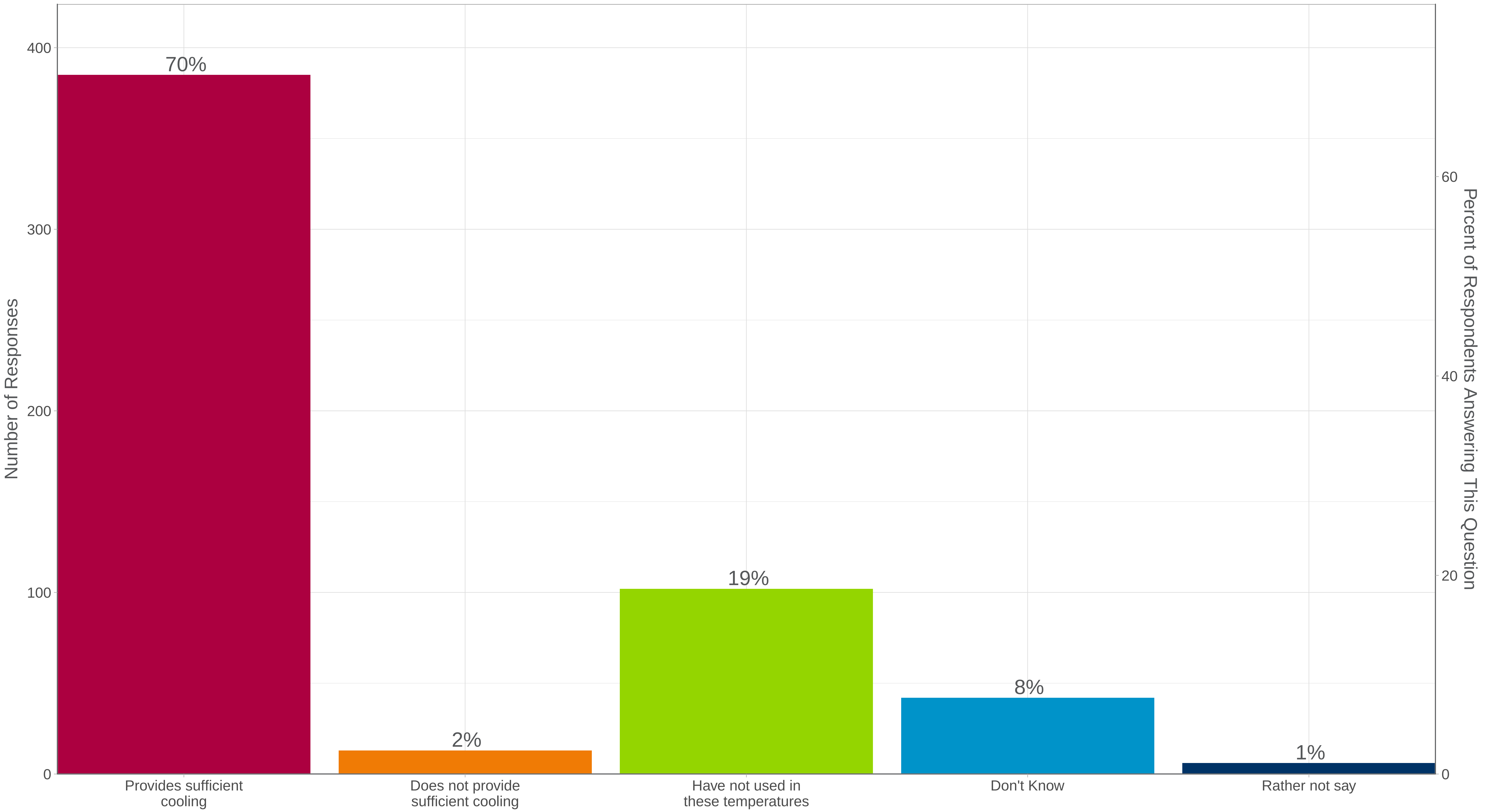
Total responses: 552
Total respondents: 552
Source: Navigant Analysis

1.28 Question QF4e: How has the ductless mini-split heat pump system performed in terms of cooling during warm temperatures between 80°F and 90°F?



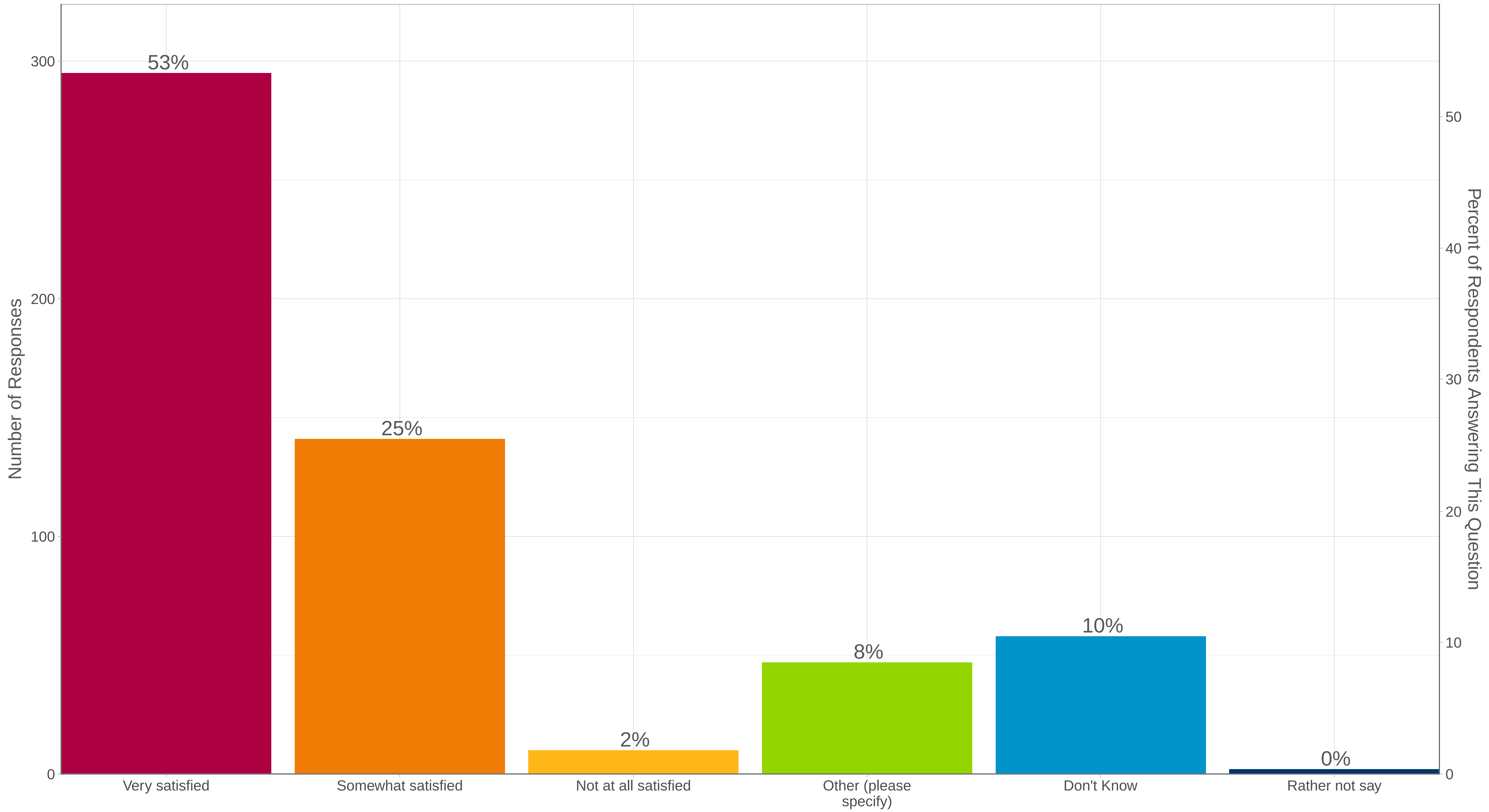
Total responses: 551
Total respondents: 551
Source: Navigant Analysis

1.29 Question QF4f: How has the ductless mini-split heat pump system performed in terms of cooling during extremely hot temperatures above 90°F?



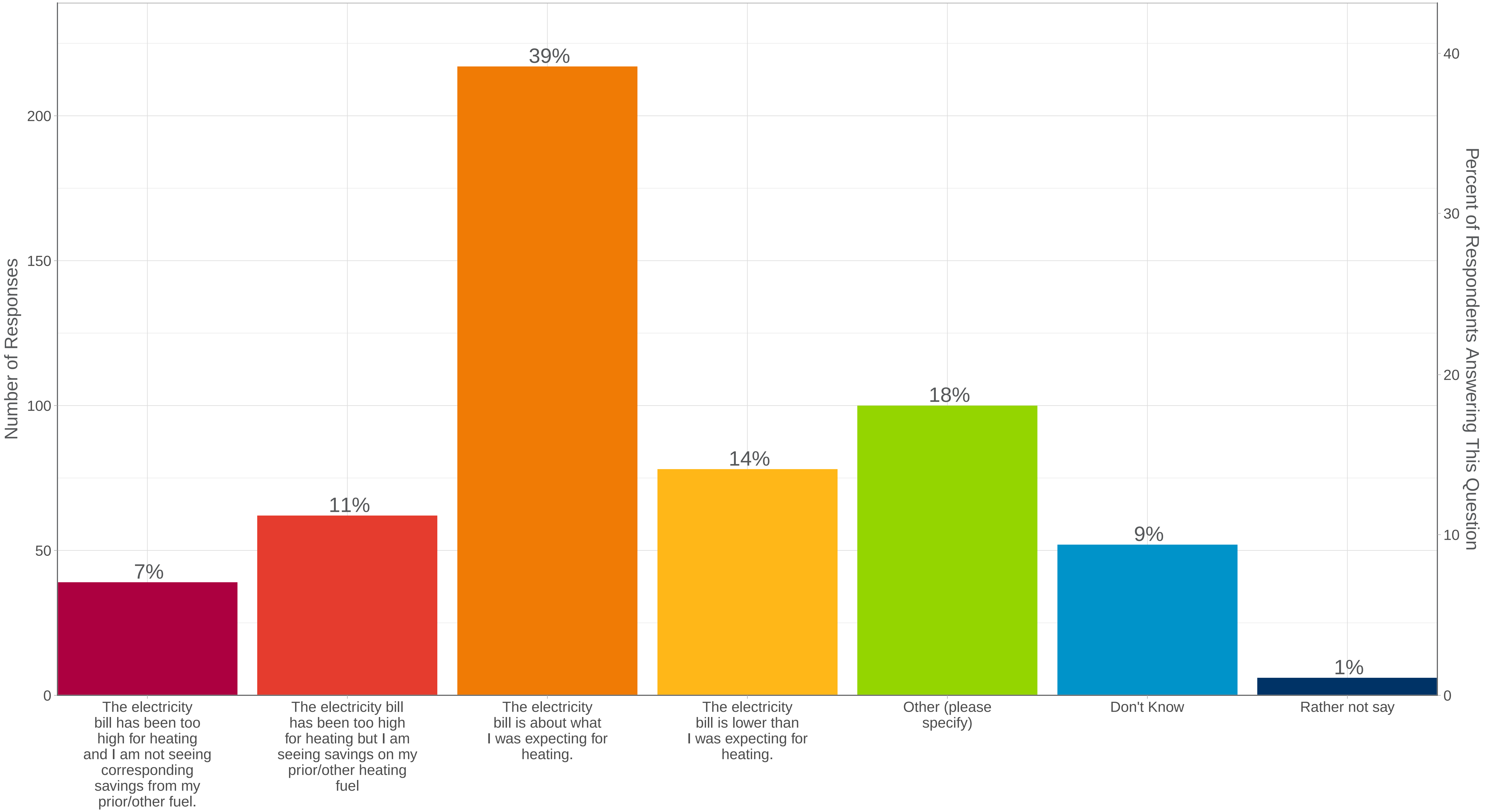
Total responses: 548
Total respondents: 548
Source: Navigant Analysis

1.30 Question QF5: So far, how satisfied have you been with the cost of your heating using the ductless mini-split heat pump?



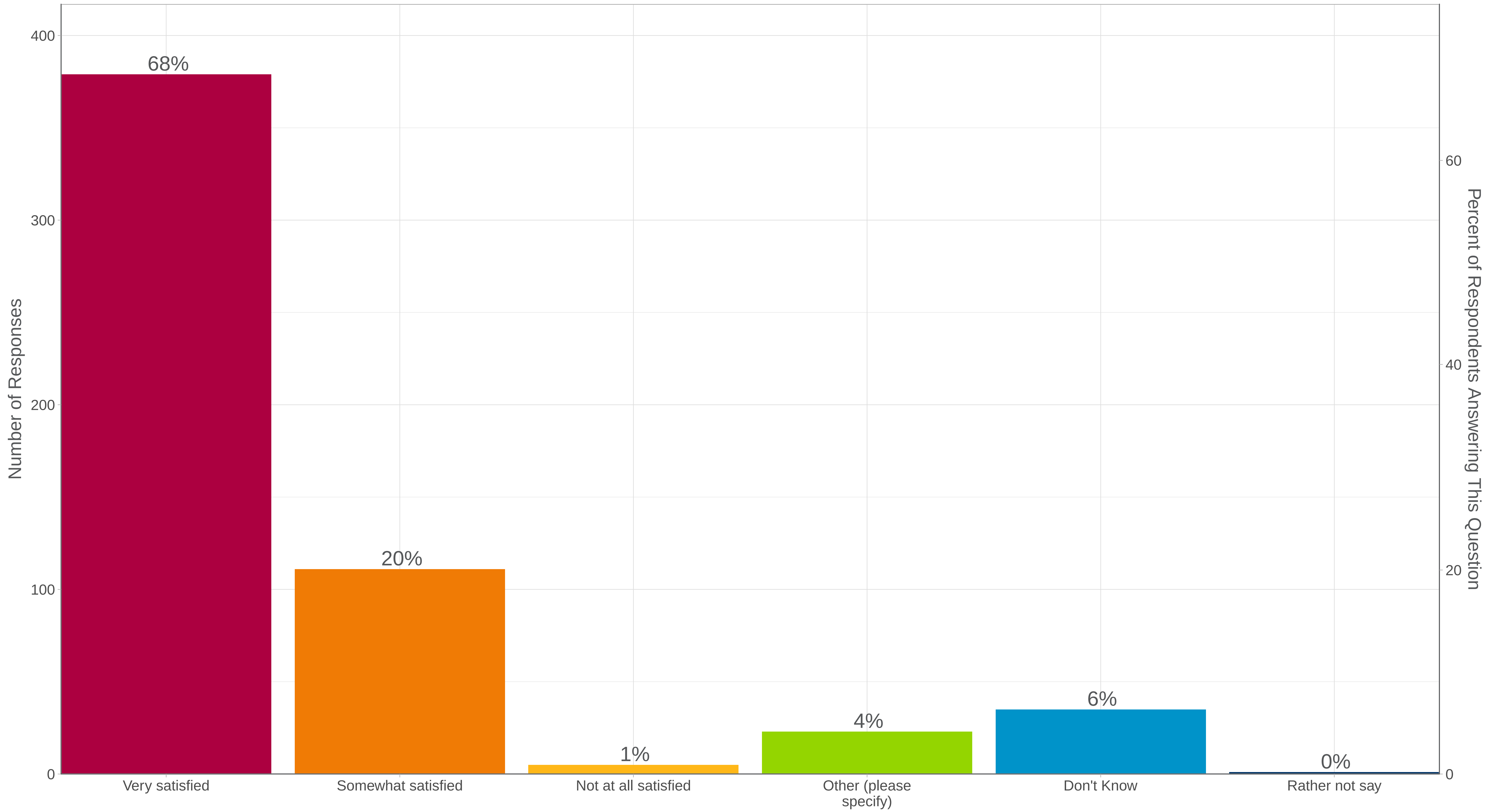
Total responses: 553
Total respondents: 553
Source: Navigant Analysis

1.31 Question QF6: Why did you give the rating that you did on the previous question?



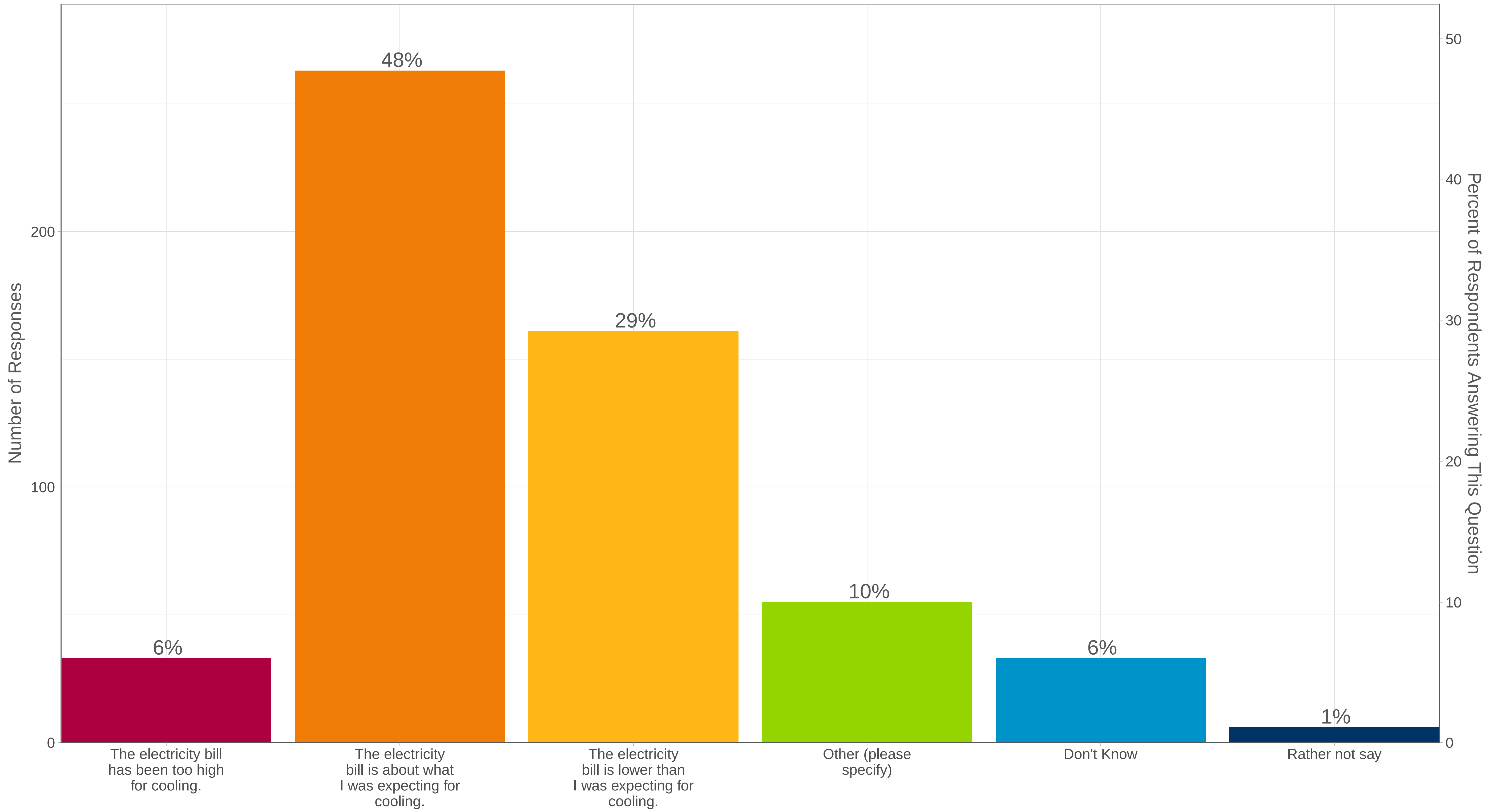
Total responses: 554
Total respondents: 554
Source: Navigant Analysis

1.32 Question QF7: So far, how satisfied have you been with the cost of your cooling using the ductless mini-split heat pump?



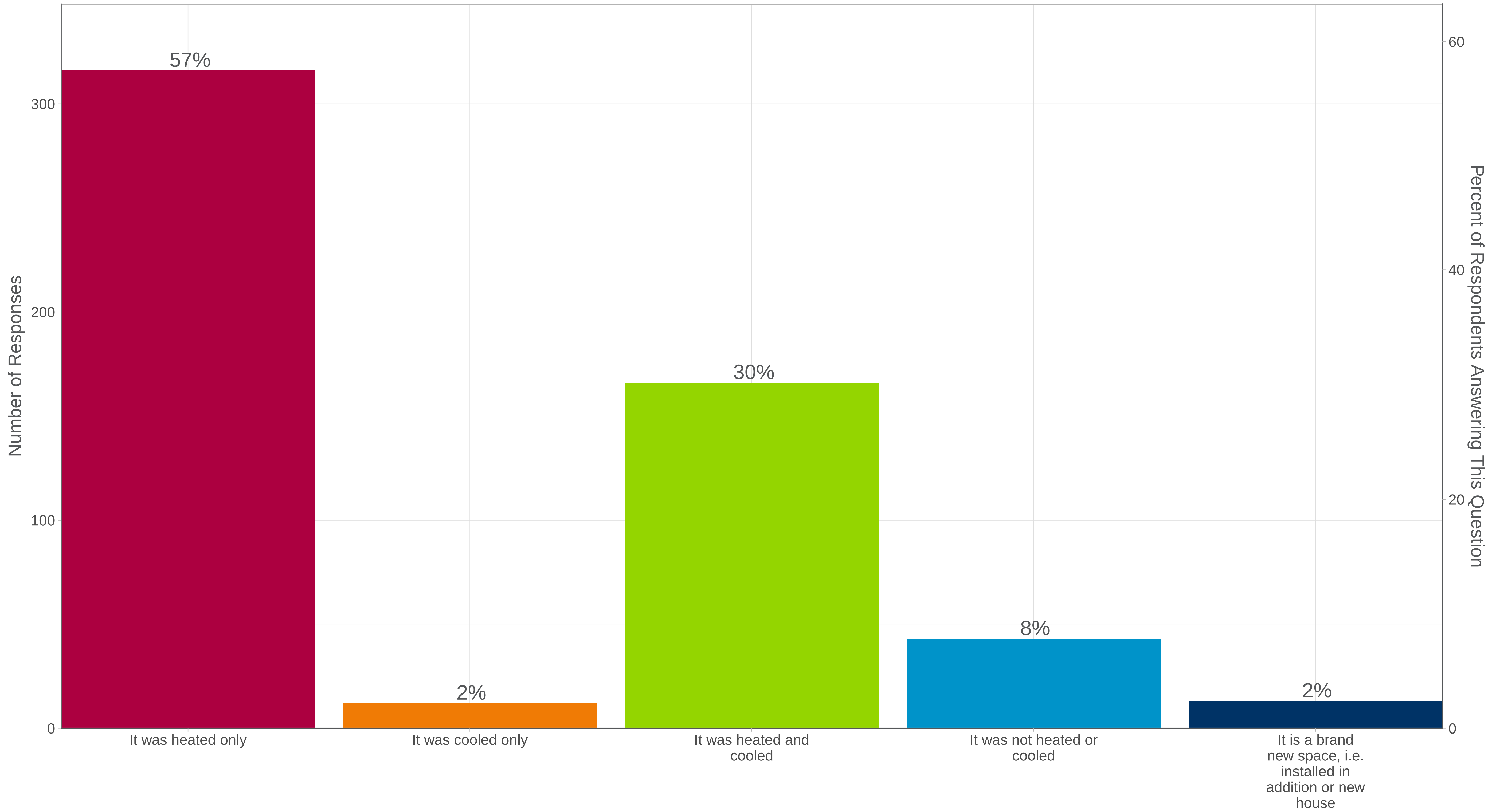
Total responses: 554
Total respondents: 554
Source: Navigant Analysis

1.33 Question QF8: Why did you give the rating that you did on the previous question?



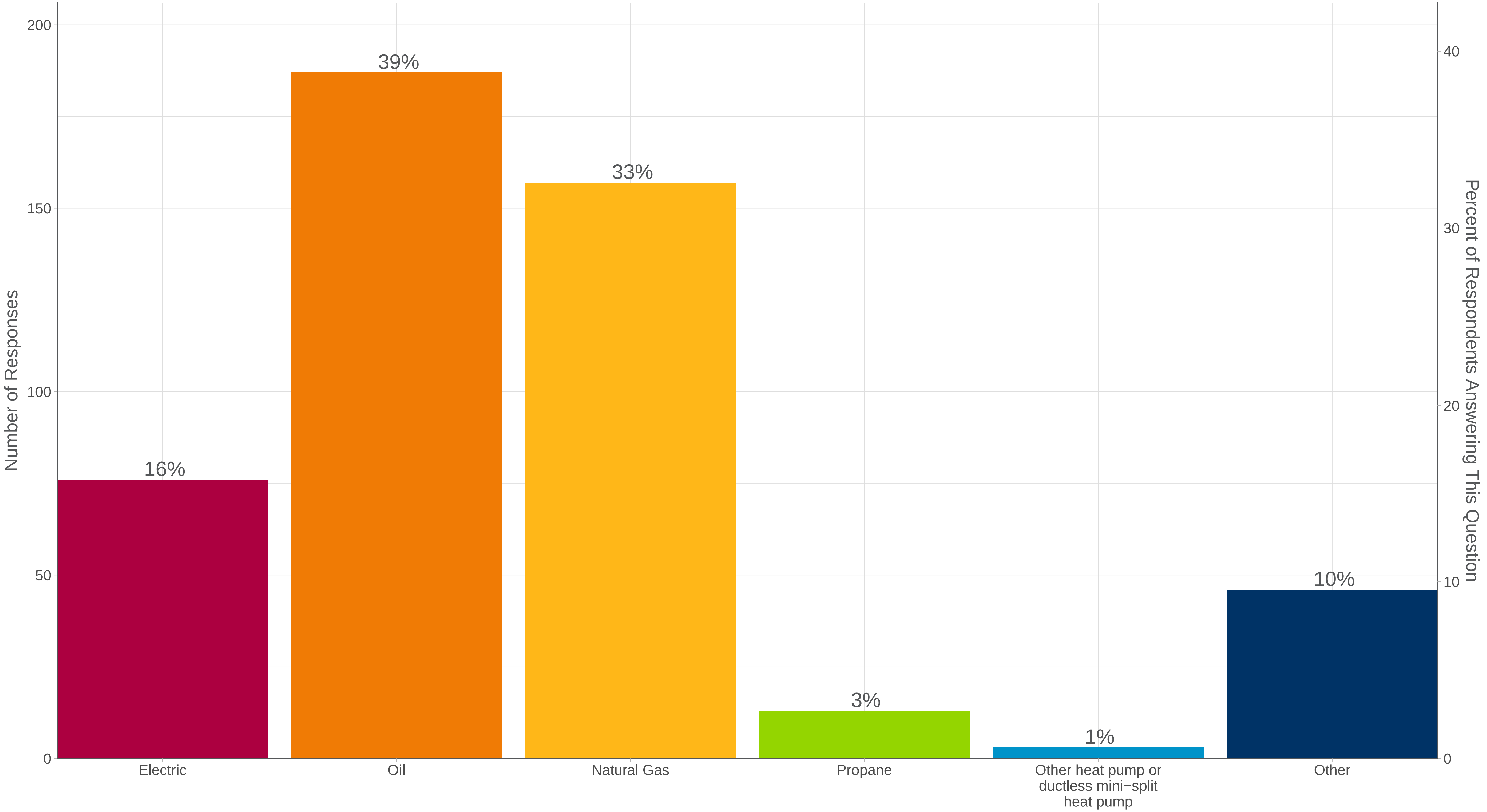
Total responses: 551
Total respondents: 551
Source: Navigant Analysis

1.34 Question QB1: Was the space heated and/or cooled before the installation of the ductless mini-split heat pump?



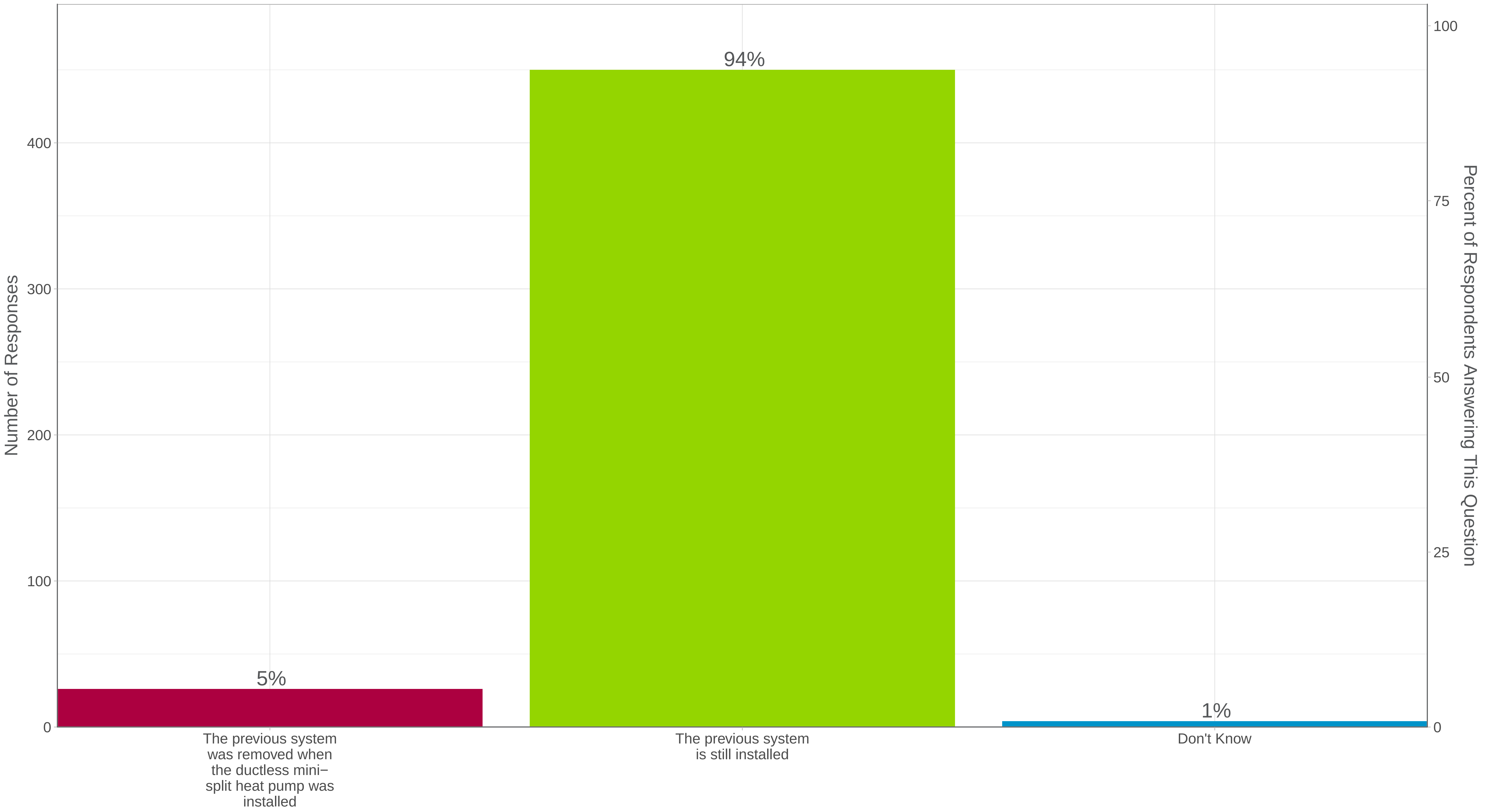
Total responses: 550
Total respondents: 550
Source: Navigant Analysis

1.35 Question QB2: What was the primary system that heated the space before the ductless mini-split heat pump was installed?



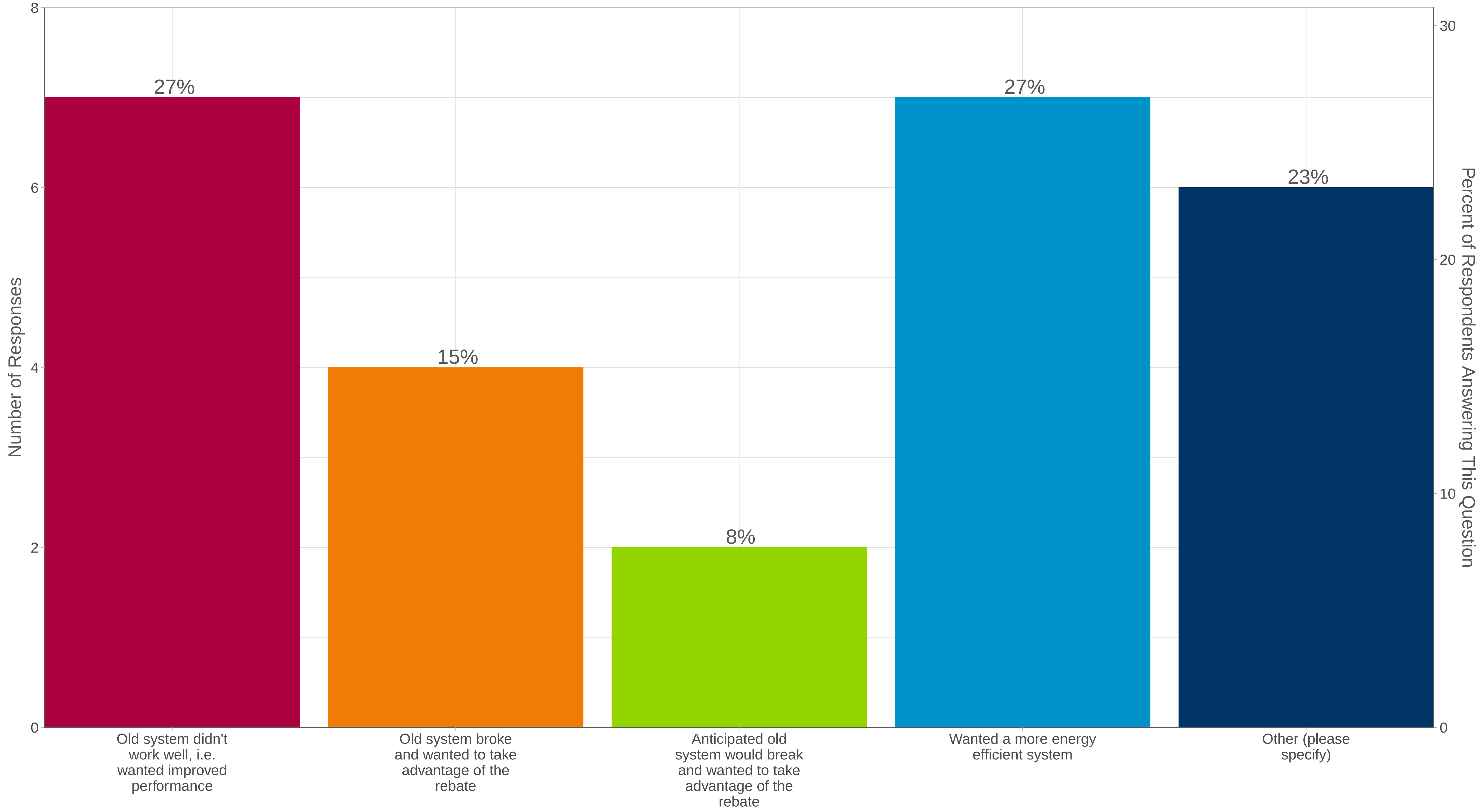
Total responses: 482
Total respondents: 482
Source: Navigant Analysis

1.36 Question QB3: When the ductless mini-split heat pump was installed was the previous heating system serving the space removed or is it still installed?



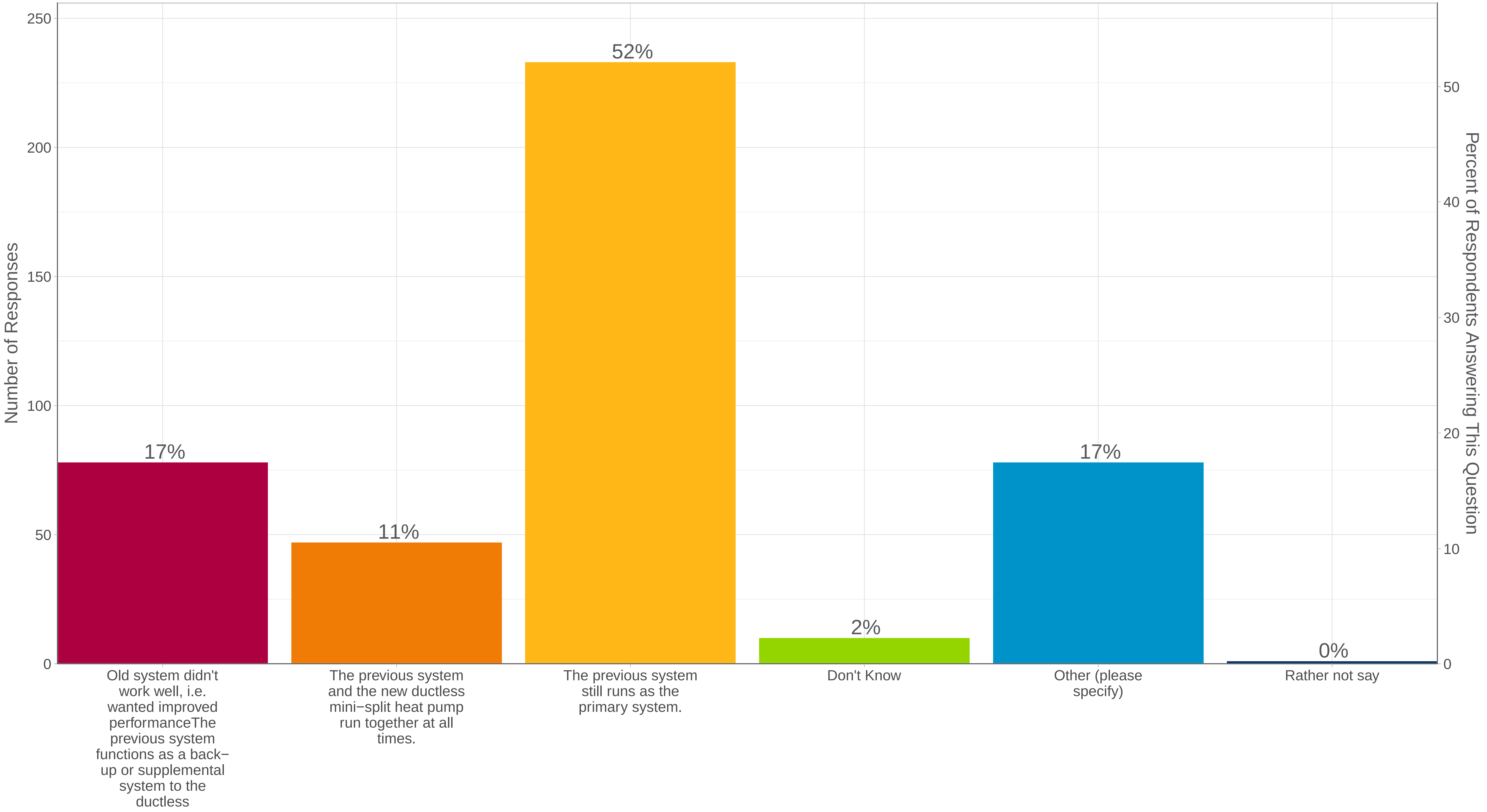
Total responses: 480
Total respondents: 480
Source: Navigant Analysis

1.37 Question QB4: Why did you replace your existing heating system?



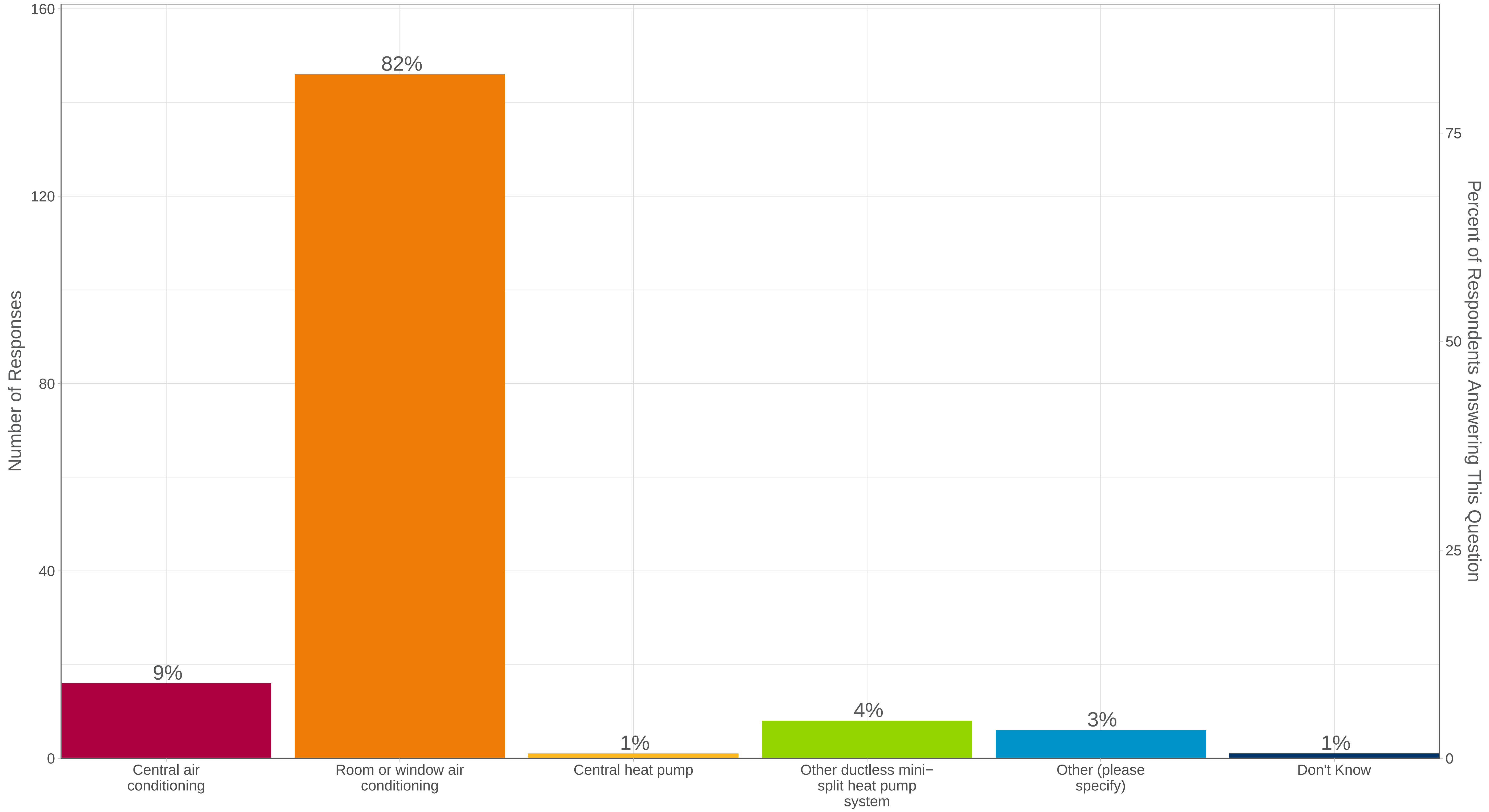
Total responses: 26
Total respondents: 26
Source: Navigant Analysis

1.38 Question QB3b: How does the previous heating system function today with the ductless mini-split heat pump?



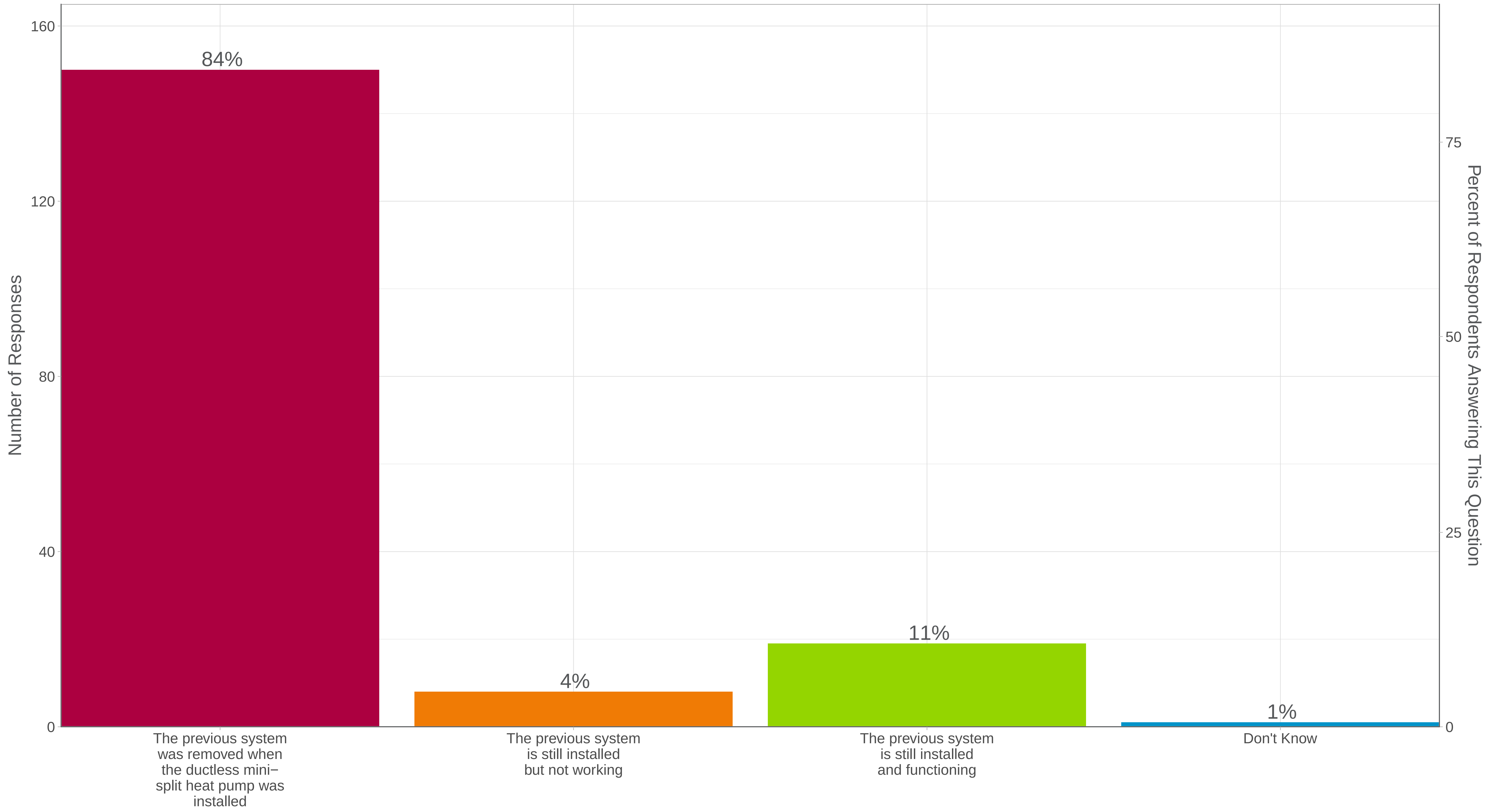
Total responses: 447
Total respondents: 447
Source: Navigant Analysis

1.39 Question QB6: What was the primary system that cooled the space before the ductless mini-split heat pump was installed?



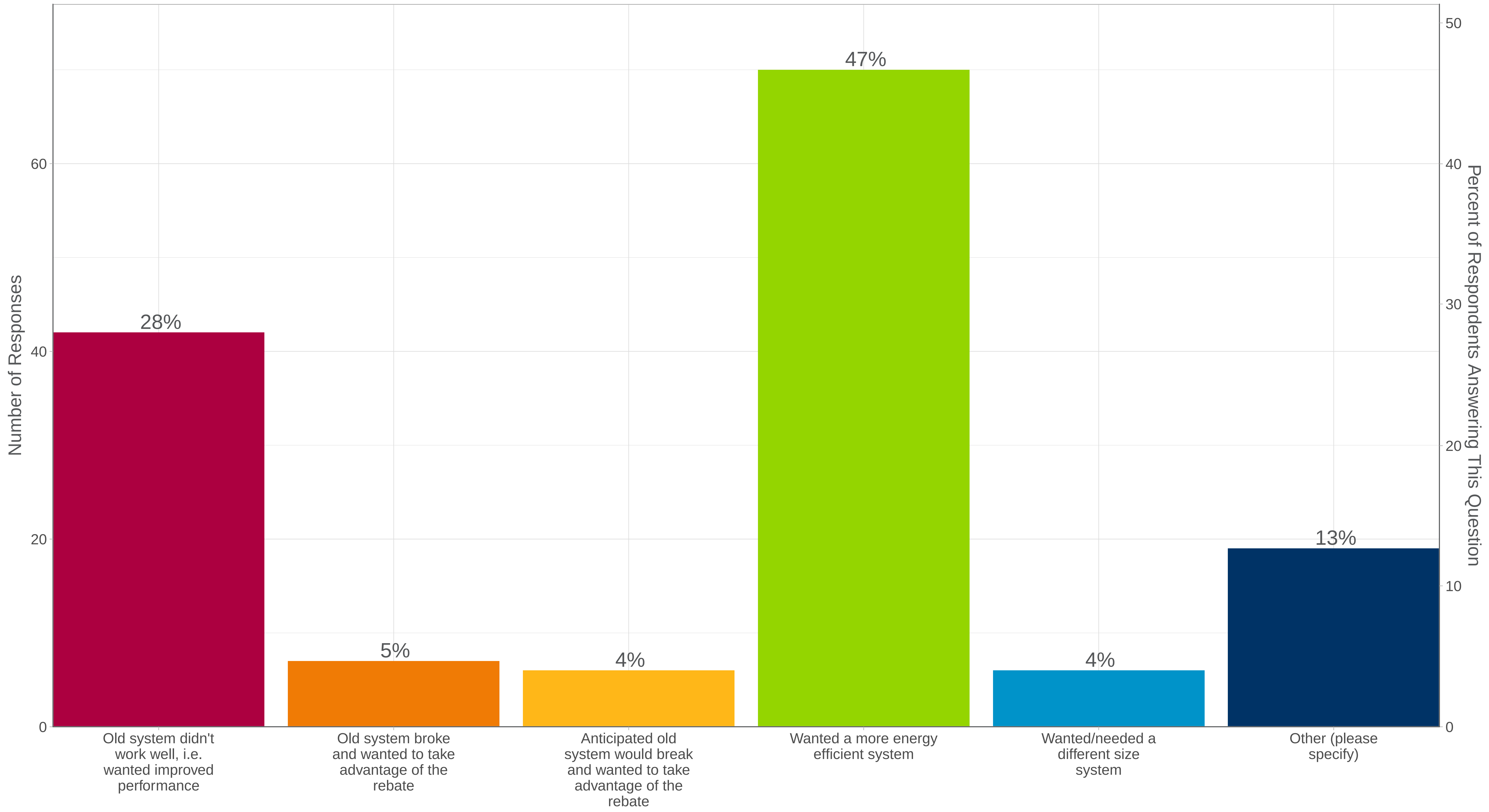
Total responses: 178
Total respondents: 178
Source: Navigant Analysis

1.40 Question QB7a: When the ductless mini-split heat pump was installed was the previous cooling system serving the space removed or is it still installed?



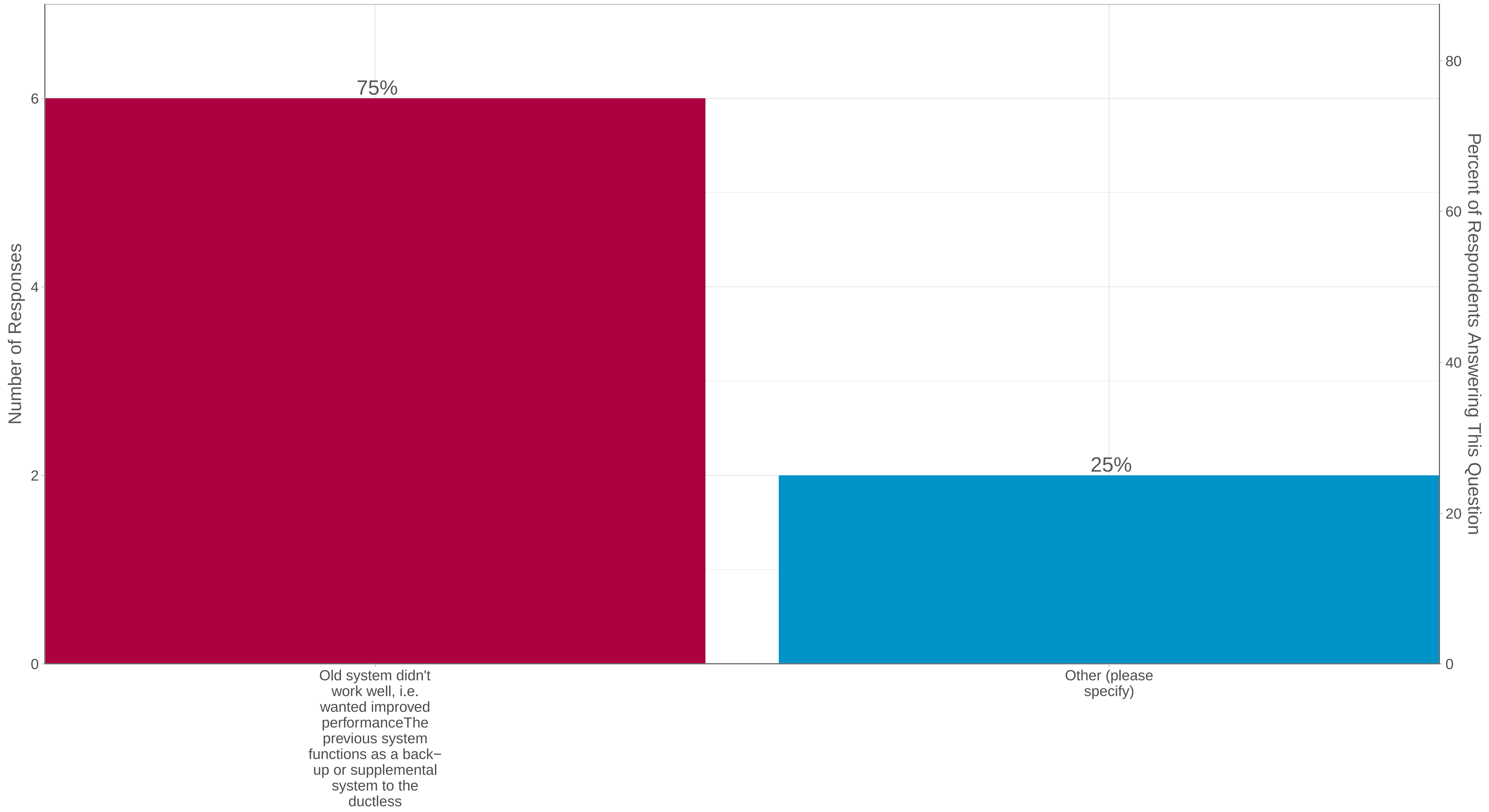
Total responses: 178
Total respondents: 178
Source: Navigant Analysis

1.41 Question QB8: Why did you replace your existing cooling system?



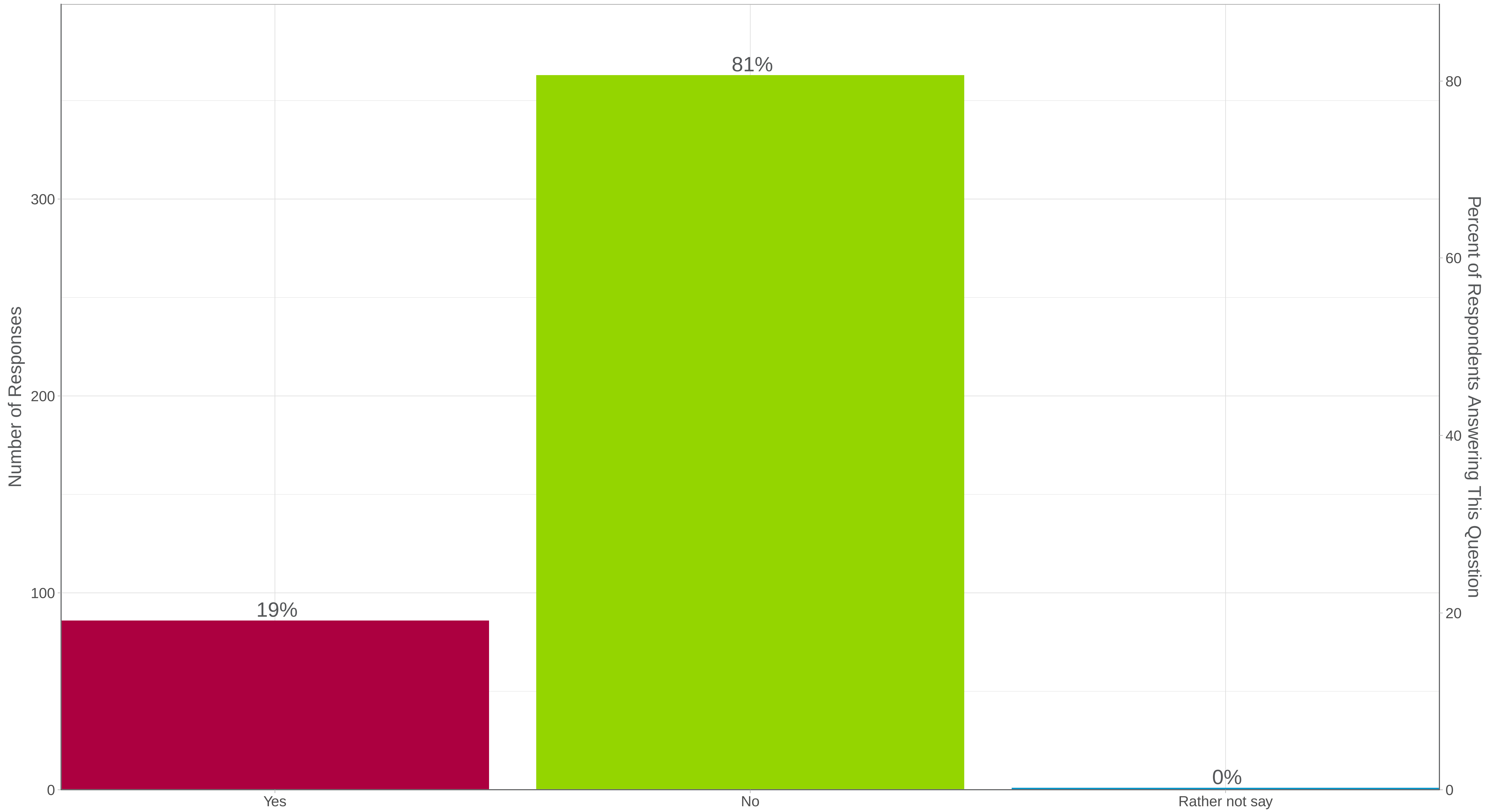
Total responses: 150
Total respondents: 150
Source: Navigant Analysis

1.42 Question QB7b: How does the previous cooling system function today with the ductless mini-split heat pump?



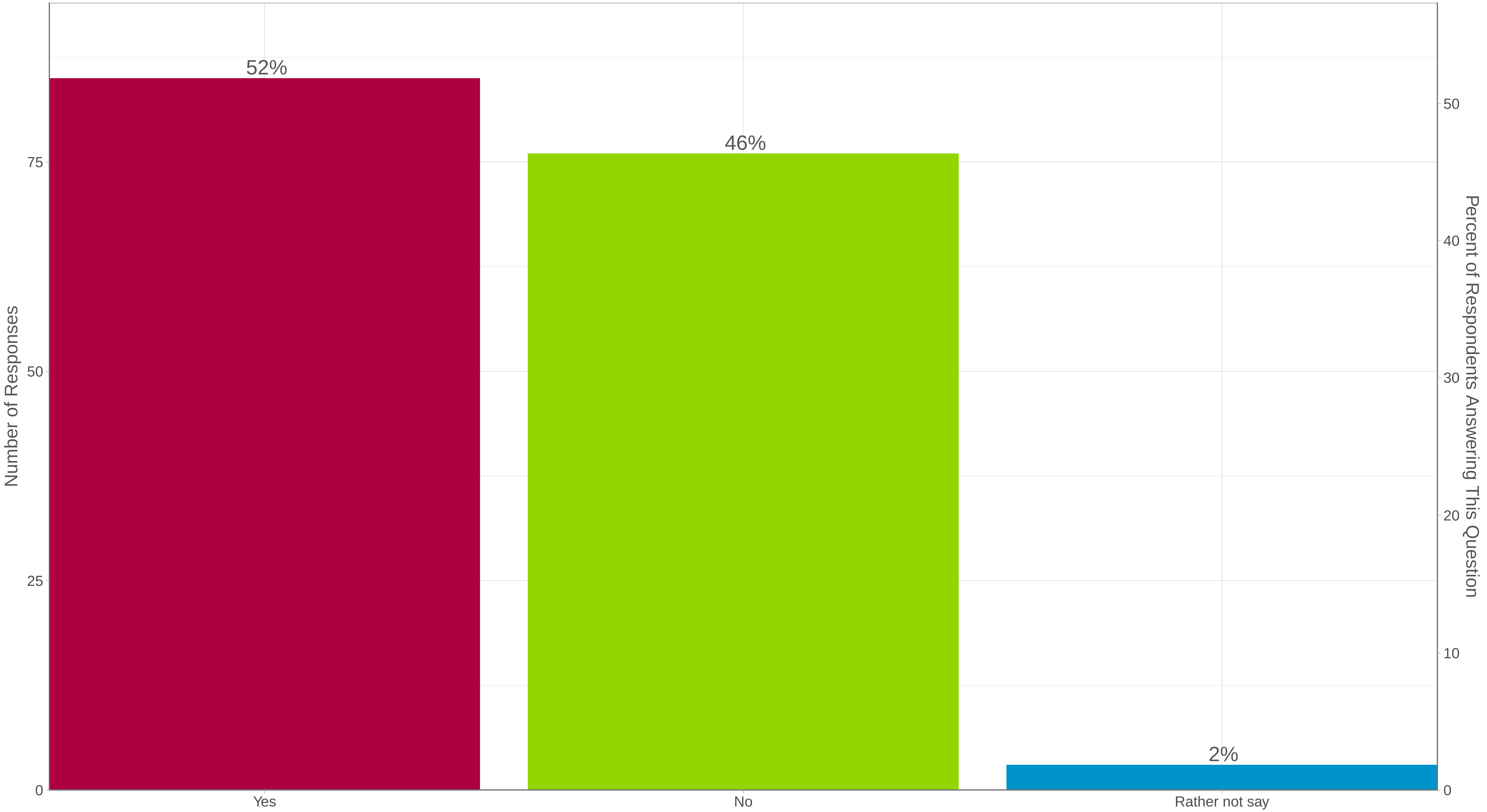
Total responses: 8
Total respondents: 8
Source: Navigant Analysis

1.43 Question QB10a: Other than the ductless mini-split heat pump and the existing heating or cooling system, does another system provide heating or cooling to the space?



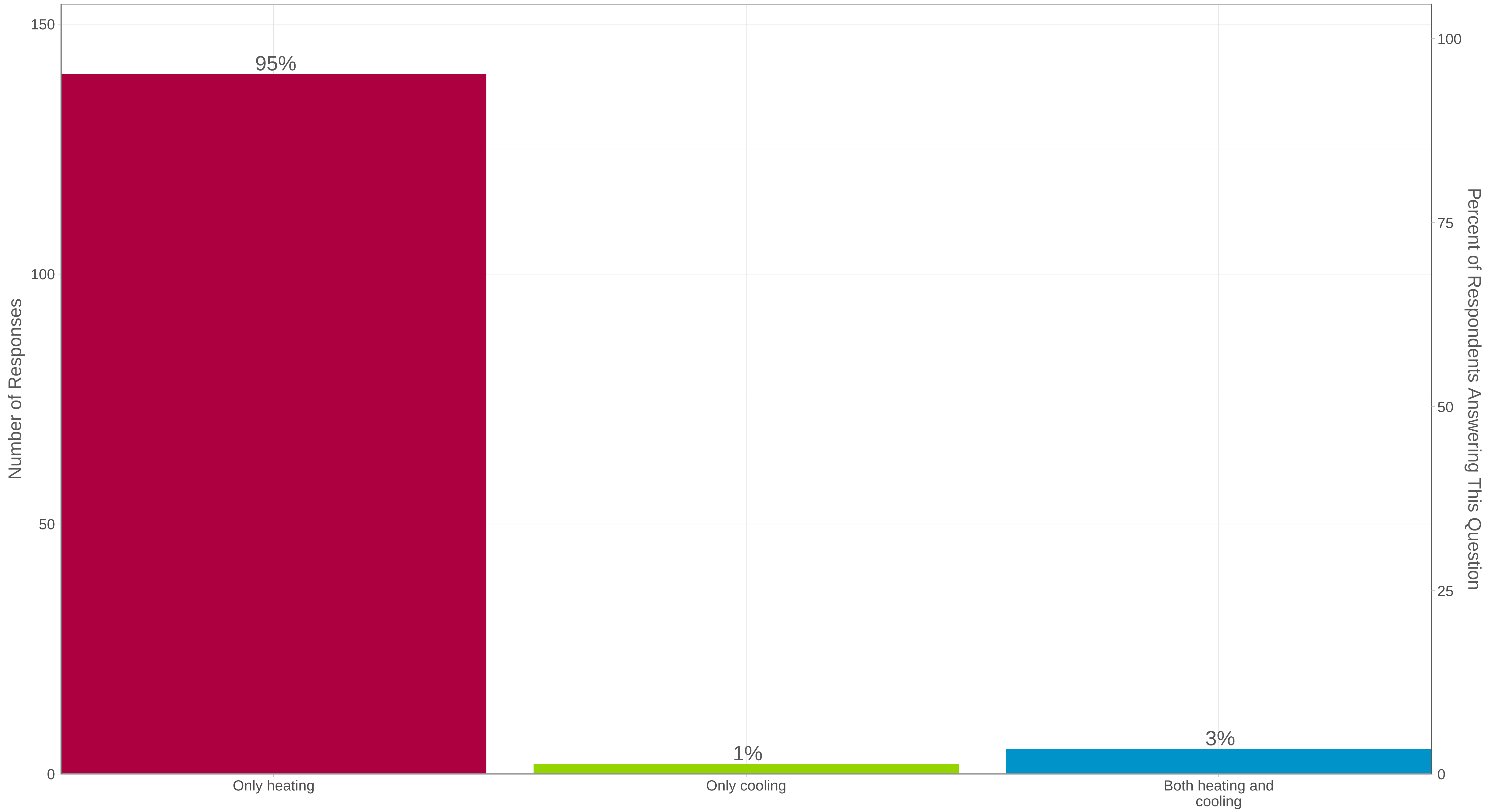
Total responses: 450
Total respondents: 450
Source: Navigant Analysis

1.44 Question QB10b: Other than the ductless mini-split heat pump, does any other system provide heating or cooling to the space?



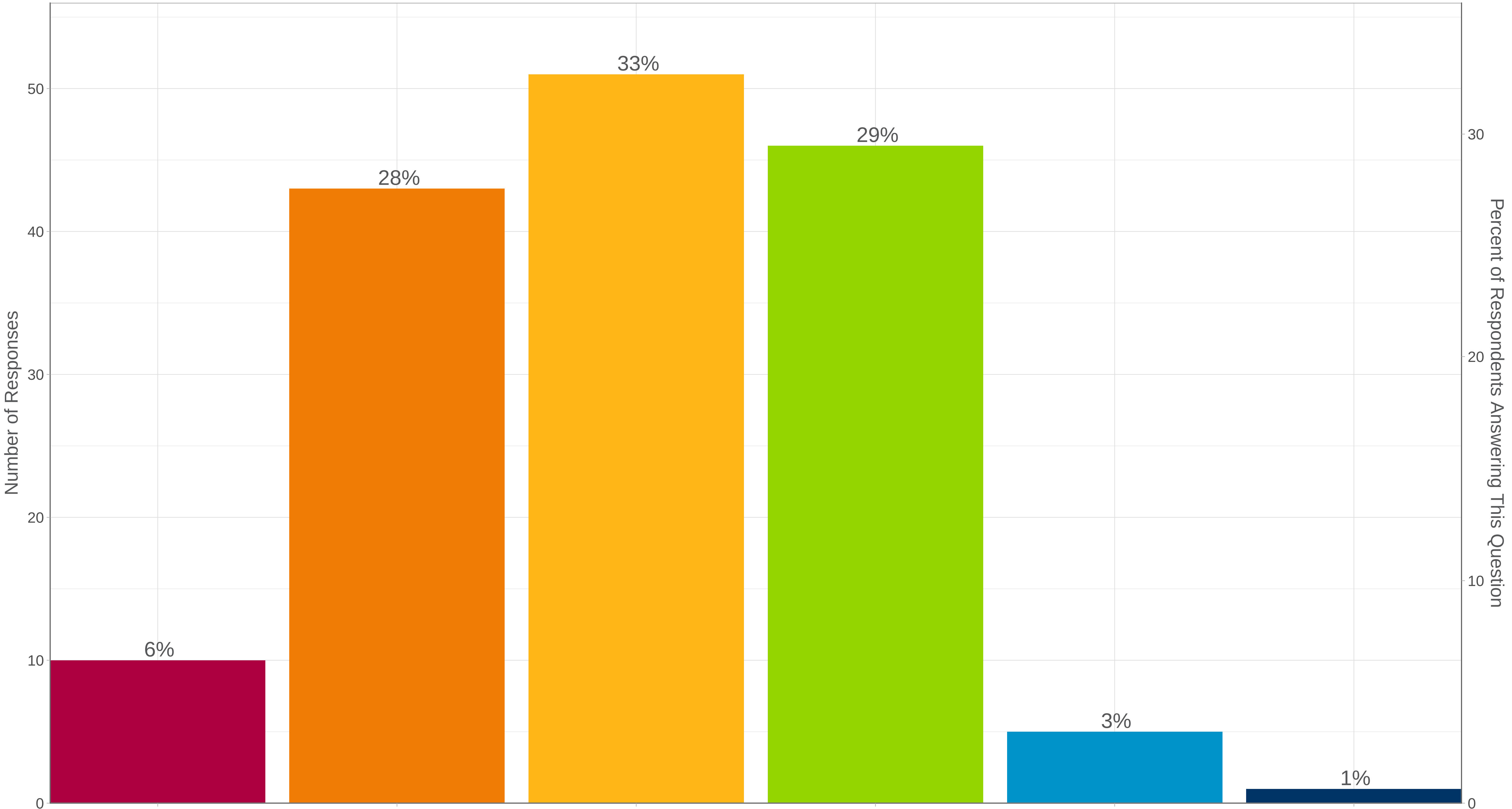
Total responses: 164
Total respondents: 164
Source: Navigant Analysis

1.45 Question QB11: Does this “other” system you indicated provide heating or cooling?



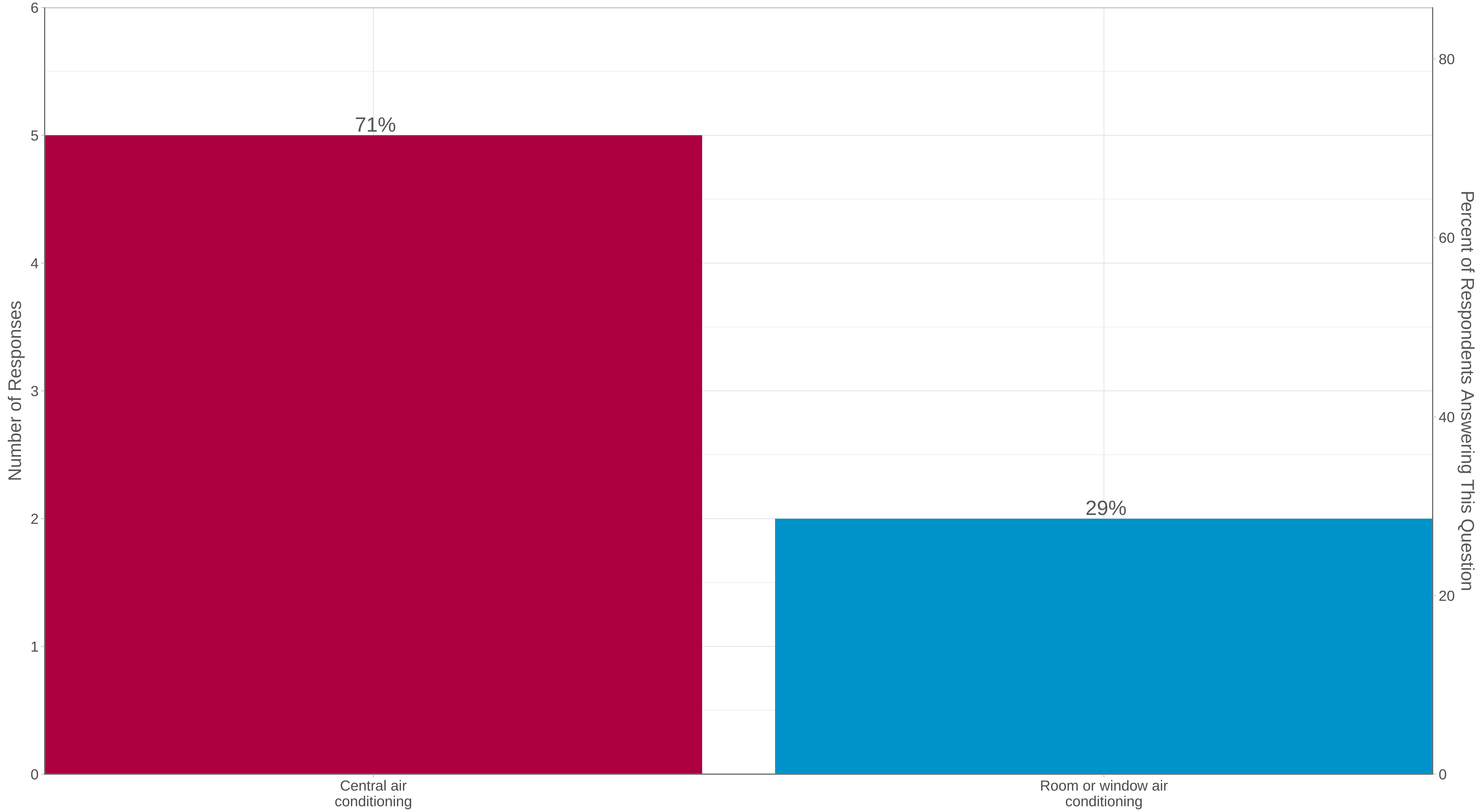
Total responses: 147
Total respondents: 147
Source: Navigant Analysis

1.46 Question QB12a: What is the other heating system that provides heating?



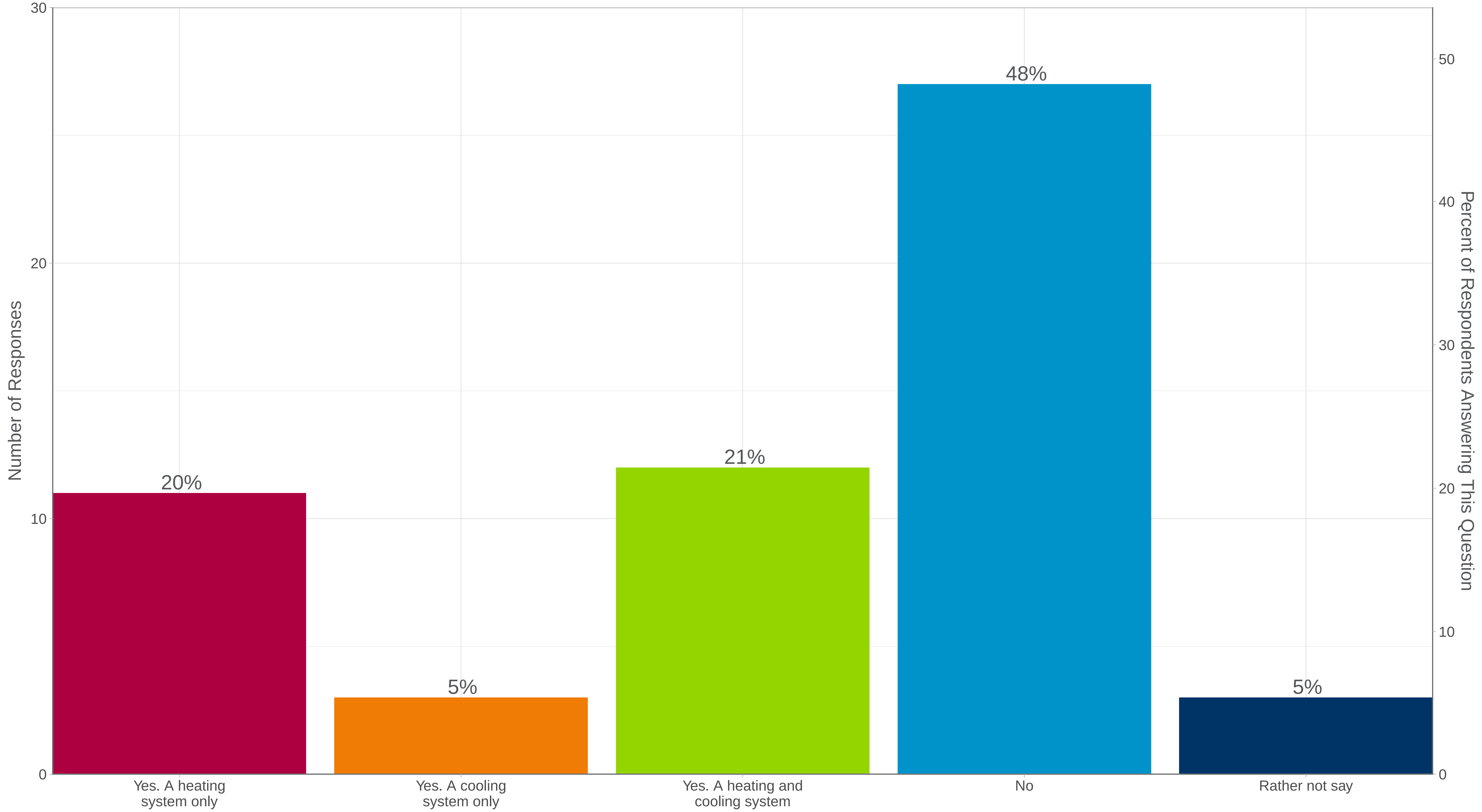
Total responses: 156
Total respondents: 145
Source: Navigant Analysis

1.47 Question QB12b: What is the other cooling system that provides cooling?



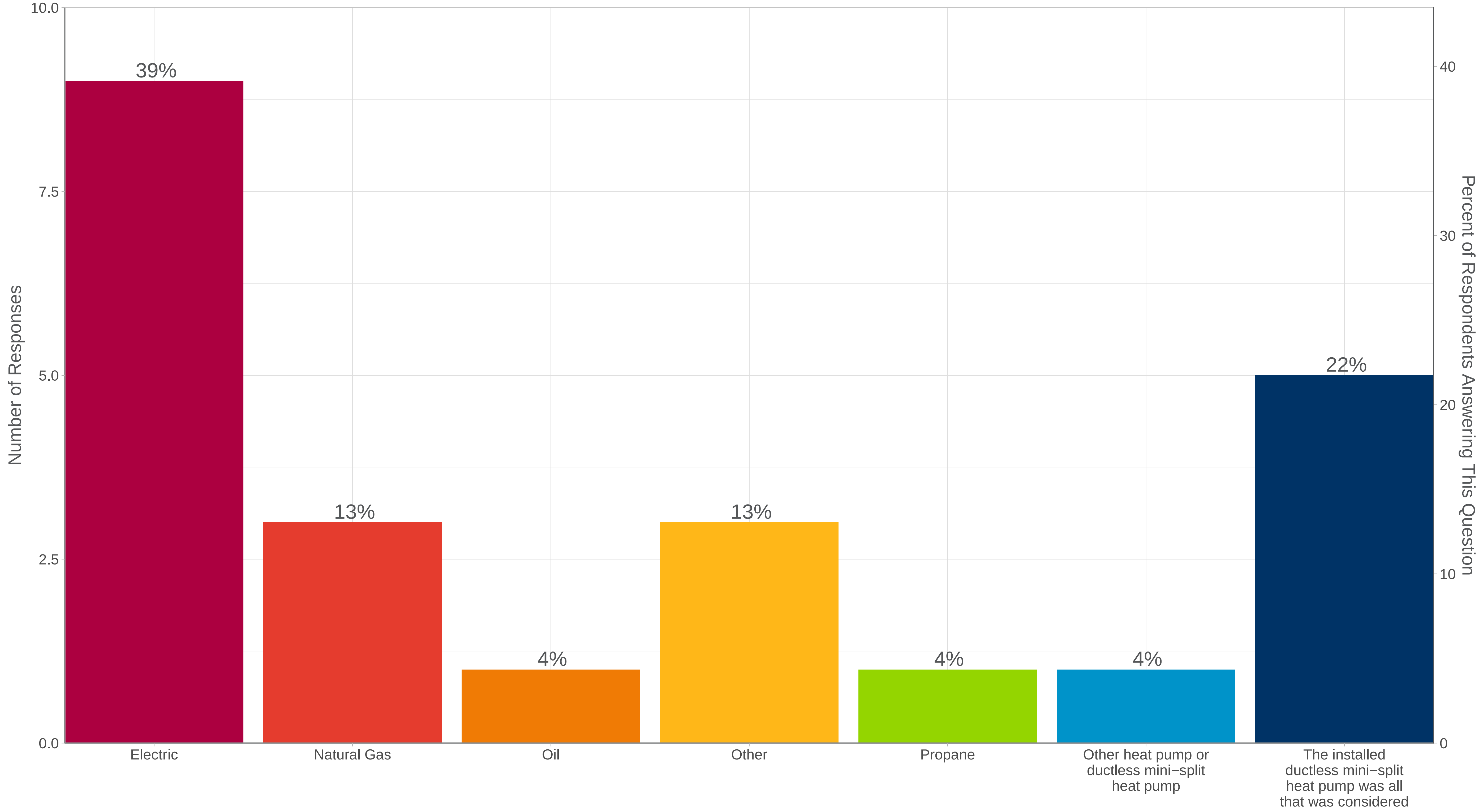
Total responses: 7
Total respondents: 7
Source: Navigant Analysis

1.48 Question QB15: If you had not installed a ductless mini-split heat pump, would you have installed a different type of heating or cooling system?



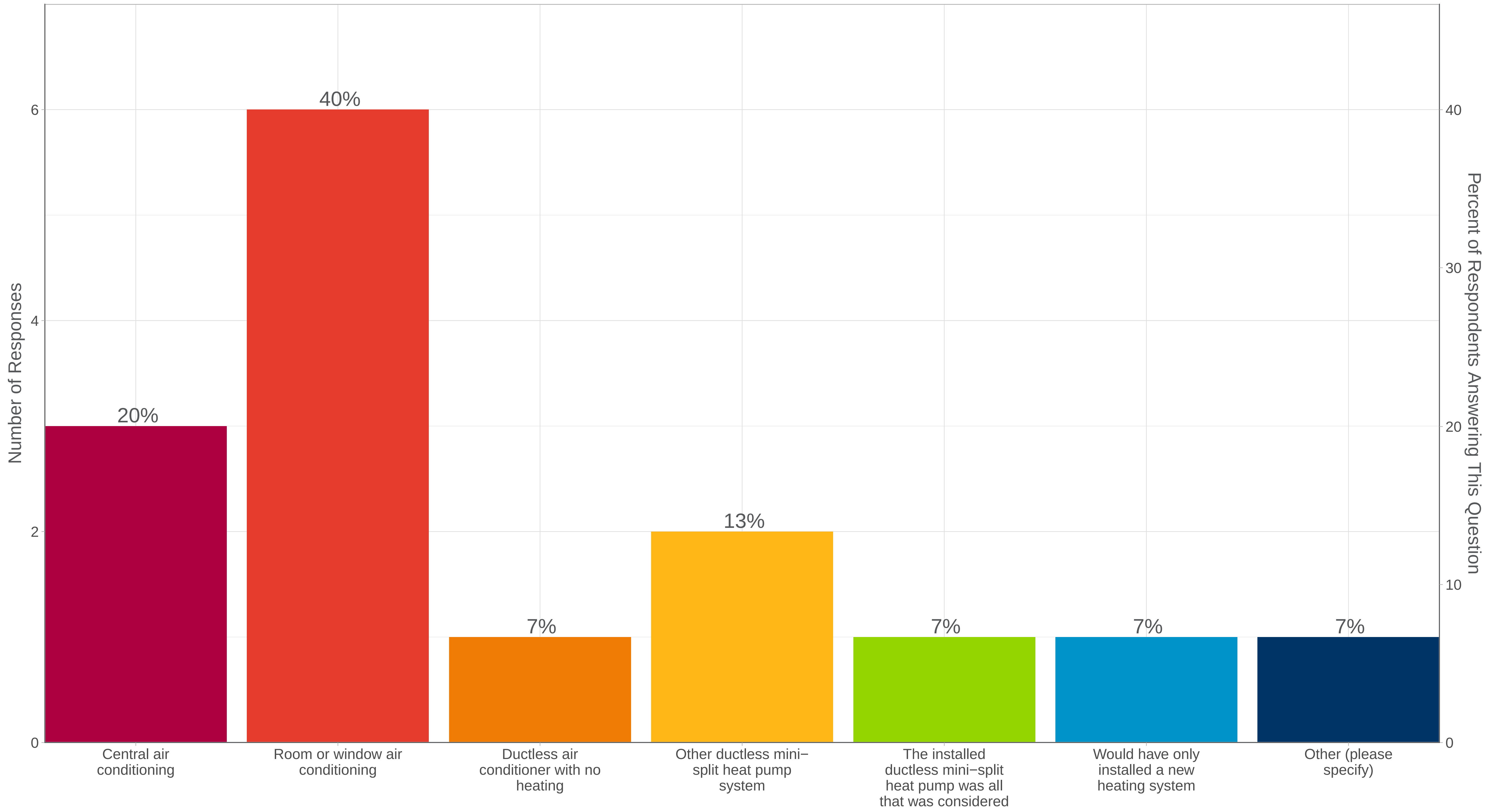
Total responses: 56
Total respondents: 56
Source: Navigant Analysis

1.49 Question QB16a: What Heating System Would You Have Installed?



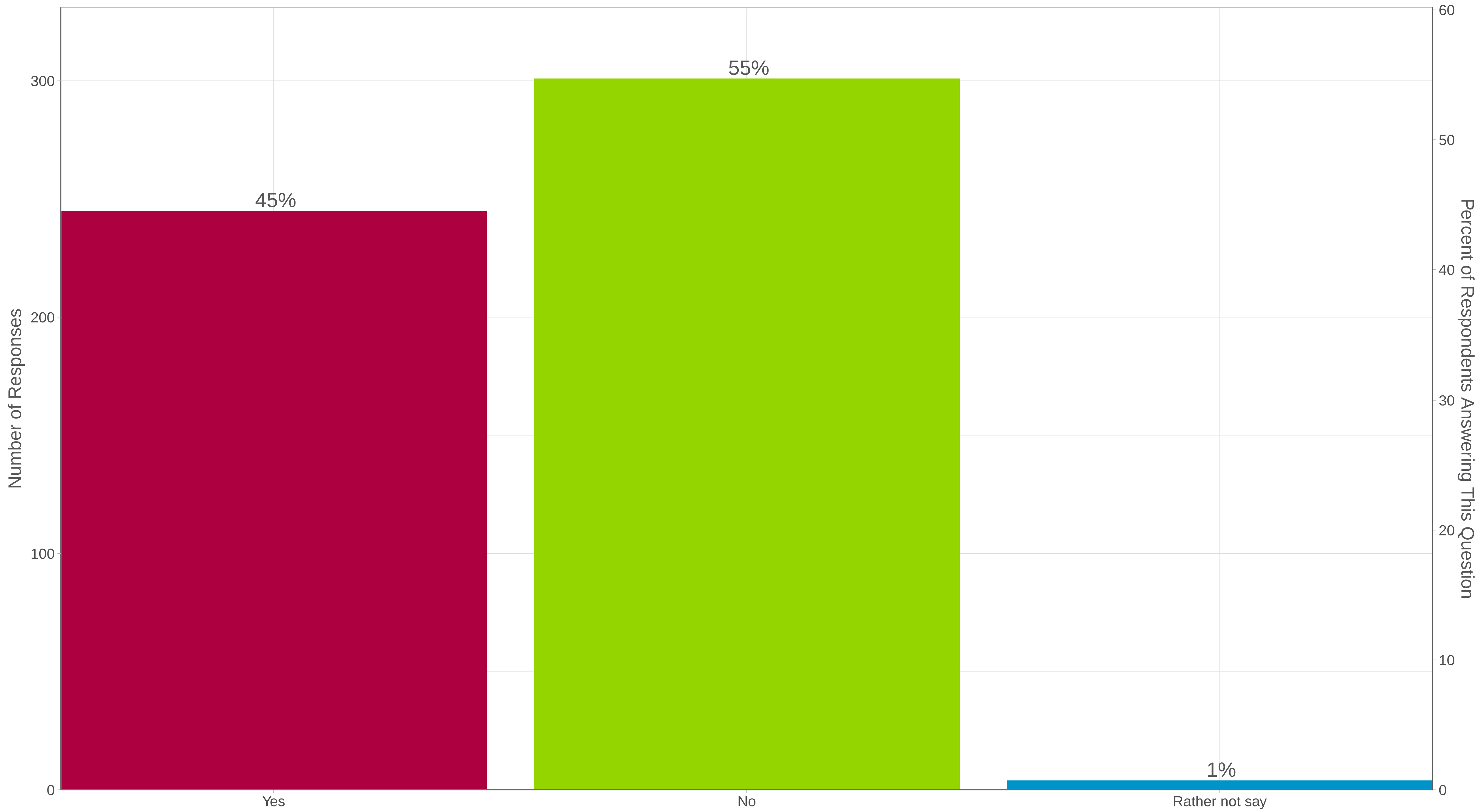
Total responses: 23
Total respondents: 23
Source: Navigant Analysis

1.50 Question QB16b: If you had not installed a ductless mini-split heat pump in the space, what type of cooling system would you have most likely installed?



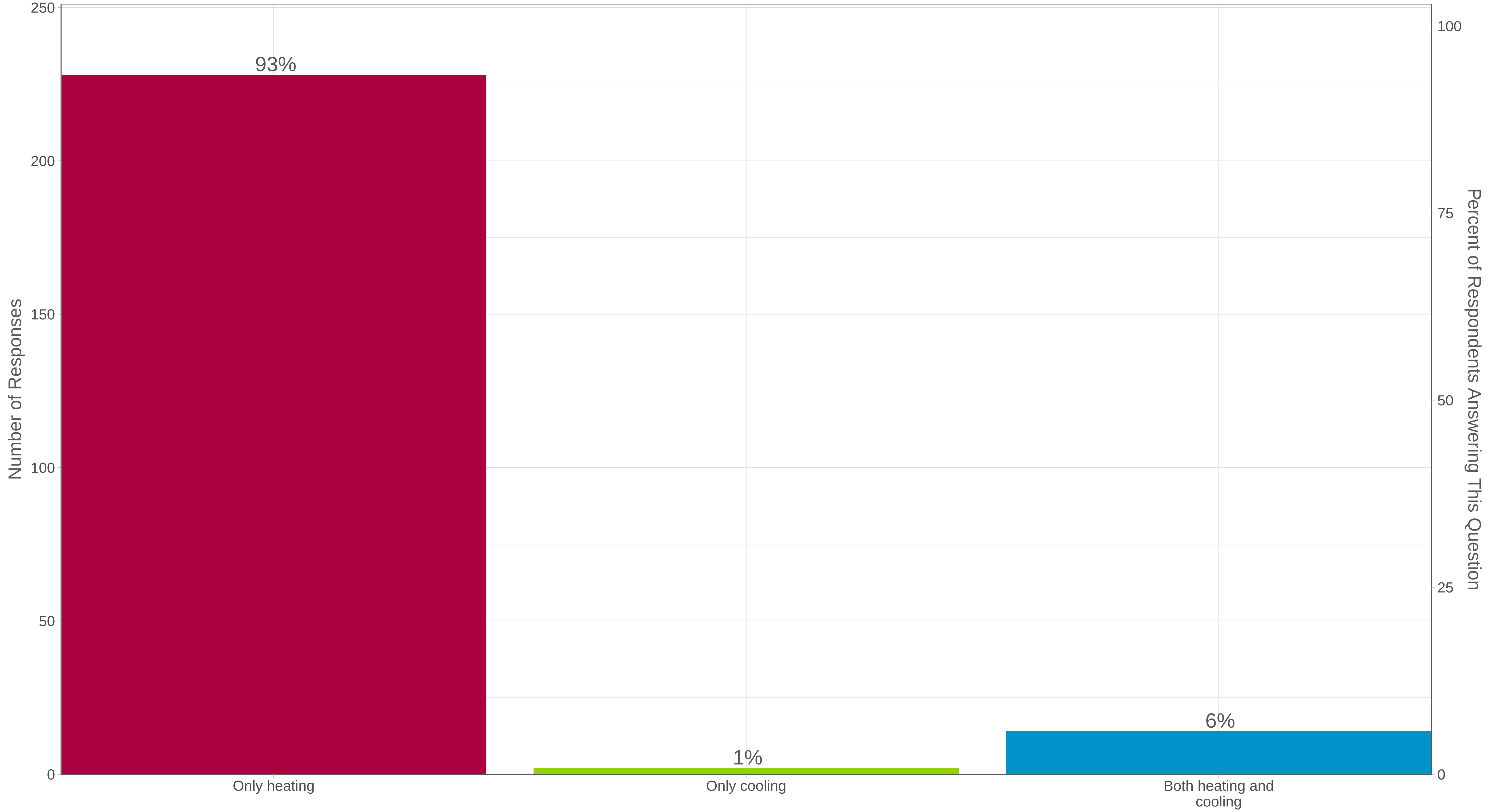
Total responses: 15
Total respondents: 15
Source: Navigant Analysis

1.51 Question QB17: Other than the ductless mini-split heat pump, does any other system provide heating or cooling to the space?



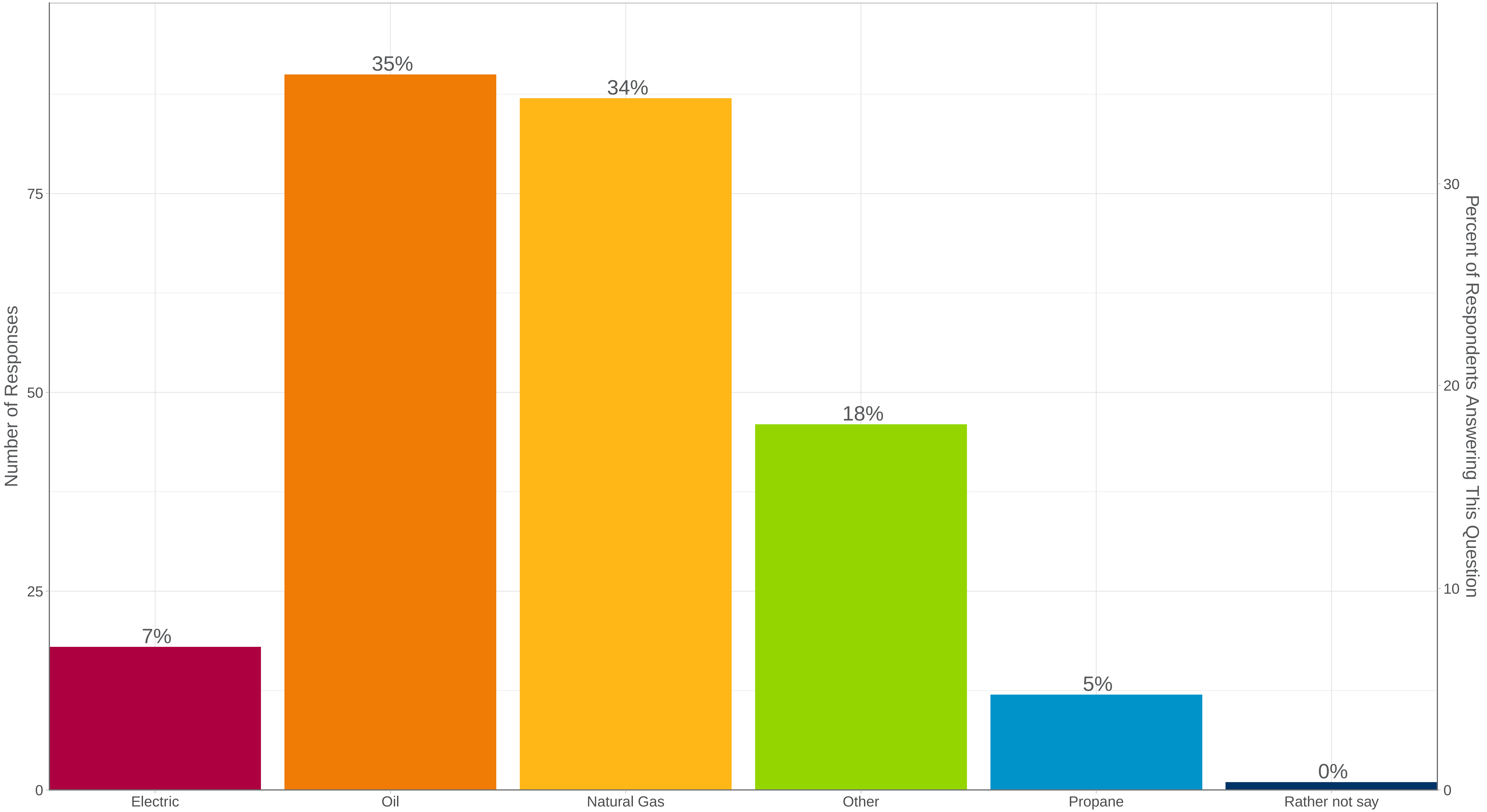
Total responses: 550
Total respondents: 550
Source: Navigant Analysis

1.52 Question QB18: Does this “other” system you indicated provide heating or cooling?



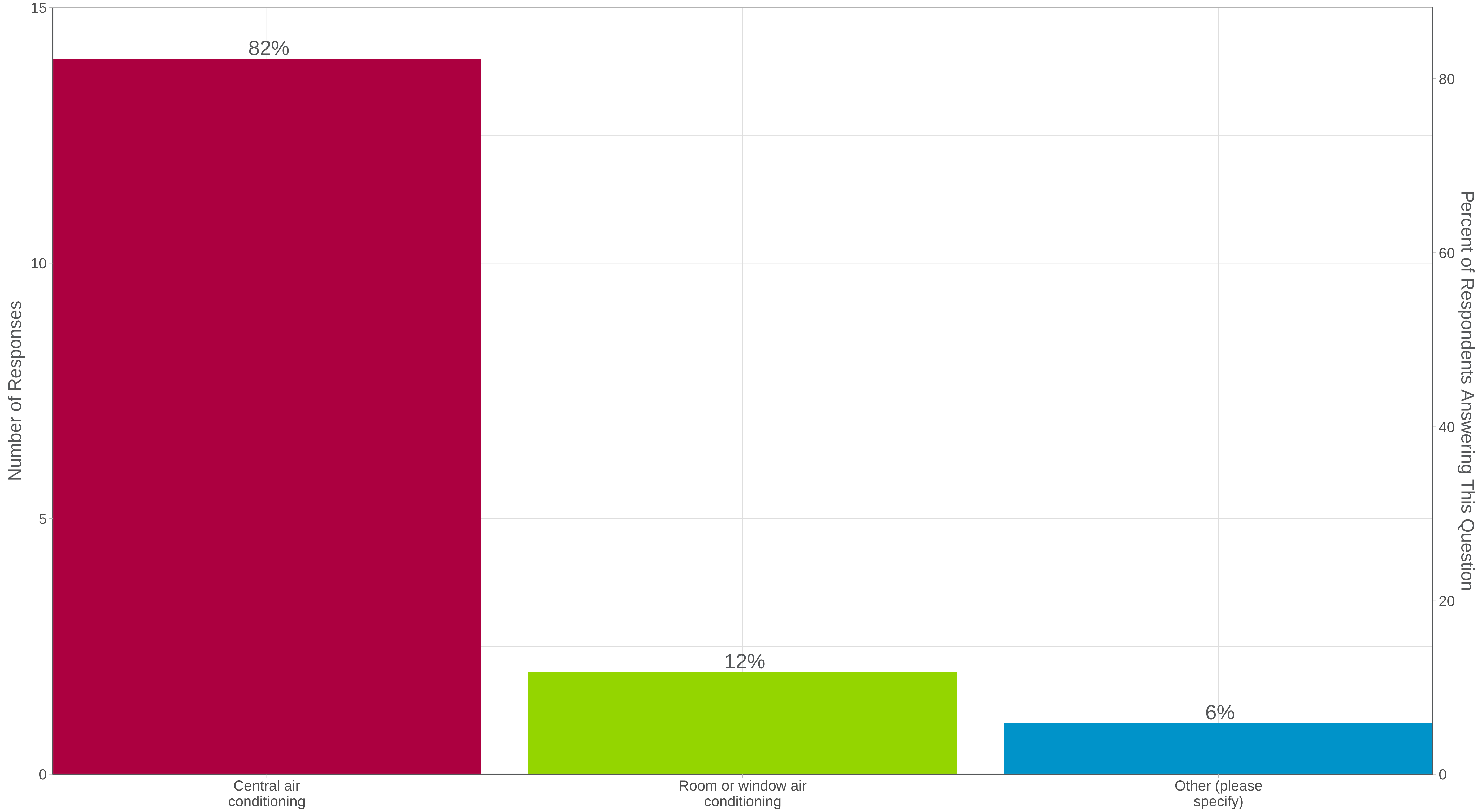
Total responses: 244
Total respondents: 244
Source: Navigant Analysis

1.53 Question QB19a: What is the other heating system that provides heating?



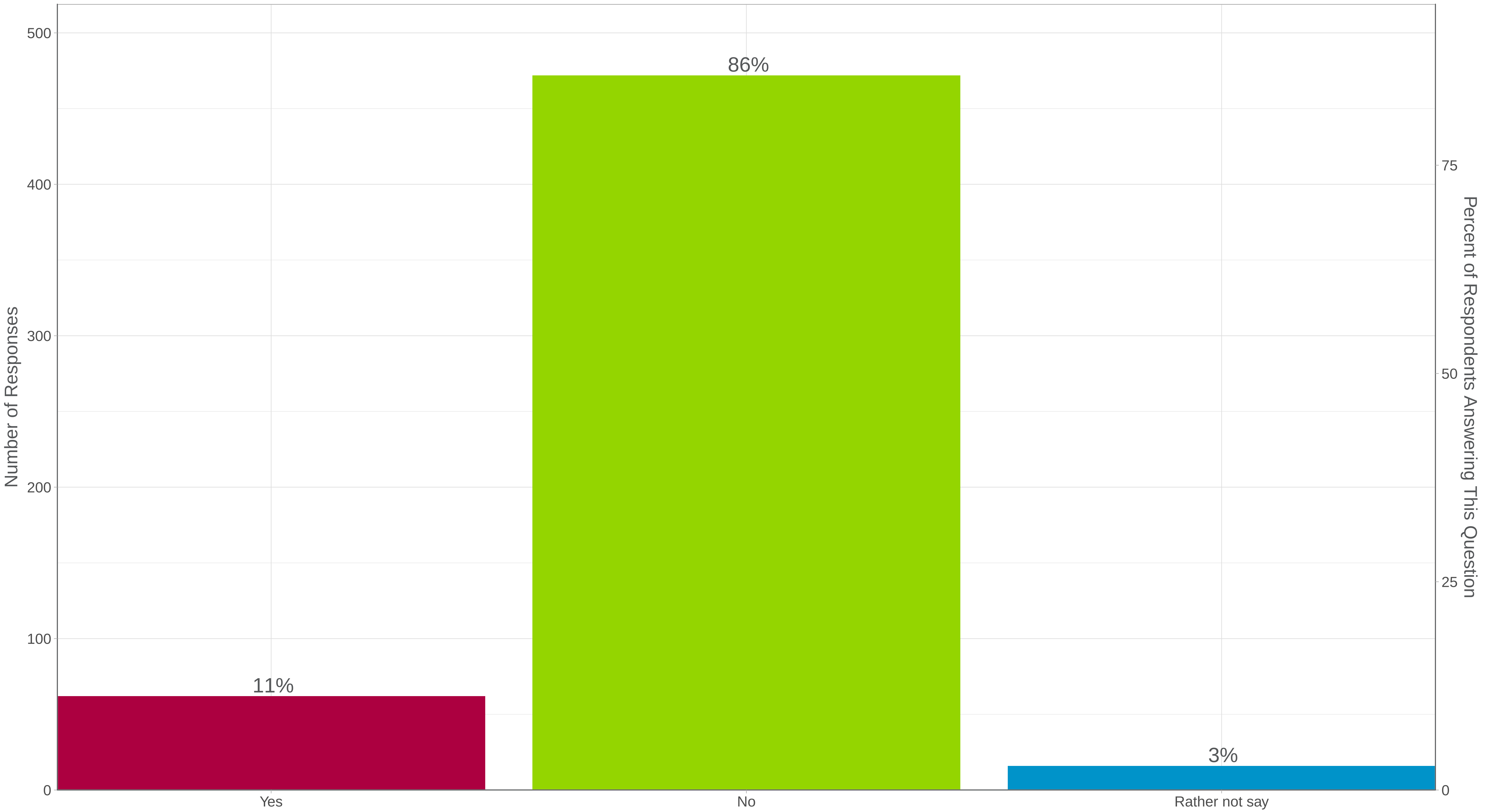
Total responses: 254
Total respondents: 242
Source: Navigant Analysis

1.54 Question QB19b: What is the other cooling system that provides cooling?



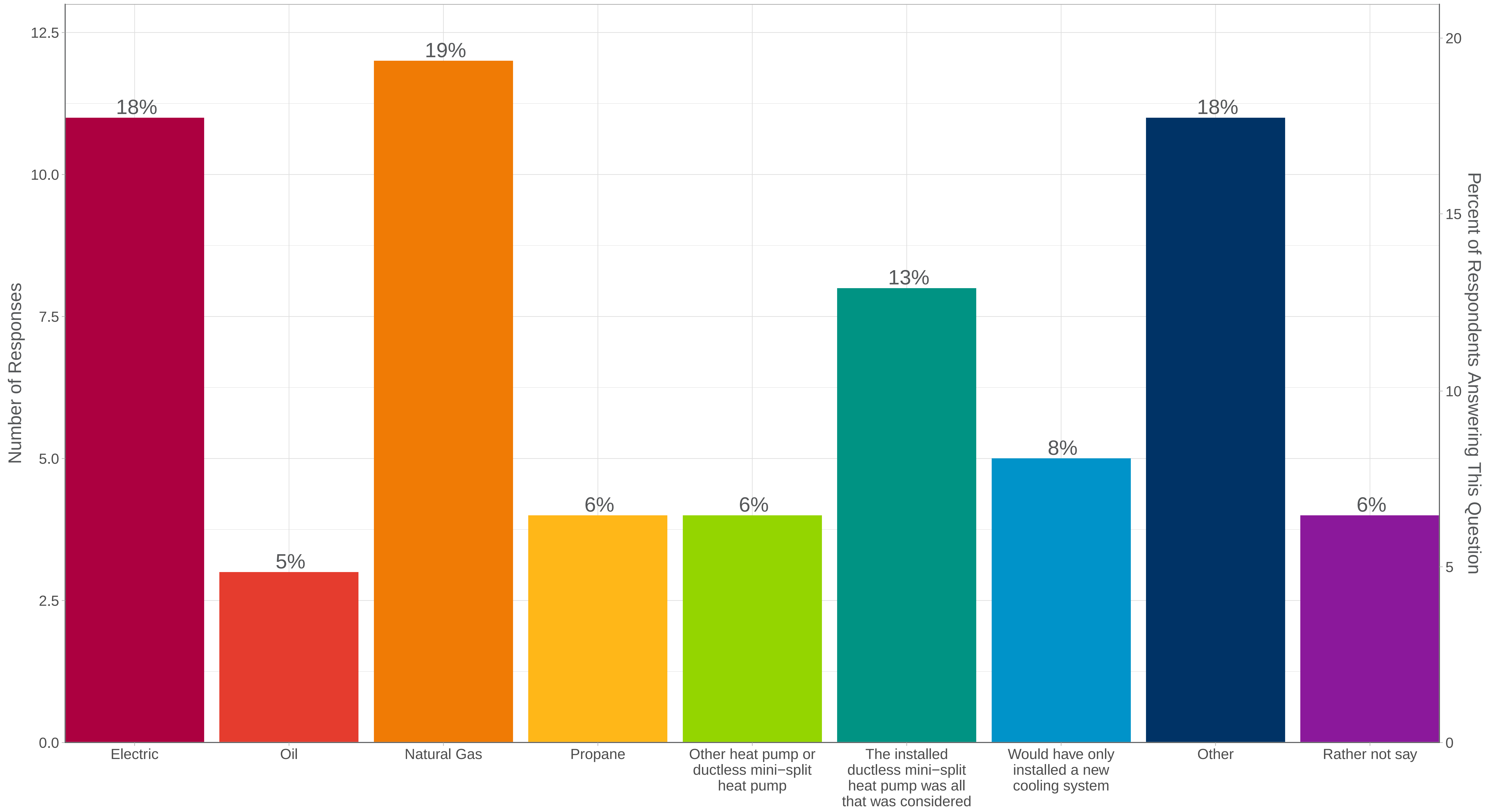
Total responses: 17
Total respondents: 16
Source: Navigant Analysis

1.55 Question QB20a: If you had not installed a ductless mini-split heat pump, would you have installed a different heating system?



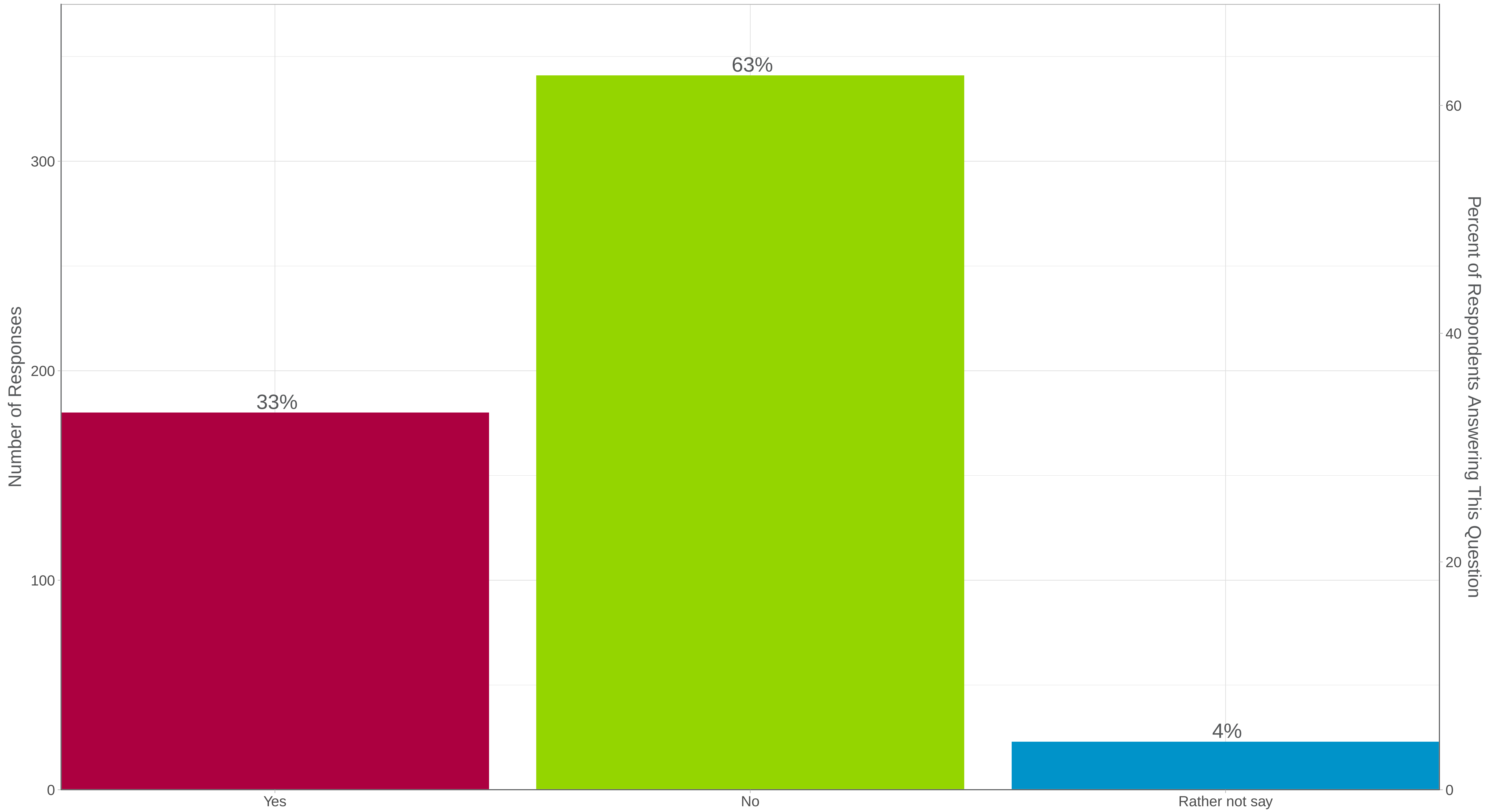
Total responses: 550
Total respondents: 550
Source: Navigant Analysis

1.56 Question QB20b: What Heating System Would You Have Installed?



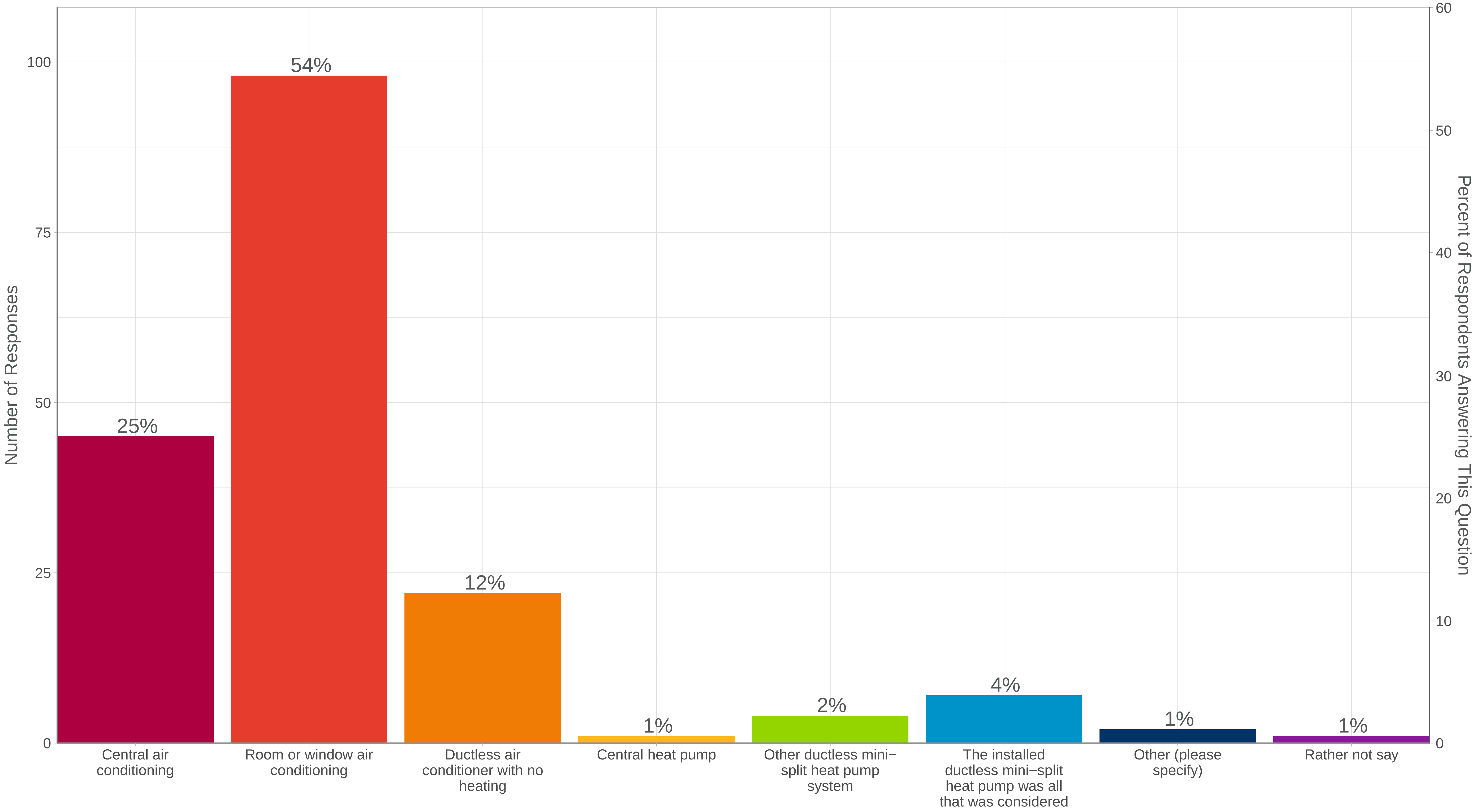
Total responses: 62
Total respondents: 62
Source: Navigant Analysis

1.57 Question QB21a: If you had not installed a ductless mini-split heat pump, would you have installed a different cooling system?



Total responses: 544
Total respondents: 544
Source: Navigant Analysis

1.58 Question QB21b: What type of cooling system would you have most likely installed?



Total responses: 180
Total respondents: 180
Source: Navigant Analysis

Ductless Mini-Split Heat Pump Survey (RES 29)

Open Ended Questions

Prepared for:

BERKSHIRE GAS
BLACKSTONE GAS COMPANY
Cape Light Compact
Columbia Gas of Massachusetts
A NiSource Company
EVERSOURCE
Liberty Utilities
nationalgrid
HERE WITH YOU. HERE FOR YOU.
Unitil
energy for life

Prepared by:
NAVIGANT

2.1 Question Q1: Before we finish do you have any other feedback about the Mass Save Program or the rebate you received for your ductless mini-split heat pump? (Program)

(Results are representative, not comprehensive of those received)

- I love the Mass Save program
- Great program
- Thank you
- It was a great rebate and audit was impressive
- Mass Save is great. The Mass Save audit identified some missing (or inferior) insulation areas in the wall but missed some others. I wish they were more thorough in finding problem spots.
- The Mass Save Program is very useful to help homeowners get better energy efficient equipment at better cost. Very useful.
- Highly recommend this program to others. I installed an efficient cooling system at a reasonable price. System works very well so far.
- very difficult...paperwork got lost had to be resubmitted...a contractor wanted to do an inspection was totally inflexible on times to do it
- It would be helpful if you provided additional information to homeowners or other potential installers on the selection of an installer. We made the mistake of checking credentials for State licensing, and found that our contractor (YearRound Heating & Cooling, Hatfield) was licensed by the state. However, as we learned after the fact, even through he represented himself as an authorized installer, he never had any training by Fujitsu (or Mitsubishi), and it was very clear from his installation that there were significant limitations in his knowledge of how to install the Fujitsu systems. We are now faced with the need to re-position 2 of the indoor units that were installed only 3 feet above the floor, and to have additional exterior work done to keep nesting animals from chewing away at exposed tubing insulation.
- The program helped make the decision easier, caused us to tell others about it, and the program seemed well-run and our submission was processed very promptly Thank You!
- The program is excellent - every resident in MA should take advantage of it. I am extremely impressed and pleased with everyone involved. Thank you!!

2.2 Question Q1: Before we finish do you have any other feedback about the Mass Save Program or the rebate you received for your ductless mini-split heat pump? (Rebate)

(Results are representative, not comprehensive of those received)

- Very prompt payment of rebates.
- First, I thought the rebate took WAY too long to receive. These days, things should simply not take 8-10 weeks. Second, while the MASS Save website stated that I'd be getting $500 in rebate, I actually only got $300, which was also, understandably disappointing.
- The rebate should probably be higher than $100/300 to help incentivize others.
- I understand that there was a larger rebate than the $300 that I received, but that I had to use a contractor on a specific list provided by the state and I did not know that prior to having the unit installed.
- There was a serious problem in processing my rebate. Well over 3 months. Many phone calls made and the problem was identified early yet never resolved. Only when I quit calling and took a chance with an email did the rebate process.
- I really appreciated the rebate we received. It helped make the DMSHP more affordable for us. It was still a large investment even with the rebate.
- Rebate should be more like $500, $100 is kind of low. These units are expensive.
- Rebates are sufficient and appreciated to help offset costs of home improvements that may not have made otherwise.
- I never received the proper rebate amount for the mini-split system. I installed one outside condenser and two indoor heads. The Rebate team could never read and interpret the contract or my clarifications - so they gave me a $300 rebate for one of the indoor heads. When trying to pursue the rebate for the second head, they said that a mistake was made and I should have received only $100 for the first head and, therefore, the $300 would cover the two heads. The certificate information I provided and the ratings on the Mass Save web site clearly stated that I should get $300 per unit. I tried to pursue but was 'shutdown' by every attempt I made. This rebate system is a fraud. The people would attempted to help were clearly instructed to not provide the proper rebate.
- I had two 18kW units installed. One had wall mount indoor, the 2nd had floor mount indoor. I got only $100 for the floor mount because the SEER was 1% different, AND yet, this unit so far produces better heat than the wall mount. Mass Save needs to recalibrate your rebate method!
- Mass Save rebate came quickly. Mass CEC rebate has yet to arrive.
- The online system is very clunky and fails often. It could use improvement. Phone support staff is excellent. I never received and explanation for the rebate we received. We installed 8 mini splits and only got $800 despite having 6 units that were eligible for the $300 rebate.

2.3 Question Q2: Additionally, do you have any overall comments on the performance of your ductless mini-split heat pump that you would like to share? (System)

(Results are representative, not comprehensive of those received)

- Very much satisfied with a choice to go with ductless system. Will use in future if ever need a replacement of existing heating or cooling unit in main house.
- The system should come with a smart programmable thermostat beyond the included remote. The fact that I can’t manage this system remotely to be more efficient is a loss.
- If possible, estimates should be given for operating costs of the system for both heating and cooling prior to any purchase. Also the drawbacks of using the system as the primary heat source should be made clear.
- I would like assistance in learning how to operate the heating portion of the ductless heat pump. I can’t seem to get them working.
- I am in the process of contacting the contractor who installed the mini-split heat pump because even though I've turned off the heat pump system, it sounds like it's still running outside and our electric bill was very high still.
- The ductless system did not provide the savings compared to window units we were told it would. And it was very expensive to install
- we are getting more use from the mini-splits as a cooling system versus heating.
- I need to contact my installer to guide me in using the heat pumps along with my oil burning furnace for adequate warmth in the cold winter. I tried just using the heat pumps and was cold most of the time!
- If the instruction about how to operate the pump most efficiently can be provided on Mass save website, it will be even better.

2.4 Question Q2: Additionally, do you have any overall comments on the performance of your ductless mini-split heat pump that you would like to share? (System Performance)

(Results are representative, not comprehensive of those received)

- It’s too expensive to use electric. Would love a gas option.
- Love it. Room unusable before heat pump.
- The mini-split is making the master bedroom so comfortable summer and winter that I want to add units to heat and cool the other second story rooms that are inadequately heated and cooled at present.
- Love them. Wish had installed years earlier.
- The air conditioning works great. We've used the air purifier a couple of times and that works well also. we've only used the heat once or twice and it did take the chill off the room. We are not sure if we can use the unit when the temperature is below 30 - we are afraid of condensation freezing in the pipes or the unit. We will use it more for cooling in the spring and summer. We are still getting to know how to operate the units.
- It has performed better than expected.
- It is a good system but the bills are higher than I expected and the heating isn't as efficient in all rooms when the temp is below 15 degrees. Will need to supplement with other heat at those times.
- We don't heat with it. The units are high, so we don't know how to get the heat down to the lower part of the rooms.
- The performance for heating and cooling far surpassed my expectations. The heating capability was a pleasant bonus!
- I’m just not sure how to work The heating feature
- Up until this arctic freeze, we were happy with the mini-splits, but they do not seem to be able to handle this level of cold very well.
- I do not use it below 30 degrees because it was recommended by the contractor not to use it at such a low temperature.
- I installed it for cooling but have found myself using it for heating a lot more than I anticipated. I love it.
- I am shocked and dismayed at the cost. I was hoping to save money and it did the opposite. My electric bill has gone from $30/mo to $238/mo and I have solar on my house. This makes no sense, wish I had not spent the money on this

Massachusetts Residential HVAC Net-to-Gross and Market Effects Study (TXC34)

Final Draft

July 27, 2018

SUBMITTED TO:
Massachusetts Electric & Gas Program Administrators

SUBMITTED BY:
NMR Group, Inc.
Tetra Tech, Inc.

Executive Summary

Background

Study Purpose

The primary purpose of this study was to estimate and recommend net-to-gross ratios (NTGRs) for selected heating, cooling, and water heating measures that will receive Mass Save® Standard rebates in 2019-2021. Another purpose was to measure market effects indictors for evidence of progress toward market transformation that may be attributed to the program, and to set baselines for comparison with future measurements.

Study Description

NMR fielded participant and contractor quantitative web and phone surveys in 2017 and 2018. A Consensus Group used those results to recommend NTGRs for Massachusetts planning tools, such as the 2019-2021 Technical Reference Manual and benefit-cost ratio models. Surveys also asked about market effects and other topics.

Results

NTG Results

This study's recommended NTGRs differ from current TRM values, which are mostly based on a 2012 study. The recommended 2019-2021 NTGRs for ductless mini-split heat pumps (DMSHPs) and boilers increased from the 2016-2018 NTGRs. The recommended NTGRs for heat pump water heaters (HPWHs), central air conditioning (CAC), central heat pumps (CHP), and furnaces decreased.

Consensus Group Recommended 2019-2021 Net-to-Gross Ratios

Measure	Previous	Recommended
Ductless MSHP	0.62	0.77
Heat pump water heater	1.00	0.83
Central air conditioner	0.86	0.67
Central heat pump	0.86	0.60
Furnace	0.81	0.76
Hot water boiler	0.77	0.79
Condensing combination boiler	0.74	0.79

Market Effects Results

Contractors offered anecdotal evidence that, to some degree, the program's intended effects on stocking have occurred. Attribution question results for equipment costs provide anecdotal evidence that the programs played a modest role in effecting changes in the high-efficiency versus standard efficiency equipment prices that contractors incur. Additionally, customer demand for high-efficiency HVAC equipment has increased, and contractors attributed much of this change to the programs.

Contractor Influence Results

Both participant and contractor survey results indicate that contractors' recommendations have a strong influence on the models of equipment customers choose. Contractors perceived that their own recommendations, compared to other factors, have had the most influence on their non-program high-efficiency sales; moreover, the programs strongly influence their recommendations. This suggests that the programs have substantial indirect influence on what appears to be the strongest driver in the selection of qualifying equipment outside the program.

Note: Because the number of contractors asked these questions was small, this finding should be generalized with caution.

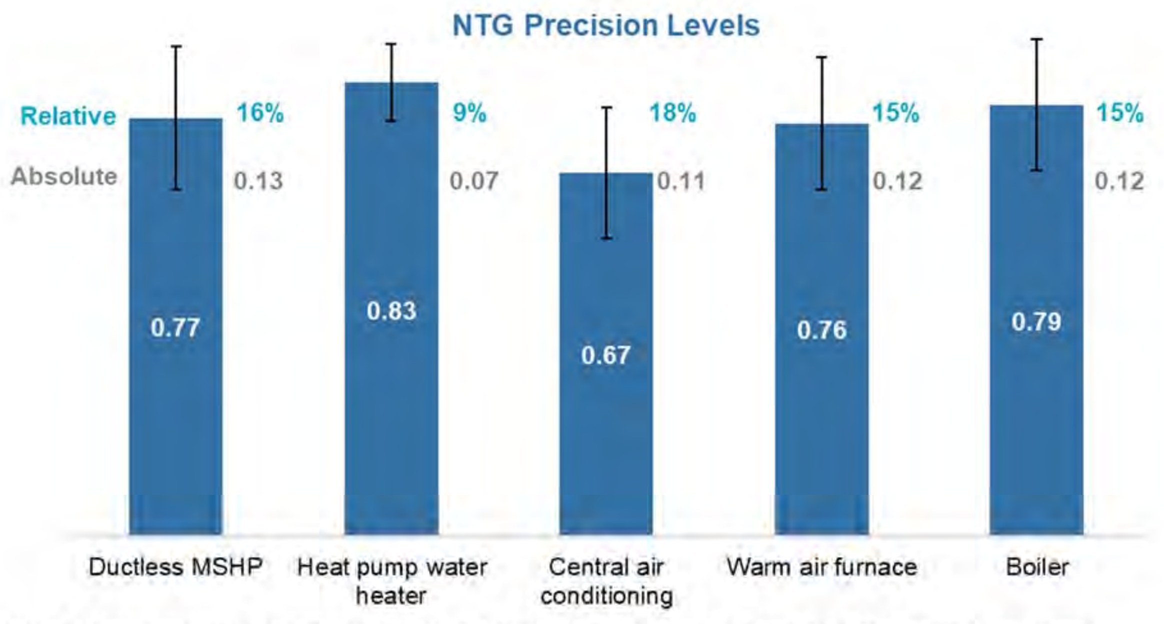
Quantitative Methods

Completed Surveys	Participants	Contractors
Ductless MSHP	66	51
Heat pump water heater	79	41
Central air conditioner	66	28
Central heat pump	35	16
Furnace	61	42
Boiler	60	49

Counts of completed NTG batteries

Methodological Limitations

Contractor and participant survey sample sizes were low because of poor response rates. Moreover, contractors struggled to interpret some NTG questions, which were excluded from the analysis. Sampling error among contractors was between +/-11% and 15% at the 90% confidence level, with the exception of CHPs (20%). Participant sampling error was narrower, ranging from +/-9% to 13%. Despite this, NTGRs passed Massachusetts' informal guidance that estimates should meet 10% absolute precision or 25% relative precision at the 90% confidence level.



Note: Absolute precision represents the NTGR standard error times the z-score for a 90% confidence interval (1.645), while relative precision compares those values as percentage changes from the recommended NTGR. Because the Consensus Group selected CHP NTGR (meaning it is not derived from raw data), we do not present it here. CHP NTGR in the raw data was 0.58 with 0.11 absolute precision and 18% relative precision.

Recommendations

- Incorporate the NTGRs recommended by the Consensus Group for equipment incented with "Standard" rebates into the 2019-2021 Technical Reference Manual.
- Measure the same market indicators in future studies of the programs' residential HVAC activities, and compare the results to track progress over time. Future measurements of reduced cost barriers should allow for a comparison between changes in costs of high-efficiency and standard equipment to assess whether contractors perceive prices of high-efficiency equipment as changing at faster, slower, or the same rates as those of standard standard-efficiency equipment. To claim savings from market effects, market share data must be available for analysis. Changes in the indicators assessed in this report could corroborate findings from market share data analysis.

- While the market effects results show that customer demand for high-efficiency equipment has increased over the last three years, and participant survey results indicate that contractors' recommendations have considerable influence on the models of equipment customers choose to install, customers are important drivers of decision making for certain equipment types. Given this, the programs should continue to target both customers and contractors.

Considerations

- The evaluation team has previously attempted to obtain Massachusetts HVAC market share data from manufacturers on behalf of the PAs, and is currently attempting to obtain Massachusetts unit sales data from distributors. The team has encountered considerable difficultly obtaining meaningful state-level data from HVAC industry players. There remain two ready sources of HVAC market share data that the PAs previously examined and may wish to consider using in the future: the national ENERGY STAR® shipment data and HARDI HVAC data from D&R International. The PAs have previously chosen not to rely on either data source because the data were not sufficiently representative of Massachusetts. Since the completion of this evaluation, D&R International has informed the evaluation team that they have successfully brought on board a distributor with many Massachusetts outlets. D&R estimates that the data they now have in hand for Massachusetts represents slightly over 35% of the state's market for furnaces, CAC, and ASHP equipment. This is more than double the previous representation, and the data go back several years.
- Another approach the PAs may want to consider in the future is to leverage national ENERGY STAR shipment data. This would involve asking manufacturers to estimate the Massachusetts market share of ENERGY STAR-qualified HVAC equipment in relation to the national data, with some consideration of attribution. While this would be less expensive than purchasing D&R data, and likely less expensive than the approach taken in this evaluation, it would not be as precise as either. ENERGY STAR also does not equate directly with Mass Save program capacity and efficiency requirements.
- Consider how changes in NTGRs may affect the PAs' benefit/cost ratio models and decisions to continue to support each of the measures at the current efficiency specification and rebate levels.
- Improve contractor contact information tracking (e.g., develop contractor IDs, require email addresses). It would better serve future evaluation efforts.
- In the future, consider using in-depth interviews rather than programmed surveys with contractors to estimate market shares and program influence. The complexity involved in these questions requires abstract consistency checks that are difficult to implement through a programmed survey with no trained expert guiding respondents to correctly interpret the questions.

Table of Contents

1

Section 1 Introduction & Background

This report summarizes the results of a study that measured net-to-gross ratios (NTGRs) for selected residential HVAC equipment supported by Mass Save. The study's goals were to (1) measure one-year retrospective NTGRs and develop estimates of three-year prospective NTGRs for the equipment, and (2) inform future measurement of the effects of Mass Save programs on residential HVAC markets. The study specifically focused on "standard" rebates – not early replacement rebates. The RES36 study evaluated early replacement rebates.

This report is organized as follows:

- This **Introduction and Background** section describes the program. It explains, via a logic model, how the program is expected to change end-user and market actor decision-making and HVAC equipment markets.
- **Research Methodology** (Section 2) details our research approach, which was primarily based on surveys with participating customers and contractors. We concluded our research with a Consensus Group to recommend retrospective and prospective NTGRs.
- **Net-to-Gross Results** (Section 3) walks readers through preliminary free-ridership (FR) and spillover (SO) results, NTG algorithms, and precision of results; reports contractors' market share predictions; describes the decision-making process that the Consensus Group undertook to arrive at the recommended NTGRs; and walks readers through the NTGR precision calculations.
- **Market Effects** (Section 4) explains how we operationalized indicators of the effects of the programs on residential HVAC equipment markets, including stocking, equipment costs, and customer attitudes and demand, and presents the results.
- **Contractor Influence, Equipment Replacement, and Fuel Switching** (Section 5) analyzes other important topics addressed by the surveys, including program awareness, influence of contractors on customer decision-making, price sensitivity, equipment replacement, fuel switching, and demographic characteristics.
- **Results, Recommendations, and Considerations** (Section 6) summarizes key results from the study and offers related recommendations and considerations to improve program design, outcomes, and processes.

The appendices include additional methodological details, background information, findings, participant demographics (Appendix A), and data collection instruments (Appendix B).

1.1 EQUIPMENT ADDRESSED

This study presents results for the following equipment types installed in residential settings: central air-conditioning (CAC) systems, central heat pumps (CHPs), natural gas furnaces, natural gas boilers, ductless mini-split heat pumps (DMSHPs), and heat pump water heaters (HPWHs). We analyzed hot water boilers and condensing boilers with on-demand hot water (i.e., combination units) in aggregate.

1.2 PROGRAM BACKGROUND

The objectives of the Residential Heating and Cooling gas and electric initiatives (referred to collectively here as "the programs") are two-fold: (1) to encourage consumers to purchase the most efficient HVAC and HPWH technologies available, both when replacing older, less efficient equipment and when considering equipment in new construction, and (2) to encourage contractors to follow installation best practices. Section 2.3 shows participation levels.

Table 1 outlines the measures currently supported by the programs, efficiency requirements, rebate amounts, and savings assumptions.

Table 1: Residential Heating and Cooling Programs' Efficiency Requirements, Rebate Amounts, and Savings Assumptions, 2016 through 2018

Program Measures	Efficiency Requirement	Rebate Amount[1]	Savings Assumptions
Electric			**kWh**
Ductless MSHP	SEER ≥ 18, HSPF ≥ 9	$250	286
	SEER ≥ 20, HSPF ≥ 11	$500	330
Heat pump water heater[2]	55 gallons or less, ≥ 2.3 EF	$750	1,654
	More than 55 gallons, ≥ 3.0 EF	$150	Not published
Central air conditioning	SEER ≥ 16, EER ≥ 13	$250	198.8
Central heat pump	SEER ≥ 16, HSPF ≥ 8.5	$250	450.3
	SEER ≥ 18, HSPF ≥ 9.6	$500	1,077.8
Gas			**MMBtu**
Warm air furnace	≥ 95% AFUE rating equipped with Electronic Commutated Motor (ECM)	$300	8.1
	≥ 97% AFUE rating equipped with ECM	$600	9.2
Hot water boiler	≥ 90% AFUE rating	$1,000	11.4
	≥ 95% AFUE rating	$1,500	14.1
Condensing Boiler w/ On-Demand Hot Water Heater	≥ 90% AFUE boiler rating	$1,200	10.3
	≥ 95% AFUE boiler rating	$1,600	12.8

[1] Standard rebates only (not early replacement)

[2] The electric program added larger (>55 gallon) HPWHs in 2017; the TRM does not establish savings for this system size. In 2018, the minimum EF requirements decreased for both sizes, to 2.0 and 2.7, respectively. Rebate amounts did not change.

In addition to providing downstream rebates, the programs' outreach services include education and support in the field through visits and calls to HVAC distributors, supply houses, and contractors via a shared circuit rider. The circuit rider also participates in training, trade shows, and related industry events, and visits big box stores to educate partners and to support optimal stocking practices, sales training, and distribution of point-of-purchase rebate materials.

To qualify for a rebate, customers must work with a licensed contractor and include the contractor's invoice with their rebate application. This invoice must itemize the equipment purchased, show required proof of purchase, and indicate the equipment type, size, make, model, efficiency rating, name of purchaser, installation date and location, date of purchase, and total installed cost. (In practice, most contractors take the lead role in submitting this information for their customers, according to PA staff.) The electric program encourages, but does not require, customers installing electric equipment to use an Airflow and Charge (AC) Check-trained contractor to make sure the equipment is installed to manufacturer specifications. The program maintains a listing of AC Check-trained contractors. Such contractors are eligible to receive incentives for installation and verification work, as well as reimbursements for training and diagnostic tool purchases.

While both programs promote early replacement by offering larger Early Replacement rebates for certain equipment types, this study examined Standard rebates only.[1]

1.3 PROGRAM LOGIC MODEL

Figure 1 and Figure 2 depict program logic by fuel type. They also show how the programs are meant to affect decisions of market actors and, ultimately, the demand for high-efficiency residential HVAC equipment. The programs' long-term goals are to increase the market penetration of, and develop a sustainable market for, the equipment types.[2] The program activities seek to address the following barriers:

- Financial, such as higher initial cost of high-efficiency equipment
- Lack of target audience awareness of high-efficiency equipment
- Lack of market infrastructure for the equipment, such as weak distribution networks, lack of trained installer base, and contractor resistance to selling the highest efficiency equipment
- Aesthetics and appearance of equipment
- Product or service drawbacks

While they are not depicted in the logic models, external influences can affect the program outcomes. External influences include ENERGY STAR; Air Conditioning Contractors of America (ACCA); the Air-Conditioning, Heating, and Refrigeration Institute (AHRI); the Northeast Energy Efficiency Partnerships (NEEP); the Consortium for Energy Efficiency (CEE); and equipment manufacturers. Another external influence is the availability of rebates from other sources. As we describe in Appendix A.1.6, the Massachusetts Clean Energy Center (MassCEC) offers sizable rebates for some of the same models of air source heat pumps as the program. If respondents received rebates from both the CEC and Mass Save,

---

[1] The HVAC Early Replacement (RES36) study examined early replacement rebates for residential HVAC equipment. Customers who apply for an early replacement rebate must go through the Home Energy Services (HES) core initiative or receive an AC Check. The TXC34 and RES36 teams coordinated data collection and measurement and analysis methodology where appropriate and possible.

[2] The logic model also includes a quality installation component that is outside the scope of this study.

the survey asked them to consider only the effects of the Mass Save rebates, not the CEC rebates.

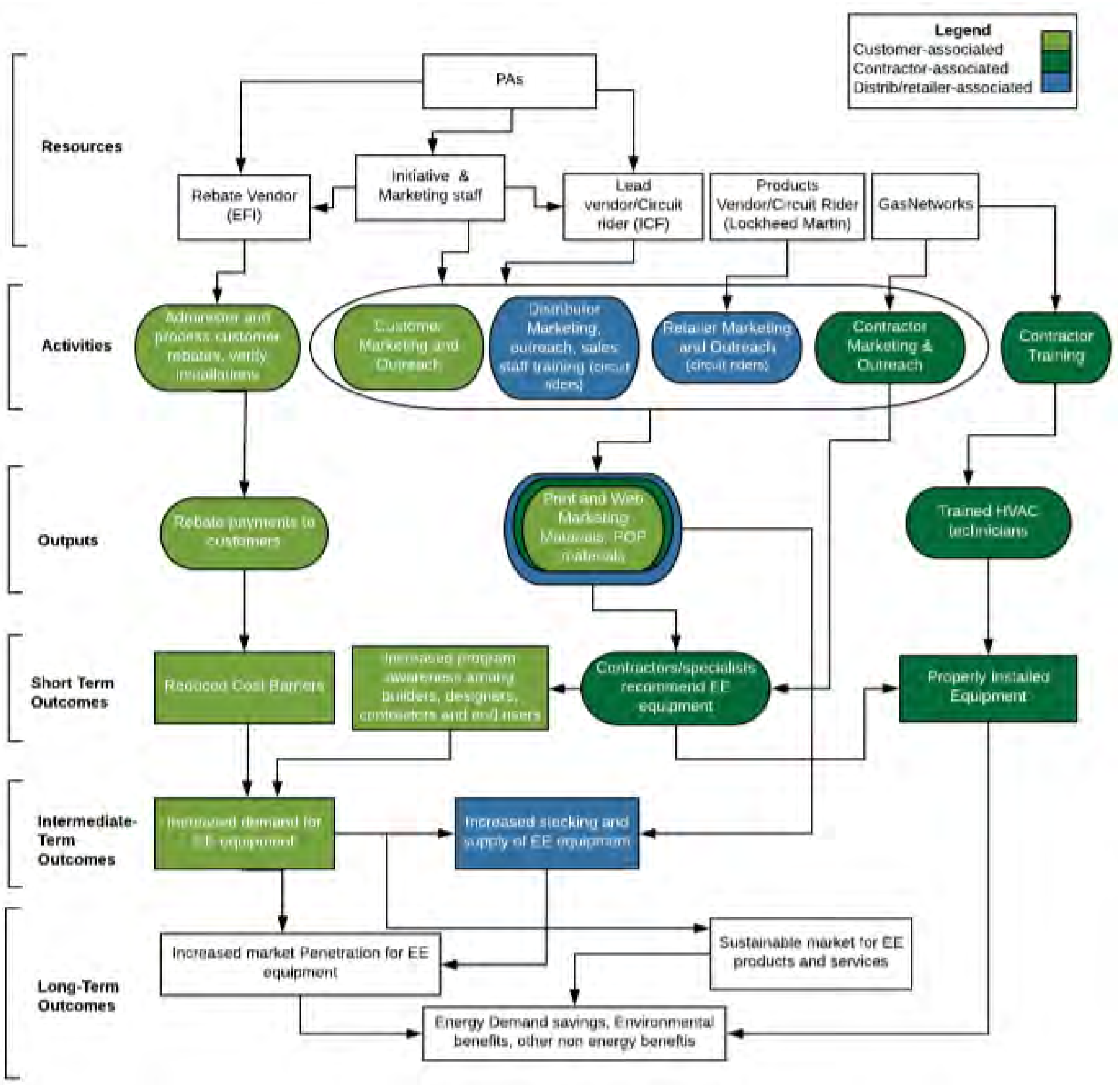
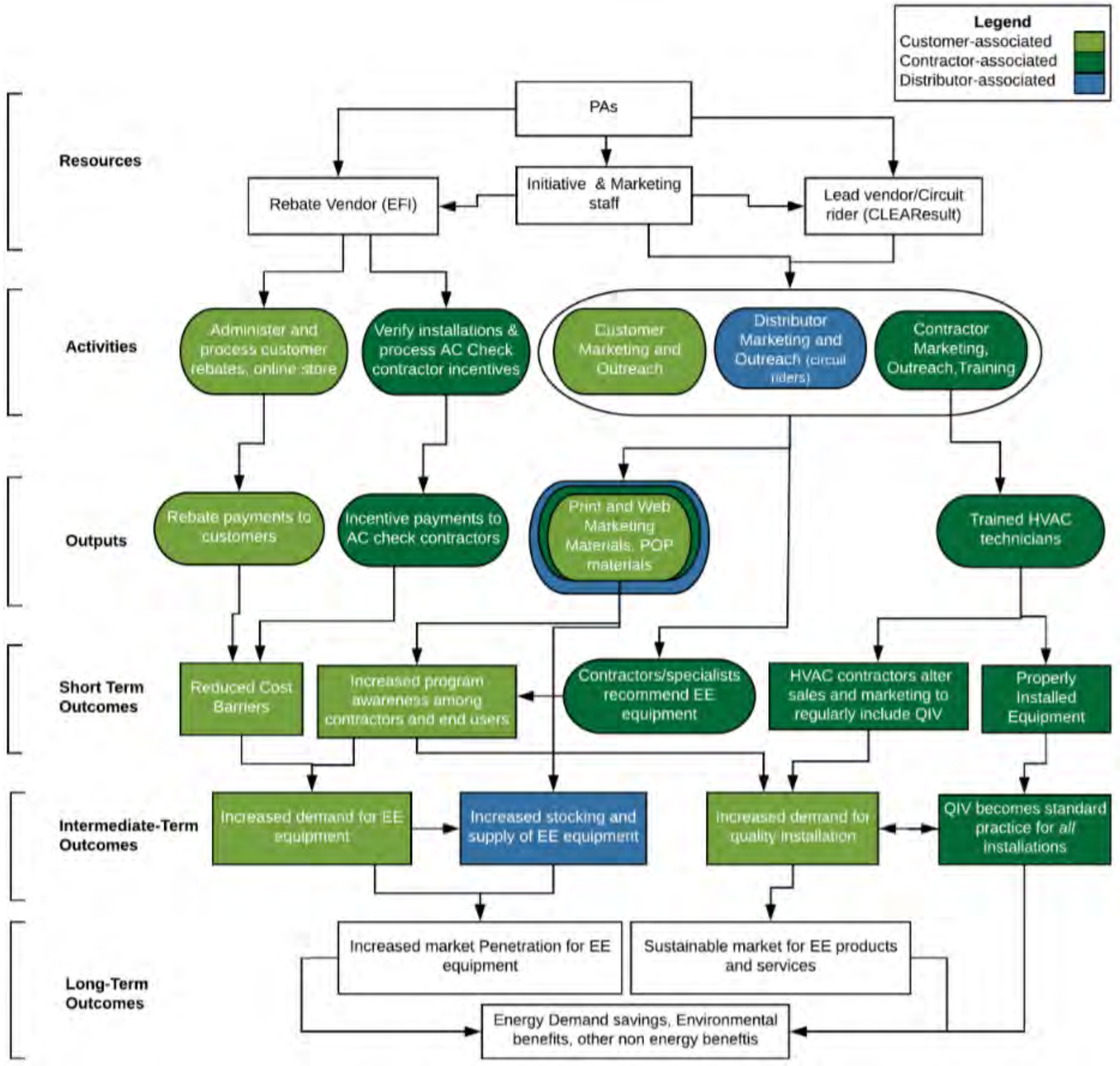


Figure 1: Program Logic Model – Gas Measures

Figure 2: Program Logic Model – Electric Measures



1.4 EXPECTED PROGRAM CHANGES

As the PAs explain in their Draft Three-Year Energy Efficiency Plan for 2019-2021, dated April 30, 2018, the Residential Heating and Cooling gas and electric initiatives will be redesigned and reorganized to better meet the core principle of the 2019-2021 program design, which is to keep the customer at the center of program design and evolution. Residential heating, cooling, and water heating equipment will continue to be supported with rebates through the new “Residential Coordinated Delivery” (RCD) and “Residential Retail” Initiatives. These initiatives will be fuel-blind, meaning customers can participate regardless of their current heating fuel type. The initiatives will potentially present customers with a broader array of rebate options for heating, cooling, and water heating equipment measures (as appropriate). These rebate options will be offered in conjunction with an HEA through RCD, directly through an HVAC contractor, and through retail and online outlets. Customers and their contractors will be able to apply for equipment rebates as they had under the Residential Heating and Cooling gas and electric initiatives.

Streamlining the participant experience. Under the Residential Coordinated Delivery initiative, customers can expect more facilitated options to support them in making decisions to install high-efficiency heating, cooling, and water heating equipment, as well as other measures. To this end, the initiative will enhance relationships with trade allies to interact with customers at all entry points and help them to secure ancillary services. For example, the PAs are exploring new ways of partnering with such trade allies, including HVAC contractors and electricians. These new efforts may include helping customers secure service providers to eliminate barriers to installing certain measures, and inducements to encourage HVAC contractors and electricians to connect their customers to additional facilitated solutions the PAs plan to offer.

Improving customer education. To foster informed customer choices, customers participating in the Residential Coordinated Delivery initiative will also receive more education about their measure options and about available technology to help them operate their new systems optimally and efficiently.

2

Section 2 Research Methodology

For this study, the team conducted in-depth interviews with program staff and mixed-mode (web and telephone) surveys of customers and contractors. The team refined the NTGRs developed through this research via a "NTG Consensus Group" (i.e., a group of PA, EEAC, and consulting team representatives who come to a consensus on retrospective and prospective NTGRs). Each aspect of data collection served a specific purpose. The primary purpose of the interviews with program staff was to solidify our understanding of the program structure and inform evaluation planning. The primary purpose of the customer and contractor surveys was to collect inputs with which to develop initial estimates of NTGRs, and to establish initial measurements of market effects indicators with these market actors to use in future market effects evaluations. The surveys also obtained information about market shares and trends, established industry standard practices, and assessed the program's role in changes to standard practices. The surveys focused on customers who participated in the program in 2016 and the first part of 2017, and contractors who installed program equipment in 2016.

Table 2 shows the purpose of each data collection effort and the specific elements of NTG measured by each.

Table 2: Primary Purpose of Research Tasks

Task	n	Free-Ridership	Spillover	Market Effects	Program Information
In-depth interviews	5 PAs				✓
Participant surveys	346 end-users	✓	✓ (PSO)	✓	
Contractor surveys	166 participant contractors	✓	✓ (NPSO)	✓	
Consensus Group	3 constituent groups	✓	✓		

We based our decision to collect the elements of NTG from each group (as shown above) on previous Massachusetts studies:

- We considered the recommendations outlined in the 2011 Massachusetts study *Cross-Cutting Net to Gross Methodology Study for Residential Programs – Suggested Approaches*.[3] This study encourages the use of (1) self-report counterfactual customer and contractor surveys to measure free-ridership (FR) and spillover (SO) and (2) contractor and supplier interviews in comparison areas to measure market effects by gathering sales levels and market share of efficient

---

[3] NMR, Tetra Tech, and KEMA. "Cross-Cutting Net to Gross Methodology Study for Residential Programs – Suggested Approaches." July 20, 2011.

equipment. We conducted the former, but not the latter. This study also noted that conducting market sales data analysis of sales and shipment data is an ideal approach to measuring NTG, but acknowledges the difficulty of obtaining market-wide sales and shipment data. The study outlined key survey design elements that we employed, such as using multiple questions to limit potential for misunderstanding, incorporating consistency check questions, and allowing for the capture of partial FR and SO (e.g., quantities, efficiency level, and timing).

- In 2012, Cadmus estimated NTGRs for four of the same equipment types: DMSHPs, CAC, furnaces, and boilers in their *Residential Heating, Water Heating, and Cooling Equipment Evaluation: Net-to-Gross, Market Effects, and Equipment Replacement Timing* report.[4] They also estimated an NTGR for water heaters, but we looked at HPWHs, specifically, for TXC34. They did not study CHPs. We looked to their NTG estimation method as a guide to remain consistent. The most notable difference was the addition of PSO and contractor FR in TXC34 (described in Section 3).

When applicable, we coordinated our fielding and analysis methods with the HVAC Early Replacement study (RES36), which was undertaken concurrently by the Navigant Residential HVAC evaluation team. For example, we jointly fielded our contractor surveys. We also studied each other's NTG analysis methodology to make the studies' approaches as consistent as possible, given the inherent differences between how Standard and Early Replacement HVAC rebates are administered and the differing goals of the two studies.

2.1 IN-DEPTH INTERVIEWS

In July 2017, NMR conducted a total of two roundtable interviews via web and phone with six PA representatives who were involved with the management of the programs. The interviewees included program managers representing Cape Light Compact, Columbia Gas, Eversource, National Grid, and Unitil.[5] Most interviewees had been involved with their companies' residential HVAC programs for between two and five years and were responsible for other programs, as well as for one or more of the Residential Heating and Cooling gas and electric initiatives.[6]

As part of the interviews, we presented interviewees with the logic models created for the initiatives in 2014 and asked for help in refining and updating them. In addition to updating and improving the logic models, we used the information from the interviews to ensure that we could design the customer and contractor surveys in a way that accurately reflected the current structure of the initiatives from the perspectives of these audiences.

---

[4] The Cadmus Group, Inc. "2012 Residential Heating, Water Heating, and Cooling Equipment Evaluation: Net-to-Gross, Market Effects, and Equipment Replacement Timing." June 2013.

[5] The TXC34 PA Study Lead also attended one of the roundtables but did not share program information. One of the National Grid interviewees focuses on program strategy and is not specifically a program manager.

[6] We originally planned to include interviews with program implementation vendors in this task; however, PA representatives' responses were comprehensive enough that we deemed it unnecessary. Instead, we emailed implementation vendors – CLEAResult, Lockheed Martin, and ICF – the program logic models and a description of our understanding of the program; they confirmed that our depictions were correct.

2.2 CONTRACTOR SURVEYS

In December of 2017 and January of 2018, the team surveyed a sample of 166 participating Standard (i.e., not Early Replacement) program contractors by telephone and web. To maximize the representativeness of our results, we focused our initial recruiting on the most active contractors, based on number of program units installed, and contractors who had installed the least common measures (CHPs and CACs). Due to poor response rates after many contact attempts over several weeks, we ultimately attempted surveys with all participating contractors, resulting in a simple random sample. To limit survey fatigue, we conducted NTG batteries for up to two measures with each respondent. At the start of fielding, contractors who had installed more than two measure types were asked about the measures they installed that were less common in the sample frame. Though infrequent, it meant that a few of the very active furnace, boiler, and DMSHP contractors were not asked about those measures when they responded to the survey.

Table 3 shows sampling error by measure for contractor non-participant spillover (NPSO). The absolute sampling error ranged from 11% to 15% across measure types, with the exception of CHPs (20%). Throughout this report, sample sizes vary because some contractors terminated the survey after answering NTG questions, or gave answers that appeared to be invalid, implying that they misunderstood some questions. We weighted survey responses by the number of standard rebated units that contractors verified installing, unless noted otherwise.

Table 3. Contractor Survey Non-Participant Spillover Sampling Error

Measure	Surveyed Population[1]		Total Population		Sampling Error (90% CI)	
	Contractors	Rebates[2]	Contractors	Rebates	Absolute	Relative
DMSHP	51	458	995	7,757	11%	23%
HPWH	41	82	970	1,633	13%	25%
CAC	28	287	315	2,256	15%	30%
CHP	16	46	118	311	20%	39%
Furnace	42	165	804	3,891	13%	25%
Boiler	49	127	1,640	4,520	12%	23%

[1] Counts include those completing NPSO module (intended as the key contractor-derived NTG contribution).

[2] Represent the verified number of Standard program rebates submitted by each contractor.

The contractor population consisted of 3,191 unique contractors who had installed at least one rebated Standard program unit (for the measures of interest) in the 2016 EFI project database. Removing records without usable contact information resulted in a sample frame of 2,741 Standard program contractor contacts – a 14% loss of potential contacts. The amount of work required to clean the contractor data to develop a sample for evaluation purposes demonstrates the need for a better system of tracking contractor contact information (such as consistently using unique company *and* contact identification numbers).

The response rate across all measures was 9%.[7] Table 4 shows sample disposition and response rate by measure.

Table 4. Contractor Survey Disposition and Response Rate by Measure

Disposition	DMSHP	HPWH	CAC	CHP	Furnace	Boiler	Total
Request call back	167	108	59	27	157	234	**469**
Completed[1]	79	51	32	18	57	69	**166**
Not familiar	18	28	5	3	17	30	**70**
No response	377	370	109	31	251	446	**1,097**
Refused	154	136	56	16	130	195	**436**
Screened out	34	24	11	5	26	47	**95**
Timed out online	5	3	3	4	4	3	**7**
Total contacted[2]	**834**	**720**	**275**	**104**	**642**	**1024**	**2,340**
Response Rate	**9%**	**7%**	**12%**	**17%**	**9%**	**7%**	**9%**

[1] Includes those who may have completed the survey but were not included in the NPSO analysis due to invalid responses.

[2] Table excludes contacts whose dispositions implied they did not receive an email, voice message, or any type of "successful" contact (e.g., no answering service and email bounce back). Contractors may have installed more than one measure type through the standard rebate program, so columns sum to more than the Total. Respondents were not necessarily asked about each measure type they verified installing through the program.

2.3 PARTICIPANT SURVEYS

At the same time as the contractor survey, the team fielded surveys with customers who had received program rebates in 2016 and early 2017. While we invited most participants to respond to the web-based survey via email, we made a few exceptions: our pre-test effort used letters to invite 100 participants to respond online; CHP participants did not have email addresses in program data, so we mailed them invitations; and we conducted telephone calls with less responsive strata and telephone callbacks with some participants who had initially screened out of the survey (explained below).

We asked each participant about up to two measure types. We weighted survey responses by the number of units that participants verified installing, unless noted otherwise.

Table 5 shows sampling error by measure for FR. Absolute sampling error ranged from 9% to 13% across measure types. Throughout this report, sample sizes vary because some participants terminated the survey after answering NTG questions or may have given invalid responses.

---

[7] Response rates are the ratio of completed surveys to number of contractors "successfully" reached, such as contacts with delivered emails without bounce back.

Table 5. Participant Survey Free-Ridership Sampling Error

Measure	Survey Completes[1]		Total Population		Sampling Error (90% CI)	
	Participants	Units[2]	Participants	Units	Absolute	Relative
DMSHP	66	85	8,169	10,539	10%	20%
HPWH	79	80	1,967	2,054	9%	18%
CAC	66	72	2,653	2,920	10%	20%
CHP	35	41	385	423	13%	27%
Furnace	61	68	4,435	4,866	11%	21%
Boiler	60	69	6,181	7,071	11%	21%

[1] Counts include those completing FR module (intended as the key participant-derived NTG contribution).
[2] Represent the number of units the participant verified installing.

One key takeaway from the program staff interviews was that it may be difficult for customers to discern the difference between the HES energy specialist who conducted their HEA and the HVAC installation contractors who may facilitate or promote the rebates. For this reason, we initially elected to limit the chances of double counting by excluding customers who had participated in HES or received Early Retirement incentives (which we discerned through the program database) from the sample frame. However, after we began fielding the survey, we found that many HES participants remained in the sample frame, primarily because the program rebate data did not reflect their participation in previous years.[8] Given this, as well as concerns that we may be excluding an important subset of participants, it was decided mid-fielding that we should include HES participants in the sample after all. We modified the survey instrument to this end and re-contacted participants who had previously been screened out (because they self-reported as HES participants), offering them a $10 Amazon gift card as an apology for the inconvenience. We did not reach everyone who had been screened out, and ultimately the final sample underrepresented HES participants, especially those who installed electric measures. Table 6 shows the percentage of participating customers who reported receiving an HEA through HES. In Appendix A.1.4, we discuss differences between HES and non-HES respondent FR and why we believe that the differences between the groups do not warrant concern.

---

[8] Additionally, at the time of survey fielding, the RES36 Early Replacement study was conducting surveys with early replacement program participants. We excluded participants who received any type of early replacement measure from our sample to reduce confusion and the chances of angering customers. We also excluded participants who appeared to be commercial customers.

Table 6: Percentage of HVAC Participants Receiving Home Energy Assessments

Program Measures	Population		Completes (self-reported)	
	N	Percentage	n[1]	Percentage
Ductless MSHP	8,169	61%	66	35%
Heat pump water heater[2]	1,967	48%	79	3%
Central air conditioning system	2,653	58%	66	18%
Central heat pump	385	55%	35	20%
Warm air furnace	4,435	35%	61	26%
Boiler	6,181	37%	60	30%

[1] Counts include those completing FR module (intended as the key participant-derived NTG contribution).
[2] HPWH response rates were excellent from the start and the stratum closed early, so we did not include them in the HES callbacks.

Across all measures, the participant response rate was 8%.[9] Because response rates were initially very low, we took the opportunity during follow-up calls to ask participants why they had not yet responded to the survey; they said they either had not noticed the email or letter or simply had not gotten around to it. Table 7 shows survey disposition and response rates by measure. Six respondents reported installing the measures but were not aware of receiving a rebate for them. These respondents are excluded from sampling error calculations but included in these response rates since they completed the survey, despite being excluded from NTG analysis.

Table 7. Participant Survey Disposition and Response Rate by Measure

Disposition	DMSHP	HPWH	CAC	CHP	Furnace	Boiler	Total
Requested callback	0	0	11	15	13	4	29
Completed[1]	69	83	74	37	63	60	346
No response	769	639	606	98	971	1,138	3,961
Refused	1	1	9	9	9	4	23
Screened out[2]	2	27	2	2	5	3	38
Timed out online	22	24	10	16	8	18	90
Unsubscribed	1	1	4	1	3	1	11
Total contacted[3]	**864**	**775**	**716**	**178**	**1,072**	**1,228**	**4,498**
Response Rate	**8%**	**11%**	**10%**	**21%**	**6%**	**5%**	**8%**

[1] Includes respondents who may not have been included in the NTG analysis but did complete the survey.
[2] Respondents were screened out if they were not familiar with the installation and/or were unable to connect us with household members who were. HPWH screen out includes the HES respondents who were initially excluded.
[3] Table excludes contacts whose dispositions implied they did not receive an email, voice message, or any type of "successful" contact (e.g., no answering service and email bounced back). Participants may have installed more than one measure type, so columns sum to greater than the Total.

---

[9] Response rates are the ratio of completed surveys to number of contractors "successfully" reached, such as contacts with delivered emails without bounce back.

2.4 CONSENSUS GROUP

After analyzing the data collected and developing a series of NTGR recommendations using a variety of methods, the team presented the ratios to a Consensus Group of PA, EEAC, and NMR Cross-cutting evaluation team representatives with options for consideration. The primary strength of the consensus approach to estimating NTG is the balancing of the diverse set of strengths, weaknesses, potential biases, and threats to validity associated with the various individual methods used to estimate NTG. Relying on a single approach to estimating NTG comes with its own limitations; however, drawing on estimates from multiple approaches requires a consensus group to consider, weigh, and triangulate the different methods based on their relative strengths and shortcomings.

In early February 2018, the team issued a memo to the Consensus Group with the following information:

- Preliminary NTG estimates drawing on results from participant and contractor surveys (Sections 3.1 through Section 3.5)
- Contractors' estimates of program market effects on the Massachusetts HVAC market (Section 3.6)
- NTG estimates from residential rebate program evaluations carried out in other jurisdictions (Appendix A.1.6)
- Recent and upcoming changes in federal standards, ENERGY STAR specifications, and Consortium for Energy Efficiency (CEE) tiers for residential HVAC equipment (Appendix A.5)

After reviewing the memo, Consensus Group members requested additional analysis. After several iterations, the team ultimately presented three NTG "options" to the Consensus Group. Each constituent group (PAs, EEAC, and evaluators) then developed retrospective and prospective NTG estimates by equipment type, offering explanations for each of their recommendations. NMR collected and compiled each constituent group's estimates and facilitated a webinar to review and discuss the results. The webinar compared each constituent's responses by measure and offered them the opportunity to discuss the rationales behind their recommendations. During this webinar, the group members achieved agreement on retrospective 2016 NTG estimates and prospective 2019-2021 NTG estimates. Section 3.7 outlines the reasoning behind the Consensus Group's recommendations.

3

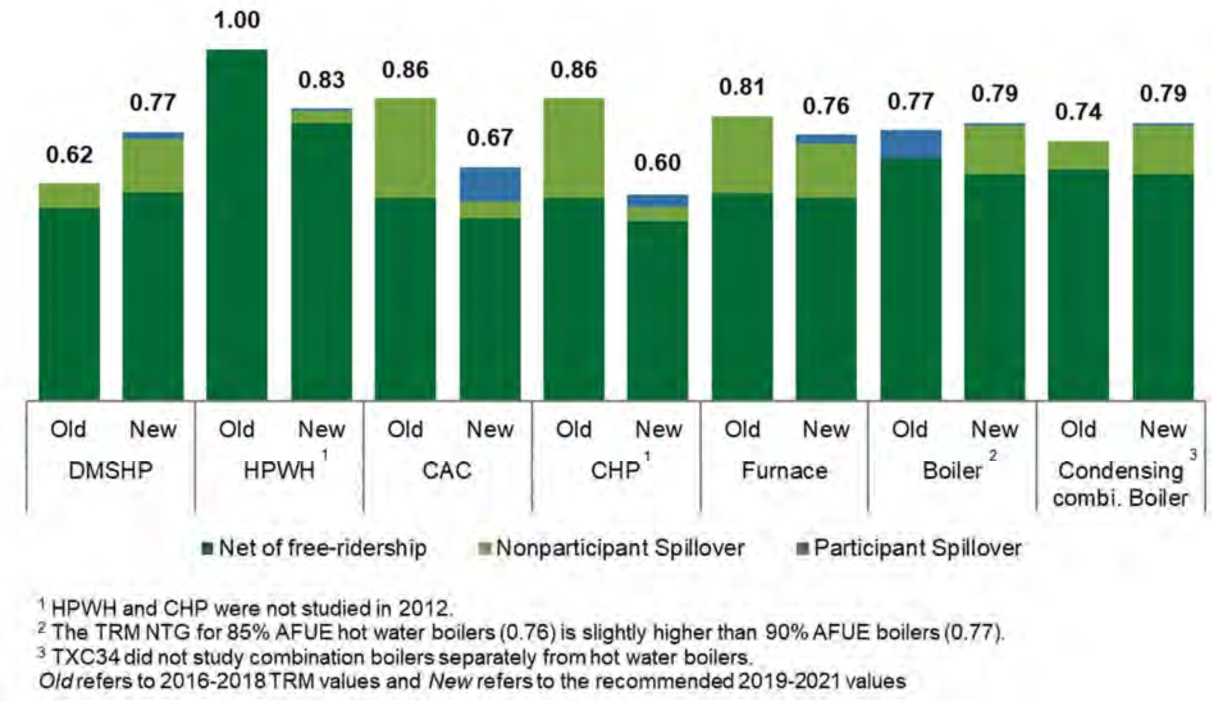
Section 3 Net-to-Gross Results

Figure 3 presents the 2019-2021 NTGRs resulting from this study. These ratios are based on four inputs: (1) estimates of free-ridership (FR) among participating customers (participants) adjusted by (2) estimates of participating contractors, (3) non-participant spillover (NPSO) among participating contractors, and (4) participant spillover (PSO) among participating customers. We used the following formula:

$$NTGR = (1 - FR) + NPSO + PSO$$

Figure 3 compares the 2019-2021 NTGRs developed by the Consensus Group with those of the 2016-2018 TRM. The NTGRs in the TRM for DMSHP, CAC, furnaces, and boilers come from Cadmus's 2012 *Residential Heating, Water Heating, and Cooling Equipment Evaluation: Net-to-Gross, Market Effects, and Equipment Replacement Timing* study.[10] The TRM assumed an NTGR of 1.0 for HPWHs and set the CHP NTG equal to that of CACs. The 2019-2021 NTGRs for DMSHPs and boilers have increased from 2016-2018. NTGRs for HPWHs, CAC, CHPs, and (to a lesser extent) furnaces have decreased from 2016-2018.

Figure 3: 2019-2021 Net-to-Gross Recommendations Compared to 2016-2018 Technical Reference Manual



[1] HPWH and CHP were not studied in 2012.
[2] The TRM NTG for 85% AFUE hot water boilers (0.76) is slightly higher than 90% AFUE boilers (0.77).
[3] TXC34 did not study combination boilers separately from hot water boilers.
Old refers to 2016-2018 TRM values and *New* refers to the recommended 2019-2021 values

Table 8 shows FR, NPSO, and PSO by measure. The following subsections describe how we estimated these inputs and came to these recommendations.

---

[10] The Cadmus Group, Inc. "2012 Residential Heating, Water Heating, and Cooling Equipment Evaluation: Net-to-Gross, Market Effects, and Equipment Replacement Timing." June 2013.

Table 8: Recommended Free-Ridership, Spillover, and Net-to-Gross Ratios (2019-2021)

Program Measures	FR	NPSO	PSO	NTGR[1]
Ductless MSHP	0.41	0.15	0.02	**0.77**
Heat pump water heater	0.21	0.04	0.01	**0.83**
Central air conditioning	0.48	0.05	0.10	**0.67**
Central heat pump	0.47	0.04	0.02	**0.60**
Warm air furnace	0.42	0.16	0.02	**0.76**
Boiler	0.35	0.14	0.01	**0.79**

[1] Values do not always sum due to rounding.

3.1 PARTICIPANT FREE-RIDERSHIP

To estimate FR, we began by estimating retrospective FR among participants. Table 10 shows the FR results. Leveraging the approach taken in Cadmus's 2012 NTG study, we calculated participant FR as a function of three credits: efficiency, timing, and quantity. The values of the credits range from 0% to 100%, where 0% is associated with the highest FR and 100% is associated with the lowest FR. Those fractions are inversed in the FR calculations themselves. Figure 4 illustrates the algorithm in full.

We applied four sensitivity methods, which toggled between maximum and mean scoring and leniency with timing credits as shown in Table 9. Methods 1 and 3 applied the maximum likelihood and influence scores into the efficiency credit, and Methods 2 and 4 applied the *mean* scores. Methods 1 and 2 use increments of 0%, 50%, and 100% when establishing the timing credit, but Methods 3 and 4 more leniently assigned 66% instead of 50% for the partial timing score.

Table 9: Participant Free-Ridership – Sensitivity Analysis Methods

Input	Method 1	Method 2	Method 3	Method 4
Influence scores/rating	Maximum	Average	Maximum	Average
Timing credit for units that would have been replaced within 6-12 months	50%	50%	66%	66%

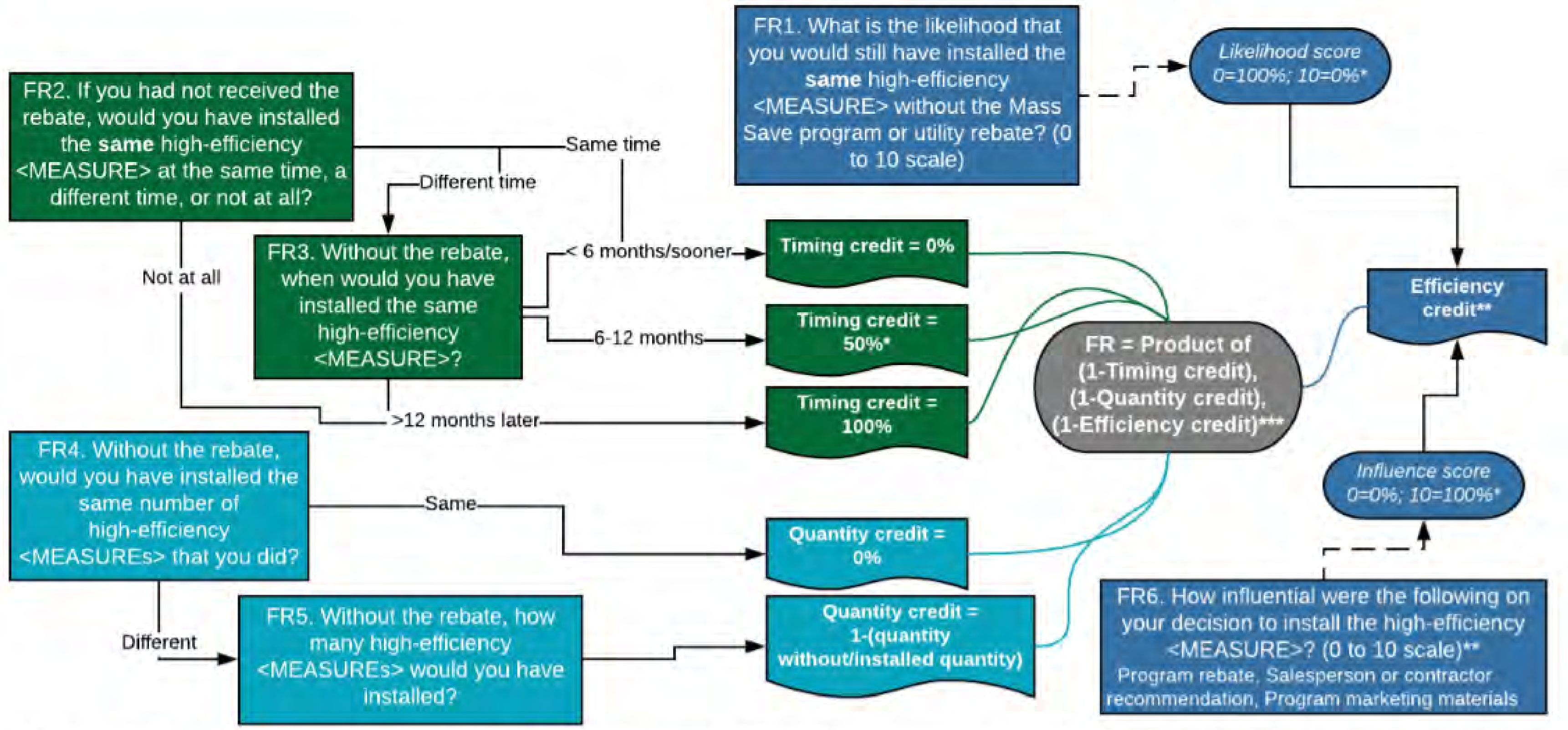
The results from Methods 3 and 4 did not differ from those from Methods 1 and 2, respectively, so we excluded them from further analysis. **The Consensus Group agreed to use the Maximum Method alone because, in their opinion, the Means Method unfairly penalized the program.** Section 3.3 explains the rationale behind this decision. This approach is consistent with the industry trend towards using a maximum versus mean scoring approach.

Table 10: Participant Free-Ridership Results

Program Measures	n[1]	Quantity (units)	FR by Sensitivity Method		
			Maximum Method (1)	Means Method (2)	Average
Ductless MSHP	66	85	0.21	0.51	**0.36**
Heat pump water heater	79	80	0.08	0.21	**0.14**
Central air conditioning	66	72	0.23	0.57	**0.40**
Central heat pump	35	41	0.31	0.54	**0.43**
Warm air furnace	61	68	0.15	0.44	**0.29**
Boiler	60	69	0.11	0.32	**0.21**

[1] The sample underrepresented HES participants despite a mid-fielding pivot (Section 2.2), but this did not appear to impact FR results (Appendix A.1.4).

Figure 4: Participant Free-Ridership Algorithm



* Two sensitivity analysis methods apply a timing credit of 66% instead of 50%. Influence/likelihood scores incrementally change by 10% per rating point.
** Depending on the sensitivity analysis, we use maximum or average influence/likelihood scores.
*** If participants installed only one measure through the program, the quantity credit will be excluded from the formula

3.2 CONTRACTOR FREE-RIDERSHIP

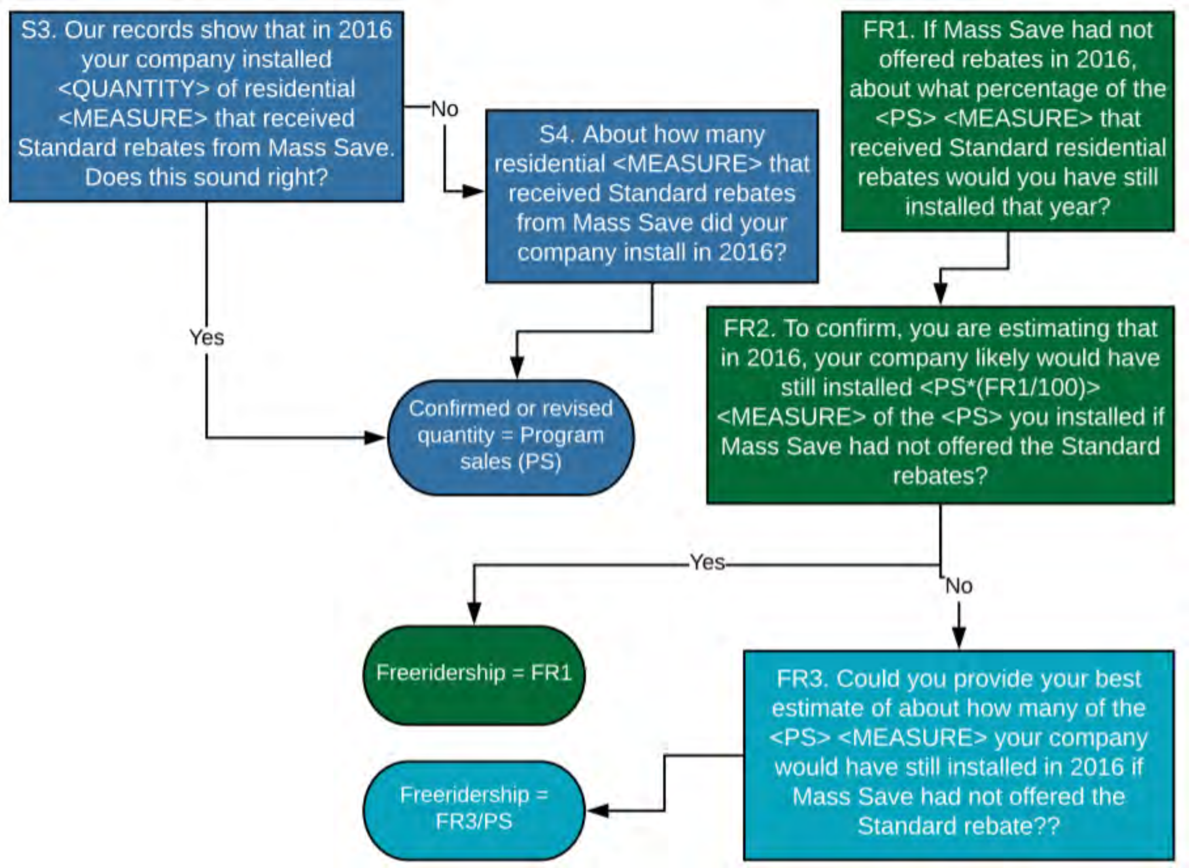
Next, we estimated retrospective FR among participating contractors. After confirming their 2016 program sales, contractors estimated the percentage of program sales that would have occurred had program rebates not been offered. Some contractors struggled to interpret these questions; we excluded these contractors from the NTG analysis or revised their responses if needed and appropriate. (See Appendix A.1.3.2 for details.) Table 11 shows the results of these calculations, weighted by the quantity of program units that contractors verified installing. Figure 5 maps the algorithm.

Table 11: Contractor Free-Ridership Results

Program Measures	n	Sum of 2016 Verified Program Sales (units)	Weighted FR
Ductless MSHP	53	462	**0.50**
Heat pump water heater	38	80	**0.32**
Central air conditioning	23	260	**0.58**
Central heat pump	16	44	**0.58**
Warm air furnace	33	256	**0.53**
Boiler	34	108	**0.41**

[1] Respondents who did not appear to understand the question series were removed from the analysis; therefore, sampling error for some measures changed for this module: absolute sampling error increased to 16% for CHPs and 14% for furnaces and boilers.

Figure 5: Contractor Free-Ridership Algorithm



3.3 CONTRACTOR FREE-RIDERSHIP ADJUSTMENT

While contractor FR was notably higher than customer FR, and contractor FR sample sizes were small, customers' responses emphasized the importance of contractors' recommendations to the customers' decision-making processes. Therefore, we explored adjusting participant FR by contractor FR. We used six different methods for this exploration, which we refer to as Methods A through F. Methods A through D adjust the participant FR resulting from averaging the Maximum and Means Method results. Methods A and B set high thresholds for adjusting participant FR. As Figure 6 shows, we developed three adjusted FR options using the averages of two of each of the methods. The methods are as follows:

- **"Selected Equipment Method" (A).** This method conservatively follows NMR's 2010 approach in the *Massachusetts High-Efficiency Heating Equipment (HEHE) Process and Impact*[11] study. Participants who said they did their own research and selected their equipment, or whose contractor presented them with a variety of models and they (the participants) chose which model to install, kept their original FR rate. In

---

[11] NMR Group, Inc., "HEHE Process and Impact Evaluation," Submitted to *GasNetworks*, October 27, 2010, http://ma-eeac.org/wordpress/wp-content/uploads/High-Efficiency-Heating-and-Water-Heating-Program-Process-and-Impact-Evaluation-Final-Report.pdf.

cases where the contractor presented the participant with just one model, and they selected that model, we averaged the participant's FR with the overall contractor FR.[12]

- **"Top Rating Method" (B).** If a participant rated the salesperson or installation contractor's recommendations a 10 on the 0 to 10 importance scale and did not provide a rating of 10 for either the program rebate or marketing materials, then the contractor FR replaced that participant's FR.

Methods C through F lowered the threshold for adjusting participant FR with contractor FR.

- **"Selected or Recommended Equipment Method" (C).** This method mimics NMR's 2010 approach in the *Massachusetts High-Efficiency Heating Equipment (HEHE) Process and Impact* study. Participants who said they did their own research and selected their equipment kept their original FR rate. For those who said that the contractor presented them with a variety of models and they (the participants) chose which model to install, we averaged their FR with the overall contractor FR rate. Finally, in cases where the contractor selected and presented the participant with just one model, we replaced the participant's FR with the overall contractor FR.
- **"High Rating Method" (D).** If a participant rated the salesperson or installation contractor's recommendations a 7 or higher on the 0 to 10 importance scale, then the contractor FR replaced that participant's FR.
- **"Selected or Recommended Method" (E).** The general approach was similar to Method C. As with Method C, participants who said they did their own research and selected their equipment kept their original FR rate. For those who said that the contractor presented them with a variety of models and they (the participants) chose which model to install, we averaged their FR with the overall contractor FR rate. If the contractor selected and presented the participant with just one model, we replaced the participant's FR with the overall contractor FR. The difference from Method C is that the original participant FR rate that we considered for adjustment was that of participant FR Method 1, the *maximum* method, only (not the average of Methods 1 and 2).
- **"High Rating Method" (F).** This was similar to Method D. As with Method D, if a participant rated the salesperson or installation contractor's recommendations a 7 or higher on the 0 to 10 importance scale, then the contractor FR replaced that participant's FR. However, like Method E, the original participant FR rate that we considered for adjustment was that of participant FR Method 1, the *maximum* method only.

---

[12] Figure 12 in Section 5.1 illustrates their responses.

Figure 6: Free-Ridership Adjustment Methods

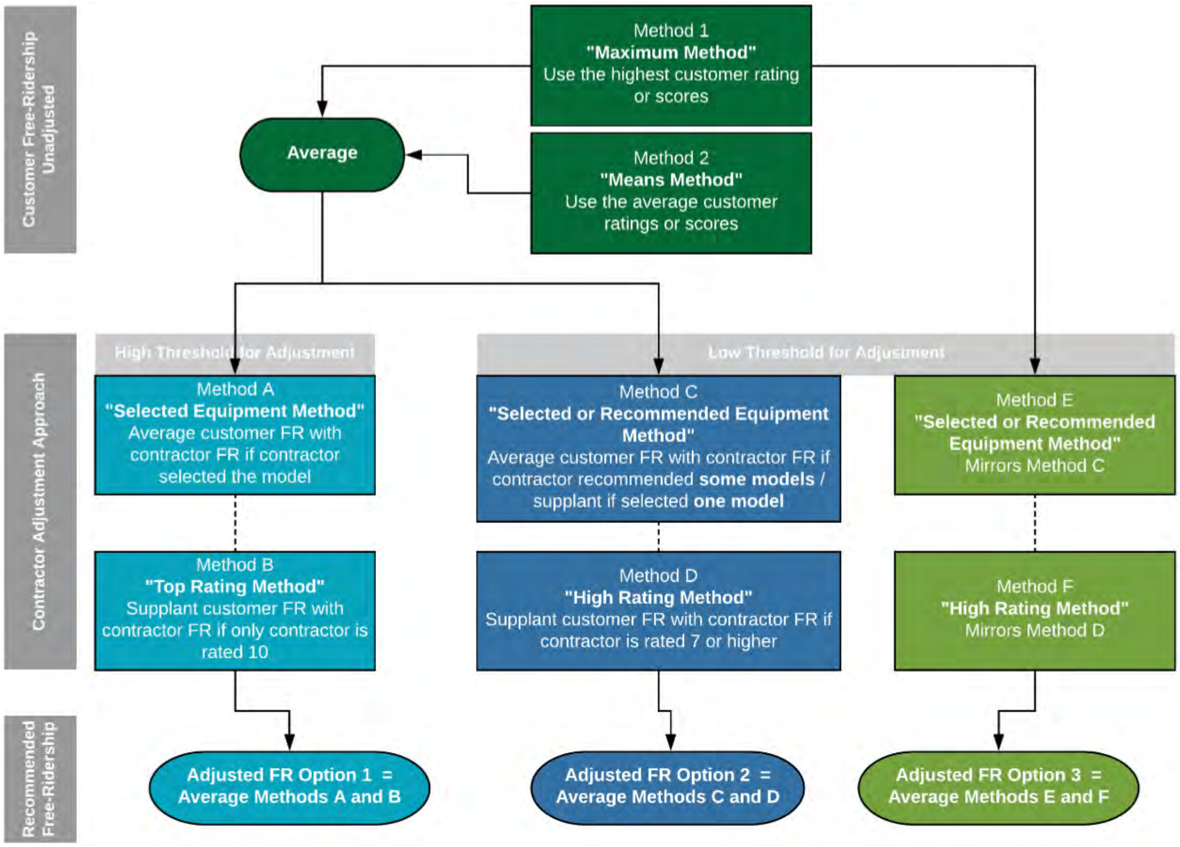


Table 12 shows the adjusted FR resulting from each of the three options. **The Consensus Group favored the Adjusted FR Option 3, which averages two low-threshold adjustment methods (E and F) after they have been applied to the participant FR Maximum Method.** There were two primary reasons for this decision:

1. **Averaging the means in Options 1 and 2 unfairly penalizes the program.** While the participant might attribute a great deal of importance to the program rebate, they could still give a low rating to the importance of program materials for any number of reasons, such as not being well emphasized or compelling. (Indeed, the program materials consistently received the lowest rating of importance to decision-making.) Averaging the participants' assessments of the rebates with those of the materials would lessen a high rating for the rebate, the key feature of the program.
2. **The Top Rating Method (B), which is incorporated into Option 1, does not strike an adequate balance between participant and contractor perspectives.** Many participants assigned a great deal of influence to the contractor. Using the Top Rating Method would undervalue the contractors' influence and not adequately reflect contractors' assessments of the program's importance. In the words of one Consensus Group member, Option 1 would "ascribe high program influence in a fair number of cases when all that is really going on is that the contractor is doing business as usual, and the participant is doing what the contractor recommends."

Table 12: Free-Ridership Results – Adjusted with Contractor Estimates

Program Measures	Contractor Adjustment Method		
High Threshold Adjustments[1]			
Adjusted FR Option 1: Averaging *Maximum* and *Means Methods*	**Selected Equipment (A)**	**Top Rating (B)**	**Average A and B**
Ductless MSHP	0.38	0.39	**0.39**
Heat pump water heater	0.17	0.14	**0.16**
Central air conditioning	0.42	0.44	**0.43**
Central heat pump	0.46	0.45	**0.46**
Warm air furnace	0.34	0.32	**0.33**
Boiler	0.27	0.22	**0.24**
Low Threshold Adjustments[2]			
Adjusted FR Option 2: Averaging *Maximum* and *Means Methods*	**Selected or Recommended (C)**	**High Rating (D)**	**Average C and D**
Ductless MSHP	0.42	0.48	**0.45**
Heat pump water heater	0.21	0.25	**0.23**
Central air conditioning	0.49	0.57	**0.53**
Central heat pump	0.52	0.56	**0.54**
Warm air furnace	0.45	0.47	**0.46**
Boiler	0.37	0.39	**0.38**
Adjusted FR Option 3: Averaging *Maximum Methods*	**Selected or Recommended (E)**	**High Rating (F)**	**Average E and F**
Ductless MSHP	0.36	0.45	**0.41**
Heat pump water heater	0.19	0.23	**0.21**
Central air conditioning	0.43	0.53	**0.48**
Central heat pump	0.46	0.52	**0.49**
Warm air furnace	0.40	0.44	**0.42**
Boiler	0.34	0.37	**0.35**

3.4 NON-PARTICIPANT SPILLOVER

Table 13 shows contractor self-reported program-eligible non-program sales and the resulting NPSO by the sensitivity methods described in Appendix A.1.2. Some contractors appeared to struggle to interpret these questions, so we excluded these contractors from the analysis or revised their responses (Appendix A.1.3.2). We used the average value across the four sensitivity methods (described below) because of the degree of variation of results across methods for some measures. Figure 7 depicts our methodology for calculating NPSO among participating contractors.

Results indicate that there is program influence on sales outside the program. This is particularly true when it comes to furnaces, DMSHPs, and boilers, for which NPSO are 0.16, 0.15, and 0.14, respectively. Contractors often explained that program-eligible non-program installations do not receive program rebates because customers who were influenced by the program do not follow through with the application process.

Table 13: Contractor Non-Participant Spillover Results

Program Measures	n	Non-program Sales (units)[1]	NPSO by Sensitivity Method[3]				Average NPSO across Methods (Recommended)
			Method 1	Method 2	Method 3	Method 4	
DMSHP[2]	51	153	0.23	0.16	0.15	0.08	**0.15**
HPWH	41	14	0.08	0.05	0.01	0.00	**0.04**
CAC	28	22	0.06	0.05	0.05	0.04	**0.05**
CHP	16	8	0.05	0.05	0.05	0.04	**0.04**
Furnace	42	81	0.25	0.17	0.14	0.07	**0.16**
Boiler	49	63	0.23	0.14	0.11	0.06	**0.14**

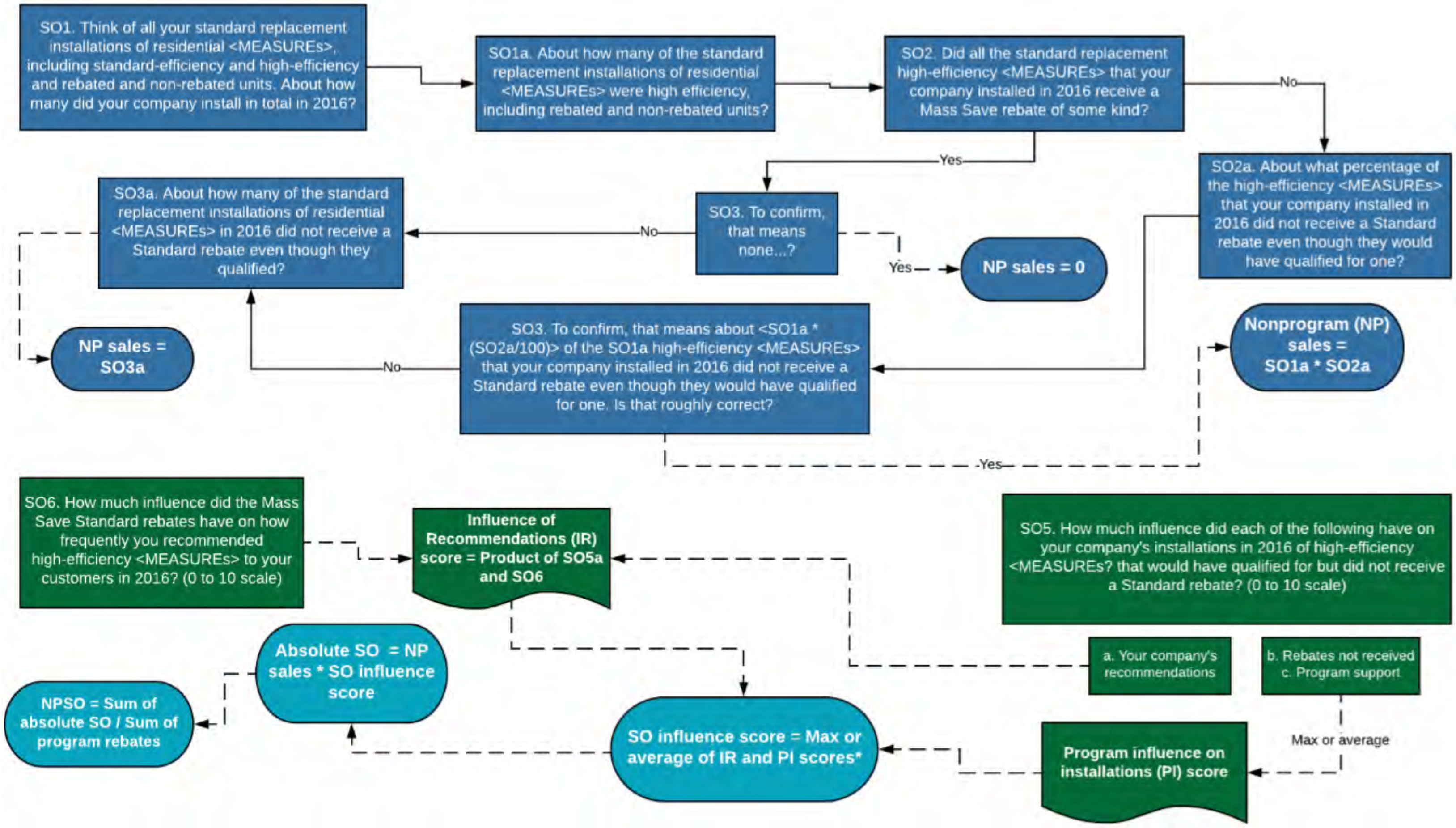
[1] Refers to *program-eligible* non-program sales.
[2] Fewer DMSHP contractors answered this question compared to the FR series because some discontinued the survey after answering the FR series. This did not affect precision.
[3] Sensitivity analysis methods toggle between using maximum and mean scoring and the thresholds for assigning those scores.

The methodology modifies the 2012 approach. NPSO is a function of the number of non-program unit sales by contractor respondents (i.e., total high-efficiency unit sales that did not receive program rebates) and the level of influence that the program had on the non-program sales. After calculating contractors' 2016 non-program sales, we applied their responses to other questions to produce three scores:

- **Influence of Recommendations (IR)**. Using responses to two 0 to 10 rating questions, the IR score is a function of the program's influence on the frequency with which contractors recommend high-efficiency equipment *and* the influence of their own recommendations on their high-efficiency non-program sales.
- **Program Influence (PI) on Installations**. Using responses to another 0 to 10 rating question, we associate the PI score with the level of influence on their sales that contractors report is from program rebates and support, such as marketing.
- **Spillover Influence**. Depending on the sensitivity method described below, this is either the maximum or average of the IR and PI scores, and directly funnels into the absolute spillover.

As noted, we calculated IR and PI scores using contractors' responses to influence questions with a 0-to-10 response scale. In this scale, 0 equals 0.0 and 10 equals 1.0; interim ratings (1 to 9) vary by sensitivity method. We then calculated Absolute SO for each respondent by measure type, multiplying their non-program sales by the SO Influence score. After summing Absolute SO across all respondents, we divided it by the sum of program sales across all respondents who were asked about the measure. The result is the NPSO.

Figure 7: Non-Participant Spillover Algorithm (Participating Contractor Survey)



* Depending on the sensitivity analysis method, we apply either the average or maximum values from SO5b and SO5c for the PI score and IR and PI scores for the SO influence score.
IR, PI, and Influence scores range from 0 to 1. Ratings of 0 (no influence) are equal to 0 and ratings of 10 (a great deal of influence) are equal to 1; ratings between vary by sensitivity method.

3.5 PARTICIPANT SPILLOVER

After receiving a program rebate, customers might install additional energy-efficient measures. If these measures do not receive any type of rebate and customers' decisions to install them are influenced by their experiences with the program, some programs claim the savings, which are referred to as Participant Spillover (PSO). There are two types of PSO: *like* and *unlike*. Like PSO refers to situations in which customers install additional measures of the same type as those that received a rebate through the program. Unlike PSO refers to situations in which customers install different types of energy-efficient measures than those supported by the program (e.g., installing an energy-efficient clothes washer after receiving a rebate for installing an energy-efficient HPWH).

For this study, the evaluation team followed the approach outlined in the Illinois 2017 TRM[13] to account for like and unlike retrospective PSO among participants. This approach had two steps: (1) summing the savings[14] associated with SO-eligible measures and (2) dividing that by the sum of savings associated with the installed measures in the survey sample. Table 14 presents PSO results. We found some PSO. The PSO rate among CAC participants (0.10) was relatively high, largely due to one respondent who reported that the program influenced them to make several upgrades, including air and duct sealing and installations of insulation and ENERGY STAR appliances.

Table 14: Participant Spillover Results

Program Measures	n[1]	Program Savings (kWh)[2]	Spillover Savings (kWh)	Spillover Rate
Ductless MSHP	65	26,620	528	**0.02**
Heat pump water heater	79	132,320	711	**0.01**
Central air conditioning	66	14,313	1,386	**0.10**
Central heat pump	35	31,640	733	**0.02**
Warm air furnace	61	173,632	4,050	**0.02**
Boiler	60	262,410	1,876	**0.01**

[1] One ductless MSHP participant discontinued after answering the FR series, but it did not affect precision.
[2] Program savings estimates are associated with all participants who answered spillover questions.

Figure 8 illustrates the key components involved in determining eligibility. After identifying unrebated measures that were potentially influenced by the program, we asked two influence questions. The first asked participants to rate the importance of the program's influence was on their decision to install the unrebated measure using a 0 to 10 scale, where 0 is *not at all important* and 10 is *very important*. The second asked them to rate how likely they would

---

[13] *Illinois Statewide Technical Reference Manual for Energy Efficiency*, Version 6.0, s.v. "4.1.2 Participant Spillover," February 8, 2017, http://ilsagfiles.org/SAG_files/Technical_Reference_Manual/Version_6/Final/IL-TRM_Version_6.0_dated_February_8_2017_Final_Volumes_1-4_Compiled.pdf

[14] Savings come from the MA TRM and secondary research. Where uncertain, we conservatively modified those savings with assumptions that non-program measures would likely not be as efficient as program measures and/or needed to speculate on home size or other key inputs.

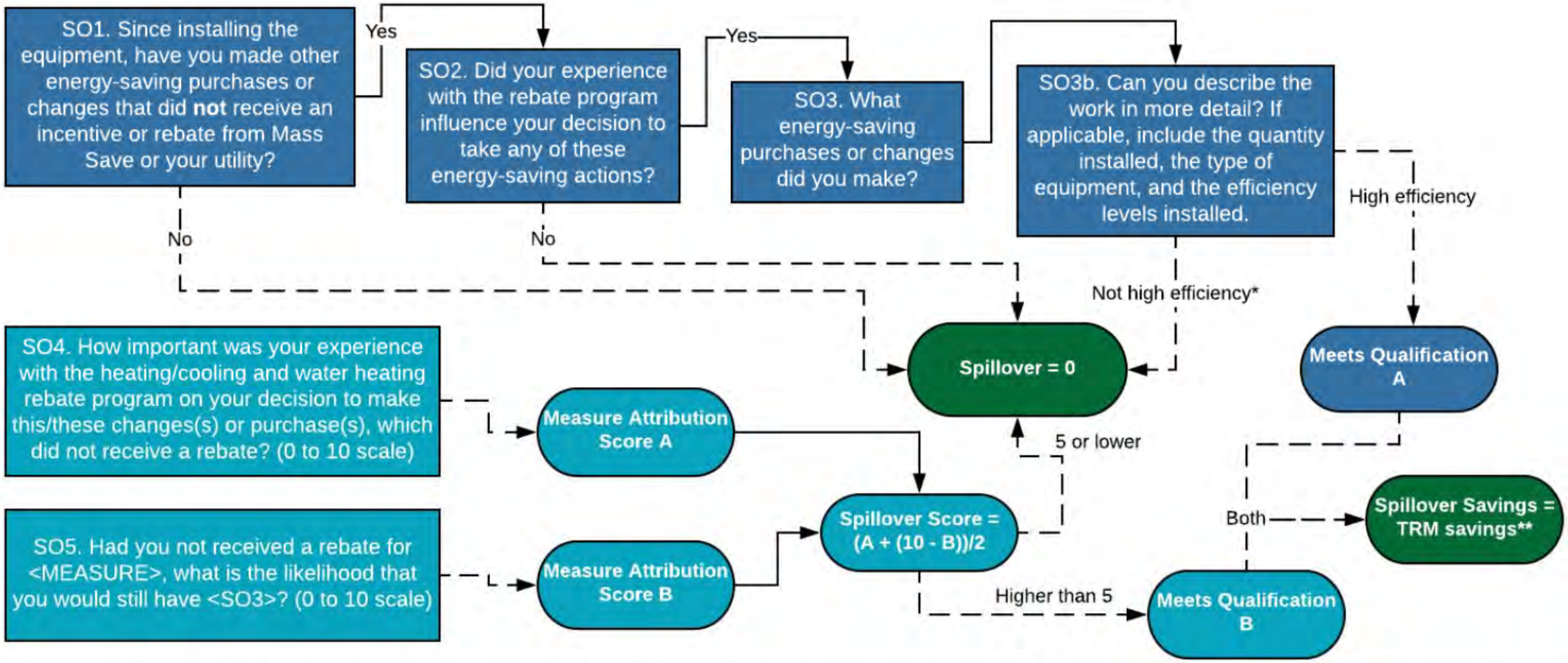
have been to install the unrebated measure (without their experience with the program) using a 0 to 10 scale, where 0 is *definitely would not have made the improvements* and 10 is *definitely would have made the improvements*.

For a measure to be SO-eligible, two qualifications (A and B) needed to be met:

- **Qualification A**. Non-rebated measures that either meet program specifications or are more efficient than federal standards (where applicable) meet Qualification A.
- **Qualification B**. The average of the participants' ratings for the program's importance and inverse likelihood ratings (on scales of 0 to 10) assigns the measure an SO Score. In line with the Illinois cut point, if the SO Score is higher than 5, then the measure meets Qualification B.

Appendix A.1.5 lists the reported spillover measures and their associated savings.

Figure 8: Participant Spillover Algorithm



* Efficiency specifications use TRM specifications for measures eligible for PA programs. For measures not offered by the PAs, we sought to determine if the measures were higher than federal standards. Customers were explicitly asked if appliances were ENERGY STAR-qualified.

** If Qualifications A and B are not *both* met, then spillover = 0. We used secondary sources to estimate savings for non-like measures if they were not available in the MA TRM. Spillover rates are equal to the sum of the saving associated with the spillover measures divided by the sum of the savings associated with respondents participating measures.

3.6 MARKET SHARE PREDICTIONS

Survey responses did not directly yield prospective NTG estimates. Instead, we asked Consensus Group members to assess prospective NTG, taking into consideration the retrospective NTG results presented above, as well as contractors' estimates of the percentages of their sales they expect to meet program requirements in three years under two different scenarios. The scenarios were (1) if the program were to continue, and (2) if the program were to end after 2017. Table 15 shows contractors' average estimates for both scenarios and the difference between the two. The differences between the scenarios varied by equipment type. Contractors predicted only a four-percentage point decrease in their CHP sales without the program (though the CHP sample size was small).

Table 15: Contractor Sales Projections of Energy-Efficient Units as Percentage of Total Sales Three Years from Now

Program Measures	n[1]	2016 Sales[2]		% of Respondents Expecting Change	Average Estimates		Difference
		Program	Total		Program Continues	Program Ends	
DMSHP[3]	45	463	983	54%	86%	72%	**14%**
HPWH	36	83	260	64%	70%	48%	**22%**
CAC	22	203	722	85%	82%	34%	**48%**
CHP	11	33	203	18%	63%	59%	**4%**
Furnace	38	307	899	80%	80%	49%	**31%**
Boiler	44	131	822	66%	75%	58%	**17%**

[1] Survey wording was adjusted for the new year on January 5 instead of January 1, 2018. (The wording was originally "at the end of this year" and it was updated to "the end of 2017.") Six contractors responded to the survey between January 1 and January 4, 2018; we omitted their responses. Note that CHP sample size decreased to n=11 for this question series, widening absolute sampling error to +/-25%.

[2] We weighted responses by contractors' self-reported total 2016 sales, including program, non-program, and early and standard replacement.

[3] These questions asked about number of indoor ductless MSHP heads since the program structure used number of indoor heads as a unit of measurement starting in 2017. Before 2017, it focused on number of outdoor heads, so retrospective NTG questions asked about outdoor heads.

3.7 CONSENSUS GROUP RESULTS

In Table 16, we show three NTG options that we presented to the Consensus Group for their consideration. These NTG options correspond to the three adjusted FR options described in Section 3.3. For all measures except CHPs, the Consensus Group decided to use NTG Option 3 results for both retrospective and prospective NTG. For CHPs, the Consensus Group decided to use a modified version of NTG Option 3 results. Below, we explain this in more detail and the rationale for these decisions.

Table 16: Net-to-Gross Options Considered by Consensus Group

Free-Ridership Approach		Program Measures	FR	NPSO	PSO	NTGR[1]
Participant FR	Adjustment					
NTG Option 1						
Average *Maximum* and Means *Methods*	**Average of *Selected* Equipment and *Top Rating Methods***	Ductless MSHP	0.39	0.15	0.02	**0.79**
		Heat pump water heater	0.16	0.04	0.01	**0.89**
		Central air conditioning	0.43	0.05	0.10	**0.72**
		Central heat pump	0.46	0.04	0.02	**0.61**
		Warm air furnace	0.33	0.16	0.02	**0.85**
		Boiler	0.24	0.14	0.01	**0.90**
NTG Option 2						
Average *Maximum* and Means *Methods*	**Average of *Selected or Recommended* Equipment and *High Rating Methods***	Ductless MSHP	0.45	0.15	0.02	**0.72**
		Heat pump water heater	0.23	0.04	0.01	**0.81**
		Central air conditioning	0.53	0.05	0.10	**0.62**
		Central heat pump	0.54	0.04	0.02	**0.53**
		Warm air furnace	0.46	0.16	0.02	**0.72**
		Boiler	0.38	0.14	0.01	**0.77**
NTG Option 3						
***Maximum Method* only**	**Average of *Selected or Recommended* Equipment and *High Rating Methods***	Ductless MSHP	0.41	0.15	0.02	**0.77**
		Heat pump water heater	0.21	0.04	0.01	**0.83**
		Central air conditioning	0.48	0.05	0.10	**0.67**
		Central heat pump[2]	0.49	0.04	0.02	**0.58**
		Warm air furnace	0.42	0.16	0.02	**0.76**
		Boiler	0.35	0.14	0.01	**0.79**

[1] Values may not sum due to rounding.
[2] The Consensus Group recommended Option 3 estimates for all measures except CHPs.

After reviewing the options and results described in the table, as well as additional information that we provided – including a summary of current equipment standards and specifications, results from other studies, and contractors' observations about program market effects – Consensus Group members independently developed retrospective and prospective NTG estimates by equipment type. We consolidated and anonymized the estimates then sent them back to Group members. The Group then met to discuss their recommendations and the rationales behind them. In addition to agreeing on the FR adjustment methods (described in Section 3.3), two other themes and decisions emerged from this meeting:

Central heat pumps need special consideration. Given that the CHP sampling error was particularly large, the Consensus Group hesitated to accept Option 3 without further adjustment. One of the three parties represented in the group proposed to average the NTG Option 3 values for CHP (0.58) with CAC (0.67) NTG, which would result in a CHP NTGR of 0.63. The rationale for this adjustment was that CAC NTG has previously been used to approximate CHP NTG. The other two parties expressed concern about taking this approach without information about NTG precision. NTG precision had not been calculated at the time of the discussion, so the group agreed to use an average of their three separate CHP NTG estimates (0.58, 0.58, and 0.63), or 0.60, as a placeholder. Section □ shows the final precision results and describes how the NTGRs meet a precision threshold defined by the PAs.

The Consensus Group agreed to use the 2016 retrospective NTG estimates for 2019, 2020, and 2021 for a variety of reasons:

- Contractor responses do not indicate consistent projections of future program trends. When asked to predict sales with and without the program, their forecasts varied widely by equipment type and were inconsistent with current estimates.
- There are no concrete plans to change the design of the programs, and the reliably stable market for these equipment types does not indicate a need to adjust NTG estimates during this period.
- The programs' requirements already exceed federal standards and both ENERGY STAR and CEE specifications. There are no imminent changes planned to federal standards or to specifications, and it seems unlikely that changes to standards for these equipment types will be proposed under the current federal administration.

3.8 NET-TO-GROSS PRECISION

To accept a study's estimated NTGRs, the Massachusetts PAs have provided the general guidance that estimates should meet 10% absolute precision *or* 25% relative precision at the 90% confidence level. Table 17 shows the absolute and relative precision of the Option 3 NTGRs. Appendix A.1.1 details these calculations. All measures meet the relative precision requisite (less than 25%) for Methods E and F.

Table 17: Net-to-Gross Precision for Option 3

Measure	Method	FR		Net of FR		NPSO		PSO		SO		NTGR[1]				Precision	
		Estimate	Standard Error	Estimate	Standard Error	Estimate	Standard Error	Estimate	Standard Error	Estimate	Standard Error	Midpoint	Standard Error	Confidence Interval (90%)		Absolute	Relative
														Lower	Upper		
DMSHP	**E**	0.36	0.03	0.64	0.03	**0.15**	0.07	**0.02**	0.02	**0.17**	0.07	0.81	0.08	0.68	0.94	0.13	16%
	F	0.45	0.02	0.55	0.02							0.72	0.08	0.60	0.84	0.12	17%
	Avg.	**0.41**	0.03	**0.59**	0.03							**0.77**	0.08	**0.64**	**0.89**	**0.13**	**16%**
HPWH	**E**	0.19	0.03	0.81	0.03	**0.04**	0.03	**0.01**	0.00	**0.04**	0.03	0.85	0.04	0.78	0.93	0.07	8%
	F	0.23	0.03	0.77	0.03							0.81	0.04	0.74	0.88	0.07	9%
	Avg.	**0.21**	0.03	**0.79**	0.03							**0.83**	0.04	**0.76**	**0.90**	**0.07**	**9%**
CAC	**E**	0.43	0.03	0.57	0.03	**0.05**	0.04	**0.10**	0.06	**0.15**	0.07	0.71	0.08	0.59	0.84	0.12	17%
	F	0.53	0.03	0.47	0.03							0.62	0.07	0.50	0.73	0.12	19%
	Avg.	**0.48**	0.03	**0.52**	0.03							**0.66**	0.07	**0.54**	**0.79**	**0.12**	**18%**
CHP	**E**	0.46	0.05	0.54	0.05	**0.04**	0.04	**0.02**	0.02	**0.07**	0.04	0.61	0.07	0.50	0.72	0.11	18%
	F	0.52	0.05	0.48	0.05							0.55	0.06	0.44	0.65	0.10	19%
	Avg.	**0.49**	0.05	**0.51**	0.05							**0.58**	0.06	**0.47**	**0.68**	**0.11**	**18%**
Furnace	**E**	0.40	0.03	0.60	0.03	**0.16**	0.06	**0.02**	0.01	**0.18**	0.06	0.78	0.07	0.66	0.90	0.12	15%
	F	0.44	0.03	0.56	0.03							0.74	0.07	0.62	0.85	0.11	15%
	Avg.	**0.42**	0.03	**0.58**	0.03							**0.76**	0.07	**0.64**	**0.87**	**0.12**	**15%**
Boiler	**E**	0.34	0.04	0.66	0.04	**0.14**	0.06	**0.01**	0.00	**0.14**	0.06	0.80	0.07	0.69	0.92	0.12	15%
	F	0.37	0.04	0.63	0.04							0.78	0.07	0.66	0.89	0.12	15%
	Avg.	**0.35**	0.04	**0.65**	0.04							**0.79**	0.07	**0.67**	**0.91**	**0.12**	**15%**

Blue signifies that overall precision meets PA requirements (0.10 for absolute precision and 25% for relative precision).

[1] The NTGR's SE is the square root of the sum of net-of-FR SE squared and the SO SE squared. Confidence intervals are the midpoints +/- 1.645 times SE.

4

Section 4 Market Effects Results

The logic models presented in Section 1.3 illustrated key market outcomes that the programs seek to achieve. Table 18 shows the indicators we used to assess progress toward the expected outcomes and how we measured these through questions in the contractor survey.[15] For each equipment type, we first asked contractors if they had observed changes in the market in the previous three years. We then asked those who said yes to rate the programs' level of influence on the changes using a 0 to 10 scale, where 0 is *not at all influential* and 10 is *very influential*.

Table 18: Market Effects Progress Indicators

Expected Outcome or Market Effect	Market Effects Progress Indicator	Survey Question
		Over the past three years, have you observed an increase, decrease, or no change in the following?
Increased stocking and supply of energy-efficient equipment	Rate at which distributors have the models of high-efficiency equipment that contractors need in stock	*How often distributors have the models of high-efficiency residential [MEASURE] that you need in stock?*
Reduced cost barriers	Cost contractors pay for high-efficiency equipment	*The cost that YOU, as the contractor, pay for high-efficiency residential [MEASURE]?*
Increased demand for energy-efficient equipment	Frequency with which customers ask for high-efficiency equipment	*The frequency with which customers ask for high-efficiency residential [MEASURE]?*

Figure 9, Figure 10, and Figure 11 show the percentages of contractors who observed changes in the indicators over the previous three years, as well as their assessments of the programs' influence on those changes.

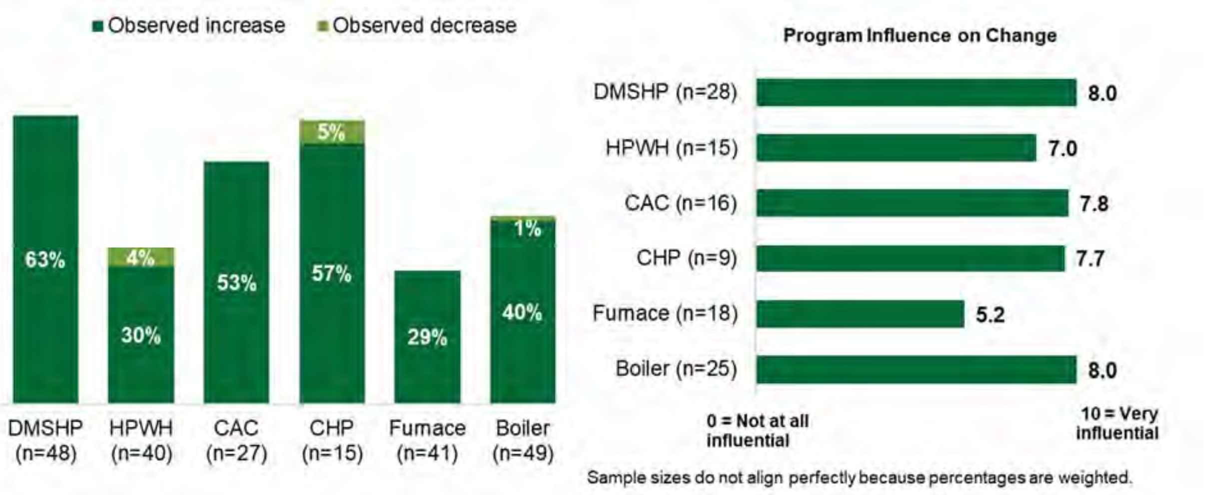
Stocking and supply of high-efficiency equipment. As Figure 9 shows, the majorities of DMSHP (63%), CHP (57%), and CAC (53%) contractors had observed increases in the frequency with which distributors stock the high-efficiency models they need. Contractors attributed much of this change to the programs (with influence rated between 7.0 and 8.0 for all of the equipment types except furnaces, for which the programs' influence has been more modest, at 5.2 on the same scale).

---

[15] We did not factor market effects results into NTGRs.

Figure 9: Changes in Frequency That Distributors Have Needed High-Efficiency Models in Stock

(Reported by Contractors)

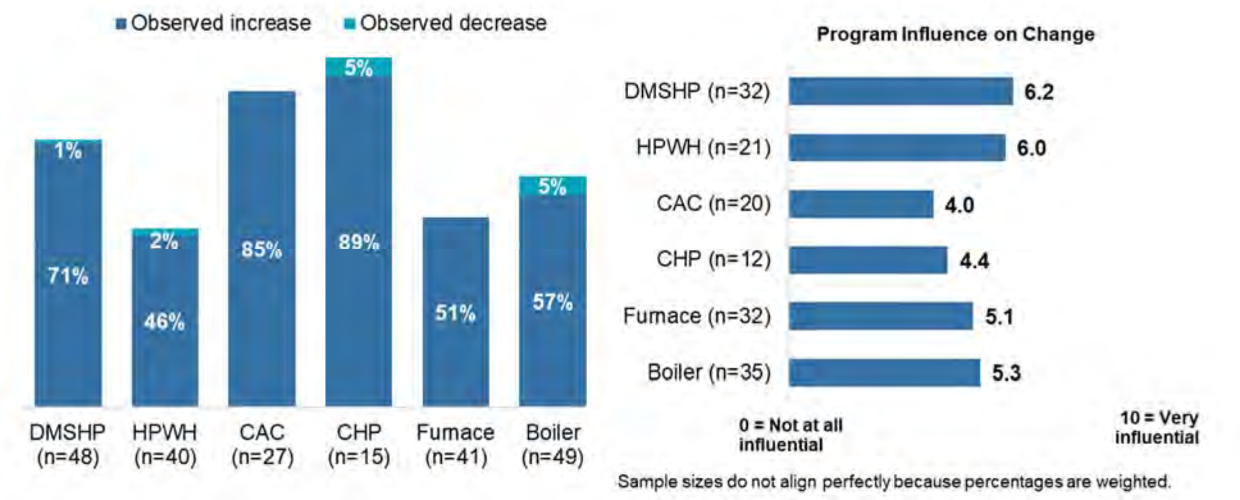


Cost barriers. The logic models predict that, over time, program activities will result in reduced costs for high-efficiency equipment relative to standard-efficiency equipment. For all measures, either the majority of contractors (51% to 89%, depending on the measure) or nearly one-half (46%) of contractors reported having incurred increased costs for purchasing high-efficiency models (Figure 10). This finding suggests that assessing whether contractors perceived prices of high-efficiency equipment as changing at faster, slower, or the same rates as standard-efficiency equipment will be useful for measuring market effects going forward.

The programs' effects on equipment costs were not as pronounced as on other market effects discussed in this section, providing anecdotal evidence that the programs played a modest role in affecting changes in cost. Contractors reported that the programs had a somewhat greater effect on the costs of DMSHPs and HPWHs compared to other equipment. Given that DMSHPs are a newer type of technology, and HPWHs are relatively rare in Massachusetts, it seems logical to expect that the programs would have a greater effect on cost than for equipment that is more commonly installed in Massachusetts homes.

Figure 10: Changes in Costs Contractors Pay for High-Efficiency Measures

(Reported by Contractors)

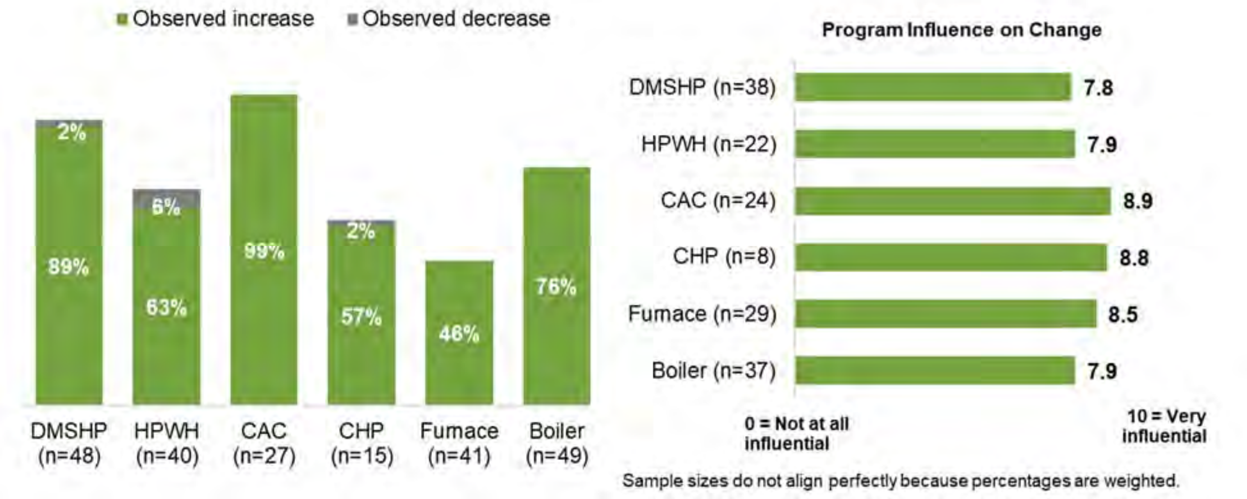


Sample sizes do not align perfectly because percentages are weighted.

Demand for energy-efficient equipment. For all but one measure, the majority of contractors (57% or more) observed increases in customer demand for high-efficiency models in the previous three years (Figure 11). Contractors reported seeing the strongest increases in demand for CAC (99%), DMSHPs (89%), and boilers (76%). With attribution ratings for all equipment types ranging from nearly 8 to nearly 9 on a scale of 0 to 10, contractors attribute much of this change in demand to the programs.

Figure 11: Changes in Frequency at Which Customers Ask for High-Efficiency Measures

(Reported by Contractors)



Sample sizes do not align perfectly because percentages are weighted.

The savings associated with program influence on changes in stocking practices are somewhat reflected in NPSO savings (especially in the case of replace on failure). Changes in these indicators over time could corroborate a market share analysis, which could quantify market effects.

5

Section 5 Contractor Influence, Equipment Replacement, and Fuel Switching

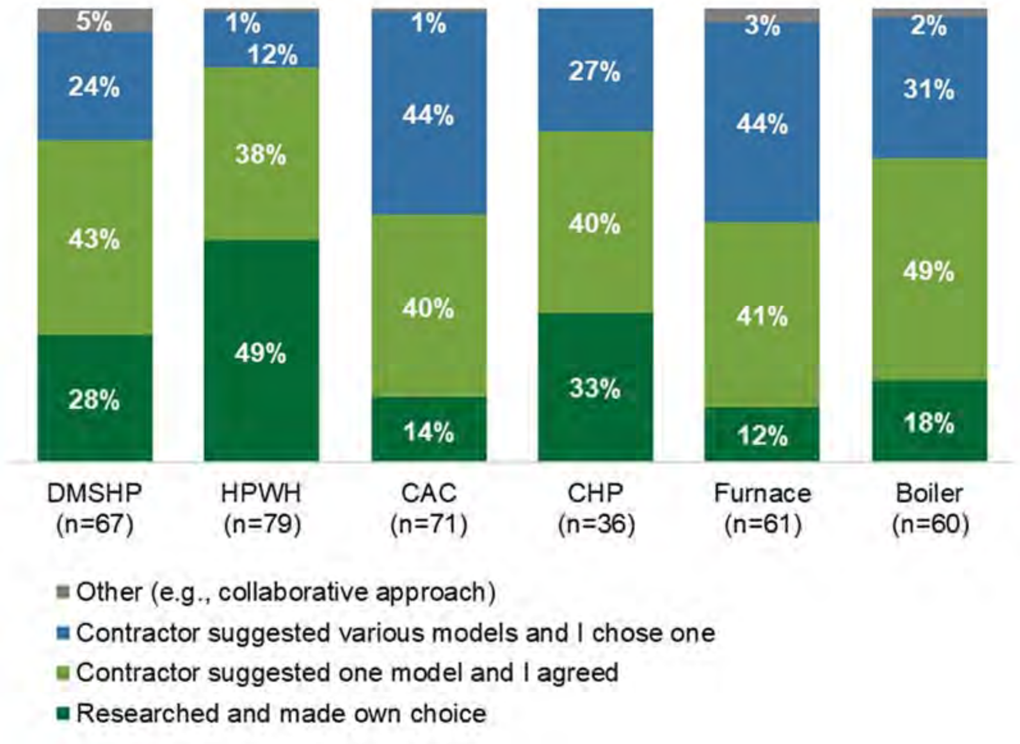
Research results also offer insights into the influence of contractor recommendations on customer decision-making, lost opportunities for early equipment replacement rebates, and fuel switching.

5.1 CONTRACTOR INFLUENCE

Participant survey results indicate that contractors' recommendations have considerable influence on customer decisions about the models of equipment they choose to install. For each measure type, between more than one-third (38%) and nearly one-half (49%) of respondents reported that their contractors suggested just *one* model, which the customer then agreed to have installed (Figure 12). With the exception of HPWHs, two-thirds or more of customers reported that the contractor either suggested one model or various models, and the customer agreed to install one of the models. Contractor recommendations appear to be less influential when it comes to heat pump systems, whether for domestic hot water or for heating and cooling purposes. These systems in and of themselves are often indicative of increased energy efficiency. Nearly one-half of participants who installed HPWHs (49%), one-third of participants who installed CHPs (33%), and more than one-quarter of participants who installed DMSHPs (28%) reported researching and selecting the equipment themselves. It may be the case that if participants selected heat pump measures, they were looking to improve their home's energy efficiency and had, therefore, already conducted some background research before engaging their contractor.

Figure 12. How Participants Selected Equipment Models

(Reported by Participants)



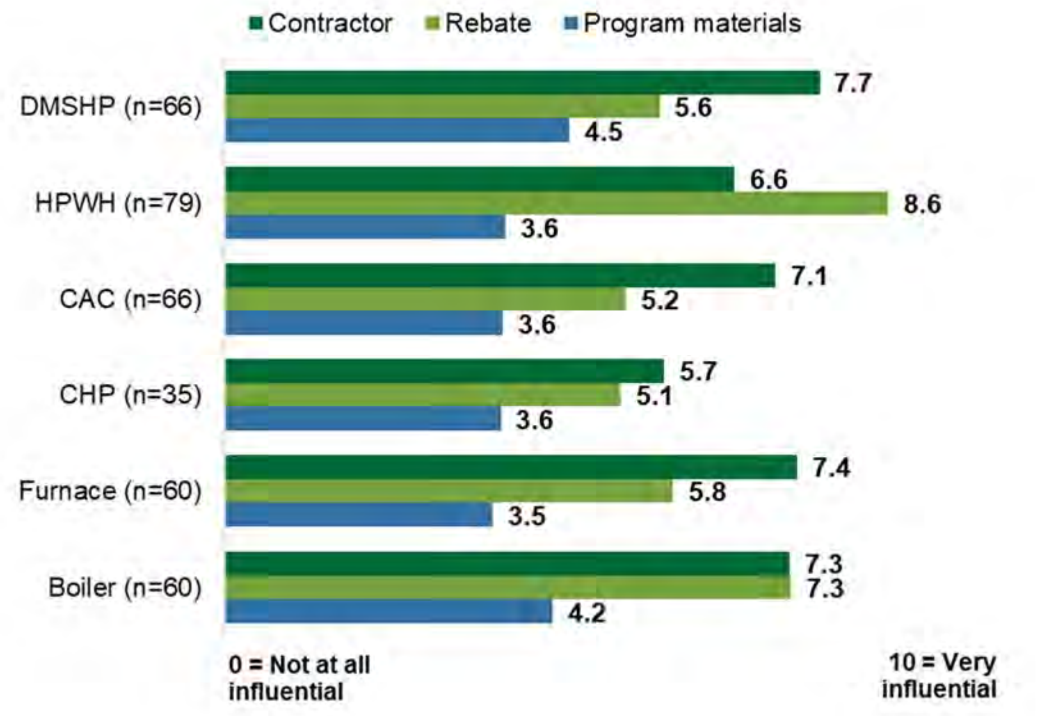
As Figure 13 shows, on average, participants rated the influence of their contractors' suggestions on their decision making for nearly all measures as high as or higher than the influence of program rebates or program materials.[16] Again, HPWHs were an exception: for this equipment type, participants rated the influence of the program rebate considerably higher than the influence of their contractor (8.6 versus 6.6, on average).

---

[16] Program materials were worded as "Mass Save or utility marketing materials (advertising, mailers)."

Figure 13: Influence of Contractor Compared to Program Rebate and Materials

(Average Ratings among Participants)



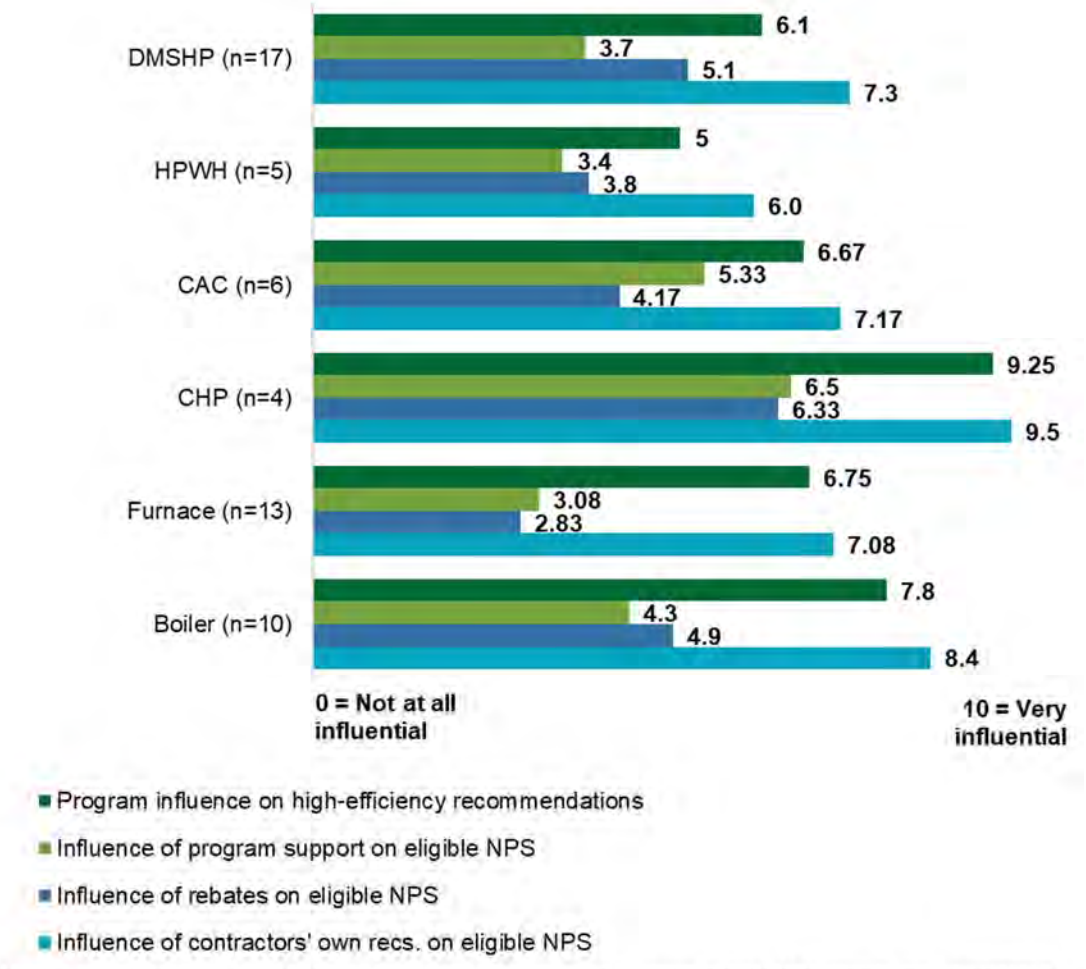
As discussed in Section 3.4, some contractors reported having installed program-eligible equipment that did not receive program rebates. We asked these contractors spillover questions to assess their perceptions of the influence of the following factors on their sales of high-efficiency equipment outside the program:

- Their recommendations to customers;
- Mass Save Standard rebates offered but not received; and
- Other support offered through the program, such as marketing, advertising, education, training, or seminars.

We also asked them about the influence of the Mass Save Standard rebates on the frequency with which they recommended high-efficiency measures to their customers who did not receive rebates. Their ratings were on a scale of 0 to 10, where 0 is *no influence* and 10 is *a great deal of influence*. Figure 14 compares the average ratings for each of these questions by equipment type. The results indicate that contractors felt their own recommendations had the most influence on customer installations of qualifying non-program equipment (ranging by equipment type from 5.0 to 9.25 on the scale), and that the programs strongly influenced their recommendations (ranging by equipment type from 6.0 to 9.5 on the scale). The results suggest that the programs have substantial indirect influence on what appears to be the strongest driver in the selection of qualifying equipment outside the program. (Since the number of contractors asked this question for each equipment type was quite small, ranging from four to 17, these results should be generalized with caution.)

Figure 14: Contractor Perceptions of Influential Factors on Non-Program Sales

(Average Ratings among Contractors)



Note: Sample sizes are small because few contractors reported program-eligible NPS; results are unweighted.

5.2 EQUIPMENT REPLACEMENT AND FUEL SWITCHING

Mass Save offers higher rebates for replacing older (but functioning), inefficient heating and cooling equipment.[17] Prior to receiving an Early Replacement rebate, the homeowner must receive an HEA through HES or receive an AC Check, where energy specialists/contractors verify that the equipment to be replaced qualifies by meeting all of the following criteria:

- Is functioning
- Meets the minimum age (specific to equipment type)[18]
- Has a remaining working life of at least two years

---

[17] https://www.masssave.com/en/saving/residential-rebates/early-heating-and-cooling/

[18] Replaced equipment must be 12 years or older, except in the case of boilers, where the replaced boiler must be 30 years or older.

- Is the same fuel and measure type as the rebated equipment

The program offers Early Replacement rebates for four of the six measures that we studied: CACs, CHPs, furnaces, and boilers. Though the participant survey respondents did not receive Early Replacement rebates for the measures in question, it is possible that they would have qualified for one had they elected to go through the verification process before installation, so we asked about their replaced equipment to identify these cases.[19] Because results are based on customer self-reports and the equipment replaced has already been removed such that the customer could not verify its age, readers should interpret customers' answers to these questions with caution.

The Team adapted the approach to identifying early replacement equipment outlined in Cadmus's 2012 study to the data collected for this study. The Cadmus 2012 study categorized installations into four types: *new installation*, *replace on failure*, *early replacement*, and *in-between replacement*:

- **New installation**. The study considered a measure to be a *new installation* if it did not replace anything. For example, if a participant had not had a CAC before installing one through the program, then the program-supported CAC was considered a *new installation*.
- **Replace on failure**. The analysis considered a measure to be *replace on failure* in a few scenarios. First, if a measure replaced existing heating or cooling equipment that was not working or needed major repairs, then they considered it a *replace on failure*. If respondents projected that their replaced measures would have lasted one year or less, then it was a *replace on failure*, too. The 2012 study also considered systems that had been repaired twice in the year before they were replaced as *replace on failure.* (Since the current study did not ask about number of repairs, the Team could not categorize installations as replace on failure.)
- **Early replacement**. If replaced equipment had been working or needed only minor repairs and respondents estimated it would have last four or more years, then the analysis considered them *early replacement*.
- **In-between replacement**. If respondents estimated that replaced equipment would have likely lasted two to three years, then the study considered them *in-between replacement*.

If a system was deemed *early* or *in-between replacement* based on those conditions, then the 2012 study asked about the importance of the system's lifetime on the decision to replace it and adjusted categorizations as needed.[20] The current study did not ask this question.

Figure 15 illustrates the distribution of installation types in the current study based on the 2012 study's criteria. Note that Mass Save's Early Replacement rebate criteria are different from the 2012 study's criteria. Unlike the 2012 study's criteria, Mass Save's Early

---

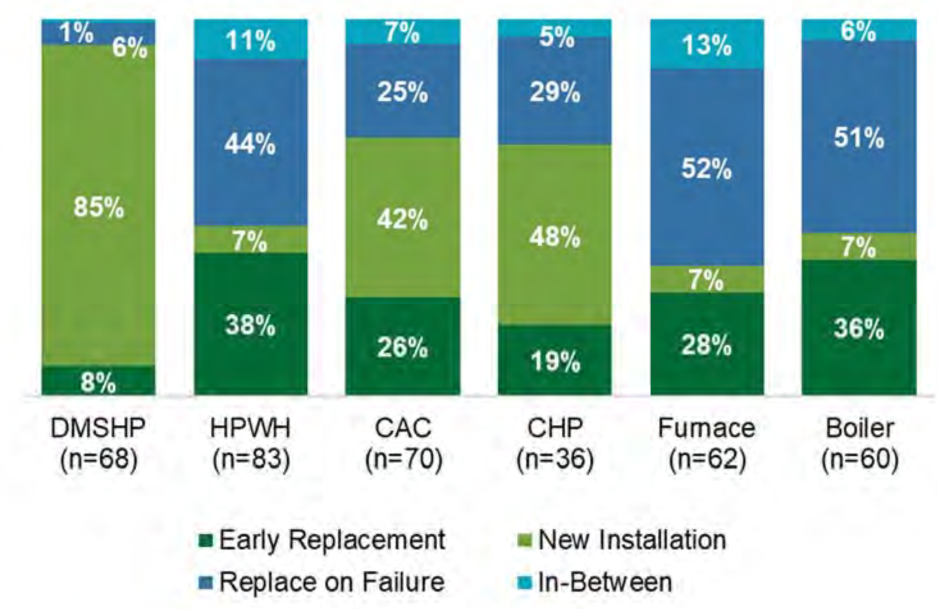
[19] As noted, the RES36 study examined the early replacement program in greater detail.

[20] The survey asked, "How important of a reason for you was the fact that your system might be reaching the end of life and might fail in the near future on your decision to replace?" If it was "very" important, then Cadmus recategorized the measure as *replace on failure* and if it was "somewhat" important, then they considered it an *in-between replacement*.

Replacement rebate requires that (1) program measures must replace like measures (e.g., gas furnace replacing a gas furnace), (2) replaced equipment must be of a certain age, (3) replaced equipment is expected to last at least two more years, not at least four more years, and (4) the participant's importance rating of the expected lifetime of the replaced equipment is not a factor. If the team were to implement Mass Save's criteria for the four relevant measures strictly, different proportions would have been eligible for Early Replacement rebates compared to the results below. Larger shares of furnaces (33% vs. 28%) and CHPs (26% vs. 19%) would have qualified and smaller shares of CACs (11% vs. 26%) and boilers (4% vs. 36%) would have qualified.

Figure 15: Installation Types

(Based on Participant Self-Reports)



Currently, Mass Save does not directly support fuel conversions (although National Grid does subsidize conversions from fuel oil to natural gas). The contractor survey included a small battery of fuel switching questions. Eighty-five percent of contractors (n=143) reported that their company assists customers in switching from either propane or oil to natural gas or electricity for heating equipment. They estimated that their companies complete between one and 50 fuel switching projects a year, with a median of 6.0 and mean of 9.6 projects annually.

Based on participants' responses, 23% of boiler installations and 7% of furnace installations were part of oil-to-gas conversions. Two percent of DMSHP installations were part of oil-to-electric conversions, and 1% were part of gas-to-electric conversions. No CHP installations were part of fuel conversions (Figure 16).

Figure 16: Fuel Switching

(Based on Participant Self-Reports)

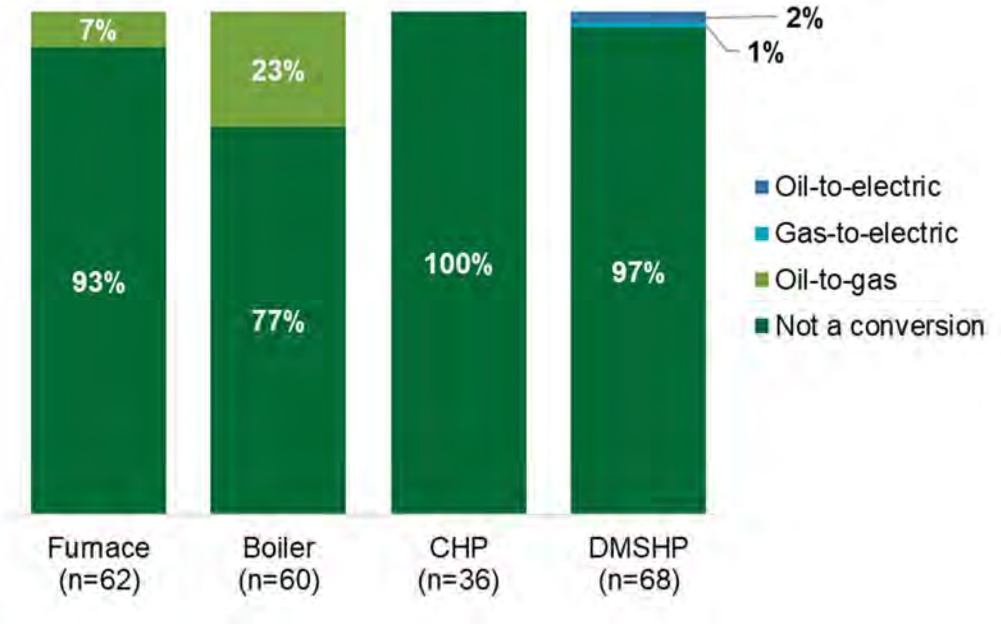


Table 19 compares fuel switching by installation type.

Table 19: Fuel Switching by Installation Type

Installation Type	Fuel Conversion	Furnace (n=62)	Boiler (n=60)	DMSHP (n=68)
Early Replacement	**Yes**	**-**	**13%**	**2%**
	No	28%	23%	6%
Replace on Failure	**Yes**	**6%**	**10%**	**1%**
	No	46%	41%	5%
In-Between	**Yes**	**1%**	**-**	**-**
	No	12%	6%	1%
New Installation	(No)	7%	7%	85%
Total	**All**	**100%**	**100%**	**100%**

Appendix A.1.6 reports participants' other responses about equipment replacement.

6 Section 6 Results, Recommendations, and Considerations

In this section, we summarize the key results from the study and offer recommendations and considerations to improve program outcomes.

6.1 NET-TO-GROSS RATIOS

Using primary data collection and a Consensus Group approach, this study estimated NTGRs for DMSHPs, HPWHs, CACs, CHPs, furnaces, and boilers that are incented with Standard rebates.

Results

Compared to the 2016-2018 ratios, the 2019-2021 NTGRs developed via this study are higher for DMSHPs and boilers, and lower for HPWHs, CAC, CHPs, and (to a lesser extent) furnaces.

Recommendation

The team recommends using the NTGRs shown in Table 20 for measures incented with Standard rebates in program years 2019-2021.

Table 20: Recommended Net-to-Gross Ratios
(2019-2021)

Program Measures	NTG
Ductless MSHP	0.77
Heat pump water heater	0.83
Central air conditioning	0.67
Central heat pump	0.60
Warm air furnace	0.76
Boiler	0.79

Considerations

Consider how changes in NTGRs may affect the PAs' benefit/cost ratio models and decisions about continuing to support each of the measures at the current efficiency specification and rebate levels.

6.2 MARKET EFFECTS

In accordance with the logic models presented in Section 1.3, this study measured three market effects indictors to provide anecdotal evidence of progress toward market transformation and set baselines for comparison with future studies. It also assessed the degree to which the progress measured could be attributed to the programs. The outcomes and related indicators are as follows:

- Outcome: Increased stocking and supply of energy-efficient equipment. Indicator: The rate at which distributors have the models of high-efficiency equipment that contractors need in stock, as perceived by contractors.
- Outcome: Reduced cost barriers. Indicator: The cost contractors pay for high-efficiency equipment, as perceived by contractors.
- Outcome: Increased demand for energy-efficient equipment. Indicator: Frequency with which customers ask for high-efficiency equipment, as perceived by contractors.

Results

Stocking and supply of high-efficiency equipment. The logic models predict that the program efforts would result in increased stocking and supply of energy-efficient equipment. Contractors offered anecdotal evidence that, to some degree, the programs' intended effects on stocking are occurring – particularly for equipment supported by the electric program. The majorities of contractors who installed DMSHP (63%), CHP (57%), and CAC (53%) equipment observed increases in the frequency with which distributors stock the high-efficiency models they need. They attributed much of this change to the programs, saying that they had considerable influence on these outcomes (with influence rated between 7.0 and 8.0 on a 0-10 scale for all equipment types except furnaces, for which their influence has been more modest, at 5.2 on the same scale).

Cost barriers. The logic models predict that, over time, program activities will result in reduced costs for high-efficiency equipment relative to standard-efficiency equipment. For nearly all measures, the majority of contractors reported having incurred increased costs for purchasing high-efficiency models. To limit respondent fatigue, survey questions did not ask contractors to compare changes in costs between high-efficiency and standard equipment.

The results of the attribution questions for equipment costs provide anecdotal evidence that the programs played a modest role in affecting changes in cost.

Demand for energy-efficient equipment. This indicator offers evidence that customer demand for high-efficiency HVAC equipment is increasing, and that contractors attribute much of this change to the programs.

Recommendation

Measure the same market indicators in future studies of the programs' activities, and compare the results to track progress over time. Future measurements of the indicator of reduced cost barriers should allow for a comparison between changes in costs of high-efficiency and standard equipment to assess whether contractors perceived prices of high-efficiency equipment as changing at faster, slower, or the same rates as standard efficiency equipment. To claim savings from market effects, market share data must be available for analysis. Changes in the indicators assessed in this report could corroborate findings from market share data analysis.

Consideration

The evaluation team has previously attempted to obtain Massachusetts HVAC market share data from manufacturers on behalf of the PAs, and is currently attempting to obtain Massachusetts unit sales data from distributors. The team has encountered considerable difficultly obtaining meaningful state-level data from HVAC industry players. There remain two ready sources of HVAC market share data that the PAs previously examined and may wish to consider using in the future: the national ENERGY STAR® shipment data and HARDI HVAC data from D&R International. The PAs have previously chosen not to rely on either data source because the data were not sufficiently representative of Massachusetts. Since the completion of this evaluation, D&R International has informed the evaluation team that they have successfully brought on board a distributor with many Massachusetts outlets. D&R estimates that the data they now have in hand for Massachusetts represents slightly over 35% of the state's market for furnaces, CAC, and ASHP equipment. This is more than double the previous representation, and the data go back several years.

Another approach the PAs may want to consider in the future is to leverage national ENERGY STAR shipment data. This would involve asking manufacturers to estimate the Massachusetts market share of ENERGY STAR-qualified HVAC equipment in relation to the national data, with some consideration of attribution. While this would be less expensive than purchasing D&R data, and likely less expensive than the approach taken in this evaluation, it would not be as precise as either. ENERGY STAR also does not equate directly with Mass Save program capacity and efficiency requirements.

6.3 CONTRACTOR INFLUENCE

Both customers and contractors have important roles to play in advancing equipment markets to the next level of efficiency. It benefits contractors to be conservative in recommending or choosing equipment for their customers, since returning to fix problems with equipment can spell the difference between profit and loss on a job. Innovator and early-adopter customers can help move contractors when technology is newer and less proven. When technology is more mainstream, contractors can help late-majority and late-adopter customers move forward.

Results

Participant survey results indicate that contractors' recommendations have considerable influence on customer decisions about the models of equipment they choose to install. Contractor recommendations appear to be less influential when it comes to equipment that is generally high-efficiency (i.e., heat pump technology): nearly one-half of participants who installed HPWHs (49%), one-third of participants who installed CHPs (33%), and more than one-quarter of participants who installed DMSHPs (28%) reported researching and selecting the equipment themselves. The results indicate that contractors felt their own recommendations had the most influence on customer installations of qualifying non-program equipment, and that the programs strongly influenced their recommendations. The results suggest that the programs have substantial indirect influence on what appears to be the strongest driver in the selection of qualifying equipment outside the program. (Since the number of contractors asked this question for each equipment type was quite small, ranging from four to 17, these results should be generalized with caution.)

Recommendation

While the market effects indicator results show that customer demand for high-efficiency equipment has increased over the last three years, and participant survey results indicate that contractors' recommendations have considerable influence on customer decisions about the models of equipment they choose to install, for certain equipment types, customers are important drivers of decision-making. Given this, the programs should continue to target both customers and contractors.

6.4 RESULTS AND CONSIDERATIONS

Results

The team conducted a large amount of work to clean program data to develop a contractor survey sample for evaluation purposes. This suggests a need for a better system of tracking contractor contact information (such as consistently using unique company and contact identification numbers).

Considerations

Improve contractor contact information tracking (e.g., develop contractor IDs, require email addresses)to better prepare for future evaluation efforts.

In the future, consider using in-depth interviews rather than programmed surveys with contractors to estimate market shares and program influence. The complexity involved in these questions requires abstract consistency checks that are difficult to implement through a programmed survey with no trained expert guiding respondents to correctly interpret the questions.

A

Appendix A Additional Details

This appendix offers additional details that were referenced in the body of the report. These include FR standard error calculation details; descriptions of the NTG sensitivity analyses; NTG consistency checks and revisions; HES participation cross-tabulation; benchmarking of the NTG results; and background on HVAC equipment standards.

A.1 NET-TO-GROSS ANALYSIS

A.1.1 Net-to-Gross Precision

To accept a study's estimated NTGRs, the Massachusetts PAs have provided the general guidance that estimates should meet 10% absolute precision *or* 25% relative precision at the 90% confidence level. Because the NTGR is a sum of two components (FR and SO), the same formula used to calculate the standard error (SE) associated with the combined SO components can be used to calculate the SE of the NTGR.

NTGR – Standard Error Formula

$$SE\langle NTGR\rangle = \sqrt{SE\langle FR\rangle^2 + SE\langle SO\rangle^2 + 2Cov\langle FR, SO\rangle}$$

We assume that $Cov\langle FR, SO\rangle = 0$, so that:

$$SE\langle NTGR\rangle = \sqrt{SE\langle FR\rangle^2 + SE\langle SO\rangle^2}$$

We describe these inputs in more detail below.

A.1.1.1 Free-Ridership Standard Error Formulae

As described earlier, the Consensus Group preferred the Option 3 FR adjustment method. Option 3 is the average result of two adjustment methods: the first (Method E), which left alone, averaged, or replaced a participant's FR with that of the contractor depending on the extent of the contractor's involvement in the selection process, and the second (Method F), which replaced a participant's FR if the participant rated highly the influence of their contractor. We estimated precision for each method.

Since FR was a product of two independent samples (participants and contractors), we blend the Uniform Methods Project's (UMP's)[21] algorithms for calculating precision, using formulae for calculating standard error (SE) of either a sum or a product. The formulae below use data from four elements: (1) count and FR rates among participants whose FR was unadjusted, (2) count and FR rates among participants whose FR was averaged with that of contractors, (3) proportion of participants whose FR was replaced with that of the contractor, and (4) FR

---

[21] National Renewable Energy Laboratory. "The Uniform Methods Project: Methods for Determining Energy Efficiency Savings for Specific Measures." Chapter 11: Sample Design Cross-Cutting Protocol. September 2017.

rates among contractors. **Error! Reference source not found.** defines the parameters in these two formulae. Below we provide more details on the derivation of this relationship.

Free-Ridership Method E – Standard Error Formula

$$SE(FR^{\sim}) = \sqrt{\begin{gathered} {f_c'}^2 SE^2(FR_c) + {FR_c}^2 SE^2(f_c) + \left(SE(f_c)SE(FR_c)\right)^2 + \left(1 - f_c'\right)^2 SE^2\left(FR_p\right) + \\ {FR_{poa}}^2 SE^2(f_c) + \left(SE(f_c)SE\left(FR_p\right)\right)^2 - 2SE^2(f_c)FR_cFR_{poa} \end{gathered}}$$

Free-Ridership Method F – Standard Error Formula

$$SE(FR) = \sqrt{\begin{gathered} {f_c}^2 SE^2(FR_c) + {FR_c}^2 SE^2(f_c) + \left(SE(f_c)SE(FR_c)\right)^2 + (1 - f_c)^2 SE^2\left(FR_p\right) + \\ {FR_p}^2 SE^2(f_c) + \left(SE(f_c)SE\left(FR_p\right)\right)^2 - 2SE^2(f_c)FR_cFR_p \end{gathered}}$$

Table 21: Free-Ridership – Standard Error Formulae Parameters

Parameter	Description
f_c	Proportion of participants whose FR was replaced by that of contractors
f_a	Proportion of participants whose FR was averaged with that of contractors
FR_c	Average FR among contractors
FR_p	Average FR among customers whose FR was not adjusted
f_c'	Proportion of participants whose FR was averaged with that of contractors divided by two and added to the proportion of participants whose FR was replaced by that of contractors: (f_a / 2) + f_c
FR_{PoA}	Sum of unadjusted FR divided by count of respondents
$FR^{\sim}$	((1 – f_c') * FR_{POA}) + (f_c' * FR_c)

Starting with Method F, in which there is no averaging for individual customers, FR is calculated as:

$$FR = f_oFR_p + f_cFR_c = (1 - f_c)FR_p + f_cFR_c$$

Where FR_p is the FR rate based on customer survey responses, FR_c is the FR rate based solely from the contractor survey, f_o is the fraction of observations based on the participants' own response, and f_c is the fraction of observations based on the contractor survey.

The SE of this is derived from the equation presented in the UMP Sample Design, Section 7.4 for the SE of a sum.

$$SE(FR) = \sqrt{SE^2(f_cFR_c) + SE^2\left((1 - f_c)FR_p\right) + 2Cov\left(f_cFR_c, (1 - f_c)FR_p\right)}$$

or

$$SE^2(FR) = SE^2(f_cFR_c) + SE^2\left((1-f_c)FR_p\right) + 2Cov\left(f_cFR_c, (1-f_c)FR_p\right)$$

Since FR_c and FR_p come from different samples and are independent. Similarly, FR_c and f_c are independent. As a simplifying approximation, we also assume that f_c (or $(1-f_c)$) is independent of FR_p. That is, there is no relationship between what fraction of customers in the sample are in the group that uses the participants' FR information directly and the average FR value found in the sample for that group. This is a reasonable assumption because we might over- or under-sample the self-reportable group relative to the population, but that would not swing the expected FR value for that group one way or the other.

Therefore:

$$Cov\left(f_cFR_c, (1-f_c)FR_p\right) = -Var(f_c)FR_cFR_p = -SE^2(f_c)FR_cFR_p$$

To calculate $SE^2(f_cFR_c)$ and $SE^2\left((1-f_c)FR_p\right)$, we apply the formula for the product of two independent quantities from the UMP, Section 7.5.

$$SE(f_cFR_c) = \sqrt{{f_c}^2SE^2(FR_c) + {FR_c}^2SE^2(f_c) + \left(SE(f_c)SE(FR_c)\right)^2}$$

or

$$SE(f_cFR_c)^2 = {f_c}^2SE^2(FR_c) + {FR_c}^2SE^2(f_c) + \left(SE(f_c)SE(FR_c)\right)^2$$

and

$$SE\left((1-f_c)FR_c\right)^2 = (1-f_c)^2SE^2\left(FR_p\right) + {FR_p}^2SE^2(1-f_c) + \left(SE(1-f_c)SE\left(FR_p\right)\right)^2$$

thus

$$SE(FR) = \sqrt{\begin{gathered}{f_c}^2SE^2(FR_c) + {FR_c}^2SE^2(f_c) + \left(SE(f_c)SE(FR_c)\right)^2 + (1-f_c)^2SE^2\left(FR_p\right) + \\ {FR_p}^2SE^2(1-f_c) + \left(SE(1-f_c)SE\left(FR_p\right)\right)^2 - 2SE^2(f_c)FR_cFR_p\end{gathered}}$$

And since $SE(1-f_c) = SE(f_c)$

$$SE(FR) = \sqrt{\begin{gathered}{f_c}^2SE^2(FR_c) + {FR_c}^2SE^2(f_c) + \left(SE(f_c)SE(FR_c)\right)^2 + (1-f_c)^2SE^2\left(FR_p\right) + \\ {FR_p}^2SE^2(f_c) + \left(SE(f_c)SE\left(FR_p\right)\right)^2 - 2SE^2(f_c)FR_cFR_p\end{gathered}}$$

The equation shown directly above is what is used to calculate the SE for Method F, when only participant or contractor FR values are used. In the more complicated case of Method E, in which participant, contractor, or an average FR value are used, there is not a straightforward analytic solution. As an approximation, the FR is calculated in the same way using an average of the values included, and then calculating the SE of that. An approximate FR value is used as a substitute in the SE formula. The formula for actual FR in Method E is given by:

$$FR = f_o FR_o + \frac{f_a}{2} FR_a + \left(\frac{f_a}{2} + f_c\right) FR_c$$

To calculate the SE, the same equation above is used while substituting an approximate FR given by:

$$FR^{\sim} = (1 - f_c{}')FR_{poa} + f_c{}'FR_c$$

where

$$FR_{poa} = \left(\sum_{j}^{n_0+n_a} FR_{pj}\right) \Big/ (n_0 + n_a)$$

and

$$f_c{}' = \frac{f_a}{2} + f_c$$

So that $f_c{}'$ is used in place of f_c and FR_{poa} is used in place of FR_o.

A.1.1.2 Spillover Standard Error Formulae

We calculated NPSO and PSO precision separately. As described in Section 3.4, for each equipment type, NPSO is the ratio of the sum of non-program sales times each contractor's influence score divided by the sum of all program sales. The confidence intervals associated with these estimates are calculated using the formula presented in the UMP to calculate the SE for a ratio estimator.

Non-Participant Spillover Formula

$$NPSO = \frac{\sum_i^n (NonProgramSales_i * InfluenceScore_i)}{\sum_i^n ProgramSales_i}$$

Where *n* is the number of contractors, *i*.

Non-Participant Spillover – Standard Error Formula

$$SE = \frac{1}{\sqrt{n}} \sqrt{\sum_i^n \frac{([NonProgramSales_i * InfluenceScore_i] - [NPSO * ProgramSales_i])^2}{\left(\frac{\sum_i^n ProgramSales_i}{n}\right)^2 * (n-1)}}$$

The PSO estimation method described in Section 3.5 and its SE formula mirror those of the NPSO. The central estimate for each equipment type is calculated as a ratio of all spillover savings divided by program savings.

Non-Participant Spillover Formula

$$PSO = \frac{\sum_i^n SpilloverSavings_i}{\sum_i^n ProgramSavings_i}$$

Participant Spillover – Standard Error Formula

$$SE = \frac{1}{\sqrt{n}} \sqrt{\sum_i^n \frac{\left(\sum_i^n SpilloverSavings_i - [PSO * ProgramSavings_i]\right)^2}{\left(\frac{\sum_i^n ProgramSavings_i}{n}\right)^2 * (n-1)}}$$

An overall spillover value is generated by summing the NPSO and PSO for each equipment type. Similarly, the confidence intervals associated with the overall spillover estimates are generated using the formula for the SE of an estimated sum from the UMP's section 7.4, just as the SE for the overall NTGR is calculated by combining the SE of FR and SO.

Overall Spillover – Standard Error Formula

$$SE\langle SO\rangle = \sqrt{SE\langle NPSO\rangle^2 + SE\langle PSO\rangle^2 + 2Cov\langle NPSO, PSO\rangle}$$

We assume that $Cov\langle NPSO, PSO\rangle = 0$, so that:

$$SE\langle SO\rangle = \sqrt{SE\langle NPSO\rangle^2 + SE\langle PSO\rangle^2}$$

Where $SE\langle SO\rangle$ is the SE of the SO estimate, $SE\langle NPSO\rangle$ is the SE of NPSO, $SE\langle PSO\rangle$ is the SE of the PSO estimate, and $Cov\langle NPSO, PSO\rangle$ is the covariance of NPSO and PSO. For this calculation, we again make the simplifying assumption that $Cov\langle NPSO, PSO\rangle = 0$, which is warranted since the two estimates are drawn from separate samples (contractors and participants, respectively).

A.1.2 Sensitivity Analyses

We conducted sensitivity analyses for participant FR and contractor NPSO.

A.1.2.1 Participant Sensitivity Analysis

We used a modified version of Cadmus's four sensitivity testing methods to examine participant FR (Table 22). Methods 1 and 3 – the "Maximum" methods – applied the maximum likelihood and influence scores into the efficiency credit, and Methods 2 and 4 – the "Means" methods – applied the *mean* scores.[22] Methods 1 and 2 use increments of 0%, 50%, and 100% when establishing the timing credit, but Methods 3 and 4 more leniently assigned 66% instead of 50% for the partial timing score. The differences with adjusting the timing credit had close to no influence. As a result, we set aside the results of Methods 3 and 4.

The industry has slowly moved towards using a maximum versus mean scoring approach. However, we observed instances where the program rebate has nearly no influence, but program marketing materials have high influence. In these instances, awarding a very large efficiency credit could mean assigning someone *no* FR. These scenarios led us to continue considering the Means Method in our analysis. Nonetheless, the Consensus Group chose to move forward with the Maximum Method alone.

Table 22: Participant Free-Ridership – Sensitivity Analysis Methods

Input	Method 1	Method 2	Method 3	Method 4
Influence scores/rating	Maximum	Average	Maximum	Average
Timing credit for units that would have been replaced within 6-12 months	50%	50%	66%	66%

A.1.2.2 Contractor Sensitivity Analysis

For contractor NPSO, we toggled maximums and averages and then created thresholds for assigning IR and PI scores. The first two methods divide ratings by ten (e.g., 1 = 0.10 and 9 = 0.90) to calculate incrementally increasing scores. For the last two methods, any rating below 6 equals 0.0, and ratings of 6 to 9 incrementally increase by fifths (e.g., 6 = 0.20 and 9 = 0.80). We recommended applying the average value across methods.

---

[22] As noted, we began allowing HES participants into our sample mid-fielding. We asked those participants about HES technician's level of influence as well, but those responses are not incorporated into our algorithm.

Table 23: Contractor Non-Participant Spillover – Sensitivity Analysis Methods

Input	Method 1	Method 2	Method 3	Method 4
Spillover Influence Score	Maximum	Average	Maximum	Average
IR and PI Scoring				
Cutoff points	**None**	**None**	**High**	**High**
0	-	-	-	-
1	0.1	0.1	-	-
2	0.2	0.2	-	-
3	0.3	0.3	-	-
4	0.4	0.4	-	-
5	0.5	0.5	-	-
6	0.6	0.6	0.20	0.20
7	0.7	0.7	0.40	0.40
8	0.8	0.8	0.60	0.60
9	0.9	0.9	0.80	0.80
10	1.0	1.0	1.0	1.0

A.1.3 Consistency Checks and Revisions

Nearly all responses required careful examination after applying the standard algorithm. In a number of cases, we manually revised scores/ratios to account for inconsistencies.

A.1.3.1 Participant Consistency Checks and Revisions

We asked participants who gave conflicting likelihood and influence scores in the FR module why they gave the scores they did. Table 24 lists some FR revisions we made based on open-end responses to consistency checks.

Table 24: Participant Respondent-Level Free-Ridership Revisions

Raw Inputs[1]				How did the rebate impact your decision to install the measure?	FR	
Rebate Influence Rating (0-10)	Likelihood Rating (0-10)	Timing Credit (0-100%)	Quantity Credit (0-100%)		Orig.	Rev.
10	10	0%	n/a	“It was such a small amount for the rebate, I still would have done it”	**0.35**	**1.00**
10	10	0%	n/a	“The rebate sealed the deal. It was important to which model we purchased”	**0.25**	**0.10**
10	10	100%	n/a	“It was money back on a system that I had to purchase”	**0.00**	**0.80**
8	8	0%	0%	“The rebate was influential in terms of *which* furnace to install. Ours was going to need to be replaced, but the rebate allowed us to purchase a more efficient and slightly more expensive furnace.”	**0.38**	**0.20**

[1] Ratings for contractors and program materials were also factored in but did not trigger open-end questions.

Table 25 lists a few participant-reported non-program measures that participants claimed were influenced by the program in the SO module, but that their open-end responses indicate were already rebated or the program had no influence on them.

Table 25: Customer Respondent-Level Participant Spillover Exclusions

Ratings		How did the rebate influence your decision to install the non-rebated measure?
Program Importance	Likelihood to Install	
10	4	"In my case it had no effect on it; [the insulation] was done years before the heat pump."
10	8	"The rebate for the thermostat was through Eversource. I would not have gotten the smart thermostat without the Eversource rebate, as it is way too expensive.
10	5	"The rebate on the boiler did not influence the insulation decision. A potential rebate for the insulation itself did."

A.1.3.2 Contractor Consistency Checks and Revisions

Table 26 lists some FR revisions we made based on contractors' open-end responses to consistency checks. We excluded contractors whose responses indicated that they did not understand we were asking about high-efficiency models (versus *any* models).

Table 26: Contractor Respondent-Level Free-Ridership Revisions

Percentage Installed in Absence of Program	Why do you give that response?	FR	
		Original	Revised
60%	"A lot of people do it because of rebates, and the rebates make the installation cost a better value."	0.60	0.25
25%	"They would not have been high-efficiency."	0.20	0.00
100%	"[The customer] needed to have it replaced anyway."	1.00	Exclude
70%	"Most units I install are cracked heat-exchangers or failing equipment that needs to be replaced."	0.70	Exclude

While contractors were asked to estimate non-program sales that would have qualified for the program but did not go through the program, open-end responses revealed cases where those sales would not have been program-eligible anyhow, so we changed their reported non-program sales to zero for the NPSO analysis. Table 27 lists typical responses that warranted this treatment. We also judiciously normalized reported non-program sales on a case-by-case basis where the basic math did not add up.

Table 27: Contractor Respondent-Level Non-Participant Spillover Revisions

Spillover Comment	Non-program Sales	
	Original	Revised
"They were installed in a [geographical] area that the rebates do not cover."	4	0
"I wasn't sure if SEER 14 was high enough."	3	0
"[They] were not high-efficiency."	2	0

A.1.4 Free-Ridership by HES Participation

We compared HES and non-HES participant FR to determine if weighting was necessary to fully represent the HES population. At the measure-level, HES sample sizes were often too small and would have had excessive weight on results if we weighted them back to the full population. Therefore, we looked holistically at the results across measures to assess the overall differences between the two populations. Considering the averages between the Maximum and Means Methods, we found a 0.05 difference between HES (0.26) and non-HES (0.32) participant FR. Given that this was not a statistically significant difference at a 95% confidence level, we set aside the concern and did not weight results by HES participation.

Table 28: Unadjusted Participant Free-Ridership Results by HES Participation

Program Measures	Non-HES		HES	
	n	FR	n	FR
Ductless MSHP	43	0.43	23	0.27
Heat pump water heater	77	0.14	2	0.10
Central air conditioning	54	0.44	12	0.23
Central heat pump	28	0.43	7	0.42
Warm air furnace	45	0.31	16	0.26
Boiler	42	0.22	18	0.21
Weighted average	**289**	**0.31**	**79**	**0.26**

A.1.5 Participant Spillover Savings

Table 29 shows the measures that qualified towards PSO. Respondents also confirmed installing energy-efficient lighting, but we excluded those responses from the analysis because they may have been incented upstream.

Table 29: Participant Spillover Measure-Level Savings

Spillover-Eligible Measures	n	Annual Estimated Savings (kWh)
Smart thermostat	5	3,473
Insulation	3	2,034
Appliances	6	1,442
HVAC equipment	1	1,286
Ductwork and air sealing	2	1048

A.1.6 Massachusetts Clean Energy Center Rebates

The MassCEC, an economic development agency in the Commonwealth, offers rebates to customers of Eversource, National Grid, Unitil, and some municipal electric utilities for installing air-source heat pumps (ASHPs). A homeowner can receive MassCEC rebates of up to $2,500 for installing ASHPs.[23]

While we did not incorporate outside rebates and incentives into our analysis, we did ask survey respondents if they received rebates or incentives from sources besides Mass Save. For those that did, we directed them to focus only on the Mass Save rebate when answering our survey questions.

One-fifth of DMSHP respondents (21%) confirmed receiving MassCEC rebates for their DMSHPs, and one CHP respondent received a MassCEC rebate for their CHP. Because the MassCEC rebates are so sizeable, the value of the Mass Save rebate could be called into question when participants receive both. However, the average FR rate among MassCEC DMSHP rebate recipients was lower than that of DMSHP recipients who did not receive the MassCEC rebate (0.34 versus 0.42). The evaluation team speculates that FR may be lower for two reasons: (1) participants' pursuit of two rebates may indicate a greater need for financial support, making all financial support vital; and/or (2) respondents disregarded the prompt and could not isolate the importance of the Mass Save rebate from that of the MassCEC rebate.

A.2 EQUIPMENT REPLACEMENT

To understand if participants may have been eligible for Early Replacement rebates, we asked them about the nature of their installations. These tables show the topline results.

Table 30: Participant Survey – Heating Equipment Installations

	Ductless MSHP (n=68)	Central Heat Pump (n=36)	Furnace (n=62)	Boiler (n=60)
ER1. Was the new measure in stalled to do one of the following?				
Replace	15%	56%	92%	95%
Supplement	49%	11%	8%	5%
Neither	37%	33%	-	-
ER2. What type of [heating] equipment did it replace?				
Boiler	1%	-	2%	80%
Furnace	1%	-	87%	25%
Central heat pump	1%	47%	-	-
Other	3%	-	3%	5%
ER3. What type of fuel did your old heating system that you replaced use?				
Oil	1%	-	8%	23%
Natural Gas	1%	-	81%	70%
Electricity	4%	47%	2%	2%
Other	-	-	2%	-

---

[23] See http://www.masscec.com/air-source-heat-pumps for more details.

ER4. What best describes the condition of your old heating system that you replaced?				
Working - no need of repair	-	17%	16%	23%
Working - need minor repair	1%	6%	23%	23%
Working - need major repair	4%	17%	39%	30%
Not working	1%	8%	15%	18%
ER5. Was your old system repairable or was it beyond repair?				
Repairable	-	3%	2%	2%
Beyond repair	1%	6%	13%	17%
ER6. How old do you think your old heating system was?				
11 years or less	1%	-	10%	13%
12 to 19 years	4%	25%	27%	22%
20 to 29 years	-	8%	37%	32%
30 years or older	1%	14%	16%	23%
Don't know	-	-	2%	5%
ER7. How long do you think your old system would have lasted?				
1 year or less	1%	14%	24%	30%
2 to 3 years	3%	19%	32%	15%
4 to 5 years	1%	6%	15%	8%
More than 5 years	6%	3%	8%	25%

Table 31: Participant Survey – Cooling Equipment Installations

	Ductless MSHP (n=68)	Central Heat Pump (n=36)	CAC (n=70)
ER1. Was the new measure installed to do one of the following?			
Replace	15%	56%	59%
Supplement	49%	8%	9%
Neither	37%	33%	33%
ER2. What type of [cooling] equipment did it replace?			
CAC	4%	11%	56%
Central heat pump	1%	47%	-
Other	7%	-	3%
ER8. What best describes the condition of your old cooling system that you replaced?			
Working - no need of repair	6%	19%	23%
Working - need minor repair	1%	6%	13%
Working - need major repair	4%	19%	17%
Not working	1%	11%	6%
ER9. Was your old system repairable or was it beyond repair?			
Repairable	-	-	1%
Beyond repair	1%	11%	4%
ER10. How old do you think your old cooling system was?			
11 years or less	6%	8%	7%

12 to 19 years	4%	22%	13%
20 to 29 years	1%	11%	34%
30 years or older	1%	14%	4%
ER11. How long do you think your old system would have lasted?			
1 year or less	4%	19%	20%
2 to 3 years	3%	14%	20%
4 to 5 years	1%	8%	10%
More than 5 years	3%	3%	4%

Table 32: Participant Survey – Heat Pump Water Heater Installations

	(n=83)
EW0. Did the new heat pump water heater replace an existing water heater?	
Yes	93%
No	7%
EW1. What type of fuel did your old water heater use?	
Oil	13%
Natural Gas	1%
Electricity	75%
Propane	4%
EW1A. What best describes the condition of your old water heater?	
Working w/ no need of repair	35%
Working with need of minor repair	22%
Working with need of major repair	23%
Not working	13%
EW2. Was your old water heater repairable or was it beyond repair?	
Repairable	-
Beyond repair	13%
EW3. How old do you think your old water heater was?	
6 years or less	5%
7 to 11 years	33%
12 to 19 years	35%
20 to 29 years	14%
30 years or older	4%
Don't know	2%
EW4. How long do you think your old water heater would have lasted?	
1 year or less	31%
2 to 3 years	29%
4 to 5 years	8%
More than 5 years	11%

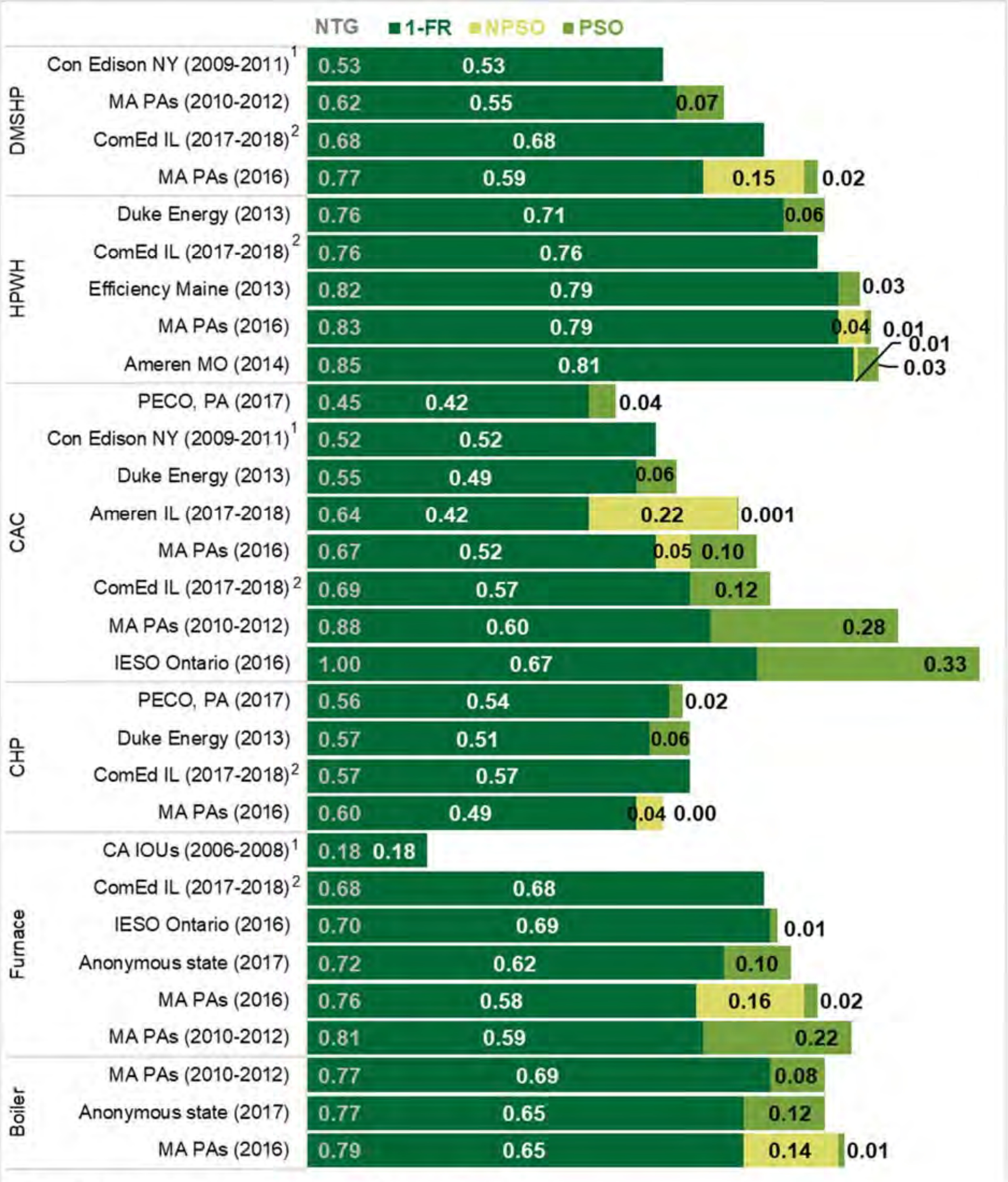
A.3 PRICE SENSITIVITY

Participants (six respondents representing seven measures) who were unaware they received a rebate but confirmed installing measures answered questions about price sensitivity. While the number of respondents who answered is too small to generalize to the population, their responses provide some insight into price sensitivity. Four respondents who installed one measure each speculated that they would have purchased the measure without the rebate if the price were increased by the rebate amount (presented in Section 1.2). These respondents explained that this was because they either were not worried about price or were intent on upgrading to more energy-efficient equipment. Two respondents who installed either one or two measures speculated that they would not have purchased the equipment if the price were increased by the rebate amount. Their reasoning was that they were disappointed with their equipment in retrospect, or had replaced functioning equipment and thus were more price sensitive.

A.4 BENCHMARKING

Figure 17 compares TXC34 NTG recommendations with those from several other jurisdictions. Efficiency levels of equipment covered by programs in these other jurisdictions are generally comparable to that of Mass Save. However, the Consensus Group agreed that other programs may differ substantially in terms of incentive levels and delivery methods. Moreover, NTG estimation methods could differ dramatically. Therefore, they determined that comparing TXC34 results against these was not valuable.

Figure 17: TXC34 NTG Estimates Compared to Other Jurisdictions



[1] The PSO estimate is zero, which is not shown on the graph.

[2] The ComEd IL study only assessed NTG components for CACs. NTG estimates for other equipment were derived from secondary sources.

A.5 HVAC EQUIPMENT STANDARDS

For additional context on the equipment offered through the Mass Save program, we compared the equipment requirements for the Mass Save program to federal standards,[24] ENERGY STAR specifications,[25] and Consortium for Energy Efficiency (CEE) tiers[26] (see Figure 18 and Table 33). In general, we found that equipment offered through the Mass Save program exceeds federal standards and, in most instances, meets or exceeds ENERGY STAR and CEE specifications. In addition to examining current standards and specifications, we investigated the extent to which future changes to efficiency standards may impact the HVAC market. *Our research revealed that there are no imminent changes related to these equipment types.* Below, we summarize our findings related to current standards and specifications for the equipment covered in this study.

- **Central air conditioning:** The program supports CAC systems that meet the minimum requirement of 16 SEER, 13 EER, which is higher than minimum federal requirements and ENERGY STAR specifications for single package units and split systems, and meets the CEE Tier 2 threshold for both types of equipment.
- **Central heat pumps:** The program provides rebates for two minimum levels of efficiency: 16 SEER, 8.5 HSFP and 18 SEER, 9.6 HSPF. These requirements are higher than both the minimum federal standards and ENERGY STAR specifications. The program's 16 SEER central heat pumps exceed the CEE Tier 2 level for single package units and CEE Tier 1 level for split systems. The 18 SEER equipment exceeds the CEE specifications for single package and split systems.
- **Mini-split heat pumps:** The PAs offer rebates for two minimum levels of efficiency: 18 SEER, 9 HSPF and 20 SEER, 11 HSPF. Both of these are more efficient that the federal standard and ENERGY STAR specifications for single package units and split systems. The program's 18 SEER DMSHP surpass the CEE Tier 2 specification for single package units and CEE Tier 2 standard for split systems. The 20 SEER equipment exceeds the CEE specification for single package and split systems.
- **Heat pump water heaters:** The program supports two levels of efficiency: ≤ 55 gallons with an EF ≥ 2.3 and > 55 gallons with an EF ≥ 3.0. Massachusetts' program requirements are higher than federal standards and ENERGY STAR specifications. CEE does not have a specification for heat pump water heaters.
- **Furnaces:** The program offers rebates for two minimum efficiency levels: 95% AFUE and 97% AFUE, which are higher than the federal standard and CEE Tier 0. ENERGY STAR has a minimum specification of 95% AFUE, and CEE has a minimum specification of 95% AFUE for Tier 1 and 97% for Tier 2.

---

[24] US Department of Energy: Office of Energy Efficiency & Renewable Energy – *CFR 430.32 13.0.* https://www.gpo.gov/fdsys/pkg/CFR-2013-title10-vol3/pdf/CFR-2013-title10-vol3-part430-subpartC.pdf.

[25] ENERGY STAR specifications listed by equipment type at: https://www.energystar.gov/products/heating_cooling and https://www.energystar.gov/products/water_heaters/heat_pump_water_heaters.

[26] CEE specifications are available at: https://library.cee1.org/system/files/library/9570/CEE_ResHVAC_CAC_ASHP_Specifications_1January2015.pdf and https://library.cee1.org/system/files/library/12048/CEE_ResHVAC_FurnaceBoilerSpecifications_1August2015.pdf.

- **Boilers:** The program promotes boilers with a minimum efficiency of 90% and 95% AFUE, which is more efficient than the federal standard and CEE Tiers 0 and 1. The ENERGY STAR minimum specification is 90%, and the CEE Tier 2 minimum is 95% AFUE.

Figure 18: Comparison of Equipment Standards

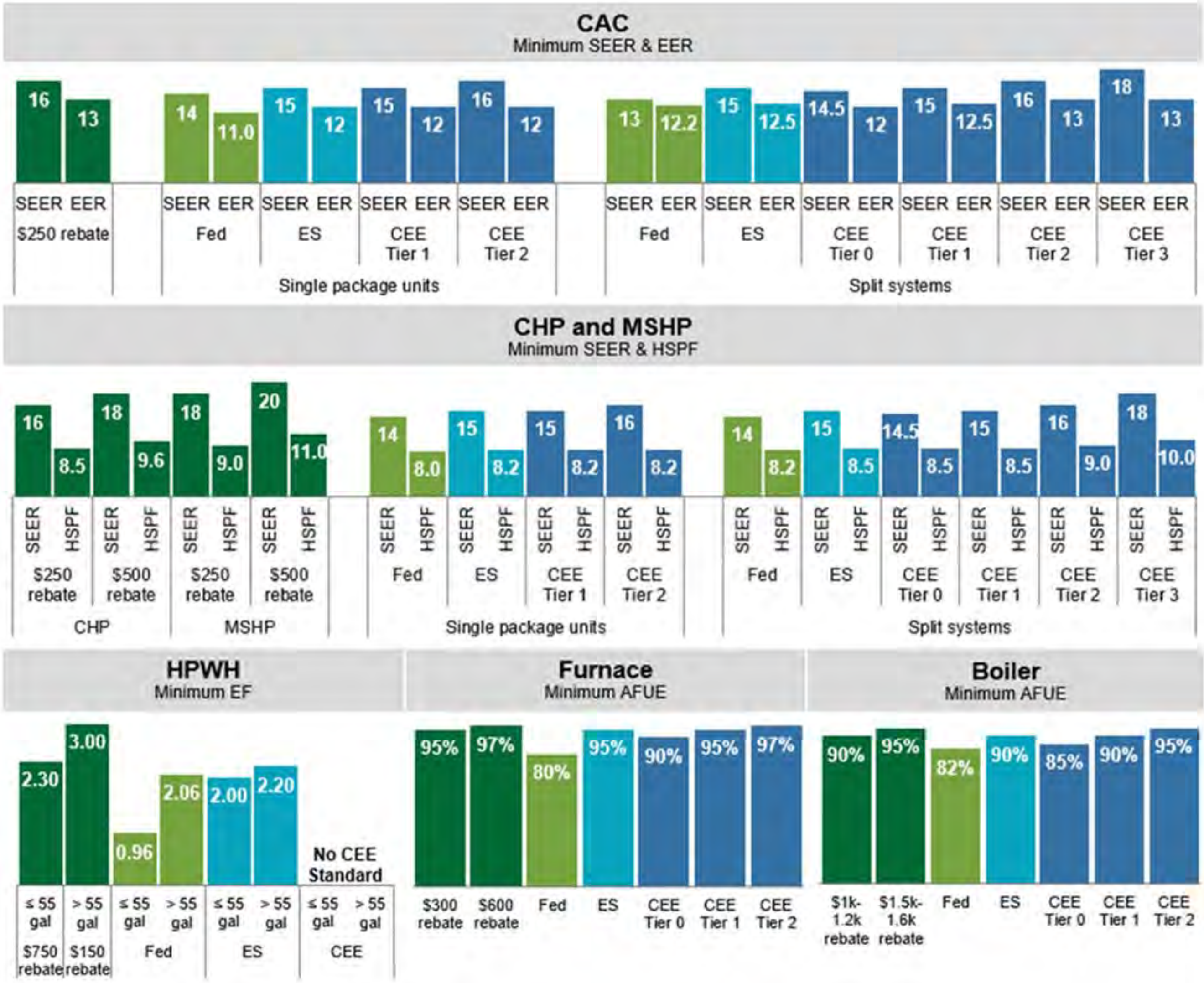


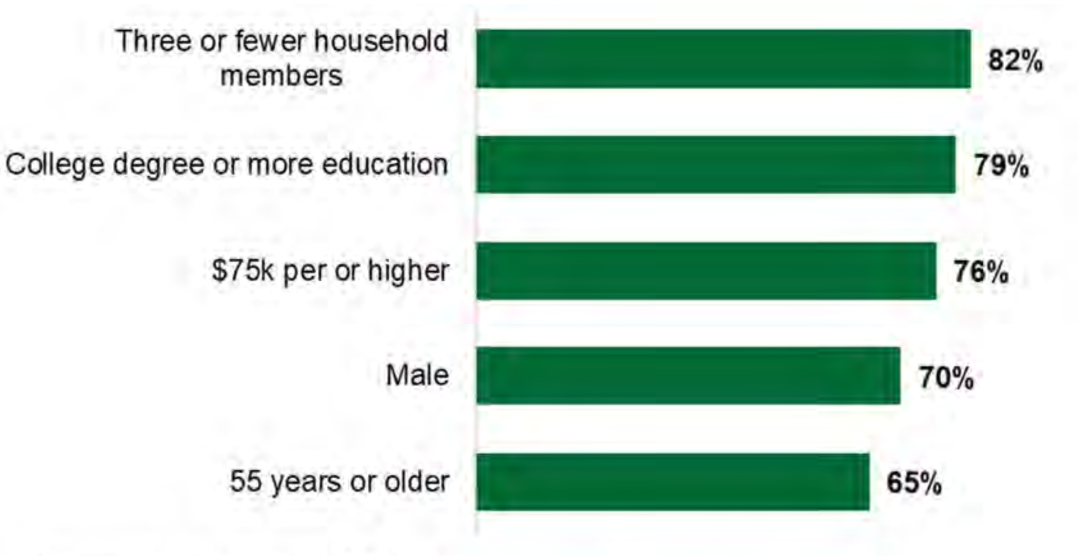
Table 33: Comparison of HVAC Equipment Standards

Program Equipment	MA Program Requirement	Federal Requirement	ENERY STAR Requirement	CEE Requirement
Electric Equipment				
Central air conditioning	SEER ≥ 16, EER ≥ 13	*Single package units:* SEER ≥ 14, EER ≥ 11.0 *Split systems:* SEER ≥ 13, EER ≥ 12.2 (1/1/15)	*Single package units:* SEER ≥ 15, EER ≥ 12.0 *Split systems:* SEER ≥ 15, EER ≥ 12.5 (9/15/15 [v5.0])	*Single package units:* Tier 1: SEER ≥ 15, EER ≥ 12 Tier 2: SEER ≥ 16, EER ≥ 12 *Split systems:* Tier 0: SEER ≥ 14.5, EER ≥ 12 Tier 1: SEER ≥ 15, EER ≥ 12.5 Tier 2: SEER ≥ 16, EER ≥ 13 Tier 3: SEER ≥ 18, EER ≥ 13 (1/1/15) (3/1/14 [Tier 3 split CAC])
Central heat pump	SEER ≥ 16, HSPF ≥ 8.5 SEER ≥ 18, HSPF ≥ 9.6	*Single package units:* SEER ≥ 14, HSPF ≥ 8.0 *Split systems:* SEER ≥ 14, HSPF ≥ 8.2 (1/1/15)	*Single package units:* SEER ≥ 15, HSPF ≥ 8.2 *Split systems:* SEER ≥ 15, HSPF ≥ 8.5 (9/15/15 [v5.0])	*Single package units:* Tier 1: SEER ≥ 15, HSPF ≥ 8.2 Tier 2: SEER ≥ 16, HSPF ≥ 9.2 *Split systems:* Tier 0: SEER ≥ HSPF ≥ 8.5 Tier 1: SEER ≥ 15, HSPF ≥ 8.5 Tier 2: SEER ≥ 16, HSPF ≥ 9.0 Tier 3: SEER ≥ 18, HSPF ≥ 10.0 (1/1/15)
Ductless MSHP	SEER ≥18, HSPF ≥9 SEER ≥20, HSPF ≥11			
Heat pump water heater	≤ 55 gallons: EF ≥ 2.3 > 55 gallons: EF ≥ 3.0	≤ 55 gallons: EF ≥ 0.960 > 55 gallons: EF ≥ 2.057 (4/16/15)	≤ 55 gallons: EF ≥ 2.0 > 55 gallons: EF ≥ 2.20 (4/16/15 [v3.2])	No standard
Gas Equipment				
Furnace	≥ 95% AFUE ≥ 97% AFUE	≥ 80% AFUE (11/19/15)	≥ 95% AFUE, ECM, 2% air leakage (2/1/13 [v4.1])	Tier 1: ≥ 90% AFUE Tier 2: ≥ 95% AFUE Tier 3: ≥ 97% AFUE (6/1/15)
Boiler	≥ 90% AFUE ≥ 95% AFUE	≥ 82% AFUE (1/1/12 – 1/15/21)	≥ 90% AFUE (10/1/14 [v3.0])	Tier 0: ≥ 85% AFUE Tier 1: ≥ 90% AFUE Tier 2: ≥ 95% AFUE (6/1/15)

A.6 PARTICIPANT DEMOGRAPHICS

As illustrated in Figure 19, survey respondents were most often 45 years or older (85%), in relatively small households (2.5 on average), educated (80%), in moderate to high-income households (76%), and male (71%). These demographics may not necessarily represent the average participant; rather, they may represent the type of participant who wished to complete the survey.

Figure 19: Participant Survey Demographics



[1] Average household size = 2.5 members
Percentage bases exclude refusals so sample sizes vary (n=317 or fewer).

B Appendix B Survey Instruments

B.1 PARTICIPANT SURVEY

B.1.1 Sample Variable List

Variable	Format	Notes	Type
PA	String	Eversource, National Grid, etc.	Read-in
PA_CONTACT	String	Contact name at PA	Read-in
MEASURE1	Numeric	First sampled measure 1 – Central heat pump 2 – Central air conditioning system 3 – Heat pump water heater 4 – Mini-split heat pump 5 – Boiler 6 - Furnace	Skips and read-in
MEASURE2	Numeric	Second sampled measure 0 – No second measure 2 – Central air conditioning system 3 – Heat pump water heater 4 – Mini-split heat pump 5 – Boiler 6 - Furnace	Skips and read-in
MEASURE3	Numeric	Third sampled measure 4 – Mini-split heat pump 5 – Boiler 6 - Furnace	Skips and read-in
MEASURE4	Numeric	Fourth sampled measure 4 – Mini-split heat pump	Skips and read-in
QUANTITY1	Numeric	Quantity of first sampled measure	Skips and read-in
QUANTITY2	Numeric	Quantity of second sampled measure	Skips and read-in
REBATE1	Numeric	Rebate amount for first sampled measure	Read-in
REBATE2	Numeric	Rebate amount for second sampled measure	Read-in

[BLUE] = Instructions for programmer

[Green] = Read-in variable

INTRO Thank you for your willingness to complete the survey!

As mentioned in the email or letter you received, we are conducting this survey on behalf of [PA] as part of the group of utilities who sponsor the Mass Save® energy-efficiency program. We would like to learn about your experience participating in the Mass Save® rebate program for new high-efficiency heating, water heating, or cooling equipment. Your feedback is important and will help ensure that the Sponsors of Mass

Save® continue to benefit customers like you throughout the state. This survey will last approximately 10 minutes and your responses are entirely confidential.

If you would like to verify the legitimacy of this research, you can contact [PA_CONTACT]. If you have questions about this survey you can reach our study manager, Nicole Rosenberg, at (617) 284-6230 extension 9 or nrosenberg@nmrgroupinc.com.

Please use the survey's navigational buttons to move between questions. Do not use your browser's "Back" and "Forward" buttons.

B.1.2 Screening

S1. In the last two years, have you received a home energy assessment from Mass Save or your utility company? An energy specialist would have visited your home and provided you with recommendations to improve your home's energy efficiency. They may also have installed free energy saving equipment. (Select one)

1. Yes
2. No
98. Don't know

S1A. [IF S1 = 1] Over the course of this survey, we ask you to think about equipment you appear to have installed and received a rebate for **before or after** the audit—**not** during the audit.

[ASK FOR MEASURE1 THROUGH MEASURE4 – START ROSTER]

S2. Our records show that in 2016 or 2017 you or your HVAC contractor received a rebate from Mass Save® or your utility for a high-efficiency [MEASURE]. Is that correct? (Select one)

1. Yes
2. No
98. Don't know

S3. [ASK IF S2=2 OR 98] In 2016 or 2017, did you install [MEASURE]? (Select one)

1. Yes
2. No
98. Don't know

[END ROSTER]

TERM1. [IF S2R1, S3R1, S2R2, S3R2 all <>1] Thank you for your willingness to complete this survey. Unfortunately, we are only conducting this survey with participants who are able to confirm installing the equipment. [TERMINATE]

S4. Are you the person in your household who is most familiar with the decision making that went into purchasing the equipment? (Select one)

1. Yes
2. No

S4A. [IF S4 = 2, READ] Is the person most familiar with the decision making that went into purchasing the equipment available to complete this survey at this time? If so, we will return to the first question. (Select one)

1. Yes, that person is available [SKIP TO INTRO]
2. No, that person is not available

S4B. [IF S4A = 2, READ] What is that person's email address? We will invite them to respond to this survey instead.

1. [OPEN END]
2. Would rather not provide/Don't know

S4C. [IF S4B = 2, READ] Would you be willing to forward them the link we provided to you to complete this survey?

1. Yes
2. No

TERM3. [IF S4B=2 AND S4C=2] Thank you for your time. Have a good day. [TERMINATE]

TERM2. [IF S4A OR S4B = 2] On behalf of the Sponsors of Mass Save, we thank you for your willingness to complete this survey. Have a great day. PRESS NEXT TO RESTART SURVEY

AWARE. [IF (S2R1=2 OR S2R1=98) AND (S2R2=2 OR S2R2=98), COMPUTE AWARE=0; ELSE AWARE=1]

[IF AWARE=0, SKIP TO ER1]

[ASK FOR MEASURE1 AND MEASURE2 – START ROSTER]

S5. [SKIP IF INSTALL=1] Our records show that you installed [QUANTITY] [MEASURE](s) that received a rebate from Mass Save® or your utility. Is that correct? (Select one)

1. Yes
2. No

S6. [ASK IF S5 = 2] How many [MEASURE]s did you install? [OPEN END NUMERIC]

[IF S5=2, COMPUTE QUANTITY=S5]

[END ROSTER]

B.1.3 Introduction

IN1. How did you learn about the Mass Save® or utility rebates for high-efficiency heating, water heating, and cooling equipment? (Select all that apply) [ALLOW MULTIPLE RESPONSES]

1. Mass Save® television, radio, or print advertisements
2. [PA] advertising (bill inserts, mailers)
3. Word of mouth (friend, neighbor, or coworker)
4. The contractor who installed the equipment
5. The retailer who sold you the equipment
6. Other [SPECIFY]
7. Don't recall

IN2. Other than the rebate(s) you received from Mass Save® or your utility, which of the following rebates or incentives did you receive for your new heating, water heating, or cooling equipment? (Please select all that apply) [ALLOW MULTIPLE RESPONSES]

1. No other rebates received
2. Tax credits
3. Massachusetts Clean Energy Center (CEC) Rebates
4. Other rebates or incentives [SPECIFY]

IN2A. [IF IN2 = 2, 3, or 4, READ] For the remainder of this survey, when we refer to "the rebate," we are referring ONLY to the rebate you or your contractor received from Mass Save® or your utility company for your new high-efficiency heating, water heating, or cooling equipment. [CONTINUE]

B.1.4 Early Replacement – Heating and Cooling

[ASK FOR MEASURE1 AND MEASURE2 – START ROSTER]

[IF MEASURE=3 (Heat Pump Water Heater), SKIP TO NEXT MODULE/MEASURE]

ER1. Was the new [MEASURE] installed to do one of the following? (Select one)

1. Replace existing equipment
2. Supplement a primary heating or cooling system
3. Serve as the primary equipment to heat or cool my home [SKIP TO NEXT MODULE/MEASURE]

ER2. [ASK IF ER1 = 1] What type of equipment did it replace? (Select all that apply) [ALLOW MULTIPLE RESPONSES]

[HIDE CATEGORY 4, 5, AND 6 IF MEASURE = 5 OR 6 (Boiler or Furnace); HIDE CATEGORIES 1 - 3 IF MEASURE = 2 (Central AC)]

1. Boiler
2. Furnace
3. Another type of heating system
4. Central air conditioning system
5. Central heat pump
6. Another type of cooling system (e.g., window or room A/C units)

ER2S. [ASK IF ER1 = 2] What equipment is **primarily** used to condition the space? (Select all that apply) [ALLOW MULTIPLE RESPONSES]

[HIDE CATEGORIES 4, 5, 6 IF MEASURE = 5 OR 6 (Boiler or Furnace); HIDE CATEGORIES 1, 2 3 IF MEASURE = 2 (Central AC)]

1. Boiler
2. Furnace
3. Another type of heating system
4. Central air conditioning system
5. Central heat pump
6. Another type of cooling system (e.g., window or room A/C units)

[END ROSTER]

HEAT [IF ER2R1 or ER2R2 = 1, 2, 3, OR 5, COMPUTE HEAT = 1; ELSE HEAT=0]

COOL [IF ER2R1 or ER2R2 = 4, 5, OR 6, COMPUTE COOL = 1; ELSE COOL=0]

S_HEAT [IF ER2SR1 or ER2SR2 = 1, 2, 3, OR 5, COMPUTE S_HEAT = 1; ELSE S_HEAT=0]

S_COOL [IF ER2SR1 or ER2SR2 = 4, 5, OR 6, COMPUTE S_COOL = 1; ELSE S_COOL=0]

ER3. [ASK IF ER2R1 OR ER2R2 = 1, 2, OR 3] What type(s) of fuel did your old heating system that you replaced use? (Select all that apply) [ALLOW MULTIPLE RESPONSES]

1. Oil
2. Natural Gas
3. Electricity
4. Propane
5. Kerosene
6. Pellets
7. Wood
8. Solar
9. Other

ER4. [ASK IF HEAT = 1] Which of the following best describes the condition of your old **heating** system that you replaced? (Select one)

1. Working with no need of repair
2. Working with need of minor repair
3. Working with need of major repair
4. Not working at all

ER5. [ASK IF ER4 = 4] Was your old **heating** system repairable or was it beyond repair? (Select one)

1. Repairable
2. Beyond repair

ER6. [ASK IF HEAT = 1] How old do you think your old **heating** system was? (Select one)

1. 11 years or less
2. 12 to 19 years
3. 20 to 29 years
4. 30 years or older

98. Don’t know

ER7. [SKIP IF ER5 = 2 OR HEAT = 0] How long do you think your old **heating** system would have lasted if you had not replaced it with the new equipment? (Select one)

1. 1 year or less
2. 2 to 3 years
3. 4 to 5 years
4. More than 5 years

ER8. [ASK IF COOL = 1] Which of the following best describes the condition of your old **cooling** system that you replaced? (Select one)

1. Working with no need of repair
2. Working with need of minor repair
3. Working with need of major repair
4. Not working at all

ER9. [ASK IF ER8 = 4] Was your old **cooling** system repairable or was it beyond repair? (Select one)

1. Repairable
2. Beyond repair

ER10. [ASK IF COOL = 1] How old do you think your old **cooling** system was? (Select one)

1. 11 years or less
2. 12 to 19 years
3. 20 to 29 years
4. 30 years or older
98. Don't know

ER11. [SKIP IF ER9 = 2 OR COOL = 0] How long do you think your old **cooling** system would have lasted if you had not replaced it with the new equipment? (Select one)

1. 1 year or less
2. 2 to 3 years
3. 4 to 5 years
4. More than 5 years

ER3S. [ASK IF ER2SR1 OR ER2SR2 = 1, 2, OR 3] What type(s) of fuel does your primary heating system use? (Select all that apply) [ALLOW MULTIPLE RESPONSES]

1. Oil
2. Natural Gas
3. Electricity
4. Propane
5. Kerosene
6. Pellets
7. Wood
8. Solar
9. Other

ER4S. [ASK IF S_HEAT = 1] Which of the following best describes the condition of your primary **heating** system? (Select one)

1. Working with no need of repair
2. Working with need of minor repair
3. Working with need of major repair
4. Not working at all

ER5S. [ASK IF S_HEAT = 1] How old do you think your primary **heating** system is? (Select one)

1. 11 years or less
2. 12 to 19 years
3. 20 to 29 years
4. 30 years or older
98. Don't know

ER6S. [ASK IF S_COOL = 1] Which of the following best describes the condition of your primary **cooling** system? (Select one)

1. Working with no need of repair
2. Working with need of minor repair
3. Working with need of major repair
4. Not working at all

ER7S. [ASK IF S_COOL = 1] How old do you think your primary **cooling** system is? (Select one)

1. 11 years or less
2. 12 to 19 years
3. 20 to 29 years
4. 30 years or older
98. Don't know

B.1.5 Early Replacement – Water Heater

[ASK IF MEASURE1 OR MEASURE2 = 3 (Heat Pump Water Heater)]

EW0. Did the new heat pump water heater you installed replace an existing water heater? (Select one)

1. Yes
2. No [SKIP TO FR1]

EW1. What type of fuel did your old water heater use?

1. Oil
2. Natural Gas
3. Electricity
4. Propane
5. Kerosene
6. Pellets
7. Wood
8. Solar
9. Other

EW1A. Which of the following best describes the condition of your old water heater? (Select one)

1. Working with no need of repair
2. Working with need of minor repair
3. Working with need of major repair
4. Not working at all

EW2. [ASK IF EW1A = 4] Was your old water heater repairable or was it beyond repair? (Select one)

1. Repairable
2. Beyond repair

EW3. How old do you think your old water heater was? (Select one)

1. 6 years or less
2. 7 to 11 years
2. 12 to 19 years
3. 20 to 29 years
4. 30 years or older
98. Don’t know

EW4. [SKIP IF EW2 = 2] How long do you think your old water heater would have lasted if you had not replaced it with the new heat pump water heater? (Select one)

1. 1 year or less
2. 2 to 3 years
3. 4 to 5 years
4. More than 5 years

B.1.6 Free-Ridership

[IF AWARE = 0, SKIP TO C1]

[ASK FOR MEASURE1 AND MEASURE2 – START ROSTER]

[IF INSTALL=1, SKIP TO NEXT MODULE/MEASURE]

FR1. On a scale of 0 to 10, where 0 is “definitely would NOT have installed it” and 10 is “definitely WOULD have installed it,” what is the likelihood that you would have installed the **same high-efficiency** [MEASURE] without the Mass Save® or utility rebate? (Select one) [ALLOW RESPONSES FROM 0 TO 10]

FR2. [ASK IF FR1 > 0] If you had not received the Mass Save® or utility rebate, would you have installed the **same high-efficiency** [MEASURE] at the *same* time, a *different* time, or *not at all*? (Select one)

1. Same time
2. Different time
3. Not at all

FR3. [ASK IF FR2 = 2] Without the rebate, **when** would you have installed the same high-efficiency [MEASURE]? (Select one)

1. At the same time
2. Sooner
3. Within 6 months
4. Six to 12 months later
5. More than 12 months later

FR4. [ASK IF QUANTITY > 1] Without the rebate, would you have installed the same number of high-efficiency [MEASURE]s that you did? (Select one)

1. Yes
2. No

FR5. [ASK IF FR4 = 2] Without the rebate, how many high-efficiency [MEASURE]s would you have installed? (Record whole number) [OPEN END NUMERIC]

FR6. On a scale of 0 to 10, where 0 is “not at all influential” and 10 is “very influential,” how influential were the following on your decision to install the high-efficiency [MEASURE]? (Select one for each) [FOR EACH, ALLOW RESPONSES FROM 0 TO 10; INCLUDE 96 “Not applicable” OPTION FOR b AND c]

a. The Mass Save® or utility rebate
b. Salesperson or contractor recommendations [IF S1 = 1]. Only think of the company who installed [MEASURE], not the auditor you interacted with during your home energy assessment.
c. Mass Save® or utility marketing materials (advertising, mailers)

FR7. [ASK IF ((FR6a < 3 or FR6c < 3) AND FR1 < 3) OR ((FR6a > 7 or (FR6c > 7 and FR6c<>96)) AND FR1 > 7); **ELSE SKIP TO NEXT MODULE/MEASURE**] Some of your answers (shown below) appear inconsistent with respect to the rebate’s importance in your decision to install the [MEASURE]. Do you want to change your responses to one or both questions? Enter your final answers below.

		Your response	Revised response [ALLOW 0 TO 10 RESPONSES]
FR7a2	On a scale of 0 to 10, where 0 is “definitely would NOT have installed it” and 10 is “definitely WOULD have installed it” **without the Mass Save® or utility rebate**, what is the likelihood that you would have still installed the same high-efficiency [MEASURE]?	[FR1]	
FR7b2	On a scale of 0 to 10, where 0 is “not at all influential” and 10 is “very influential,” how influential was the Mass Save® or utility rebate on your decision to install the high-efficiency [MEASURE]?	[FR6a]	

FR8. [READ IF FR7b < 3 AND FR7a < 3] You say that, without the Mass Save® or utility rebate, you would have been unlikely to install the [MEASURE], but at the same time you say that the rebate was not influential in your decision to install it.

[READ IF FR7b > 7 AND FR7a > 7] You say that, without the Mass Save® or utility rebate, you would have been likely to install the [MEASURE], but at the same time you say that the rebate was influential in your decision to install it.

[READ FOR ALL] Could you explain how the rebate played into your decision? [OPEN END]

[END ROSTER]

B.1.7 Contractor Influence

[ASK FOR MEASURE1 AND MEASURE2 – START ROSTER]

C1. Before speaking with your contractor, had you already been considering high-efficiency options for the [MEASURE]? By "high-efficiency," we mean [MEASURE]s that use considerably less energy than the typical, standard efficiency [MEASURE]s that are available. (Select one)

1. Yes
2. No
98. Don't remember

C2. Which of the following *best* describes how you ultimately selected the new [MEASURE]? (Select one) [ALLOW ONE RESPONSE; RANDOMLY ROTATE 1 THROUGH 3]

1. I did some research on [MEASURE]s and made my own choice
2. My contractor suggested one [MEASURE] model, and I agreed
3. My contractor suggested various [MEASURE] models, and I chose one
4. Something else [SPECIFY]

[IF AWARE = 1, SKIP TO NEXT MODULE/MEASURE]

C3. [ASK IF C2 = 3] About how many [MEASURE] models did the contractor offer you? [OPEN END NUMERIC]

C4. Did your [MEASURE] contractor emphasize the benefits of high-efficiency equipment?

1. Yes
2. No

C5. On a scale of 0 to 10, where 0 is "not at all influential" and 10 is "very influential," how influential was the following on your decision to install the high-efficiency [MEASURE] that you did? (Select one for each) [FOR EACH, ALLOW RESPONSES FROM 0 TO 10; INCLUDE 96 "Not applicable"]

a. Materials, such as brochures, that you received from the contractor
b. Salesperson or contractor's recommendations

C6. How did the contractor influence your purchase decision? [OPEN END]

[END ROSTER]

B.1.8 Price Sensitivity

[IF AWARE = 1, SKIP TO SO1]

[ASK FOR MEASURE1 AND MEASURE2 – START ROSTER]

PR1. **Approximately** how much did the [MEASURE](s) cost in dollars, including installation?

[OPEN END NUMERIC]

98. Don't know

PR2. Would you have purchased the exact same high-efficiency [MEASURE] if the price was $[REBATE] higher? If you installed more than one [MEASURE], assume this price increase is for each one you installed.

1. Yes
2. No

PR3. Why do you say that? [OPEN END]

[END ROSTER]

B.1.9 Spillover

[IF AWARE = 0, SKIP TO D1]

SO1. Since installing the equipment, have you made other energy-saving purchases or changes that did **not** receive an incentive or rebate from Mass Save® or your utility? (Select one)

1. Yes
2. No [SKIP TO FR6d]

SO2. Did your experience with the Mass Save® or utility rebate program influence your decision to take any of these energy-saving actions? (Select one)

1. Yes
2. No [SKIP TO FR6d]

SO3. What energy-saving purchases or changes did you make? (Select all that apply) [ALLOW MULTIPLE RESPONSES]

1. Energy-efficient light bulbs
2. Energy-efficient appliance(s) [SPECIFY]
3. Attic, wall, or basement insulation
4. Duct sealing or duct insulation
5. Air sealing of leaks
6 Smart thermostat
7. Other purchases or changes [OPEN END]

SO3a. [ASK IF SO3 = 2] Were any of the appliances ENERGY STAR-labeled? (Select one)

1. Yes
2. No
3. Don't know

[ASK FOR EACH MEASURE SELECTED IN SO3 – START ROSTER]

SO3b. [ASK IF SO3 = 3, 4, 5, 7] Can you describe the [SO3] work in more detail? If applicable, include the quantity installed, the type of equipment, and the efficiency levels installed? [OPEN END]

SO4. On a scale of 0 to 10, where 0 is "not at all important" and 10 is "very important," how important was your experience with the Mass Save® or utility rebate program on your decision to [INSERT TEXT BELOW], which did not receive a rebate?

[ALLOW RESPONSES FROM 0 TO 10]

[IF SO3 = 1] purchase energy-efficient light bulbs
[IF SO3 = 2] purchase energy-efficient appliance(s)
[IF SO3 = 3] install attic, wall, or basement insulation
[IF SO3 = 4] install duct sealing or duct insulation
[IF SO3 = 5] seal air leaks
[IF SO3 = 6] purchase a smart thermostat
[IF SO3 = 7] purchase/install [SO3 OPEN END RESPONSE]

SO5. On a scale of 0 to 10, where 0 is "definitely would NOT have made the improvements" and 10 is "definitely WOULD have made the improvements," had you *not* received a rebate for the [MEASURE1] [IF MEASURE2>0, SHOW: "and MEASURE2]"], what is the likelihood that you would still have [INSERT TEXT BELOW]?

[ALLOW RESPONSES FROM 0 TO 10]

[IF SO3 = 1] purchased energy-efficient light bulbs
[IF SO3 = 2] purchased energy-efficient appliance(s)
[IF SO3 = 3] installed attic, wall, or basement insulation
[IF SO3 = 4] installed duct sealing or duct insulation
[IF SO3 = 5] sealed air leaks
[IF SO3 = 6] purchased a smart thermostat
[IF SO3 = 7] purchased/installed [SO3 OPEN END RESPONSE]

SO6. [ASK IF ANY SO4 > 7 OR SO5 < 3] How did the rebate(s) for the [MEASURE1] [IF APPLICABLE: "and MEASURE2]"] influence your decision to [INSERT TEXT BELOW]?

[ALLOW OPEN ENDED RESPONSES]

[IF SO3 = 1] Purchase energy-efficient light bulbs
[IF SO3 = 2] Purchase energy-efficient appliance(s)
[IF SO3 = 3] Installed attic, wall, or basement insulation
[IF SO3 = 4] Installed duct sealing or duct insulation
[IF SO3 = 5] Sealed air leaks
[IF SO3 = 6] Purchase a Smart thermostat
[IF SO3 = 7] Purchase/install [SO3 OPEN END RESPONSE]

FR6d. [ASK IF S1 = 1] Shifting gears, think back to the home energy assessment you received. On a scale of 0 to 10, where 0 is "not at all influential" and 10 is "very influential," how influential was the auditor who performed your home energy assessment on your decision to install the high-efficiency [MEASURE]? [ALLOW RESPONSES FROM 0 TO 10; and INCLUDE 96 "Not applicable"]

[END ROSTER]

B.1.10 Demographics

TEXT1. You're nearly done. We have some questions for statistical purposes about you and your household. Your responses are strictly confidential.

D1. Including yourself, how many people live in your home most of the year?

[OPEN END NUMERIC]
98. Would rather not answer

D2. What is the highest level of education that you have completed? (Select one)

1. Less than high school
2. High school graduate
3. Technical or trade school graduate
4. Some college
5. College graduate
6. Some graduate school
7. Graduate degree
98. Would rather not answer

D3. Which of the following category best describes your age? (Select one)

1. 18 to 24
2. 25 to 34
3. 35 to 44
4. 45 to 54
5. 55 to 64
6. 65 or over
98. Would rather not answer

D4. What category best describes your total household income in 2016, before taxes? (Select one)

1. Less than $35,000
2. $35,000 to $49,999
3. $50,000 to $74,999
4. $75,000 to $99,999
5. $100,000 to $149,999
6. $150,000 to $199,999
7. $200,000 or more
98. Would rather not answer

➢ D5. Which of the following best describes you? (Select one)

1. Male
2. Female
3. Other
98. Would rather not answer

Those are all the questions we have. On behalf of the utilities that sponsor the Mass Save® rebate program, thank you for completing our survey.

B.2 CONTRACTOR SURVEY

[BLUE] = Instructions for programmer

[Green] = Read-in variable

B.2.1 Introduction

Thank you for agreeing to take part in this survey!

As mentioned in the email you received, we are conducting this survey on behalf of the utilities and energy efficiency service providers that sponsor Mass Save®. We would like to learn about your experiences with the Mass Save rebate program for high-efficiency heating, water heating, and cooling equipment. Your feedback will help make sure that the Sponsors of Mass Save continue to benefit customers and contractors such as yourself. If you are eligible for the survey and complete it, we will send you a $50 Amazon gift card or check or donate $50 to one of these charities: Hurricane Relief Fund, Big Brothers Big Sisters of Massachusetts Bay, or the Berkshire Humane Society. Our questions should take less than 25 minutes of your time and your answers will be kept confidential.

[IF PHONE, SHOW "IF NEEDED:"] Questions about the legitimacy of this research? Contact Chris Chan, Eversource, at (781) 441-8544 or christopher.chan@eversource.com or study manager Nicole Rosenberg at (617) 284-6230 x9.

[IF WEB, LINK A POP UP TO FIRST MENTION OF MASS SAVE: "Mass Save® is a collaborative of Massachusetts' natural gas and electric utilities and energy efficiency service providers including Berkshire Gas, Blackstone Gas, Cape Light Compact JPE, Columbia Gas of Massachusetts, Eversource, Liberty Utilities, National Grid, and Unitil. They empower residents, businesses, and communities to make energy-efficient upgrades by offering a wide range of services, rebates, incentives, trainings, and information."]

[IF PHONE] IF SAYS JUST RESPONDED TO ANOTHER SURVEY: The sponsors of Mass Save are conducting two surveys. *This* survey is about how the Mass Save rebates affect the decisions that you and your customers make. The *other* survey is about the costs to purchase and install certain types of residential water heating and cooling equipment. We really appreciate your answering both surveys, and we hope you can take a little time today to answer these questions too.

B.2.2 Screening

S1. Let's first make sure that you are eligible to complete the survey. Does your company install residential heating, water heating, and cooling equipment in single-family homes in Massachusetts? [IF RESPONSE CATEGORIES ARE IN PARENTHESES, EXCLUDE FROM WEB SURVEY; DON'T KNOW/REFUSED SHOULD NEVER BE READ ALOUD ON PHONE]

1. Yes
2. No
98. Don't know
99. (Refused)

[IF S1 < > 1] Unfortunately, you are not eligible to complete this survey. Thank you for your time. [TERMINATE]

S1a. Are you familiar with your company's installation of high-efficiency heating, water heating, and cooling equipment for which customers received rebates from the Sponsors of Mass Save?

1. Yes
2. No
98. Don't know
99. (Refused)

[IF S1a < > 1, READ] Would you be able to refer us to a colleague who is familiar with your participation in these programs and can respond to this survey? [WILL WORK WITH SURVEY PROGRAMMERS ON BEST FOLLOW-UP APPROACH FOR EACH MODE TO OBTAIN CONTACT INFORMATION]

S1b. [WEB ONLY; SKIP AFTER REACHING P77 QUOTA (n=20)] Does your company install either of the following types of equipment in commercial or industrial buildings in Massachusetts?

a. Small commercial water heaters, including tankless or tank-style residential-style units

b. Large commercial water heaters, such as dedicated domestic hot water boilers and combined heating/DHW boilers

[FOR EACH]

1. Yes
2. No
98. Don't know
99. (Refused)

S1bb. [ASK IF S1b_a OR S1b_b = 1] Would you be willing to answer additional questions about your company's installations of commercial water heaters at the end of this survey, for an additional $30 gift card?

1. Yes
2. No
99. (Refused)

[COMPUTE P77 = 0; IF S1bb = 1, THEN P77 = 1]

S2_TEXT. The Sponsors of Mass Save offer two levels of rebates to encourage residential customers to replace less efficient heating and cooling equipment with high-efficiency equipment: **Early-Replacement** and **Standard**. Early Replacement rebates are offered for functioning furnaces, central air conditioning systems, and central heat pumps that are 12 or more years old, or functioning boilers that are 30 or more years old; and are expected to function and operate for the foreseeable future. Early Replacement rebates are about two and a half times as much as Standard rebates.

S2INTRO. [ASK IF STANDARD = 1 AND ER = 1] Our records indicate in 2016 your company installed equipment for which both Standard and Early Replacement rebates were claimed. To your knowledge, is that correct?

1. Yes, both Standard and Early Replacement rebates
2. No, just Standard rebates
3. No, just Early Replacement rebates
98. Don’t know
99. (Refused)

S2INTROa. [ASK IF STANDARD = 1 AND ER = 0] Our records indicate in 2016 your company installed equipment for **Standard** rebates were claimed, but not for Early Replacement rebates. To your knowledge, is that correct?

1. Yes, just Standard rebates
2. No, just Early Replacement rebates
3. No, both Standard and Early Replacement rebates
98. Don’t know
99. (Refused)

S2INTROb. [ASK IF STANDARD = 0 AND ER = 1] Our records indicate in 2016 your company installed equipment for which Early Replacement rebates were claimed, but not for Standard rebates. To your knowledge, is that correct?

1. Yes, just Early Replacement rebates
2. No, just Standard rebates
3. No, both Standard and Early Replacement rebates
98. Don’t know
99. (Refused)

[IF S2INTRO, S2INTROa, OR S2INTROb = 98 OR 99, READ] Is there a colleague of yours who is familiar with your company’s installation of rebated equipment who can respond to this survey? [WILL WORK WITH SURVEY PROGRAMMERS ON BEST FOLLOW-UP APPROACH FOR EACH MODE TO OBTAIN CONTACT INFORMATION]

[**COMPUTE V_STANDARD = STANDARD AND V_ER = ER**:
IF S2INTRO = 2, V_STANDARD = 1 AND V_ER = 0;
IF S2INTRO = 3, V_STANDARD = 0 AND V_ER = 1;
IF S2INTROa = 2, V_STANDARD = 0 AND V_ER = 1;
IF S2INTROa = 3, V_STANDARD = 1 AND V_ER = 1;
IF S2INTROb = 2, V_STANDARD = 1 AND V_ER = 0;
IF S2INTROb = 3, V_STANDARD = 1 AND V_ER = 1]

[IF V_STANDARD < > 1, SKIP TO S5]

S2. [IF V_ER = 1, INCLUDE "First, we will ask you to think about the types of residential equipment you installed that received **Standard** rebates through the Mass Save program."]

Our records show that in 2016 your company installed the following types of residential equipment for which you or your customers received **Standard** (not Early Replacement) rebates from Mass Save. Is that correct? If your company is a large retailer, only think of the installations that your store or location's installers perform. [SINGLE SCREEN]

a. [ASK IF S_MSHP = 1] Ductless mini-split heat pumps
b. [ASK IF S_HPWH = 1] Heat pump water heaters
c. [ASK IF S_CAC = 1] Central air conditioning systems
d. [ASK IF S_FURN = 1] Gas furnaces
e. [ASK IF S_BOIL = 1] Gas boilers
f. [ASK IF S_CHP = 1] Central heat pumps

[FOR EACH]
1. Yes
2. No
98. Don't know
99. (Refused)

[COMPUTE VERIFIED MEASURE VARIABLES, SERIES "VS_XX." STARTING VALUES FOR ALL THE VARIABLES IN THE VS_XX SERIES (VS_MSHP, VS_HPWH, VS_CAC, VS_FURN, VS_BOIL, VS_CHP) IS 0. RECODE VS_XX SERIES VARIABLES AS FOLLOWS:]

COMPUTE	EQUALS
VS_MSHP	0
VS_HPWH	0
VS_CAC	0
VS_FURN	0
VS_BOIL	0
VS_CHP	0

IF	THEN
S2a = 1	VS_MSHP = 1
S2b = 1	VS_HPWH = 1
S2c = 1	VS_CAC = 1
S2d = 1	VS_FURN = 1
S2e = 1	VS_BOIL = 1
S2f = 1	VS_CHP = 1

[IF ALL S2 < > 1 AND V_ER < > 1] Unfortunately, you are not eligible to complete this survey. Thank you for your time. [TERMINATE]

S3. Our records show that in 2016 your company installed the following quantities of residential equipment that received **Standard** rebates from Mass Save. Does this sound right? [SINGLE SCREEN]

a. [ASK IF VS_MSHP = 1] [SQTY_MSHP] Outdoor ductless mini-split heat pump systems
b. [ASK IF VS_HPWH = 1] [SQTY_HPWH] Heat pump water heaters
c. [ASK IF VS_CAC = 1] [SQTY_CAC] Central air conditioning systems
d. [ASK IF VS_FURN = 1] [SQTY_FURN] Gas furnaces
e. [ASK IF VS_BOIL = 1] [SQTY_BOIL] Gas boilers
f. [ASK IF VS_CHP = 1] [SQTY_CHP] Central heat pumps

[FOR EACH]
1. Yes
2. No
98. Don't know
99. (Refused)

S4. [ASK FOR EACH WHERE S3 > 1] About how many residential [MEASURE] that received **Standard** rebates from Mass Save did your company install in 2016?

[PHONE ONLY: "IF NEEDED:"] We'll need a rough estimate to continue the survey.

[OPEN END NUMERIC]
9998. Don't know
. (Refused)

[COMPUTE VERIFIED STANDARD QUANTITY VARIABLES, "VSQTY_X" SERIES. STARTING VALUES FOR ALL THE VARIABLES IN THE SERIES SHOULD EQUAL THE VALUES FOR THE SQTY_XX SERIES, AS SHOWN IN THE FIRST TABLE BELOW]

COMPUTE	EQUALS
VSQTY_MSHP	SQTY_MSHP
VSQTY_HPWH	SQTY_HPWH
VSQTY_CAC	SQTY_CAC
VSQTY_FURN	SQTY_FURN
VSQTY_BOIL	SQTY_BOIL
VSQTY_CHP	SQTY_CHP

IF	THEN
S3A < > 1	VSQTY_MSHP = S4A
S3B < > 1	VSQTY_HPWH = S4B
S3C < > 1	VSQTY_CAC = S4C
S3D < > 1	VSQTY_FURN = S4D
S3E < > 1	VSQTY_BOIL = S4E
S3F < > 1	VSQTY_CHP = S4F

IF	OR	THEN
S4A = 9998 or 9999	S2A < > 1	VSQTY_MSHP = 0
S4B = 9998 or 9999	S2B < > 1	VSQTY_HPWH = 0
S4C = 9998 or 9999	S2C < > 1	VSQTY_CAC = 0
S4D = 9998 or 9999	S2D < > 1	VSQTY_FURN = 0
S4E = 9998 or 9999	S2E < > 1	VSQTY_BOIL = 0
S4F = 9998 or 9999	S2F < > 1	VSQTY_CHP = 0

[COMPUTE **S_MEASURE_1 AND S_MEASURE_2 VARIABLES**: RANDOMLY SELECT UP TO TWO MEASURES AND ASSIGN THEM WHERE THEY SATISFY THE REQUIREMENTS IN COLUMN 1 AND IN THE ORDER DEFINED IN COLUMN 3 IN THE TABLE BELOW] (as an example, a respondent installs central heat pumps, boilers, and furnaces only, we would assign s_measure_1 as *central heat pumps* and s_measure_2 as *furnaces*; we would not assign *boilers* to that respondent unless the other strata are full)

IF	S_MEASURE_1 OR S_MEASURE_2 =	PRIORITY
VSQTY_MSHP > 0	outdoor ductless mini-split heat pump systems	5
VSQTY_HPWH > 0	heat pump water heaters	4
VSQTY_CAC > 0	central air conditioning systems	2
VSQTY_FURN > 0	gas furnaces	3
VSQTY_BOIL > 0	gas boilers	6
VSQTY_CHP > 0	central heat pumps	1

[IF V_ER < > 1 AND ALL VSQTY_XX = 0, SKIP TO TERM4]

S5. [IF V_ER = 1, INCLUDE "Next, we'll ask you to think about the types of residential equipment you installed that received **Early Replacement** rebates through the Mass Save program [SINGLE SCREEN]."]

Our records show that in 2016 your company installed the following types of residential equipment for which you or your customers received **Early Replacement** rebates from Mass Save. Is that correct? If your company is a large retailer, only think of the installations that your store or location's installers perform.

a. [ASK IF ER_CAC = 1] Central air conditioning systems
b. [ASK IF ER_FURN = 1] Furnaces
c. [ASK IF ER_BOIL = 1] Boilers
d. [ASK IF ER_CHP = 1] Central heat pumps

[FOR EACH]

1. Yes
2. No
98. Don't know
99. (Refused)

[COMPUTE VERIFIED MEASURE VARIABLES, "VER_XX" SERIES]

COMPUTE	EQUALS
VER_CAC	0
VER_FURN	0
VER_BOIL	0
VER_CHP	0

IF	THEN
S5a = 1	VER_CAC = 1
S5b = 1	VER_FURN = 1
S5c = 1	VER_BOIL = 1
S5d = 1	VER_CHP = 1

[IF ALL S5 < > 1 AND V_STANDARD = 0] Unfortunately, you are not eligible to complete this survey. Thank you for your time. [TERMINATE]

9999. (Refused)

B.2.3 Standard Free-Ridership (TXC34)

[IF V_STANDARD = 0, SKIP MODULE]

FRINTRO. [READ IF V_ER = 1] For the next set of questions, we are going to ask you to think about your company's experiences with **Standard** rebates only. Later, we will ask you some questions about your company's experiences with Early Replacement rebates.

[CYCLE THROUGH MODULE FOR S_MEASURE_1 AND S_MEASURE_2; INPUT THE ASSOCIATED VSQTY_XX_1 AND VSQTY_XX_2 WITH CORRESPONDING MEASURE AS SHOWN IN TABLE]

IF MEASURE EQUALS	**THEN**
Outdoor ductless mini-split heat pump systems	VSQTY_XX = VSQTY_MSHP
Heat pump water heaters	VSQTY_XX = VSQTY_HPWH
Central air conditioning systems	VSQTY_XX = VSQTY_CAC
Gas furnaces	VSQTY_XX = VSQTY_FURN
Gas boilers	VSQTY_XX = VSQTY_BOIL
Central heat pumps	VSQTY_XX = VSQTY_CHP

FR1. If Mass Save had not offered rebates in 2016, about what percentage of the [VSQTY_XX] [MEASURE] that received **Standard** residential rebates would you have still installed that year? If you only installed 1, then enter 0 or 100.

[0 TO 100]
998. Don't know
999. (Refused)

FR2. [ASK IF FR1 < = 100] To confirm, you are estimating that in 2016, your company likely would still have installed [VSQTY_XX * (S_FR1 / 100)] [MEASURE] of the [VSQTY_XX] you installed if Mass Save had not offered the standard rebates. Is that **roughly** correct? [ROUND READ-IN CALCULATION TO NEAREST WHOLE NUMBER]

1. Yes
2. No
98. Don't know

S_FR3. [ASK IF S_FR2 > 1 OR FR1 > 100] Could you provide your best estimate of about how many of the [VSQTY_XX] [MEASURE] your company would still have installed in 2016 if Mass Save had not offered the Standard rebate?

[OPEN-END NUMERIC]
9998. (Don't know)

S_FR4. Why do you give that response?

(Don't know)

B.2.4 Early Replacement Free-Ridership (RES36)

[IF ER < > 1, SKIP MODULE]

ERFRINTRO. Next, I'd like you to think specifically about equipment you have installed that received an Early Replacement rebate. As a reminder, this would be equipment that was expected to work for at least two more years and met the program's age requirements.

[CYCLE THROUGH MODULE FOR ER_MEASURE_1 AND ER_MEASURE_2]

ER_FR1. About what percentage of your [ERQTY_XX] [MEASURE] that received **Early Replacement** residential rebates would you have installed in 2016 if the Mass Save rebates had not existed?

[0 TO 100(Don't know)

ER_FR2. [ASK IF ER_FR1 < = 100] To confirm, you are estimating that in 2016, your company likely would have installed [ERQTY_XX * (ER_FR1 / 100)] [MEASURE] of the [ERQTY_XX] that received residential **Early Replacement** rebates from Mass Save if the rebates had not existed. Is that **roughly** correct? [ROUND READ-IN CALCULATION TO NEAREST WHOLE NUMBER]

1. Yes
2. No
(Don't know)

ER_FR3. [ASK IF ER_FR2 = 2 OR ER_FR1 > 100] How many of the [ERQTY_XX] [MEASURE] that received **Early Replacement** rebates from Mass Save would you have installed in 2016 if the rebates had not existed?

[OPEN-END NUMERIC]
9998. (Don't know)
99999999. (Refused)

FR4. [SKIP IF FR3 = 9998 OR 9999] Why do you estimate that number would have still been installed in 2016 if Mass Save had not offered the Standard rebate
98. Don't know
9999. (Refused)

99. (Refused)

B.2.5 Standard Non-Participant Spillover (TXC34)

[IF V_STANDARD < > 1, SKIP MODULE]

[CYCLE THROUGH MODULE FOR S_MEASURE_1 AND S_MEASURE_2]

SO1. As a reminder, we consider equipment early replacement when they are expected to function and operate for the foreseeable future. Think of all your **standard replacement (not early replacement)** installations of residential [MEASURE], including standard-efficiency and high-efficiency and rebated and non-rebated units. About how many did your company install **in total** in 2016?

[OPEN END NUMERIC]
9998. Don’t know
9999. (Refused)

The next questions ask about **high-efficiency** [MEASURE]. When they are standard replacements, we consider them high-efficiency if they [EFFICIENCY]. [PHONE ONLY: “PRONOUNCIATIONS: A-F-U-E, seer, E-C-M, H-S-P-F.”]

MEASURE	**EFFICIENCY read-in**
Gas boilers	have an AFUE of 90% or higher
Gas furnaces	have an AFUE of 95% or higher with ECM
Heat pump water heaters	are 55 gallons or less with an energy factor of 2.3 or higher OR more than 55 gallons with an energy factor of 3.0 or higher
Central air conditioning systems	are SEER 16 or higher
Central heat pumps	are SEER 16 or higher and HSPF of 8.5 or higher
Outdoor ductless mini-split heat pump systems	are SEER 18 or higher and HSPF of 9 or higher

SO1a. About how many of the **standard replacement** installations of residential [MEASURE] in 2016 were high-efficiency, including rebated and non-rebated units?

[OPEN END NUMERIC]
9998. Don’t know
9999. (Refused)

SO2. Did all the standard replacement high-efficiency [MEASURE] that your company installed in 2016 receive a **Mass Save** rebate of some kind?

[0 TO 100]

1. Yes
2. No
98. Don’t know
99. (Refused)

999. (Refused)

[IF SO2 = 1, S_SO2a = 0]

SO2a. [SKIP IF SO2 = 1] About what percentage of the high-efficiency [MEASURE] that your company installed in 2016 did not receive a **Standard Rebate** even though they would have qualified for one?

[0 TO 100]
998. Don’t know
999. (Refused)

SO3. [ASK IF SO1a AND SO2a < 9998] To confirm, that means about [(SO1a) * (SO2a / 100)] of the [SO1a] high-efficiency [MEASURE] your company installed in 2016 did not receive **a** Standard **rebate** even though they would have qualified for one. Is that **roughly** correct? [ROUND READ-IN CALCULATIONS TO NEAREST WHOLE NUMBER]

1. Yes
2. No
98. Don’t know
99. (Refused)

99. (Refused)

SO3a. [ASK IF SO3 = 2 OR 98] About how many of the **standard replacement** installations of residential [MEASURE] in 2016 did not receive a Standard rebate even though they qualified?

[OPEN END NUMERIC]
9998. Don’t know
9999. (Refused)

[IF NONE INSTALLED OUTSIDE PROGRAM ((SO3a = 0, 9998, OR 9999) OR (SO2 = 1 AND SO3 = 1)), SKIP TO NEXT MEASURE/MODULE]

SO4. Why do you think those high-efficiency [MEASURE] were installed without receiving a Standard rebate even though they were qualified for one?

[OPEN END]
98. Don’t know
99. (Refused)

SO5. How much influence did each of the following have on your company’s installations in 2016 of high-efficiency [MEASURE] that would have **qualified for but did not receive a Standard Rebate**. Please use a scale of 0 to 10, where 0 is no influence and 10 is a great deal of influence. [RANDOMIZE]

a. Your recommendations to customers

b. Incentives and rebates offered but not received through the program

c. Other support offered through the program, such as marketing, advertising, education, training, and seminars

[ALLOW 0 TO 10]
98. Don’t know
99. (Refused)

SO6. Using a scale of 0 to 10, where 0 is no influence and 10 is a great deal of influence, how much influence did the Mass Save **Standard rebates** have on how frequently you recommended high-efficiency [MEASURE] to your customers in 2016?

[ALLOW 0 TO 10]
98. Don’t know
99. (Refused)

99. (Refused)

B.2.6 Prospective NTG (TXC34)

[IF V_STANDARD < > 1, SKIP MODULE]

P1. [ASK IF MEASURE = VS_MSHP] In 2016, about how many residential ductless mini-split heat pump systems, as measured by the number of outdoor compressor/condenser units, did your firm install? This includes systems that were both standard-efficiency and high-efficiency.

[OPEN END NUMERIC]
9998. Don’t know

P1T. [IF MEASURE = VS_MSHP, READ Beginning this year, the Mass Save program began offering its ductless mini-split heat pump rebates based on the number of **indoor** head units (evaporators), as opposed to previous years when the rebates were based on number of **outdoor** compressor/condenser units. For the following questions, please think of **indoor** head units only. [MEASURE READ-IN VALUE MUST CHANGE FROM “outdoor ductless mini-split heat pump systems” TO “**indoor** ductless mini-split heat pump systems” FOR THIS MODULE]

P2. In the coming years, various market factors in addition to Mass Save rebates could influence your company’s installations of high-efficiency equipment. For example, upfront costs of equipment could increase or decrease, customer demand could increase or decrease, regulations could be imposed or removed, energy-efficiency specifications could be made more stringent or more lenient, model availability could change, and weather patterns could become less predictable.

If the Mass Save rebates stay the same, about what percentage of the total number of [MEASURE] your company installs do you think will be high-efficiency in three years from now?

998. Don’t know
999. (Refused)

P3. Now I’d like you to imagine that the Mass Save rebates for [MEASURE] were to stop at the end of this year.

If this were to happen, about what percentage of the total number of residential [MEASURE] your company installs three years from now would be high-efficiency? [PHONE ONLY, IF NEEDED: There are no plans to stop the Mass Save rebates for [MEASURE].

[0 TO 100]

998. Don’t know

[IF P2 OR P3 > = 998, SKIP TO NEXT MODULE]

P4. [ASK IF P2 < > P3] Your responses indicate that you expect that the continued existence of the Mass Save rebates will influence the number of your company's installations of high-efficiency residential [MEASURE] in the future. Why?

[OPEN END]
98. Don't know

P5. [ASK IF P2 = P3] Your responses indicate that you do **not** expect that the continued existence of the Mass Save rebates will influence the number of your company's installations of high-efficiency residential [MEASURE] in the future. Why not?

[OPEN END]
998. Don't know
999. (Refused)

B.2.7 Market Effects (TXC34)

[IF V_STANDARD < > 1, SKIP MODULE]

[CYCLE THROUGH MODULE FOR S_MEASURE_1 AND S_MEASURE_2]

[IF MEASURE = VS_MSHP, READ] Let's turn back to ductless mini-split heat pump systems, as measured by the number of outdoor compressor/condenser units. [MEASURE READ-IN VALUE MUST CHANGE BACK TO "**outdoor** ductless mini-split heat pump systems"]

ME1. Over the past three years, have you observed an increase, decrease, or no change in the following?

a. How often distributors have the models of high-efficiency residential [MEASURE] that you need in stock

b. The cost that YOU, as the contractor, pay for high-efficiency residential [MEASURE]

c. The frequency with which customers ask for high-efficiency residential [MEASURE]

[FOR EACH]
1. Increase
2. Decrease
3. No change
98. Don't know
99. (Refused)

ME2. [ASK WHERE ME1 = 1 OR 2] Using a scale from 0 to 10, where 0 is “not at all influential” and 10 is “very influential,” how influential would you say the existence of the **Standard** Mass Save residential rebates has been on the change you observed in…

a. How often distributors have the models of high-efficiency residential [MEASURE] that you need in stock

b. The cost that YOU pay for high-efficiency residential [MEASURE]

c. The frequency with which customers ask for high-efficiency residential [MEASURE]

[FOR EACH]
[ALLOW 0 TO 10]
98. Don’t know

B.2.8 Early Replacement Net-to-Gross Context (RES36)

[IF V_ER < > 1, SKIP MODULE]

Let’s discuss your experiences with the Early Replacement rebates in 2016.

ER1. [ASK IF VER_FURN, VER_BOIL, OR VER_CHP = 1] Customers who receive an Early Replacement rebate for furnaces, boilers, or heat pumps must get a Mass Save Home Energy Assessment to verify eligibility. What percentage of customers who receive an Early Replacement rebate…

a. **First** receives a Home Energy Assessment, **then** contacts you to install their HVAC equipment?

b. Works with you **first**, and then you refer them to the Home Energy Assessment to verify eligibility?

[ALLOW 0 TO 100; WHOLE NUMBERS]
998. Don’t know
999. (Refused)

ER2. Thinking about all of the HVAC equipment your company has installed that received Early Replacement rebates, how influential was the program, including the rebates and information provided, in your customers’ decisions to replace their older HVAC equipment before it stopped functioning? Would you say the program was….

1. Very influential
2. Somewhat influential
3. Not very influential
4. Not at all influential
98. Don’t know
99. (Refused)

ER3. Think about ALL of the customers you worked with who received an Early Replacement rebate for any equipment type. If the Early Replacement program had not existed, what percent of those customers would have likely still replaced their old functioning equipment at the same time without the rebate?

[FOR EACH ALLOW 0 TO 100; WHOLE NUMBERS]
998. Don’t know
999. (Refused)

ER4. [SKIP IF ER3 > 100] You said that [ER3] percent of customers would have still replaced their old functioning equipment at the same time without the Early Retirement rebate. Does this vary by the type of equipment they are looking to replace? In other words, are there certain types of heating and cooling equipment that customers are more or less likely to replace before they fail?

1. Yes
2. No
98. Don’t know
99. (Refused)

ER4a. [ASK IF ER4 = 1] How and why does this vary by equipment?

[OPEN END]
98. Don’t know
99. (Refused)

ER4b. [ASK IF VER_FURN OR VER_BOIL = 1)] Does this vary based on whether the equipment uses gas, oil, propane, or another fuel type? In other words, are customers more or less likely to replace HVAC systems that use gas, oil, or propane before they fail?

1. Yes
2. No
98. Don’t know
99. (Refused)

ER4c. [ASK IF ER4b = 1] How and why does this vary by fuel?

[OPEN END]
98. Don’t know
99. (Refused)

ER5. In your own words, can you please describe the influence of the Early Replacement rebate on your customers’ decisions to replace their old functioning HVAC equipment?

[OPEN END]
98. Don't know
99. (Refused)

ER6. We'd like to understand if there is any program-eligible equipment being installed without program rebates.

Since you began participating in the program, have you ever replaced any old, functioning equipment that you feel was eligible for the Early Replacement rebate, but did not receive one?

1. Yes
2. No
98. Don't know
99. (Refused)

ER7. [ASK IF ER6 = 1] Did any of these customers receive a Standard Program rebate instead?

1. Yes
2. No
98. Don't know
99. (Refused)

ER7A. [ASK IF ER7 = 1] What percent of customers would you say received a Standard rebate instead of an Early Replacement rebate even though they were eligible for an Early Replacement rebate?

[ALLOW 0 TO 100; WHOLE NUMBERS]
998. Don't know
999. (Refused)

ER8. [ASK IF ER6 = 1] About how many Early Replacement program-eligible projects did your company install that did not receive an Early Replacement rebate for each of the following equipment types? Include all installations, whether they received a Standard rebate or not. Your best guess is fine.

a. Furnaces
b. Boilers
c. Central air conditioners
d. Central heat pumps

[FOR EACH]
[OPEN-END NUMERIC]
998. Don't know
999. (Refused)

ER8. [ASK IF ER6 = 1] Why do you think these customers were eligible to receive an Early Replacement rebate, but did not get one?

[OPEN END]
998. Don’t know
999. (Refused)

B.2.9 Fuel Types

F1. [SKIP IF V_ER < > 1] Our records indicate that your company installs equipment with the following fuel types. Does your company in fact install these? [SINGLE SCREEN]

a. [IF GAS_B = 1 AND VER_BOIL = 1] **Natural gas** hot water or steam boilers
b. [IF PROPANE_B = 1 AND VER_BOIL = 1] **Propane hot water or steam** boilers
c. [IF OIL_B = 1 AND VER_BOIL = 1] **Oil hot water or steam** boilers
d. [IF GAS_F = 1 AND VER_FURN = 1; SKIP IF VS_FURN = 1] **Natural gas** furnaces
e. [IF PROPANE_F = 1 AND VER_FURN = 1] **Propane** furnaces
f. [IF OIL_F = 1 AND VER_FURN = 1] **Oil** furnaces

[FOR EACH]
1. Yes
2. No
98. Don’t know
99. (Refused)

F2. Are there instances when your company helps a customer switch from either <u>propane or oil</u> **to** <u>natural gas or electricity</u> for their heating equipment?

1. Yes
2. No
98. Don’t know
99. (Refused)

F3. [IF F2 = 1] About how many fuel-switching projects does your company assist with per year?

[OPEN-END NUMERIC]
9998. Don’t know
9999. (Refused)

B.2.10 Closing for TXC34 & RES36

C1. Would you prefer that we send you an Amazon gift card or donate to a charity in your name?

1. Amazon gift card
2. Check
3. Donate to a charity in my name
4. Donate to a charity anonymously
97. None of the above [SKIP TO C2 AND C3]

C2. [ASK IF C1 = 2] Which of the following non-profit charitable organizations would you like us to donate to?

1. Hurricane Relief Fund
2. Big Brothers Big Sisters of Massachusetts Bay
3. Berkshire Humane Society

C3. What is your name and address? [IF C1 = 2: "We will make the donation in your name where possible, or you may donate anonymously."]

[NAME AND ADDRESS FIELDS]

B.2.11 Commercial Water Heaters (P77) (WEB ONLY)

[SKIP MODULE AFTER REACHING 20 COMPLETES]

[ASK IF P77 = 1]

WH1. Earlier you said you would answer questions about commercial water heaters for an additional $30. About what percentage of your company's sales or installations of commercial gas water heaters are installed in existing buildings and what percentage are installed in new buildings? [SINGLE SCREEN]

a. Existing buildings
b. New buildings
[FOR EACH]
[ALLOW 0 TO 100]
998. Don't know

WH2. [SKIP IF WH1a = 0] About what percentage of your sales or installations of commercial gas water heaters in **existing** buildings in Massachusetts are replacing units which have failed and what percentage replaced units with some useful life remaining? [SINGLE SCREEN]

a. Replaced on failure

b. Replaced with some useful life remaining
[FOR EACH]
[ALLOW 0 TO 100]
998. Don’t know

WH3. [ASK IF WH1 OR WH2 = 998] As you know, commercial gas water heaters can either **just heat water** or can provide **both heat and hot water**. They can also vary between **condensing** and **non-condensing** models.

Please estimate the percentages of your sales and installations of **all commercial gas water** heaters in Massachusetts over the past year across these categories. Your responses should sum to 100%. [SINGLE SCREEN; ALLOW 0 TO 100 FOR EACH; FORCE RESPONSES TO SUM TO 100]

Commercial Gas Water Heater Type	Efficiency
Dedicated hot water, no storage tank	a. Condensing
	b. Non-condensing
Dedicated, feeding storage tank	c. Condensing
	d. Non-condensing
Mixed heat and hot water	e. Condensing

WH4. [SKIP IF WH1a = 998 OR 0] As you know, commercial gas water heaters can either **just heat water** or can provide **both heat and hot water**. They can also vary between **condensing** and **non-condensing** models.

Please estimate the percentage of your sales and installations of commercial gas water heaters in **existing buildings** in Massachusetts over the past year which fall into the following equipment type and efficiency categories:

[REPLICATE WH3 RESPONSE CATEGORIES]

WH5. [SKIP IF WH1b = 998 OR 0] Please estimate the percentage of your sales and installations of commercial gas water heaters for **new construction** in Massachusetts over the past year which fall into the following equipment type and efficiency categories:

[REPLICATE WH3 RESPONSE CATEGORIES]

WH6. Some commercial gas water heaters are small enough to be installed in residences. You said, on average, the percentage of commercial water heater units replaced on failure was [WH2a] and the percentage replaced with useful life was [WH2b]. Would this percentage be different for smaller commercial water heaters?

1. Yes
2. No

WH7. [ASK IF WH6 = 1] Why would the percentages be different? [SINGLE RESPONSE]

1. Smaller water heaters have lower first costs
2. Smaller water heaters are more common in buildings that get retrofitted frequently
55. Other, specify [OPEN END]

WH8. [ASK IF WH6 = 1] How would these percentages be different?

[OPEN END]

B.2.12 Recruitment for RES19 & RES28 Surveys

RRS1. In a few weeks, the Mass Save sponsors will be conducting another survey of plumbers and contractors who have installed residential water heaters, boilers, furnaces, or ductless mini-split heat pumps in Massachusetts. This second survey will help the Mass Save sponsors better understand their purchase and installation costs under a wide range of scenarios, and will further support the rebate programs that encourage utility customers to upgrade their equipment. The sponsors will compensate survey participants with a $250 gift card. Are you interested in participating in this survey?

1. Yes, I am interested in participating in this survey when it becomes available
2. No, I am not interested in participating

[SKIP IF RRS1 = 2 OR RESPONSE CATEGORIES 1 THROUGH 4 ARE ALL INAPPLICABLE] RRS2. Please select the product(s) below for which you completed at least 10 installations since January 1, 2016. [MULTIPLE CHOICE]

1. [HIDE IF VSQTY_HPWH > 9] Residential water heaters
2. [HIDE IF VSQTY_BOIL > 9] Residential boilers
3. [HIDE IF VSQTY_FURN > 9] Residential furnaces
4. [HIDE IF VSQTY_MSHP > 9] Ductless mini-split heat pumps
97. None of the above

B.2.13 Final Closing

On behalf of the Sponsors of Mass Save, thank you very much for your time today.

B.3 CONSENSUS GROUP TOOL

Below are images from the TXC34 NTG Instrument along with the instructions that the evaluation team provided to the Consensus Group panelists.

Figure 20: Benchmarking NTG Estimates – Research Methods, Strengths, and Limitations

Program Administrator--Study	Research Methods	Strengths	Limitations	Notes
MA PAs--TXC34: Option 1	Self-reported counterfactual surveys: with participants (n = 332) and contractors (n = 167)	Combined NTG estimate based on results from program participants and contractors. Results incorporate estimates of both PSO and NPSO.	Self-reported data and potential for related biases. Sample sizes were small for some equipment types. Contractors represented small portions of	Contractor sample precision for most equipment types ranged between ±11% and 15% at 90% CI. CHP= ±20%
MA PAs--TXC34: Option 2				
MA PAs--TXC34: Option 2				
MA PAs--2012 Residential Heating, Water Heating, and Cooling Equipment Evaluation: Net-to-Gross, Market Effects, and Equipment Replacement Timing (2013)	Self-reported counterfactual surveys: Surveys with distributors (n = 33), contractors (n = 240), and program participants (n = 759)	Sample includes distributors and contractors who represent a substantial segment of the market and are knowledgeable about market trends.	Self-reported data and potential for related biases. NPSO was not calculated.	The relative precision was not reported.
Other Northeast and Mid-Atlantic States				
Efficiency Maine--Appliance Rebate Program Evaluation (2014)	Self-reported counterfactual surveys: participant surveys (n = 382, n = 80 for HPWH)	FR calculated for each measure.	P SO is program-wide calculation, and participants had at most a year to install additional measures. NPSO was not calculated.	The relative precision was not reported.
Con Edison NY--Impact Evaluation of CECONY Residential HVAC Electric Program (2014)	Self-reported counterfactual surveys: participant surveys (n = 192)	Similar program and climate to MA. NTGR calculated from a series of structured and open-ended questions about the influence of the program.	No calculation of NPSO.	The relative precision of the NTGRs at a 90% CI was ±11% for CAC and ±13% for MSHP.
PECO, PA--Final Annual Report to the Pennsylvania Public Utility Commission: PECO (2017)	Self-reported counterfactual surveys: participant surveys (n = 75)	Self-report with program participants. FR includes equally weighted components for participant intention and program influence.	Self-reports relies only on program participants (no NPSO). Overall program HVAC estimate includes equipment that is not specified in the report.	Relative precision for overall HVAC NTG= ±5% at 85% and 90% CI.
Anonymous state--Residential HVAC Program (2018)	Self-reported counterfactual surveys: with participants (n = 244) and contractors (n = 95)	Combined NTG estimate based on results from program participants and contractors. Results incorporate estimates of both P SO and NPSO. Values align with State's current TRM values.	Self-report bias.	The relative precision of the furnace and boiler sampling design was <10% at a 90% CI.
Outside of Northeast				
Duke Energy--2013 EM&V Report for the Home Energy Improvement Program (2015)	Self-reported counterfactual surveys: participant surveys (n = 200)	FR questions covered scope, likelihood, and timing of installation.	P SO only calculated at program level, and program is a mix of equipment and non-equipment measures. No NPSO calculated.	The relative precision was not reported.
Ameren MO--Efficient Products Impact and Process Evaluation: Program Year 2014 (2015)	Self-reported counterfactual surveys: participant surveys - phone (n=71) and online (n=197)	Calculated both PSO and NPSO for installed equipment.		The relative precision of the HPWH sampling design was ±7.8% at a 90% CI.
Ameren MO--Heating and Cooling Program Impact and Process Evaluation (2017)	Self-reported counterfactual surveys: Online participant surveys: one immediate for FR (n = 1,044) and one 6 months later for SO (n = 610). Contractor interviews for NPSO (n = 10).	Self reported participant and contractor data. Study measured, FR, SO, and NPSO.		The relative precision of the weighted FR estimates at a 90% CI was ±2% for CHPs, ±8% for MSHP, and ±2% for CACs.
Ameren IL--Company PY10 Net-to-Gross Ratios for the Energy Efficiency Portfolio (2017)	FR: PY6 (2013-4) Participant customer surveys (n=204). SO: PY5 (2012-3) Participant customer surveys for PSO (n = 210), nonparticipant contractor survey (n=65) for nonparticipant spillover.	P SO and NPSO calculated.	Values are from 4 (FR) or 5 (SO) program years previous.	The relative precision was not reported.
ComEd IL--ComEd Programs NTG Approach for EPY10 (2017)	MSHP: see limitations CAC: FR = PY8 participant self-report survey; SO = PY7 SAG consensus value for CSR HPWH: see limitations CHP: see limitations Furnace: w/ furnace upgrade = Nicor 2017 Gas study; w/o furnace upgrade = default NTG value	CAC FR values were calculated based on a self-report survey. All other values were from secondary sources or from consensus.	NTGRs based on older data or other utility studies. MSHP NTG is based on average value from 2016 Focus On Energy DMSHP study. HPWH and CHP (air-source only) NTGRs are based on 2013 Duke Energy study. Furnace NTGRs are for ECM motors only.	The relative precision was not reported.
IESO Ontario--Volume I: Final PY2016 Evaluation of Consumer Programs (2017)	Self-reported counterfactual surveys: Customer surveys (PY2016) were used for SO, FR, and rebound and contractor surveys (PY2015) were used for CAI. 143 of 52k CAC customers and 141 of 78k furnace customers were surveyed. NTGR = 1 – Free Ridership + Spillover – Rebound	Use of counterfactual self-reported data from customers. Use of contractor adjustment influence (CAI) and rebound to further inform NTGR.	No calculation of NPSO.	The relative precision was not reported.
CA IOUs--Residential Retrofit High Impact Measure Evaluation Report (2010)	Self-reported counterfactual surveys: participants (n = 301) and distributors (n = 70)	Self-reported data from program participants and furnace distributors.	Did not estimate for NPSO. Wide discrepancy between reported FR from distributors (lower) and customers (high).	The relative precision of the furnace NTGR at a 90% CI was ±4.8%.

Figure 21: Benchmarking NTG Estimates – NTG Values

Program Administrator--Study	Electric Equipment																Gas Equipment								HVAC Category/Program			
	MSHP				HPWH				CAC				CHP				Furnace				Boiler							
	FR	NPSO	PSO	NTG	FR	NPSO	PSO	NTG	FR	NPSO	PSO	NTG	FR	NPSO	PSO	NTG	FR	NPSO	PSO	NTG	FR	NPSO	PSO	NTG	FR	NPSO	PSO	NTG
MA PAs--TXC34: Option 1	0.39	0.15	0.02	0.79	0.16	0.04	0.01	0.89	0.43	0.05	0.10	0.72	0.46	0.04	0.02	0.61	0.33	0.16	0.02	0.85	0.24	0.14	0.01	0.90				
MA PAs--TXC34: Option 2	0.45	0.15	0.02	0.72	0.23	0.04	0.01	0.81	0.53	0.05	0.10	0.62	0.54	0.04	0.02	0.53	0.46	0.16	0.02	0.72	0.37	0.14	0.01	0.77				
MA PAs--TXC34: Option 2	0.41	0.15	0.02	0.77	0.21	0.04	0.01	0.83	0.48	0.05	0.10	0.67	0.49	0.04	0.02	0.58	0.42	0.16	0.02	0.76	0.35	0.14	0.01	0.79				
MA PAs--2012 Residential Heating, Water Heating, and Cooling Equipment Evaluation: Net-to-Gross, Market Effects, and Equipment Replacement Timing (2013)	0.45	--	0.07	0.62					0.4	--	0.28	0.88					0.4	--	0.22	0.81	0.3	--	0.08	0.8				
Other Northeast and Mid-Atlantic States																												
Efficiency Maine--Appliance Rebate Program Evaluation (2014)					0.21	--	0.033	0.82																				
Con Edison NY--Impact Evaluation of CECONY Residential HVAC Electric Program (2014)	0.47	--	0	0.53					0.48	--	0	0.52																
PECO, PA--Final Annual Report to the Pennsylvania Public Utility Commission: PECO (2017)									0.58	--	0.04	0.45	0.46	--	0.02	0.56									0.5	--	0.03	0.6
Anonymous state--Residential HVAC Program (2018)																	0.4	--	0.1	0.72	0.4	--	0.12	0.8				
Outside of Northeast																												
Duke Energy--2013 EM&V Report for the Home Energy Improvement Program (2015)					0.29	--	used program value	0.76	0.51	--	used program value	0.55	0.49	--	used program value	0.57									0.4	--	0.06	0.7
Ameren MO--Efficient Products Impact and Process Evaluation: Program Year 2014 (2015)					0.19	0.007	0.031	0.85																				
Ameren MO--Heating and Cooling Program Impact and Process Evaluation (2017)	0.12	0.004	0.02	0.92					0.161	0.004	0.003	0.85	0.03	0.004	0.001	0.98									0.1	0.004	0	0.9
Ameren IL--Company PY10 Net-to-Gross Ratios for the Energy Efficiency Portfolio (2017)									0.58 (ROB); 0.46 (ER)	0.22	0.001	0.641 (ROB); 0.761 (ER)																
ComEd IL--ComEd Programs NTG Approach for EPY10 (2017)	--	--	--	0.68	--	--	--	0.76	0.43	--	0.12	0.69	--	--	--	0.57	--	--	--	0.68 w/ upgrade; 0.80 w/o upgrade								
IESO Ontario--Volume I: Final PY2016 Evaluation of Consumer Programs (2017)									0.33	--	0.33	1.00					0.3	--	0.01	0.7					0.3	--	0.01	0.7
CA IOUs--Residential Retrofit High Impact Measure Evaluation Report (2010)																	0.8	--	0	0.18								

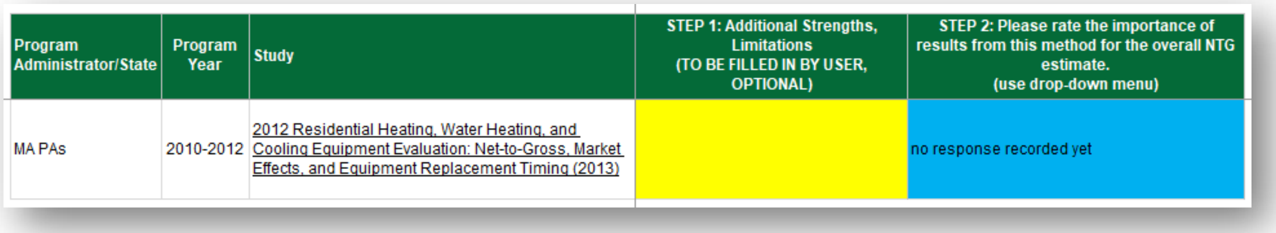
B.3.1 Steps 1 and 2: Contextualizing NTG Estimates

First, assess the importance of study results:

1. In the "NTG Estimates" tab, describe any additional strengths and limitations of each method in the yellow-shaded cells in the spreadsheet.
2. Next, rate the importance of the results from each method for the overall NTG estimate in the blue shaded cells.

Figure 22 shows the specific cells in the worksheet to fill out for these two steps.

Figure 22: Steps 1 and 2 of Deriving Your NTG Estimates



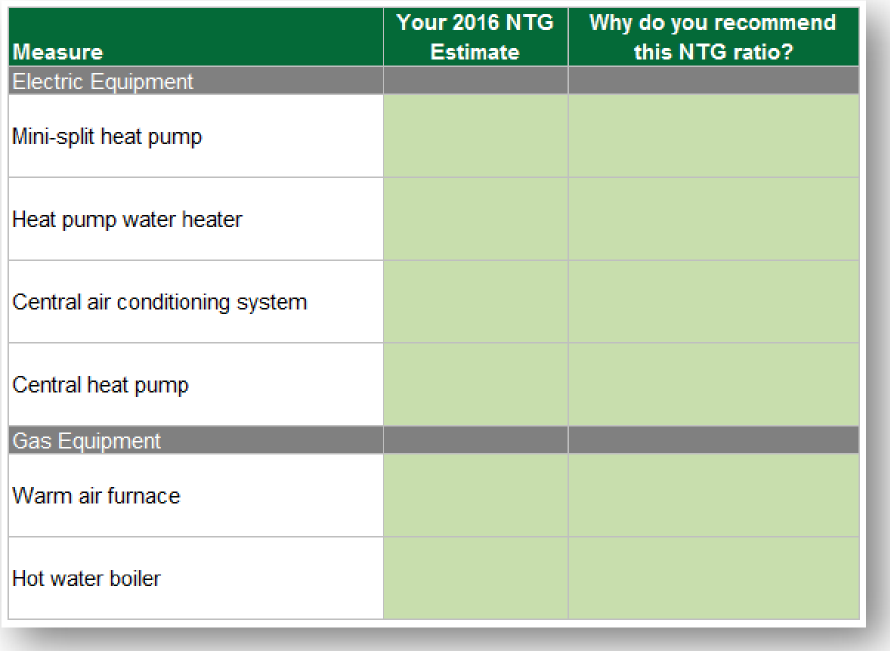
Program Administrator/State	Program Year	Study	STEP 1: Additional Strengths, Limitations (TO BE FILLED IN BY USER, OPTIONAL)	STEP 2: Please rate the importance of results from this method for the overall NTG estimate. (use drop-down menu)
MA PAs	2010-2012	2012 Residential Heating, Water Heating, and Cooling Equipment Evaluation: Net-to-Gross, Market Effects, and Equipment Replacement Timing (2013)		no response recorded yet

B.3.2 Step 3: Retrospective Estimates

Next, in the tab labeled, "Your NTG estimates," add your *own 2016 NTG estimates for each equipment type in* the green-shaded cells in Columns B and C, and explain your reasoning. Please estimate NTG levels for the **2016 program** year only, *without* taking spillover from past program efforts into account.

Figure 23 shows the specific cells in the worksheet to fill out for this step.

Figure 23: Entering Your 2016 NTG Estimates and Rationales



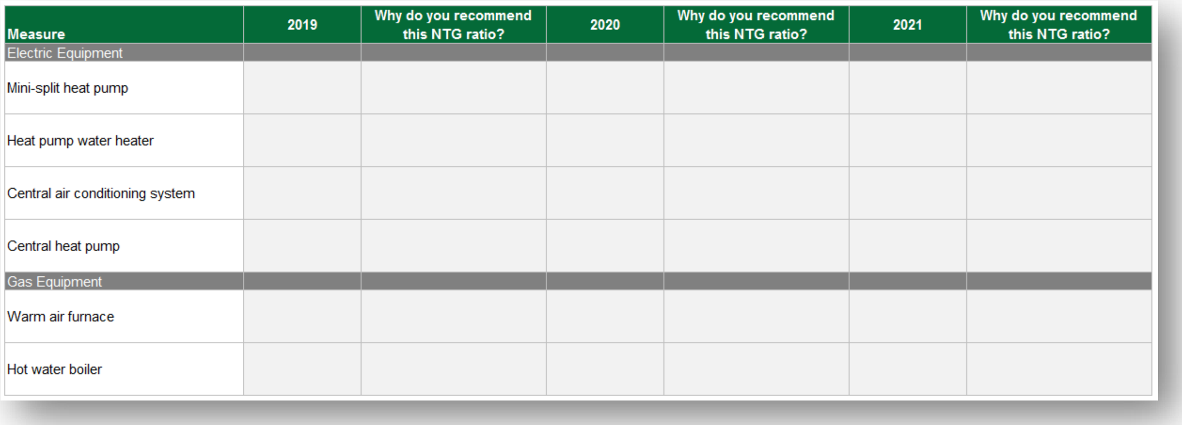
Measure	Your 2016 NTG Estimate	Why do you recommend this NTG ratio?
Electric Equipment		
Mini-split heat pump		
Heat pump water heater		
Central air conditioning system		
Central heat pump		
Gas Equipment		
Warm air furnace		
Hot water boiler		

B.3.3 Step 4: Prospective Estimates

In the same, “NTG Estimates” tab, please fill out the grey cells with your prospective estimates for 2019-2021 and your rationale for these estimates. Please **do not** take spillover from pre-2016 programs into account.

Figure 24 shows the specific cells in the worksheet to fill out for this step.

Figure 24: Entering Your 2019-2021 NTG Estimates and Rationales



Measure	2019	Why do you recommend this NTG ratio?	2020	Why do you recommend this NTG ratio?	2021	Why do you recommend this NTG ratio?
Electric Equipment						
Mini-split heat pump						
Heat pump water heater						
Central air conditioning system						
Central heat pump						
Gas Equipment						
Warm air furnace						
Hot water boiler						

B.3.4 Step 5: Submitting your NTG Estimates

After you finish, please **save the Excel file** with your affiliation (e.g., PAs, EEAC, or evaluators) as part of the file name, and email it **by 12pm ET, February 20, 2018**. We will aim to compile and distribute responses by COB February 21, 2018, so you can review them before the NTG Consensus Group meeting schedule

---

PUC 2-5

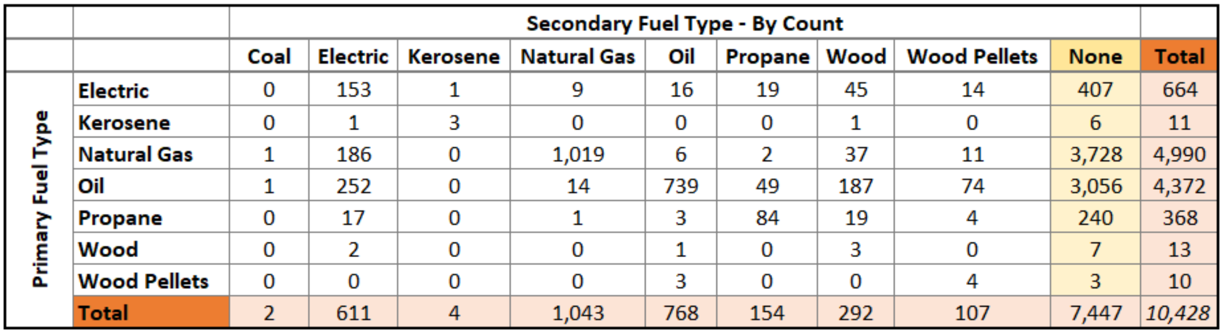
Request:

In response to PUC 4-3 in Docket No. 22-33-EE, the Company explained that "from 2018 to 2022, the EnergyWise tracking system indicates that 12% of assessments have a secondary heating system." Please update this response with the percentage of assessments performed through the EnergyWise program in 2023 that identified accounts with a secondary heating system. Please also break down the account data by primary heating source.

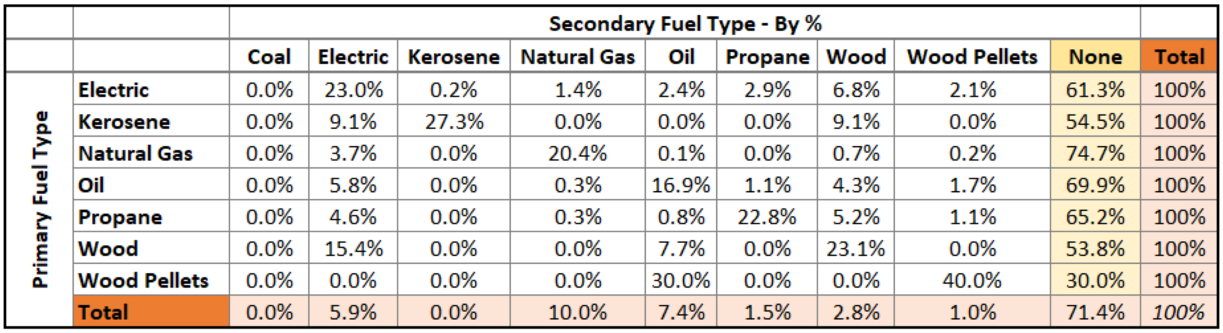
Response:

The percentage of assessments performed through the EnergyWise program in 2023 (YTD as of 11/13/23) that identified accounts with a secondary heating system is 29%.

Please see below for customer data by primary heating source.



		Secondary Fuel Type - By Count									
		Coal	**Electric**	**Kerosene**	**Natural Gas**	**Oil**	**Propane**	**Wood**	**Wood Pellets**	**None**	**Total**
Primary Fuel Type	**Electric**	0	153	1	9	16	19	45	14	407	664
	Kerosene	0	1	3	0	0	0	1	0	6	11
	Natural Gas	1	186	0	1,019	6	2	37	11	3,728	4,990
	Oil	1	252	0	14	739	49	187	74	3,056	4,372
	Propane	0	17	0	1	3	84	19	4	240	368
	Wood	0	2	0	0	1	0	3	0	7	13
	Wood Pellets	0	0	0	0	3	0	0	4	3	10
	Total	2	611	4	1,043	768	154	292	107	7,447	*10,428*



		Secondary Fuel Type - By %									
		Coal	**Electric**	**Kerosene**	**Natural Gas**	**Oil**	**Propane**	**Wood**	**Wood Pellets**	**None**	**Total**
Primary Fuel Type	**Electric**	0.0%	23.0%	0.2%	1.4%	2.4%	2.9%	6.8%	2.1%	61.3%	100%
	Kerosene	0.0%	9.1%	27.3%	0.0%	0.0%	0.0%	9.1%	0.0%	54.5%	100%
	Natural Gas	0.0%	3.7%	0.0%	20.4%	0.1%	0.0%	0.7%	0.2%	74.7%	100%
	Oil	0.0%	5.8%	0.0%	0.3%	16.9%	1.1%	4.3%	1.7%	69.9%	100%
	Propane	0.0%	4.6%	0.0%	0.3%	0.8%	22.8%	5.2%	1.1%	65.2%	100%
	Wood	0.0%	15.4%	0.0%	0.0%	7.7%	0.0%	23.1%	0.0%	53.8%	100%
	Wood Pellets	0.0%	0.0%	0.0%	0.0%	30.0%	0.0%	0.0%	40.0%	30.0%	100%
	Total	0.0%	5.9%	0.0%	10.0%	7.4%	1.5%	2.8%	1.0%	71.4%	*100%*

Data Range: 1/1/2023 - 11/13/2023

Prepared by or under the supervision of: Spencer Lawrence

PUC 2-6

Request:

Bates page 213 of the Plan indicates that the Company considers the cost of "Income Eligible Rate Discounts" when performing the cost of supply analysis. The Company describes the cost category as "costs associated with energy being sold at the income eligible rate" and indicates that the cost of Income Eligible Rate Discounts that would be incurred in 2024 but for the proposed energy efficiency portfolio would be $115,675 for electric and $35,514 for gas (Bates page 214). Please explain why this cost category is appropriate to include in the cost of supply analysis. In your response, specifically address whether this cost represents a marginal cost that can be avoided through energy efficiency or simply a reallocation of cost between ratepayers (e.g. customers on the discount rates vs. all other customers).

Response:

The Company considers it to be appropriate to include the "Income Eligible Rate Discount" in the cost of supply analysis because it is a utility system benefit. The calculation of the benefit assumes that the discount is applied volumetrically. When consumption in the Income Eligible sector is reduced due to implementation of energy efficiency measures, fewer rate discounts are provided.

The discount is recovered across all rate classes. Therefore, in a steady state, the rate discount could be considered to represent a reallocation of costs between ratepayers. However, with the reduction of consumption due to energy efficiency, the total amount of discount provided is reduced and fewer funds need to be collected to support the discounts.

PUC 2-7

Request:

Table 10 on Bates page 214 shows the difference between the cost of energy efficiency and the cost of energy supply for the proposed 2024 Annual Gas and Electric Plans. Please provide a series of tables that express this difference on a $/kWh basis for the 2024 Electric Plan at both the program and portfolio levels, and on a $/MMBtu basis for the 2024 Gas Plan at both the program and portfolio levels.

Response:

Please see Tables 1a and 1b below for the difference between the cost of energy efficiency and the cost of energy supply on a $ / lifetime kWh basis for the 2024 Electric Plan at both the program and portfolio levels. Table 1a shows data representing all cost of energy supply benefits. Table 1b shows data representing Rhode Island intrastate cost of energy supply benefits only.

Please see Tables 2a and 2b below for the difference between the cost of energy efficiency and the cost of energy supply on a $ / lifetime MMBtu basis for the 2024 Gas Plan at both the program and portfolio levels. Table 2a shows data representing all cost of energy supply benefits. Table 2b shows data representing Rhode Island intrastate cost of energy supply benefits only.

In all below tables, the $/kWh and $/MMBtu values are calculated by taking the "Difference" column and dividing by the corresponding program-level lifetime kWh / MMBtu values. Please note that some programs within the Electric and Gas portfolios have negative cost of supply values because the pre-defined list of cost of energy supply benefits excludes many non-energy impacts.

PUC 2-7, Page 2

Table 1a: Difference Between the Cost of Energy Efficiency and the Cost of Energy Supply, Electric Plan Total

	Cost of Supply	Cost of EE	Difference	Total Cost of Supply per Lifetime kWh
Residential	**$55,254,141**	**$38,939,732**	**$16,314,410**	**$0.086**
Residential New Construction	$4,785,751	$1,839,571	$2,946,180	$0.185
Residential HVAC	$17,184,330	$10,014,153	$7,170,177	$0.063
EnergyWise Single Family	$21,802,165	$20,743,642	$1,058,523	$0.071
EnergyWise Multifamily	$1,775,018	$1,564,374	$210,643	$0.026
Home Energy Reports	$5,756,280	$2,340,198	$3,416,081	$0.146
Residential Consumer Products	$3,950,598	$2,437,793	$1,512,805	$0.099
Income Eligible Residential	**$12,579,465**	**$17,109,718**	**-$4,530,253**	**-$0.082**
Income Eligible Single Family	$10,173,815	$13,068,518	-$2,894,703	-$0.079
Income Eligible Multifamily	$2,405,650	$4,041,201	-$1,635,551	-$0.088
Commercial & Industrial	**$94,070,155**	**$57,754,797**	**$36,315,358**	**$0.075**
Large C&I New Construction	$31,178,349	$11,695,283	$19,483,066	$0.107
Large C&I Retrofit	$53,172,840	$35,472,653	$17,700,188	$0.073
Small Business Direct Install	$9,718,966	$10,586,861	-$867,896	-$0.015
Total	**$161,903,761**	**$113,804,247**	**$48,099,514**	**$0.066**

PUC 2-7, Page 3

Table 1b: Difference Between the Cost of Energy Efficiency and the Cost of Energy Supply, Electric Plan Intrastate Only

	Cost of Supply	Cost of EE	Difference	Total Cost of Supply per Lifetime kWh
Residential	**$49,617,564**	**$38,939,732**	**$10,677,832**	**$0.056**
Residential New Construction	$4,522,211	$1,839,571	$2,682,641	$0.169
Residential HVAC	$14,538,188	$10,014,153	$4,524,035	$0.040
EnergyWise Single Family	$21,159,543	$20,743,642	$415,901	$0.028
EnergyWise Multifamily	$1,555,538	$1,564,374	-$8,836	-$0.001
Home Energy Reports	$4,707,171	$2,340,198	$2,366,972	$0.101
Residential Consumer Products	$3,134,913	$2,437,793	$697,120	$0.045
Income Eligible Residential	**$11,029,923**	**$17,109,718**	**-$6,079,795**	**-$0.110**
Income Eligible Single Family	$8,947,103	$13,068,518	-$4,121,415	-$0.112
Income Eligible Multifamily	$2,082,821	$4,041,201	-$1,958,380	-$0.106
Commercial & Industrial	**$74,197,008**	**$57,754,797**	**$16,442,211**	**$0.034**
Large C&I New Construction	$25,141,786	$11,695,283	$13,446,503	$0.074
Large C&I Retrofit	$41,567,971	$35,472,653	$6,095,318	$0.025
Small Business Direct Install	$7,487,251	$10,586,861	-$3,099,611	-$0.053
Total	**$134,844,494**	**$113,804,247**	**$21,040,248**	**$0.029**

Table 2a: Difference Between the Cost of Energy Efficiency and the Cost of Energy Supply, Gas Plan Total

	Cost of Supply	Cost of EE	Difference	Total Cost of Supply per Lifetime MMBtu
Residential	**$17,496,821**	**$19,486,780**	**-$1,989,959**	**-$1.81**
Residential New Construction	$1,097,663	$931,809	$165,854	$2.26
Residential HVAC	$3,281,422	$3,502,611	-$221,189	-$1.00
EnergyWise Single Family	$10,070,379	$13,052,080	-$2,981,701	-$4.86
EnergyWise Multifamily	$1,608,265	$1,616,105	-$7,840	-$0.08
Home Energy Reports	$1,439,092	$384,174	$1,054,917	$12.31
Income Eligible Residential	**$4,742,017**	**$8,148,053**	**-$3,406,037**	**-$11.85**
Income Eligible Single Family	$2,027,559	$4,843,565	-$2,816,006	-$23.21
Income Eligible Multifamily	$2,714,458	$3,304,489	-$590,031	-$3.55
Commercial & Industrial	**$29,755,724**	**$13,379,559**	**$16,376,165**	**$8.54**
Large C&I New Construction	$10,078,198	$2,846,540	$7,231,658	$11.00
Large C&I Retrofit	$16,830,854	$8,141,435	$8,689,419	$8.08
Small Business Direct Install	$1,798,537	$1,087,929	$710,608	$5.99
C&I Multifamily	$1,048,135	$1,303,655	-$255,520	-$3.89
Total	**$51,994,562**	**$41,014,392**	**$10,980,170**	**$3.32**

PUC 2-7, Page 5

Table 2b: Difference Between the Cost of Energy Efficiency and the Cost of Energy Supply, Gas Plan Intrastate Only

	Cost of Supply	Cost of EE	Difference	Total Cost of Supply per Lifetime MMBtu
Residential	**$17,358,932**	**$19,486,780**	**-$2,127,848**	**-$1.94**
Residential New Construction	$1,097,663	$931,809	$165,854	$2.26
Residential HVAC	$3,286,165	$3,502,611	-$216,447	-$0.98
EnergyWise Single Family	$9,937,308	$13,052,080	-$3,114,772	-$5.08
EnergyWise Multifamily	$1,598,705	$1,616,105	-$17,400	-$0.17
Home Energy Reports	$1,439,092	$384,174	$1,054,917	$12.31
Income Eligible Residential	**$4,696,757**	**$8,148,053**	**-$3,451,296**	**-$12.01**
Income Eligible Single Family	$1,999,700	$4,843,565	-$2,843,865	-$23.44
Income Eligible Multifamily	$2,697,057	$3,304,489	-$607,431	-$3.66
Commercial & Industrial	**$29,646,519**	**$13,379,559**	**$16,266,960**	**$8.49**
Large C&I New Construction	$9,976,520	$2,846,540	$7,129,980	$10.84
Large C&I Retrofit	$16,830,854	$8,141,435	$8,689,419	$8.08
Small Business Direct Install	$1,798,537	$1,087,929	$710,608	$5.99
C&I Multifamily	$1,040,607	$1,303,655	-$263,048	-$4.01
Total	**$51,702,208**	**$41,014,392**	**$10,687,816**	**$3.24**

PUC 2-8

Request:

Please provide a table with the following information for each of the three component program years in the proposed 2024-2026 Three-Year Plan:

a. Annual electric savings (MWh)

b. Lifetime electric savings (MWh)

c. Annual Gas savings (MMBtu)

d. Lifetime Gas savings (MMBtu)

e. Annual oil savings (MMBtu)

f. Lifetime oil savings (MMBtu)

g. Annual propane savings (MMBtu)

h. Lifetime propane savings (MMBtu)

Response:

Please see Table 1 below for information from the electric 2024-2026 Three-Year Plan. Please see Table 2 below for information from the gas 2024-2026 Three-Year Plan.

Table 1. 2024-26 Plan, electric portfolio savings data

Category	**2024**	**2025**	**2026**
Annual electric savings (MWh)	94,198	94,839	94,877
Lifetime electric savings (MWh)	729,294	761,976	788,783
Annual Gas savings (MMBtu)	-12,122	-7,682	-3,441
Lifetime Gas savings (MMBtu)	-62,995	-21,219	17,950
Annual oil savings (MMBtu)	33,167	38,833	40,445
Lifetime oil savings (MMBtu)	673,646	731,690	757,279
Annual propane savings (MMBtu)	4,789	5,280	5,837
Lifetime propane savings (MMBtu)	98,989	104,809	120,978

PUC 2-8, Page 2

Table 2. 2024-26 Plan, gas portfolio savings data

Category	**2024**	**2025**	**2026**
Annual electric savings (MWh)	229	233	242
Lifetime electric savings (MWh)	4,496	4,513	4,760
Annual Gas savings (MMBtu)	312,846	325,816	338,595
Lifetime Gas savings (MMBtu)	3,302,603	3,448,012	3,584,964
Annual oil savings (MMBtu)	0	0	0
Lifetime oil savings (MMBtu)	0	0	0
Annual propane savings (MMBtu)	0	0	0
Lifetime propane savings (MMBtu)	0	0	0

PUC 2-9

Request:

Referencing Table 6 on Bates page 115, please explain the following:

a. Define "state" programming and explain how the Company developed the $106 million "total associated 3-yr budget."

b. Within which row of the table, if any, are federal energy efficiency tax credits captured? If they are not included in this table, explain why the Company did not include them.

c. Referencing the $106 million three-year budget associated with state programming, please provide a breakdown of that expected three-year budget by fuel type (e.g. how much of the $106 million will be spent to deliver electric savings vs. natural gas savings vs. delivered fuel savings).

d. Please provide the underlying workpapers and/or calculations that illustrate how the Company derived the fuel-specific savings estimates associated with each of the four budget line items (RIE, non-programmatic adoption, state, other RI utilities).

e. Explain why the Company believes no delivered fuels savings will be delivered through Rhode Island Energy's energy efficiency program. Reconcile your response against Table E-6A on Bates page 408, which shows that the Company's proposed 2024 Annual Electric Efficiency Plan will deliver 33,167 MMBtu of oil savings (annual) and 4,789 MMBtu of propane savings (annual).

f. Explain why the Company believes no delivered fuels savings will be delivered through non-programmatic adoption.

Response:

a. The Company defined "state" programming as any energy efficiency program that is administered by Rhode Island using federal funding or using state funds. The Company calculated the total budget for these state programs by estimating federal and state funding expected to be spent over the three-year period based on published estimates and assuming a consistent allocation across the three-year period. The Company used published information to estimate CleanHeat RI (also known as HHPP or Rhode Island's High-efficiency Heat Pump Program), Home Efficiency Rebates (HOMES), Home Electrification and Appliance Rebates (known as HEAR or

HEEHRA) budgets. For the Rhode Island Infrastructure Bank (RIIB), Weatherization Assistance Program (WAP), and Regional Greenhouse Gas Initiative (RGGI) we utilized recent year spending to estimate annual budgets and assumed consistent spend over the three-year period.

During the review of the $106 million budget, the Company realized it reported total funding from the federal programs assuming it would all be spent during the three-year term and did not allocate the funds over the anticipated eight-year implementation period. When the federal funds are reallocated, the total funding for "state" programs in 2025-27 is $65.7 million. The Company's updated savings calculations are provided in **Revised Table 6**.

b. Federal energy efficiency tax credits were not captured in Table 6. The Company did not include them because the Company did not have the data to forecast the tax credit influx. The Company will consider pathways to estimate this for future annual analyses.

c. The estimated breakdown of the state's three-year budget by fuel type is illustrated in Table 1 below.

Table 1: *State Funding Allocation Across Fuel Types*

	Electric Savings	Gas Savings	Delivered Fuel	Total
Budget ($)	$46,802,153	$13,382,499	$5,509,988	$65,694,641
Budget (%)	71%	20%	8%	100%

d. The Company's underlying work papers are provided in Attachment PUC 2-9 EE Distribution Analysis. The attachment reflects the corrections made to the analysis as indicated in parts (a) and (e) of this response in addition to a calculation correction to the total energy saved. **Revised Table 6** and **Revised Table 7** below update Table 6 and Table 7 on Bates page 115.

e. The Company unintentionally omitted the delivered fuel savings presented in Table E-6A from Table 6 and has now included them in the analysis. The Company has updated the calculation in Attachment PUC 2-9 and also shows the delivered fuel impacts in **Revised Table 6** and **Revised Table 7.**

f. Concurrent with omitting the delivered fuel savings from the Company's programs, the Company unintentionally omitted the delivered fuel savings for non-programmatic adoption. The Company has updated the calculation in Attachment PUC 2-9 and also shows the delivered fuel impacts in **Revised Table 6** and **Revised Table 7,** below.

Revised Table 6: State of Rhode Island, Energy Savings

		Electricity (MWh)	% Savings	Natural Gas (MMBtu)	% Savings	Delivered Fuel (MMBtu)	% Savings	Total Energy Saved (MMBtu)	% Savings	Total Associated Budget 3YR ($)	% Budget
Annual	RIE	283,914	68%	977,257	79%	128,353	79%	2,074,364	74%	$ 402,853,585	84%
	Non Programmatic Adoption	97,770	24%	192,361	16%	25,064	16%	551,032	20%	$ -	0%
	State	26,651	6%	64,454	5%	8,141	5%	163,533	6%	$ 65,694,641	14%
	Other RI Utilities (Pascoag + Block Island)	7,045	2%	-	0%	-	0%	24,038	1%	$ 9,996,207	2%
	Total	**415,381**	**100%**	**1,234,072**	**100%**	**161,558**	**100%**	**2,812,968**	**100%**	**$ 478,544,433**	**100%**
Lifetime	RIE	2,280,053	68%	10,335,579	72%	2,487,391	80%	20,602,835	71%	NA	NA
	Non Programmatic Adoption	883,277	26%	2,965,054	21%	485,244	16%	6,464,164	22%	NA	NA
	State	157,664	5%	1,143,208	8%	145,913	5%	1,827,094	6%	NA	NA
	Other RI Utilities (Pascoag + Block Island)	49,455	1%	-	0%	-	0%	168,748	1%	NA	NA
	Total	**3,370,449**	**100%**	**14,443,841**	**100%**	**3,118,548**	**100%**	**29,062,841**	**100%**	**NA**	**NA**

Revised Table 7: State of Rhode Island, Emission Savings

PUC 2-9, Page 4

		Electricity (metric tons CO2)	% Savings	Natural Gas (metric tons CO2)	% Savings	Delivered Fuel (metric tons CO2)	% Savings	Total Avoided Emissions (metric tons CO2)	% Savings
Annual	RIE	201,295	68%	51,795	79%	6,803	79%	259,892	71%
	Non Programmatic Adoption	69,319	24%	10,195	16%	1,328	16%	80,843	22%
	State	18,896	6%	3,416	5%	431	5%	22,743	6%
	Other RI Utilities (Pascoag + Block Island)	4,995	2%	-	0%	-	0%	4,995	1%
	Total	**294,505**	**100%**	**65,406**	**100%**	**8,563**	**100%**	**368,473**	**100%**
Lifetime	RIE	1,616,558	68%	547,786	72%	131,832	80%	2,296,175	69%
	Non Programmatic Adoption	626,243	26%	157,148	21%	25,718	16%	809,109	24%
	State	111,784	5%	60,590	8%	7,733	5%	180,107	5%
	Other RI Utilities (Pascoag + Block Island)	35,064	1%	-	0%	-	0%	35,064	1%
	Total	**2,389,649**	**100%**	**765,524**	**100%**	**165,283**	**100%**	**3,320,455**	**100%**

3 YP Tables

Energy Saved

		Electricity (MWh)	% Savings	Natural Gas (MMBtu)	% Savings	Delivered Fuel (MMBtu)	% Savings	Total Energy Saved (MMBtu)	% Savings	Total Associated Budget 3YR ($)	% Budget
Annual	RIE	283,914	68%	977,257	79%	128,353	79%	2,074,364	74%	$ 402,853,585	84%
	Non Programmatic Adoption	97,770	24%	192,361	16%	25,064	16%	551,032	20%	$ -	0%
	State	26,651	6%	64,454	5%	8,141	5%	163,533	6%	$ 65,694,641	14%
	Other RI Utilities (Pascoag + Block Island)	7,045	2%	-	0%	-	0%	24,038	1%	$ 9,996,207	2%
	Total	**415,381**	**100%**	**1,234,072**	**100%**	**161,558**	**100%**	**2,812,968**	**100%**	**$ 478,544,433**	**100%**
Lifetime	RIE	2,280,053	68%	10,335,579	72%	2,487,391	80%	20,602,835	71%	NA	NA
	Non Programmatic Adoption	883,277	26%	2,965,054	21%	485,244	16%	6,464,164	22%	NA	NA
	State	157,664	5%	1,143,208	8%	145,913	5%	1,827,094	6%	NA	NA
	Other RI Utilities (Pascoag + Block Island)	49,455	1%	-	0%	-	0%	168,748	1%	NA	NA
	Total	**3,370,449**	**100%**	**14,443,841**	**100%**	**3,118,548**	**100%**	**29,062,841**	**100%**	**NA**	**NA**

3 YP Tables

Avoided Emissions

		Electricity (metric tons CO2)	% Savings	Natural Gas (metric tons CO2)	% Savings	Delivered Fuel (metric tons CO2)	% Savings	Total Avoided Emissions (metric tons CO2)	% Savings
Annual	RIE	201,295	68%	51,795	79%	6,803	79%	259,892	71%
	Non Programmatic Adoption	69,319	24%	10,195	16%	1,328	16%	80,843	22%
	State	18,896	6%	3,416	5%	431	5%	22,743	6%
	Other RI Utilities (Pascoag + Block Island)	4,995	2%	-	0%	-	0%	4,995	1%
	Total	**294,505**	**100%**	**65,406**	**100%**	**8,563**	**100%**	**368,473**	**100%**
Lifetime	RIE	1,616,558	68%	547,786	72%	131,832	80%	2,296,175	69%
	Non Programmatic Adoption	626,243	26%	157,148	21%	25,718	16%	809,109	24%
	State	111,784	5%	60,590	8%	7,733	5%	180,107	5%
	Other RI Utilities (Pascoag + Block Island)	35,064	1%	-	0%	-	0%	35,064	1%
	Total	**2,389,649**	**100%**	**765,524**	**100%**	**165,283**	**100%**	**3,320,455**	**100%**

IR Additional Request

Budget Distribution by Fuel Type

	Electric	Gas	Delivered Fuel	Totals
Budget ($)	$ 46,802,153	$ 13,382,499	$ 5,509,988	$ 65,694,641
Budget (%)	71%	20%	8%	100%

Conversions

Conversions

Metric Tons CO2/MWh	0.709
Metric Tons CO2/MMBtu	0.053
MWh -> MMBtu	3.412142

RIE Inputs - Electric

Savings (MWh)

Year	Annual	Lifetime	Notes
2024	94,198	729,294	24-26 Plan
2025	94,839	761,976	
2026	94,877	788,783	
Total	283,914	2,280,053	

Budget ($)

Year	Total	Notes
2024	$ 96,308,493	24-26 Plan
2025	$ 99,514,133	
2026	$ 103,073,728	
Total	$ 298,896,354	

RIE Inputs - Gas

Savings (MMBtu)

Year	Annual	Lifetime	Notes
2024	312,846	3,302,603	24-26 Plan
2025	325,816	3,448,012	
2026	338,595	3,584,964	
Total	977,257	10,335,579	

Budget ($)

Year	Total	Notes
2024	$ 34,159,984	24-26 Plan
2025	$ 34,846,414	
2026	$ 34,950,833	
Total	$ 103,957,231	

RIE Inputs - Delivered Fuels

Savings (MMBtu)

Year	Annual	Lifetime	Notes
2024	37,956	772,636	24-26 Plan
2025	44,114	836,499	
2026	46,283	878,257	
Total	128,353	2,487,391	

State Inputs

HHPP:	Annual	Lifetime	Notes
Federal Funds	$25,000,000.00		EERMC - sourced
Federal Funds for next 3 Years (adjusted taking out PPA)	$23,250,000.00		Assume 7% covers PPA
MMBtu Savings/$	0.002156224	0.038644376	2023 BCR
Estimate Total Savings (MMBtu) (3 yr)	50,132.22	898,481.74	Calc (assumes $25M spent over 3-year period)
% Delivered Fuel Customers participating in EE	16.24%		Delivered Fuel Bill Impact Model
Estimated Total Gas Savings (MMBtu)	41,990.75	752,568.31	Calc (assumes $25M spent over 3-year period)
Estimated Total Delivered Fuel Savings (MMBtu) (3 yr)	8,141.47	145,913.43	Calc (assumes $25M spent over 3-year period)

IRA: HOMES	Annual	Lifetime	Notes
Federal Funds Total	$32,006,100.00		OER sourced - 8 years of funding
Federal Funds for next 3 Years	$12,002,287.50		estimated 3 year spend
Federal Funds for next 3 Years (adjusted taking out PPA)	$11,162,127.38		Assume 7% covers PPA
MWh Savings/$	0.001425098	0.007797323	BCR
Estimated Total Savings (MWh) (3yr)	15,907.13	87,034.71	Calc

IRA: HEEHRA - Electrification	Annual	Lifetime	Source
Federal Funds Total	$31,820,030.00		OER soruced - 8 years of funding
Federal Funds for next 3 Years	$11,932,511.25		estimated 3 year spend
Federal Funds for next 3 Years (adjusted taking out PPA)	$11,097,235.46		Assume 7% covers PPA
MMBtu Savings/$	0.002024228	0.035201527	2023 BCR
Estimated Total Savings (MMBTu)	22,463.33	390,639.64	Calc

RIIB Savings:	Annual	Lifteime	Source
Estimated Total 3 YR Spend	$8,659,877.90		Assumed identical spend over 3 years, utilized 2017-2022 ratio spend to calculate baseline
Total Annual Savings (MWh) (3yr)	7217.87	42,441.06	Assumed identical savings over 3 years, utilized 2017-2022 ratio savings to calculate baseline

RGGI EE	Annual	Lifetime	Source
Total Funds (3 Year)	$3,750,000.00		Assume indentical spend seen in 2023 proposed plan and only 50% of EE/Renewable energy projects in RI associated to EE, 7% PPA.
Total Funds (adjusted taking out PPA)	$3,487,500.00		Assume 7% covers PPA
MWh Savings/$	0.001011119	0.008082695	24-26 BCR
Estiamted Total Savings (MWh) (3yr)	3,526.28	28,188.40	Calc

WAP Funding (3Yr)	Annual	Lifteime	Source
Total Funding	$4,349,964.00		Savings are caputred under RIE, assume even split amongst gas/electric/delivered fuel budgets

Savings Totals

Fuel Type	Annual	Lifetime
Electric (MWh)	26,651.27	157,664.17
Gas (MMBtu)	64,454.08	1,143,207.94
Delivered Fuels (MMBtu)	8,141.47	145,913.43

Non-Programmatic Savings

Electric Savings (MWh)

Year	Annual	Lifetime	Notes
2024	31,466	280,768	Free ridership rates from the 24-26 BCR was applied to electric savings to estimate non-programmatic savings
2025	32,106	293,123	
2026	34,199	309,386	
Total	97,770	883,277	

Gas Savings (MMBtu)

Year	Annual	Lifetime	Notes
2024	61,368	953,765	Free ridership rates from the 24-26 BCR was applied to gas savings to estimate non-programmatic savings
2025	64,080	988,642	
2026	66,913	1,022,647	
Total	192,361	2,965,054	

Delivered Fuel Savings (MMBtu)

Year	Annual	Lifetime	Notes
2024	7,715	154,932	Free ridership rates from the 24-26 BCR was applied to delivered fuel savings to estimate non-programmatic savings
2025	8,494	161,387	
2026	8,855	168,925	
Total	25,064	485,244	

Other RI Utility Inputs - Electric (MWh)

Utility	Annual	Lifetime	Notes
Pascoag Utility (MWh)	7014	49238.28	Sourced from ACCEE 2022 Annual Scorecard, lifetime assumed 702% increase based on RIE increase from annual to lifetime savings)
Block Island Savings (MWh)	30.9	216.918	Sourced from ACCEE 2022 Annual Scorecard, lifetime assumed 702% increase based on RIE increase from annual to lifetime savings)
Total Savings	7044.9	49455.198	Sum

Utility	Budget	Notes
Pascoag + Block Island	$ 9,996,207.38	Assumed similar saving/spend ratio to RIE