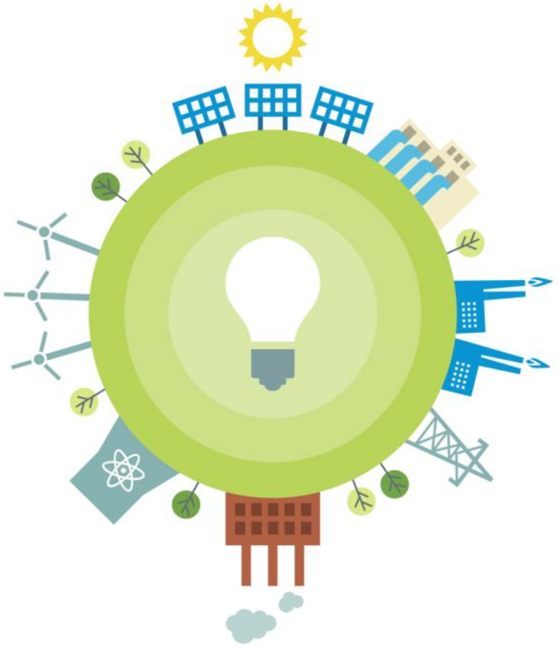
MAY 1, 2021

Final 2021 Heating Electrification Forecast

Outline

- Introduction & Forecast Framework
- Air-Source Heat Pump (ASHP) Adoption
- ASHP Energy Forecast
- ASHP Demand Forecast



Acronyms

- **AMI** – Advanced Metering Infrastructure
- **ASHP** – Air-Source Heat Pump
- **CELT** – Capacity, Energy, Loads and Transmission
- **GHG** – Greenhouse Gas
- **GSHP** – Ground-Source Heat Pumps
- **GWH** – Gigawatt-Hour
- **HDD** – Heating Degree Days
- **HE** – Hour Ending
- **LFC** – Load Forecast Committee
- **MW** – Megawatt
- **RSP** – Regional System Plan

Introduction

- Heating electrification is expected to play a pivotal role in the achievement of New England state greenhouse gas (GHG) reduction mandates and goals
- Forecasted impacts of heating electrification on state and regional electric energy and demand are included as part of the 2021 Capacity, Energy, Loads, and Transmission (CELT) forecast
  - The ISO recognizes that heating electrification is a nascent trend, and expects that while its 2021 forecast methodology builds on the methodology used for the 2020 forecast, further improvements will be needed as policy drivers and state initiatives are developed and additional data become available
- The 2021 heating electrification forecast focuses on adoption of air-source heat pumps (ASHPs)
  - Consideration of other heating electrification technologies, such as ground source heat pumps (GSHPs) and heat pump hot water heaters (HPHWs), may also be warranted in future forecasts
  - **Forecast is relevant for winter months only (January-April, and October-December)**
- ISO discussed methodology, assumptions, and related energy and demand impacts associated with the heating electrification forecast at the NEPOOL Load Forecast Committee (LFC), including the following presentations:
  - Background and assumptions the September 25, 2020 and November 13, 20120 LFC meetings;
  - The draft 2021 electrification forecast at the December 11, 2020 LFC meeting;
  - The final draft 2021 electrification forecast at the February 19, 2021 LFC meeting

Forecast Framework

- There are two general components to the forecast:
  1. Forecast the adoption of ASHPs for each state and the region over the next ten years
     - *New in 2021 Forecast:* *Include a breakdown of shares of ASHPs that are expected to be installed in full versus partial heating applications*
  2. Use data-driven assumptions to convert the ASHP adoption forecast into estimated impacts on monthly energy and demand by state
     - *New in 2021 Forecast:* *Updated data-driven assumptions for both partial and full heating ASHP applications*

ASHP ADOPTION FORECAST

ASHP Adoption Assumptions

State	State Guidance on ASHP Adoption Assumptions	Shares (Partial/Full) of Heating Provided by ASHP Growth
CT	CT officials provided values for 2021-2030	Approximately 16% are full heating, 2021-2030
MA	2021 planned installations provided by MA EE Program Administrators; growth thereafter provided by MA	10% of annual growth is full heating in 2021, with shares increasing each year until reaching 40% full heating by 2030
ME	2021-2022 values from Efficiency Maine Trust; 3% annual growth assumed thereafter; adoption values align with Maine's Climate Action Plan	Based on Maine's Climate Action Plan, ASHP shares in full heating applications total almost 35,000 by 2025 and almost 116,000 by 2030
NH	2021 Planned installations provided by NH EE Program Administrators; 20% annual growth thereafter	2% of annual growth is full heating over 2021-2023, with shares increasing 2% each year thereafter
RI	2021 planned installations provided by RI EE Program Administrators; 20% annual growth thereafter	10% of annual growth is full heating in 2021, with shares increasing each year until reaching 40% full heating by 2030
VT	2021-2030 values provided by Efficiency Vermont	10% of annual growth is full heating in 2021, with shares increasing each year until reaching 40% full heating by 2030

ASHP Adoption Forecast

Includes Assumed Legacy Electric Heat Replacement

Year	Annual ASHP Installs (Thousands)						
	CT	MA	ME	NH	RI	VT	ISO-NE
2021	3.0	18.4	17.8	2.9	1.9	6.0	50.0
2022	3.5	21.1	22.2	3.9	2.3	6.2	59.2
2023	4.0	24.3	22.9	5.1	2.7	6.9	65.9
2024	4.6	42.0	23.5	5.6	3.3	7.5	86.5
2025	5.2	59.6	24.3	6.2	3.9	8.0	107.2
2026	6.1	75.5	25.0	6.8	4.7	8.5	126.5
2027	7.0	89.4	25.7	7.5	5.7	9.0	144.2
2028	8.0	103.6	26.5	8.2	6.8	9.5	162.6
2029	9.2	114.3	27.3	9.1	8.2	10.0	178.0
2030	10.6	121.9	28.1	10.0	9.8	10.5	190.8
Cumulative Total	**61.0**	**669.9**	**243.3**	**65.4**	**49.4**	**82.2**	**1171.1**

Approx. Share of Households with ASHP in 2030 (%) *	**4.2%**	**23.4%**	**40.2%**	**10.9%**	**11.0%**	**29.5%**	**18.8%**
Approx. Share of Legacy Electric Heat Replacement **	**16%**	**15%**	**6%**	**9%**	**10%**	**5%**	**13%**

* Based on Moody's Analytics November 2020 forecast of number of households by state

** Source: U.S. Census Bureau, Selected Housing Characteristics, 2013-2017 American Community Survey 5-year Estimates

Final 2021 ASHP Adoption Forecast

Excludes *Assumed Legacy Electric Heat Replacement*

- ASPH adoption values tabulated are net of installations assumed to replace legacy electric resistance heat
  - Assumed state shares of ASHP installations that replace resistance heat are based on state residential shares with electric heat listed as primary heat source in 2017 census data (see prior slide)

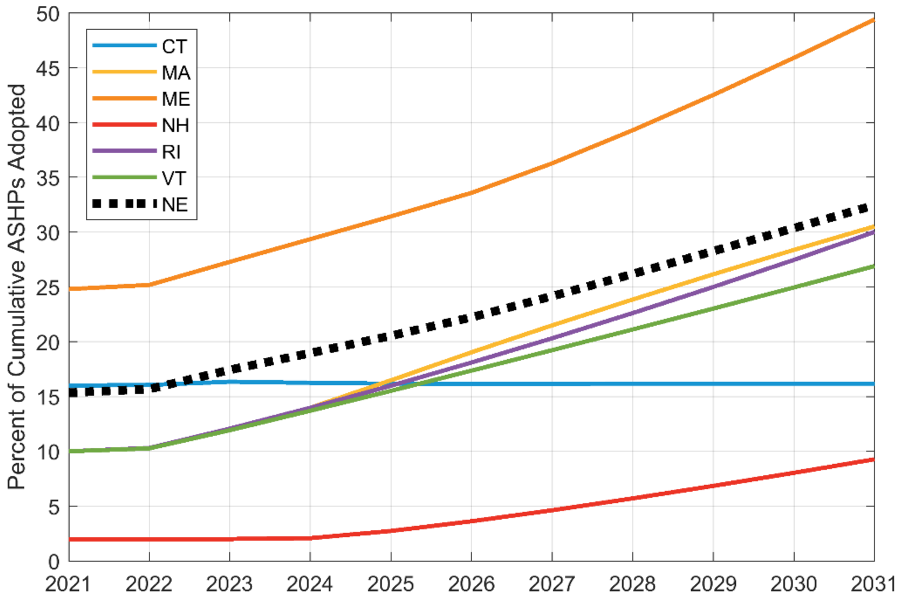
- Without data to verify otherwise, no net impact on winter energy and demand is assumed for applications with legacy electric heat, recognizing:
  - Some installations will replace active resistance heating systems (resulting in decreased electricity use), but others may replace unused resistance heating systems (resulting in increased electricity use) or result in continued use of resistance or other pre-existing backup systems during cold weather conditions

Year	Annual ASHP Installs (Thousands)						
	CT	MA	ME	NH	RI	VT	ISO-NE
2021	2.5	15.6	16.7	2.7	1.7	5.7	44.9
2022	2.9	17.9	20.9	3.6	2.1	5.9	53.3
2023	3.3	20.7	21.5	4.7	2.5	6.6	59.2
2024	3.8	35.7	22.1	5.1	3.0	7.1	76.9
2025	4.4	50.7	22.8	5.6	3.6	7.6	94.6
2026	5.1	64.1	23.5	6.2	4.3	8.1	111.2
2027	5.8	75.9	24.2	6.8	5.1	8.6	126.5
2028	6.7	88.0	24.9	7.5	6.1	9.0	142.3
2029	7.7	97.1	25.7	8.2	7.4	9.5	155.6
2030	8.9	103.6	26.4	9.1	8.8	10.0	166.8
Cumulative Total	**51.2**	**569.4**	**228.7**	**59.5**	**44.5**	**78.1**	**1031.3**

Full Heating ASHPs

Shares of Cumulative ASHP Adoption

- Regional shares of forecast ASHP adoption that are assumed to be installed in full heat applications increase over time
  - Partial heating applications are assumed to make up the remainder of ASHP installations
- The growing share of ASHPs in full heating applications drives a significant share of the energy and demand forecast growth in the later years of the heating electrification forecast

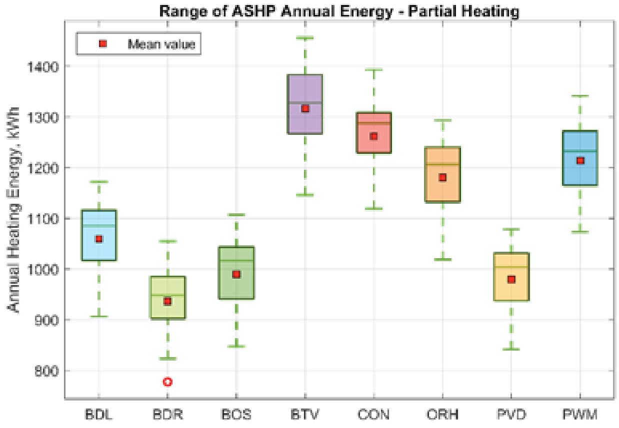


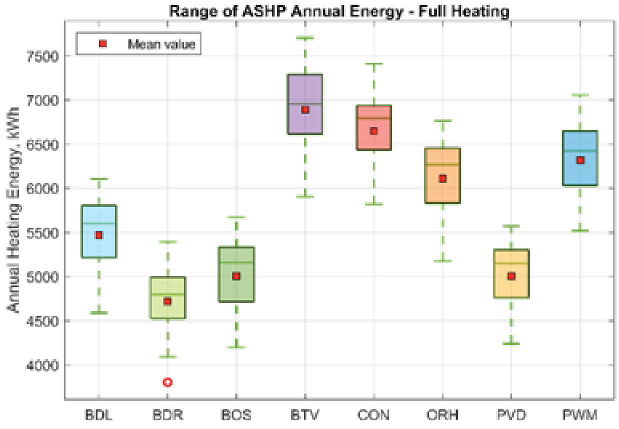
FINAL 2021 HEATING ELECTRIFICATION ENERGY FORECAST

Historical Simulations Using ASHP Models

- Hourly partial and full ASHP profiles were simulated based on regression models described in the Appendix and weather over the period 1996-2015 (20 years)
  - Corresponds to the "weather normal" period used for gross energy modeling
- Based on historical weather associated with ISO's 8 weather stations, the boxplots to the right reflect the varying amounts of annual ASHP heating energy (in kWh)
  - Modeled hourly demand is summed to annual heating energy
  - Mean values plotted represent "weather normal" energy per ASHP at each station

City, State	Weather Station
Boston, MA	BOS
Bridgeport, CT	BDR
Burlington, VT	BTV
Concord, NH	CON
Portland, ME	PWM
Providence, RI	PVD
Windsor Locks, CT	BDL
Worcester, MA	ORH





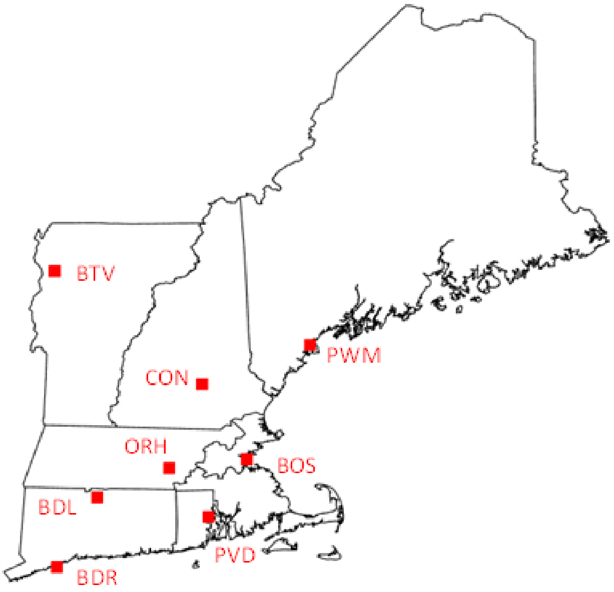
Weather Station Based ASHP Profiles

Station Weights for Each State

State ASHP energy are derived using station weights tabulated below

Weather Station (City, State)	Weather Station	CT	MA	ME	NH	RI	VT
Boston, MA	BOS	-	0.44	-	-	-	-
Bridgeport, CT	BDR	0.17	-	-	-	-	-
Burlington, VT	BTV	-	-	-	-	-	1.00
Concord, NH	CON	-	-	-	1.00	-	-
Portland, ME	PWM	-	-	1.00	-	-	-
Providence, RI	PVD	-	0.27	-	-	1.00	-
Windsor Locks, CT	BDL	0.83	0.16	-	-	-	-
Worcester, MA	ORH	-	0.13	-	-	-	-

Locations of weather stations



Estimating Energy Impacts of ASHP Adoption

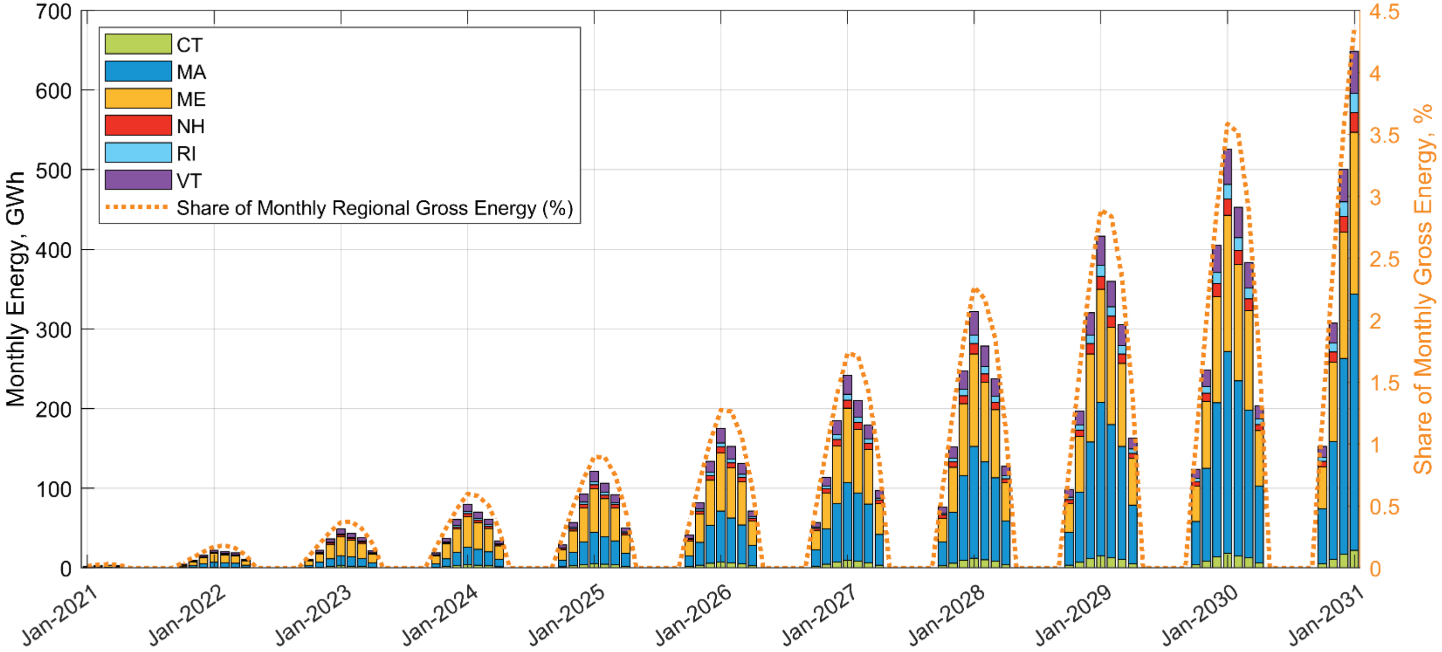
- The process for estimating monthly energy impacts for each state is as follows:
  1. Calculate the mean monthly energy value for the hourly demand simulations generated for each type of ASHP (i.e., full/partial) based on station-level weather described on previous slides
  2. Use station weights tabulated on slide 13 to convert to a state weather basis
  3. Multiply by the appropriate monthly ASHP adoption values for each ASHP type
  4. Sum resulting energy values for both ASHP type (i.e., full + partial ASHPs)
  5. Gross up by 6% to account for assumed transmission and distribution losses, consistent with other forecast processes

- Regional ASHP energy is the sum of the resulting state ASHP energy values

- Refer to slides 39-42 of the ISO's Long-Term Load Forecast Methodology Overview for background information on the methodology used for the gross energy forecast

Final 2021 Heating Electrification Forecast

Monthly Energy, GWh



Final 2021 Heating Electrification Forecast

Annual Energy, GWh

	Annual Energy (GWh)									
State	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Connecticut	2	7	13	19	27	35	45	57	70	85
Massachusetts	11	37	71	123	209	334	496	698	941	1,219
Maine	20	70	133	201	277	362	458	567	688	822
New Hampshire	2	6	12	19	28	38	50	64	81	100
Rhode Island	1	4	8	13	19	27	37	51	68	89
Vermont	5	17	31	48	68	90	115	144	176	211
Total	40	142	267	424	628	886	1,203	1,581	2,023	2,526

FINAL 2021 HEATING ELECTRIFICATION DEMAND FORECAST

Estimating Demand Impacts of ASHP Adoption

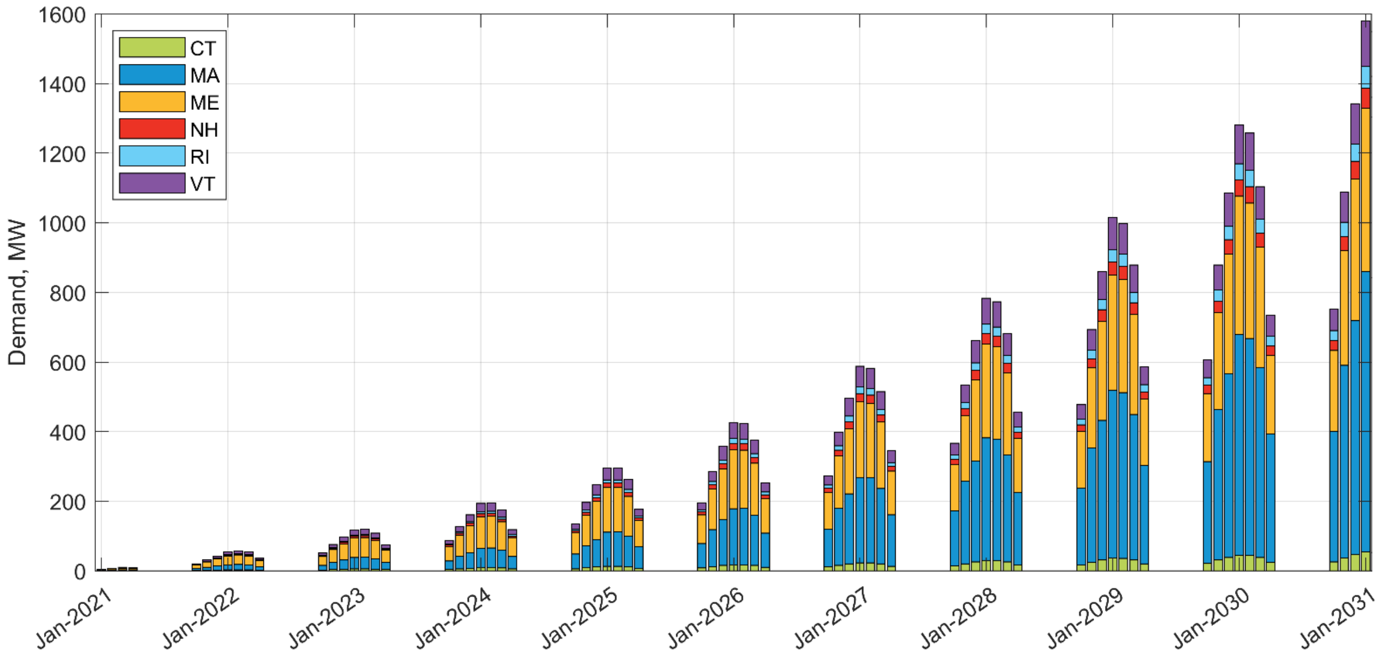
- The weekly weather distributions used to generate weekly gross load forecast distributions are used to estimate monthly ASHP demand impacts for each state as follows:
  1. Input weekly state weather distributions (for each week in a given month) to the hour ending 18 demand regression model for each type of ASHP (i.e., full/partial)
  2. Multiply resulting per ASHP demand value by the appropriate monthly ASHP adoption values for each ASHP type
  3. Sum resulting demand values for both ASHP type (i.e., full + partial ASHPs)
  4. Calculate the "50/50" (i.e., "P95") and "90/10" (i.e., "P99") values for each week of the forecast; maximum 50/50 and 90/10 values in each month are monthly demand forecasts
     - Aligns with the percentiles used in the gross load forecast
  5. Gross up by 8% to account for assumed transmission and distribution losses, consistent with other forecast processes

- Regional ASHP demand is the sum of the resulting coincident state ASHP demand values

- Refer to slides 43-49 of the ISO's Long-Term Load Forecast Methodology Overview for background information on the methodology used for the gross demand forecast

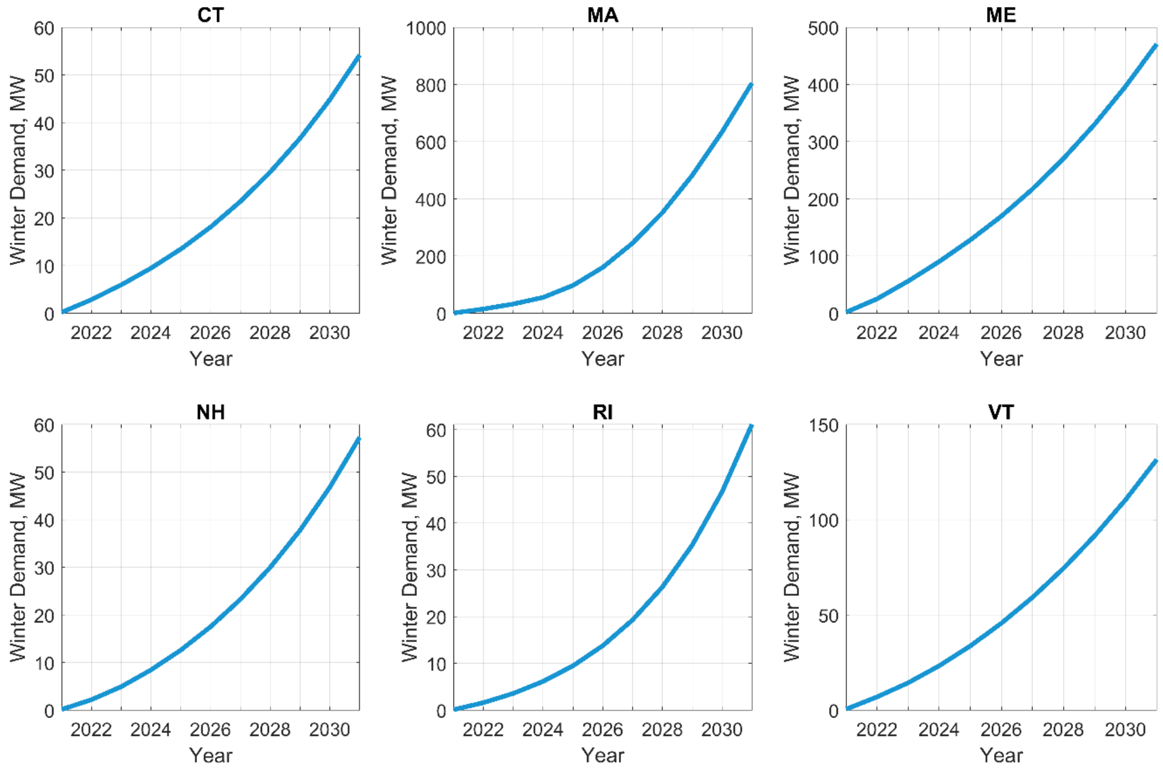
Final 2021 Heating Electrification Forecast

Monthly Demand, MW (50/50)



Final 2021 Heating Electrification Forecast

State-by-State Winter (January) Peak Demand, MW (50/50)



Final 2021 Heating Electrification Forecast

Winter (January) Demand, MW (50/50)

	Winter Peak (MW)									
State	**2021-22**	**2022-23**	**2023-24**	**2024-25**	**2025-26**	**2026-27**	**2027-28**	**2028-29**	**2029-30**	**2030-31**
Connecticut	3	6	9	13	18	23	28	36	44	53
Massachusetts	14	30	52	92	151	234	342	477	628	799
Maine	25	55	87	123	161	208	255	322	388	461
New Hampshire	2	5	8	12	17	23	29	37	46	56
Rhode Island	2	3	6	9	13	18	26	34	46	59
Vermont	7	14	22	33	45	58	71	89	107	128
Total	**52**	**114**	**185**	**283**	**406**	**563**	**751**	**995**	**1,259**	**1,556**

Heating Electrification Forecast

Reporting and Publications

- The final 2021 heating electrification forecast described herein is included in CELT 2021
  - All gross and net energy and demand forecasts reported in both 2021 CELT and in the 2021 Forecast Data workbook are inclusive of heating electrification
  - Breakout of annual energy and seasonal demand are reported in 2021 CELT Section 1.7, and 2021 Forecast Data worksheet 16
- For the 2021 forecast, the state energy and demand heating electrification forecasts are allocated to ISO Load Zones and Regional System Plan (RSP) Subareas based on information obtained during the ISO's annual Multiregional Modeling Working Group (MMWG) network model creation process
  - Load shares by substation are submitted by Transmission Owners, as described in Section 2.3 of the Transmission Planning Technical Guide Appendix J: Load Modeling Guide

APPENDIX

Analysis Supporting New Assumptions for 2021 Forecast

Using AMI Data for Insights

- The ISO updated its license with Sagewell, Inc. for anonymized advanced metering infrastructure (AMI) and associated data to help gain insights about changes to electricity consumption patterns due to the adoption of ASHPs
- Additionally, the ISO consulted with Sagewell to perform analysis to isolate the electricity demand impacts of two categories of ASHP installations:
  1. Partial heating applications – ASHPs that do not supply sufficient heat to meet full heating requirements
  2. Full heating applications – ASHPs that provide >95% of overall heating requirements, effectively heating the entire home

Peer Group Analysis

Development of Peer Groups

- To isolate the demand impacts of ASHP adoption within each category, Sagewell developed corresponding **peer groups** of AMI data to estimate the average electricity consumption of analogous homes without ASHPs

- Development of respective peer groups was designed to control for the demand effects of the following in the ASHP samples:
  - Building category (i.e., single family, condo, 2 family, etc.)
  - Photovoltaics installations
  - Electric vehicle charging
  - Gross living area
  - Legacy heating fuel

- Composition of final peer groups
  - Partial heating sample:
    - Exclude homes with PV
    - Used a portfolio comparison of similar homes
    - Consistent sample of approximately 5,500 homes
  - Full heating sample:
    - Include approximately 50 homes that matched the characteristics of **each** home in the ASHP sample

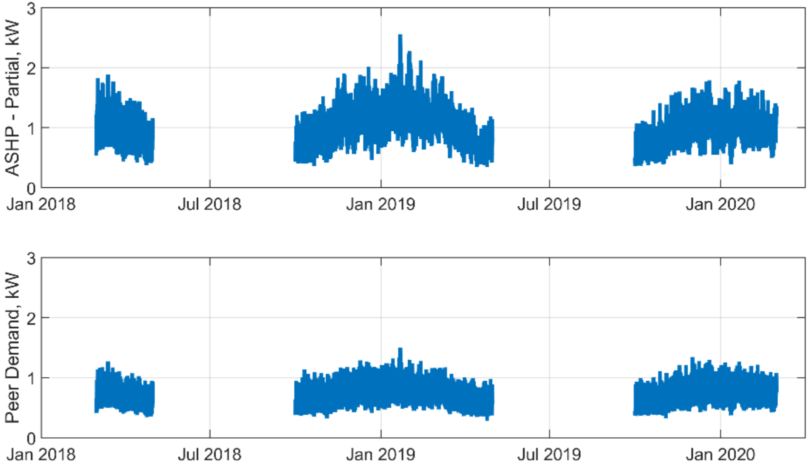
ASHP Category	# Homes in ASHP Sample	# Homes in Peer Group	Length of Data Period
Partial Heating	57-105	~5,500	2 years
Full Heating	6-14	250-800	1 year

Peer Group Analysis

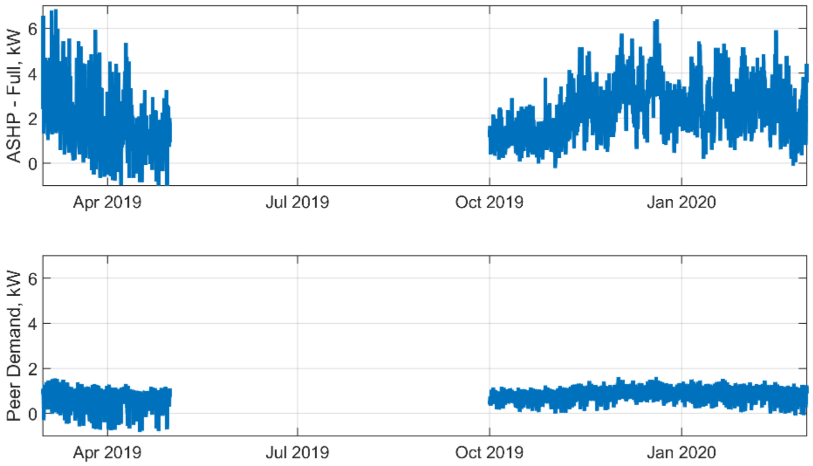
Resulting Demand Comparisons

- Average residential profiles within each ASHP category are compared to the average profiles of their respective peer group
  - Plots of hourly profiles from each ASHP category (top) and its peer group (bottom) are below
  - Both datasets end prior to the COVID-19 pandemic

Partial ASHP Heat & Peers

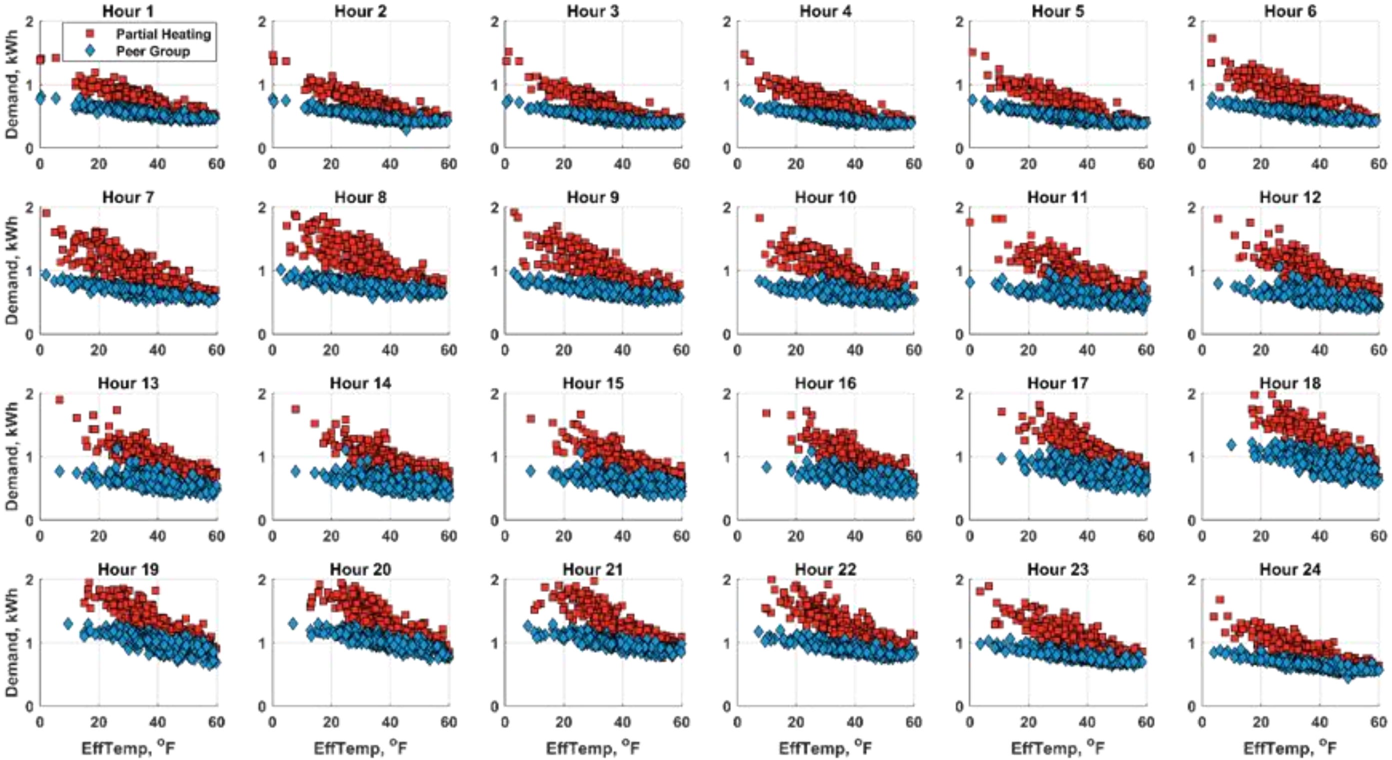


Full ASHP Heat & Peers



Peer Group Analysis – ASHP Partial Heating

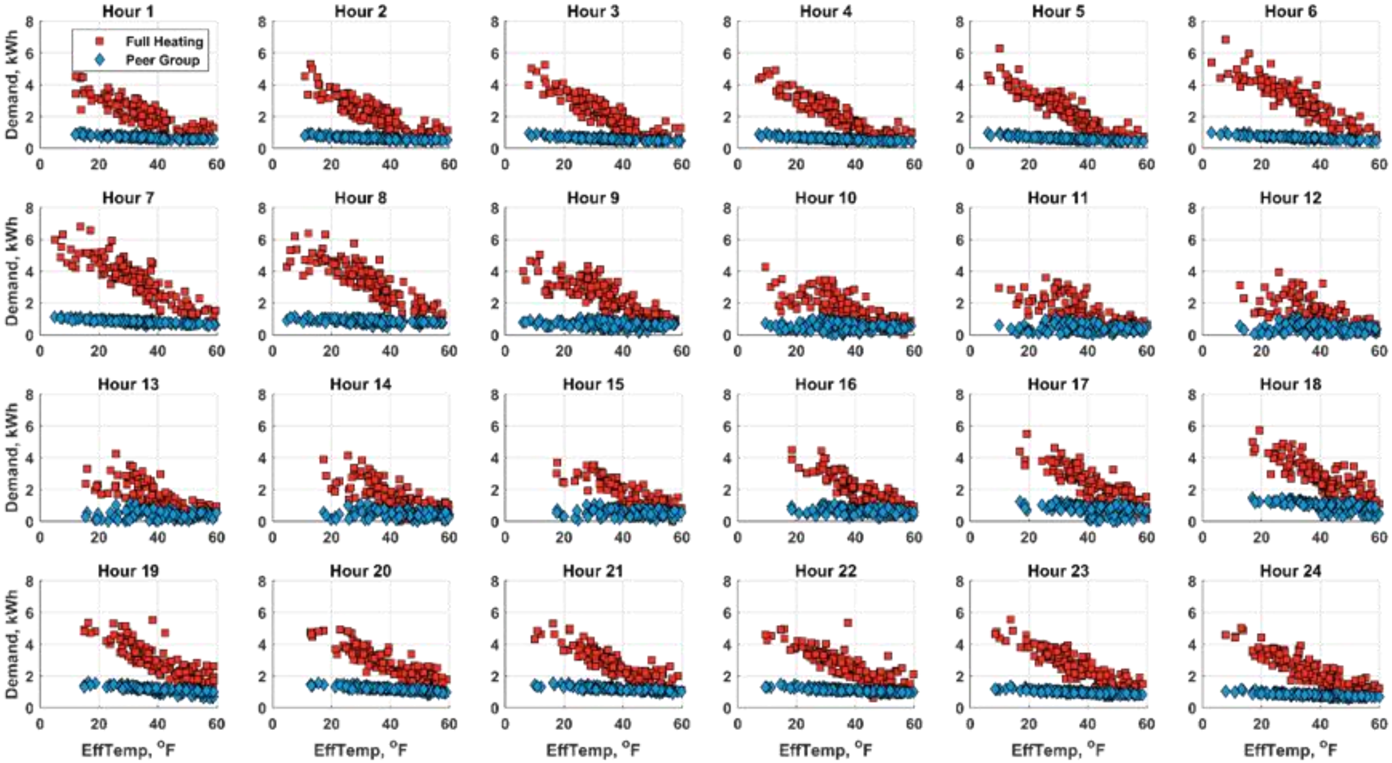
Winter Non-Holiday Weekdays



Note: Data illustrated reflect average total household demand

Peer Group Analysis – ASHP Full Heating

Winter Non-Holiday Weekdays



Note: Data illustrated reflect average total household demand

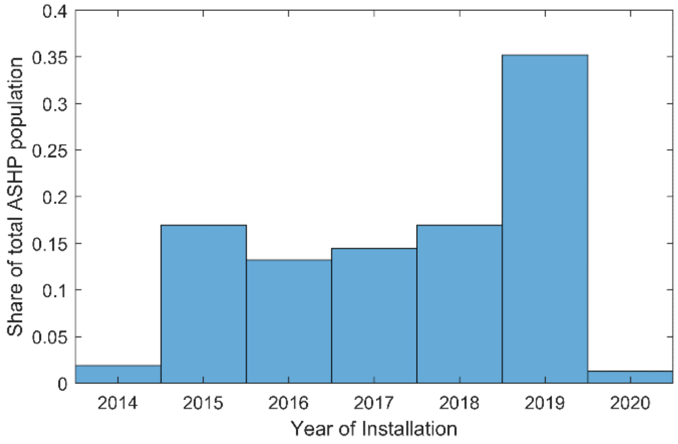
Normalization of Resulting ASHP Demand

- Raw ASHP demand profiles resulting from peer group analysis reflect:
  1. Distribution of home sizes within the ASHP AMI samples (see table)
  2. State-of-the-art of ASHP technologies commercially-available at the time of installation (see histogram of installation years)

- In comparison, the average New England home is ~1,700 square feet (SF), and ASHP technologies deployed in the coming years are expected to improve in terms of their overall coefficient of performance (COP)
  – Appropriate to "normalize" input data to reflect these factors

- As such, the following two scalar adjustment factors will be applied to raw ASHP demand profiles:
  1. House size adjustment factor
     - Partial heating: scaling factor = (1700/2000) = 0.85
     - Full heating: scaling factor = (1700/2100) = 0.81
  2. Forward-looking ASHP efficiency adjustment factor
     - Scaling factor = 0.90 (i.e., assumes a 10% improvement in ASHP average COP)

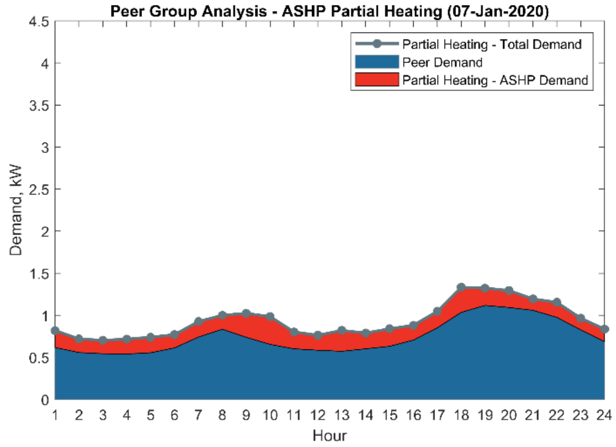
ASHP Group	Mean ASHP House Size
Partial Heating	2,000 SF
Full Heating	2,100 SF

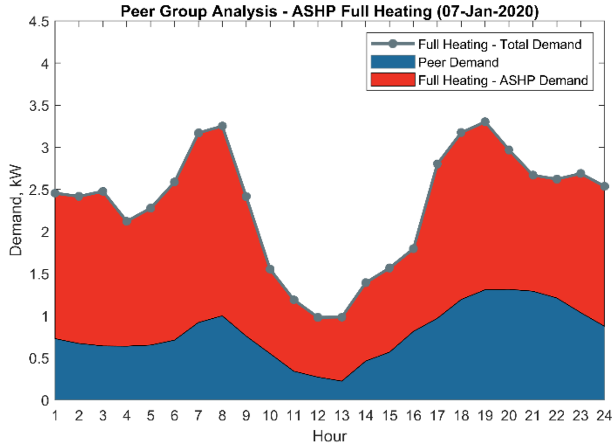


Final ASHP Demand

Example Day

- The final results of the peer group analysis and normalization are illustrated for January 7, 2020
  - Top plot: partial heating
  - Bottom plot: full heating
- Red area represents the estimated ASHP demand
  - Differences between the two red areas reflect the much greater ASHP utilization in full heating applications



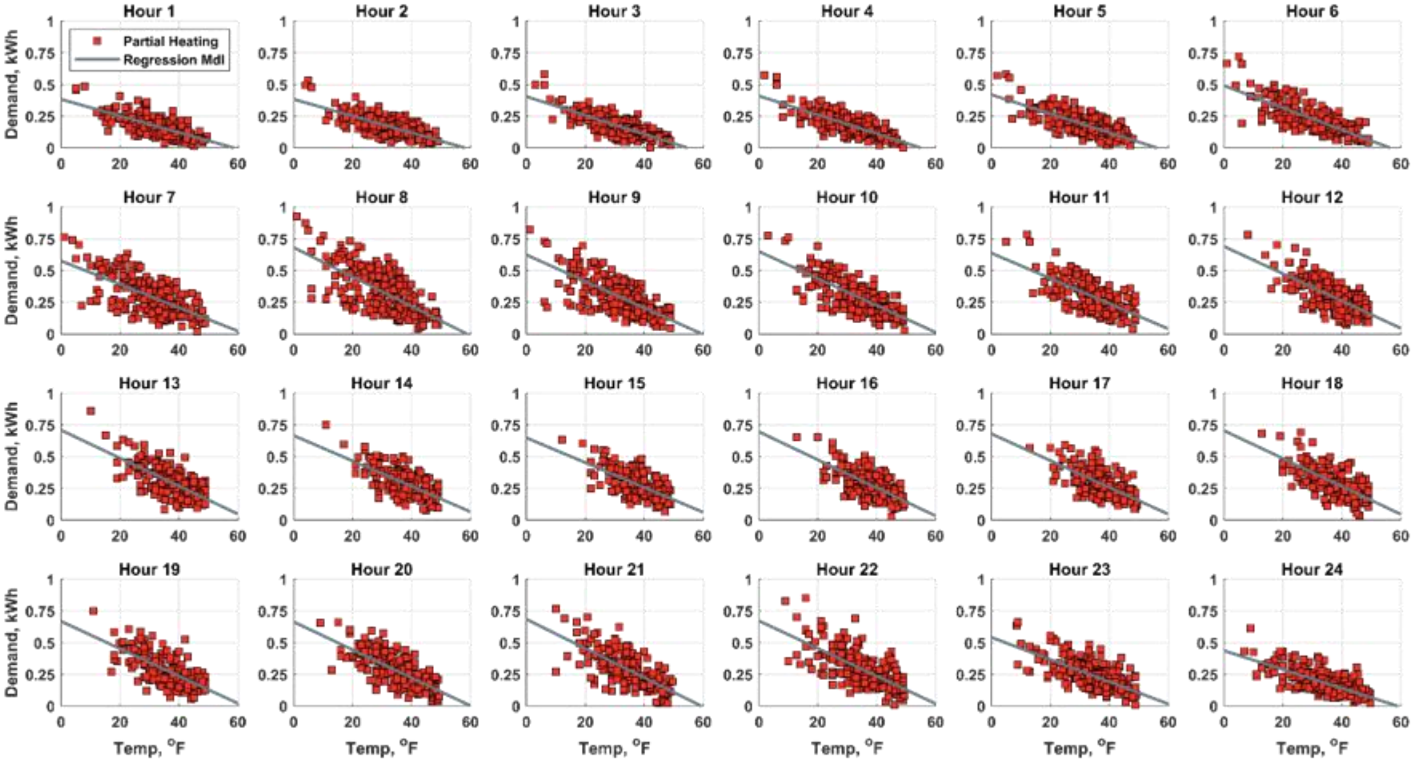


Modeling for 2021 Forecast

- Using the normalized ASHP demand data from Sagewell's peer group analysis, ISO developed hourly regression models for full and partial ASHP heating demand
  - Simple linear regression models for heating months (October-April)
    - Dry bulb temperature
  - Separate sets of models developed for:
    - Non-holiday weekdays
    - Holidays/weekends
- Scatter plots and resulting regression models for non-holiday weekdays are shown for ASHP partial and full heating datasets on the next slides
  - ASHP data reflect the normalization based on home size and ASHP technology improvements

Modeling – Partial Heating Applications

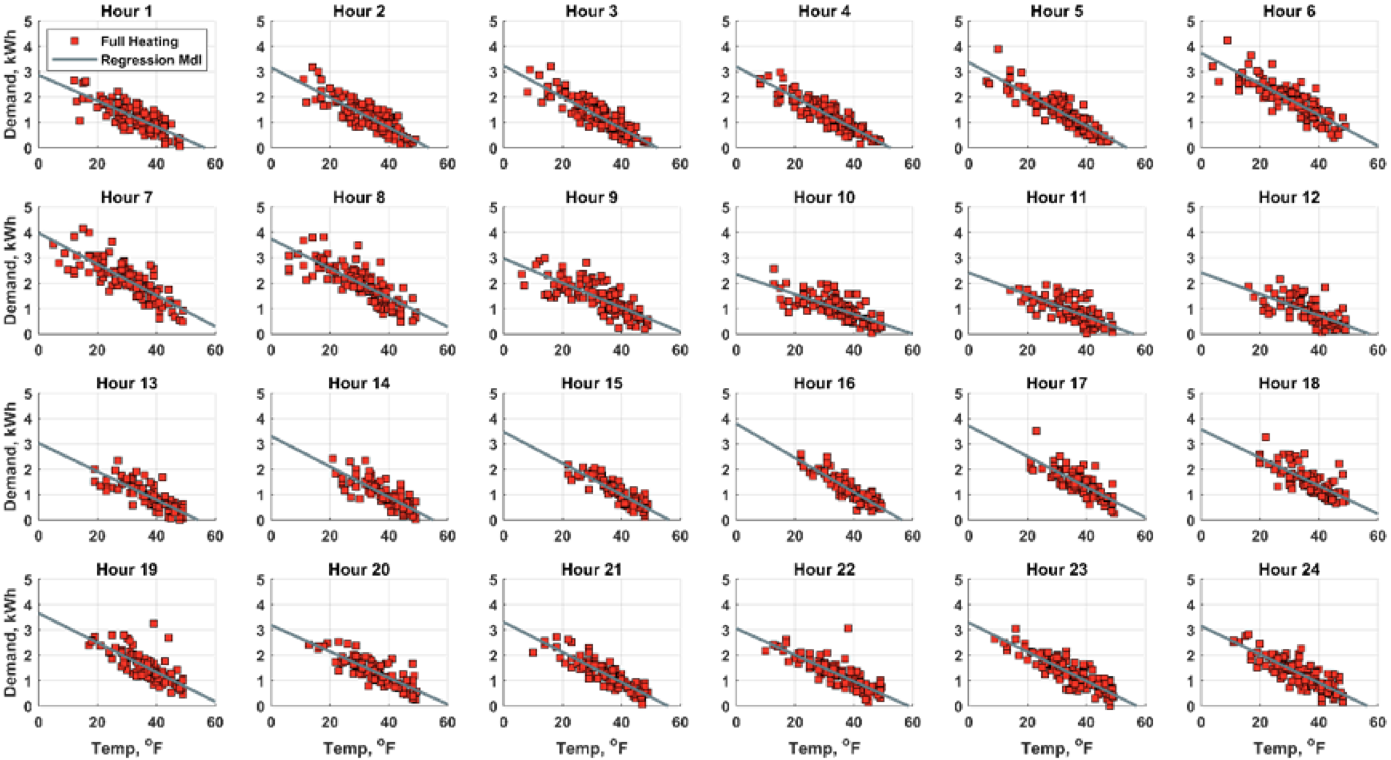
Winter Non-Holiday Weekdays Only



Note: Data illustrated reflect average ASHP demand (i.e., not total household demand) during hours with temperatures less than 50 degrees

Modeling – Full Heating Applications

Winter Non-Holiday Weekdays Only



Note: Data illustrated reflect average ASHP demand (i.e., not total household demand) during hours with temperatures less than 50 degrees