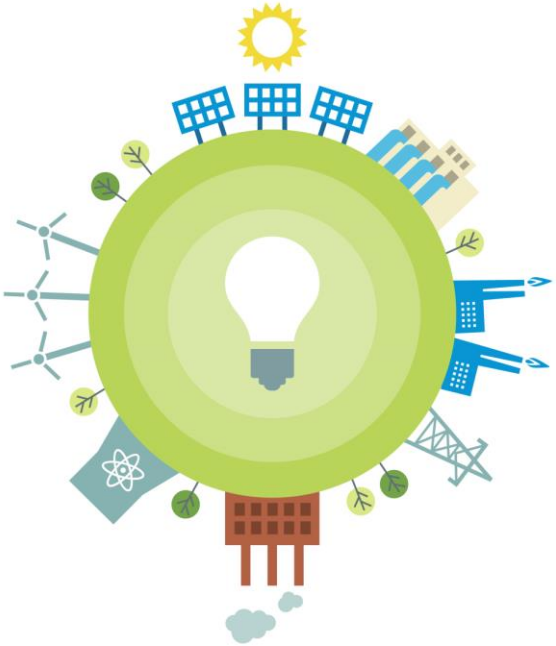
APRIL 28, 2022

Final 2022 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 2022 Capacity, Energy, Loads, and Transmission (CELT) forecast
- The 2022 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 November 12, 2021 LFC meetings;
  - The draft 2022 electrification forecast at the December 10, 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
  2. Use data-driven assumptions to convert the ASHP adoption forecast into estimated impacts on monthly energy and demand by state

ASHP ADOPTION FORECAST

ASHP Adoption Assumptions

State	State Guidance on ASHP Adoption Assumptions	Shares (Partial/Full) of Heating Provided by ASHP Growth
CT	Based on values provided by CT officials for the 2021 adoption forecast	Approximately 16% are full heating, 2022-2031
MA	Based on 2021 planned installations provided by MA EE Program Administrators; growth thereafter provided by MA officials	13% of annual growth is full heating in 2022, with annual shares increasing each year until reaching 43% full heating by 2031
ME	2022 values from Efficiency Maine Trust; 3% annual growth assumed thereafter; adoption values align with Maine's Climate Action Plan	29% of annual growth is full heating in 2022, with annual shares increasing each year until reaching 83% full heating by 2031
NH	Based on 2021 Planned installations provided by NH EE Program Administrators; 20% annual growth thereafter	2% of annual growth is full heating over period 2022-2023, with annual shares increasing 2% each year, reaching 18% in 2031
RI	Based on 2021 planned installations provided by RI EE Program Administrators; 20% annual growth thereafter	13% of annual growth is full heating in 2022, with annual shares increasing each year until reaching 43% full heating by 2031
VT	2022-2031 values provided by Vermont officials	13% of annual growth is full heating in 2022, with annual shares increasing each year until reaching 43% full heating by 2031

ASHP Adoption Forecast

Includes Assumed Legacy Electric Heat Replacement

Year	Annual ASHP Installs (Thousands)						
	CT	MA	ME	NH	RI	VT	ISO-NE
2022	3.5	21.1	22.2	3.9	2.3	10.7	63.7
2023	4.0	24.3	22.9	5.1	2.7	11.0	70.0
2024	4.6	42.0	23.5	5.6	3.3	11.4	90.4
2025	5.2	59.6	24.3	6.2	3.9	11.7	111.0
2026	6.1	75.5	25.0	6.8	4.7	12.0	130.1
2027	7.0	89.4	25.7	7.5	5.7	12.3	147.5
2028	8.0	103.6	26.5	8.2	6.8	12.7	165.8
2029	9.2	114.3	27.3	9.1	8.2	13.1	181.1
2030	10.6	121.9	28.1	10.0	9.8	12.2	192.5
2031	12.1	128.0	29.0	11.0	11.8	11.5	203.4
Cumulative Total	**70.1**	**779.5**	**254.5**	**73.4**	**59.3**	**118.6**	**1,355.4**
Approx. Share of Households with ASHP in 2031 (%) *	6.2%	28.9%	54.3%	13.9%	15.3%	51.4%	24.3%
Approx. Share of Legacy Electric Heat Replacement **	17%	16%	7%	9%	11%	6%	14%

* Based on Moody's Analytics February 2021 forecast of number of household by state

** Source: U.S. Census Bureau, Selected Housing Characteristics, 2015-2019 American Community Survey 5-year Estimates

Final 2022 ASHP Adoption Forecast

Excludes *Assumed Legacy Electric Heat Replacement*

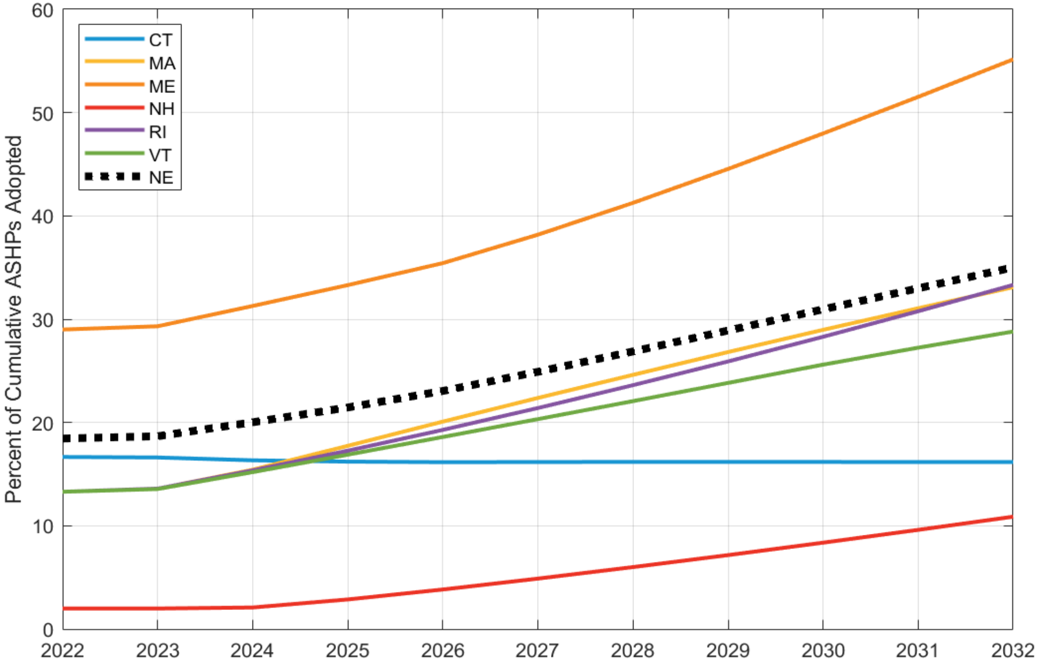
- ASPH adoption values tabulated are net of installations assumed to replace legacy electric resistance heat
  - Assumed state shares of ASHP installations that replace resistance heat are based on state residential shares with electric heat listed as primary heat source in 2019 American Community Survey 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
2022	2.9	17.7	20.6	3.6	2.0	10.1	57.0
2023	3.3	20.4	21.3	4.7	2.4	10.4	62.5
2024	3.8	35.3	21.6	5.1	2.9	10.7	79.7
2025	4.3	50.0	22.6	5.6	3.5	11.0	97.1
2026	5.0	63.4	23.3	6.2	4.2	11.3	113.4
2027	5.8	75.0	23.9	6.8	5.1	11.6	128.2
2028	6.6	87.0	24.6	7.5	6.1	11.9	143.7
2029	7.6	96.0	25.4	8.2	7.3	12.3	156.8
2030	8.8	102.4	26.1	9.1	8.7	11..4	166.5
2031	10.1	107.5	27.0	10.0	10.5	10.8	175.6
Cumulative Total	**58.2**	**654.7**	**236.4**	**66.8**	**52.7**	**100.1**	**1,180.5**

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

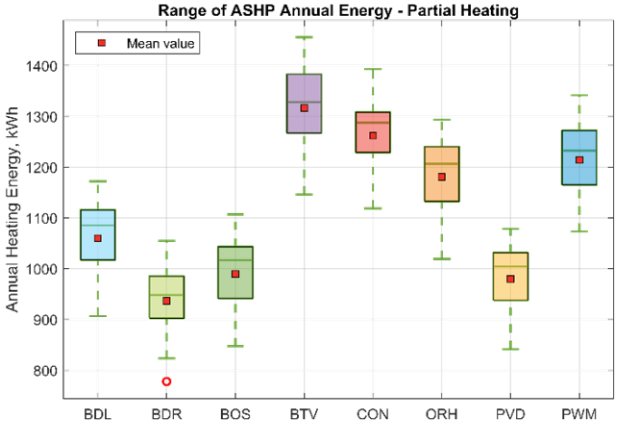


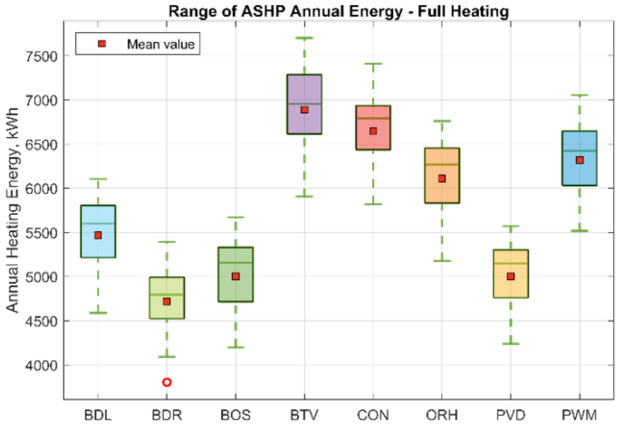
FINAL 2022 HEATING ELECTRIFICATION ENERGY FORECAST

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 1991-2020 (30 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





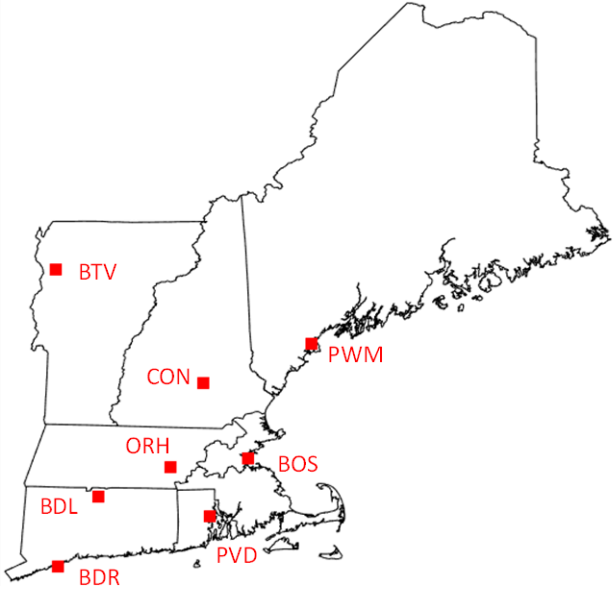
Weather Station Based ASHP Profiles

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

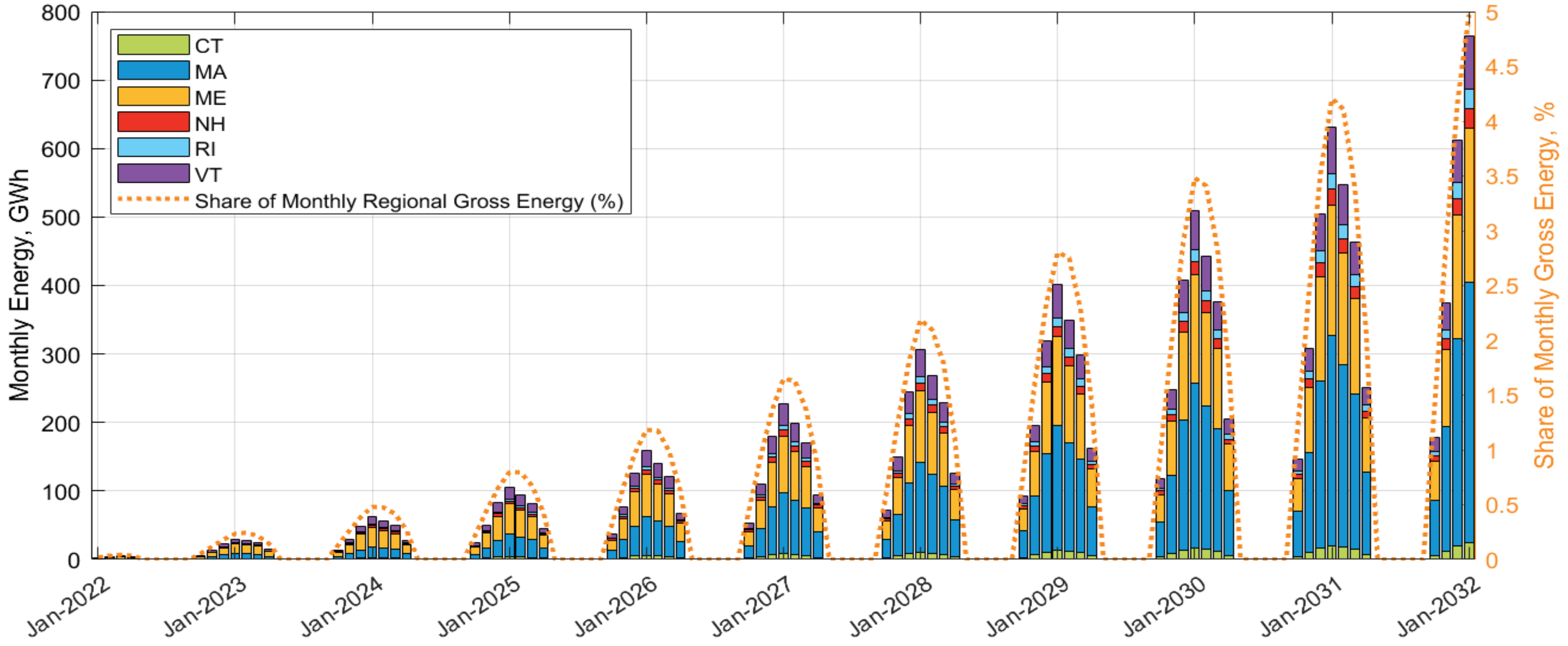
- The process for estimating monthly energy impacts for each state is as follows:
  1. Calculate the mean monthly energy value for the hourly demand simulations generated for each type of ASHP (i.e., full/partial) based on station-level weather described on previous slides
  2. Use station weights tabulated 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 37-40 of the ISO's Long-Term Load Forecast Methodology Overview for background information on the methodology used for the gross energy forecast

Final 2022 Heating Electrification Forecast

Monthly Energy, GWh



Final 2022 Heating Electrification Forecast

Annual Energy, GWh

	Annual Energy (GWh)									
Year	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
Connecticut	2	8	15	22	30	40	52	65	80	97
Massachusetts	13	46	98	184	306	467	666	906	1,180	1,487
Maine	27	89	157	233	317	413	521	641	775	923
New Hampshire	2	8	16	24	35	47	61	77	96	118
Rhode Island	1	5	10	16	24	35	48	64	85	112
Vermont	10	33	59	88	120	154	193	234	277	320
Total	**56**	**189**	**354**	**566**	**832**	**1,155**	**1,539**	**1,987**	**2,493**	**3,056**

FINAL 2022 HEATING ELECTRIFICATION DEMAND FORECAST

Estimating Demand Impacts of ASHP Adoption

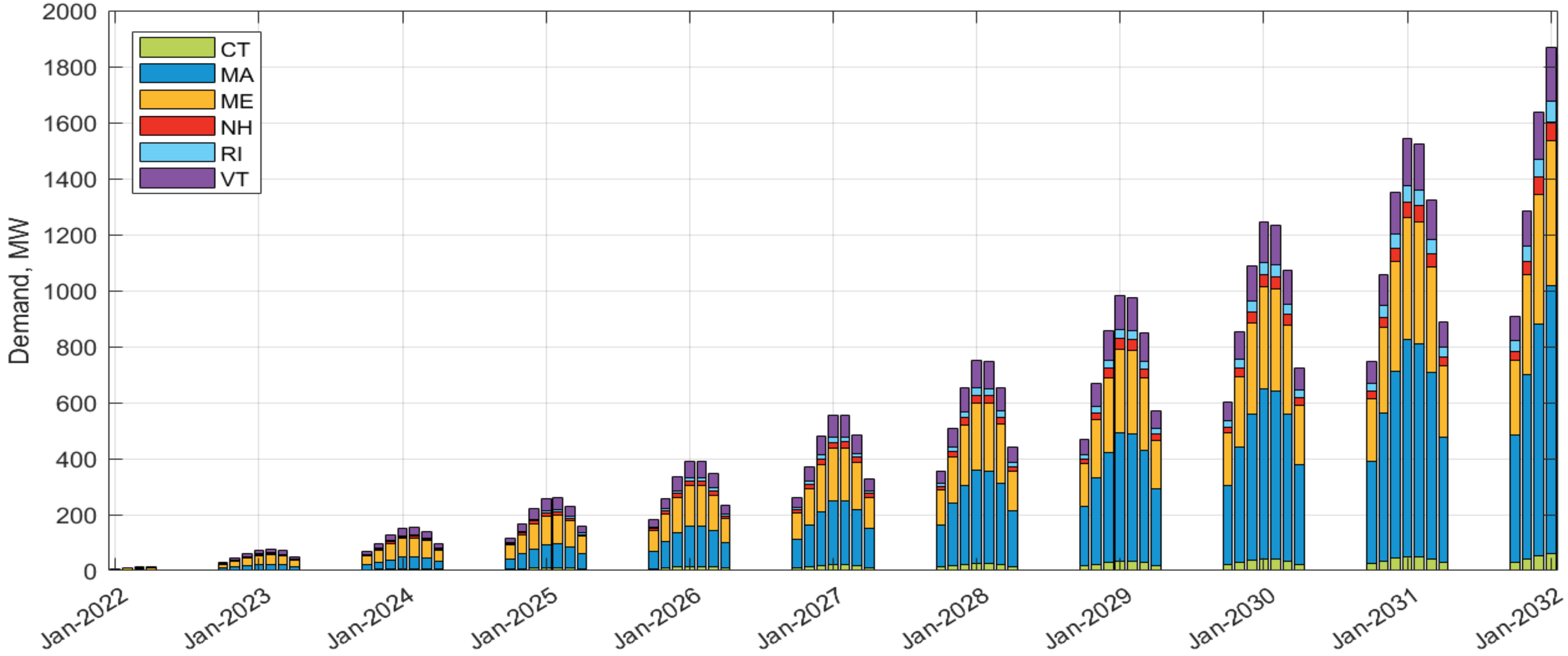
- The weekly weather distributions used to generate weekly gross load forecast distributions are used to estimate monthly ASHP demand impacts for each state as follows:
  1. Input weekly state weather distributions (for each week in a given month) to the hour ending 18 demand regression model for each 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 41-47 of the ISO's Long-Term Load Forecast Methodology Overview for background information on the methodology used for the gross demand forecast

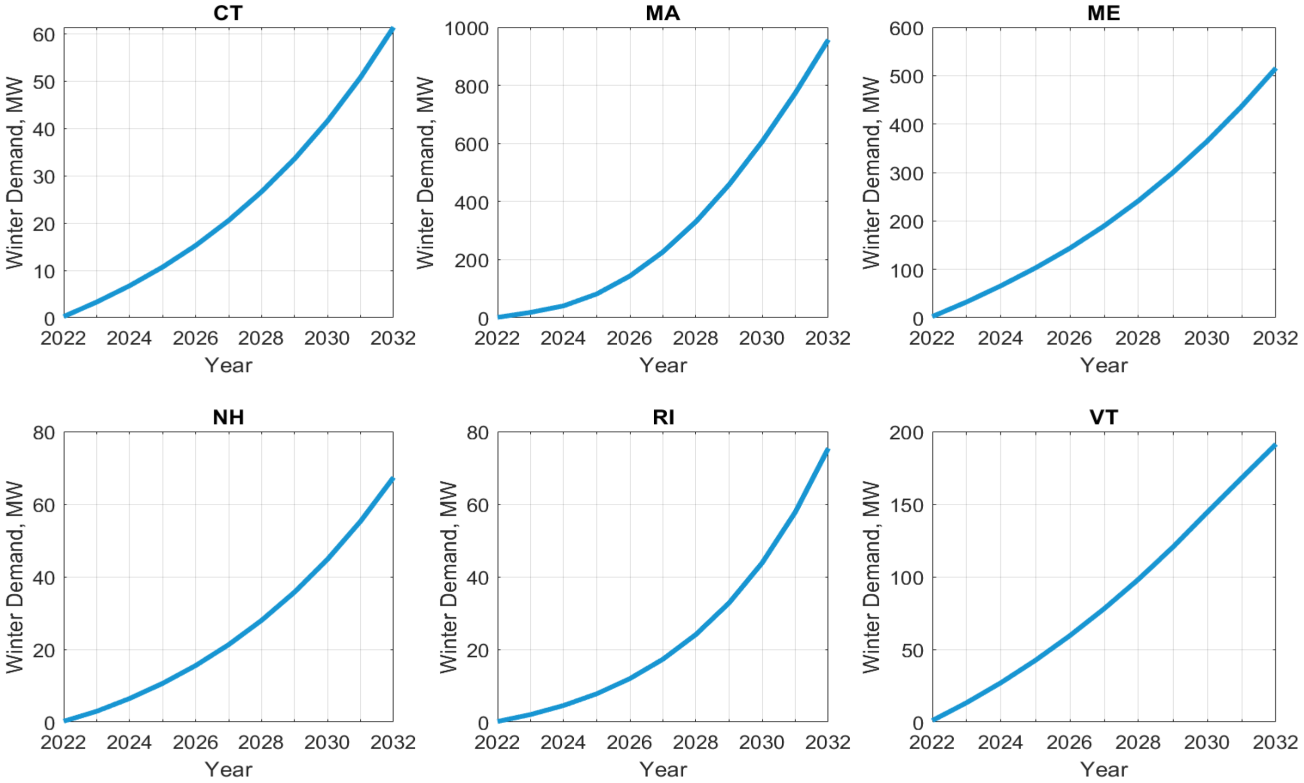
Final 2022 Heating Electrification Forecast

Monthly Demand, MW (50/50)



Final 2022 Heating Electrification Forecast

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



Final 2022 Heating Electrification Forecast

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

	Winter Peak (MW)									
Year	2022-23	2023-24	2024-25	2025-26	2026-27	2027-28	2028-29	2029-30	2030-31	2031-32
Connecticut	3	7	10	15	20	26	34	42	52	63
Massachusetts	17	37	77	137	218	326	449	594	766	962
Maine	31	63	101	144	188	236	294	359	445	533
New Hampshire	3	6	10	15	21	27	35	44	55	67
Rhode Island	2	4	7	12	18	24	33	44	58	78
Vermont	13	26	41	57	76	96	118	145	169	196
Total	**68**	**143**	**247**	**379**	**542**	**736**	**963**	**1,227**	**1,544**	**1,899**

Heating Electrification Forecast

Reporting and Publications

- The final 2022 heating electrification forecast described herein is included in CELT 2022
  - All gross and net energy and demand forecasts reported in both 2022 CELT and in the 2022 Forecast Data workbook are inclusive of heating electrification
  - Breakout of annual energy and seasonal demand are reported in 2022 CELT Section 1.7, and 2022 Forecast Data worksheet 16
- For the 2022 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

Modeling the Impacts of ASHP Adoption

Using AMI Data for Insights

- For the 2021 Forecast, ISO-NE 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, ISO-NE 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

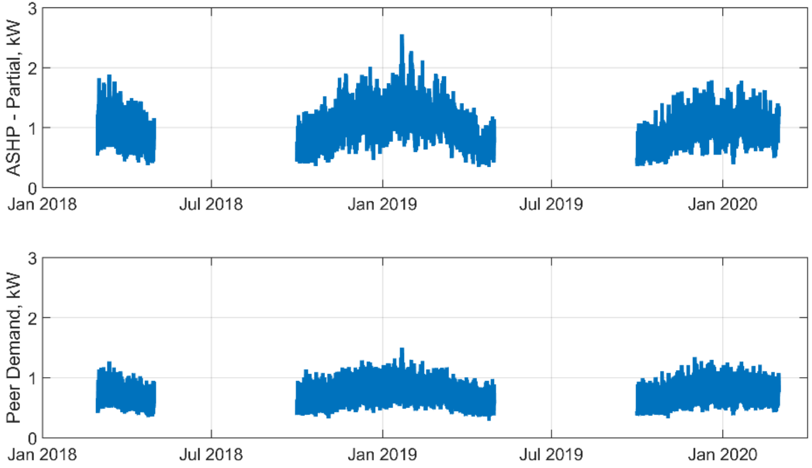
ASHP Category	# Homes in ASHP Sample	# Homes in Peer Group	Length of Data Period
Partial Heating	57-105	~5,500	2 years
Full Heating	6-14	250-800	1 year

Peer Group Analysis

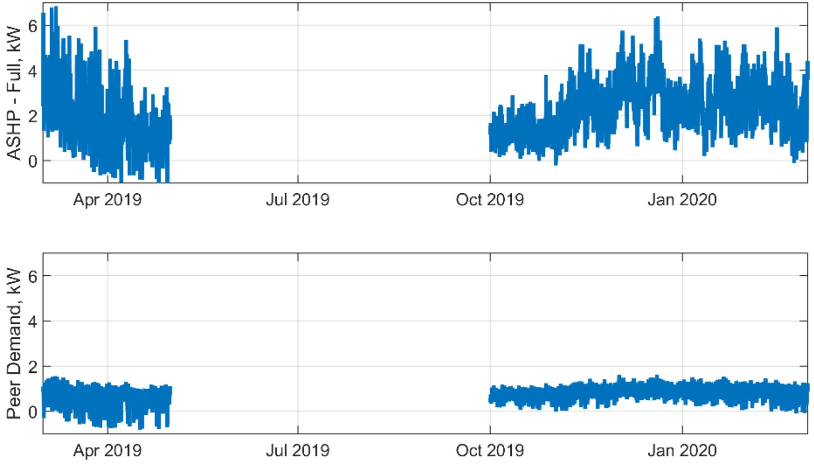
Resulting Demand Comparisons

- 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

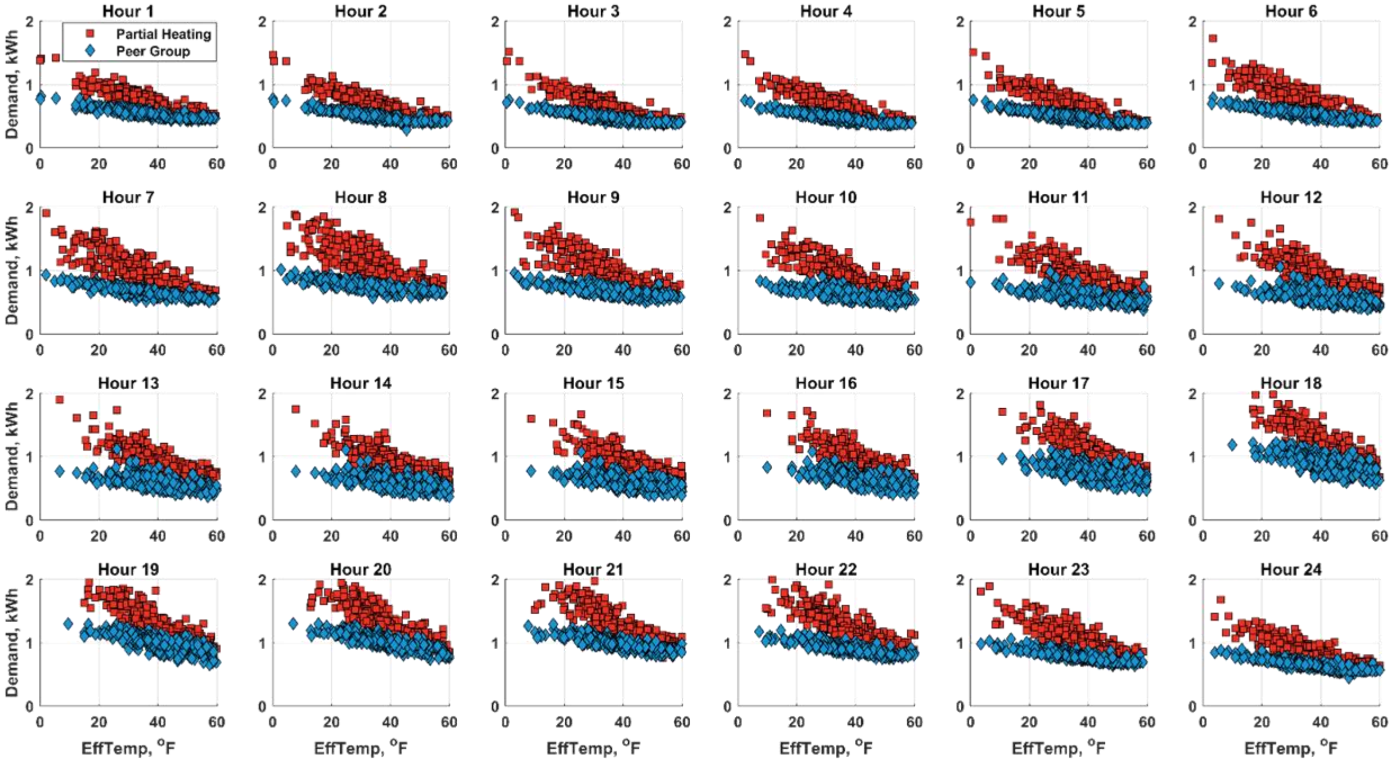


Full ASHP Heat & Peers



Peer Group Analysis – ASHP Partial Heating

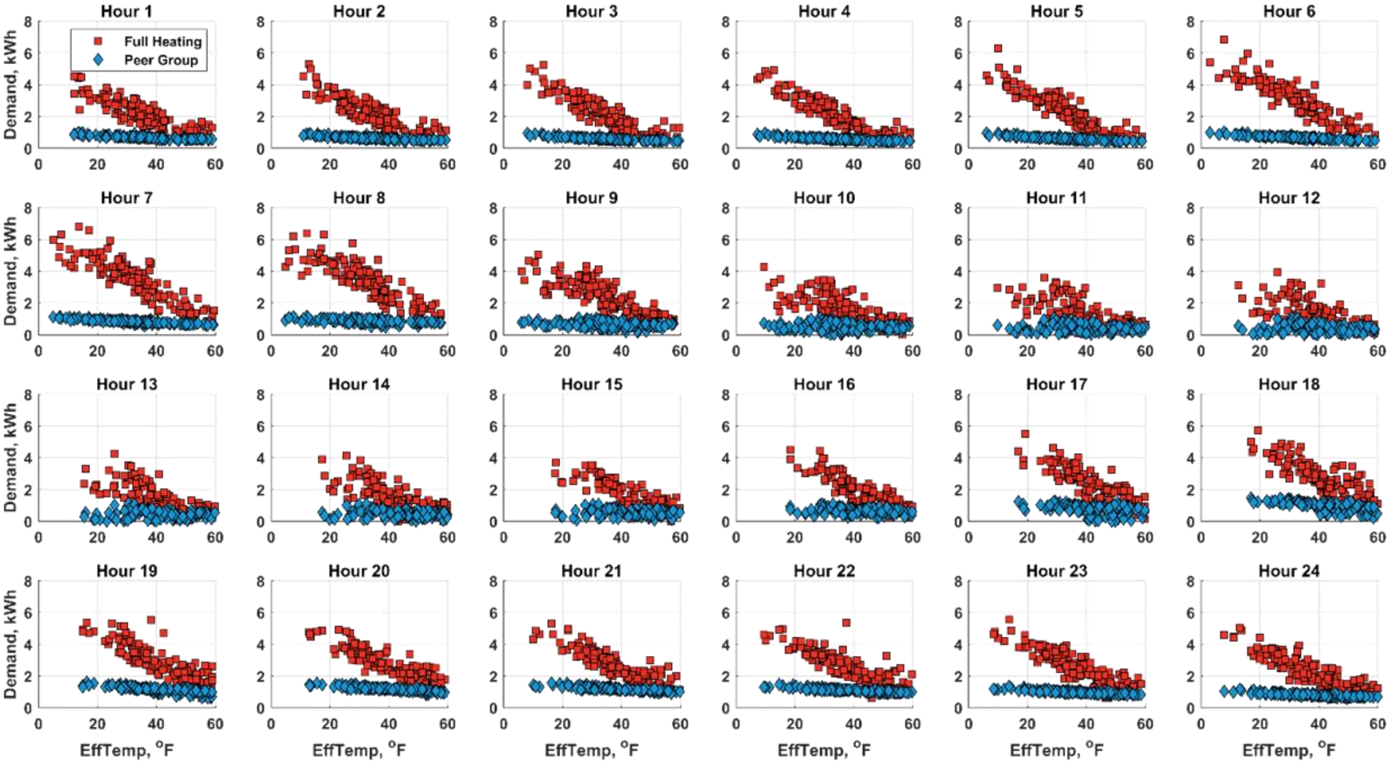
Winter Non-Holiday Weekdays



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

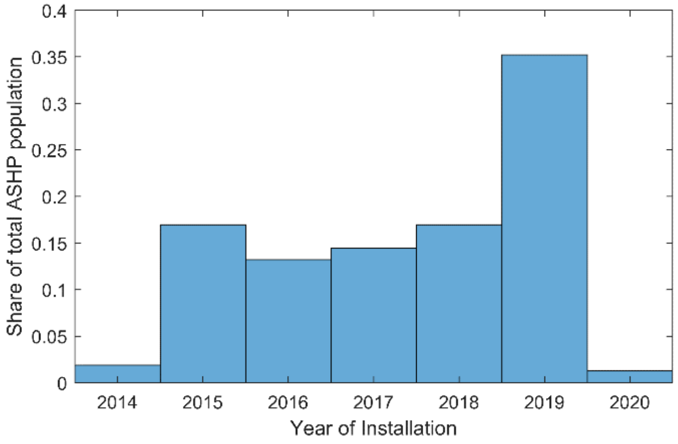
Normalization of Resulting ASHP Demand

- 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)

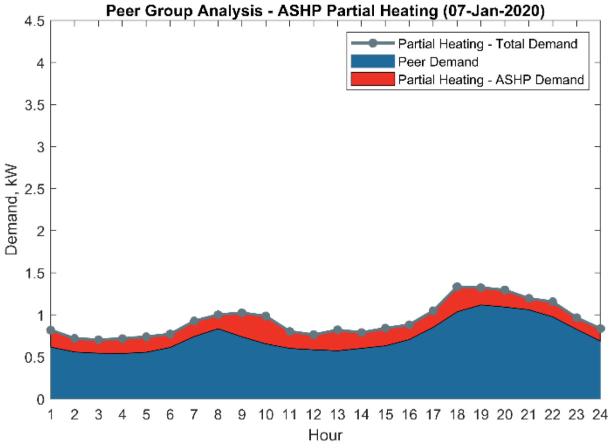
ASHP Group	Mean ASHP House Size
Partial Heating	2,000 SF
Full Heating	2,100 SF

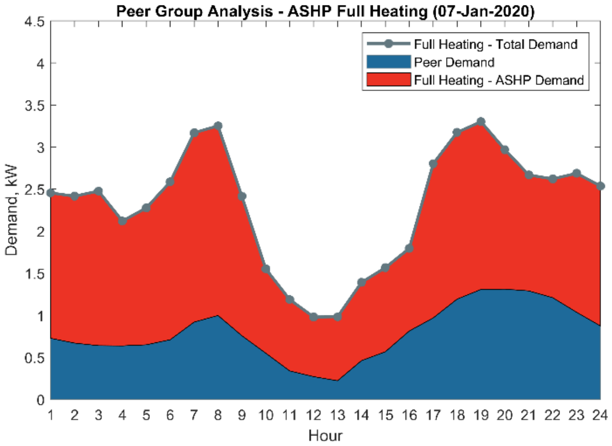


Final ASHP Demand

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



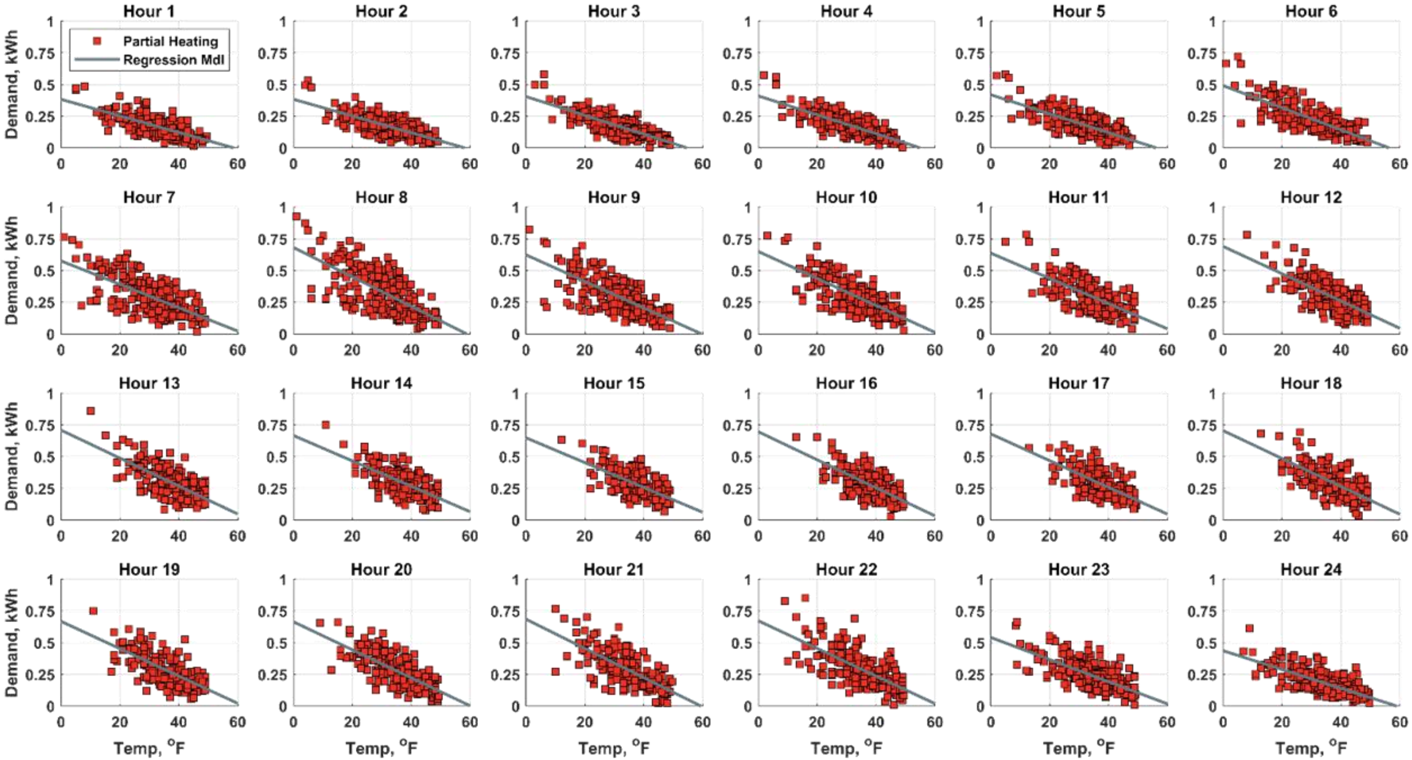


Modeling for 2021 Forecast

- 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

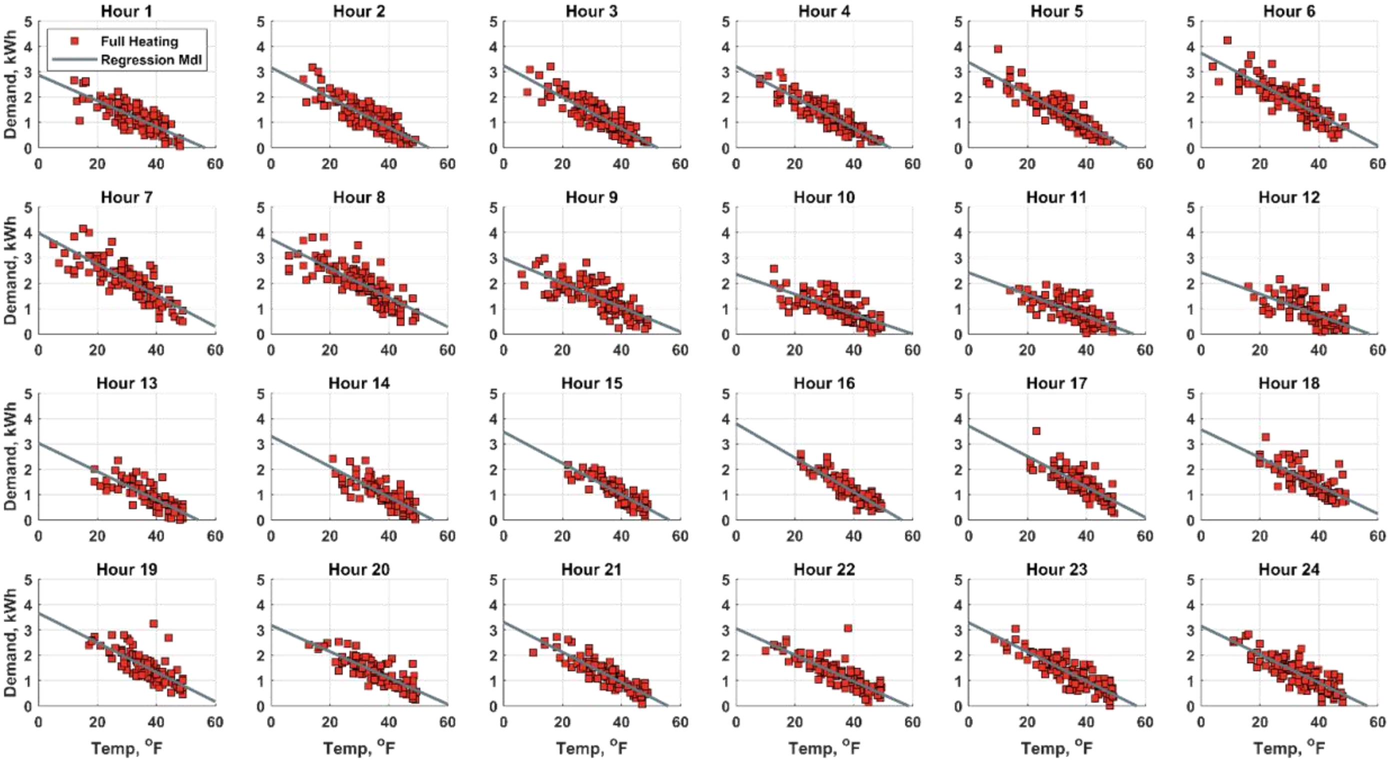
Winter Non-Holiday Weekdays Only



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