New York ISO
Independent System Operator

Heat Pump Assessment Study – an EPRI Report

Arthur Maniaci

Principal Forecaster

Load Forecasting Task Force

December 19, 2022

Study Purpose

- This study's primary purpose was to determine the contribution to peak electric load in winter of air source heat pumps and supplemental electric resistance heating in single family homes. Annual performance and summer cooling energy usage was also examined.
- The combined impact of heat pumps and supplemental electric resistance heat at design winter conditions is difficult to determine without performing detailed numerical calculations on an hourly basis. The study employed the EnergyPlus building simulation tool to perform these calculations.
- The Electric Power Research Institute performed the analytical work, provided analysis and discussion of results with the NYISO

New York ISO

Study Objectives

- Understand the heating and cooling usage of a single-family home with various heating and cooling systems. To accomplish this, building simulations to generate 8,760 hourly data were performed.
- Heating technologies include:
  - cold climate air source heat pumps,
  - electric resistance heating, and
  - gas furnace heating
- The EnergyPlus™ building simulation tool was used to study the heating and cooling requirements of a single-family home, using building characteristics located in Albany, NY obtained from the NREL ResStock database.
- All HVAC systems were sized all to provide sufficient heating energy at winter design conditions.

Executive Summary

- This study examined the performance of a gas furnace, an electric furnace using resistance heating and a cold climate air source heat pump with supplemental electric resistance heat. All heating systems were sized to meet the heating requirements of a 2,600 square foot home located in Albany, NY. The EnergyPlus™ building simulation tool was employed to obtain hourly results for each system.
- Air source heat pumps are an effective means of reducing seasonal heating energy usage. Heat pump energy supplied, including supplemental heat, was about 65% less than furnaces fueled by natural gas and 59% less than electric resistance heating. During the entire heating season, the calculated COP of the heat pump was 2.44; including supplemental heat, the COP was 2.30.
- Air source heat pump performance decreases with decreasing outdoor air temperature, resulting in the need to provide supplemental heat at an increasing rate in order to meet the home's heating load. As a result, heat pumps are much less effective at reducing winter peak demand. At the design winter conditions in Albany of -3°F the calculated COP of the heat pump was 1.43; including supplemental heat, the COP was 1.12.
- The air source heat pumps examined all met the forthcoming Energy Star requirements to deliver 70% of rated capacity at 5°F. Rated capacity is typically determined at 47°F.

New York ISO

Building Energy Simulation Using EnergyPlus

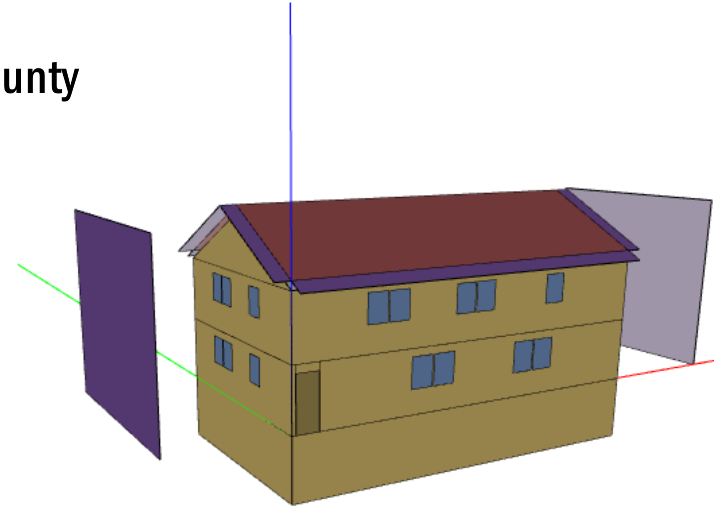
Advanced Modeling Capabilities of EnergyPlusTM

- Developed by U.S. Department of Energy
- EnergyPlusTM version 9.5 was used
- Accurately represents physics and technologies to evaluate energy use and equipment sizes
- Considers occupancy schedules, building envelope parameters, HVAC performance curves
- Transparent source code, reference data & engineering assumptions
- Industry standard building modeling tool

ENERGYPLUS is a **trademark** of U.S. Department of Energy.

NREL ResStock Database

- NREL developed building simulation models for over 30,000 homes in New York, representative of current housing stocks & equipment types.
- A single-family, two-story home located in Albany County was selected for use in this study.
- The home had 2600 square feet of interior space, excluding the basement.
- Heating was provided by natural gas.
- Cooling was provided by a central air conditioner.
- Heating and cooling distribution was via ductwork using circulation fans.
- Development by NREL began in 2014 and is ongoing.



https://www.nrel.gov/buildings/resstock.html

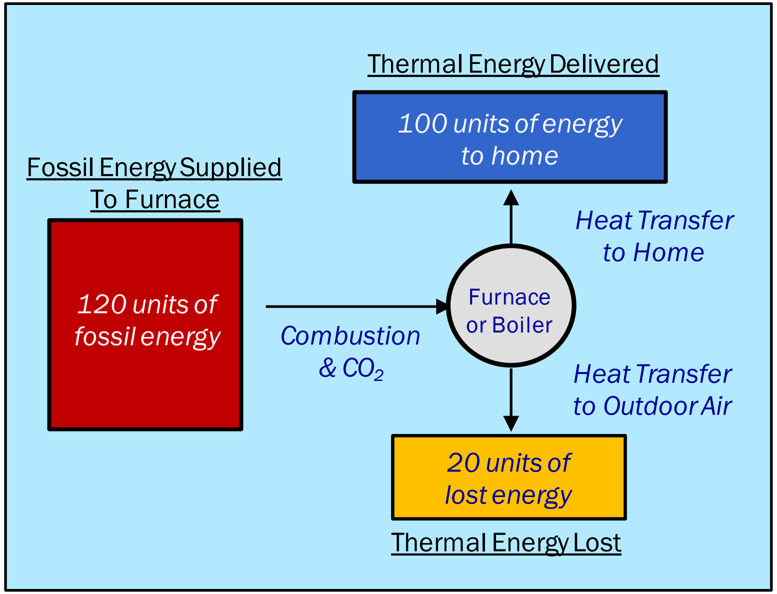
Technology Overview

Air Source Heat Pump Principles of Operation

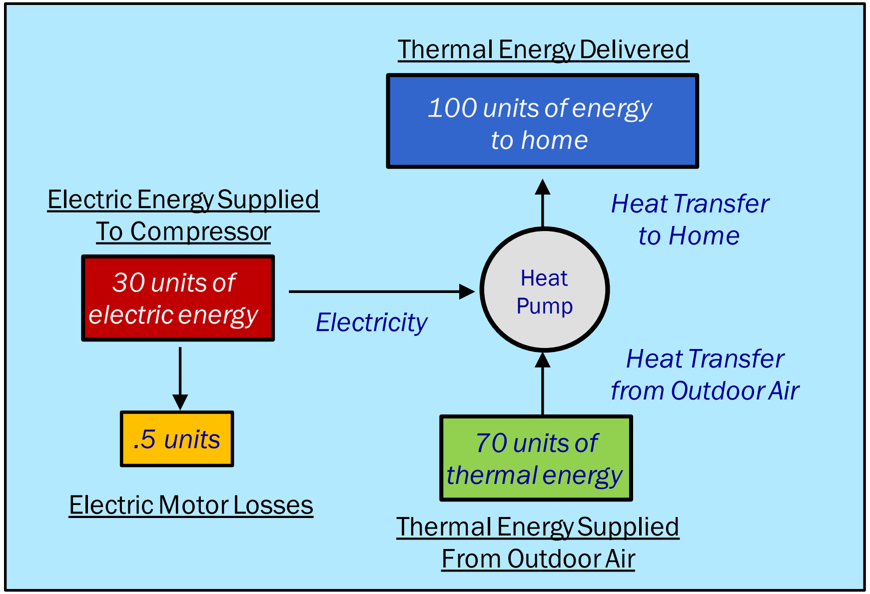
- An efficient electric technology to provide space heating and cooling.
- Works by moving thermal energy heat between indoor and outdoor spaces, similar to a refrigerator or air conditioner
- Air source heat pump performance is highly dependent on the outside air temperature.
  - Heating capacity and efficiency decreases the colder it gets in winter
  - Cooling capacity and efficiency decreases the warmer it gets in summer
- Below a certain temperature, supplemental heat is needed in winter to maintain room temperature at its set point.

Comparison of Fossil Fuel Furnace Operation vs Air Source Heat Pump

Fossil Fuel Furnace



Air Source Heat Pump



Notes:

(1) The heat pump diagram does not include any supplemental heat which may be needed in very cold operating conditions.

(2) The relative proportions of electric energy and thermal energy for the heat pump vary considerably with outdoor temperature. The specific values shown are illustrative only.

The Challenge of Low-Temperature Operation with Current Air Source Heat Pumps

Current air-source heat pumps face three major technical issues when operating at the coldest outside air temperatures (5 F and below), such that they produce only 40% to 80% of heating capacity as compared to heating capacity at their rated temperature (45°F to 50°F).

Performance Issues

Impact on Equipment

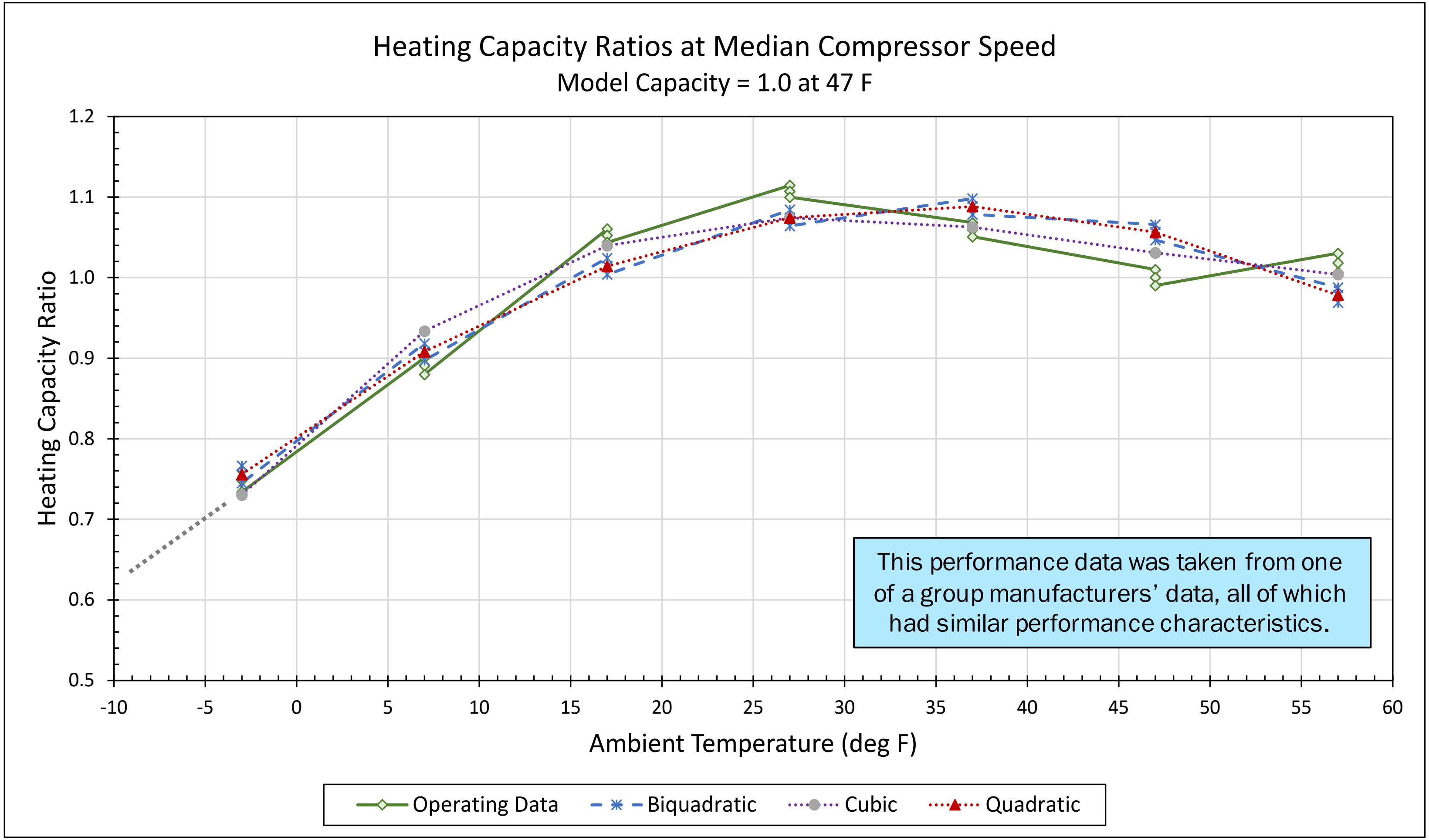
Reduced capacity at low temperatures, compressor failure

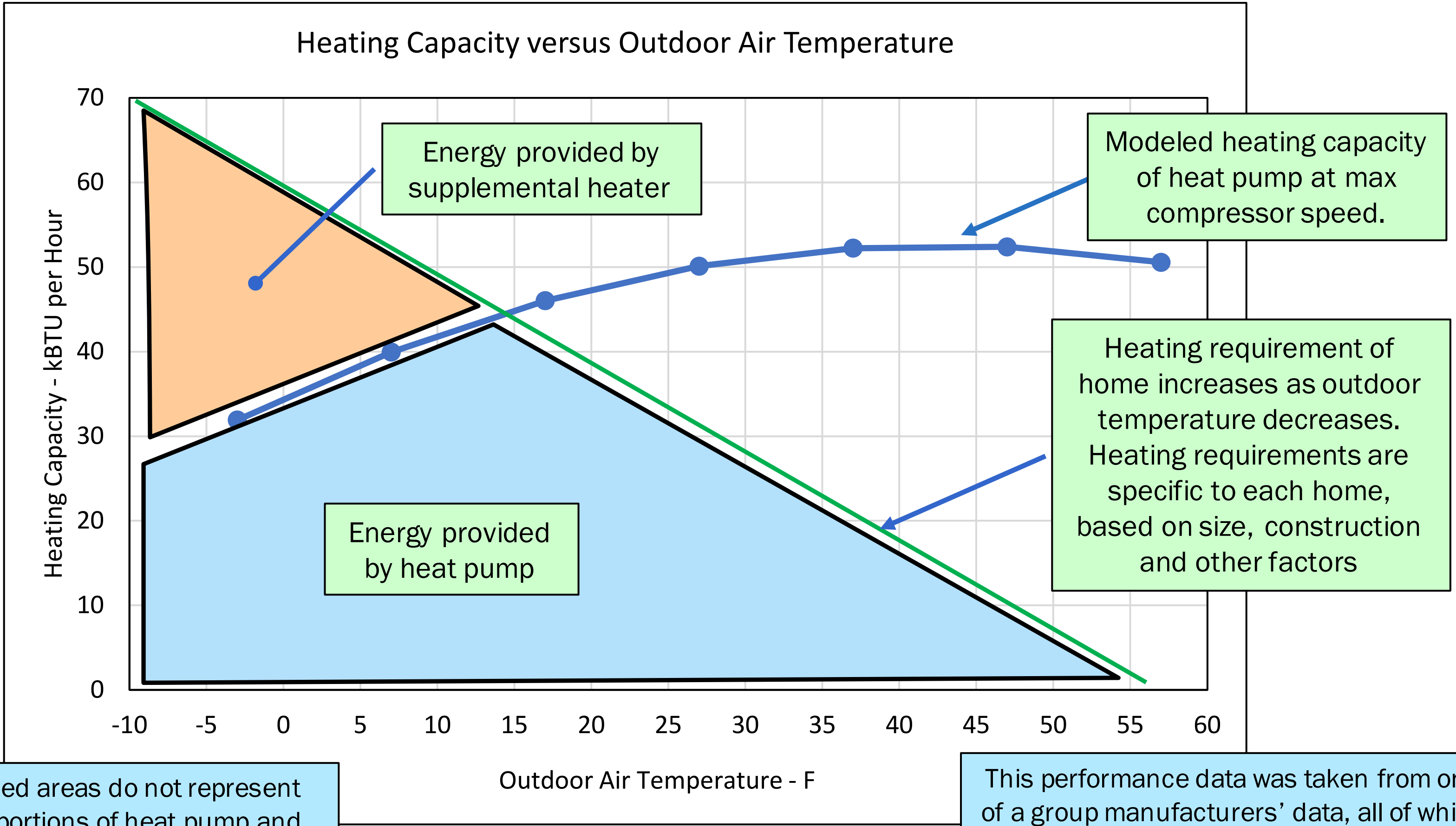
Macro-level Effects

- Heat pump rated capacity must be significantly increased in size

OR

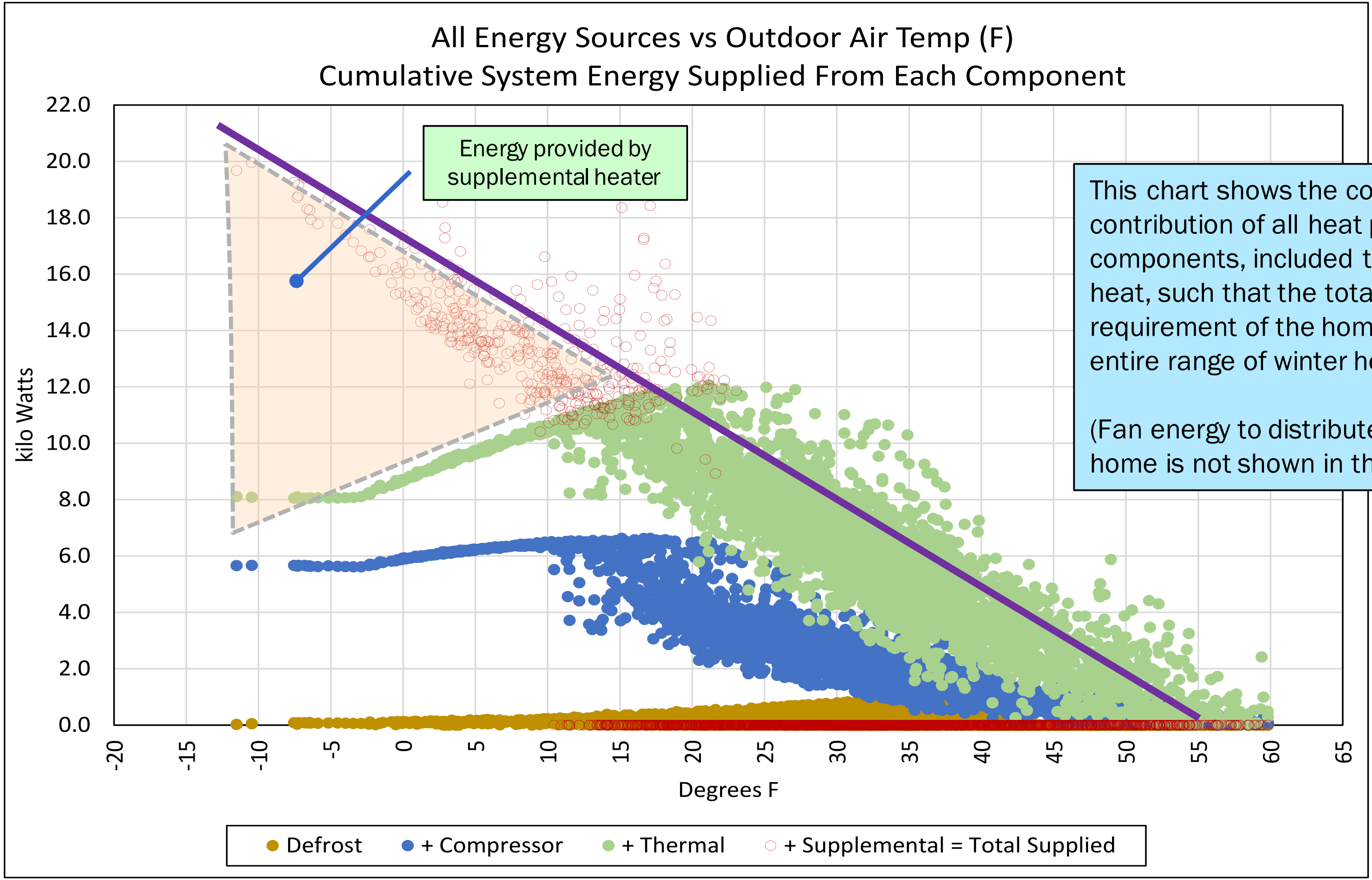
- Supplemental heat source must be used (Electric Resistance, Fossil Fuel etc.)


Heating Capacity Ratios at Median Compressor Speed
Model Capacity = 1.0 at 47 F
Heating Capacity Ratio
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
-10
-5
0
5
10
15
20
25
30
35
40
45
50
55
60
Ambient Temperature (deg F)
This performance data was taken from one of a group manufacturers' data, all of which had similar performance characteristics.
Operating Data
Biquadratic
Cubic
Quadratic



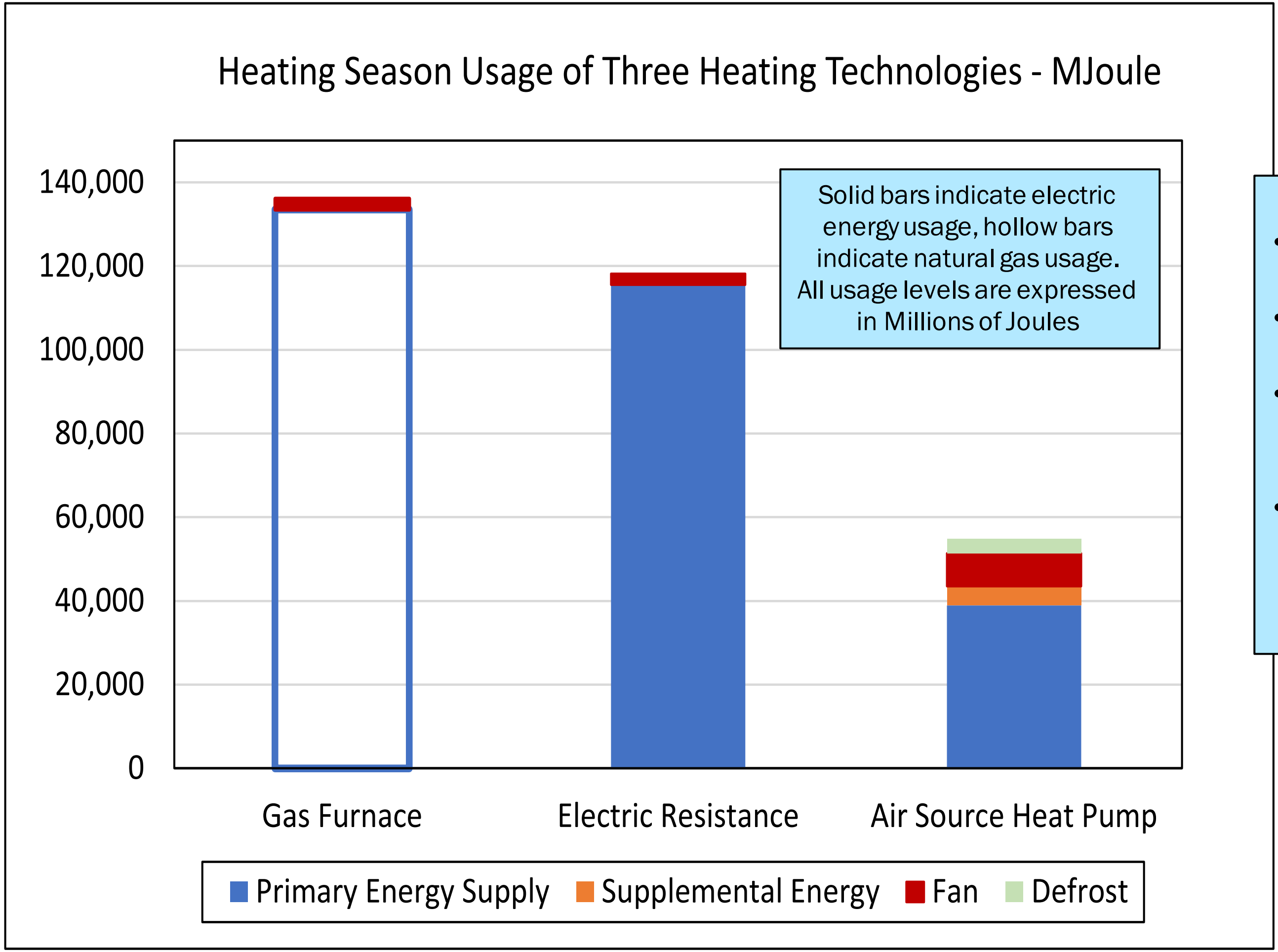
Note: The shaded areas do not represent the relative proportions of heat pump and supplemental energy used annually.

This performance data was taken from one of a group manufacturers' data, all of which had similar performance characteristics.



This chart shows the combined contribution of all heat pump components, included the supplemental heat, such that the total heating requirement of the home is met over the entire range of winter heating conditions.

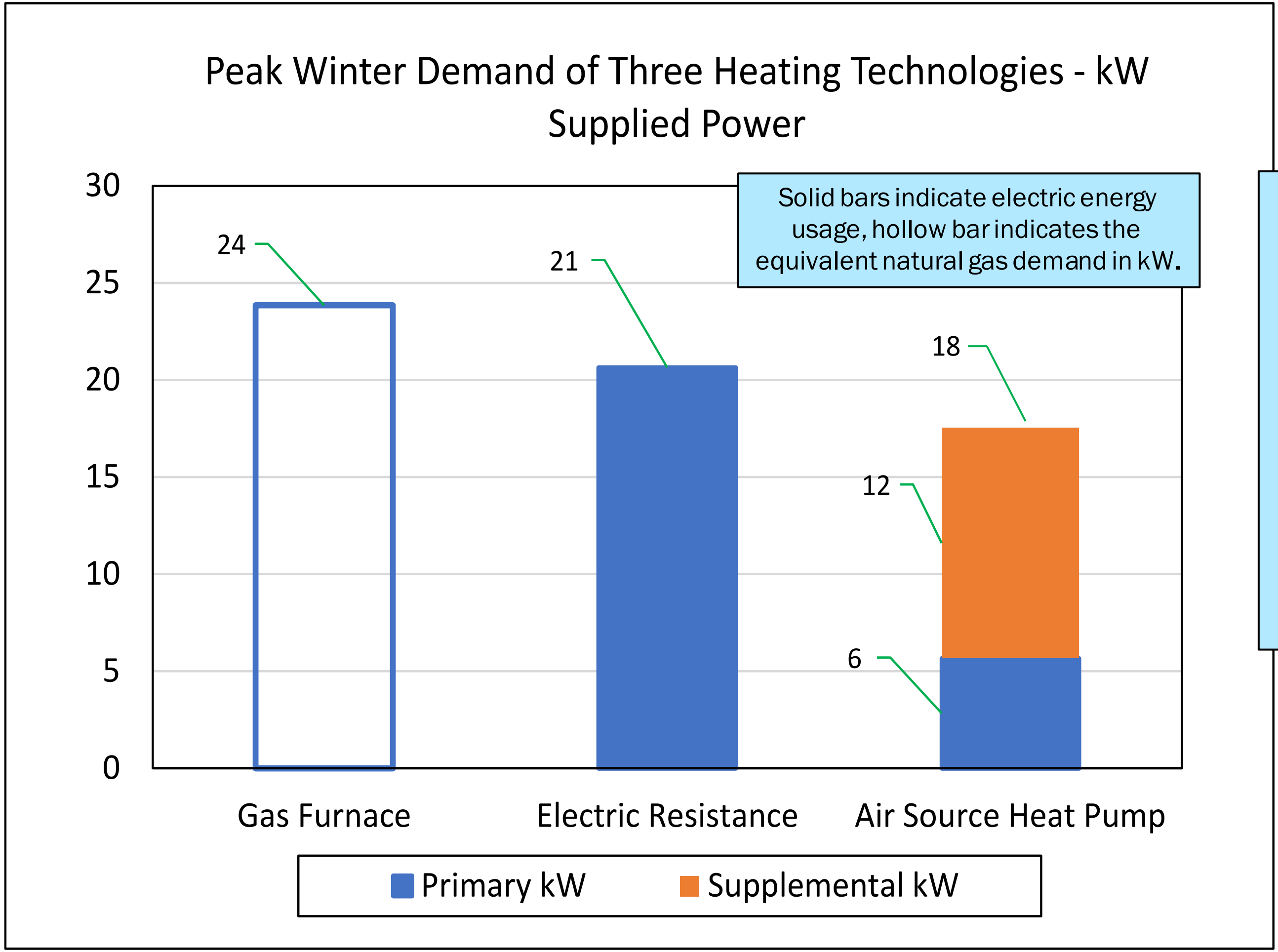
(Fan energy to distribute the air within the home is not shown in this chart.)



Key Points

- Primary energy varies based on technology efficiency or COP
- Heat pump system requires defrost and supplemental energy
- Fan energy usage is greater for heat pumps than gas or electric furnaces
- Heat pump system uses 60% less energy than natural gas and 55% less energy than electric resistance heat.

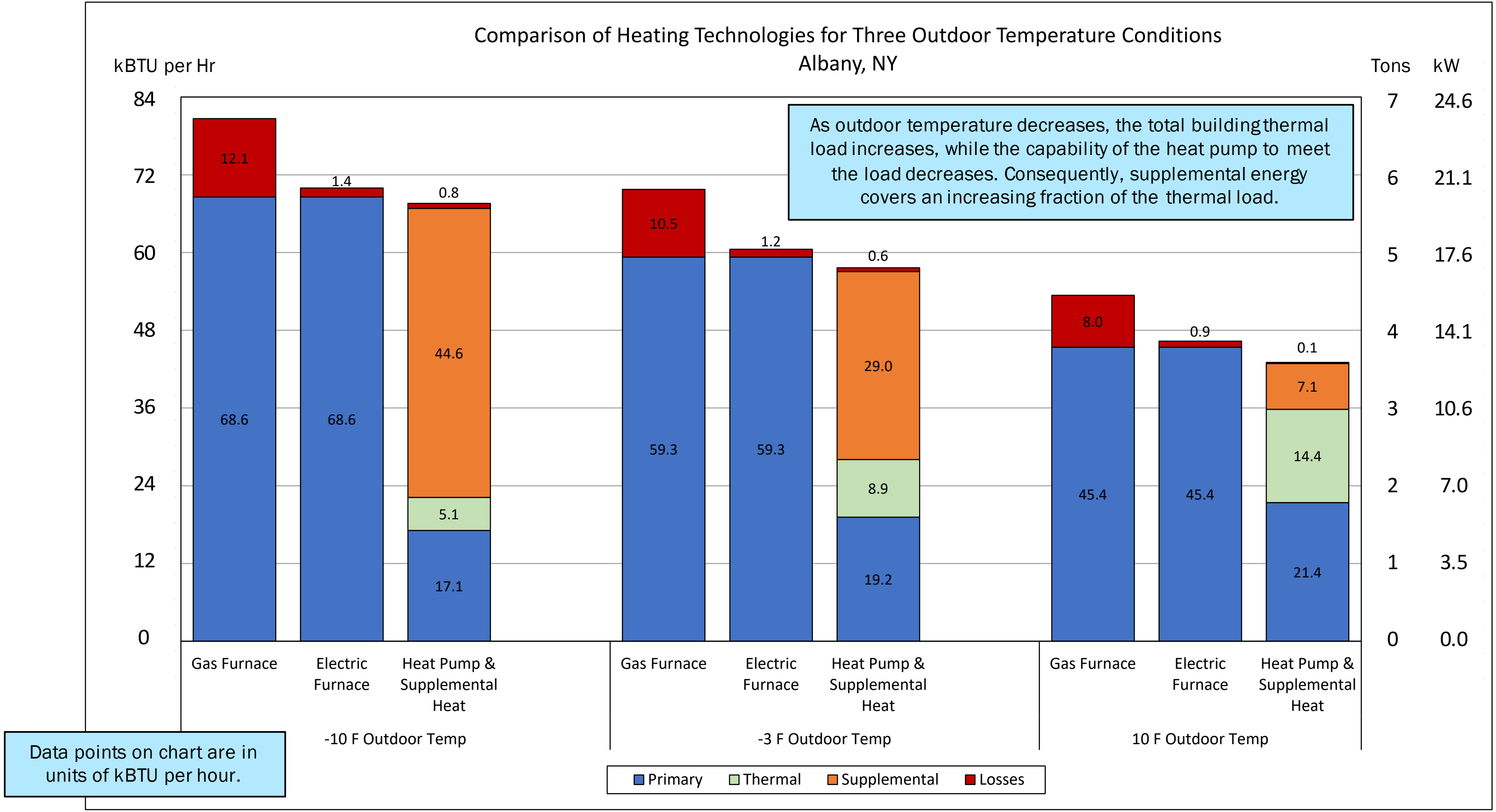
Note – All technologies have their usage expressed in millions of Joules.
1 kWh = 3.6 MJ
1 kBTU = 1.055 MJ
1 kWh = 3.412 kBTU



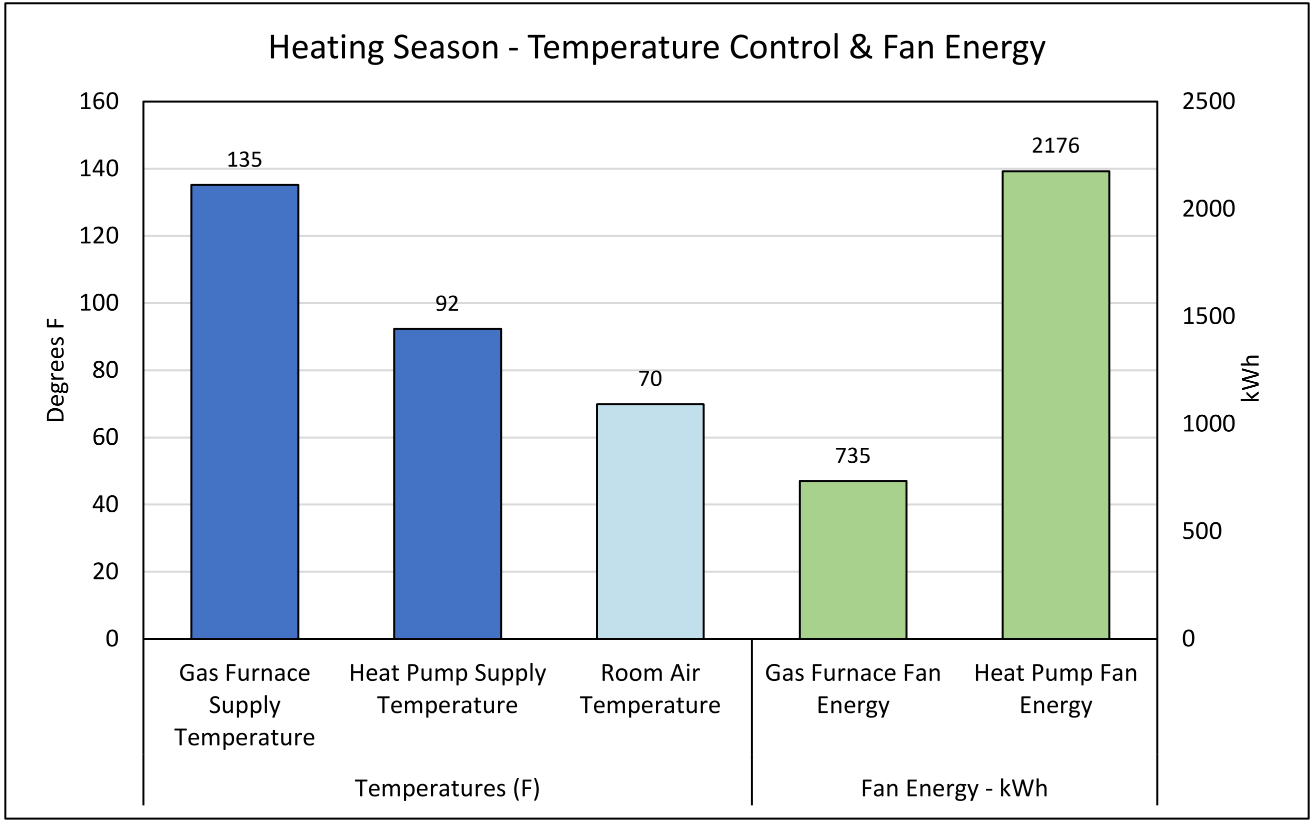
Key Points

- Primary energy varies based on technology efficiency or COP
- Heat pump system requires no defrost at peak hour.
- Heat pump system uses 15% less energy than electric resistance heating at peak hour.
- Supplemental energy provides 67% of the load at winter peak conditions, heat pump system provides 33%.

Note – The peak output of the gas furnace is 81,200 BTU per hour, including the energy lost through combustion.

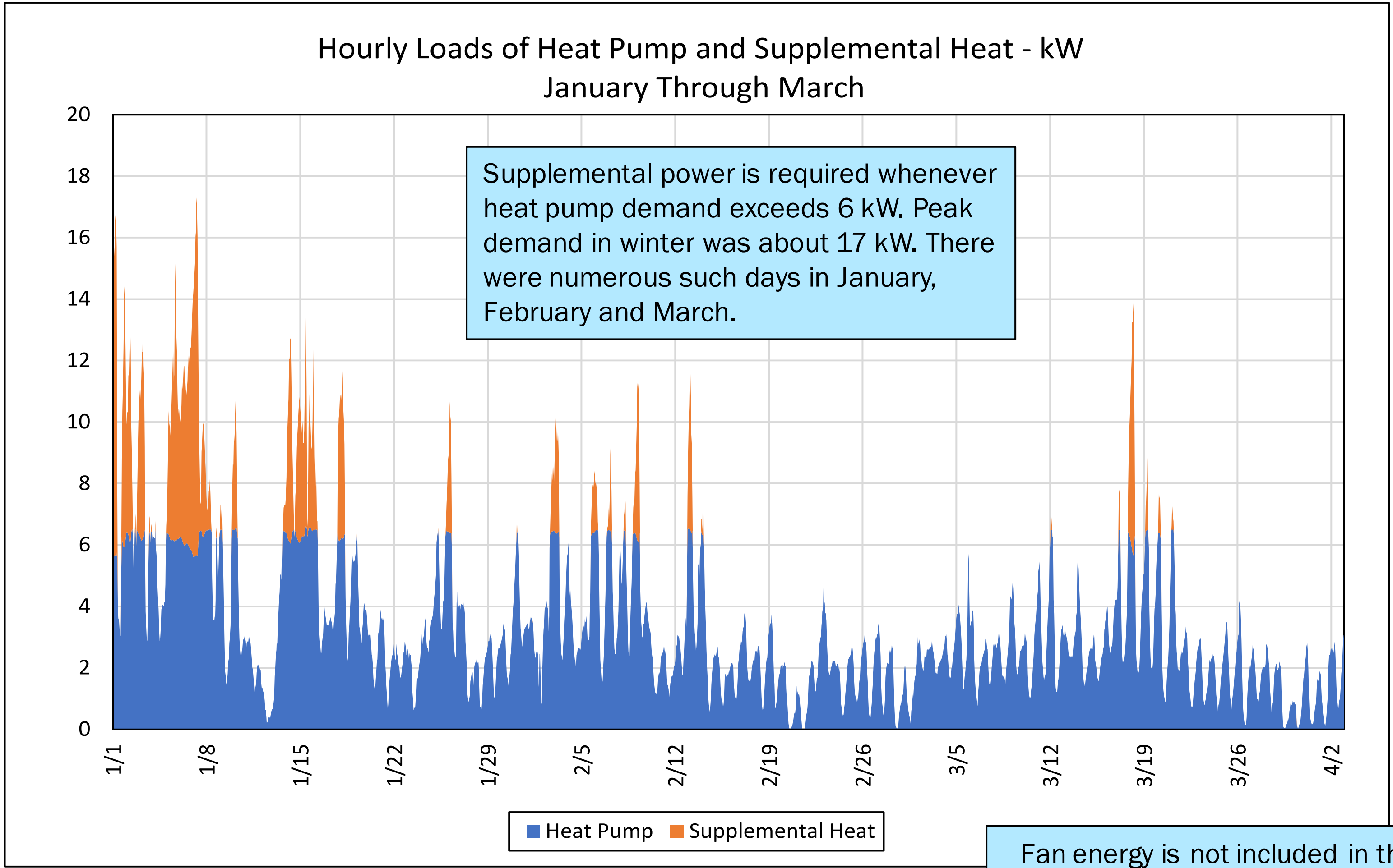


Comparison of Heating Technologies for Three Outdoor Temperature Conditions
Albany, NY
kBTU per Hr
Tons
kW
84
72
60
48
36
24
12
0
7
6
5
4
3
2
1
0
24.6
21.1
17.6
14.1
10.6
7.0
3.5
0.0
As outdoor temperature decreases, the total building thermal load increases, while the capability of the heat pump to meet the load decreases. Consequently, supplemental energy covers an increasing fraction of the thermal load.
12.1
68.6
1.4
68.6
0.8
44.6
5.1
17.1
10.5
59.3
1.2
59.3
0.6
29.0
8.9
19.2
8.0
45.4
0.9
45.4
0.1
7.1
14.4
21.4
Gas Furnace
Electric Furnace
Heat Pump & Supplemental Heat
-10 F Outdoor Temp
-3 F Outdoor Temp
10 F Outdoor Temp
Primary
Thermal
Supplemental
Losses
Data points on chart are in units of kBTU per hour.

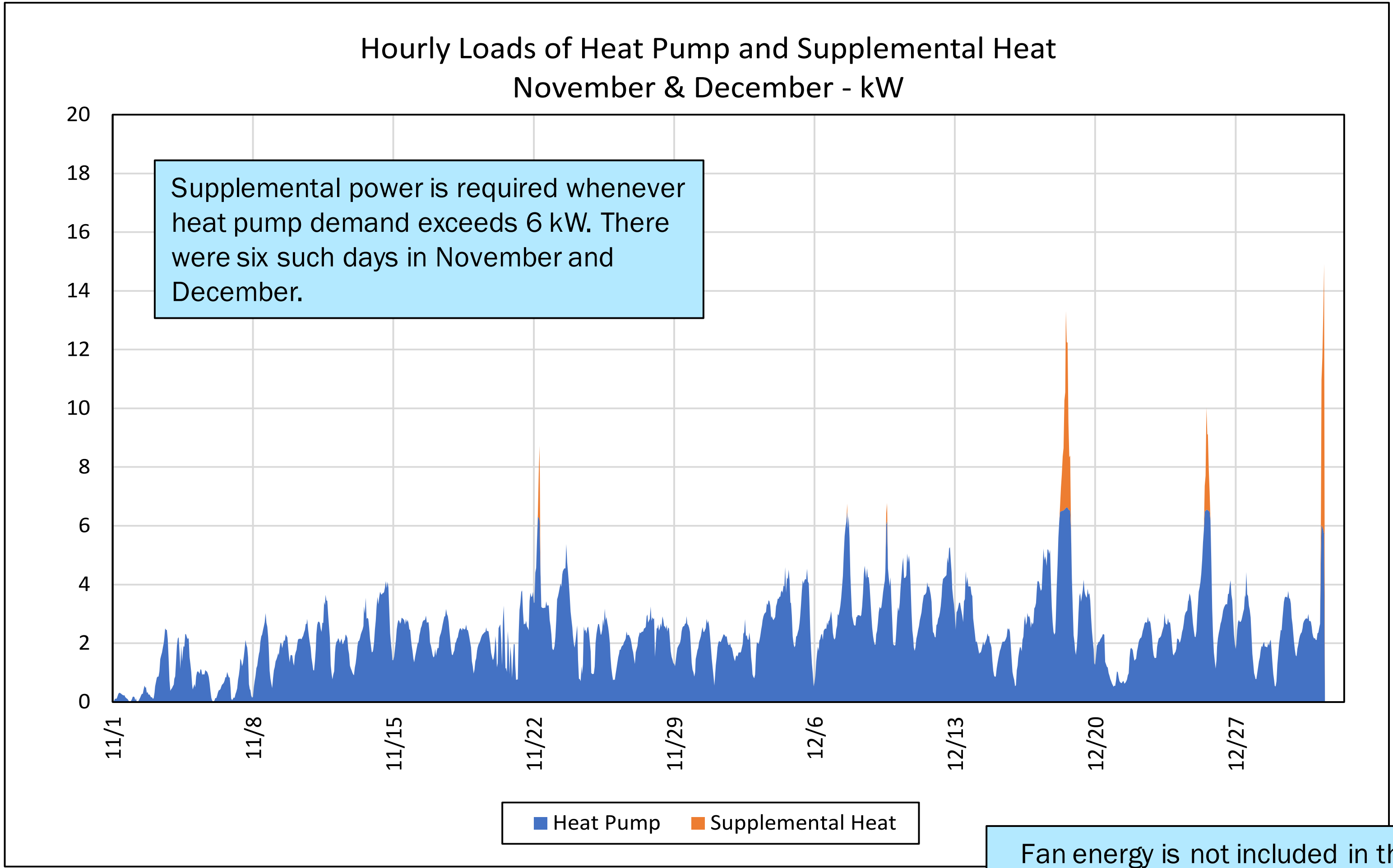


The supply of warm air from the heat pump was 92°F, significantly cooler than the 135°F supply of warm air from the gas furnace. In both cases, the room air was maintained at 70°F in winter months.

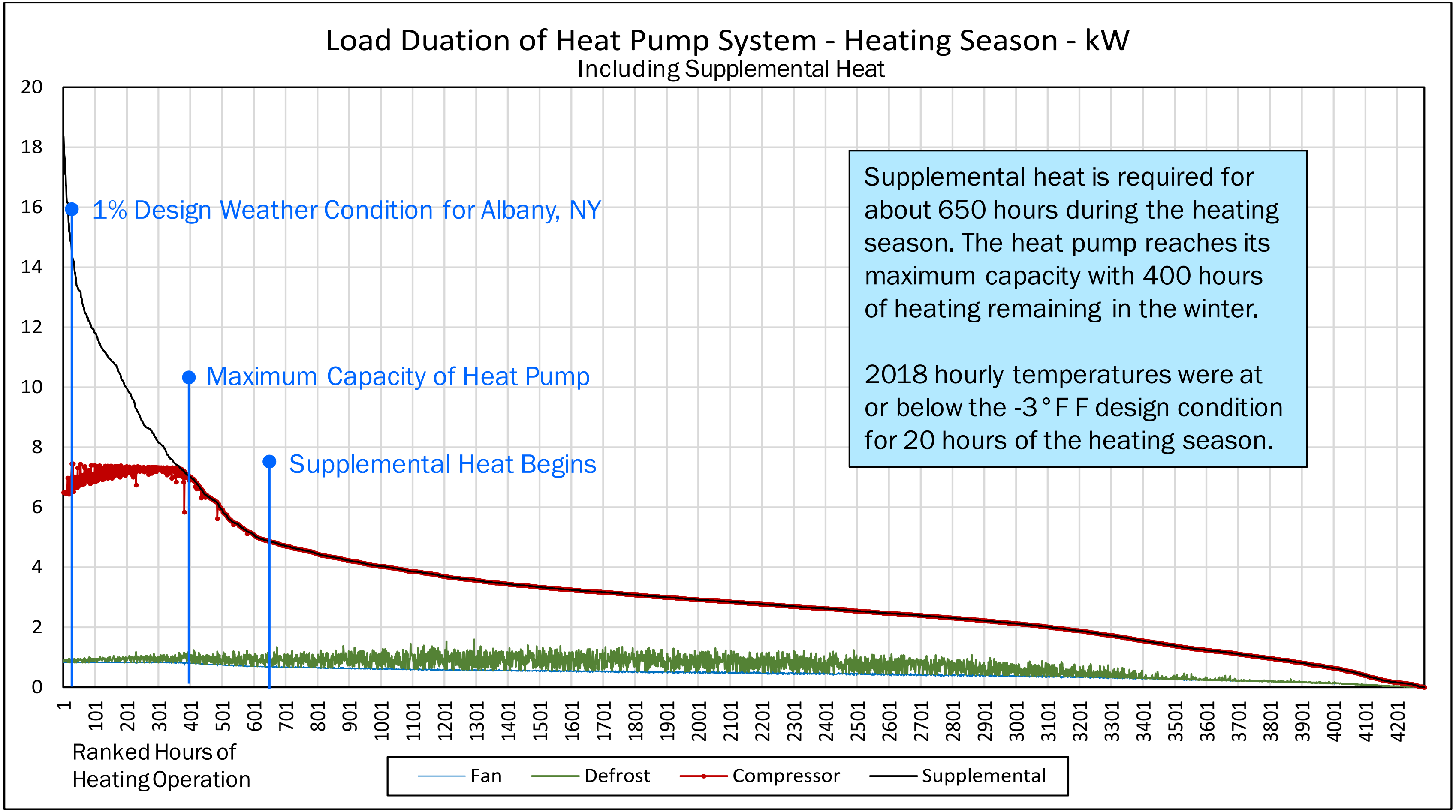
In order to provide an equal amount of heat to the home, the heat pump fan used three times as much energy as the gas furnace fan.



Fan energy is not included in this chart.



Fan energy is not included in this chart.



Load Duation of Heat Pump System - Heating Season - kW
Including Supplemental Heat
1% Design Weather Condition for Albany, NY
Maximum Capacity of Heat Pump
Supplemental Heat Begins
Supplemental heat is required for about 650 hours during the heating season. The heat pump reaches its maximum capacity with 400 hours of heating remaining in the winter.
2018 hourly temperatures were at or below the -3 ° F F design condition for 20 hours of the heating season.
0
2
4
6
8
10
12
14
16
18
20
1
101
201
301
401
501
601
701
801
901
1001
1101
1201
1301
1401
1501
1601
1701
1801
1901
2001
2101
2201
2301
2401
2501
2601
2701
2801
2901
3001
3101
3201
3301
3401
3501
3601
3701
3801
3901
4001
4101
4201
Ranked Hours of Heating Operation
Fan
Defrost
Compressor
Supplemental

Appendix 1 – Detailed Tables

Technology Comparison

Monthly Thermal Energy Delivered - kWh
Single Family Home

Month	Gas Furnace	Electric Furnace	Heat Pump & Suplemental Heat
1	7,374	7,374	7,046
2	4,755	4,755	4,539
3	5,062	5,062	4,827
4	2,978	2,978	2,845
5	293	293	285
6	61	61	60
7	0	0	0
8	0	0	0
9	175	175	165
10	1,382	1,382	1,323
11	3,794	3,794	3,624
12	5,582	5,582	5,319
Annual	**31,456**	**31,456**	**30,034**

Max Thermal Capacity Delivered - kBTU per Hour
Single Family Home

Month	Gas Furnace	Electric Furnace	Heat Pump & Suplemental Heat
1	68.99	68.99	67.27
2	56.22	56.22	53.33
3	58.53	58.53	56.10
4	36.21	36.21	33.91
5	15.26	15.26	14.60
6	7.97	7.97	7.75
7	0.67	0.67	0.00
8	10.44	10.44	0.74
9	24.95	24.95	8.95
10	44.14	44.14	22.70
11	64.69	64.69	41.12
12	68.99	68.99	59.34
Annual	**68.99**	**68.99**	**67.27**

Electric Capacity Supplied - kW
Single Family Home

Month	Gas Furnace, Equivalent kW	Electric Furnace	Heat Pump & Suplemental Heat
1	23.84	20.63	17.53
2	19.42	16.81	11.71
3	20.22	17.51	14.03
4	12.51	10.83	4.27
5	5.28	4.56	1.28
6	2.75	2.38	0.61
7	0.23	0.20	0.02
8	3.61	3.12	0.05
9	8.62	7.46	0.72
10	15.25	13.20	2.91
11	22.35	19.34	8.77
12	23.84	20.63	15.11
Annual	**23.84**	**20.63**	**17.53**

These tables report the energy and peak demand of the furnace or heat pump only, excluding fan energy. Heat pump delivered energy includes compressor energy, thermal energy from the environment and supplemental heat. Heat pump energy supplied excludes thermal energy because it does not require electricity.

Notes

1. The gas furnace energy delivered and supplied in these tables have been converted from kBTU to kWh or kBTU per hour to kW in order to compare its usage and capacity to the electric furnace and heat pump. Gas usage does not contribute to electric energy or electric peak demand.
2. Heating operation occurred in a small number of spring and summer hours.
3. Gas furnace efficiency is 85%, electric furnace efficiency is 98%. Gas furnace supply includes a small amount of ancillary electric usage.

Gas Furnace Results – Energy

Gas Furnace - Ducted Forced Air System
Monthly Energy - kWh

	Fan	Natural Gas Furnace - Ducted Forced Air					Furnace + Fan
(1)	(2)	(3)	(4)	(5)	(6)=(4)+(5)	(7) = (3)/(6)	(8) = (2)+(6)
Month	Fan Energy, Heating	Furnace Heat Delivered	Furnace Heat Supplied	Ancillary Electric	Total Furnace Heat Supplied	Furnace Efficiency	Heating + Fan Energy
1	172	7,374	8,675	17	8,692	85%	8,865
2	111	4,755	5,594	11	5,605	85%	5,716
3	118	5,062	5,955	12	5,966	85%	6,085
4	70	2,978	3,503	7	3,510	85%	3,580
5	7	293	345	1	346	85%	352
6	1	61	72	0	72	85%	73
7	0	0	0	0	0	0%	0
8	0	0	0	0	0	85%	0
9	4	175	206	0	207	85%	211
10	32	1,382	1,625	3	1,629	85%	1,661
11	89	3,794	4,463	9	4,472	85%	4,561
12	130	5,582	6,567	13	6,580	85%	6,710
Annual	**735**	**31,456**	**37,007**	**73**	**37,079**	**85%**	**37,814**

The gas furnace energy delivered and supplied in these tables have been converted from kBTU to kWh in order to compare its usage to the electric furnace and heat pump in other tables. Gas usage does not contribute to electric energy or electric peak demand.

Gas Furnace Results – Coincident Peak Demand

Gas Furnace - Ducted Forced Air
Monthly Coincident Peak Demand - kW

	Fan	Ducted Forced Air - Natural Gas Furnace					Furnace + Fan
(1)	(2)	(3)	(4)	(5)	(6)=(4)+(5)	(7) = (3)/(6)	(8) = (2)+(6)
Month	Fan Energy, Heating	Furnace Heat Delivered	Furnace Heat Supplied	Ancillary Electric	Total Furnace Heat Supplied	Furnace Efficiency	Heating + Fan Energy
1	0.47	20.22	23.79	0.05	23.84	85%	24.31
2	0.39	16.48	19.38	0.04	19.42	85%	19.81
3	0.40	17.16	20.18	0.04	20.22	85%	20.62
4	0.25	10.61	12.49	0.03	12.51	85%	12.76
5	0.11	4.47	5.26	0.01	5.28	85%	5.38
6	0.06	2.34	2.75	0.01	2.75	85%	2.81
7	0.00	0.00	0.00	0.00	0.00	0%	0.00
8	0.01	0.20	0.23	0.00	0.23	86%	0.24
9	0.07	3.06	3.60	0.01	3.61	85%	3.68
10	0.17	7.31	8.61	0.02	8.62	85%	8.79
11	0.30	12.94	15.22	0.03	15.25	85%	15.55
12	0.44	18.96	22.30	0.04	22.35	85%	22.79
Coin. Peak	**0.47**	**20.22**	**23.79**	**0.05**	**23.84**	**85%**	**24.31**

The gas furnace energy delivered and supplied in these tables have been converted from kBTU per hour to kW in order to compare its usage to the electric furnace and heat pump in other tables. Gas usage does not contribute to electric energy or electric peak demand. Coincident peak values are those that correspond to the monthly peak demand reported in Column 8.

Heat Pump Results – Energy (1 of 2)

Cold Climate Air Source Heat Pump - Ducted Forced Air System
Monthly Energy - kWh

	Fan	Air Source Heat Pump - Ducted Forced Air System						
(1)	(2)	(3)	(4)	(5)=(3)+(4)	(6)	(7)	(8)=(6)+(7)	(9)=(5)/(8)
Month	Fan Energy, Heating	Thermal Energy Delivered	Compressor Energy Delivered	Heat Pump Energy Delivered	Compressor Energy Supplied	Defrost Energy Supplied	Heat Pump Energy Supplied	Heat Pump COP
1	473	3,228	2,879	6,106	2,879	170	3,049	2.00
2	332	2,679	1,723	4,402	1,723	159	1,882	2.34
3	354	3,014	1,733	4,746	1,733	140	1,873	2.53
4	213	1,964	882	2,845	882	91	973	2.92
5	21	210	75	285	75	0	75	3.78
6	5	44	16	60	16	0	16	3.77
7	0	0	0	0	0	0	0	0.00
8	0	0	0	0	0	0	0	4.33
9	12	121	43	165	43	0	43	3.80
10	102	942	381	1,323	381	70	451	2.93
11	277	2,443	1,176	3,620	1,176	181	1,358	2.67
12	388	3,334	1,904	5,238	1,904	188	2,092	2.50
Annual	**2,176**	**17,979**	**10,812**	**28,791**	**10,812**	**1,000**	**11,812**	**2.44**

Thermal energy delivered (Col. 3) is energy obtained from the external environment via the heat exchanger of the heat pump.

Heat Pump Results – Energy (2 of 2)

Cold Climate Air Source Heat Pump - Ducted Forced Air System
Monthly Energy - kWh

	Supplemental Electric Resistance Heat			Total Home Heating Usage			Heating + Fan
(1)	(10)	(11)	(12) = (10)/(11)	(13)=(5)+(10)	(14)=(8)+(11)	(15) = (13)/(14)	(16)=(2)+(14)
Month	Supplemental Heat Delivered	Supplemental Heat Supplied	Supplemental Heat Efficiency	Total Heating Energy Delivered	Total Heating Energy Supplied	Total Heating COP	Heating + Fan Energy
1	940	959	98%	7,046	4,008	1.76	4,481
2	137	140	98%	4,539	2,022	2.24	2,354
3	81	82	98%	4,827	1,955	2.47	2,309
4	0	0	0%	2,845	973	0.00	1,186
5	0	0	0%	285	75	0.00	97
6	0	0	0%	60	16	0.00	20
7	0	0	0%	0	0	0.00	0
8	0	0	0%	0	0	0.00	0
9	0	0	0%	165	43	0.00	56
10	0	0	0%	1,323	451	0.00	553
11	4	4	98%	3,624	1,362	2.66	1,639
12	81	83	98%	5,319	2,174	2.45	2,563
Annual	**1,243**	**1,269**	**98%**	**30,034**	**13,081**	**2.30**	**15,257**

Heat Pump Results – Coincident Peak Demand (1 of 2)

Cold Climate Air Source Heat Pump - Ducted Forced Air System
Monthly Coincident Peak Demand - kW

	Fan	Air Source Heat Pump - Ducted Forced Air System						
(1)	(2)	(3)	(4)	(5)=(3)+(4)	(6)	(7)	(8)=(6)+(7)	(9)=(5)/(8)
Month	**Fan Peak, Heating**	**Thermal Peak Delivered**	**Compressor Peak Delivered**	**Heat Pump Peak Delivered**	**Compressor Peak Supplied**	**Defrost Peak Supplied**	**Heat Pump Peak Supplied**	**Heat Pump COP at Peak**
1	0.83	2.47	5.62	8.09	5.62	0.05	5.67	1.43
2	0.83	4.18	6.35	10.53	6.35	0.16	6.51	1.62
3	0.83	2.62	5.63	8.24	5.63	0.03	5.66	1.46
4	0.70	5.81	4.13	9.94	4.13	0.14	4.27	2.33
5	0.33	2.99	1.28	4.28	1.28	0.00	1.28	3.33
6	0.16	1.66	0.61	2.27	0.61	0.00	0.61	3.70
7	0.00	0.00	0.02	0.00	0.02	0.00	0.02	0.00
8	0.02	0.17	0.05	0.22	0.05	0.00	0.05	4.33
9	0.18	1.90	0.72	2.62	0.72	0.00	0.72	3.64
10	0.54	4.56	2.09	6.65	2.09	0.82	2.91	2.28
11	0.83	3.51	6.00	9.51	6.00	0.18	6.18	1.54
12	0.83	2.58	5.60	8.18	5.60	0.11	5.71	1.43
Coin. Peak	**0.83**	**2.47**	**5.62**	**8.09**	**5.62**	**0.05**	**5.67**	**1.43**

Thermal peak delivered (Col. 3) is energy obtained from the external environment via the heat exchanger of the heat pump. Coincident peak values are those that correspond to the monthly peak demand reported in Column 16.

Heat Pump Results – Coincident Peak Demand (2 of 2)

Cold Climate Air Source Heat Pump - Ducted Forced Air System
Monthly Coincident Peak Demand - kW

							Heating + Fan
(1)	(10)	(11)	(12) = (10)/(11)	(13)=(5)+(10)	(14)=(8)+(11)	(15) = (13)/(14)	(16)=(2)+(14)
Month	Supplemental Peak Delivered	Supplemental Peak Supplied	Supplemental Efficiency	Total Heating Peak Delivered	Total Heating Peak Supplied	Total Heating COP at Peak	Heating + Fan Peak
1	11.63	11.87	98%	19.72	17.53	1.12	18.36
2	5.10	5.20	98%	15.63	11.71	1.34	12.53
3	8.20	8.36	98%	16.44	14.03	1.17	14.85
4	0.00	0.00	0%	9.94	4.27	0.00	4.96
5	0.00	0.00	0%	4.28	1.28	0.00	1.61
6	0.00	0.00	0%	2.27	0.61	0.00	0.78
7	0.00	0.00	0%	0.00	0.02	0.00	0.02
8	0.00	0.00	0%	0.22	0.05	0.00	0.07
9	0.00	0.00	0%	2.62	0.72	0.00	0.90
10	0.00	0.00	0%	6.65	2.91	0.00	3.45
11	2.54	2.59	98%	12.05	8.77	1.37	9.60
12	9.21	9.40	98%	17.39	15.11	1.15	15.94
Coin. Peak	**11.63**	**11.87**	**98%**	**19.72**	**17.53**	**1.12**	**18.36**

Coincident peak values are those that correspond to the monthly peak demand reported in Column 16.

Our Mission & Vision

Mission

Ensure power system reliability and competitive markets for New York in a clean energy future

Vision

Working together with stakeholders to build the cleanest, most reliable electric system in the nation

New York ISO

Questions?