2021 Whole Home Heat Pump Study
Commissioned by the Efficiency Maine Trust
Conducted by DNV

Background:

Efficiency Maine commissioned a study of 10 homes that used heat pumps as their primary heat source. The aim of the study was to learn more about the performance of whole-home heat pumps as a primary, year-round heating solution in Maine homes. The study was designed as a set of case studies, rather than a randomly sampled measurement and verification project, to learn detailed information about performance, system configuration, and homeowner satisfaction.

A diverse group of homes of varying ages and airtightness was selected for monitoring to help discover if heat pumps could meet the heating needs of many kinds of homes. The homes selected included both new homes with heat pumps installed as the primary heating source and whole-home heat pump solutions, which replaced fossil fuel heating systems. Of the ten homes that were selected for the study, nine were heated with ducted air-source heat pumps and one with an air-to-water heat pump and radiant heating distribution system. All the homes in the study had moved to heat pumps as their primary heat source before the start of the monitoring period.

The study was conducted by DNV; participating homes were metered from February 2021 through June 2021.

Study Goals:

The study set out to answer several questions, including:

- How well do heat pumps perform as the primary and/or sole heating system?
- Can heat pumps maintain home comfort levels during colder temperatures?
- How do heat pumps perform at various outdoor temperatures?
- How do homeowners rate the performance of their heat pumps?
- What motivated homeowners to install and use heat pumps as their primary heating source?
- How much backup heat is used by homes with heat pumps and when are these backup heating sources typically used?
- What are the greenhouse gas (GHG) emissions reductions from heat pump systems compared to fossil fuel alternatives?
- Does the addition of a heat pump system require upgrades to backup power systems?

Methodology:

- Sites were selected for detailed monitoring – the result was 10 individual, technical case studies. (Because the case studies are technical in nature, a glossary of terms is included at the end of this cover note for reference.)
- Energy output was calculated from the difference in heat content of the supply air and return air and the flow rate of the supply air.
- Energy input was calculated from the metered power use of the heat pump.

- Some heat pumps were not fully metered throughout the metering period due to meter failures, which are detailed in the individual case studies.

Participating Sites:

- Ten sites were selected in Maine, with the farthest north on Mount Desert Island.
- Nine of 10 sites are single family homes; one site is a condominium.
- Nine of 10 sites had air-to-air heat pump systems; one site had an air-to-water system.
- Participating homes reflect a wide range of building sizes and ages.
- Site Summary:

Site ID	Location	Home Description	Conditioned Space	Air Leakage CFM50	Heat Pump System Description	Other Heating Systems
01	Mount Desert Island	1770 single-family	1,850	2,897	Air-to-water with 10 zones	Electric coil and wood stove
02	Sanford	2000 single-family	4,000	1,879	Ducted air-to-air single-zone	Space heater in basement and hot water coil (oil)
03	Gardiner	1803 single-family	2,300	5,696	2 ducted air-to-air 2+1 zones	Wood fireplace
04	Great Diamond Island	1935 single-family	1,200	4,938	Ducted air-to-air (1 zone) Ductless air-to-air (3 zones)	Wood fireplace
05	Great Diamond Island	1993 single-family	1,700	7,330	Ducted air-to-air (1 zone) Ductless air-to-air (2 zones)	Kerosene heater and wood stove
06	Great Diamond Island	2003 single-family	2,400	3,731	Ducted air-to-air 3 zones (2 on 1st, 1 on 2nd)	Electric heater in bathroom and wood stove
07	Great Diamond Island	1904 condominium	1,370	5,428	Ducted/Ductless air-to-air 2 zones (ductless on 1st, ducted on 2nd)	Oil boiler
08	Cumberland	1900 single-family	1,500	4,294	Ducted air-to-air 1 zone	Two wood stoves
09	Greene	2013 single-family	1,760	608	Ducted air-to-air 1 zone	Electric coil

Site ID	Location	Home Description	Conditioned Space	Air Leakage CFM50	Heat Pump System Description	Other Heating Systems
10	Arundel	2000 single-family	1,846	720	Ducted air-to-air 2 zones (1 for bedroom, 1 for rest of home)	Electric coil and propane fireplace

Findings:

- The metered heat pumps met the needs of the homeowners as year-round, primary heating systems;
- Seven out of 10 homes did not use supplementary heating to any significant degree in addition to the heat pumps;
- All homeowners were satisfied or very satisfied with their heat pump systems and the comfort of their homes;
- The coefficient of performance (Energy Output/Energy Input) for the heat pumps ranged from 1.7 to 3.9 for the performance measured over the study period; and
- Heat pumps functioned as the primary heat sources in a number of different kinds of homes, of varying ages.

Acronym List/Glossary of Terms

Air-to-Air Heat Pump: A heating system that extracts heat from outdoor air and transfers it to indoor air through indoor units that include fans and heat exchangers. The heat flow is reversed for cooling and extracts heat from the indoor air through the indoor units and transfers it outdoors through the outdoor unit.
Air-to-Water Heat Pump: A heating system that extracts heat from outdoor air and transfers it to a hydronic heat distribution system.
AFUE (Annual Fuel Utilization Efficiency): A thermal efficiency measure of space-heating furnaces and boilers that compares the annual heat supplied to the annual fuel consumed.
Blower door test: A test to determine a building's airtightness, typically measured in pascals at CFM50. Higher numbers indicate a leakier house that will generally have higher heating needs.
Btu/h (British Thermal Units per hour): The measurement of the capacity of a heating system.
Buffer Tank: An insulated tank that adds additional volume to the heating system and stores energy from the heat pump.
CFM50 (Cubic Feet per Minute at 50 Pascals): The most common measure of building airtightness.
CMP (Central Maine Power Company): An electricity transmission and distribution utility in Maine.
COP (Coefficient of Performance): A measurement of a heat pump's performance, defined as the relationship between the heating or cooling supplied by the heat pump compared to the work or energy used to provide it.
Ducted Heat Pump: A heating system where the indoor unit provides heated/cooled air into ducts that distribute the heating/cooling to the rooms it serves.
Ductless Heat Pump: A heating system where the indoor units provide heated/cooled air directly into the rooms it serves.
ERV (Energy Recovery Ventilation): A system that exchanges the energy and moisture from exhaust air leaving the building to incoming fresh air being supplied into the building.
kW (Kilowatt(s)): A unit of power; a measure of 1,000 watts of electrical power.
kWh- (Kilowatt-Hour(s)): A measurement of energy; one kilowatt of power for one hour.
MMBtu (Million British Thermal Unit(s)): A thermal unit of measurement.
Pa (Pascal): A unit of pressure.
RedLINK Gateway System: Honeywell brand platform to control wireless thermostats and other home technology.

Whole Home Heat Pump Case Study: Mt Desert ME Site #1

Heat pump: 60,000 Btu/h air-to-water heat pump
Heat provided by heat pump: 38.4 MM Btu
Electricity used for heat pump: 3,580 kWh
Overall COP: 3.1
Greenhouse gas savings: 3.7 metric tons

Site Description

The site is a 2,300 square foot single-family ranch house built in 1760. It is wood frame construction with an asphalt shingle roof. The building is moderately air-tight, with a blower-door test of 1,900 cfm at 50 Pa.

The Heat Pump System

The heat pump is an Arctic 60,000 Btu/h air-to-water heat pump. It uses a 50-gallon buffer tank with a 12-kW electric coil that serves as a back-up heat source and as a domestic hot water pre-heater. The hydronic heating system serves ten rooms, each with its own thermostatic valve.

The homeowner installed the heat pump to replace an end-of-life oil-fired boiler, to lower energy costs over the long term, and to lower the site's carbon footprint.

Heat Pump

Buffer Tank

The homeowner's experience with the heat pump experience has been positive. "It's been problem free," he said. "My house feels warmer than before with baseboard heat. My cost is about what I was expecting."

However, the homeowner did observe that extreme temperatures posed challenges to the heat pump system. "It tends to struggle in extreme temperatures and is slow to recover from low temperatures. I can't really turn it down a lot at night and up in the morning; it takes a while to gain temperature." Asked to rate his satisfaction with the comfort provided by the heat pump on a five-point scale, he gave it a rating of 4 out of 5 "as I can't really crank it up that high."

Other Heating and Energy Systems

The house also has electric baseboard heating and a wood stove which the homeowner said he uses "for backup heat and power outages." Before the installation of the heat pump system, the wood stove was the primary heating source. The property also has an (estimated) 6 kW, ground-mounted photovoltaic array. NREL's PVWatts solar tool estimates that a 6-kW system should generate 8,243 kWh of electricity per year, much more than the 3,526 kWh used by the heat pump. This means that on a net basis, the heat pump was 100% powered by clean energy.

PV Array

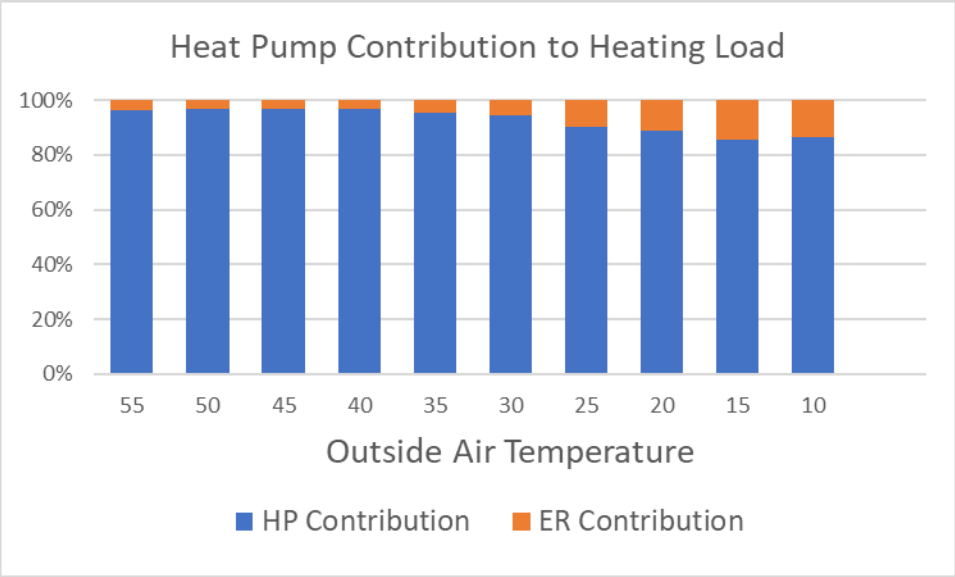
Wood Stove

Heat Pump Performance

DNV measured the kWh used by the heat pump outdoor unit. It installed metering in the middle of February 2021 and removed it in the middle of May. Using the rated efficiency of the Arctic heat pump as a function of outdoor air temperature, DNV was able to determine how the heat pump performed during the heating season, and how much supplemental electricity was supplied to the coil in the buffer tank.

The heat pump did most of the heating during the winter, as shown below in Figure 1. The electric resistance back-up heat mostly came on at the coldest temperatures. The homeowner also uses a wood stove for supplemental heat, but DNV was not able to directly measure the heating contribution from the wood stove. “We use it on most, but not all days,” said the owner. “We don’t use it when the outdoor temperature gets above 40 degrees, and we stopped using it in mid-April.”

Figure 1. Heat Pump Performance



The heat pump performance over two cold days can be seen in Figure 2. On an evening with outside air temperature approaching zero degrees, the house did show a decline in indoor air temperature as it got colder outside.

Figure 2. Temperature Maintained Over Two Days

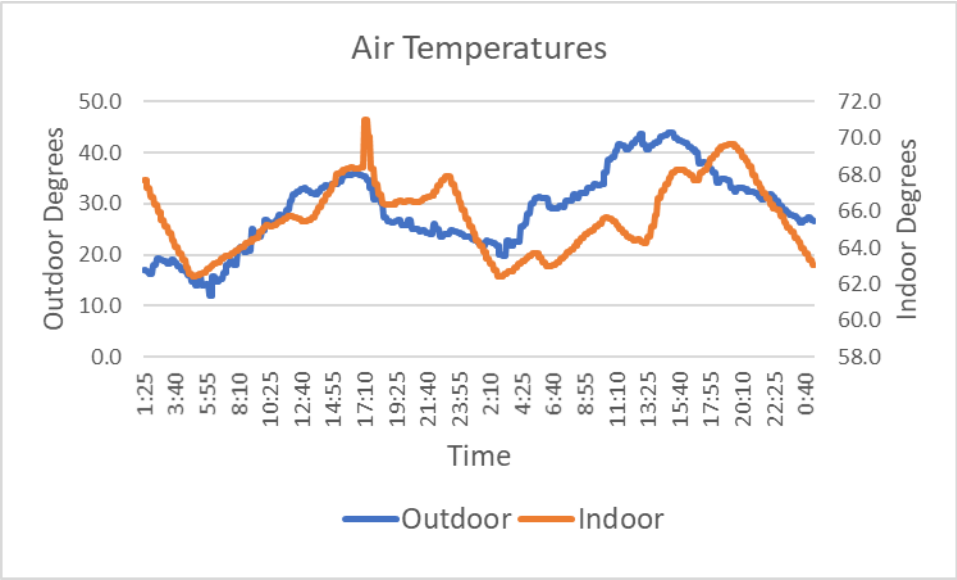
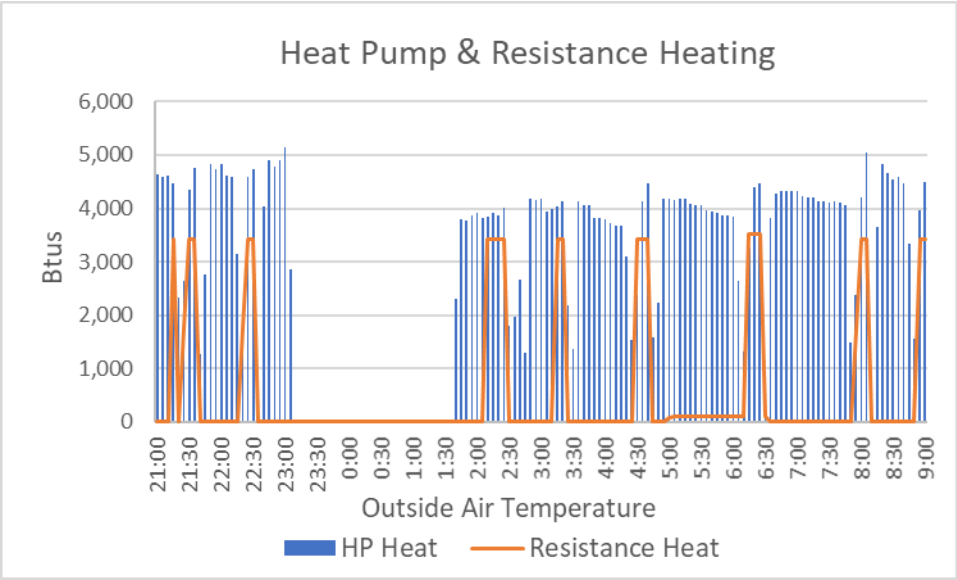


Figure 3 below shows an evening where neither the heat pump nor the electric resistance heat were on from around 11:00 pm to 1:30 am, presumably due to thermostat settings. Had either heat source been on during this time, the indoor air might have been kept warmer. It is also interesting that the electric resistance heat often comes on briefly when the heat pump is between cycles. Better coordination of thermostats possibly could eliminate or reduce the need for electric resistance heat.

Figure 3. Heat Pump and Electric Resistance Output on a Winter Evening



Whole Home Heat Pump Case Study: Sanford ME Site #2

Heat pump: 48,000 Btu/h ducted air-source heat pump
Heat provided by heat pump: 23.1 MM Btu
Electricity used by heat pump: 3,295 kWh
Overall COP: 2.1
Greenhouse gas savings: 2.0 metric tons

Site Description

The site is a 4,000 square foot single-family ranch house built in 2001. It is a wood-frame house with an asphalt shingle roof. The home is moderately air-tight, with a blower-door test of 1,900 cfm at 50 Pa. The site is on Central Maine Power's residential time-of-use rate. A time-of-use rate can be used in conjunction with a smart thermostat to shift some electric use to times when electricity is less expensive. The home uses a maximum of about 2,600 kWh per month at the height of the heating season.

The Heat Pump System

The main floor is heated and cooled primarily by a 48,000 Btu/h Mitsubishi model PVFY-P48-NAMU-E1 air-source heat pump in conjunction with an air handler, located in the basement. Air is pre-conditioned before reaching the air handler with a Carrier energy recovery ventilator.

"We used to have an older original heat pump system …. But about two years ago the compressor blew …. so we needed a new heat pump solution," the homeowner explained. One of the homeowner's requirements for the new system was that the outdoor part of the system (compressor) and the indoor part of the system (air handler) could be powered independently, and they opted for a commercial-grade system to meet this requirement. "The system we ultimately went with now is actually slightly over-sized for our home, and so we're never running the system flat out," the homeowner observed.

The following pictures show various components of the heat pump system. The system is controlled by a thermostat that hooks up to a RedLINK gateway system. Because the thermostat did not recognize the system's drying capabilities, the homeowner purchased a Wi-Fi enabled "bot." "With the bot I could remotely turn the system off, then cycle it into drying

mode. We went the whole summer with this automatic system to allow us to operate in drying mode all summer," said the homeowner.

Heat Pump

Indoor Air Handler

Energy Recovery Ventilator

The homeowner was very pleased with the heat provided by the new heat pump system. "We're very happy with the comfort level the system provides … We'd give it a 5 [on a five-point rating scale]. We still use separate stand-alone humidification in the winter if needed and have no installed inline humidifier in the duct system, but still, we're generally running around 70-71 degrees, which is very comfortable.

The homeowner was also happy with the ability of the system to reduce their cooling costs. "Our system has a drying mode, which I basically consider an ultra-slow cooling mode. We will use that function to dehumidify in the summer and slowly cool the home at about half the electricity we would use in cooling mode."

Other Heating and Hot Water Systems

The home has some additional heating and hot water systems besides the heat pump. The basement is heated by a 5-kW permanent wall-mount-style electric space heater.[1] Domestic hot water is heated by a 177,000 Btu/hour 86% AFUE hydronic oil-fired boiler. The boiler can supply building heat in an emergency via a hot water coil in the air handler, but it is rarely used. "This past winter, we didn't have to resort to that at all," the homeowner reported.

The home also has a solar photovoltaic system (estimated 9-kW capacity) which is large enough to supply all the home's electricity needs during the summer. NREL's PVWatts calculator estimates that a 9-kW system in Sanford would generate 12,347 kWh per year. As the heat pump in the study period only used 3,295 kWh, the photovoltaic system generation accounted for all the electricity used by the heat pump. This means that on a net basis the home was heated 100% carbon-free.

Oil-Fired Boiler

Heat Pump Performance

The homeowner also reported being "very satisfied" with the system's performance and observed the benefits of the heat pump during the cooling season. "We'd rate it a 5 out of 5." DNV measured the electricity used by the heat pump outdoor unit and by the electric resistance heat (in kWh). It also measured the air handler power draw and the temperature and the humidity of the supply and return air to and from the air handler. With these values, DNV was able to calculate the amount of heat delivered by the heat pump.

[1] Since the conclusion of the study, the homeowner has disabled the electric space heater in the basement and run an additional duct from the heat pump distribution system into the basement.

DNV installed metering the last week of January 2021 and removed it the first week of June. This allowed DNV to understand how the heat pump performed during the heating season. The heat pump did most of the heating during the winter, as shown in Figure 1. Even at temperatures of -5ºF, the heat pump contributed 86% of the heat required by the entire house. As the electric resistance heat serves only the basement, it was assumed that the heat pump was able to provide all heat for the main floor. In addition, the homeowners appear to have turned off the basement heater in May, but not the heat pump.

Figure 1. Heat Pump Contribution as a Function of Outdoor Air Temperature

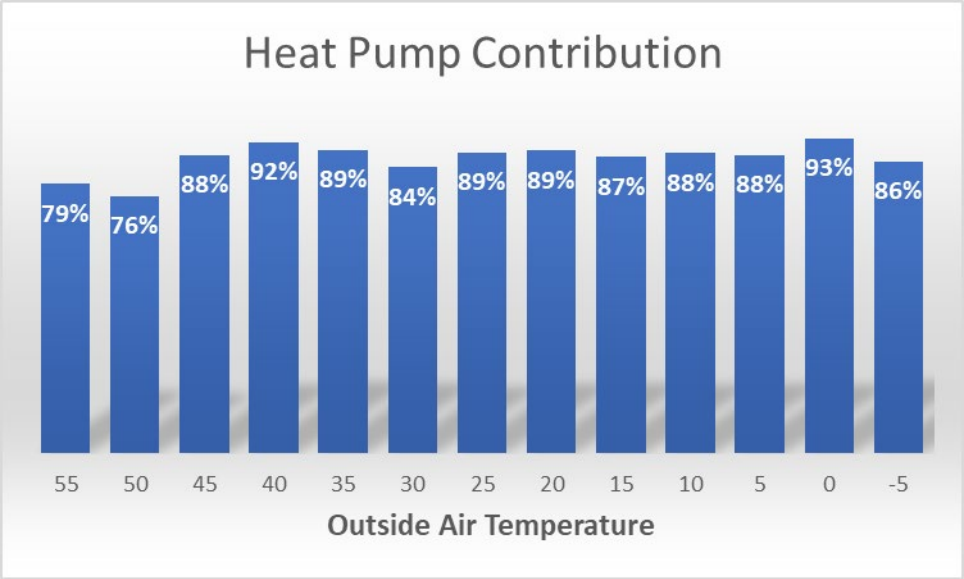
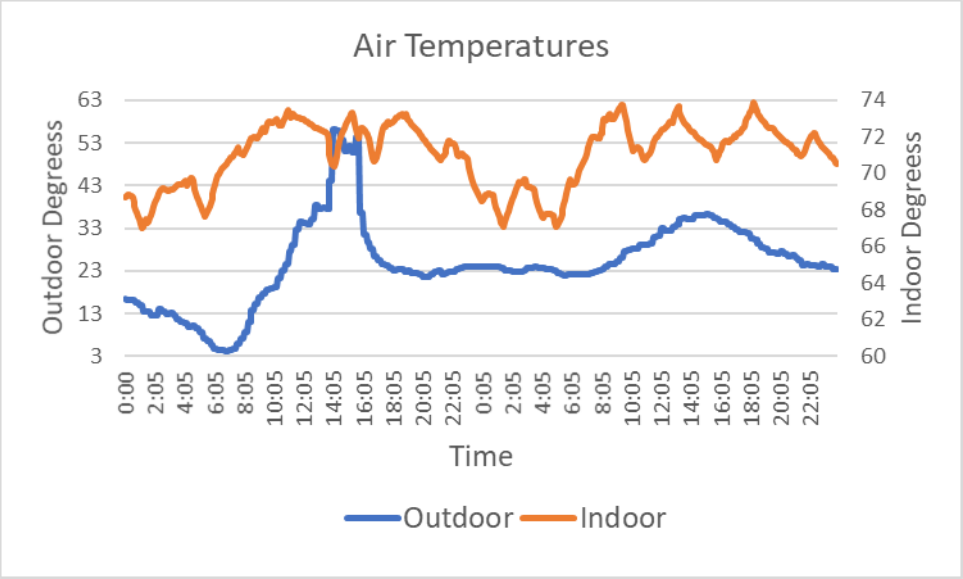


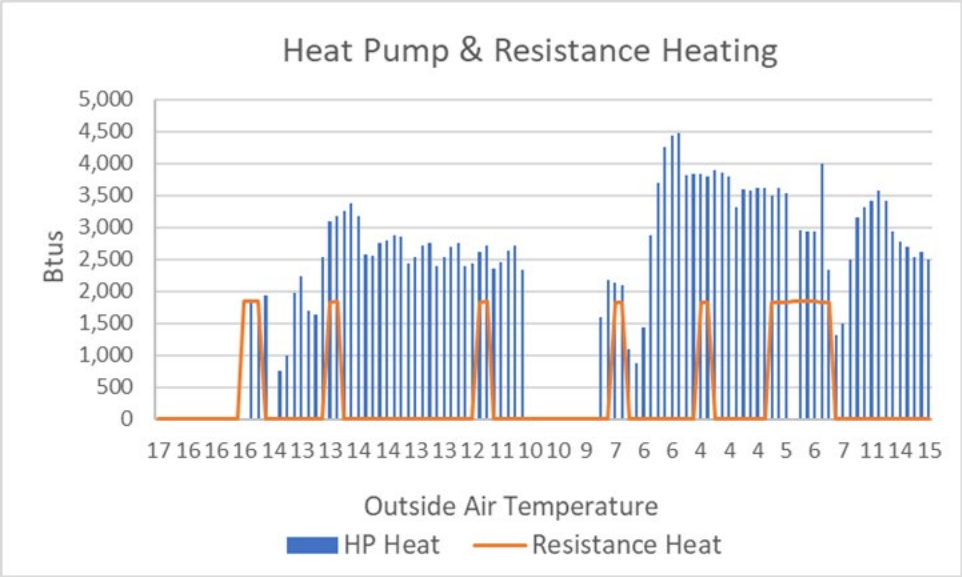
Figure 2 shows that the heat pump maintained a comfortable indoor temperature throughout the evening. In fact, the indoor temperature actually increased during the coldest part of the morning. Figure 3 compares the heating contribution of the heat pump vs. the electric resistance heat source for the same cold evening depicted in Figure 2.

Figure 2. Indoor Air Temperature Maintained vs Outdoor Air Temperature



The spike in outdoor temperature in early afternoon is likely caused by solar heating of the temperature sensor mounted on a west-facing wall.

Figure 3. Heat Pump and Electric Resistance Contribution on a Cold Evening



Power Backup

An issue that is sometimes raised concerning heat pumps is whether power backup systems, like portable generators, can handle the additional electric load demanded by the heat pumps. “In the event of a power outage, we would revert to our

existing oil boiler to power a back-up hydronic coil within the air handler. The boiler is original equipment, we just added the hydronic coil for back-up heating," the homeowner explained. "We have a 1200-watt portable generator; this is what we use to run the backup boiler and air handler. The generator just can't run the outdoor compressor."

Whole Home Heat Pump Case Study: Gardiner ME Site #3

Heat pumps: Two 36,000 Btu/h ducted air-source
Installed: November 2019
Heat provided by heat pump: 82.4 MM Btu
Electricity used by heat pumps: 7,452 kWh
Overall COP: 3.2
Greenhouse gas savings: 7.1 metric tons

Site Description

The site is a 2,300 square foot single-family house. The original structure was built in 1803 with two additions – the first in 1920, which is used as a home office, and the second in 1995. The house is wood-frame construction with an asphalt shingle roof. As might be expected of a house of that age, it is not very air-tight, with a blower-door test value of 5,700 cfm at 50 Pa. The home is occupied year-round, with residents mostly at home during the day, especially since the COVID-19 pandemic started.

The site also has a large (26 kW) photovoltaic array on an adjacent barn. It's estimated electricity generation is four times that of the electricity consumed by the heat pump during the months metered, meaning that the heat pumps were 100% carbon-free on a net basis. This photovoltaic system also supports electric vehicle charging.

The Heat Pump System

The house is heated by two 36,000 Btu/h Mitsubishi air-source heat pumps, one supplying two air handling units in the main house and the addition and one supplying an air handler for the office. The following pictures show various components of the heat pump system. There is no back-up heating system beyond wood stoves that are only used on an as-needed basis. The homeowner wanted to install heat pumps first to provide central cooling, taking advantage of their heating capability as a bonus.

Overall, the homeowners were pleased with the heat pumps. "In terms of performance, they are great," they said. "They've actually worked really well." Asked to rate their level of comfort on a five-point scale, the homeowners gave a five-point rating.

However, the homeowners were dissatisfied with the thermostats that came with the system. "They are very difficult to program. It's not a good system and while the override works, we didn't want to have to manually do that on a constant

basis. One reason we went with a three-zone system was so we wouldn't have to constantly balance the system, but we have to do that now anyway." Due to the issues with the thermostats, they gave a 4.8 rating (out of 5) for the overall system performance.

Heat Pump Outdoor Units

Indoor Air Handler #1

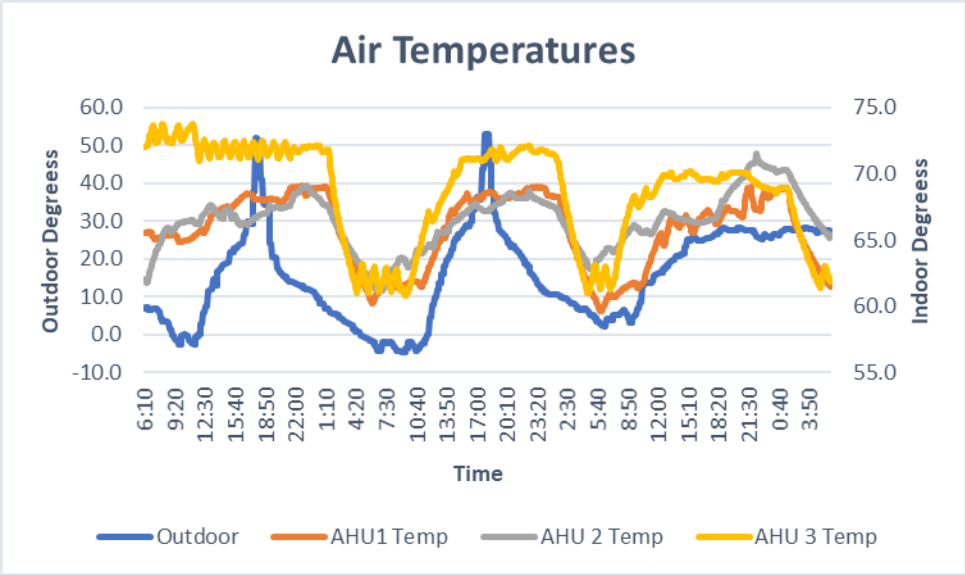
Indoor Air Handler #2

Heat Pump Performance

DNV measured the kWh used by the heat pump outdoor units. It also measured the air handler power draw and the temperatures and the humidity levels of the supply and return air to and from the air handlers. DNV installed metering the last week of January 2021 and removed it in the middle of May.

With the data collected, DNV was able to determine how the heat pump performed during the heating season. The heat pumps were able to heat the entire house over the winter months that were monitored. Figure 1 shows that indoor temperatures were maintained despite it being one of the coldest evenings of the winter.

Figure 1: Site Temperatures



Power Backup

An issue that is sometimes raised concerning heat pumps is whether power backup systems, like portable generators, can handle the additional electric load demanded by the heat pumps.

“If we have a power outage, we have two options,” the homeowner reported. “If it looks like it's short term, we have wood stoves in key locations in the house. But if it's something longer term, like the big ice storm we've had before, then we have an auxiliary portable generator and can select which circuits we want to energize. It's not big enough to run the whole house at full bore, but it is large enough to operate the heat pumps—or at least one of the two (outdoor) units. We estimate the generator could pick up about 75% of the house’s load.”

Whole Home Heat Pump Case Study: Great Diamond Island Site #4

Heat pumps: 24,000 Btu/h ducted and 36,000 Btu/h ductless air-source
Installed: 2020
Heat provided by heat pump system: 25.5 MM Btu
Electricity used by heat pump system: 3,792 kWh
Overall COP: 2.0
Greenhouse gas savings: 1.7 metric tons

Site Description

The site is a 1,200 square foot single-family home built in 1935. It is a wood-frame building with an asphalt shingle roof. Until recently, it had been a seasonal house which was seldom used in the winter. The construction is not at all air-tight, with a blower-door test value of over 4,900 cfm at 50 Pa. However, the homeowners had recently decided to occupy the house for longer periods and had a heat pump system installed in 2020 along with other winterization improvements. “We moved back in at the end of April … and are staying there probably through December,” said the homeowner.

The Heat Pump System

The heat pumps that were installed included a 24,000 Btu/h Daikin ducted model and a 36,000 Btu/h Daikin model. Both are air-source. There is no back-up heating system besides a fireplace which the homeowner said was mostly used “for atmosphere.” The following pictures show the heat pump system’s indoor units, outdoor units, and air handler.

Indoor Unit

“ Outdoor” Unit

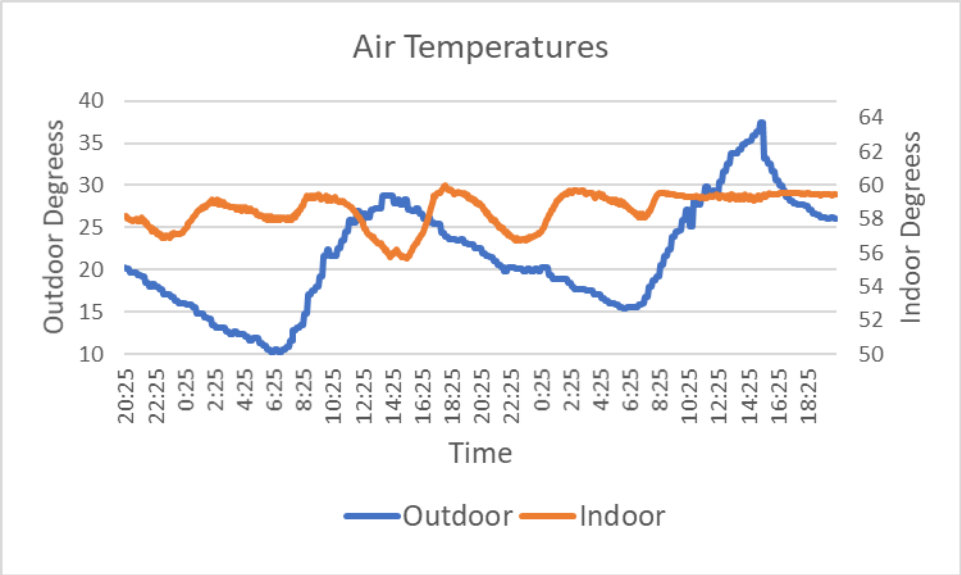
Air Handler

Heat Pump Performance

DNV measured the kWh used by the heat pump’s outdoor unit, the temperature and the humidity of the supply and return air. DNV installed its metering in the first week of February 2021 and removed it in the first week of June. With the data collected, DNV was able to understand how the ducted heat pump performed during the heating season. Figure 1 shows the indoor temperature plotted against the outdoor air temperature over two of the coldest winter evenings. It shows that the indoor temperature remained relatively constant even when the outdoor temperature dipped to 10 degrees Fahrenheit.

“We’d give [the heat pump system] a 5 out of 5 for both overall satisfaction and for comfort,” said the homeowner. “Everything worked great with the system. It was very comfortable in summer, even though it was hot a few times.” The homeowner was also pleased with how easy it was to control the heat pump system and with the system’s energy efficiency. “We made some minor adjustments day to day, but basically it is just a ‘set and forget.’ We put it on cool and then switched to heat for the colder days. Even when it was mildly chilly, we were hardly using any electricity.”

Figure 1. Indoor vs Outdoor Temperatures Over Two Days



Backup Power

An issue that is sometimes raised concerning heat pumps is whether power backup systems, like portable generators, can handle the additional electric load demanded by the heat pumps. The homeowner did not currently have a back-up power system but was thinking of getting one. “We had a few minor outages, but not long enough to affect heating or cooling,” said the homeowner. “We might install propane tanks…. for …. a backup generator - a thought for the future but we haven't decided yet. [If acquired,] a generator would provide power to just a portion of our load, just what is essential.”

Whole Home Heat Pump Case Study: Great Diamond Island Site #5

Heat pumps: 36,000 & 24,000 Btu/h air-source ductless
Date installed: 2020
Heat provided by heat pumps: 12.0 MM Btu
Electricity used by heat pumps: 1,329 kWh
Overall COP: 2.6
Greenhouse gas saved: 0.87 metric tons

Site Description

The site is a 1,700 square foot single-family home built in 1993. It is a wood-frame building with an asphalt shingle roof. The building is very leaky, with a blower-door test value of over 7,000 cfm at 50 Pa. The leakiness is likely due to a unique ceiling construction of wood that has gaps to an open attic. The house had been primarily used as a summer cottage, but it was recently winterized for year-round occupancy. “We have had the house for 30 years, it's our cottage,” the owner explained. “We are close to retirement, so we moved back to Maine to weatherize the cottage.” Since the start of the COVID pandemic, the house has been occupied year-round.

The Heat Pump System

The house is heated by a 24,000 Btu/h and a 36,000 Btu/h Daikin ductless air-source heat pumps which were installed in 2020. The pictures below show the indoor and outdoor units of this system. “Before the heat pump we had a kerosene heater and woodstove. We would get to the Maine cottage in April and leave around December 1. Those worked but one season the pipes froze … so we had to make a change.”

In addition to this incident, the homeowners had concerns about of the reliability of delivered fuels. Finally, they wanted to take advantage of the cooling capabilities of the heat pump.

“The reason why we went with heat pump is that it was the best alternative,” said the homeowner. “The only other option besides the heat pump is putting in a natural gas furnace, so we said: “let’s give this heat pump thing a try. We’ve read so much about it and it being used so much more in cold climates.”

The homeowners have been very satisfied with the heat pumps, rating the comfort level as a five on a five-point scale. They were especially satisfied with the cooling capabilities of the system: “In the summer we have the AC running and it's awesome. It is getting warmer and warmer [outside] and we had probably half a dozen 90-degree days and I can't stand the heat, I hate it,” said the homeowner. “And so having that [air conditioning] availability is fantastic.”

Heat Pump Outdoor Units

Indoor Ductless Units

Other Heating Systems

The home has additional heating systems besides the heat pump including a kerosene-fired direct vent heater and a wood stove. "In the winter, we put the [vent heater] on at 60-62 degrees, and it kicks on in the kitchen, since part of the kitchen is uninsulated,” said the homeowner. He said that the wood stove was used infrequently. “It’s maybe used once a week and mostly for aesthetics.”

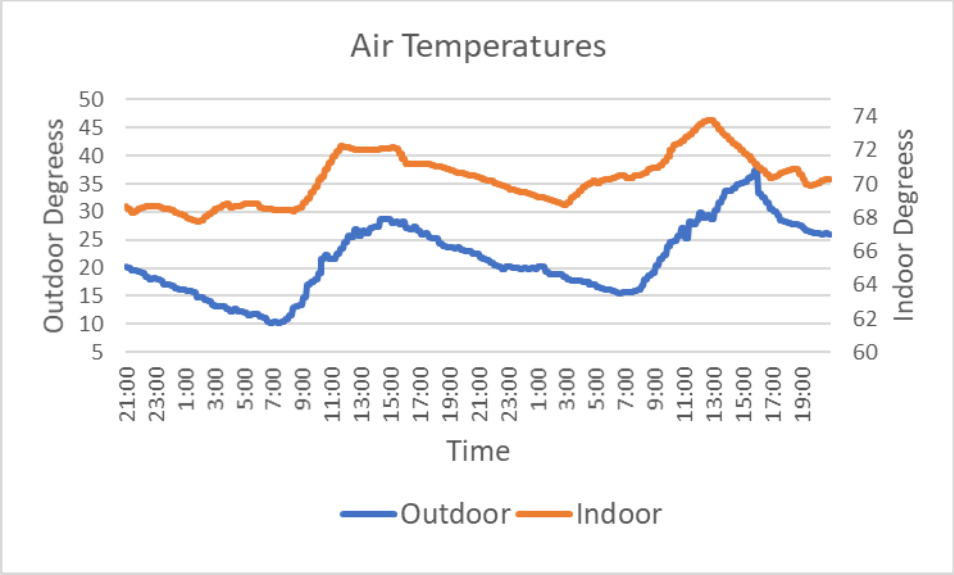
Space Heater

Wood Stove

Heat Pump Performance

DNV was only able to measure the performance of one of the ductless heat pumps due to accessibility issues. For the one that could be metered, DNV measured the kWh used by the heat pump outdoor unit, the air handler power draw, and the temperature and the humidity of the supply and return air to and from the air handler. With these values, DNV was able to calculate the amount of heat delivered by the heat pump. Figure 1 shows that the indoor temperature was maintained at 68 degrees despite it being two cold evenings.

Figure 1: Indoor vs Outdoor Air Temperature Over Two Days



Because they are difficult to measure precisely, DNV was not able to determine the contribution to the heating load by either the direct-vent heater or the wood stove. However, as noted above, the homeowner reported using the wood stove infrequently and the vent heater was used as a supplementary heating source primarily for just one room – the uninsulated kitchen.

Power Backup

An issue that is sometimes raised concerning heat pumps is whether power backup systems, like portable generators, can handle the additional electric load demanded by the heat pumps. This was not an issue for this household due to the size of the generator. “We have a stand-alone Koehler generator that uses natural gas. It’s a big one and it powers the whole house, said the homeowner. “If we lose power out here with ice storms it can be out up to a week. Sometimes two weeks. The generator runs the heat pump with no problem.”

Whole Home Heat Pump Case Study: Great Diamond Island Site #6

Heat pump: 56,000 Btu/h ducted air-source
Heat provided by heat pump: 34.4 MM Btu
Electricity used by heat pump: 6,450 kWh
Overall COP: 1.6
Greenhouse gas savings: 3.0 metric tons

Site Description

The site is a 2,300 square foot single-family home built in 2003. It is a wood-frame building with an asphalt shingle roof. A blower door test of the house found that it was not particularly air tight – the result was 3,700 cfm at 50 Pa.

The house is heated and cooled by a 56,000 Btu/h ducted Bosch air-source heat pump via an air handler in the basement (see pictures). The homeowner installed the heat pump to replace an old oil heating system which had a deteriorating oil tank. The house also has a small electric resistance heater in a bathroom and a wood stove. The heat pump can provide air conditioning which the house did not previously have.

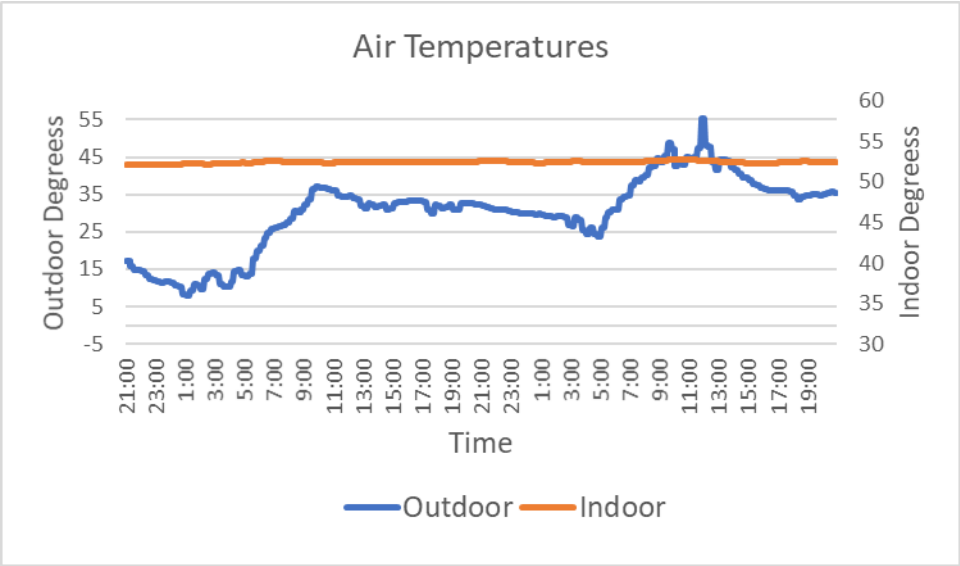
Heat Pump

Air Handler

DNV measured the kWh used by the heat pump outdoor unit, the temperature and the humidity of the supply and return air, and the output of the supply fan. DNV installed the metering the first week of February 2021 and removed it the first week of May. This metering enabled DNV to calculate the amount of heat delivered and the amount of electricity consumed. However, it was not possible to measure the amount of wood that was burned over the study period.

Figure 1 shows how the turn-down temperature of 50 degrees was exactly maintained despite 0-degree weather.

Figure 1. Indoor vs. Outdoor Air Temperatures Over Two Days



Whole Home Heat Pump Case Study: Great Diamond Island Site #7

Heat pump: 36,000 Btu/h ductless/ducted air-source
Heat provided by heat pump: 51.1 MM Btu
Electricity used by heat pump: 4,241 kWh
Overall COP: 3.5
Greenhouse gas savings: 3.9 metric tons

Site Description

The site is a 1,370 square foot single-family home built in 1850. It is a brick building with an asphalt shingle roof. The construction is not air-tight; the blower-door test result was 5,500 cfm at 50 Pa. The home is occupied year-round. Since the COVID-19 pandemic, the resident has been working from home and so there is little or no temperature setback.

The Heat Pump System

The previous owner had heat pumps installed to minimize the home's carbon footprint. These included a ductless heat pump for heat and one for domestic hot water.

The home is heated by both a 36,000 Btu/h Mitsubishi heat pump and a 121 MBtu/h oil-fired boiler (see pictures). The heat pump has two refrigerant circuits, one serving an air handler in the attic and one serving a first-floor wall unit (see picture).

The homeowner gave the heat pump a comfort rating of 5 on a 5-point scale. "I personally prefer a colder climate in general," he said. "I don't turn the burner on until I really need to in November and shut it off when it's not needed."

Heat Pump Outdoor Unit

Indoor Wall Unit

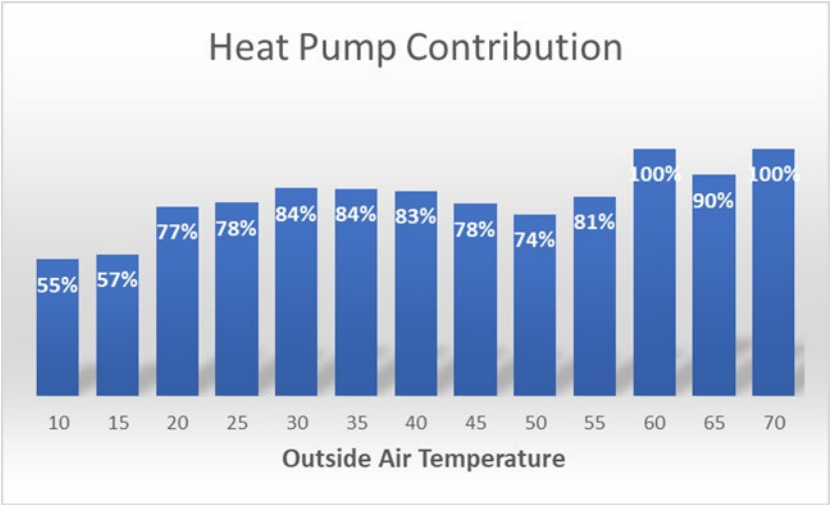
Boiler

Heat Pump Performance

The homeowner rated the performance of the heat pump as a 4 on 5-point scale. “Overall, it's been very positive,” he said. “A lot of the residents out here in Diamond Cove are summer only, and I live here year-round. The heat pump is helpful in the winter and summer. It supplements the baseboard burner year-round.” The one issue the homeowner had with the heat pump performance was that there was a power surge which damaged the boards of the outside unit which caused the heat pump to be down for a month.

DNV measured the kWh used by the heat pump outdoor unit, the temperature and the humidity of the supply and return air. DNV installed the metering in the first week of February 2021 and removed it in the first week of June. These metered data, together with the expected performance of the heat pump, allowed DNV to calculate the amount of heat delivered. Figure 1 shows that the heat pump contributed most of the heat during all the temperature ranges although the heating contributions of the heat pumps and the boiler were almost equal during the coldest temperatures.

Figure 1. Heat Pump Contribution to Heating Load



The heat pump demonstrated its ability to heat the home on its own, at least down to 10 degrees. Figure 2 below shows the indoor temperature was kept in the mid-seventies without any contribution from the back-up boiler.

Figure 2. Indoor vs. Outdoor Air Temperatures

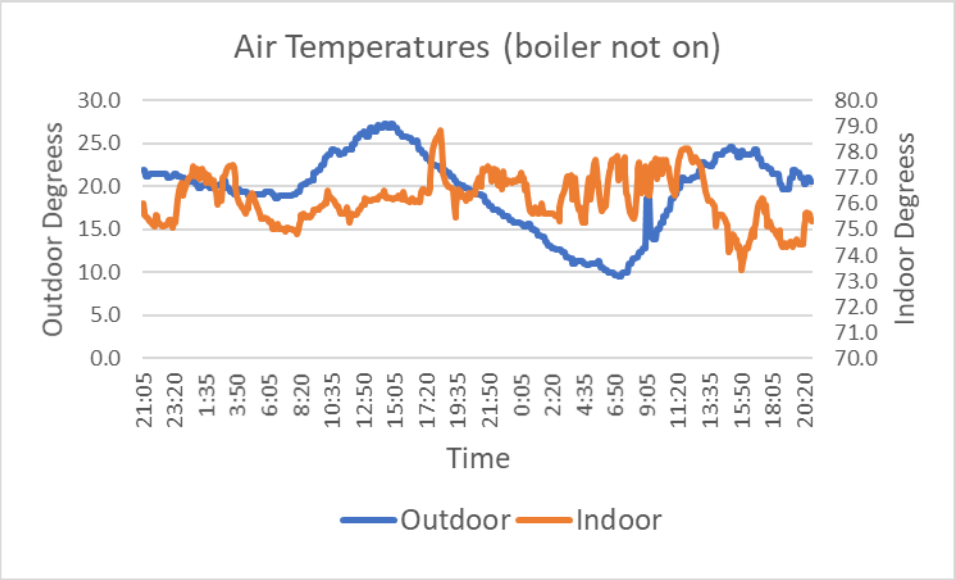
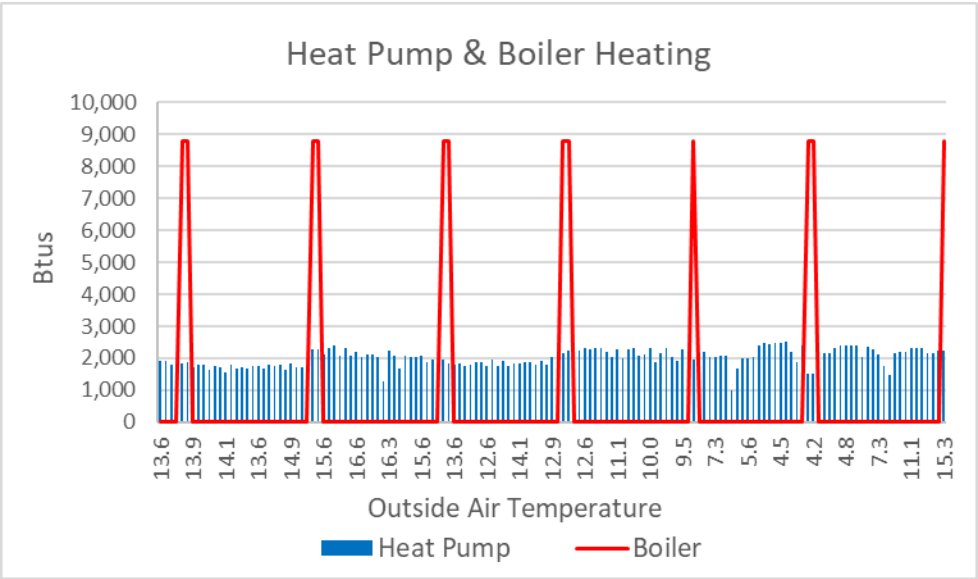


Figure 3 shows the operation of the heat pump and boiler over another cold evening. It is interesting to note that while the heat pump is on almost constantly, the boiler only comes on very briefly at regular intervals. This may be the boiler cycling just to maintain a minimum water temperature, in which case boiler operation might be eliminated completely with the proper controls.

Figure 3. Heat Pump and Boiler Operation on a Cold Evening



Power Backup

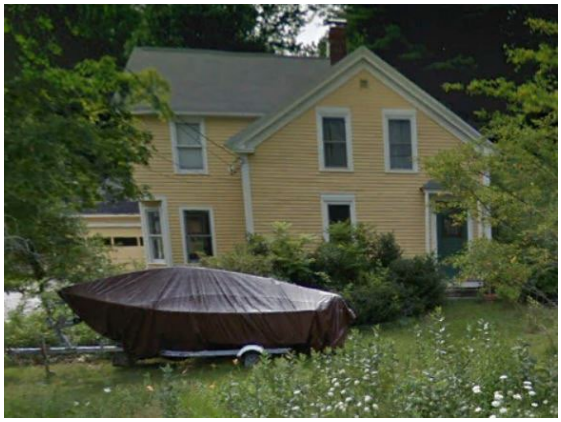
An issue that is sometimes raised concerning heat pumps is whether power backup systems, like portable generators, can handle the additional electric load demanded by the heat pumps. The homeowner said that he has a generator for backup power (which he shares with another family member in a separate dwelling unit) and has a few things plugged into the generator. He has never tested whether the generator can power the entire home but said that “power outages are infrequent and brief when they happen.”

Whole Home Heat Pump Case Study: Cumberland Site #8

Heat pump: 42,000 Btu/h ducted air-source
Heat provided by heat pump: 43.2 MM Btu
Electricity used by heat pump: 3,214 kWh
Overall COP: 3.9
Greenhouse gas savings: 3.3 metric tons

Site Description

The site is a 2,150 square foot single-family home built in 1850. It is a wood-frame building with an asphalt shingle roof. The construction is not very air-tight with a blower-door test value of over 4,300 cfm at 50 Pa.



The homeowners have been upgrading the house step-by-step. They have been home more often since the start of the COVID-19 pandemic and so they are heating their home more than they used to do. Since their old oil furnace was reaching the end of its useful life, they decided to make the change to a heat pump.

The Heat Pump System

The home is heated by a 42,000 Btu/h-ton ducted Mitsubishi air-source heat pump and two small wood stoves (see pictures). The homeowner gave the heat pump a satisfaction rating of 5 on a 5-point scale for comfort. “It keeps our house warmer than we used to,” said the homeowner. “We used to run the wood stoves a lot and kept it a bit chilly until we got the heat pumps.” Now that they have the heat pump, they run the wood stoves rarely -- for aesthetics or when they had a power outage the previous winter. “We also buy clean energy and have solar panels so now that we produce our own electricity, we can keep the house warmer,” the homeowner commented.

Outdoor Unit

Air Handler

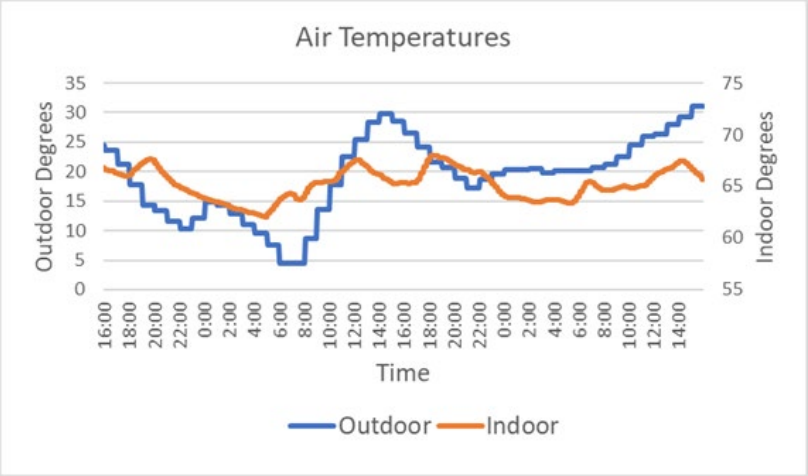
Wood Stoves

Heat Pump Performance

The homeowner also gave the heat pump a satisfaction rating of 5 on a 5-point scale for its performance. “Internally its quiet and it's working beautifully … It’s been quite dependable.” They have had a few minor issues with the outdoor unit. “It’s a little noisy and it faces the neighbors,” said the homeowner. On one occasion, the neighbor blew some snow into the outdoor unit and the homeowner may put a fence around it to avoid these issues in the future. They also had a power outage the previous winter which forced them to rely on their wood stoves for heat (they do not have a backup power generator).

DNV measured the kWh used by the heat pump outdoor unit, the temperature and the humidity of the supply and return air, and the output of the supply fan. DNV installed the metering the second week of February 2021 and removed it the first week of May. These enabled DNV to calculate the amount of heat delivered and the amount of electricity consumed. Based on the homeowners’ comments, the wood stoves were used very little, and the heat pump supplied almost all of the heating. Figure 1 shows that the indoor temperature was maintained at 65 degrees on a cold evening despite the outdoor temperature dipping to almost 0 degrees.

Figure 1. Indoor vs. Outdoor Air Temperature



Whole Home Heat Pump Case Study: Greene Site #9

Heat pump: 48,000 Btu/h ducted air-source
Installed: 2013

Site Description

The site is a 1,760 square foot single-family home built in 2013; the homeowners built the home to be low-energy and reduce their carbon footprint. It is a wood frame building with an asphalt shingle roof. With a blower door test of only 608 cfm at 50 Pa, this new house is very airtight. In 2015 the homeowners had an 8.3 kW ground-mounted photovoltaic array installed and in 2021 they added additional solar panels. “Our goal is to have a net zero house,” said the homeowner. “… One of the benefits of a heat pump and all electric is that we can use the panels to generate all of our needs.”

The Heat Pump

The house is heated and cooled by a 48,000 Btu/h Bryant ducted air-source heat pump via an air handler in the basement (see pictures). The air handler has electric resistance heating coils. Make-up air to the air handler is pre-conditioned by an energy recovery ventilator (see picture). The heat pump system gauges the most efficient way to heat the house whether this involves the heat pump, the fan coils, or both.

Air Handler

Energy Recovery Ventilator

Outdoor Unit

The homeowner was very pleased with the comfort provided by the heat pump giving it a 5-point satisfaction rating on a 5-point scale. “It keeps every room at the desired temperature without fan noise.” The homeowner was also happy with the energy savings that the heat pump provided. “It's very efficient. Our utility bills are quite low compared to the ones of our former [oil-heated] house.”

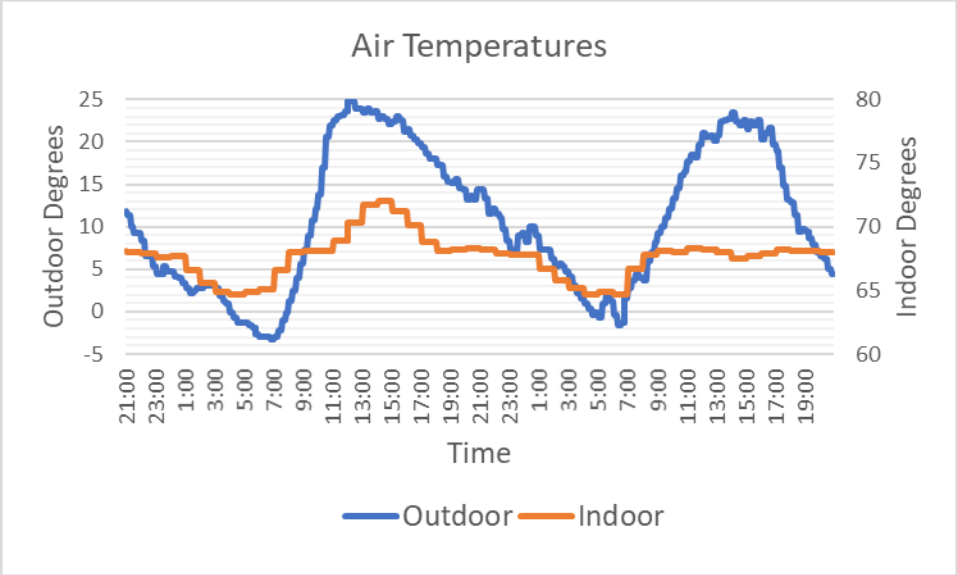
Heat Pump Performance

The homeowner was also very satisfied with the heat pump’s performance giving it a satisfaction rating of 5 on a 5-point scale. “Our experience was positive. We have the whole house ducted system that works flawlessly … because it has modulating fans. Because these modulate the fan speeds, the system does not come on strong like the old one but is quiet and we hardly know it's there.”

DNV measured the temperature and the humidity of the supply and return air, and the output of the supply fan, and the power used for the electric resistance heat in the air handler. DNV installed the metering in the second week of February 2021 and removed it in the first week of May. Due to metering equipment failures, DNV was not possible to determine the amount of power used by the heat pump.

Figure 1 demonstrates that the heating system was able to maintain a comfortable temperature even when the outdoor temperature was below zero. However, due to the metering failures, DNV was unable to separate out when the heat was provided by the heat pump, electric resistance coils, or both.

Figure 1. Indoor vs Outdoor Temperatures Over Two Days



Power Backup

An issue that is sometimes raised concerning heat pumps is whether power backup systems, like portable generators, can handle the additional electric load demanded by the heat pumps. The homeowner has a 4,500 W generator for backup power, but he uses it for loads like the refrigerator, water pump and lights rather than the heat pump. “We haven't had any

power outages for which we needed to provide extra heat," he said. "We have a well-insulated house, and so if the power goes out, there is no need to do anything."

Whole Home Heat Pump Case Study: Arundel Site #10

Heat pump: 36,000 Btu/h ducted air-source
Heat provided by heat pump: 5.4 MM Btu
Electricity used by heat pump: 936 kWh
Overall COP: 1.7
Greenhouse gas savings: 0.3 metric tons

Site Description

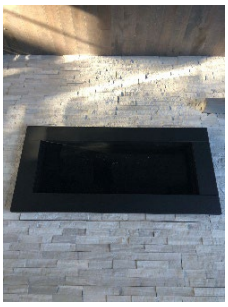
The site is a 1,900 square foot single-family home built in 2020. The owners moved in December of that year. It is a wood-frame building with an asphalt shingle roof. This new house is very airtight with a blower door test of only 720 cfm at 50 Pa.

The Heat Pump System

The house is heated and cooled by a 36,000 Btu/h Mitsubishi heat pump via an air handler in the basement, supplemented by electric resistance heat. The house also has a propane fireplace in the living room and a portable dehumidifier in the basement (see pictures). The homeowner said that they use the fireplace “for ambiance mostly.”

Outdoor Unit

Air Handler



Propane Fireplace

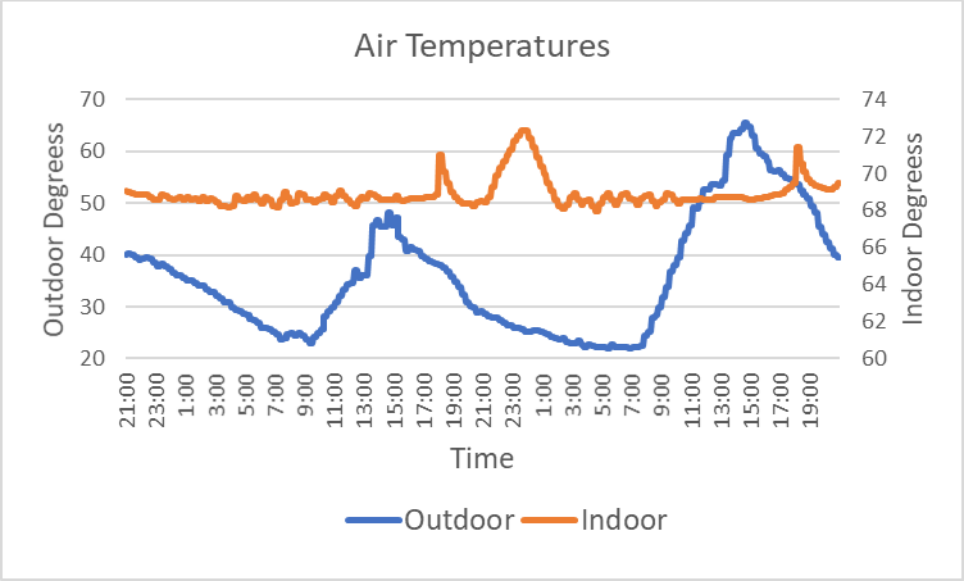
Dehumidifier

Heat Pump Performance

The homeowner gave ratings of 5 on a 5-point scale for both the comfort provided by the heat pump system and the system's performance. "I think pretty much it has all been positive," he said. "Having come from the house before with a forced hot air system which was loud and you could feel the air running, [this heat pump] is quiet in the background and you don't hear it or feel it unless you're on a register."

DNV measured the kWh used by the heat pump outdoor unit, the temperature and the humidity of the supply and return air, and the output of the supply fan. It installed the metering in the third week of February 2021 and removed it in the first week of May. This metering data enabled DNV to calculate the amount of heat delivered and the amount of electricity consumed by the heat pump. However, due to a metering equipment failure, it was not possible to determine the amount of resistance heat used. Figure 1 shows that the heating system maintained the indoor air at 68 degrees while the outdoor temperature fell to 25 degrees.

Figure 1. Indoor vs Outdoor Temperatures Over Two Days



Power Backup

An issue that is sometimes raised concerning heat pumps is whether power backup systems, like portable generators, can handle the additional electric load demanded by the heat pumps. The homeowner said that they have a generator large enough to power the whole house, but they have not had much opportunity to use it. "As for outages, we haven't really had one long enough to worry about it, he said. "In the few times it has happened it's only been for a few hours." He also noted that they can use the propane fireplace as a backup heat source.