ONTARIO ENERGY BOARD

EB-2021-0002

IN THE MATTER OF the *Ontario Energy Board Act*, 1998, S. O. 1998, c. 15, Schedule B;

AND IN THE MATTER OF an application for a Multi-Year Natural Gas Demand Side Management Plan (2022 to 2027).

Compendium of Environmental Defence

Technical Conference – Enbridge Panel 1 – February 28, 2022

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MC-994-2021-723

November 15, 2021

Mr. Richard Dicerni
Chair
Ontario Energy Board
2300 Yonge Street, 27th floor
PO Box 2319
Toronto ON M4P 1E4

Dear Mr. Dicerni:

Thank you for your letter dated July 27, 2021 presenting the Ministry of Energy (ENERGY) with the Ontario Energy Board's (OEB) 2021 Annual Report for the fiscal year ending March 31, 2021. I have accepted the Annual Report and tabled it with the Legislative Assembly of Ontario on September 28, 2021. The report should now be made available on the OEB's website (as required by our Memorandum of Understanding).

The 2020/2021 Annual Report captures the progress the OEB made toward modernization in the year that it transitioned to its new governance structure. The OEB's commitment to modernization is further reflected in the report card on the Mandate Letter that you submitted to me on September 20, 2021.

The Mandate Letter provided to the OEB on October 1, 2020 showed an ambitious multi-year agenda for a modernized OEB. I am pleased that the OEB has taken such significant steps to promote regulatory excellence within the organization. This work was accomplished while facing the challenges associated with the COVID-19 pandemic. This period saw the OEB adapt to a remote work environment while also moving quickly to support consumers experiencing difficulties with their energy bills and industry as it responded to the crisis. I want to thank you along with the OEB's leadership team, Commissioners and dedicated staff for the incredible work done in support of Ontarians over the past year.

As you begin planning for your next Business Plan, it is my responsibility as Minister to provide you with a renewed Mandate Letter to update you on the government's priorities for the energy sector and my expectations for the OEB for the upcoming three-year planning period. It is essential that the OEB continues to make progress in implementing the priorities of the 2020 Mandate Letter, including robust performance measurement, transparent engagement with stakeholders and red tape reduction.

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The OEB has incorporated these priorities into the Strategic Themes of its 2021/22 – 2025/26 Strategic Plan – evolving to become a top quartile regulator, driving energy sector performance, protecting the public and facilitating innovation. These themes remain both relevant and necessary as the OEB updates its Business Plan to reflect the priorities set out below.

The government's priorities for the energy sector are about promoting reliability, affordability, sustainability and consumer choice. I know that the OEB has begun grappling with important questions related to these priorities, such as how to consider greenhouse gas emissions and decarbonization within the energy sector activity that the OEB regulates. I have confidence in the OEB, its commitment to modernization and that it will set its priorities and undertake its work with an eye to addressing the challenges and opportunities facing Ontario's energy sector. Within that context, I would like to highlight some initiatives where the OEB's role in delivering these priorities will be critical over the next three years:

- The OEB should continue to prioritize its work facilitating and enabling innovation and adoption of new technologies where it makes sense for customers, including implementation of the government's Green Button and Community Net Metering initiatives. Developing policies that support the adoption of non-wires and non-pipeline alternatives to traditional forms of capital investment, where cost-effective, will be essential in maintaining an effective regulatory environment amidst the increasing adoption of Distributed Energy Resources. Work that is already underway, like the Framework for Energy Innovation, should continue. I am pleased with the increased co-ordination and collaboration with stakeholders, especially the Independent Electricity System Operator (IESO). This ongoing collaboration is critical to ensure that initiatives are evaluated and decisions are made with both cost and reliability in mind.

- Increased adoption of electric vehicles (EVs) is expected to impact Ontario's electricity system in the coming years and the OEB must take steps to facilitate their efficient integration into the provincial electricity system, including providing guidance to Local Distribution Companies (LDCs) on system investments to prepare for EV adoption. I am pleased that the OEB is participating in the government's Transportation Electrification Council. I will write to you in the near future on this matter, as it relates to the OEB's Regulated Price Plan (RPP) Roadmap to improve system efficiency and give customers greater control.

- The OEB has done extensive work studying dynamic pricing plans for Class B customers. As Ontario recovers from COVID-19-related economic hardships, we must find ways to support small businesses and give businesses the tools to keep energy prices low so as to not pass on those costs to consumers. I ask that the OEB work with the IESO to develop a plan to design and implement a dynamic pricing pilot to assess the benefits for non-RPP Class B customers.

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- I expect to see the establishment of multi-year natural gas Demand Side Management (DSM) programming and the implementation of the OEB's Integrated Resource Planning framework for assessing demand-side and supply-side alternatives to pipeline infrastructure in meeting natural gas system needs. I would like to express my strong interest in a framework that delivers increased natural gas conservation savings and reduces greenhouse gas emissions. Conservation is a strong driver for cost savings for ratepayers, and with the introduction of carbon pricing, conservation can also transform homes and help protect ratepayers from the impact of the carbon tax. Natural gas conservation programs have delivered continued value for money for ratepayers – based on OEB-verified results for 2019, every dollar spent on natural gas DSM has resulted in up to $3 in participant and social benefits.

- With regard to the next multi-year DSM programming period, it is important that the regulatory processes are optimized to increase efficiency so that they do not hinder Ontarians' access to the real savings that result from these programs. It is also important that the DSM Framework be implemented in a way that enables customers to lower energy bills in the most cost-effective way possible, and help customers make the right choices regardless of whether that is through more efficient gas or electric equipment. I also wish to stress the continued need to foster integration and alignment between natural gas and electricity conservation programs to find efficiencies and to facilitate a streamlined customer experience, where feasible. That said, I am pleased to see the continued collaboration between the IESO Conservation and Demand Management (CDM) and DSM programs in the low-income space and encourage further collaboration, as appropriate. Likewise, as communicated in a recent letter from the Ministry to the federal government encouraging collaboration between DSM and the new Canada Greener Homes Program, it is important that the OEB considers how to use Ontario's DSM programs to leverage these federal funds to benefit Ontario ratepayers.

- The *Supporting Broadband and Infrastructure Expansion Act, 2021* (Bill 257) received Royal Assent on April 12, 2021. This Act contains amendments to the *Ontario Energy Board Act, 1998* that, when proclaimed into force, would establish new authorities in support of the use of and access to electricity infrastructure for non-electricity purposes. As ENERGY considers how these authorities can support the government's objectives for rural broadband expansion, continued consultation and collaboration with the OEB will be essential.

- Modernizing and streamlining processes to reduce regulatory burden is vitally important to the work of an efficient and effective regulator. I am pleased that the OEB has taken steps in this direction in response to the 2020 Mandate Letter, including reviewing how filing requirements can be tailored to LDC size, releasing the Chief Commissioner's Plan with initiatives to enhance adjudicative processes and launching a review of the Reporting & Record-keeping Requirements.

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These plans should continue, ensuring they reflect the feedback of stakeholders and deliver results in the coming fiscal year. The OEB should also continue its work reviewing intervenor processes to identify opportunities to improve the efficiency and effectiveness.

- The OEB should continue to ensure that the structure and operations of the distribution sector constantly evolve towards optimal efficiency. To that end, the OEB should explore opportunities to enable proactive investment in energy infrastructure, such as protection and refurbishment, where utilities can prove there are long-term economic and reliability benefits to ratepayers. In previous years, these efficiencies have been found both through utility mergers/ acquisitions and with the formation of innovative partnerships between utilities. Considering this, I also ask that the OEB require LDCs with fewer than 30,000 customers to file information within their cost-of-service applications on the extent to which they have investigated potential opportunities from consolidation or collaboration/partnerships with other distributors.

- Over the coming year, the government will continue its review of Ontario's long-term energy planning framework to increase the effectiveness, certainty, transparency and accountability of energy decision-making in Ontario while protecting the interests of ratepayers. I want to thank OEB staff and leadership for their contribution to the process so far and look forward to continued collaboration as we consider an appropriate role for the OEB in long-term planning.

Through these priorities we can ensure that the OEB is continuing to deliver value for Ontario's energy consumers. We are confident that as we recover from the COVID-19 pandemic, the people of Ontario are going to unleash the economic growth that is necessary for job creation, prosperity and a stronger province.

This Mandate Letter is also my opportunity to provide you with the government's broad priorities for board-governed agencies. As part of the Government of Ontario, agencies are expected to act in the best interests of Ontarians by being efficient, effective and providing value-for-money to the people of Ontario. Our government's primary focus is to protect every life and every job we possibly can. Without healthy people, we cannot have a healthy economy. As you implement your modernization plan for the OEB, I ask that you do so in a manner consistent with Ontario's priorities for board-governed agencies that are appended to this Letter.

Finally, in the coming months, my staff will continue to work with the OEB to prepare for the conclusion of the two-year transition period related to the establishment of the new governance structure. I am confident that the OEB will emerge from the transition period in October 2022 in a strong position to fully deliver on its statutory responsibilities.

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I thank you and your fellow board members for your continued support and for your valuable contributions. Should you have any questions/concerns regarding this Mandate Letter, please feel free to contact Karen Moore, Assistant Deputy Minister – Strategic, Network and Agency Policy Division at karen.moore@ontario.ca.

Sincerely,

Todd Smith
Minister

c: David Donovan, Chief of Staff to the Minister of Energy
Dominic Roszak, Deputy Chief of Staff to the Minister of Energy
Stephen Rhodes, Deputy Minister of Energy
Susanna Zagar, CEO, Ontario Energy Board

APPENDIX: Government of Ontario Priorities for Board-Governed Agencies

1. **Competitiveness, Sustainability and Expenditure Management**
    - Operating within your agency's financial allocations;
    - Complying with applicable direction related to supply chain centralization and Realty Interim Measures for agency office space;
    - Leveraging and meeting benchmarked outcomes for compensation strategies and directives; and
    - Working with the ministry, where appropriate, to advance the *Ontario Onwards Action Plan.*

2. **Transparency and Accountability**
    - Abiding by applicable government directives and policies and ensuring transparency and accountability in reporting;
    - Adhering to requirements of the Agencies and Appointments Directive, accounting standards and practices, and the *Public Service of Ontario Act* ethical framework and responding to audit findings, where applicable; and
    - Identifying appropriate skills, knowledge and experience needed to effectively support the board's role in agency governance and accountability.

3. **Risk Management**
    - Developing and implementing an effective process for the identification, assessment and mitigation of risks, including planning for and responding to health and other emergency situations, including but not limited to COVID-19; and
    - Developing a continuity of operations plan that identifies time critical/essential services and personnel.

4. **Workforce Management**
    - Optimizing your organizational capacity to support the best possible public service delivery; and
    - Modernizing and redeploying resources to priority areas when or where they are needed.

5. **Data Collection**
    - Improving how the agency uses data in decision-making, information-sharing and reporting, including by leveraging available or new data solutions to inform outcome-based reporting and improve service delivery; and
    - Supporting transparency and privacy requirements of data work and data sharing with the ministry, as appropriate.

6. **Digital Delivery and Customer Service**
   - Exploring and implementing digitization or digital modernization strategies for online service delivery and continuing to meet and exceed customer service standards through transition; and
   - Adopting digital approaches, such as user research, agile development and product management.

7. **Diversity and Inclusion**
   - Developing and encouraging diversity and inclusion initiatives promoting an equitable, inclusive, accessible, anti-racist and diverse workplace;
   - Demonstrating leadership of an inclusive environment free of harassment; and
   - Adopting an inclusion engagement process to ensure all voices are heard to inform policies and decision-making.

8. **COVID-19 Recovery**
   - Identifying and pursuing service delivery methods (digital or other) that have evolved since the start of COVID-19; and
   - Supporting the recovery efforts from COVID-19.

Government of Canada Gouvernement du Canada

Heating and Cooling With a Heat Pump

Table of Contents

Introduction

If you are exploring options to heat and cool your home or reduce your energy bills, you might want to consider a heat pump system. Heat pumps are a proven and reliable technology in Canada, capable of providing year-round comfort control for your home by supplying heat in the winter, cooling in the summer, and in some cases, heating hot water for your home.

Heat pumps can be an excellent choice in a variety of applications, and for both new homes and retrofits of existing heating and cooling systems. They are also an option when replacing existing air conditioning systems, as the incremental cost to move from a cooling-only system to a heat pump is often quite low. Given the wealth of different system types and options, it can often be difficult to determine if a heat pump is the right option for your home.

If you are considering a heat pump, you likely have a number of questions, including:

- What types of heat pumps are available?
- How much of my annual heating and cooling needs can a heat pump provide?
- What size of heat pump do I need for my home and application?
- How much do heat pumps cost compared with other systems, and how much could I save on my energy bill?
- Will I need to make additional modifications to my home?
- How much servicing will the system require?

This booklet provides important facts on heat pumps to help you be more informed, supporting you to make the right choice for your home. Using these questions as a guide, this booklet describes the most common types of heat pumps, and discusses the factors involved in choosing, installing, operating, and maintaining a heat pump.

Intended Audience

This booklet is intended for homeowners looking for background information on heat pump technologies in order to support informed decision making regarding system selection and integration, operation and maintenance. The information provided here is general, and specific details may vary depending on your installation and system type. This booklet should not replace working with a contractor or energy advisor, who will ensure that your installation meets your needs and desired objectives.

A Note on Energy Management in the Home

Heat pumps are very efficient heating and cooling systems and can significantly reduce your energy costs. In thinking of the home as a system, it is recommended that heat losses from your home be minimized from areas such as air leakage (through cracks, holes), poorly insulated walls, ceilings, windows and doors.

Tackling these issues first can allow you to use a smaller heat pump size, thereby reducing heat pump equipment costs and allowing your system to operate more efficiently.

A number of publications explaining how to do this are available from Natural Resources Canada.

What Is a Heat Pump, and How Does It Work?

Heat pumps are a proven technology that have been used for decades, both in Canada and globally, to efficiently provide heating, cooling, and in some cases, hot water to buildings. In fact, it is likely that you interact with heat pump technology on a daily basis: refrigerators and air conditioners operate using the same principles and technology. This section presents the basics of how a heat pump works, and introduces different system types.

Heat Pump Basic Concepts

A heat pump is an electrically driven device that extracts heat from a low temperature place (a **source**), and delivers it to a higher temperature place (a **sink**).

To understand this process, think about a bicycle ride over a hill: No effort is required to go from the top of the hill to the bottom, as the bike and rider will move naturally from a high place to a lower one. However, going up the hill requires a lot more work, as the bike is moving against the natural direction of motion.

In a similar manner, heat naturally flows from places with higher temperature to locations with lower temperatures (e.g., in the winter, heat from inside the building is lost to the outside). A heat pump uses additional electrical energy to counter the natural flow of heat, and *pump* the energy available in a colder place to a warmer one.

So how does a heat pump heat or cool your home? As energy is extracted from a **source**, the temperature of the source is reduced. If the home is used as the source, thermal energy will be removed, *cooling* this space. This is how a heat pump operates in cooling mode, and is the same principle used by air conditioners and refrigerators. Similarly, as energy is added to a **sink**, its temperature increases. If the home is used as a sink, thermal energy will be added, heating the space. A heat pump is fully reversible, meaning that it can both heat and cool your home, providing year-round comfort.

Sources and Sinks for Heat Pumps

Selecting the source and sink for your heat pump system goes a long way in determining the performance, capital costs and operating costs of your system. This section provides a brief overview of common sources and sinks for residential applications in Canada.

Sources: Two sources of thermal energy are most commonly used for heating homes with heat pumps in Canada:

- **Air-Source:** The heat pump draws heat from the outside air during the heating season and rejects heat outside during the summer cooling season.
  It may be surprising to know that even when outdoor temperatures are cold, a good deal of energy is still available that can be extracted and delivered to the building. For example, the heat content of air at -18°C equates to 85% of the heat contained at 21°C. This allows the heat pump to provide a good deal of heating, even during colder weather.

Air-source systems are the most common on the Canadian market, with over 700,000 installed units across Canada.
This type of system is discussed in more detail in the *Air-Source Heat Pumps section*.

- **Ground-Source:** A ground-source heat pump uses the earth, ground water, or both as the source of heat in the winter, and as a reservoir to reject heat removed from the home in the summer.
  These heat pumps are less common than air-source units, but are becoming more widely used in all provinces of Canada. Their primary advantage is that they are not subject to extreme temperature fluctuations, using the ground as a constant temperature source, resulting in the most energy efficient type of heat pump system.
  This type of system is discussed in more detail in the *Ground-Source Heat Pumps* section.

Sinks: Two sinks for thermal energy are most commonly used for heating homes with heat pumps in Canada:

- Indoor air is heated by the heat pump. This can be done through:
  - A centrally ducted system or
  - A ductless indoor unit, such as a wall mounted unit.
- Water inside the building is heated. This water can then be used to serve terminal systems like radiators, a radiant floor, or fan coil units via a hydronic system.

An Introduction to Heat Pump Efficiency

Furnaces and boilers provide space heating by adding heat to the air through the combustion of a fuel such as natural gas or heating oil. While efficiencies have continually improved, they still remain below 100%, meaning that not all the available energy from combustion is used to heat the air.

Heat pumps operate on a different principle. The electricity input into the heat pump is used to *transfer* thermal energy between two locations. This allows the heat pump to operate more efficiently, with typical efficiencies well over
100%, i.e. *more* thermal energy is produced than the amount of electric energy used to pump it.

It is important to note that the efficiency of the heat pump depends greatly on the temperatures of the **source** and **sink**. Just like a steeper hill requires more effort to climb on a bike, greater temperature differences between the source and sink of the heat pump require it to work harder, and can reduce efficiency. Determining the right size of heat pump to maximize seasonal efficiencies is critical. These aspects are discussed in more detail in the *Air-Source Heat Pumps* and *Ground-Source Heat Pumps* sections.

Efficiency Terminology

A variety of efficiency metrics are used in manufacturer catalogues, which can make understanding system performance somewhat confusing for a first time buyer. Below is a breakdown of some commonly used efficiency terms:

Steady-State Metrics: These measures describe heat pump efficiency in a 'steady-state,' i.e., without real-life fluctuations in season and temperature. As such, their value can change significantly as source and sink temperatures, and other operational parameters, change. Steady state metrics include:

Coefficient of Performance (COP): The COP is a ratio between the rate at which the heat pump transfers thermal energy (in kW), and the amount of electrical power required to do the pumping (in kW). For example, if a heat pump used 1kW of electrical energy to transfer 3 kW of heat, the COP would be 3.

Energy Efficiency Ratio (EER): The EER is similar to the COP, and describes the steady-state cooling efficiency of a heat pump. It is determined by dividing the cooling capacity of the heat pump in Btu/h by the electrical energy input in Watts (W) at a specific temperature. EER is strictly associated with describing the steady-state cooling efficiency, unlike COP which can be used to express the efficiency of a heat pump in heating as well as cooling.

Seasonal Performance Metrics: These measures are designed to give a better estimate of performance over a heating or cooling season, by incorporating "real life" variations in temperatures across the season.

Seasonal metrics include:

Heating Seasonal Performance Factor (HSPF): HSPF is a ratio of how much energy the heat pump delivers to the building over the full heating season (in Btu), to the total energy (in Watthours) it uses over the same period.
Weather data characteristics of long-term climate conditions are used to represent the heating season in calculating the HSPF. However, this calculation is typically limited to a single region, and may not fully represent performance across Canada. Some manufacturers can provide an HSPF for another climate region upon request; however typically HSPFs are reported for Region 4, representing climates similar to the Midwestern US. Region 5 would cover most of the southern half of the provinces in Canada, from the B.C interior through New Brunswick [1].

Seasonal Energy Efficiency Ratio (SEER): SEER measures the cooling efficiency of the heat pump over the entire cooling season. It is determined by dividing the total cooling provided over the cooling season (in Btu) by the total energy used by the heat pump during that time (in Watt-hours). The SEER is based on a climate with an average summer temperature of 28°C.

Important Terminology for Heat Pump Systems

Here are some common terms you may come across while investigating heat pumps.

Heat Pump System Components

The **refrigerant** is the fluid that circulates through the heat pump, alternately absorbing, transporting and releasing heat. Depending on its location, the fluid may be liquid, gaseous, or a gas/vapour mixture

The **reversing valve** controls the direction of flow of the refrigerant in the heat pump and changes the heat pump from heating to cooling mode or vice versa.

A **coil** is a loop, or loops, of tubing where heat transfer between the source/sink and refrigerant takes place. The tubing may have fins to increase the surface area available for heat exchange.

The **evaporator** is a coil in which the refrigerant absorbs heat from its surroundings and boils to become a low-temperature vapour. As the refrigerant passes from the reversing valve to the compressor, the accumulator collects any excess liquid that did not vaporize into a gas. Not all heat pumps, however, have an accumulator.

The **compressor** squeezes the molecules of the refrigerant gas together, increasing the temperature of the refrigerant. This device helps to transfer thermal energy between the source and sink.

The **condenser** is a coil in which the refrigerant gives off heat to its surroundings and becomes a liquid.

The **expansion** device lowers the pressure created by the compressor. This causes the temperature to drop, and the refrigerant becomes a low-temperature vapour/liquid mixture.

The **outdoor unit** is where heat is transferred to/from the outdoor air in an air-source heat pump. This unit generally contains a heat exchanger coil, the compressor, and the expansion valve. It looks and operates in the same manner as the outdoor portion of an air-conditioner.

The **indoor coil** is where heat is transferred to/from indoor air in certain types of air-source heat pumps. Generally, the indoor unit contains a heat exchanger coil, and may also include an additional fan to circulate heated or cooled air to the occupied space.

The **plenum** , only seen in ducted installations, is part of the air distribution network. The plenum is an air compartment that forms part of the system for distributing heated or cooled air through the house. It is generally a large compartment immediately above or around the heat exchanger.

Other Terms

Units of measurement for capacity, or power use:

A Btu/h, or British thermal unit per hour, is a unit used to measure the heat output of a heating system. One Btu is the amount of heat energy given off by a typical birthday candle. If this heat energy were released over the course of one hour, it would be the equivalent of one Btu/h.

A **kW**, or **kilowatt**, is equal to 1000 watts. This is the amount of power required by ten 100-watt light bulbs.
A **ton** is a measure of heat pump capacity. It is equivalent to 3.5 kW or 12 000 Btu/h.

Air-Source Heat Pumps

Air-source heat pumps use the outdoor air as a source of thermal energy in heating mode, and as a sink to reject energy when in cooling mode. These types of systems can generally be classified into two categories:

Air-Air Heat Pumps. These units heat or cool the air inside your home, and represent the vast majority of air-source heat pump integrations in Canada. They can be further classified according to the type of installation:

- **Ducted:** The indoor coil of the heat pump is located in a duct. Air is heated or cooled by passing over the coil, before being distributed via the ductwork to different locations in the home.
- **Ductless:** The indoor coil of the heat pump is located in an indoor unit. These indoor units are generally located on the floor or wall of an occupied space, and heat or cool the air in that space directly. Among these units, you may see the terms mini- and multi-split:
    - **Mini-Split:** A single indoor unit is located inside the home, served by a single outdoor unit.
    - **Multi-Split:** Multiple indoor units are located in the home, and are served by a single outdoor unit.

Air-air systems are more efficient when the temperature difference between inside and outside is smaller. Because of this, air-air heat pumps generally try to optimize their efficiency by providing a higher volume of warm air, and heating that air to a lower temperature (normally between 25 and 45°C). This contrasts with furnace systems, which deliver a smaller volume of air, but heat that air to higher temperatures (between 55°C and 60°C). If you are switching to a heat pump from a furnace, you may notice this when you begin using your new heat pump.

Air-Water Heat Pumps: Less common in Canada, air-water heat pumps heat or cool water, and are used in homes with hydronic (water-based) distribution systems such as low temperature radiators, radiant floors, or fan coil units. In heating mode, the heat pump provides thermal energy to the hydronic system. This process is reversed in cooling mode, and thermal energy is extracted from the hydronic system and rejected to the outdoor air.

Operating temperatures in the hydronic system are critical when evaluating air-water heat pumps. Air-water heat pumps operate more efficiently when heating the water to lower temperatures, i.e., below 45 to 50°C, and as such are a better match for radiant floors or fan coil systems. Care should be taken if considering their use with high temperature radiators that require water temperatures above 60°C, as these temperatures generally exceed the limits of most residential heat pumps.

Major Benefits of Air-Source Heat Pumps

Installing an air-source heat pump can offer you a number of benefits. This section explores how air-source heat pumps can benefit your household energy footprint.

Efficiency

The major benefit of using an air-source heat pump is the high efficiency it can provide in heating compared to typical systems like furnaces, boilers and electric baseboards. At 8°C, the coefficient of performance (COP) of air-source heat pumps typically ranges from between 2.0 and 5.4. This means that, for units with a COP of 5, 5 kilowatt hours (kWh) of heat are transferred for every kWh of electricity supplied to the heat pump. As the outdoor air temperature drops, COPs are lower, as the heat pump must work across a greater temperature difference between the indoor and outdoor space. At –8°C, COPs can range from 1.1 to 3.7.

On a seasonal basis, the heating seasonal performance factor (HSPF) of market available units can vary from 7.1 to 13.2 (Region V). It is important to note that these HSPF estimates are for an area with a climate similar to Ottawa. Actual savings are highly dependant on the location of your heat pump installation.

Energy Savings

The higher efficiency of the heat pump can translate into significant energy use reductions. Actual savings in your house will depend on a number of factors, including your local climate, efficiency of your current system, size and type of heat pump, and the control strategy. Many online calculators are available to provide a quick estimation of how much energy savings you can expect for your particular application. NRCan's ASHP-Eval tool is freely available and could be used by installers and mechanical designers to help advise on your situation.

How Does an Air-Source Heat Pump Work?

An air-source heat pump has three cycles:

- The Heating Cycle: Providing thermal energy to the building
- The Cooling Cycle: Removing

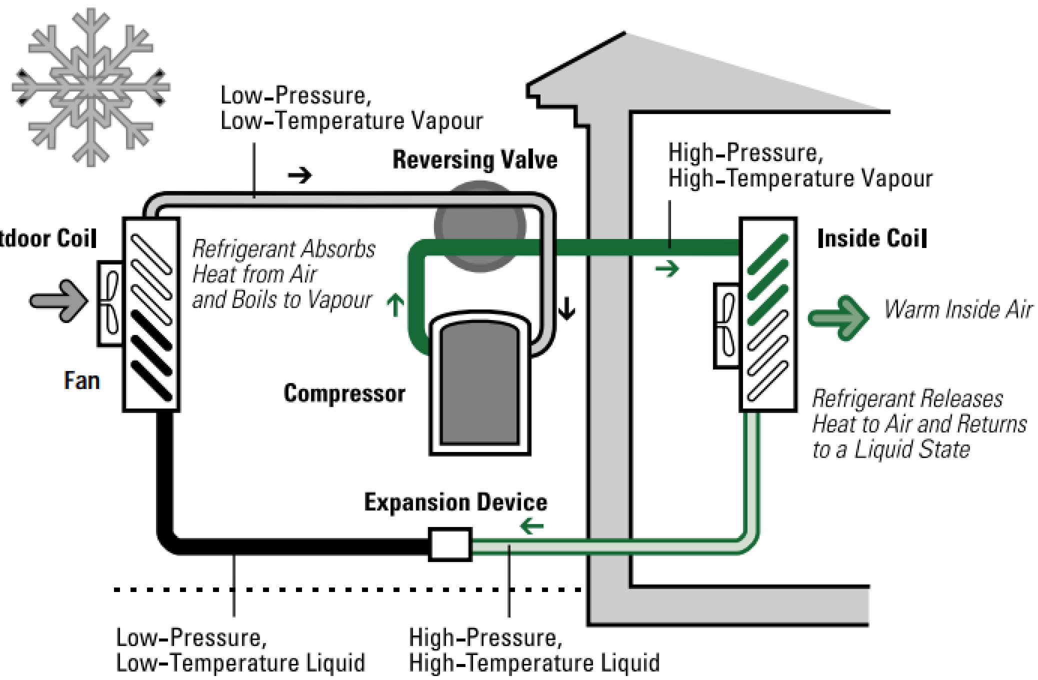
thermal energy from the building

▶ Transcript

- The Defrost Cycle: Removing frost build-up on outdoor coils

The Heating Cycle

During the heating cycle, heat is taken from outdoor air and "pumped" indoors.

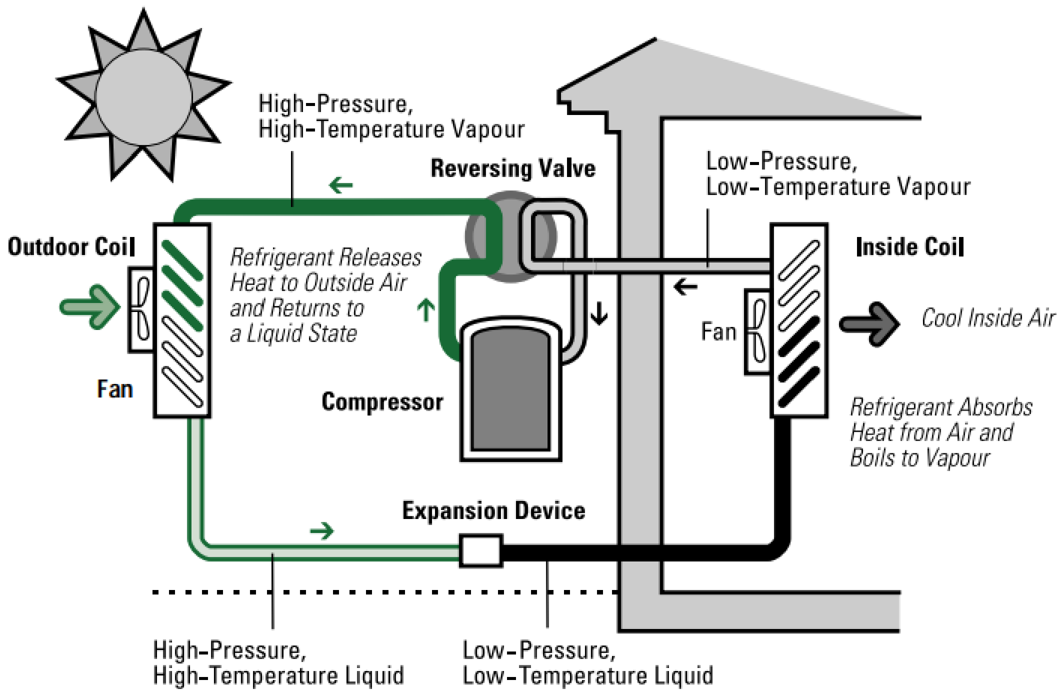


- First, the liquid refrigerant passes through the expansion device, changing to a low-pressure liquid/vapour mixture. It then goes to the outdoor coil, which acts as the evaporator coil. The liquid refrigerant absorbs heat from the outdoor air and boils, becoming a low-temperature vapour.
- This vapour passes through the reversing valve to the accumulator, which collects any remaining liquid before the vapour enters the compressor. The vapour is then compressed, reducing its volume and causing it to heat up.
- Finally, the reversing valve sends the gas, which is now hot, to the indoor coil, which is the condenser. The heat from the hot gas is transferred to the indoor air, causing the refrigerant to condense into a liquid. This liquid returns to the expansion device and the cycle is repeated. The indoor coil is located in the ductwork, close to the furnace.

The ability of the heat pump to transfer heat from the outside air to the house depends on the outdoor temperature. As this temperature drops, the ability of the heat pump to absorb heat also drops. For many air-source heat pump installations, this means that there is a temperature (called the thermal balance point) when the heat pump's heating capacity is equal to the heat loss of the house. Below this outdoor ambient temperature, the heat pump can supply only part of the heat required to keep the living space comfortable, and supplementary heat is required.

It is important to note that the vast majority of air-source heat pumps have a minimum operating temperature, below which they are unable to operate. For newer models, this can range from between -15°C to -25°C. Below this temperature, a supplemental system must be used to provide heating to the building.

The Cooling Cycle



The cycle described above is reversed to cool the house during the summer. The unit takes heat out of the indoor air and rejects it outside.

- As in the heating cycle, the liquid refrigerant passes through the expansion device, changing to a low-pressure liquid/vapour mixture. It then goes to the indoor coil, which acts as the evaporator. The liquid refrigerant absorbs heat from the indoor air and boils, becoming a low-temperature vapour.
- This vapour passes through the reversing valve to the accumulator, which collects any remaining liquid, and then to the compressor. The vapour is then compressed, reducing its volume and causing it to heat up.
- Finally, the gas, which is now hot, passes through the reversing valve to the outdoor coil, which acts as the condenser. The heat from the hot gas is transferred to the outdoor air, causing the refrigerant to condense into a liquid. This liquid returns to the expansion device, and the cycle is repeated.

During the cooling cycle, the heat pump also dehumidifies the indoor air. Moisture in the air passing over the indoor coil condenses on the coil's surface and is collected in a pan at the bottom of the coil. A condensate drain connects this pan to the house drain.

The Defrost Cycle

If the outdoor temperature falls to near or below freezing when the heat pump is operating in the heating mode, moisture in the air passing over the outside coil will condense and freeze on it. The amount of frost buildup depends on the outdoor temperature and the amount of moisture in the air.

This frost buildup decreases the efficiency of the coil by reducing its ability to transfer heat to the refrigerant. At some point, the frost must be removed. To do this, the heat pump switches into defrost mode. The most common approach is:

- First, the reversing valve switches the device to the cooling mode. This sends hot gas to the outdoor coil to melt the frost. At the same time the outdoor fan, which normally blows cold air over the coil, is shut off in order to reduce the amount of heat needed to melt the frost.
- While this is happening, the heat pump is cooling the air in the ductwork. The heating system would normally warm this air as it is distributed throughout the house.

One of two methods is used to determine when the unit goes into defrost mode:

- Demand-frost controls monitor airflow, refrigerant pressure, air or coil temperature and pressure differential across the outdoor coil to detect frost accumulation.
- Time-temperature defrost is started and ended by a pre-set interval timer or a temperature sensor located on the outside coil. The cycle can be initiated every 30, 60 or 90 minutes, depending on the climate and the design of the system.

Unnecessary defrost cycles reduce the seasonal performance of the heat pump. As a result, the demand-frost method is generally more efficient since it starts the defrost cycle only when it is required.

Supplementary Heat Sources

Since air-source heat pumps have a minimum outdoor operating temperature (between -15°C to -25°C) and reduced heating capacity at very cold temperatures, it is important to consider a **supplemental heating source** for air-source heat pump operations. Supplementary heating may also be required when the heat pump is defrosting. Different options are available:

- **All Electric:** In this configuration, heat pump operations are supplemented with electric resistance elements located in the ductwork or with electric baseboards. These resistance elements are less efficient than the heat pump, but their ability to provide heating is independent of outdoor temperature.
- **Hybrid System:** In a hybrid system, the air-source heat pump uses a supplemental system such as a furnace or boiler. This option can be used in new installations, and is also a good option where a heat pump is added to an existing system, for example, when a heat pump is installed as a replacement for a central air-conditioner.

See the final section of this booklet, *Related Equipment*, for more information on systems that use supplementary heating sources. There, you can find discussion of options for how to program your system to transition between heat pump use and supplementary heat source use.

Energy Efficiency Considerations

To support understanding of this section, refer to the earlier section called *An introduction to Heat Pump Efficiency* for an explanation of what HSPFs and SEERs represent.

In Canada, energy efficiency regulations prescribe a minimum seasonal efficiency in heating and cooling that must be achieved for the product to be sold in the Canadian market. In addition to these regulations, your province or territory may have more stringent requirements.

Minimum performance for Canada as a whole, and typical ranges for market-available products, are summarized below for heating and cooling. It is important to also check to see whether any additional regulations are in place in your region before selecting your system.

Cooling Seasonal Performance, SEER:

- Minimum SEER (Canada): 14
- Range, SEER in Market Available Products: 14 to 42

Heating Seasonal Performance, HSPF

- Minimum HSPF (Canada): 7.1 (for Region V)
- Range, HSPF in Market Available Products: 7.1 to 13.2 (for Region V)

Note: HSPF factors are provided for AHRI Climate Zone V, which has a similar climate to Ottawa. Actual seasonal efficiencies may vary depending on your region. A new performance standard that aims to better represent performance of these systems in Canadian regions is currently under development.

The actual SEER or HSPF values depend on a variety of factors primarily related to heat pump design. Current performance has evolved significantly over the last 15 years, driven by new developments in compressor technology, heat exchanger design, and improved refrigerant flow and control.

Single Speed and Variable Speed Heat Pumps

Of particular importance when considering efficiency is the role of new compressor designs in improving seasonal performance. Typically, units operating at the minimum prescribed SEER and HSPF are characterized by **single speed** heat pumps. **Variable speed** air-source heat pumps are now available that are designed to vary the capacity of the system to more closely match the heating/cooling demand of the house at a given moment. This helps to maintain peak efficiency at all times, including during milder conditions when there is lower-demand on the system.

More recently, air-source heat pumps that are better adapted to operating in the cold Canadian climate have been introduced to the market. These systems, often called **cold climate heat pumps**, combine variable capacity compressors with improved heat exchanger designs and controls to maximize heating capacity at colder air temperatures, while maintaining high efficiencies during milder conditions. These types of systems typically have higher SEER and HSPF values, with some systems reaching SEERs up to 42, and HSPFs approaching 13.

Certification, Standards, and Rating Scales

The Canadian Standards Association (CSA) currently verifies all heat pumps for electrical safety. A performance standard specifies tests and test conditions at which heat pump heating and cooling capacities and efficiency are determined. The performance testing standards for air-source heat pumps are CSA C656, which (as of 2014) has been harmonised with ANSI/AHRI 210/240-2008, Performance Rating of Unitary Air-Conditioning & Air-Source Heat Pump Equipment. It also replaces CAN/CSA-C273.3-M91, Performance Standard for Split-System Central Air-Conditioners and Heat Pumps.

Sizing Considerations

To appropriately size your heat pump system, it is important to understand the heating and cooling needs for your home. It is recommended that a heating and cooling professional be retained to undertake the required calculations. Heating and cooling loads should be determined by using a recognized sizing method such as CSA F280-12, "Determining the Required Capacity of Residential Space Heating and Cooling Appliances."

The sizing of your heat pump system should be done according to your climate, heating and cooling building loads, and the objectives of your installation (e.g., maximizing heating energy savings vs. displacing an existing system during certain periods of the year). To help with this process, NRCan has developed an *Air-Source Heat Pump Sizing and Selection Guide*. This guide, along with a companion software tool, is intended for energy advisors and mechanical designers, and is freely available to provide guidance on appropriate sizing.

If a heat pump is undersized, you will notice that the supplemental heating system will be used more frequently. While an undersized system will still operate efficiently, you may not get the anticipated energy savings due to a high use of a supplemental heating system.

Likewise, if a heat pump is oversized, the desired energy savings may not be realized due to inefficient operation during milder conditions. While the supplemental heating system operates less frequently, under warmer ambient conditions, the heat pump produces too much heat and the unit cycles on and off leading to discomfort, wear on the heat pump, and stand-by electric power draw. It is therefore important to have a good understanding of your heating load and what the heat pump operating characteristics are to achieve optimal energy savings.

Other Selection Criteria

Apart from sizing, several additional performance factors should be considered:

- **HSPF:** Select a unit with as high an HSPF as practical. For units with comparable HSPF ratings, check their steady-state ratings at –8.3°C, the low temperature rating. The unit with the higher value will be the most efficient one in most regions of Canada.
- **Defrost:** Select a unit with demand-defrost control. This minimizes defrost cycles, which reduces supplementary and heat pump energy use.
- **Sound Rating:** Sound is measured in units called decibels (dB). The lower the value, the lower the sound power emitted by the outdoor unit. The higher the decibel level, the louder the noise. Most heat pumps have a sound rating of 76 dB or lower.

Installation Considerations

Air-source heat pumps should be installed by a qualified contractor. Consult a local heating and cooling professional to size, install, and maintain your equipment to ensure efficient and reliable operations. If you are looking to implement a heat pump to replace or supplement your central furnace, you should be aware that heat pumps generally operate at higher airflows than furnace systems. Depending on the size of your new heat pump, some modifications may be needed to your ductwork to avoid added noise and fan energy use. Your contractor will be able to give you guidance on your specific case.

The cost of installing an air-source heat pump depends on the type of system, your design objectives, and any existing heating equipment and ductwork in your home. In some cases, additional modifications to the ductwork or electrical services may be required to support your new heat pump installation.

Operation Considerations

You should note several important things when operating your heat pump:

- **Optimize Heat Pump and Supplemental System Set-points.** If you have an electric supplemental system (e.g., baseboards or resistance elements in duct), be sure to use a lower temperature set-point for your supplemental system. This will help to maximize the amount of heating the heat pump provides to your home, lowering your energy use and utility bills. A set-point of 2°C to 3°C below the heat pump heating temperature set-point is recommended. Consult your installation contractor on the optimal set-point for your system.
- **Set Up for an Efficient Defrost.** You can reduce energy use by having your system set up to turn off the indoor fan during defrost cycles. This can be performed by your installer. However, it is important to note that defrost may take a little longer with this set up.
- **Minimize Temperature Setbacks.** Heat pumps have a slower response than furnace systems, so they have more difficultly responding to deep temperature setbacks. Moderated setbacks of not more than 2°C should be employed or a “smart” thermostat that switches the system

on early, in anticipation of a recovery from setback, should be used. Again, consult your installation contractor on the optimal setback temperature for your system.

- **Optimize Your Airflow Direction.** If you have a wall mounted indoor unit, consider adjusting the airflow direction to maximize your comfort. Most manufacturers recommend directing airflow downwards when heating, and towards occupants when in cooling.
- **Optimize fan settings.** Also, be sure to adjust fan settings to maximize comfort. To maximize the heat delivered of the heat pump, it is recommended to set the fan speed to high or 'Auto'. Under cooling, to also improve dehumidification, the 'low' fan speed is recommended.

Maintenance Considerations

Proper maintenance is critical to ensure your heat pump operates efficiently, reliably, and has a long service life. You should have a qualified contractor do annual maintenance on your unit to ensure everything is in good working order.

Aside from annual maintenance, there are a few simple things you can do to ensure reliable and efficient operations. Be sure to change or clean your air filter every 3 months, as clogged filters will decrease airflow and reduce the efficiency of your system. Also, be sure that vents and air registers in your home are not blocked by furniture or carpeting, as inadequate airflow to or from your unit can shorten equipment lifespans and reduce efficiency of the system.

Operating Costs

The energy savings from installing a heat pump can help to reduce your monthly energy bills. Achieving a reduction in your energy bills greatly depends on the price of electricity in relation to other fuels such as natural gas or heating oil, and, in retrofit applications, what type of system is being replaced.

Heat pumps in general come at a higher cost compared to other systems such as furnaces or electric baseboards due the number of components in the system. In some regions and cases, this added cost can be recouped in a relatively short time period through the utility cost savings. However, in other regions, varying utility rates can extend this period. It is important to work with your contractor or energy advisor to get an estimate of the economics of heat pumps in your area, and the potential savings you can achieve.

Life Expectancy and Warranties

Air-source heat pumps have a service life of between 15 and 20 years. The compressor is the critical component of the system.

Most heat pumps are covered by a one-year warranty on parts and labour, and an additional five- to ten-year warranty on the compressor (for parts only). However, warranties vary between manufacturers, so check the fine print.

Ground-Source Heat Pumps

Ground-source heat pumps use the earth or ground water as a source of thermal energy in heating mode, and as a sink to reject energy when in cooling mode. These types of systems contain two key components:

- **Ground Heat Exchanger:** This is the heat exchanger used to add or remove thermal energy from the earth or ground. Various heat exchanger configurations are possible, and are explained later in this section.
- **Heat Pump:** Instead of air, ground-source heat pumps use a fluid flowing through the ground heat exchanger as their source (in heating) or sink (in cooling).
  On the building side, both air and hydronic (water) systems are possible. Operating temperatures on the building side are very important in hydronic applications. Heat pumps operate more efficiently when heating at lower temperatures of below 45 to 50°C, making them a better match for radiant floors or fan coil systems. Care should be taken if considering their use with high temperature radiators that require water temperatures above 60°C, as these temperatures generally exceed the limits of most residential heat pumps.

Depending on how the heat pump and ground heat exchanger interact, two different system classifications are possible:

- **Secondary Loop:** A liquid (ground water or anti-freeze) is used in the ground heat exchanger. The thermal energy transferred from the ground to the liquid is delivered to the heat pump via a heat exchanger.
- Direct Expansion (DX): A refrigerant is used as the fluid in the ground heat exchanger. The thermal energy extracted by the refrigerant from the ground is used directly by the heat pump - no additional heat exchanger is needed.
  In these systems, the ground heat exchanger is a part of the heat pump itself, acting as the evaporator in heating mode and condenser in cooling mode.

Ground-source heat pumps can serve a suite of comfort needs in your home, including:

- **Heating only:** The heat pump is used only in heating. This can include both space heating and hot water production.
- **Heating with “active cooling”:** The heat pump is used in both heating and cooling
- **Heating with “passive cooling”:** The heat pump is used in heating, and bypassed in cooling. In cooling, fluid from the building is cooled directly in the ground heat exchanger.

Heating and “active cooling” operations are described in the following section.

Major Benefits of Ground-Source Heat Pump Systems

Efficiency

In Canada, where air temperatures can go below –30°C, ground-source systems are able to operate more efficiently because they take advantage of warmer and more stable ground temperatures. Typical water temperatures entering the ground-source heat pump are generally above 0°C, yielding a COP of around 3 for most systems during the coldest winter months.

Energy Savings

Ground-source systems will reduce your heating and cooling costs substantially. Heating energy cost savings compared with electric furnaces are around 65%.

On average, a well designed ground-source system will yield savings that are about 10-20% more than would be provided by a best in class, cold climate air-source heat pump sized to cover most of the building heating load. This is due to the fact that underground temperatures are higher in winter than air temperatures. As a result, a ground-source heat pump can provide more heat over the course of the winter than an air-source heat pump.

Actual energy savings will vary depending on the local climate, the efficiency of the existing heating system, the costs of fuel and electricity, the size of the heat pump installed, borefield configuration and the seasonal energy balance, and the heat pump efficiency performance at CSA rating conditions.

How Does a Ground-Source System Work?

Ground-source heat pumps consist of two main parts: A ground heat exchanger, and a heat pump. Unlike air-source heat pumps, where one heat exchanger is located outside, in ground-source systems, the heat pump unit is located inside the home.

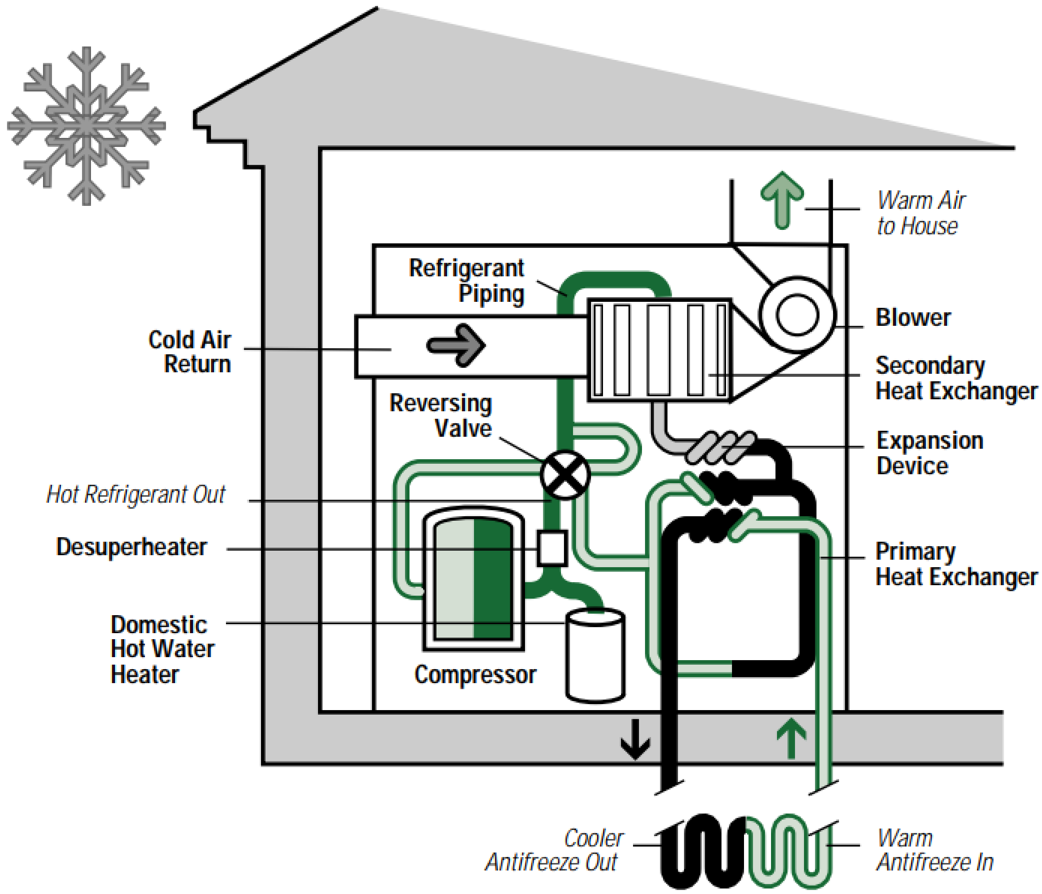
Ground heat exchanger designs can be classified as either:

- **Closed Loop:** Closed-loop systems collect heat from the ground by means of a continuous loop of piping buried underground. An antifreeze solution (or refrigerant in the case of a DX ground-source system), which has been chilled by the heat pump's refrigeration system to several degrees colder than the outside soil, circulates through the piping and absorbs heat from the soil.
  Common piping arrangements in closed loop systems include horizontal, vertical, diagonal and pond/lake ground systems (these arrangements are discussed below, under *Design Considerations*).
- **Open Loop:** Open systems take advantage of the heat retained in an underground body of water. The water is drawn up through a well directly to the heat exchanger, where its heat is extracted. The water is then discharged either to an above-ground body of water, such as a stream or pond, or back to the same underground water body through a separate well.

The selection of outdoor piping system depends on the climate, soil conditions, available land, local installation costs at the site as well as municipal and provincial regulations. For instance, open loop systems are permitted in Ontario, but are not permitted in Quebec. Some municipalities have banned DX systems because the municipal water source is the aquifer.

The Heating Cycle

In the heating cycle, the ground water, the antifreeze mixture or the refrigerant (which has circulated through the underground piping system and picked up heat from the soil) is brought back to the heat pump unit inside the house. In ground water or antifreeze mixture systems, it then passes through the refrigerant-filled primary heat exchanger. In DX systems, the refrigerant enters the compressor directly, with no intermediate heat exchanger.



The heat is transferred to the refrigerant, which boils to become a low-temperature vapour. In an open system, the ground water is then pumped back out and discharged into a pond or down a well. In a closed-loop system, the antifreeze mixture or refrigerant is pumped back out to the underground piping system to be heated again.

The reversing valve directs the refrigerant vapour to the compressor. The vapour is then compressed, which reduces its volume and causes it to heat up.

Finally, the reversing valve directs the now-hot gas to the condenser coil, where it gives up its heat to the air or hydronic system to heat the home. Having given up its heat, the refrigerant passes through the expansion device, where its temperature and pressure are dropped further before it returns to the first heat exchanger, or to the ground in a DX system, to begin the cycle again.

The Cooling Cycle

The “active cooling” cycle is basically the reverse of the heating cycle. The direction of the refrigerant flow is changed by the reversing valve. The refrigerant picks up heat from the house air and transfers it directly, in DX systems, or to the ground water or antifreeze mixture. The heat is then pumped outside, into a water body or return well (in an open system) or into the underground piping (in a closed-loop system). Some of this excess heat can be used to preheat domestic hot water.

Unlike air-source heat pumps, ground-source systems do not require a defrost cycle. Temperatures underground are much more stable than air temperatures, and the heat pump unit itself is located inside; therefore, the problems with frost do not arise.

Parts of the System

Ground-source heat pump systems have three main components: the heat pump unit itself, the liquid heat exchange medium (open system or closed loop), and a distribution system (either air-based or hydronic) that distributes the thermal energy from the heat pump to the building.

Ground-source heat pumps are designed in different ways. For air-based systems, self-contained units combine the blower, compressor, heat exchanger, and condenser coil in a single cabinet. Split systems allow the coil to be added to a forced-air furnace, and use the existing blower and furnace. For hydronic systems, both the source and sink heat exchangers and compressor are in a single cabinet.

Energy Efficiency Considerations

As with air-source heat pumps, ground-source heat pump systems are available in a range of different efficiencies. See the earlier section called *An introduction to Heat Pump Efficiency* for an explanation of what COPs and EERs represent. Ranges of COPs and EERs for market available units are provided below.

Ground water or Open-Loop Applications

Heating

- Minimum Heating COP: 3.6
- Range, Heating COP in Market Available Products: 3.8 to 5.0

Cooling

- Minimum EER: 16.2
- Range, EER in Market Available Products: 19.1 to 27.5

Closed Loop Applications

Heating

- Minimum Heating COP: 3.1
- Range, Heating COP in Market Available Products: 3.2 to 4.2

Cooling

- Minimum EER: 13.4
- Range, EER in Market Available Products: 14.6 to 20.4

The minimum efficiency for each type is regulated at the federal level as well as in some provincial jurisdictions. There has been a dramatic improvement in the efficiency of ground-source systems. The same developments in compressors, motors and controls that are available to air-source heat pump manufacturers are resulting in higher levels of efficiency for ground-source systems.

Lower-end systems typically employ two stage compressors, relatively standard size refrigerant-to-air heat exchangers, and oversized enhanced-surface refrigerant-to-water heat exchangers. Units in the high efficiency range tend to use multi-or variable speed compressors, variable speed indoor fans, or both. Find an explanation of *single speed and variable speed heat pumps in the Air-Source Heat Pump* section.

Certification, Standards, and Rating Scales

The Canadian Standards Association (CSA) currently verifies all heat pumps for electrical safety. A performance standard specifies tests and test conditions at which heat pump heating and cooling capacities and efficiency are determined. The performance testing standards for ground-source systems are CSA C13256 (for secondary loop systems) and CSA C748 (for DX systems).

Sizing Considerations

It is important that the ground heat exchanger be well matched to the heat pump capacity. Systems that are not balanced and unable to replenish the energy drawn from the borefield will continuously perform worse over time until the heat pump can no longer extract heat.

As with air-source heat pump systems, it is generally not a good idea to size a ground-source system to provide all of the heat required by a house. For cost-effectiveness, the system should generally be sized to cover the majority of the household’s annual heating energy requirement. The occasional peak heating load during severe weather conditions can be met by a supplementary heating system.

Systems are now available with variable speed fans and compressors. This type of system can meet all cooling loads and most heating loads on low speed, with high speed required only for high heating loads. Find an explanation of *single speed and variable speed heat pumps* in the *Air-Source Heat Pump* section.

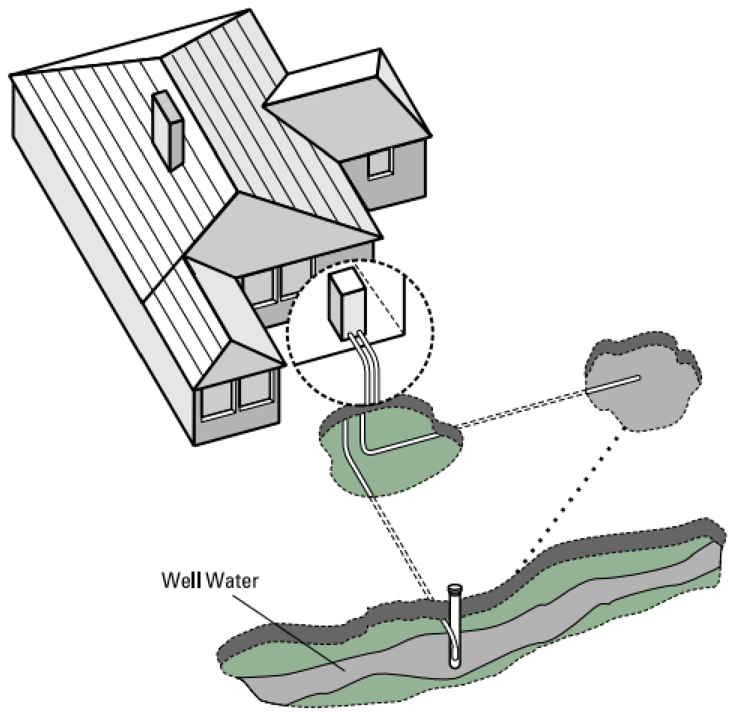
A variety of sizes of systems are available to suit the Canadian climate. Residential units range in rated size (closed loop cooling) of 1.8 kW to 21.1 kW (6 000 to 72 000 Btu/h), and include domestic hot water (DHW) options.

Design Considerations

Unlike air-source heat pumps, ground-source heat pumps require a ground heat exchanger to collect and dissipate heat underground.

Open Loop Systems

An open system uses ground water from a conventional well as a heat source. The ground water is pumped to a heat exchanger, where thermal energy is extracted and used as a source for the heat pump. The ground water exiting the heat exchanger is then reinjected into the aquifer.



Another way to release the used water is through a rejection well, which is a second well that returns the water to the ground. A rejection well must have enough capacity to dispose of all the water passed through the heat pump, and should be installed by a qualified well driller. If you have an extra existing well, your heat pump contractor should have a well driller ensure that it is suitable for use as a rejection well. Regardless of the approach used, the system should be designed to prevent any environmental damage. The heat pump simply removes or adds heat to the water; no pollutants are added. The only change in the water returned to the environment is a slight increase or decrease in temperature. It is important to check with local authorities to understand any regulations or rules regarding open loop systems in your area.

The size of the heat pump unit and the manufacturer's specifications will determine the amount of water that is needed for an open system. The water requirement for a specific model of heat pump is usually expressed in litres per second (L/s) and is listed in the specifications for that unit. A heat pump of 10-kW (34 000-Btu/h) capacity will use 0.45 to 0.75 L/s while operating.

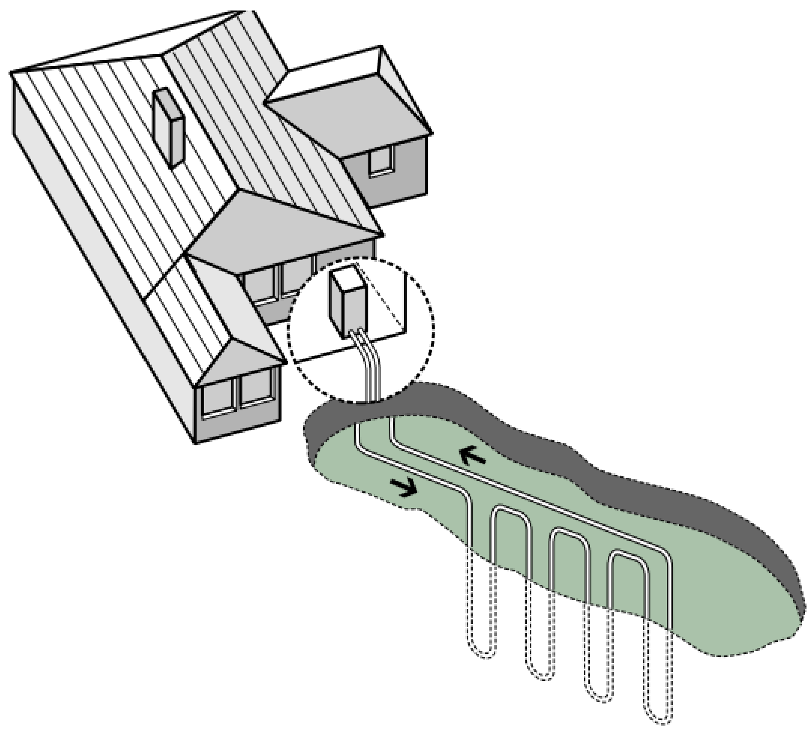
Your well and pump combination should be large enough to supply the water needed by the heat pump in addition to your domestic water requirements. You may need to enlarge your pressure tank or modify your plumbing to supply adequate water to the heat pump.

Poor water quality can cause serious problems in open systems. You should not use water from a spring, pond, river or lake as a source for your heat pump system. Particles and other matter can clog a heat pump system and make it inoperable in a short period of time. You should also have your water tested for acidity, hardness and iron content before installing a heat pump. Your contractor or equipment manufacturer can tell you what level of water quality is acceptable and under what circumstances special heat-exchanger materials may be required.

Installation of an open system is often subject to local zoning laws or licensing requirements. Check with local authorities to determine if restrictions apply in your area.

Closed-Loop Systems

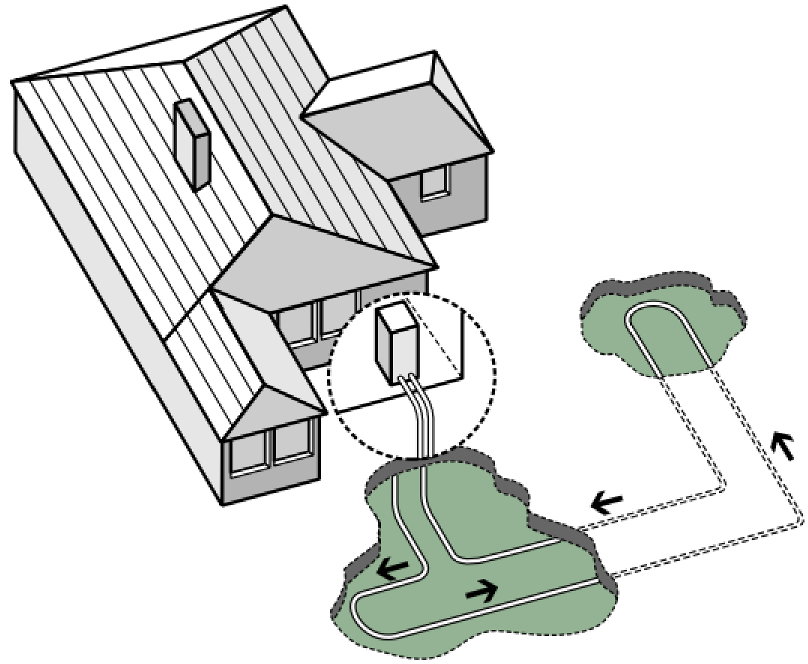
A closed-loop system draws heat from the ground itself, using a continuous loop of buried plastic pipe. Copper tubing is used in the case of DX systems. The pipe is connected to the indoor heat pump to form a sealed underground loop through which an antifreeze solution or refrigerant is circulated. While an open system drains water from a well, a closed-loop system recirculates the antifreeze solution in the pressurized pipe.



The pipe is placed in one of three types of arrangements:

- **Vertical:** A vertical closed-loop arrangement is an appropriate choice for most suburban homes, where lot space is restricted. Piping is inserted into bored holes that are 150 mm (6 in.) in diameter, to a depth of 45 to 150 m (150 to 500 ft.), depending on soil conditions and the size of the system. U-shaped loops of pipe are inserted in the holes. DX systems can have smaller diameter holes, which can lower drilling costs.

- **Diagonal (angled):** A diagonal (angled) closed-loop arrangement is similar to a vertical closed-loop arrangement; however the boreholes are angled. This type of arrangement is used where space is very limited and access is limited to one point of entry.



- **Horizontal:** The horizontal arrangement is more common in rural areas, where properties are larger. The pipe is placed in trenches normally 1.0 to 1.8 m (3 to 6 ft.) deep, depending on the number of pipes in a trench. Generally, 120 to 180 m (400 to 600 ft.) of pipe is required per ton of heat pump capacity. For example, a well-insulated, 185 m2 (2000 sq. ft.) home would usually need a three-ton system, requiring 360 to 540 m (1200 to 1800 ft.) of pipe.
  The most common horizontal heat exchanger design is two pipes placed side-by-side in the same trench. Other horizontal loop designs use four or six pipes in each trench, if land area is limited. Another design sometimes used where area is limited is a “spiral” – which describes its shape.

Regardless of the arrangement you choose, all piping for antifreeze solution systems must be at least series 100 polyethylene or polybutylene with thermally fused joints (as opposed to barbed fittings, clamps or glued joints), to ensure leak-free connections for the life of the piping. Properly installed, these pipes will last anywhere from 25 to 75 years. They are unaffected by chemicals found in soil and have good heat-conducting properties. The antifreeze solution must be acceptable to local environmental officials. DX systems use refrigeration-grade copper tubing.

Neither vertical nor horizontal loops have an adverse impact on the landscape as long as the vertical boreholes and trenches are properly backfilled and tamped (packed down firmly).

Horizontal loop installations use trenches anywhere from 150 to 600 mm (6 to 24 in.) wide. This leaves bare areas that can be restored with grass seed or sod. Vertical loops require little space and result in less lawn damage.

It is important that horizontal and vertical loops be installed by a qualified contractor. Plastic piping must be thermally fused, and there must be good earth-to-pipe contact to ensure good heat transfer, such as that achieved by Tremie-grouting of boreholes. The latter is particularly important for vertical heat-exchanger systems. Improper installation may result in poorer heat pump performance.

Installation Considerations

As with air-source heat pump systems, ground-source heat pumps must be designed and installed by qualified contractors. Consult a local heat pump contractor to design, install and service your equipment to ensure efficient and reliable operation. Also, be sure that all manufacturers' instructions are followed carefully. All installations should meet the requirements of CSA C448 Series 16, an installation standard set by the Canadian Standards Association.

The total installed cost of ground-source systems varies according to site-specific conditions. Installation costs vary depending on the type of ground collector and the equipment specifications. The incremental cost of such a system can be recovered through energy cost savings over a period as low as 5 years. Payback period is dependent on a variety of factors such as soil conditions, heating and cooling loads, the complexity of HVAC retrofits, local utility rates, and the heating fuel source being replaced. Check with your electric utility to assess the benefits of investing in a ground-source system. Sometimes a low-cost financing plan or incentive is offered for approved installations. It is important to work with your contractor or energy advisor to get an estimate of the economics of heat pumps in your area, and the potential savings you can achieve.

Operation Considerations

You should note several important things when operating your heat pump:

- **Optimize Heat Pump and Supplemental System Set-points.** If you have an electric supplemental system (e.g., baseboards or resistance elements in duct), be sure to use a lower temperature set-point for your supplemental system. This will help to maximize the amount of heating the heat pump provides to your home, lowering your energy use and utility bills. A set-point of 2°C to 3°C below the heat pump heating temperature set-point is recommended. Consult your installation contractor on the optimal set-point for your system.
- **Minimize Temperature Setbacks.** Heat pumps have a slower response than furnace systems, so they have more difficultly responding to deep temperature setbacks. Moderated setbacks of not more than 2°C should be employed or a “smart” thermostat that switches the system on early, in anticipation of a recovery from setback, should be used. Again, consult your installation contractor on the optimal setback temperature for your system.

Maintenance Considerations

You should have a qualified contractor perform annual maintenance once per year to ensure your system remains efficient and reliable.

If you have an air-based distribution system, you can also support more efficient operations by replacing or cleaning your filter every 3 months. You should also ensure that your air vents and registers are not blocked by any furniture, carpeting or other items that would impede airflow.

Operating Costs

The operating costs of a ground-source system are usually considerably lower than those of other heating systems, because of the savings in fuel. Qualified heat pump installers should be able to give you information on how much electricity a particular ground-source system would use.

Relative savings will depend on whether you are currently using electricity, oil or natural gas, and on the relative costs of different energy sources in your area. By running a heat pump, you will use less gas or oil, but more electricity. If you live in an area where electricity is expensive, your operating costs may be higher.

Life Expectancy and Warranties

Ground-source heat pumps generally have a life expectancy of about 20 to 25 years. This is higher than for air-source heat pumps because the compressor has less thermal and mechanical stress, and is protected from the environment. The lifespan of the ground loop itself approaches 75 years.

Most ground-source heat pump units are covered by a one-year warranty on parts and labour, and some manufacturers offer extended warranty programs. However, warranties vary between manufacturers, so be sure to check the fine print.

Related Equipment

Upgrading the Electrical Service

Generally speaking, it is not necessary to upgrade the electrical service when installing an air-source add-on heat pump. However, the age of the service and the total electrical load of the house may make it necessary to upgrade.

A 200 ampere electrical service is normally required for the installation of either an all-electric air-source heat pump or a ground-source heat pump. If transitioning from a natural gas or fuel oil based heating system, it may be necessary to upgrade your electrical panel.

Supplementary Heating Systems

Air-Source Heat Pump Systems

Air-source heat pumps have a minimum outdoor operating temperature, and may lose some of their ability to heat at very cold temperatures. Because of this, most air-source installations require a supplementary heating source to maintain indoor temperatures during the coldest days. Supplementary heating may also be required when the heat pump is defrosting.

Most air-source systems shut off at one of three temperatures, which can be set by your installation contractor:

- **Thermal Balance Point:** The temperature below which the heat pump does not have enough capacity to meet the heating needs of the building on its own.
- **Economic Balance Point:** The temperature below which the ratio of electricity to a supplemental fuel (e.g., natural gas) means that using the supplementary system is more cost effective.
- **Cut-Off Temperature:** The minimum operating temperature for the heat pump.

Most supplementary systems can be classed into two categories:

- **Hybrid Systems:** In a hybrid system, the air-source heat pump uses a supplemental system such as a furnace or boiler. This option can be used in new installations, and is also a good option where a heat pump is added to an existing system, for example, when a heat pump is installed as a replacement for a central air-conditioner.
  These types of systems support switching between heat pump and supplementary operations according to the thermal or economic balance point.
  These systems cannot be run simultaneously with the heat pump – either the heat pump operates or the gas/oil furnace operates.
- **All Electric Systems:** In this configuration, heat pump operations are supplemented with electric resistance elements located in the ductwork or with electric baseboards.
  These systems can be run simultaneously with the heat pump, and can therefore be used in balance point or cut-off temperature control strategies.

An outdoor temperature sensor shuts the heat pump off when the temperature falls below the pre-set limit. Below this temperature, only the supplementary heating system operates. The sensor is usually set to shut off at the temperature corresponding to the economic balance point, or at the outdoor temperature below which it is cheaper to heat with the supplementary heating system instead of the heat pump.

Ground-Source Heat Pump Systems

Ground-source systems continue to operate regardless of the outdoor temperature, and as such are not subject to the same sort of operating restrictions. The supplementary heating system only provides heat that is beyond the rated capacity of the ground-source unit.

Thermostats

Conventional Thermostats

Most ducted residential single-speed heat pump systems are installed with a **"two-stage heat/one-stage cool"** indoor thermostat. Stage one calls for heat from the heat pump if the temperature falls below the pre-set level. Stage two calls for heat from the supplementary heating system if the indoor temperature continues to fall below the desired temperature. Ductless residential air-source heat pumps are typically installed with a single stage heating/cooling thermostat or in many instances a built in thermostat set by a remote that comes with the unit.

The most common type of thermostat used is the **"set and forget"** type. The installer consults with you prior to setting the desired temperature. Once this is done, you can forget about the thermostat; it will automatically switch the system from heating to cooling mode or vice versa.

There are two types of outdoor thermostats used with these systems. The first type controls the operation of the electric resistance supplementary heating system. This is the same type of thermostat that is used with an electric furnace. It turns on various stages of heaters as the outdoor temperature drops progressively lower. This ensures that the correct amount of supplementary heat is provided in response to outdoor conditions, which maximizes efficiency and saves you money. The second type simply shuts off the air-source heat pump when the outdoor temperature falls below a specified level.

Thermostat setbacks may not yield the same kind of benefits with heat pump systems as with more conventional heating systems. Depending upon the amount of the setback and temperature drop, the heat pump may not be able to supply all of the heat required to bring the temperature back up to the desired level on short notice. This may mean that the supplementary heating system operates until the heat pump "catches up." This will reduce the savings that you might have expected to achieve by installing the heat pump. See discussion in previous sections on minimizing temperature setbacks.

Programmable Thermostats

Programmable heat pump thermostats are available today from most heat pump manufacturers and their representatives. Unlike conventional thermostats, these thermostats achieve savings from temperature setback during unoccupied periods, or overnight. Although this is accomplished in different ways by different manufacturers, the heat pump brings the house back to the desired temperature level with or without minimal supplementary heating. For those accustomed to thermostat setback and programmable thermostats, this may be a worthwhile investment. Other features available with some of these electronic thermostats include the following:

- Programmable control to allow for user selection of automatic heat pump or fan-only operation, by time of day and day of the week.
- Improved temperature control, as compared to conventional thermostats.
- No need for outdoor thermostats, as the electronic thermostat calls for supplementary heat only when needed.
- No need for an outdoor thermostat control on add-on heat pumps.

Savings from programmable thermostats are highly dependant on the type and sizing of your heat pump system. For variable speed systems, setbacks may allow the system to operate at a lower speed, reducing wear on the compressor and helping to increase system efficiency.

Heat Distribution Systems

Heat pump systems generally supply a greater volume of airflow at lower temperature compared to furnace systems. As such, it is very important to examine the supply airflow of your system, and how it may compare to the airflow capacity of your existing ducts. If the heat pump airflow exceeds the capacity of your existing ducting, you may have noise issues or increased fan energy use.

New heat pump systems should be designed according to established practice. If the installation is a retrofit, the existing duct system should be carefully examined to ensure that it is adequate.

Footnotes

1 The Region 5 HSPF is most reflective of heat pump performance in the Ottawa region. Actual HSPFs may be lower in regions with increased heating degree days. While many colder Canadian regions are still classified under Region 5, the HSPF value provided may not fully reflect actual system performance.

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The addition of heat pump electricity load profiles to GB electricity demand: Evidence from a heat pump field trial

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HIGHLIGHTS

- An aggregated load profile is constructed using data from 696 heat pumps in GB.
- It contains a morning and evening peak, falling to 40% of its peak value overnight.
- After diversity maximum demand is calculated as 1.7 kWe per heat pump.
- A first order approximation of the impact of 20% uptake of heat pumps is presented.
- This is shown to lead to the GB national grid evening peak increasing by 14%.

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ABSTRACT

Previous studies on the effect of mass uptake of heat pumps on the capability of local or national electricity grids have relied on modelling or small datasets to create the aggregated heat pump load profile. This article uses the UK Renewable Heat Premium Payment dataset, which records the electricity consumption of nearly 700 domestic heat pump installations every 2 minutes, to create an aggregated load profile using an order of magnitude more sites than previously available. The aggregated profile is presented on cold and medium winter weekdays and weekends and is shown to contain two peaks per day, dropping overnight to around 40% of its peak. After Diversity Maximum Demand (ADMD) for the population of heat pumps is calculated as 1.7 kW per site; this occurs in the morning, whereas the peak national grid demand occurs in the evening. Analysis is carried out on how heat pump ADMD varies with number of heat pumps in the sample. A simple upscaling exercise is presented to give a first order approximation of the increase in GB peak electricity demand with mass deployment of heat pumps. It is found that peak grid demand increases by 7.5 GW (14%) with 20% of households using heat pumps. The effect of the same heat pump uptake on grid ramp rate is also discussed; this effect is found to be minor. Finally, a comparison of heat pump and gas boiler operation is given, discussing day and night time operation and mean and peak power at different external temperatures.

1. Introduction

As the UK moves to a low fossil fuel future, heating of its 27 million dwellings needs to shift from the current predominance of CO_2-intensive, individual gas boilers [1]. One option is a significant increase of electrification of heating (coupled with the decarbonisation of electricity), of which the most energy efficient option is heat pumps [2,3] at either a dwelling or community scale. In most

Abbreviations: ADMD, After Diversity Maximum Demand; ASHP, Air Source Heat Pump; CLNR, Customer Led Network Revolution; DNO, Distribution Network Operator; EDRP, Energy Demand Research Project; GSHP, Ground Source Heat Pump; RHPP, Renewable Heat Premium Payment; SAP, Standard Assessment Procedure; TSO, Transmission System Operator.

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areas, heat demand density is not high enough to allow heat networks to be cost-effective [4] so individual heat pumps are likely to be a key technology [5].

During winter periods heating energy demand can reach around 5 times the magnitude of electricity demand in UK dwellings [1]. As such it is anticipated that a high uptake of individual heat pumps will have a significant effect on electric power demand and therefore the requirements of the local and national electricity grid at certain times of day and year [6].

Four potential grid problems arising from mass deployment of heat pumps arise, at either a national level (under the Transmission System Operator, or TSO) or substation level (under the Distribution Network Operator, or DNO).

The national scale problems are *peak demand increase* and *ramp rate increase*. Peak demand reflects the greatest demands on both the capacity of the transmission network and the generation infrastructure, in terms of both real and reactive power. Increases in peak demand are therefore likely to lead to investment in both new transmission capacity, and new generation capacity, if security of supply is to be maintained. Ramp rate reflects the need for electricity demand and supply to match on the grid, at a sub-minutely timescale. Currently the most rapid increase in demand over the day occurs between 06:00 and 07:00 in the morning, requiring supply to increase within this time too. If that morning ramp-up in demand were to coincide with heat pumps turning on, then further flexible plant would be required to provide the extra ramp up.

At the DNO scale, dwellings in areas that are connected to the gas network will generally have distribution network capacities designed for very little electric heating. The problems associated with connecting large number of heat pumps are excessive v*oltage drop* beyond allowed limits [7] and insufficient *thermal capacity* of the Low Voltage feeder and transformer leading to overheating of these elements unless they are reinforced [8,9].

This article will focus primarily on the national level, due to the availability of data from the national grid. It will however refer to substation level studies and metrics where relevant. Furthermore, the scope of the article will be real power (Watts) only, as opposed to apparent power (var), again due to the nature of the data available.

The relevant metrics for the impact of heat pumps on the national grid are national half-hourly averaged peak electricity demand (GW) and maximum ramp rate (GW/half hour). The half hour timestep is used for averaging here since this is the trading period of the national grid. The relevant metric to use to construct an aggregated heat pump load profile is After Diversity Maximum Demand, which is now described.

It is known that for networks where demand is aggregated over a number of customers N, the magnitude of peak power demand is less than the simple addition of peak power per customer over all customers. This is due to the phenomenon of diversity: the notion that as the number of customers increases, the maximum time-coincident demand per customer falls [10]. The metric to be used to describe peak power is therefore known as the After Diversity Maximum Demand (ADMD) [11]. To calculate ADMD, demand per consumer is summed at each timestep, then the maximum of the resulting timeseries is found. This is shown in Eq. (1).

$$ADMD = \max_{t}\left(\sum_{n=1}^{n=N} demand_n(t)\right) \tag{1}$$

where t = time, n = customer, N = all customers

ADMD accounts for the coincident peak load a network is likely to experience over its lifetime [10]. This is typically defined for a local network. If households form all of the load on the network, then dividing ADMD by N customers gives an *ADMD per customer*. Relating this specifically to heat pumps, *ADMD per heat pump* is taken to be the per-house ADMD of solely the aggregated heat pump demand, without the rest of the household electricity use. In this article, we define all ADMD using half hourly averaged data in accordance with Barteczko-Hibbert [10] and also to be consistent with the national metrics of grid peak demand and ramp rate given above, although it could underestimate effects on distribution networks [12].

Given these metrics, three questions can now be posed as follows. If large scale deployment of heat pumps occurs, what is the resulting peak demand of the national grid, what is the resulting ramp rate, and are either of these two outcomes then likely to be problematic? Answering these requires knowledge of not just the ADMD per heat pump, but the timing of the heat pumps' peak aggregated demand compared to the grid peak demand on a national scale.

2. Literature and previous datasets

We now describe the data and methods used in previous literature to construct aggregated heat pump load profiles and evaluate its potential effects on local or national electricity grids.

Most studies investigate aggregation of heat pump load profiles using modelled (synthetic) electricity load profiles. These in turn are based on heat demand which is either measured from conventional heating systems [13,14] or modelled. Methods of modelling heat demand include use of static or dynamic building modelling (e.g. [15–17]), simple mathematical functions [18] or assumption of flat (continuous) heating [19].

For example, acknowledging the lack of real heat pump electricity data, Navarro-Espinosa et al. [13] start with monitored heat demand profiles from conventional heating systems and infer electricity consumption, taking into account variable heat pump efficiency (although from manufacturers' datasheets as opposed to in situ data) and assuming a use profile of auxiliary heating. In a study combining heat pumps and electric vehicles, Papadaskalopoulos et al. [20] take a sample of building types from the UK building stock in different regions, derive heat and electricity demand profiles from the dynamic simulation tool Energy Plus, and add a certain number of these together according to different heat pump uptake scenarios (10–30% penetration). This methodology of aggregate load profile creation is interesting in terms of combining different building types and regions but does not fully capture the phenomenon of diversity as introduced in Section 1.

An approach to creating an aggregated load profile which does recreate diversity to some extent is found in Pudjianto et al. [21], in which data from 21 monitored systems were aggregated to create assumed heat pump profiles. However the data were derived from boiler and micro-CHP systems, as opposed to heat pumps. Another method incorporating diversity is to use 'top down' modelling [22], starting with total UK gas used for heating and dividing it by an assumed average heat pump efficiency to derive hourly and seasonal electricity demand which would be required if heat pumps replaced conventional gas boilers.

However, the heat pump demand profiles in the above studies are all based on an assumption that heat pumps are run at the same times of day as conventional heating systems (or micro CHP in the case of [21]), and thus that data derived from heating systems other than heat pumps can be used to determine the timing characteristics of heat pumps. This assumption is not verified in the literature for the UK context. The timing characteristics of heat pump operation compared to the current dominant domestic heating system – gas boilers - then becomes an additional question to be investigated in this article.

In contrast to the above, an aggregation exercise by Veldman et al. [23] focussing on the Netherlands was based on measurements from a small number of heat pumps. A large number of heat pumps were simulated from a small number of initial sites by creating a synthetic profile for each site and applying a mathematical function which randomises when the compressor is on, representing random customer behaviour [24]. This is an example of creating diversity synthetically but without empirical verification.

We now turn to available datasets on UK heat pump electricity use. The largest used in previously published research was gathered in the Customer Led Networks Revolution (CLNR) project [25]. This yielded good quality data for 89 heat pumps (out of an original 381 installations), and monthly load profiles were constructed from aggregation of this data across the sites at the half-hourly level. ADMD per customer of the heat pumps, dwellings, and heat pump-dwelling combinations was then calculated through a process of curve fitting and extrapolation [10]. The extrapolation went to 100 customers because this was judged to be a stable ADMD for the dwelling-only case.

For 100 customers, the ADMD per heat pump was around 1.3 kW; the ADMD of the dwelling without the heat pump was around 1.2 kW, and the ADMD of the dwelling-heat pump combination was around 2 kW. It is interesting that the total is less than the sum of the components; this indicates that the daily peak in heat pump use was not concurrent with the daily peak of the rest of the dwelling.

The above result highlights the importance of knowing the timing of daily peak demands, not just of the heat pumps but of the other electrical loads consuming power from the same cables. In this case the dwelling peak demand was indicated to occur at a different time from the heat pump peak demand, which mitigates the overall ADMD per customer.

A conclusion emerging from the literature is as follows. In attempting to aggregate and upscale heat pump electricity demand to a national level using a mass uptake scenario, it is extremely challenging to incorporate all of the following three aspects: timing characteristics of real heat pumps, diversity arising from large numbers of installations, and representativeness of a sample of heat pumps (real or modelled).

These three aspects are not all combined in this current study; however, the first two are attempted, addressing the well defined gap in the literature of studies which use real profiles of electricity demand from a population of heat pumps large enough to demonstrate that diversity effects have been captured. Incorporation of representativeness is the subject of further work.

3. Data

This current study utilises a newly available dataset of heat pump electricity consumption almost an order of magnitude larger than the CLNR dataset. The UK Government's Renewable Heat Premium Payment (RHPP) scheme included high frequency monitoring of electricity consumption, heat output and system temperature data for a subset of heat pump installations in the scheme, resulting in a dataset covering 696 sites. The dataset is introduced below.

3.1. Range of sites

The RHPP heat pump dataset was collected from a sample of 703 domestic heat pump installations from the wider population of installations in the RHPP scheme in Great Britain over the period December 2011–March 2015. Each site has a different metering start date within the overall trial period and around two years of data.

The sites included a range of dwelling types and ages. However, the majority of installations involved replacing an existing heating system with a new heat pump; as such most of the dwellings were not purpose-built to be heated by heat pumps. The RHPP gave grants for heat pumps in homes not heated by mains gas, but with basic energy efficiency measures in place: 250 mm loft insulation and cavity wall insulation, where practical [26]. Two thirds of installations (473) were in social housing and the remainder in private housing.

3.2. Range of heat pump systems

The RHPP project monitored 120 different models of heat pumps produced by 24 manufacturers and covered at least 25 configurations of heat pump connected to ancillary equipment such as a domestic hot water (DHW) cylinder. A principal characteristic was the heat source: 530 installations were air source heat pumps (75%), and 173 sites were ground source heat pumps (25%).

Additional variations included whether the heat pump provided domestic hot water (DHW) or just space heating, and whether it incorporated one or more of a number of types of supplementary electric resistance heating.

The metering strategy was adapted for each heat pump configuration in order to capture as far as possible the same variables across the range of configurations. However, the heterogeneous nature of the population of heat pumps and ancillary equipment leads to challenges in ensuring consistency in monitoring. For example, some systems had internal boost heating which is within the heat pump electricity consumption, whereas others used boost heating supplementary to the heat pump's electricity consumption.

3.3. Representativeness of dataset compared to wider heat pump population

The mean capacities of heat pumps in the dataset, measured in kW (thermal) and for those sites where data is available, is 8.11 (ASHPs) and 8.21 (GSHPs). This is smaller than the mean of the population of sites in the RHPP scheme from which the sample was drawn (10.9 for ASHPs, 11.3 for GSHPs), and also smaller than the mean of other heat pumps installed over the same period but not part of the RHPP scheme (10.2 for ASHPs, 14.7 for GSHPs [27]). Furthermore, the predominance of social housing in the RHPP sample is not typical of GB heat pump installations of which the largest sector is owner-occupied [28]. The dataset is therefore not representative of current GB heat pump installations; in Section 4 the relevance of the dataset to future installations is discussed.

3.4. Contents of dataset

The RHPP dataset consists of timeseries data recorded at two-minute intervals for 696 sites; 7 of the original 703 did not provide data or metadata. These data include:

- Heat output and electricity consumption of the heat pump, integrated over each 2 min;
- Flow data from which the heat output was calculated;
- Four temperatures from the system: space heating flow temperature, domestic hot water flow temperature, temperature at the heat pump condenser, and temperature of the ground loop or evaporator;
- In some cases, separately metered heat to the DHW circuit and/or separately metered electrical boost. The latter can include DHW immersion heating, space-only boost or whole-system boost.

Electricity consumption from circulation pumps was not separately metered. Furthermore, contextual variables such as dwelling internal temperature were not monitored. A metadata file accompanying the data provides some contextual information (e.g.

dwelling tenure, heating emitter type) but lacks some important information to aid interpretation of the timeseries, e.g. which heat pumps have buffer tanks and how the controls were set up. Finally, since the measurement of electricity consumption consists of integration over two minutes, short term effects such as start-up currents are not observable in the data. Consideration of the real and reactive power demand implications of these effects are therefore outside the scope of this study.

The data used in this article are all available on the UK Data Archive [29]. A number of anomalies are known to be present in the published data [30]. However, the available data and metadata do not allow categorical statement of whether the anomalies are metering errors or genuine data points. The dataset with the most anomalies was found to be the heat data; therefore, this article focuses on analysis of the electricity data only, without comment on heat pump efficiency, heat demand or other uses of the heat data.

4. Methods

4.1. Construction of two-minutely aggregated load profile

Of the 696 heat pump installations for which data is available, Fig. 1 shows the number in the dataset at each two-minutely period. This varies, firstly because the start and end dates for each site were different, and secondly because sites with missing data for given time periods were excluded during those time periods (but the sites in question were not entirely discarded, unlike [25], meaning a large sample size could be maintained). The maximum number of sites with overlapping monitoring periods is 589.

From the period shown in Fig. 1, an interval of the period was taken from June 2013 to February 2015 as this time consistently had data from over 400 sites. Subsequent figures show data only for this interval of time.

The variable of focus is two-minutely heat pump electricity consumption, labelled as 'Ehp' in the published data on UKDA and given in Watt-hours per 2 min. Fig. 2 shows this transformed into kW(electrical) and averaged over all heat pumps, for each 2 min in the analysis period. (Please note that for the rest of this article, kW (electrical) is abbreviated to kW, kW(thermal) is abbreviated to kWth and kW gas is stated as it is. Also note that heat pump power in kW as given in Fig. 2 represents real power; single phase heat pumps are inductive loads and have power factors less than 1, but, as noted above, the electricity consumption data here only allows for consideration of the real part of the power). Superposed on this is daily mean external temperature from the Central England Temperature Series [31]. This of course will not be the corresponding external temperature with every site but gives an indication of the relationship between heat pump electricity consumption and external temperature across the country as a whole.

The five-minutely real power demand of the Great Britain (GB) electricity grid over the same period as the RHPP data was obtained from Elexon [32]. In Fig. 3 this is shown with the heat pump electricity consumption data; note these are again plotted using different y-axes.

The lighter series of Fig. 3 illustrates the increase in electricity demand on the GB grid occurring over the winter even with very few heat pumps connected to the grid, due to increased lighting energy consumption and electric space and water heating. Space heating causes the biggest absolute increase of these 3 electricity end uses. [33]

4.2. Calculation of half hourly ADMD per heat pump

The two-minutely heat pump electricity data shown above was aggregated half hourly and the maximum of this was then found to produce the 'ADMD per heat pump' metric presented in the Introduction.

However, ADMD is not one single number, but changes with number of heat pumps considered. For example, for one heat pump

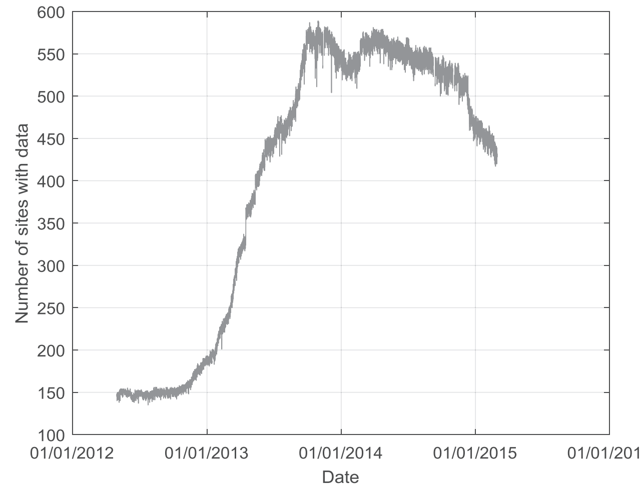

Fig. 1. Number of sites in the RHPP sample at any one time.

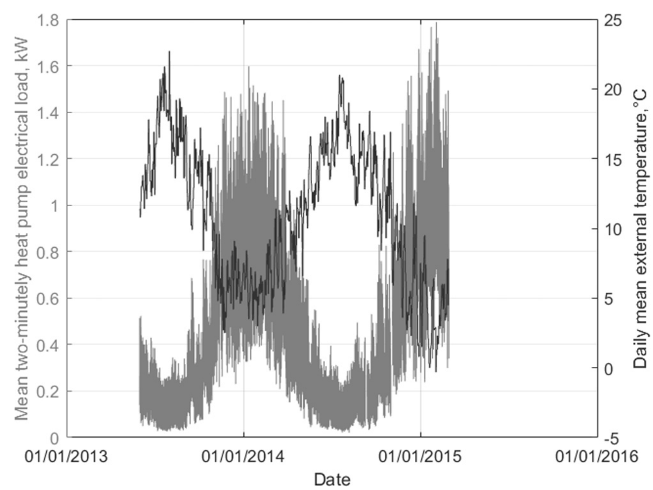

Fig. 2. Aggregated heat pump electricity consumption and external temperature timeseries.

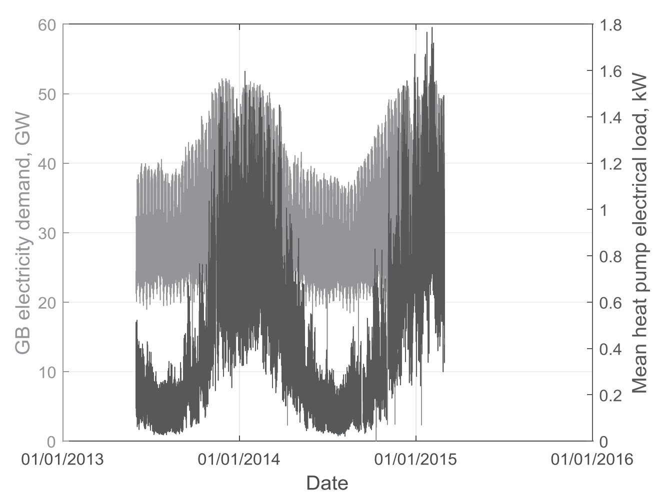

Fig. 3. E Aggregated heat pump electricity consumption and GB electricity demand.

there is no diversity and ADMD is the peak half hourly consumption of that heat pump.

To the best of our knowledge, no previous analysis uses fully empirical data to determine how ADMD per heat pump varies with number of heat pumps, so this was carried out as follows:

The heat pumps in the RHPP population were sorted randomly into an order. The ADMD of the first was calculated. Then the first and second heat pumps were taken together and the ADMD of their combined consumption was calculated. One more heat pump was added each time until all heat pumps were included in the ADMD calculation. This results in a value of ADMD for each value of N heat pumps.

For multiple reasons, we expect the ADMD vs N relationship to differ if the order of heat pumps included changes: firstly, the heat pumps vary in size from one another; secondly, ADMD might occur at different times based on which sites are included; thirdly and related to the previous point, not all sites have data for each half hour. Therefore, the above process was carried out 50 times (as a satisfactory trade-off between comprehensiveness and computation time) using different randomised orders to produce a mean estimate of the relationship between ADMD and number of heat pumps, with standard deviation.

4.3. Simple upscaling method

A simple upscaling was carried out to investigate the effect of mass deployment of heat pumps on GB electricity demand. Mean half-hourly heat pump electricity consumption as described in Section 4.2 was added to mean half hourly national grid electricity demand, under four uptake scenarios: 5%, 10%, 15% and 20% of houses having heat pumps, as in [6]. The GB national housing stock was taken as 25.8 million households [34]. The effect on peak demand and ramp rate on each of the four days was calculated.

The limitations of this method are as follows. In Section 3 it was stated that RHPP sample is not representative of current GB heat pump installations. Furthermore, it is unknown to what extent the sample will be similar to future heat pump installations in a mass deployment scenario, since the population of heat pumps in question is one that does not exist yet and whose composition and characteristics are unknown. Heat pumps are likely to become more efficient in the next decades, the way in which heat pumps are installed and used could change as the technology becomes more familiar and integrated with storage and smart grids, and heat demand could decrease as the dwelling stock becomes more thermally efficient. In parallel, future electricity consumption is likely to change over time, for example with a widespread introduction of electric vehicles and other electro-thermal technologies such as micro CHP [35], or with an increase in efficiency in other uses of electricity.

Therefore the aim of this upscaling exercise is not to predict the exact profile of the resultant electricity demand after mass uptake of heat pumps, but to observe its approximate size in comparison to the rest of GBs electricity demand and to gain insights such as whether the heat pump aggregated peak occurs at the same time as that of the rest of the national electricity demand.

In future work, a more sophisticated upscaling method will be developed which aims to create a representative aggregate load profile and consider future changes to the characteristics of national electricity demand.

4.4. Comparing heat pump operation to gas boilers

This method concerns obtaining data on gas use in boilers in a similar format to the heat pump electricity data, and comparing how both change over the day and as external temperature decreases. The EDRP dataset (DOI:10.5255/UKDA-SN-7591-1) contains half hourly gas use in 580 dwellings for space heating and is suitable for this task. However, much of the metadata about the RHPP and EDRP sites is not in the public domain so it is unclear whether the two samples are comparable in terms of their dwelling sizes and types.

For a given site in the heat pump dataset, each day of data was binned according to the external temperature that day. This was carried out by ascribing to it the closest integer value of mean daily external temperature according to the nearest weather station to the site.

Then for each bin of external temperature, the mean electricity consumption at each half hour (across all days of data in that external temperature bin) was calculated. This yielded one value of electricity consumption per half hour, per site and per external temperature bin.

Finally, the mean electricity consumption each half hour for each external temperature bin was calculated across all sites, to give a set of 24-hour profiles at different external temperatures. The process was then repeated for the gas consumption of all sites in the EDRP dataset.

The resulting electricity and gas consumption profiles were each then normalised to their daily peak, in order to compare the shapes of the profiles and specifically to observe the fraction of the peak at each time of day.

5. Results

5.1. Example aggregated heat pump load profiles

We begin by showing some example plots of the shape of daily load profiles on example days using a range of external conditions and day types. These are kept in two-minutely form to match the resolution of the heat pump electricity data. These days have been chosen because their external temperatures can be taken as representative of particular categories of typical day. By using a single day's observations in each case, we capture all the spatial diversity from the observed heat pumps, and do not introduce any inter-day smoothing which would misrepresent the issues that we are focussing on here: the particular potential strains on the electricity supply system caused by diurnal load profiles of heat pumps being added to existing electricity demand.

- Cold winter weekday/day of max ADMD per heat pump (Tuesday 03/02/2015, external temperature = −0.3 °C)
- Cold winter weekend day (Sunday 18/01/2015, external temperature = 1.4 °C)
- Medium winter weekday (Tuesday 03/03/2014, external temperature = 5 °C)
- Medium winter weekend day (Sunday 16/02/2014, external temperature = 5.2 °C)

The days to display were selected as follows. The analysis period, June 2013 to February 2015, contained atypically few very cold days in winter, so the winter months (December, January, February) from the entire RHPP monitoring period, December 2011 to March 2015, were used to determine a median winter temperature, 5.2 °C, used below as 'medium winter day'. The day on which the ADMD per heat pump of the whole dataset occurred was used for cold winter weekday. There was no very cold winter weekend day, so the coldest weekday in the analysis period was used, at 1.4 °C.

A number of observations can be made on the shape of the winter heat pump load profiles. Figs. 4-7 show that the mean heat pump daily load profile in winter has two peaks but does not fall to zero or near zero outside of the times of high demand. The first

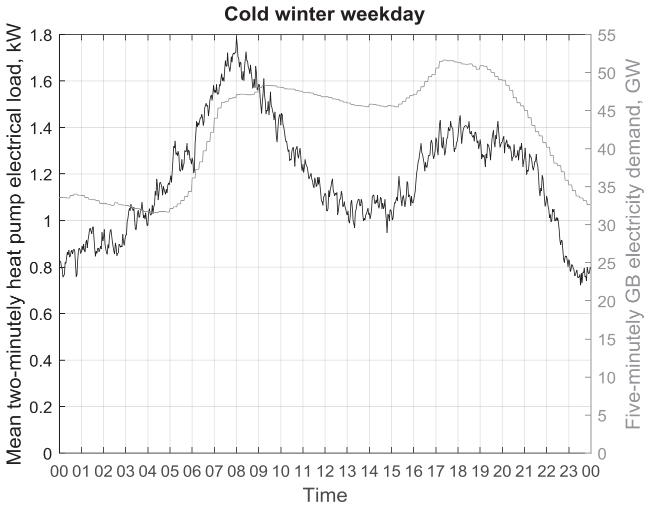

Fig. 4. Aggregated two-minute heat pump load profile for a cold winter weekday: 03/02/2015, external temperature = −0.3 °C (the day of highest aggregated HP demand).

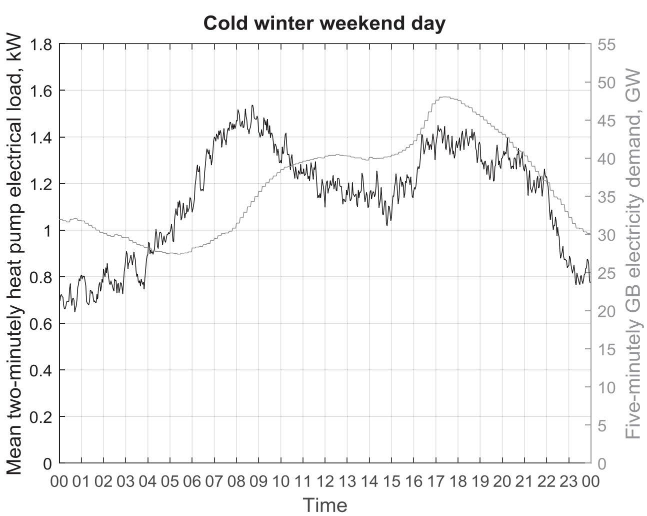

Fig. 5. Aggregated two-minute heat pump load profile for cold winter weekend day: 18/01/2015, external temperature = 1.4 °C.

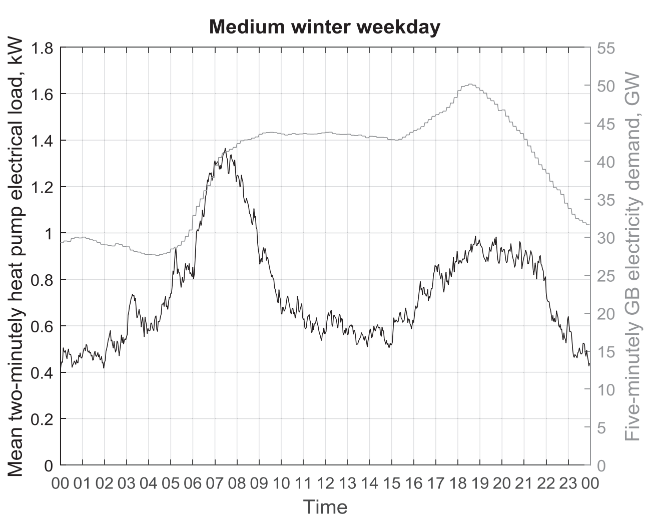

Fig. 6. Aggregated two-minute heat pump load profile for a medium weekday: 03/03/2014, external temperature = 5.0 °C.

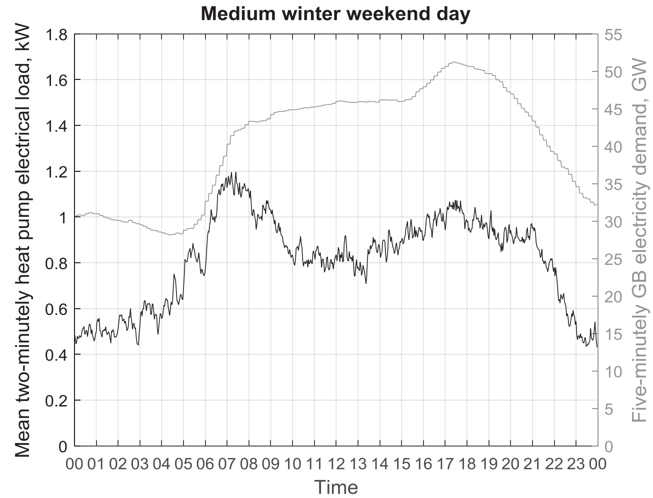

Fig. 7. Aggregated two-minute heat pump load profile for a medium winter weekend day: 16/02/2014, external temperature = 5.2 °C.

peak is around 06:00–09:00 and the second is around 16:00–21:00; the morning peak is usually higher in power and shorter in duration than the evening peak. The morning peak being higher would imply that the main cooling down period of dwellings is overnight and thus the heat pumps have to provide their highest rate of output in the morning. There is evidence of at least some heat pumps being programmed to run throughout the night: but intermittent heating still dominates, and electricity consumption falls overnight to between one half and one quarter of its peak, in the examples shown above. This is returned to later.

We now comment on the shape of the heat pump load profiles compared to the second series on Figs. 5 to 8, the power load of the GB electricity grid.

The UK electricity grid daily load profile (2013–2015) typically has the following pattern [33]:

- Baseload overnight, of which the minimum occurs around 04:00–05:00; this represents always-on appliances such as fridges and freezers; 24-h industrial, institutional and commercial processes; and off-peak electric heating.
- Rise from 05:00 until 09:00 as households begin to turn on appliances and workplaces/non-domestic premises open;
- A plateau until 16:00;
- A peak from around 16:00 to 21:00 as lighting in streets and households comes on, as do other appliances
- A decrease through the evening, dropping to the overnight baseload by shortly after midnight.

The morning peak of the heat pump load profile is coincident with or begins just before the morning rise in load on the electricity grid, and the evening peak of the heat pump load profile is coincident with the evening peak in the electricity grid.

5.2. ADMD per heat pump

The two-minutely data were aggregated to half hourly as described in Section 3.2, and the ADMD per heat pump was calculated as 1.7 kW using all of the RHPP sites.

The trajectory from one heat pump to the above number, or the change in ADMD per heat pump as number of sites increased, was calculated and is shown in Fig. 8.

Note that as shown in Fig. 1, data is not available from all 696 sites for the whole period, and that the period in which ADMD occurred for most values of the number of heat pumps on the x axis

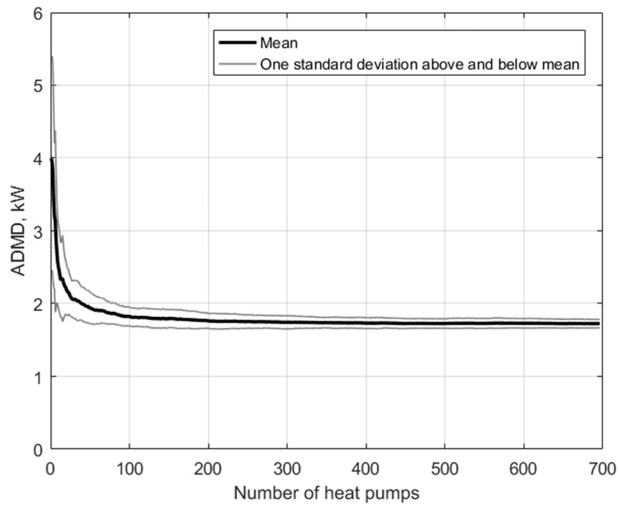

Fig. 8. ADMD per heat pump for increasing numbers of heat pumps in the RHPP population.

of Fig. 8 was early 2015, which Fig. 1 shows as containing 425–450 heat pumps.

Fig. 8 has a peak of 4.0 kW at 1 heat pump. After 40 customers ADMD falls to 2.0 kW (50% of its initial value), after 100 heat pumps it falls to 1.8 kW (45%) and at 275 heat pumps the ADMD reaches its final value (to 2 significant figures) of 1.7 kW (43%).

The standard deviation from the mean is also shown on Fig. 8 as a measure of the variation between samples [10]. As explained in Section 4.3, one reason for the variation is that that heat pumps in the real world are different sizes and draw different power according to their needs (climate, building heat demand, etc) and for this reason one sample of a fixed number of heat pumps may give a different ADMD per heat pump than another sample drawn from the same population [16]. The standard deviation is 1.5 kW at the first heat pump and 0.1 kW at the 275th (the number at which ADMD reaches its final value to two significant figures). This reflects a fairly low uncertainty in ADMD per heat pump introduced by the subsampling method.

However, ADMD per heat pump is not an especially useful metric for national grid considerations. More important is the effect on peak grid demand – the maximum of which may not occur at the same time as the ADMD of heat pumps alone. This is considered next.

5.3. Effect of mass deployment of heat pumps on the GB electricity system

We now answer two of the questions posed in the Introduction: what would be the resulting peak demand of the national grid if various mass deployment scenarios of heat pumps occurred, and what would the corresponding ramp rate increase be?

Applying the upscaling method described in Section 4.3 led to a timeseries of resultant grid demand for each heat pump uptake scenario. The maximum of each timeseries is then the grid peak demand for each scenario and is given in Table 1. Notably, the day and time at which ADMD per heat pump occurred (03/02/2015, morning) is not the same as the day and time of grid peak demand before addition of heat pump load (19/01/2015, evening). Furthermore, the results of the upscaling showed that the day and time of the grid ADMD after addition of heat pump load (02/02/2015, evening) is different again.

Fig. 9 below shows the day of the new overall grid peak in the 20% heat pump deployment scenario, before and after deployment. This is shown to illustrate the effect of the heat pump load on the previous grid load that day. It can be seen that the shape of the grid load is not changed a great deal, and that the peak is still in the evening. The heat pump load has added most to the morning, and is beginning to create a morning peak in the grid load where there was not one before. However, at 20% deployment of heat pumps this effect is not very strong. Thus, the main effect is not a change in shape of the daily grid load but the addition of a slowly varying extra load throughout the day and night.

Next, the effect of the same heat pump uptake scenarios on grid ramp rate was calculated. The day and time of maximum ramp rate prior to heat pump deployment was the morning ramp-up of 24/10/2013. This is not the middle of winter but a swing season. The day and time of maximum ramp rate after heat pump deployment was 19/01/2015.

The effect of heat pump deployment on maximum ramp rate is presented in Table 2.

Thus, the worst case scenario is an increase of 0.3 GW/half hour on current levels.

The effect on ramp rate caused by mass heat pump uptake is shown in Fig. 10. It can be seen that the effect is small.

We now move on from comparison with the electricity grid to comparison of heat pump operation with the current dominant heating system – gas boilers.

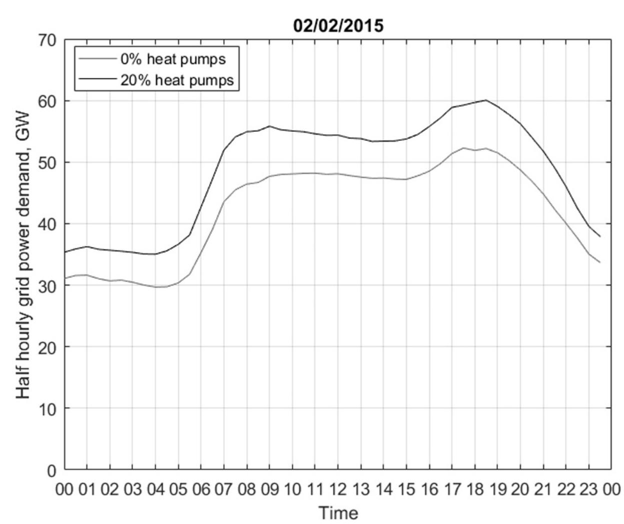

Fig. 9. Predicted national grid power demand on the day of new maximum demand under the 0% and 20% heat pump deployment scenarios.

Table 1

	Heat pump penetration				
	0%	5%	10%	15%	20%
Max demand (GW)	52.5	54.4	56.2	58.1	60.0
Increase from 0% scenario		+3.5%	+7.1%	+10.6%	+14.3%
Date of grid peak demand under this scenario	19/01/2015	19/01/2015	19/01/2015	19/01/2015	02/02/2015

Table 2
Maximum half hourly ramp rate under different heat pump uptake scenarios.

	Heat pump penetration				
	0%	5%	10%	15%	20%
Maximum ramp rate (GW/half hour)	4.7	4.7	4.8	4.9	5.0
Increase on 0% scenario		+0.6%	+2.0%	+4.1%	+6.1%
Date	24/10/2013	24/10/2013	20/01/2014	20/01/2014	20/01/2014

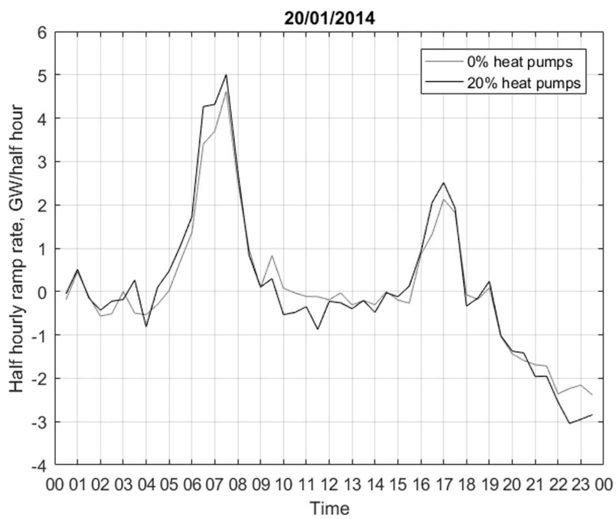

Fig. 10. Ramp rate under different heat pump uptake scenarios.

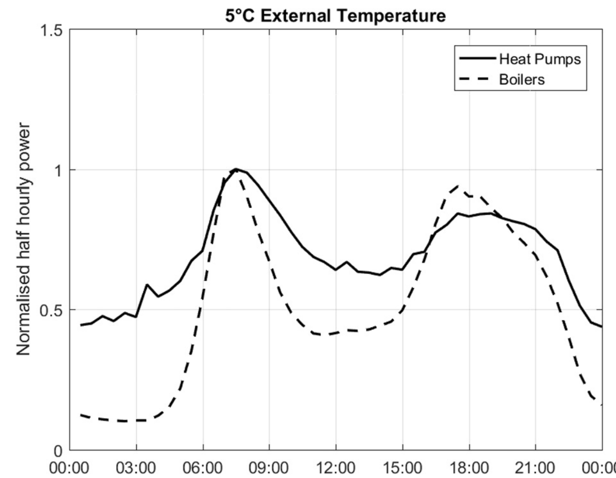

Fig. 12. Comparison of heat pump and boiler daily load profiles at 5 °C external temperature.

5.4. Heat pumps and boilers

The final question posed in the introduction was: what are the timing characteristics of heat pumps compared to conventional boilers?

This is firstly shown in timeseries form over 24 h. Using the method described in Section 4.4, gas use for boilers and electricity use for heat pumps were collated for days of similar mean external temperature. Gas boilers and heat pumps can then be compared in terms of the shape of their daily profile of gas/electricity consumption at certain external temperatures. Fig. 11 and Fig. 12 show the average gas use from boilers and electricity use from heat pumps on days on which the external temperature was 0 °C and 5 °C.

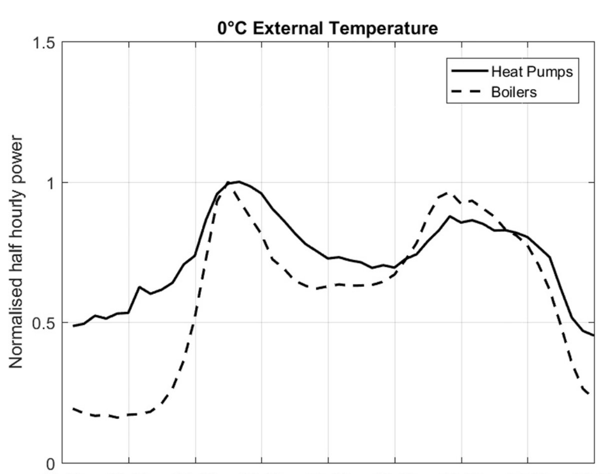

Fig. 11. Comparison of heat pump and boiler daily load profiles at 0 °C external temperature.

The two series on each plot are normalised to their respective peaks to allow easier comparison of their shapes.

A number of observations can be made from Fig. 11 and Fig. 12.

Firstly, boiler load profiles and heat pump load profiles both contain two peaks. The morning peak and evening peaks are reached at approximately the same time for both types of system, but the ramp up and down is faster for boilers (Fig. 11 and Fig. 12).

Secondly, the boiler profile varies more over the day than the heat pump profile – that is, it is more 'peaky'. Although it is not appropriate to compare the absolute size of the boiler daily peak to the heat pump daily peak (as was previously explained, the mixes of property types and heat demands served are different), the ratio of the peak to the mean of each type of heating system can be compared. At 0 °C external temperature, the peak:mean ratio for boilers is 1.67 and for heat pumps is 1.37. Similarly, the peak:trough ratio can be calculated, showing that boilers fall to 16% of their peak output at night on cold days, whereas heat pumps fall to 41%.

It could be the case that for each type of heating system the size of the morning peak is inversely related to the amount of night time delivered power. Assuming that the morning peak is serving some proportion of space heating, as opposed to domestic hot water, the consequence of significant heating overnight would then be that the dwellings with heat pumps do not cool so much in the night and therefore require less heating in the morning.

We now move on to another way of displaying the data, delivered power plotted against external temperature, elsewhere termed the 'Power-Temperature Gradient' [36]. The range of external temperature used for heat pumps is -1 to 20 °C and for boilers is -2 to 24 °C, because over these ranges at least 400 sites of each heating system type have at least one day of data.

Fig. 13 shows daily delivered power versus daily external temperature for dwellings with heat pumps and boilers. Fig. 13 was created using a similar method to Fig. 11 and Fig. 12, by taking, at each degree band of external temperature, the mean power per site on days falling into this temperature band, and then taking

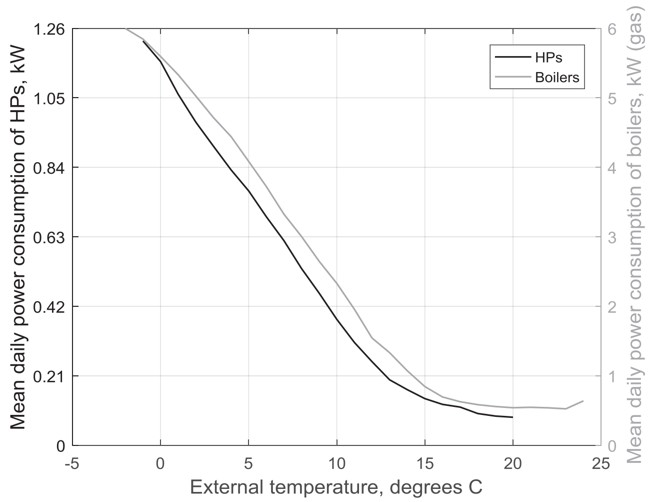

Fig. 13. Power Temperature Gradient for heat pumps and boilers using mean power consumption.

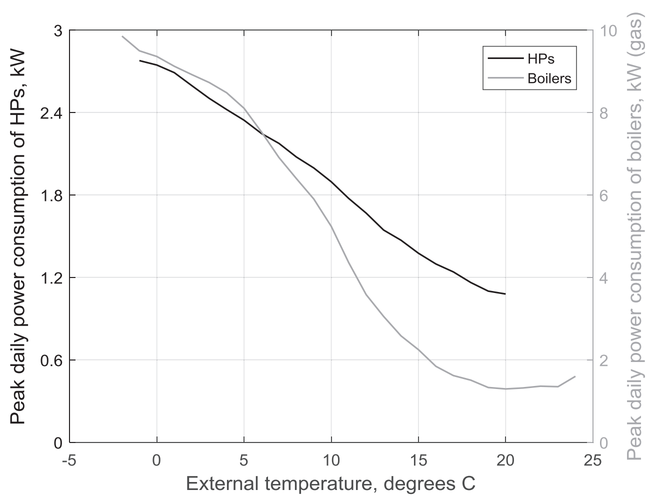

Fig. 14. Power Temperature Gradient for heat pumps and boilers using peak power consumption (at half hourly resolution).

the mean over all sites. This method was chosen to match that used in previous work on the Power Temperature Gradient [36]. In Fig. 13 heat pumps and boilers are plotted on separate y axes so that their shapes can be easily compared.

The two series on Fig. 13 are similar in shape: they are both approximately linear at external temperatures below 12–13 °C. It may have been expected that, due to a sample of heat pumps dominated by air source models which become less thermodynamically efficient as external temperature drops, the heat pump power-temperature relationship would have steepened at low external temperatures. This cannot be seen in the RHPP dataset. Further analysis is needed to uncover the factors causing the heat pump power-temperature relationship of heat pumps to result in a linear shape. In particular, more data is needed from cold days (where external temperature is below 0 °C) to observe whether the relationship is still linear.

Finally, we return to the topic of daily peak power consumption. In Fig. 14, daily peak power averaged over all sites is plotted against daily mean external temperature, for each type of heating system. Peak power was calculated as follows: for a given external temperature, all the days in the dataset from a site were selected, and the peak electricity (or gas for boilers) consumption per day averaged to obtain one value per site. These were then averaged over all sites to obtain a peak electricity (or gas) consumption for each external temperature.

The difference between the shapes of the heat pump and boiler series on Fig. 14 is notable. Boilers produce a shape resembling a logit curve. As external temperature decreases from right to left, the rate of increase in the peak power rises, then decreases at low external temperatures. The latter could be as a result of boilers reaching their maximum heat output.

Heat pumps do not produce the same shape. Below about 15 °C externally, their peak power rises fairly constantly until 0 °C where it may start to flatten, although there are not enough data points to confirm this. There are a number of possible explanations for this, each of which deserves investigation in further work. For example, it could be that the heating in gas boiler heated dwellings is used for more of the night on colder days, reducing the anticipated increase in peak (morning) load as external temperature drops, whereas heat pumps are already used more commonly in the night and this use does not increase on colder days. Alternatively, the internal boost (resistance heater) present in some models of heat pump could be coming into operation at the lowest external temperatures.

6. Discussion

This article set out to estimate two unknowns: the load profiles of a large sample of heat pumps and their timing characteristics compared to conventional boilers, and (to first order) the increase in peak half hourly demand and change in maximum ramp rate of the national grid with mass uptake of heat pumps.

6.1. Shape of aggregated load profiles

It is assumed in some previous studies that heat pump load profiles are flat, implying continuous operation [19], and in other literature that they are run at times of assumed space heating demand [13–15], giving a bimodal profile with two strong peaks similar to the load profile of gas boilers. The evidence given by recent field trials shows that the answer is somewhere in between. In the aggregated load profiles from both the RHPP data described here (containing 400–589 sites at a time) and the largest previous study (CLNR, containing 89 sites), the aggregated heat pump load profiles have two daily peaks, at 06:00–09:00 and 16:00–20:00. The CLNR sites showed a third peak at 3 a.m. which was not visible in the RHPP data. The electricity consumption in the RHPP dataset fell overnight to around 40% of its peak. The implications of this operation are discussed below.

6.2. Implications for the national grid

The current daily national grid peak occurs in the evening around 17:00–18:00. This is not the same time as the daily peak of the aggregated heat pump load profile, which occurs in the morning around 07:00–08:00.

Although as described in Section 4.3 the shape and magnitude of both aggregated heat pump demand and national grid demand in the coming decades are not likely to be exactly represented by those observed now, some general insights can be gained from the upscaling exercise carried out in this article which combined a 20% heat pump deployment scenario with current national grid demand. These insights are as follows:

1. The shape of the national grid profile is approximately preserved; heat pumps at 20% penetration do not have a large enough effect to significantly alter it – though, this may change in significantly colder weather.

2. However, 20% heat pump penetration begins to create a morning peak; higher heat pump deployment scenarios would enhance this.
3. The peak power demand (real power only) of the grid increases by 7.5 GW (14%), occurring during the evening peak.
4. The day of maximum grid demand is neither the day in which previous maximum grid demand occurred nor the day on which ADMD per heat pump occurred.

Despite both the daily maximum heat pump load and the daily national grid ramp rate being at their highest values in the morning, the 20% heat pump deployment scenario only increased maximum ramp rate by 0.3 GW/half hour (6%).

These increases in national peak demand could be mitigated by implementing heat pump control strategies that diversify the heat pump load profile, and make use of periods of lower national electricity demand (such as overnight 22.00–06.00); such strategies should also be designed to mitigate, rather than to exacerbate, the morning ramp-up of national demand. The RHPP dataset suggests that this is being carried out already to some extent. Comparison of the operation of heat pumps and boilers shows that there is more overnight operation of heat pumps than boilers; this is likely to result in the morning peak being reduced from what it would have been in the absence of night operation. However, the clear existence of peaks at the same time as those occurring in boiler-heated dwellings show that heat pumps are to an extent being used in the same manner as boilers.

As for why this might be, it is possible that this comes about as a result of some of the heat pumps in the sample being retrofitted into homes with timed heating systems (such as oil boilers) without changing the timing set up on the heating controls. However, the data and metadata from the RHPP trial are not sufficient to determine the heat pump control strategy implemented at each site; furthermore, it is not known how many sites already have and use heat storage via buffer tanks. Therefore, the technical potential for demand shifting in time cannot be determined from the current dataset.

6.3. Implications for models incorporating heat pumps

The RHPP dataset can help inform how heat pump operation is modelled. Heat pumps are represented in the UK's Standard Assessment Procedure (SAP) building energy model through a Seasonal Performance Factor and an adjustment to mean internal temperature. The latter is on the premise that heat pump operation is continuous, so dwelling mean internal temperature is higher than if a dwelling is heated using a conventional boiler and one or two heating periods a day (weekends and weekdays respectively). The Seasonal Performance Factor is also based on continuous operating conditions; these conditions allow for lowest possible supply temperatures and therefore as efficient performance as possible [30].[1] The shape of the empirical daily load profiles contrasts with this assumption of continuous operation as there exist peak times of operation. The consequence may be that the heat pumps are not operating as efficiently as possible nor as efficiently as assumed in the SAP model.

Heat pumps are also modelled in electricity system models, at both local and national levels. The results in this study showing ADMD per heat pump change with number of heat pumps are interesting for these applications. The ADMD was shown to fall to half of its initial value after 40 sites, which is similar behaviour to a previous study combining data and modelling [10]. ADMD continued to fall after 100 sites, the maximum number used in the previous study, and reached its final value to one significant figure after 275 sites. This is perhaps not important for local level considerations since substations generally do not have this many domestic connections (for example, the UK DNO Western Power Distribution report 120 customers per urban substation [37]). However, the finding is relevant at a national level. The ADMD curve for heat pumps has not previously been demonstrated fully empirically.

The bimodal shape of the aggregated load profile may not be observed in countries other than Great Britain. However, the findings presented here of the ADMD of a heterogeneous population of heat pumps reaching approximately its final value after 275 sites and the observed advantages of using real data not synthetic profiles at assumed times of heat demand may be useful results for countries seeking to carry out research into the effect of an aggregate heat pump load profile on local and national grids.

7. Conclusion and next steps

This paper utilises the largest dataset of heat pump data electricity use available in the UK for retrofitted heat pumps to existing dwellings and systems, and focusses on the electricity consumption. The aggregate winter profile shows two peak heating periods at the same time as those found in homes heated by boilers, but with lower peaks and more night time operation. The ADMD per heat pump was 1.7 kW, occurring in the morning and not concurrent with the national daily peak demand. A simple upscaling method to add heat pump electrical load to the existing national grid indicated a peak demand increase of 7.5 GW and maximum ramp rate increase of 0.3 GW/half hour.

The next steps in this exploration might be:

- To improve existing modelling of forecast load curves, combining the new results presented here with other results on load-curves for other new loads such as electric vehicles;
- A more thorough consideration of social factors and house type to give more representative and detailed estimates of national electricity demand under various heat pump uptake scenarios.

However, the results here indicate a need – and an opportunity - to implement ways to spread out the load to reduce the extra capacity required on the grid:

- Work to understand the behaviour of a fleet of heat pumps at much lower external heat pumps (as noted, the RHPP dataset included little data below 0 °C);
- An exploration of the differences between ground and air source heat pumps
- Exploring clusters of sites with different operation modes;
- Exploring space heating behaviour and DHW heating behaviour and investigating whether the bimodal daily load profile observed in winter is also apparent on a site-by-site basis or a result of some heat pumps switching off in the middle of the day and some remaining on;
- Further empirical and simulation work to understand the shape of the power-temperature curve.

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[1] SAP is also provides an option not to use this assumption, in which case a default (lower) SPF and bi-modal heating at the same times as a boiler are assumed.

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Declaration of interest

To the authors' knowledge there are no actual or potential conflicts of interest including any financial, personal or other relationships with other people or organisations within three years of beginning the submitted work that could inappropriately influence, or be perceived to influence, this work.

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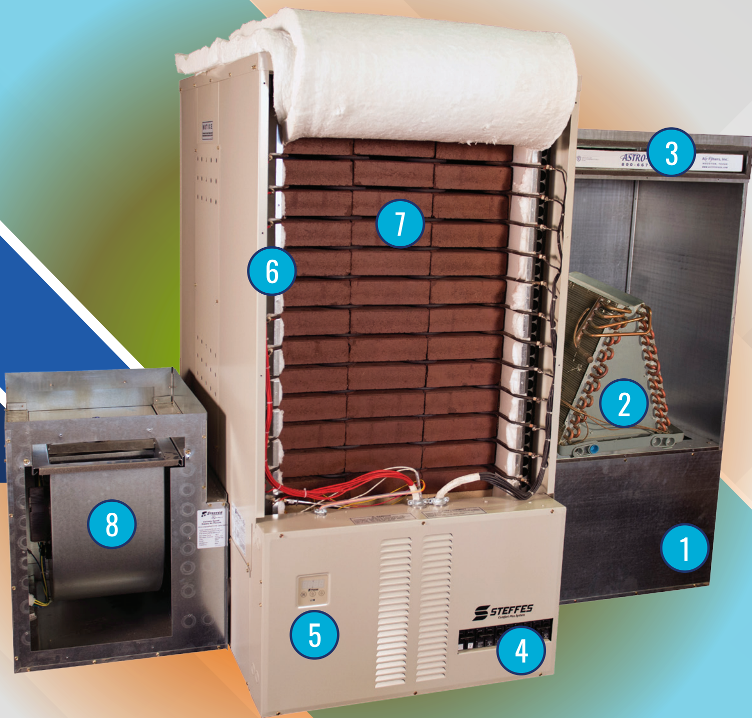
Applications and Operation

The Comfort Plus Forced Air furnace can be installed as a standalone furnace or as a supplement to other heating systems, such as a heat pump. While heat pumps are known for providing efficient low-cost heating and cooling, they require supplemental heat during colder temperatures. When demand for heat is greater than a heat pumps capacity, the Comfort Plus Forced Air furnace adds the precise amount of its stored off-peak heat as needed to ensure constant comfort while still allowing full optimization of the heat pumps efficiency.

Operation is completely automatic. A sensor monitors outdoor temperature to regulate the amount of heat stored in the bricks. The room thermostat is set to control heat delivery so the desired comfort level can be maintained using the safe, clean, reliable and economical stored off-peak heat.



Components

1. Return air plenum (separately ordered or installer supplied)
2. AC or heat pump coil (must be installer supplied, if applicable)
3. Air filter
4. Built-in circuit breakers for power disconnect
5. Programmable microprocessor based control panel and digital display
6. Electric heating elements
7. High density heat storage bricks
8. Supply air plenum with 1/2 HP or 3/4 HP variable speed blower

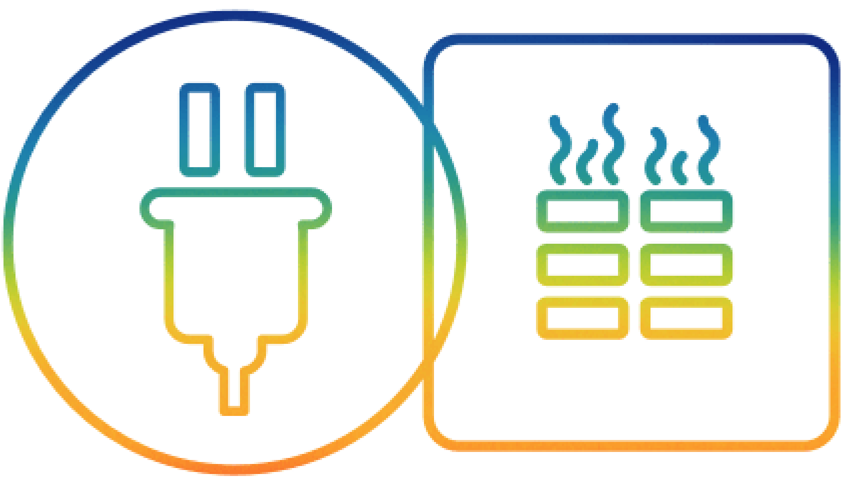
1kW = 3412 BTU/hr 1kWh = 3412 BTU **U.S. Pat #5086493 • Canada Pat #2059158** **5-year limited manufacturer's warranty**

SPECIFICATIONS For standard 240V units. 208V, 277V, and 347V configurations also available. Contact factory for technical specifications.

MODEL	4120			4130		4140	
Charging Input	14.0 kW	19.2 kW	24.8 kW	28.8 kW	37.2 kW	38.4 kW	45.6 kW
Element Current Draw	59 amps	80 amps	104 amps	120 amps	155 amps	160 amps	190 amps
Circuits Required Elements Blower/Control	1-20 amp 2-30 amp	1-30 amp 2-40 amp	1-40 amp 2-50 amp	4-40 amp	4-50 amp	4-50 amp	4-60 amp
	1-15 amp (7 amps maximum load)						
	Unit is factory-configured with multiple-line voltage, single-phase circuit connections. If single feed to the element and blowers/controls circuits is desired, an optional single-feed kit is available. Phase-balancing is recommended when making connections in 3-phase applications.						
Storage Capacity	120 kWh (409,440 BTU)			180 kWh (614,160 BTU)		240 kWh (818,880 BTU)	
	The size and heating ability of the system required for an application is dependent on the heat loss of the area and the power company's off-peak hours. Refer to the Maximum Maintainable Heat Loss for heating abilities in specific charge strategies.						
Approximate Installed Weight	2,267 lbs			3,139 lbs		3,991 lbs	
	Contact a building contractor or architect if you have structural weight concerns of the installation surface selected. Adhere to all national and local electrical and building code placement requirements for electric heating appliances.						
Unit Dimensions - W x D x H w/o Ducting w/ Factory-Built Ducting (1/2 HP) w/ Factory-Built Ducting (3/4 HP)	29.2" x 47.4" x 46.6" 77.6" x 47.4" x 46.6" 82.1" x 47.4" x 46.6"			29.2" x 47.4" x 57.6" 77.6" x 47.4" x 57.6" 82.1" x 47.4" x 57.6"		29.2" x 47.4" x 68.6" 77.6" x 47.4" x 68.6" 82.1" x 47.4" x 68.6"	
	There are required installation clearances to account for. Contact the factory for information.						
Duct Openings Supply Air Outlet (1/2 HP) Supply Air Outlet (3/4 HP) Return Air Inlet	18" x 22.6" (in factory-built plenum) 22.5" x 22.6" (in factory-built plenum) 10.5" x 22.3" (in unit) or 26.2" x 22.25" (if using a factory-built plenum)						
Maximum Coil Dimensions (W x D x H)	26" x 22" x 31"						
	The factory-built return air plenum is configured for housing an indoor coil. Dimensions listed are that of the inner coil area in this plenum. For larger coils, field provisions to the plenum are necessary or it will need to be supplied by the installer.						
Supply Air Delivery (Field Selectable) 1/2 HP Variable Speed CFM ratings 3/4 HP Variable Speed CFM ratings	1000, 1200, 1400, 1600 1200, 1400, 1600, 2000						
Heating Ability Based on Charge Time (BTU/hr) 8 Consecutive Charge Hours 12 Consecutive Charge Hours 6/4/6/8 Charge Strategy	20,414 30,621 30,621	27,996 41,994 41,994	34,175 45,566 54,242	41,994 62,991 62,991	49,212 65,615 81,363	55,992 83,988 83,988	65,615 87,487 99,735
	The size and heating ability of the system required for an application is dependent on the heat loss of the area and the power company's off-peak hours. If the unit is not installed within the heated area, heat lost statically must be taken into account. Contact a local Steffes dealer or power company for assistance in selecting an appropriately sized system for your specific charge strategy. The 6/4/6/8 strategy listed is 8 hours off-peak at night plus 4 hours off-peak mid-day. (The heating ability figures listed have a heat use allowance factored in for sizing purposes. Average BTU/hr delivery rate is the listed value multiplied by .78 heat use factor.)						

Manufacturer reserves the right to discontinue or change at any time, specifications or designs, without notice or incurring obligations.

Need to replace your central heating system?



Opt for central heating with electric thermal storage and receive $10,000 in financial assistance from Hydro-Québec

About (http://www.hydroquebe	Advantages (http://www.hydroquebe	Financial assistance (http://www.hydroqu

wise/windows-heating-air-conditioning/thermal-storage/)	wise/windows-heating-air-conditioning/thermal-storage/advantages.html)	wise/windows-heating-air-conditioning/thermal-storage/financial-assistance.html)

A winning choice for its financial, technical and environmental benefits

Financial benefits

Hydro-Québec will provide $10,000 of financial assistance for the purchase and installation of a central heating ETS system. This financial assistance fully covers the additional cost of installing an ETS system as opposed to a regular system. The ETS system therefore ends up being less expense.

Receive an additional $1,500 financial assistance if you install an ENERGY STAR® heat pump at the same time as an Electric Thermal Storage system.

In addition, if you take the further step of signing up for Rate Fle D, the registration period for which is from April 1 to November 20 each year, then you could save approximately $100 to $200, if not more, every year on your electricity bill in comparison with the base rate (Rat D).

Technical benefits

- Simple, proven technology that's easy to maintain
- Quieter than a dual-energy or fuel-oil system
- Can be used with a heat pump

- No overheating in the area where the device is located, despite the high temperature of the thermal mass
- Easy connection to existing ventilation ducts (requires only slightly more space than a standard electric heating system)

Environmental benefits

A central heating ETS system is 100% electric. Since it replaces equipment that runs on fossil fuels, it protects the environment and reduces your greenhouse gas emissions, as electricity generated in Québec is 99% clean and renewable.

Flex D dynamic pricing: a further advantage

If you choose to install a central heating ETS system, we recommend signing up for Hydro Québec's new dynamic rate, Flex D, the registration period for which is from April 1 to November 20 each year. That could lead to major savings on your bill.

During winter:

Outside peak demand events, the price of electricity is below the base rate, which could mean considerable savings for you.

During peak demand events, electricity is billed at a higher rate (50¢/kWh). Since your central heating ETS system automatically turns off its heating

elements during these short periods, your overall electricity demand will be greatly reduced.

The rest of the year:

Rate D (the base rate) will apply.

All about Rate Flex D (https://www.hydroquebec.com/residential/customer-space/rates/rate-flex-d.html)

TYPES OF ETS

There are three main types of ETS systems, though all function basically the same way—they store heat while power rates are discounted, and release the heat as needed. The main types of ETS are standalone room units, whole-home central heating units, and hydronic (hot water) in-floor units. All three types can qualify for time-of-day rates with us and are great options when switching from oil.

Room unit systems

This type of ETS is the simplest to add to an existing home and any existing heating system. A standalone cabinet, you simply find a convenient place to locate it in your room, and have it hard-wired by an electrician. Cabinets vary in size, but they're generally only about 10” to 12” deep, so they integrate well into most homes' decor. The cabinet is loaded with a bank of ceramic bricks that heat up via the electric heating element that runs between them. A room unit works well as an add-on to any existing system and several room units are ideal when converting from oil.

ETS central heating

A central heating ETS replaces your existing furnace - this is an ideal solution when looking to cleaner home heating systems. These ETS systems come in both forced air and hydronic versions, so if your current home heat is distributed by forced air (through ductwork) or hot water (through radiators), there's an ETS upgrade for you. As with a room unit, the ETS furnace is filled with ceramic bricks that are heated in off-peak hours, so the heat can be released when needed. In the case of hydronic systems, the heat from the bricks is transferred via heat exchanger to water or glycol, which is then circulated through the home's existing radiators.

In-floor radiant

The big difference with in-floor radiant ETS systems is that rather than using ceramic bricks to store the heat, it uses the concrete slab of the floor itself. In this system, water is heated during off-peak hours, and pumped through the home's concrete floor(s). The concrete absorbs and holds this heat, releasing it slowly throughout the day. If your home currently has concrete in-floor heating, especially in a basement space, this could be a good option for you.

ETS/heat pump combination

A heat pump is a wonderful way to increase your home's heating efficiency. Combine your heat pump with an ETS, and you can boost your savings even more. With this setup, when your heat pump calls for additional heat from a backup source (on winter's coldest days), your ETS can kick in, releasing heat that you bought at a lower rate.

For homes with a heat pump, room unit ETSs are also a common way to heat a finished basement space. This way, a heat pump head doesn't have to be installed in the basement.

ETS contractors

Time-of-day rate

Financing your ETS

QUESTIONS?

Call us at 1-800-428-6774 outside of HRM, weekdays 8 a.m. to 8 p.m.

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21. Section 64 is replaced by the following:

“**64.** A borrower who receives financial assistance in the form of a bursary for each year of allocation during which he or she pursues a course of undergraduate studies at the university level leading to a degree, completes the studies within the number of sessions and years of study stipulated by the educational institution for completing the program as structured by the educational institution, and obtains official certification thereof is entitled, on application to the Minister and up to the amount established pursuant to sections 54 and 55, to a 15% reduction on the value of the guaranteed loans contracted to complete the program and, if applicable, on the value of the following guaranteed loans:

(1) loans contracted during his or her college studies in a course of studies leading to a diploma of college studies if he or she receives financial assistance in the form of a bursary for each year of allocation, completes the studies within the number of sessions and years of study stipulated by the educational institution for completing the program as structured by the educational institution, and obtains official certification thereof;

(2) loans contracted during his or her master’s or doctoral studies if he or she receives financial assistance in the form of a bursary, completes the studies within the number of sessions and years of study stipulated by the educational institution for completing the program as structured by the educational institution, and obtains official certification thereof.”.

22. Section 74 is amended by replacing “$260” and “$129” in the second paragraph by “$263” and “$131”, respectively.

23. Section 74.2 is amended by inserting the following at the end:

“, and, for the 2021-2022 year of allocation, any income earned by the student through employment with an organization mentioned in the third paragraph of Schedule I.”.

24. Section 82 is amended by replacing “$3,119” and “$2,336” in the third paragraph by “$3,158” and “$2,365”, respectively.

25. Section 86 is amended

(1) by replacing, respectively, the amounts provided for in subparagraphs 1 to 3 of the first paragraph by the following amounts:

(1) “$2.34”;

(2) “$3.49”;

(3) “$130.60”;

(2) by replacing “$11.54” in the second paragraph by “$11.69”.

26. Section 87.1 is amended by replacing “$395” by “$400”.

27. Section 94 is amended by replacing “less than 3 years” in the first paragraph by “5 years or less”.

28. Schedule I is amended by replacing the portion before subparagraph 1 of the third paragraph by the following:

“For the purposes of subparagraph 1 of the first paragraph, for the 2020-2021 year of allocation, employment income earned by the student during the period beginning on 13 March 2020 and ending on 31 August 2020 and, for the 2021-2022 year of allocation, employment income earned by the student during the period beginning on 1 January 2021 and ending on 31 May 2021, while employed with any of the following bodies is not taken into account:”.

29. This Regulation applies from the 2021-2022 year of allocation.

30. This Regulation comes into force on the fifteenth day following the date of its publication in the *Gazette officielle du Québec*.

105354

Gouvernement du Québec

O.C. 1412-2021, 3 November 2021

Act respecting the Ministère du Développement durable, de l’Environnement et des Parcs (chapter M-30.001)

Environment Quality Act (chapter Q-2)

Oil-fired heating appliances

Regulation respecting oil-fired heating appliances

Whereas, under subparagraph 1 of the first paragraph of section 95.1 of the Environment Quality Act (chapter Q-2), the Government may make regulations to classify contaminants and sources of contamination;

Whereas, under subparagraph 3 of the first paragraph of section 95.1 of the Act, the Government may make regulations to prohibit, limit and control sources of contamination and the release into the environment of any class of contaminants for all or part of the territory of Québec;

Whereas, under subparagraph 7 of the first paragraph of section 95.1 of the Act, the Government may make regulations to define environmental protection and quality standards for all or part of the territory of Québec;

Whereas, under subparagraph 21 of the first paragraph of section 95.1 of the Act, the Government may make regulations to prescribe the reports, documents and information that must be provided to the Minister by any person or municipality carrying on an activity governed by the Act or the regulations, determine their form and content and the conditions governing their preservation and sending;

Whereas, under subparagraph 29 of the first paragraph of section 95.1 of the Act, the Government may make regulations to prescribe any measure aimed at promoting the reduction of greenhouse gas emissions and require that climate change impact mitigation and adaptation measures be put in place;

Whereas, under section 115.27 of the Act, the Government may, in a regulation made under the Act, in particular specify that a failure to comply with the regulation may give rise to a monetary administrative penalty, and set forth the amounts;

Whereas, under the first paragraph of section 115.34 of the Act, the Government may in particular determine the regulatory provisions made under the Act whose contravention constitutes an offence and renders the offender liable to a fine the minimum and maximum amounts of which are set by the Government;

Whereas, under section 124.1 of the Act, no provision of a regulation, the coming into force of which is later than 9 November 1978, likely to affect the immovables comprised in a reserved area or in an agricultural zone established in accordance with the Act respecting the preservation of agricultural land and agricultural activities (chapter P-41.1) applies to that area or zone unless the regulation provides it expressly;

Whereas, under paragraph 8.1 of section 15.4 of the Act respecting the Ministère du Développement durable, de l'Environnement et des Parcs (chapter M-30.001), any other sum provided for by law or by a government regulation is credited to the Electrification and Climate Change Fund;

Whereas, in accordance with sections 10 and 11 of the Regulations Act (chapter R-18.1), a draft Regulation respecting oil heaters was published in Part 2 of the *Gazette officielle du Québec* of 21 April 2021 with a notice that it could be made by the Government on the expiry of 45 days following that publication;

Whereas it is expedient to make the Regulation with amendments;

It is ordered, therefore, on the recommendation of the Minister of the Environment and the Fight Against Climate Change:

That the Regulation respecting oil-fired heating appliances, attached to this Order in Council, be made.

Yves Ouellet
Clerk of the Conseil exécutif

Regulation respecting oil-fired heating appliances

Act respecting the Ministère du Développement durable, de l'Environnement et des Parcs
(chapter M-30.001, s. 15.4, par. 8.1)

Environment Quality Act
(chapter Q-2, s. 95.1, 1st par., subpars. 1, 3, 7, 21 and 29, ss. 115.27, 115.34 and 124.1)

DIVISION I
OBJECT AND SCOPE

1. The objective of this Regulation is to reduce man-made greenhouse gas emissions attributable to domestic heating by gradually prohibiting the installation and repair of certain space and water heaters powered by certain forms of energy.

2. For the purposes of this Regulation, "residential building" means any building that meets the following requirements:

(1) the building area is not more than 600 m^2;

(2) the building height is not more than 3 storeys;

(3) the major occupancy of the building is Group C – Housing and it houses only dwellings.

A building is qualified as a residential building in accordance with the National Building Code of Canada 2015 (NRCC 56190) and the Code national du bâtiment

- Canada 2015 (CNRC 56190F), second printing, published by the National Research Council of Canada and prepared by the Canadian Commission on Building and Fire Codes. Subsequent amendments to those documents by that organization do not apply, except errata.

In addition, for the purposes of this Regulation,

(1) "existing residential building" means any residential building for which a building permit was issued before 31 December 2021 by the local municipality having jurisdiction in the territory in which the construction took place;

(2) "new residential building" means any residential building for which a building permit was issued on or after 31 December 2021 by the local municipality having jurisdiction in the territory in which the construction took place;

(3) "boiler" means pressure equipment equipped with a direct power source used to heat a heat-carrying liquid or transform it into steam;

(4) "water heater" means a pressure vessel equipped with a direct energy source in which water destined for exterior use is heated to a temperature of 99°C or less and to a pressure of 1,100 kPa or less. The heat source and control devices are an integral part of the water heater;

(5) "furnace" means a heating appliance that distributes heated air through a system integrated into a building;

(6) "Minister" means the Minister responsible for the administration of the Environment Quality Act (chapter Q-2).

3. Where this Regulation applies, it covers every immovable, including immovables in a reserved area and an agricultural zone established under the Act respecting the preservation of agricultural land and agricultural activities (chapter P-41.1).

DIVISION II
PROHIBITIONS

4. This Division applies, to the extent provided for in that Division, to any residential building connected to a municipal or private electric power system governed by the Act respecting municipal and private electric power systems (chapter S-41), to the electric power system of the Coopérative régionale d'électricité de Saint-Jean-Baptiste de Rouville governed by the Act respecting the Coopérative régionale d'électricité de Saint-Jean-Baptiste de Rouville and repealing the Act to promote rural electrification by means of electricity cooperatives (1986, chapter 21), or to the Hydro-Québec electric power distribution system when carrying on electric power transmission activities, except for residential buildings connected to an independent electric power distribution system.

5. As of 31 December 2021, it is prohibited to install, or have installed, boilers, furnaces and water heaters powered in whole or in part by oil in new residential buildings.

6. As of 31 December 2023, it is prohibited to install, or have installed, boilers, furnaces and water heaters powered in whole or in part by oil in existing residential buildings.

As of that same date, it is also prohibited to install, or have installed, boilers, furnaces and water heaters powered in whole or in part by fossil fuel for the purpose of replacing appliances powered in whole or in part by oil in existing residential buildings.

7. As of 31 December 2023, it is prohibited to repair, or have repaired, boilers, furnaces and water heaters powered in whole or in part by oil in existing residential buildings in the case of

(1) boilers and furnaces installed over 20 years before; and

(2) water heaters installed over 10 years before.

For the purposes of this Regulation, "repairs" means any work done on an appliance referred to in the first paragraph in order to refurbish it, except

(1) maintenance under Annex L of the most recent version of CSA Standard B139, Installation Code for Oil-Burning Equipment, published by the CSA Group;

(2) the repair or replacement of a motor of the appliance or a mobile component activated by that motor;

(3) the repair or replacement of an electronic or electrical component related to the operation and safety controls of the appliance.

Despite subparagraph 1 of the second paragraph, the repair and replacement of an appliance's combustion chamber or heat exchanger are prohibited.

Nothing in this section prevents anyone from taking the measures necessary to stop the release of contaminants.

DIVISION III
DECLARATION

8. Any person who installs, in a residential building, a boiler, furnace or water heater powered in whole or in part by oil, or a boiler, furnace or water heater powered in whole or in part by fossil fuel for the purpose of replacing appliances powered in whole or in part by oil, must, within 30 working days after the installation, send electronically to the Minister a declaration containing

(1) their name, address and telephone number;

(2) if applicable, the number of the licence issued to them under the Building Act (chapter B-1.1);

(3) in respect of each appliance installed,

(*a*) the name, address and telephone number of the owner of the building where the appliance is located;

(*b*) the address of the building where the appliance is located;

(*c*) the date of installation;

(*d*) the type, brand and model; and

(*e*) the date of manufacture or serial number; and

(4) a description of the procedure followed when removing the tank that supplied fuel to the appliance that was replaced, if applicable.

9. Any person who replaces, in a residential building, a boiler, furnace or water heater powered in whole or in part by oil with an appliance powered by a different form of energy must, within 30 working days after the replacement, send electronically to the Minister a declaration containing

(1) their name, address and telephone number;

(2) if applicable, the number of the licence issued to them under the Building Act (chapter B-1.1);

(3) in respect of each appliance installed to replace another appliance powered in whole or in part by oil,

(*a*) the name, address and telephone number of the owner of the building where the appliance is located;

(*b*) the address of the building where the appliance is located;

(*c*) the date of installation; and

(*d*) the type and form of energy powering the appliance; and

(4) a description of the procedure followed when removing the tank that supplied fuel to the appliance that was replaced, if applicable.

DIVISION IV
PENALTIES

§I. Monetary administrative penalties

10. A monetary administrative penalty of $350 in the case of a natural person and $1,500 in other cases may be imposed on any person who fails to send to the Minister a declaration containing the information prescribed or to comply with the time or terms and conditions of transmission, in contravention of section 8 or 9.

11. A monetary administrative penalty of $1,500 in the case of a natural person and $7,500 in other cases may be imposed on any person who

(1) installs, or has installed, in a new residential building, a boiler, furnace or water heater powered in whole or in part by oil, in contravention of section 5;

(2) installs, or has installed, in an existing residential building, a boiler, furnace or water heater powered in whole or in part by fossil fuel, in contravention of section 6;

(3) repairs, or has repaired, a boiler, furnace or water heater powered in whole or in part by oil, in contravention of section 7.

§II. Penal sanctions

12. Every person who contravenes section 8 or 9 is liable to a fine of $2,000 to $100,000 in the case of a natural person or $6,000 to $600,000 in other cases.

13. Every person who contravenes section 5, 6 or 7 is liable, in the case of a natural person, to a fine of $8,000 to $500,000 or, despite article 231 of the Code of Penal Procedure (chapter C-25.1), to a maximum term of imprisonment of 18 months, or to both the fine and imprisonment, or, in other cases, to a fine of $24,000 to $3,000,000.

§III. Common provision

14. The amounts from the imposition of monetary administrative penalties and from the fines paid pursuant to this Regulation are credited to the Electrification and Climate Change Fund established under section 15.1 of the Act respecting the Ministère du Développement durable, de l'Environnement et des Parcs (chapter M-30.001).

DIVISION V
FINAL

15. This Regulation comes into force on 31 December 2021.

105355