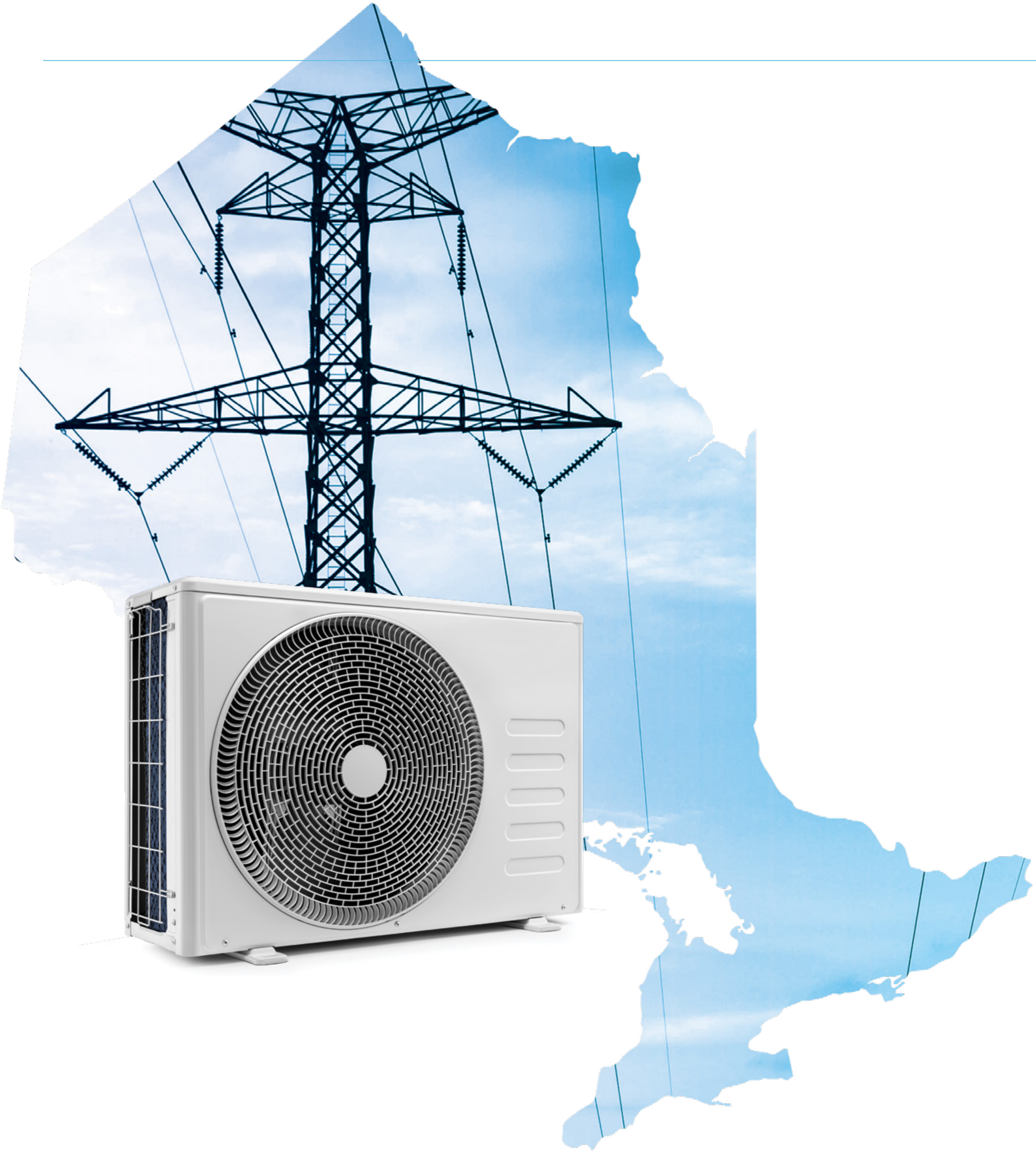
An Analysis of the Impacts of **All-Electric Heat Pumps and Peak Mitigation Technologies** on Peak Power Demand in Ontario



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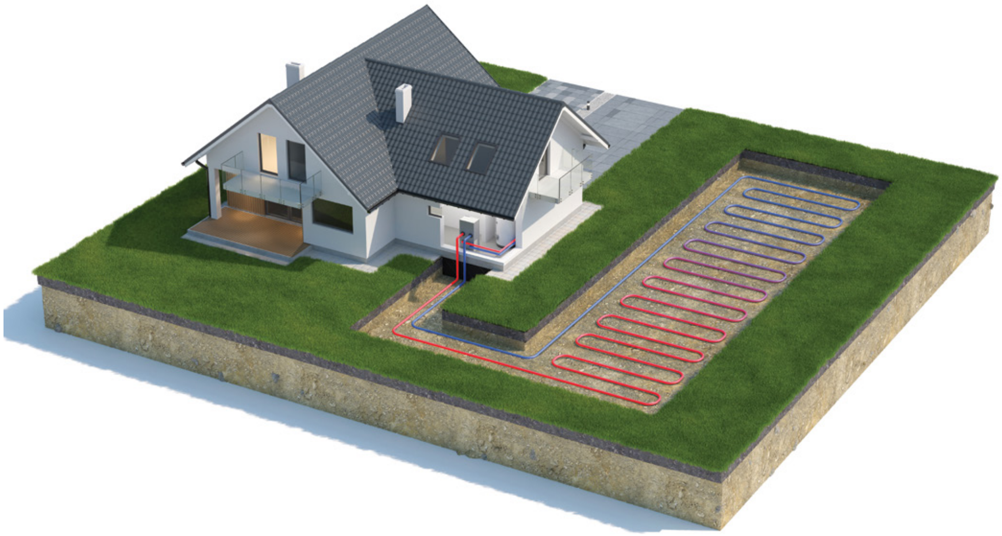
Executive Summary

All-electric heat pumps are growing in popularity across Ontario because they are incredibly efficient, they save homeowners money, they reduce carbon emissions, they can increase home comfort, and they provide both heating and cooling[1]. Concerns have been raised about the impact of electrifying home heating on power demand during winter peaks. While there is no question that Ontario must increase its power generation as all sectors of our economy electrify in line with our climate goals, this report analyzes the potential for existing technologies to reduce the peak power draws from single family homes that adopt all-electric heat pumps.

There are two key takeaways from this analysis:

1. Electric thermal storage, home batteries, EV batteries and installation of ground source heat pumps (GSHP) instead of air source heat pumps (ASHP) can all reduce the power demand from all-electric heat pumps on winter peak hours.
2. Utilities and governments should incentivize the adoption of electric thermal storage, EV bi-directional chargers and GSHPs for single family homes as these technologies can cost-effectively reduce the need for new electricity generation plus storage and associated transmission and distribution infrastructure to power heat pumps.



This report analyzes the potential for existing technologies to reduce the peak power draws from single family homes that adopt all-electric heat pumps

Background

The buildings sector, including single family home residential buildings, is the third largest source of greenhouse gases in Canada[2], and requires significant decarbonization for Canada to meet Paris Agreement goals for emissions reduction. Heat pumps are the most recommended strategy for reducing greenhouse gas emissions from the residential sector[3]. They are an integral part of nearly every municipal climate action plan, and global sales of heat pumps grew by 11% in 2022[4]. All-electric heat pumps are already more cost effective over their lifetimes than gas systems and electric resistance heaters in single family Ontario homes[5,6,7]. Heat pumps will become Ontario's dominant form of space heating and cooling, and will also be used for water heating. It is not a matter of if, it is a matter of when.

Even with significant energy efficiency measures, Ontario's electricity system must grow as our society electrifies heating for buildings, transportation and industrial processes. Ontario's Independent Electricity System Operator (IESO) and other electricity system operators are planning to add new generation and storage to accommodate this shift to electrification. Their planning is primarily based on how much power is required to meet demand on the peak days of the year. If the system has the electricity generation capacity available to meet those needs, then it can also meet all other demand.

It is important to differentiate between electricity and electric power. Electricity is measured in Watt hours (Wh) and is a measure of how much total energy is used. Electric power is the rate at which electricity is supplied and its basic unit is a Watt (W). Residential customers are charged based on how much energy (kWh) they use, but electricity system planners and operators are often concerned about the electric power demand, especially during periods of peak use (usually in giga Watts - GW).

Most heat pumps in Ontario are air source heat pumps (ASHPs). They use electrical energy to extract heat from the air and move it to where it is needed (inside in winter and outside in summer). Cold climate ASHPs that are sized for heating can achieve average heating efficiencies of up to 300% in Ontario and are more efficient than conventional ASHPs, electric resistance (baseboard) heating, and heating with oil, propane or fossil gas. Hybrid heat pumps pair an ASHP with a fossil fuel furnace that kicks in when temperatures drop below a set point. These hybrids continue reliance on fossil fuels and have associated delivery or connection fees plus carbon emissions. For this reason, all-electric heat pumps are a better option for mitigating climate change.

The buildings sector, including single family home residential buildings, is the third largest source of greenhouse gases in Canada

Because heat pumps are many times more efficient than conventional heating systems (furnaces, boilers, electric resistance heaters), the amount of total energy used to heat homes in future will be much lower once heat pumps are adopted. In other words, adoption of heat pumps is a very effective energy efficiency measure that will reduce the total energy needs of our society.

Many are concerned about the peak power draw from all-electric heat pumps, especially on cold winter days. ASHPs are less efficient on very cold days when it is harder to extract heat from the outside air and the total amount of heat that an ASHP can move also drops as temperatures fall. Heat pump efficiencies and heating capacities continue to improve but these all-electric systems may still require supplementary heat from less efficient electric resistance heating systems.

There are technologies available today that can reduce the power needed to keep an electrified home warm on cold days. Ground source heat pumps (GSHPs) extract heat from the ground and remain very efficient even when outside temperatures are very low. A report prepared for the Heating, Refrigeration and Air Conditioning Institute of Canada (HRAI), demonstrated that replacing just 10-30% of ASHPs with GSHPs can significantly reduce future total electricity generation capacity needed[8]. Furthermore, electric thermal storage can supplement an ASHP when it is charged during off peak hours and programmed to release heat during peak hours. Home batteries and electric vehicle batteries with bidirectional chargers[9] can displace an ASHP's power draw from the grid during peak hours. All these technologies allow homeowners to operate their homes without changing behaviours or comfort settings. And heat pump technology is ever improving, providing greater efficiencies at lower and lower temperatures.

This study therefore examines the total electricity and peak power demand of heat pumps in average Ontario single-family homes. The study also examines the grid impacts and utility cost effectiveness of technologies that can work alongside heat pumps to reduce peak power demand.

Adoption of heat pumps is a very effective energy efficiency measure that will reduce the total energy needs of our society

Outcomes

This report models the power draw of cold climate air source heat pumps that are sized to meet the average heating loads at the design temperatures for representative cities across Ontario[10]. The heat pump power demand was modeled at the projected outdoor temperature for these cities during the IESO's anticipated 2023/2024 winter peak hour (see **Table 1**). Detailed methodologies and assumptions can be found in the appendix to this report. The spreadsheets used in the analysis are also available on the Ontario Clean Air Alliance web site: www.CleanAirAlliance.org/Publications/.

Table 1 | Forecasted temperatures during the IESO projected 2023/2024 winter peak demand hour[11]

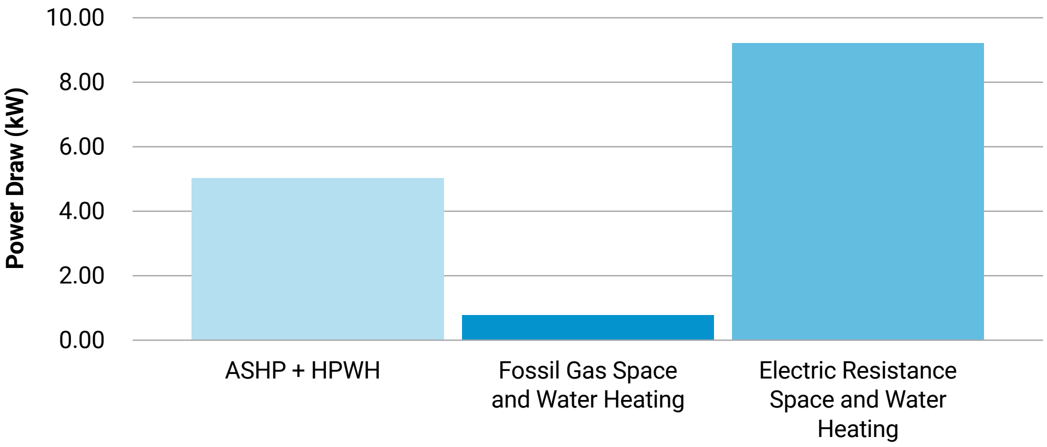
City	Temperatures
Toronto	-13.5°C
Windsor	-8.9°C
North Bay	-22.1°C
Thunder Bay	-15.9°C
Ottawa	-17.2°C
Kapuskasing	-21.1°C

Ground source heat pumps (GSHPs) extract heat from the ground and remain very efficient even when outside temperatures are very low

ASHP/HPWHs vs Conventional Heating Systems

The power demand from an ASHP paired with a heat pump water heater (HPWH) for an average Ontario single family home was modeled on the IESO projected winter peak demand hour for winter of 2023/2024 (see **Figure 1**). A population-weighted average based on projected temperatures across the province on that hour was used throughout this analysis for all of Ontario's single family homes (Toronto 66%, Ottawa 15%, Windsor 11%, North Bay and Kapuskasing 5%, Thunder Bay 2%[12]).

Figure 1 | **Power draw for three single family home heating systems during Ontario's forecasted 2023/24 winter peak electricity demand hour**



Also shown in **Figure 1** are the power draws for a gas furnace with gas water heater, and electric resistance space and water heaters. Gas furnaces and other fossil fuel furnaces use a small amount of electricity to operate the fan that distributes heat throughout the home and for safety reasons do not operate during power outages. Electric resistance heaters are far less efficient than heat pumps and draw nearly twice as much power during the winter peak.

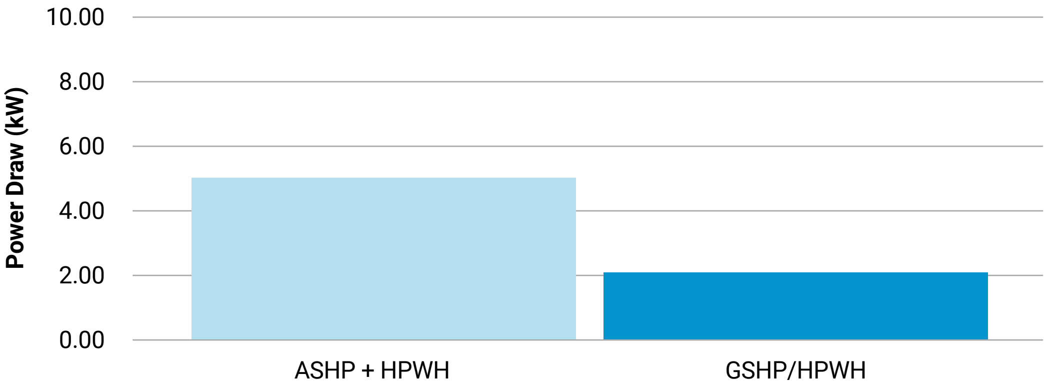
The ASHPs modeled here are designed for cold climate use. Such heat pumps are undergoing rapid advancements. Some equipment can already provide very efficient heating and high heating capacities at outside temperatures as low as -30°C. The US residential cold climate heat pump technology challenge will ensure that more manufacturers produce heat pumps with excellent heating performance at -26°C and below[13]. Increased competition, economies of scale and easier to install models are expected to reduce the upfront costs of heat pumps, making them more attractive to homeowners and accelerating their adoption.

Lower upfront costs
should accelerate the adoption of heat pumps by homeowners

ASHPs vs GSHPs

Ground source heat pumps (GSHPs) are significantly more efficient than ASHPs because they exchange heat with the ground where temperatures do not change significantly over the year. This means that they use less energy for heating and cooling than ASHPs and they also draw less power. At the projected 2023/2024 winter peak, a GSHP and HPWH will draw less than half of the power of an ASHP and HPWH as seen in **Figure 2**. In a sense, GSHPs use the ground as seasonal storage with heat absorbed from the sun and the buildings in summer made available through the winter.

Figure 2 | Power draw for different heat pump systems during Ontario's forecasted 2023/24 winter peak electricity demand hour



In this model, the GSHP included a desuperheater that uses heat from the indoor air in summer and from the ground in winter to preheat domestic hot water. A HPWH is used to provide the remainder of the home's water heating needs.

GSHPs have many advantages over ASHPs. As noted above, GSHPs have lower power demands due to their greater efficiency and this means that they will have lower power demands during summer peaks and also during extended cold snaps when batteries may lack the capacity to shift demand over multiple days. GSHPs also have longer lifespans than ASHPs and the underground loops are expected to last for 100 years or more.

GSHPs have higher upfront costs than ASHPs but because they are more efficient and have longer lifespans, they can save a homeowner thousands of dollars over their lifetimes relative to either ASHPs or gas systems[14]. Studies have shown that greater adoption of GSHPs instead of ASHPs can also save billions in Canadian grid infrastructure spending[15]. Promoting the adoption of GSHPs, especially in rural areas where lower cost horizontal ground loops can be installed, should be a priority.

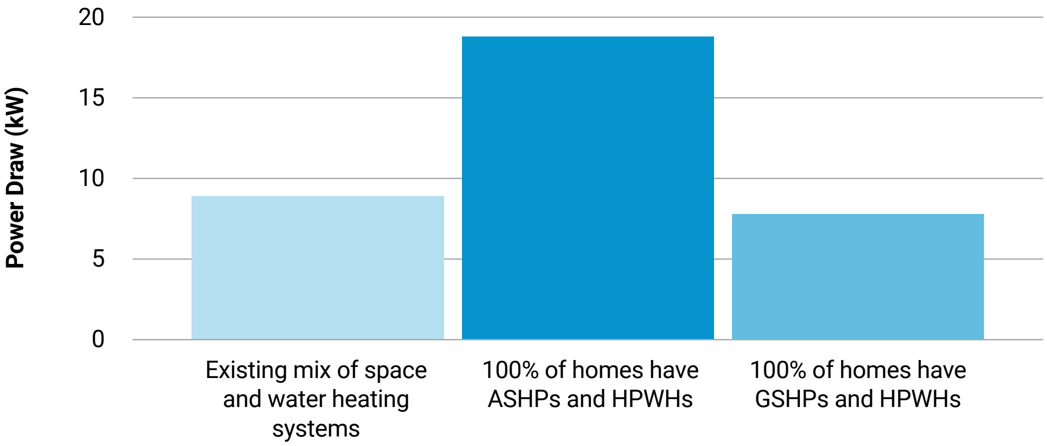
GSHPs have lower power demands and longer lifespans than ASHPs

Widespread Adoption of Heat Pumps

Figure 3 shows the forecasted total power draw from all of Ontario's single-family homes during the projected 2023/24 winter peak electricity demand hour and the projected total power draws if all of Ontario's single-family homes were to use heat pumps for space and water heating. If ASHP/HPWHs are used in all homes, the power draw would increase by nearly 10 gigawatts (GW). This represents an increase of approximately 47% over the projected total winter peak demand from all end-uses and all sectors of the Ontario economy during the 2023/24 winter peak (21.4 GW)[16]. On the other hand, with 100% adoption of GSHP/HPWHs, the total power draw for home heating would decrease slightly.

There are two reasons why this increase is not as dramatic as some might expect. Firstly, the increase in power draw arising from heat pump adoption in homes that currently use gas or other fossil fuels will be partially offset by a decrease in power draw when the 15% of homes that currently use electric resistance[17] heating switch to heat pumps. Secondly, the projected 2023/24 winter peak is not expected to occur during the coldest hour of the winter[18]. It may be some time before winter peaks occur during the coldest times when heat pumps are least efficient and may rely on backup heaters: even in 2043, the IESO projected winter peak is not during the coldest hour of the day[19].

Figure 3 | **Three scenarios for Ontario's total power draw for home heating during the forecasted 2023/24 winter peak electricity demand hour**



Single family home heating systems have lifespans of 15 to 20 years or more[20]. If all homes shift to heat pumps as their existing heating systems reach the end of life, the annual rate of heat pump adoption in Ontario would be 5.0-6.7% of the homes that currently heat with fossil fuels or electric resistance heaters. Therefore, under this scenario, all of Ontario's single-family homes would have heat pumps by 2043.

Ontario is currently a summer peaking province, and this means that there is still capacity available to support increasing adoption of electrified heating in the near term. The IESO is already planning to add extra capacity to our grid in the coming years to meet projected increases in demand from transportation, buildings,

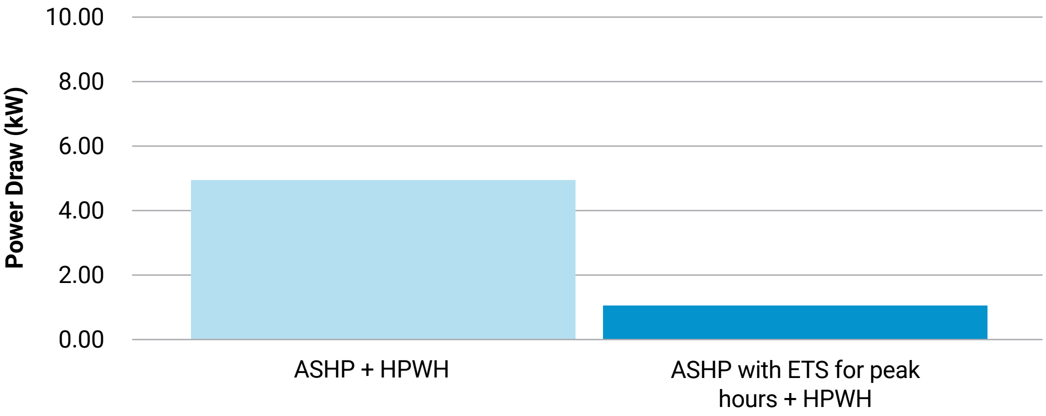
Under this scenario, all of Ontario's single-family homes would have heat pumps by
2043

industry, agriculture, and other sectors, and to replace the aging Pickering nuclear reactors that are coming to the end of their lives. The IESO does not anticipate Ontario switching from summer peaking to winter peaking until the mid-2030[21].

Electric Thermal Storage

Electric thermal storage (ETS) systems use thermal bricks, hot water, or phase change materials[22] that are charged up during off-peak hours and release their heat to the home during peak hours. This study modeled ETS systems that use thermal bricks heated with electric resistance heaters, the most common form of ETS currently available.[23] During peak hours, such as the hour modeled here, the total power draw comes from the electric circulation fan and the contribution of the HPWH. ETS systems can reduce the peak hour demand of an ASHP and HPWH by 80% (see **Figure 4**).

Figure 4 | **Power draws for a single family home's heat pumps with and without electric thermal storage during Ontario's forecasted 2023/24 peak electricity demand hour**



Electric thermal storage is a well-established technology that has been widely used in Europe[24] where energy prices are generally higher than North America, and there is growing realization of the benefits that electric thermal storage can provide to the grid. In recent years, grid operators in Quebec[25], New Brunswick[26], Prince Edward Island[27], Nova Scotia[28] and Yukon Territories[29] have all promoted or incentivized residential electric thermal storage systems.

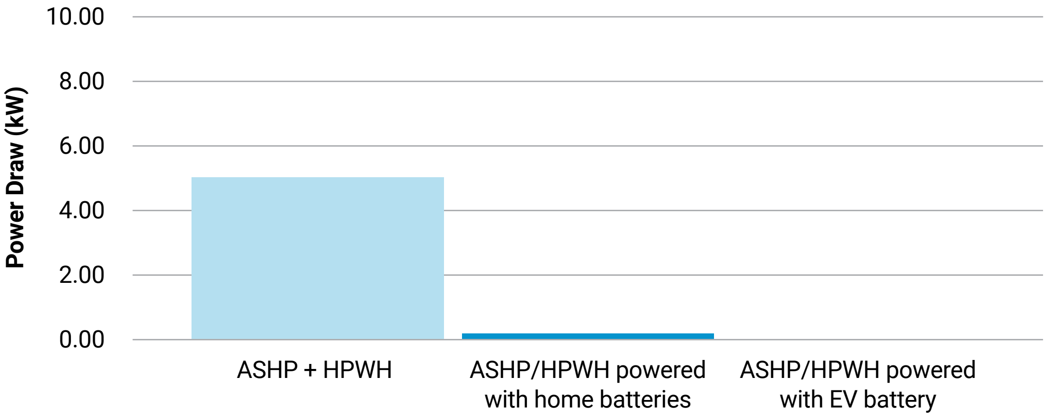
Battery Systems

Home battery systems and electric vehicle bidirectional chargers are expected to become more common as our society electrifies. These systems will allow homeowners to take advantage of time of use rates and increase their resilience to power disruptions that may become more common with climate change[30]. Annual installed home battery use in the US surged from 2.25 MWh in 2014 to 185 MWh in 2018[31] and it is expected that these systems will become more common as their prices continue to drop.

Electric thermal storage, home battery systems and electric vehicle bidirectional chargers are expected to become more common as our society electrifies

The 5 kW/13.5 kWh Tesla Powerwall battery modeled here was able to meet all of a heat pump's winter peak hour power needs for a home everywhere in Ontario except in the small number of homes in the north where heating loads are higher (see **Figure 5**). This represents an average 97% reduction in peak power draw in single family homes across Ontario. An ASHP can be fully powered by this battery system for nearly two and a half hours, which is long enough to avoid contributing to the peak hour and, when grid-integrated, can help to even out power demand across multiple homes.

Figure 5 | Power draw for a single family home's heat pumps with battery systems during Ontario's forecasted 2023/24 peak electricity demand hour



The 9.6 kW/98 kWh Ford F150 truck with bidirectional charger was able to meet all of the heat pump power needs of a home in all of Ontario during the forecasted 2023/2024 winter peak demand hour (see **Figure 5**). In other words, when a Ford F150 truck with a bidirectional charger is used, 100% of the power needs of an ASHP and HPWH can be met using the truck battery. These batteries have a maximum discharge time of 9 hours, long enough to avoid winter peak times while leaving enough charge in the truck for regular daily activities. By 2030, it is anticipated that market forces and government policies will result in over a million electric vehicles in use in Ontario[32], most of which will likely be capable of providing battery storage for homes and the grid. Smart technologies are also coming on the market that autonomously charge or discharge an EV battery in response to changes in utility rates[33].

Other Peak Mitigation Strategies

There are many strategies that can be used to reduce the power draw from heat pumps on peak demand days. It is likely that these will become more commonplace as homeowners seek to take advantage of time of use rates and other rate-based incentives. A few options have been highlighted here. As our society electrifies and more renewable energy systems are added to our grid, it is likely that further strategies will emerge to help match electricity demand to available generation.

When a Ford F150 truck with a bidirectional charger is used, 100% of the power needs of an ASHP and HPWH can be met using the truck battery

Smart technologies including grid-integrated technologies can minimize total power draw during peak hours by controlling when home appliances operate. These technologies can shift power demand to match intermittent renewable generation thereby providing valuable grid services. It is already commonplace for residential electric water heaters to have built in grid integration technologies to allow their use as virtual power plants[34], and new US standards have been set for technologies that permit grid operators to limit input power to heat pumps during critical curtailment events[35]. Ontario's Peak Perks is another program that allows homeowners to receive financial rewards when utilities adjust the thermostat during peak electricity days in summer[36].

ETS, home batteries, EV bi-directional charges and smart technologies shift electricity use rather than reducing electricity use. Capacity is therefore needed during the off-peak hours to charge these systems for use during peak hours. Ontario's current hourly demand profiles show that there is capacity to accommodate this. Aggregators that control grid-integrated technologies in multiple homes may be needed to optimize the charging and discharging of these technologies given utility needs and available capacity.

Building envelope upgrades are yet another way to reduce heat pump power draw. Average power draw decreases as the heating loads are reduced because the heating systems run for less time. When heating loads can be reduced by 15-25%, through air sealing, insulation and window upgrades, a smaller heat pump system with a lower power draw can be installed. This will also reduce total energy consumption and associated emissions while reducing homeowner energy bills and alleviating energy poverty.

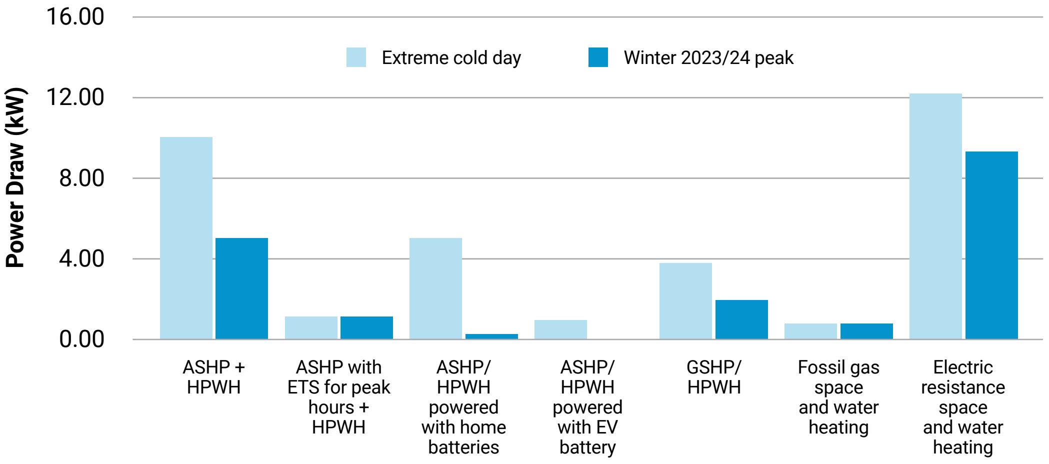
Smart technologies including grid-integrated technologies can minimize total power draw during peak hours

Sensitivity Analysis

In general, winters in Ontario are getting warmer with climate change, but we are also experiencing more extreme weather events. Extreme cold events can still occur even as the planet warms. As heating is electrified in Ontario, it is likely that annual peak days will shift from summer to winter, and they are likely to coincide with extreme cold days. We therefore modeled the power draw of heat pumps under a worst-case scenario where temperatures drop to five degrees below the local design temperature.

As **Figure 6** shows, power draw for electric heat pumps is significantly higher during an extreme cold event because of greater reliance on backup resistance heaters, especially in Northern Ontario. Homes with electric thermal storage systems and bidirectional EV batteries can maintain very low power draws even during these extreme events. Home batteries and GSHPs are also able to significantly reduce power draw at these extreme temperatures.

Figure 6 | **Power draw for single family home heating systems during Ontario's forecasted 2023/24 peak electricity demand hour**



The IESO's system planning goal is to ensure that Ontario has sufficient electricity generation capacity to meet forecasted electricity demands during normal peak demand hours (such as those modeled in Figures 1 to 5) plus a reserve margin (currently 11.8%). The reserve margin ensures that electricity is available even on extreme days (e.g. on hot summer days or extreme cold days such as Figure 6) or if unexpected power outages occur at an electricity generating station.

Total Energy Demand

Heat pumps are incredibly energy efficient because they can move many units of heat energy with a single unit of electrical energy (250-500% efficiency). Even on very cold days, most heat pumps sized and designed for cold climate heating will be more efficient than a gas furnace. On milder winter days they are far, far more efficient. This means that when heat pumps become the dominant form of heating in Ontario, significantly less energy will be needed for heating overall.

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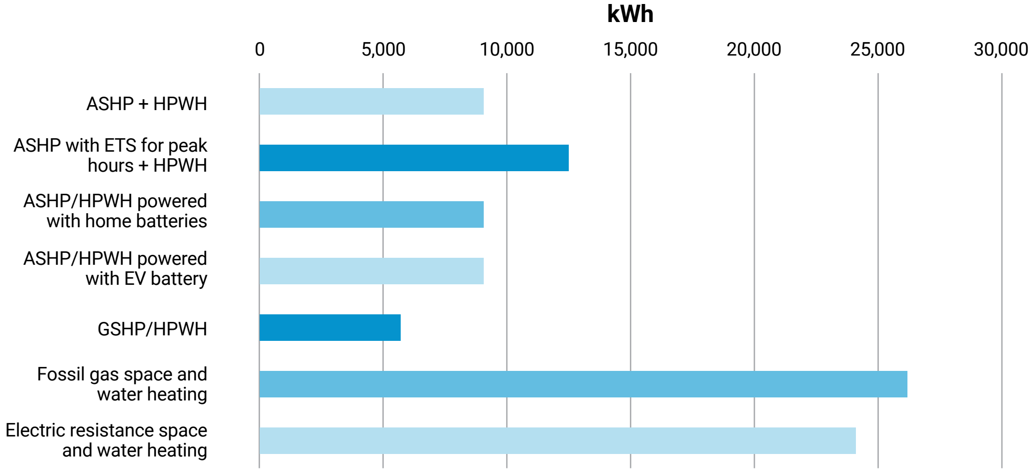
Figure 7 | **Annual energy use for space and water heating in a single family home in kWh**



The total space and water heating energy use for an average single-family home in Ontario is shown in **Figure 7** (energy from all fuels is expressed in kWh). ASHP/HPWHs use 34% and 38% of the energy of gas and electric resistance heating systems respectively. Those values drop to 24% and 26% for GSHP with a desuperheater and HPWH.

In future, total annual heating energy use for a home with heat pumps could be even lower due to efforts by manufacturers and governments to improve performance. It is anticipated that technological advancements will see average seasonal efficiencies increase by 25-50% in the coming decades[37,38], especially at very low temperatures (i.e. near -26°C)[39].

When technologies that mitigate the peak power demand are used, the total annual energy use increases slightly over the heat pump alone scenario. The electric thermal storage system modeled here is charged with less efficient electric resistance heaters at night. Batteries will also marginally increase energy use because of losses in their systems.

Cost Effectiveness of Complementary Technologies

We have compared the costs of our peak demand reduction options to the incremental cost of meeting our peak winter demands with new wind generation and storage plus the associated transmission and distribution supply-side infrastructure. Peak reduction technologies are cost-effective if they can reduce the demand for electricity at a lower cost per kW than building new electricity supply.

It currently costs Ontario approximately $600 to increase our peak winter electricity supply capacity by building an additional 1 kW of wind generation, storage, transmission and distribution capacity (see Methodology section at the end of this report). The technologies modeled here can reduce peak power draw by up to several kW.

It is anticipated that technological advancements will see average seasonal efficiencies increase by
25-50%
in the coming decades

EV batteries, ETS and GSHPs are good investments for Ontario's electricity system since their annualized capital costs of ensuring that we have sufficient peak hour capacity (see **Table 2**) are lower than the annualized capital costs of building new peak hour supply-side infrastructure ($604 per kW).

Ontario could save up to $1,996 per participating household per year by promoting the uptake of bidirectional EV chargers, ETS and GSHPs

Table 2 | Annual Financial Savings from Reducing ASHP Power Demand During Ontario Winter Peak Hour Using Available Technologies

Technology	Electric thermal storage[40]	Tesla powerwall home battery[41]	Ford F-150 bidirectional charger[42]	GSHP/HPWH
Capacity (kWh)	120	13.5	98	NA
Lifetime (yrs)	15	10	15	20[a]
Upfront cost	$10,000	$21,500	$9,950	$8,000[b]
Annualized cost	$1,030	$2,921	$1,024	$697
Maximum duration of peak reduction (hrs)	13.4	2.4	9.2	NA
During 2023/24 winter peak				
kW saved	4.0	4.9	5.0	2.9
Annualized cost per kW-year	$259	$601	$205	$241
Annual financial savings per Installation	**$1,372**	**$16**	**$1,996**	**$1,048**
During extreme cold event				
kW saved	9.0	5.0	9.3	6.1
Annualized cost per kW-year	$115	$584	$111	$114
Annual financial savings per Installation	**$4,378**	**$98**	**$4,558**	**$3,008**

[a] This is the lifespan of the GSHP mechanical equipment. The ground loop has an anticipated lifespan of 100 yrs.
[b] Incremental over ASHP/HPWH

Under the normal winter peak conditions modeled here, Ontario could save up to $1,996 per participating household per year by promoting the uptake of bidirectional EV chargers, ETS and GSHPs instead of building out new supply-side infrastructure for Ontario's electricity grid. These savings rise to a high of $4,558 if the peak day falls during an extreme cold event. These savings should be used to provide incentives for homeowners to add these technologies. Homeowners may also be able to reduce their energy bills when using these technologies with time of use or ultra-low night time electricity rates.

Further Grid Benefits of Peak Mitigation Technologies

The peak mitigating technologies described here can provide further grid benefits. These co-benefits are described below but quantifying their impacts is beyond the scope of this study.

On hot summer days, home batteries and EV bidirectional chargers can shift demand from peak to off-peak hours. ASHPs sized for heating at the design temperatures are often more efficient than the air conditioners that they replace, and this means lower summer peaks. These summer peaks can be further reduced when GSHPs are installed instead because their efficiencies do not significantly decrease as outside temperatures rise. Lower peak power draw during summer peaks also reduces the use of fossil fuel peaker plants and the associated carbon emissions.

Home batteries, bidirectional EV chargers, heat pumps water heaters and electric thermal storage systems can be grid-integrated, allowing aggregators and utilities to control their use while ensuring homeowners can use the technologies as usual while benefiting financially from the arrangement. Aggregators can help to optimize the peak power reduction potential of these technologies. Grid-integrated technologies can also be used to increase loads to avoid renewable generation curtailment thereby supporting greater use of lower cost renewable energy, or to stabilize the grid though load shedding and frequency regulation[43]. EV bidirectional chargers can even be used to provide grid frequency regulation services[44].

For a homeowner, home batteries and bidirectional EV chargers can increase resilience to power outages which may become more common with climate change. Homeowners may also receive financial compensation when they allow aggregators to share control of these technologies to provide benefits to the electricity grid.

Heat pump adoption must increase in Ontario if we are to meet our commitments under the Paris Agreement

Policy Implications

Heat pump adoption must increase in Ontario if we are to meet our commitments under the Paris Agreement. This analysis shows that there are technologies available today to cost-effectively reduce the power draws from heat pumps during winter peak hours. These technologies make it feasible to replace end of life heating systems with all-electric heat pumps in single family homes in Ontario while building out extra renewable generation capacity.

The most important policy implication of this work is that governments and utilities should invest in programs to incentivize the uptake of ETS, EV bidirectional chargers and GSHPs in single family homes. This is because it is more cost effective to incentivize the installation of these technologies than to build out the new electricity generation and associated infrastructure that would otherwise be needed.

Supporting the development of aggregators is another way to increase the uptake of ETS, home batteries and EV bidirectional chargers. Aggregators can maximize the benefits of these peak mitigation technologies and provide further grid benefits (e.g. reducing summer peaks, reducing fossil fuel-based electricity generation, reducing curtailment of renewables and grid frequency regulation), and monetize those benefits for homeowners.

Governments can also do more to encourage building owners to invest in building envelope improvements that reduce total energy costs, reduce peak power demand, improve indoor air quality, and alleviate energy poverty.

Governments can further support a low carbon transition by investing in the development and adoption of improved all-electric heat pumps and associated technologies. Strengthening the performance criteria of incentivized heat pumps will ensure reduced power demand during peak hours, improved energy efficiency, and improved cost-effectiveness of these technologies for consumers.

Finally, Ontario must invest in new, renewable power generation to meet growing demand as our society electrifies. That power generation must be zero carbon to support our climate goals, and to reduce air pollution.

Conclusions

This report demonstrates that technologies currently exist that can reduce the power draw from all-electric heat pumps on cold winter days while supporting a low carbon transition in line with the Paris Agreement. These technologies include electric thermal storage, home batteries, bidirectional chargers for electric vehicle (EV) batteries, and GSHPs installed in lieu of air source heat pumps.

Utility and government incentives should be provided for the installation of ETS, EV bidirectional charges and GSHPs because they can reduce the need for higher-cost, peaking electricity generation, storage, transmission and distribution infrastructure.

Technologies exist today to mitigate the peak power demand from all electric heat pumps. It is time to get them into Ontario homes.

Technologies exist today to mitigate the peak power demand from all electric heat pumps.

It is time

to get them into Ontario homes

Methodology

General Information

The IESO uses weather station data from six Ontario cities in predicting weather-dependent power draw in the following zones: Toronto, Windsor, Ottawa, Thunder Bay, North Bay and Kapuskasing. 2021 StatsCan data by economic region was used to assign housing to these areas. The assigning of economic regions and their percentage share of total Ontario single family housing are shown here:

Table 3 | **Percentage of Single Family Homes by City**

City	% of Single Family Housing	Zone Includes
Toronto	66%	Hamilton-Niagara, Kitchener-Waterloo-Barrie, Muskoka-Kawarthas, Stratford-Bruce Peninsula, Toronto
Windsor	11%	London, Windsor-Sarnia
Ottawa	15%	Kingston-Pembroke, Ottawa
Thunder Bay	2%	Northwest Ontario
North Bay	5%	Kapuskasing, Northeast Ontario

Heat Pump Specifications

Air source heat pump (ASHP) values for input power draw and capacity at various outdoor temperatures were collected from five major manufacturers (Daikin Comfort, Fujitsu, GE Connect, Mitsubishi Zuba, Moovair).

The heating load of the average home was defined as 36,000 BTU/hr at -20°C and extrapolated linearly from that assuming that heating was required for temperatures below +18°C (0 BTU/hr at +18°C). The air source heat pump was sized to provide the calculated heating load at the local design temperature, which can be seen in Table 3 (NRCan sizing guide option 4D). The input power draw was supplemented by electric resistance heating for use on extreme cold days.

Heat pump winter design temperatures for the modeled Ontario cities can be seen in **Table 4**. By definition, temperatures in these cities will be warmer than the design temperature 99% of the year[45].

Ground source heat pump (GSHP) operating costs and capacity for each temperature bin were collected from ClimateMaster (TE 038and TE 049 models). The heat pumps assumed horizontal ground loops and the inclusion of a desuperheater. The heating load of the average home was defined as 36,000 BTU/hr at -20°C and it was assumed that the heat pump and ground loop were sized to ensure no backup electric resistance heating was required at the local design temperature. The input power draw was supplemented by electric resistance heating for use on extreme cold days.

Table 4 | **Design Temperatures for Ontario Cities Used by the IESO for Projecting Peak Demand**

City	DesignTemperature
Toronto	-18°C
Windsor	-19°C
North Bay	-28°C
Thunder Bay	-31°C
Ottawa	-24°C
Kapuskasing	-34°C

Single Family Home Calculations

The peak power draw was calculated for outdoor temperatures in 5°C intervals between -10°C and -35°C for all sizes of heat pumps. The sizing used in the analysis is based on the heating load at the design temperature (see above). The peak power draw values were calculated for each region for each of the following conditions:

Power draw from equipment =
(average power draw) x (coincidence factor)

ASHP (from maximum power draw data by temperature bin)

- average power draw (for a given T') =
  (maximum power draw) x
  (fraction of time heat pump runs)
- fraction of time heat pump runs (for a given T' up to 100%) = $\dfrac{\text{Heating load}}{\text{Heating capacity}}$
- when heating load > heating capacity, use
  (maximum power draw) x
  (coincidence factor) +
  (heating load-heating capacity) x
  (coincidence factor)

GSHP (from operational cost data by temperature bin)

- average power draw (for a given T') = $\dfrac{\dfrac{\text{Operating cost}}{(\$/\text{kWh})}}{\text{Operating hours}}$

- when heating load > heating capacity,
  (average power draw) x (GSHP coincidence factor) +
  (heating load-heating capacity) x
  (GSHP coincidence factor)

ASHP with batteries or EV batteries =
(ASHP power draw) -
(battery discharge power); minimum 0

$$\textbf{kWh total energy use=} \quad \frac{\text{Heating load}}{\text{System efficiency}}$$

kWh water heating with GSHP + HPWH
(using desuperheater and including heating penalty
from HPWH in winter)

$$= 0.5 \times \frac{\text{Water heating load}}{\text{HPWH efficiency}} + 0.25 \times \frac{\text{Water heating load}}{\text{GSHP efficiency}}$$

kWh water heating with ASHP + HPWH
(ncluding heating penalty from HPWH in winter)

$$= \frac{\text{Water heating load}}{\text{HPWH efficiency}} + 0.5 \times \frac{\text{Water heating load}}{\text{ASHP efficiency}}$$

The weighted Ontario average single family home power draw was calculated for each of the above scenarios using the power draw for homes at each region's temperature used by the IESO for its 2023/2024 winter peak projections in the Reliability Outlook analysis[46]. In the sensitivity analysis, the weighted Ontario average single family home power draw was calculated at 5°C below the design temperature, which is intended to demonstrate power draw during a worst-case scenario. (NOTE: The IESO uses the regional temperatures on Jan 21, 1991 to project winter peak power demand. For the winter 2023/2024, the IESO uses the regional afternoon maximum temperature from Jan 21, 1991 for modeling and these are the default temperatures used for this analysis)[47].

Total space and water heating energy demand for a single-family home was calculated using NRCan's average annual heating loads[48] and an OEB report[49]. These were adjusted for heating system efficiencies (ASHP: 270%, GSHP: 370%, gas furnace: 95%, electric resistance heat: 100%, HPWH: 375%, gas water heater: 67%, electric resistance water heater: 91%). It was assumed that ETS is used for 6 hours per weekday during heating season peak hours and charged at night (78% efficiency). Stationary, and EV batteries were assumed to be discharged for 2 hours per weekday during the heating season peaks at 90% discharge efficiency[50]. For the EV battery, this can provide financial savings without depleting the battery.

Cost analysis

Table 5 shows the data and methodology used to calculate the cost of meeting 1 kW of new demand with wind energy plus storage in Ontario.

Table 5 | Ontario Electricity Grid's Cost of a Meeting a 1 kW Increase in Customer Demand During Winter Peak Demand Hour with Wind Energy and Utility-Scale Storage

Row Number	Input	Cost	Source
1	Capital Cost of Wind Energy	$1,955 per kW[51]	Clean Energy Canada
2	Annualized Capital Cost of Wind Energy	$140 per kW-Year[52]	
3	Capital Cost of 8-Hour Energy Storage	$4,810 per kW[53]	Clean Energy Canada
4	Annualized Capital Cost of 8-Hour Storage	$574 per kW-Year[54]	
5	Annualized Capital Cost of 1 kW of wind and storage capacity	$484 per kW-Year[55]	Clean Energy Canada
6	Generation Reserve Margin Adder	$57 per kW-Year[56]	North American Electric Reliability Corporation
7	Transmission Loss Adder	$15 per kW-Year[57]	IESO
8	Distribution Loss Adder	$16 per kW-Year[58]	Alectra
9	Total Annualized Capital Cost of Wind and Storage Capacity to meet 1 kW increase in customer demand [Rows: 5+6+7+8]	$573 per kW-Year	
10	Annualized Capital Cost of Additional Transmission capacity including transmission loss adder	$30 per kW-Year[59]	Dunsky Report for IESO
11	Annualized Capital Cost of Additional Distribution capacity including distribution loss adder	$1 per kW-Year[60]	Dunsky Report for IESO
12	Total Annualized Capital Cost of Meeting 1 kW increase in consumer demand [Rows: 9+10+11]	$604 per kW-Year	

The peak mitigation measures reduce Ontario's costs of meeting its electricity needs when their cost per kW to reduce our winter peak hour demands are lower than the cost of increasing our winter peak hour electricity supply capacity by a corresponding amount by building new wind generation, storage, transmission, and distribution capacity.

Adoption across Ontario analysis

The power draw for each area was calculated using the local temperatures at the time of the IESO's forecasted 2023/2024 winter peak demand hour[61], and summed together to achieve a total power draw.

Assumptions

- Ducted central system, assumes ductwork can accommodate the increased air flow
- 36,000 BTU/hr heat loss at -20°C
- Sized for heating at design temperature according to NRCan Heat Pump sizing guide, option 4D
- Indoor air temperature of 20-21°C
- Backup heater comes on once the heating load exceeds the heat pump capacity at the given temperature and only provides the heating shortfall
- Conservative coincidence factor of 100% used for ASHP, GSHP, electric resistance heating, ETS
- When modeling ASHP at -35°C or colder, assumed only backup heater was providing heat
- ASHP defrost cycles do not occur during peak demand hours
- Homes use the same fuel to heat water as they do for space heating
- Homes heated with oil, propane or other fuels are treated as though they are heated with gas
- Existing gas, heat pump and electric resistance heating systems are evenly distributed across the province
- ETS efficiency is used for 6 hours per week day over the winter season
- Stationary and EV batteries are assumed to be used for 2 hours per week day over the winter season
- Ontario only needs new infrastructure if the demand for electricity increases during the peak demand hour, not the coldest hour if it is a non-peak hour
- Internal gains assumed to be minimal for heating load calculations
- GSHP loop sized to ensure backup resistance heating is not needed
- GSHP includes desuperheater that provides 50% of the domestic hot water heating, half of which is free heat in summer
- HPWH coincidence factor is halved when paired with a GSHP to account for the fact that the GSHP provides half of the domestic hot water
- HPWH total energy use includes winter heating penalty but not summer cooling benefit

Sources

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1 https://www.cleanairalliance.org/electrifying-ontarios-gas-heated-homes-by-installing-air-source-heat-pumps/

2 https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/greenhouse-gas-emissions.html

3 Heat pumps are the top recommendation of the Intergovernmental Panel on Climate Change (IPCC), the International Energy Agency and most municipal climate action plans.

4 https://www.iea.org/data-and-statistics/charts/annual-growth-in-sales-of-heat-pumps-in-buildings-worldwide-and-in-selected-markets-2021-and-2022

5 https://www.cleanairalliance.org/electrifying-ontarios-gas-heated-homes-by-installing-air-source-heat-pumps/

6 https://www.cleanairalliance.org/the-economic-case-for-ground-source-heat-pumps/

7 https://www.cleanairalliance.org/an-analysis-of-the-potential-for-air-source-heat-pumps-to-reduce-energy-costs-and-greenhouse-gas-pollution/

8 https://www.hrai.ca/uploads/userfiles/files/Dunsky__HRAI_Benefits%20of%20GSHPs_(2020-10-30)_F.PDF

9 Bidirectional chargers can charge an electric vehicle using grid electricity and they can also use the energy stored in the electric vehicle battery to power appliances in the home or to provide power back to the grid.

10 NRCan sizing guide option 4D

11 Communications with IESO Customer Relations Dec 21, 2022

12 Ratios based on 2021 Census using economic regions

13 https://www.energy.gov/sites/default/files/2021-10/bto-cchp-tech-challenge-spec-102521.pdf

14 https://www.cleanairalliance.org/the-economic-case-for-ground-source-heat-pumps/

15 https://www.hrai.ca/uploads/userfiles/files/Dunsky__HRAI_Benefits%20of%20GSHPs_(2020-10-30)_F.PDF

16 https://www.ieso.ca/en/Sector-Participants/Planning-and-Forecasting/Reliability-Outlook

17 https://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/menus/trends/comprehensive/trends_res_on.cfm

18 The projected 2023/24 Ontario winter peak is expected at 7pm on January 31, 2024 (IESO 2022 Annual Planning Outlook) on a day that is projected to be colder in the morning.

19 The projected 2043 Ontario winter peak is expected at 9 pm on January 28, 2043 (IESO 2022 Annual Planning Outlook). In general, temperatures are at their lowest in the morning.

20 Electric resistance heaters can last longer than this, but homeowners are expected to shift to heat pumps early to realize the operational savings.

21 https://www.ieso.ca/en/Sector-Participants/Planning-and-Forecasting/Annual-Planning-Outlook

22 https://stash.energy/en/

23 These systems are charged with electric resistance elements during off-peak hours but there are systems in development that will be charged using heat from the heat pump.

24 Darby, S.J. Smart electric storage heating and potential for residential demand response. *Energy Efficiency* 11, 67–77 (2018). https://doi.org/10.1007/s12053-017-9550-3

25 https://www.hydroquebec.com/residential/energy-wise/windows-heating-air-conditioning/thermal-storage/

26 https://www.nbpower.com/media/1489367/nb_power_psa_en_outreach_report.pdf

27 https://www.princeedwardisland.ca/en/information/environment-energy-and-climate-action/energy-efficient-equipment-rebates

28 https://www.nspower.ca/your-home/energy-products/electric-thermal-storage

29 https://www.yukonconservation.ca/ets

30 https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/national-adaptation-strategy/full-strategy.html

31 https://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/how-residential-energy-storage-could-help-support-the-power-grid#/

32 https://www.oeb.ca/sites/default/files/FEIWG-Meeting3-presentation-Vehicle-to-Building%20and%20Grid.pdf

33 SolarEdge bi-directional chargers claims to respond to dynamic pricing as well as time of use: https://investors.solaredge.com/news-releases/news-release-details/intersolar-2023-solaredge-unveils-new-bi-directional-dc-coupled

34 https://guidehouseinsights.com/news-and-views/grid-interactive-water-heaters-are-important-vpp-resources

35 https://www.ahrinet.org/search-standards/ahri-1380-i-p-demand-response-through-variable-capacity-hvac-systems-residential-and-small

36 https://saveonenergy.ca/For-Your-Home/Peak-Perks

37 Jadun, Paige, Colin McMillan, Daniel Steinberg, Matteo Muratori, Laura Vimmerstedt, and Trieu Mai. 2017. Electrification Futures Study: End-Use Electric Technology Cost and Performance Projections through 2050. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-70485. https://www.nrel.gov/docs/fy18osti/70485.pdf.

38 Murphy, Caitlin, Trieu Mai, Yinong Sun, Paige Jadun, Matteo Muratori, Brent Nelson, and Ryan Jones. 2021. Electrification Futures Study: Scenarios of Power System Evolution and Infrastructure Development for the United States. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-72330. https://www.nrel.gov/docs/fy21osti/72330.pdf.

39 https://www.energy.gov/sites/default/files/2021-10/bto-cchp-tech-challenge-spec-102521.pdf

40 https://steffes.com/ets/comfort-plus-forced-air/

41 https://kubyenergy.ca/blog/complete-guide-to-tesla-powerwall-in-canada

42 The cost of the Ford F150 charger includes the charger, integration system and installation costs from https://chargers.ford.com/products/ford-charge-station-pro , not included is the price of the vehicle (suggested retail base price of $US 49,995 https://cleantechnica.com/2023/07/17/ford-f-150-lightning-price-drops-production-increasing-to-150000-year/)

43 https://rmi.org/insight/the-economics-of-electrifying-buildings/

44 https://ieeexplore.ieee.org/document/9686203

45 https://ashp-production.s3.amazonaws.com/NEEP_ccASHP+Heating+Visualization+User+Guide_v2.2_TRC_04.01.22.pdf

46 IESO Customer Relations, personal communications

47 IESO Customer Relations, personal communications

48 https://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/menus/trends/comprehensive/trends_res_on.cfm Tables 33, 16,

49 https://www.oeb.ca/sites/default/files/OEB-Natural-Gas-DSM-TRM-V5.0-20201112.pdf, see Table 1 on p31

50 https://www.tesla.com/en_ca/powerwall

51 https://cleanenergycanada.org/report/a-renewables-powerhouse/

52 According to Clean Energy Canada's Workbook, the expected economic life of new wind turbines is 31 years. We have amortized the capital cost over 31 years using a 6% cost of capital.

53 See the Workbook for Clean Energy Canada's *A Renewables Powerhouse*.

54 According to Clean Energy Canada's *Workbook*, the expected life of a new energy storage facility is 12 years. We have amortized the capital cost over 12 years using a 6% cost of capital.

55 The Clean Energy Canada report uses an energy storage to wind ratio of 60%. The combined cost is $140 per kW-Year + [$574 per kW-Year x 0.6]. Email from Evan Pivnick, Program Manager, Clean Energy Canada to Jack Gibbons, Ontario Clean Air Alliance (March 20, 2023).

56 Ontario's generation reserve margin for the winter of 2022-23 was 11.8%. The reserve margin is the amount of capacity the grid needs to have available over and above the peak demand under normal weather conditions. North American Electric Reliability Corporation, *2022-2023 Winter Reliability Assessment,* (November 2022), page 38.

57 To meet a 1 kW increase in customer demand, wind generation and storage capacity must be increased by 2.8% to account for the 2.8% energy loss in the transmission system during the winter peak. Email from Customer Relations, IESO to Jack Gibbons, Ontario Clean Air Alliance, (February 13, 2023).

58 To meet a 1 kW increase in customer demand, wind generation and storage capacity must be increased to account for the energy loss in the distribution system during the winter peak. Alectra Utilities' distribution losses during the peak winter hour are 2.92%. Email from Tom Wasik, Vice President, Asset Management, Alectra Utilities, to Jack Gibbons, Ontario Clean Air Alliance, (March 7, 2023).

59 According to a report for the IESO, the cost of new transmission capacity is $116.80 per MW-day. According to Colin Campbell of the IESO, this cost can be converted to an annual cost by multiplying it by 250 days. We have also increased the cost by 1.028 to account for the need for additional capacity to account for transmission losses. Dunsky, *Ontario's Distributed Energy Resources Potential Study*, Vol 2, (2022), page 29; and Email from Colin Campbell, IESO to Jack Gibbons, Ontario Clean Air Alliance, (January 19, 2023).

60 According to a report for the IESO, the cost of new distribution capacity is $4.46 per MW-day. According to Colin Campbell of the IESO, this cost can be converted to an annual cost by multiplying it by 250 days. We have also increased the cost by 1.0292 to account for the need for additional capacity to account for distribution losses. Dunsky, *Ontario's Distributed Energy Resources Potential Study*, Vol 2, (2022), page 29; and Email from Colin Campbell, IESO to Jack Gibbons, Ontario Clean Air Alliance, (January 19, 2023).

61 IESO Customer Relations, personal communications

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