

December 3, 2025

Infrastructure and Environment Committee
City of Toronto
100 Queen St W
Toronto, ON

Re: **IE26.3 - TransformTO Net Zero Strategy: Action Plan (2026-2030)**

Dear Mayor Chow and Members of the Infrastructure and Environment Committee,

The Boltzmann Institute (BI) is a federally incorporated Toronto- and Ottawa-based think tank committed to help eliminate harmful emissions from human energy use through research and education. Our primary focus is reducing emissions from building operations, chiefly space heating, the main source of greenhouse gas (GHG) and other emissions in many parts of Canada.

Heating buildings (and domestic hot water) causes more than 50 percent of Toronto's emissions. We are concerned that Toronto does not have a viable strategy or plan for reducing the GHG emissions from heating buildings. This poses a major risk that Toronto will badly fail to meet its GHG reduction objectives. A more viable alternative is presented below.

Reduction of building heat demand

The report from the Executive Director, Environment, Climate and Forestry, and the Chief Financial Officer and Treasurer (the staff report) being considered in the subject agenda item does not directly state, but implies that there has been little (if any) progress towards the 2021 TransformTO target of 75 percent heating demand reduction by 2040.

Extensive research in other jurisdictions has found that a realistic expectation is that retrofits can reduce the demand for heat across the complete inventory of existing buildings by only about 1 percent per year, with a long term reduction of from 10 to 20 percent. Deep reductions, exceeding 70 percent, have been achieved in only a very small fraction of buildings.

International research, supported by extensive empirical data, has thus shown that the TransformTO target of 75 percent heating demand reduction, approved by IEC and Council four years ago, is completely unrealistic. Moreover, the projected (in 2021) retrofit cost of over \$200,000 per detached home and over \$100,000 per

apartment was unaffordable and would never be recouped through reduced payments for energy.

In spite of evidence that retrofits, on average, have only a minor effect and are not cost-effective, the staff report continues to promote retrofits of existing buildings as a key measure for reducing emissions associated with buildings.

Toronto should adopt more realistic, modest expectations for heating demand reductions through building improvements, supported by evidence from international research and end-to-end affordability and cost-benefit analyses.

Two Pathways to heating decarbonization

In June 2025, BI completed a multi-year research project that compared two pathways to decarbonization of building heating:

1. **Electrification**, mostly with air-source heat pumps (ASHPs)
2. **Thermal Networks** (better known by the historical name: district heating).

This project was mostly funded, for two years, by Environment and Climate Change Canada on behalf of the [Net Zero Advisory Body](#). It included significant research contributions from a leading Canadian district energy engineering firm and the McMaster Institute for Energy Studies as well as from our own directors and members.

Measures to improve building performance and reduce the demand for heat were considered in both pathways but, as indicated above, found to be of limited (if any) value. Indeed, directing investments and efforts to thermal networks, instead of retrofits and building energy performance standards (BEPS), would be much more effective at conserving energy and reducing GHG emissions. It would also be more reliable and more equitable.

The full **Two Pathways** report, its many annexes, and a documentary video are published at <https://zenodo.org/communities/twopathways/>. The [Executive Summary](#) and an [annex](#) that specifically addresses potential implications of heating electrification on the Toronto Hydro Electric System are appended below.

1. Electrification Pathway

The study found that almost all ASHPs, installed by ordinary consumers and subject to typical maintenance over their lifetime, will require supplementary heating solutions to provide most/all heat on very cold days. (Claims that future ASHPs will be able to fully heat buildings with high efficiency at very low temperatures – e.g., –20° C – are considered wishful thinking or deceptive marketing; they defy physics

and real-world experience.) Relying on natural gas for supplementary heat will not provide a pathway to net zero GHG emissions and would be very costly to maintain for the small fraction of days it would be needed. Using electric resistance supplementary heating for most buildings would require the electric power system to have far greater capacity than can credibly be provided or afforded.

Moreover, the latest IESO Annual Planning Outlook indicates that natural gas generation will be used for both baseload and reliable peak power between now and 2040, so any incremental demand due to ASHPs will be met almost entirely by natural gas generation. The efficiency (for power delivered to consumers) of natural gas generation is about 40 percent. That means that converting from a typical natural gas furnace to an ASHP (with average efficiency of 240 percent, or seasonal COP=2.4) would reduce annual GHG emissions by only about 15 percent. (A similar GHG reduction could be achieved at much lower cost by replacing the furnace with a new very high efficiency gas furnace.) This was confirmed by detailed simulations of the Ontario power system and typical hourly heat demand.

The above results lead to the conclusion that converting natural gas heating to ASHPs, in Toronto, between now and 2040:

- would not significantly reduce GHG emissions
- would impose power system costs (generation, transmission, and distribution) that are commonly ignored, including in TransformTO reports, but that are likely to be at least four times the building owners' costs to install ASHPs
- would, if done at a scale that effectively eliminates natural gas heating, result in a doubling or more of consumers' real cost of energy, including of electricity used for non-heating purposes.

Instead of advocating the installation of ASHPs, Toronto should change its strategy and pursue aggressive implementation and conversion of heating to thermal networks for almost all existing and new buildings across the city. See what follows.

2. Thermal Networks Pathway

Other countries and cities with cold climates, notably in Europe, China, and the former Soviet Union, employ thermal networks at-scale for heating buildings. In Copenhagen, 98 percent of buildings are connected to modern, efficient thermal networks; the supplied hot water is heated almost entirely without use of fossil fuels. Comparable figures for Helsinki and Stockholm are 93% and 90%. To achieve net-zero GHG emissions, they have been and are converting heat sources from fossil fuels to biomass, municipal solid waste, nuclear, solar, geothermal, and a multitude of waste heat sources – most notably the heat from combined heat and

power (CHP) electricity generating stations and, more recently, AI data centres. The technology is mature, reliable, flexible, and efficient.

Large-scale thermal energy storage (TES) – water in tanks, pits, or caverns; aquifers and boreholes – are used to save heat that is not immediately needed for use hours, days, months, or even years later. Large-scale battery storage of electricity, by comparison, is at least 100 times more expensive per energy unit and is only viable for periods less than a day.

Like other infrastructure – electricity, gas, water, sewers, telecom – thermal networks are capital intensive; but the operating costs are low and the system lifetime exceeds 50 years. When all costs are included, including the cost of capital, thermal networks could heat almost all existing and new buildings in areas presently served by natural gas at less than one half (perhaps one third) the cost of ASHPs. For Toronto, that would be hundreds of \$billions of savings!

We will not dwell on how this conversion could be funded except to point out that it involves establishing a new utility of the kind that can be extremely attractive to patient public- and private-sector investors. Chapter 9 of our *Two Pathways* report discusses in some detail how Toronto, within current Ontario legislation, could go about raising the billions of dollars that could be needed to establish the required thermal network(s) that would be jointly owned by the municipality and one or more funding entities.

Converting Toronto from natural gas heating to thermal networks would be comparable to the conversion, 60 years ago, from fuel oil to natural gas. It could take 20 years, which would give time for progressive development of a network that connects to diverse, zero carbon heat sources and incorporates large-scale TES to allow year-round heat collection for use primarily in cold weather. Almost all buildings would be connected and their heating systems converted – just as gas lines and furnaces replaced oil furnaces and fuel delivery by truck.

While the staff report discusses thermal networks in several places, in Section 3.6, LENZ Modelling, it notes “Actions that are programmatic or exploratory (e.g., “**develop plans for low-carbon energy networks**”, “promote community engagement”, “grow green industries”) cannot be assessed in LENZ without specific, numerical targets or implementation assumptions.” [Emphasis added]

Failure to include assumptions regarding thermal networks as part of the modeling thus resulted in failure to recognize the great potential of thermal networks to solve the problem of decarbonizing building heating.

Ground-source Heat Pumps

While the Two Pathways project found that ASHPs are not a good option for decarbonizing building heating due to the excessive electric power required on very cold days, ground-source heat pumps (GSHPs) maintain a high coefficient of performance (COP) even in very cold weather; they require only about one quarter of the peak power when compared to ASHPs with electric resistance supplementary heat.

In recent years, many large buildings, including MURBs, in Toronto have been built with geexchange heating systems, which are essentially very large GSHP systems. Those systems can be a good long-term solution provided there is an annual balance of heat being extracted from the ground in cold weather and returned to the ground in warm weather. There is unfortunate experience of such systems eventually failing in Toronto due to lack of such balance. While GSHPs could be installed for detached homes and other small buildings, that is generally not done due to the need for adequate space and the high cost to drill boreholes.

The Two Pathways project found that GSHPs would be the preferred alternative to ASHPs in locations where thermal networks are not viable due to inadequate heat demand density. That might be the case for certain low density parts of Toronto. However, it is most likely that thermal networks would be viable and the most feasible and cost-effective means of decarbonizing building heating throughout Toronto.

Heating Planning

As part of the Two Pathways project, BI organized a one-day conference on Heating Planning. Five City of Toronto employees registered for the conference. A report on the conference, presentations, and other materials are available at <https://bi-ib.ca/events/>.

The focus of the conference was on heating because heating is a far greater cause of GHG emissions in Toronto when compared to cooling. However, it is natural to develop integrated heating and cooling plans since heat harvested from cooling in warm weather can be stored and then used for heating in cold weather.

The EU [Energy Efficiency Directive](#) mandates that cities over 45,000 residents must create local plans to decarbonize heating and cooling. The scope of such plans was discussed at the Heating Planning conference and in the presentations by German colleagues. The cost of developing such a plan is on the order of \$10 per resident.

We strongly encourage Toronto to undertake development of a heating and cooling plan with support from experts who have developed the expertise and tools to do this for European municipalities.

Sincerely,



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What We'll See Down

Two Pathways

To Zero Emissions From Buildings

Executive Summary

Summarized here are the purpose, key findings, and conclusions of a two-year project with the above title. The full Two Pathways report, its annexes, and a documentary video on the project can be viewed/downloaded at <https://zenodo.org/communities/twopathways/>.

Buildings are responsible for about 18% of Canada's greenhouse gas (GHG) emissions; in Toronto it's over 50%. Fossil fuel consumption by at-building equipment, for space and water heating, causes most of those emissions. Reliable, affordable heating of buildings is of critical importance for society and the economy.

The energy and power required to heat buildings in Ontario,¹ when compared to electricity, demonstrate the magnitude and nature of the heating challenge:

- The thermal energy used annually to heat buildings is comparable to the total electrical energy used for all purposes.
- The peak thermal power demand is 4 to 5 times the annual average thermal demand. For electricity, the ratio is about 1.6.
- The peak thermal power, to heat buildings (not including water heating) on the coldest days, is almost 3 times the (summertime) peak electrical power, and about 10 times the peak electrical power demand for air conditioning.

An even bigger challenge is to continue providing adequate, timely heat for buildings while transitioning, by 2050, to ways of heating buildings that do not produce GHG emissions.

Purpose

The Two Pathways study analyzes and compares two prominent approaches, or pathways, to decarbonization of (almost) all building heating by 2050:

- **Electrification:** using at-building equipment, primarily heat pumps, with the expectation that electricity utilities will supply adequate reliable power

1 For practical reasons this study has focused on Ontario, but the findings should be applicable across most of Canada.

- **Thermal Networks:** supplying heat to buildings, via heated water distributed through a network of insulated, shallow-buried pipes, as a centrally managed, reliable service—also known as district heating or district energy.

In these pathways, the electricity and heat must, by 2050, be from (nearly) zero emissions sources. The potential for building envelope improvements to reduce the demand for heat is considered in both pathways. The Two Pathways report provides an objective assessment of each pathway supported by wide-ranging research, data, and analysis.

Key Findings

Building retrofits are unlikely to significantly reduce total heat demand:

- Evidence from Canada and elsewhere indicates that envelope improvements to existing buildings should be expected to achieve average reductions of thermal energy demand in the range 10 to 20 percent by 2050—compared to optimistic claims as high as 75%. Those reductions might be mostly offset by demand created by new and replacement buildings.
- Efforts to further reduce heat demand may be counter-productive due to: (i) increased embodied emissions; (ii) excessive costs; and (iii) diversion of effort and resources from more efficient opportunities to capture and use the vast amount of existing useful heat, from centralized and distributed sources, that is otherwise lost to the environment.

Following the electrification pathway to decarbonize heating of most/all Ontario buildings would be unaffordable and essentially unworkable:

- The power demands for electrification with air-source heat pumps (ASHPs) are illustrated in Figure 5.5 of the Two Pathways report, reproduced on the next page. To meet the heating demand, the existing power system—generation, transmission, and distribution—would need massive expansion not contemplated in any current plans.
- Electricity infrastructure upgrades and expansion to provide reliable, net-zero power for ASHPs, with electric resistance back-up,² would cost ten times more than the building owners' investments to install ASHPs. Early adopters—owners of the first few percent of buildings converted from natural gas to ASHPs—receive almost 90% hidden electricity subsidies from the millions of other electricity customers. The cost of producing electricity for ASHPs will grow in proportion to the number installed and, with current rate structures, so will the hidden subsidy paid by every customer for every kWh they use. The electricity infrastructure costs are dominant, and should be included in electrification pathway economic analysis, as was done in this study.

2 Evidence and analysis do not support suggestions that zero-emissions gases could provide affordable back-up heating for most buildings.

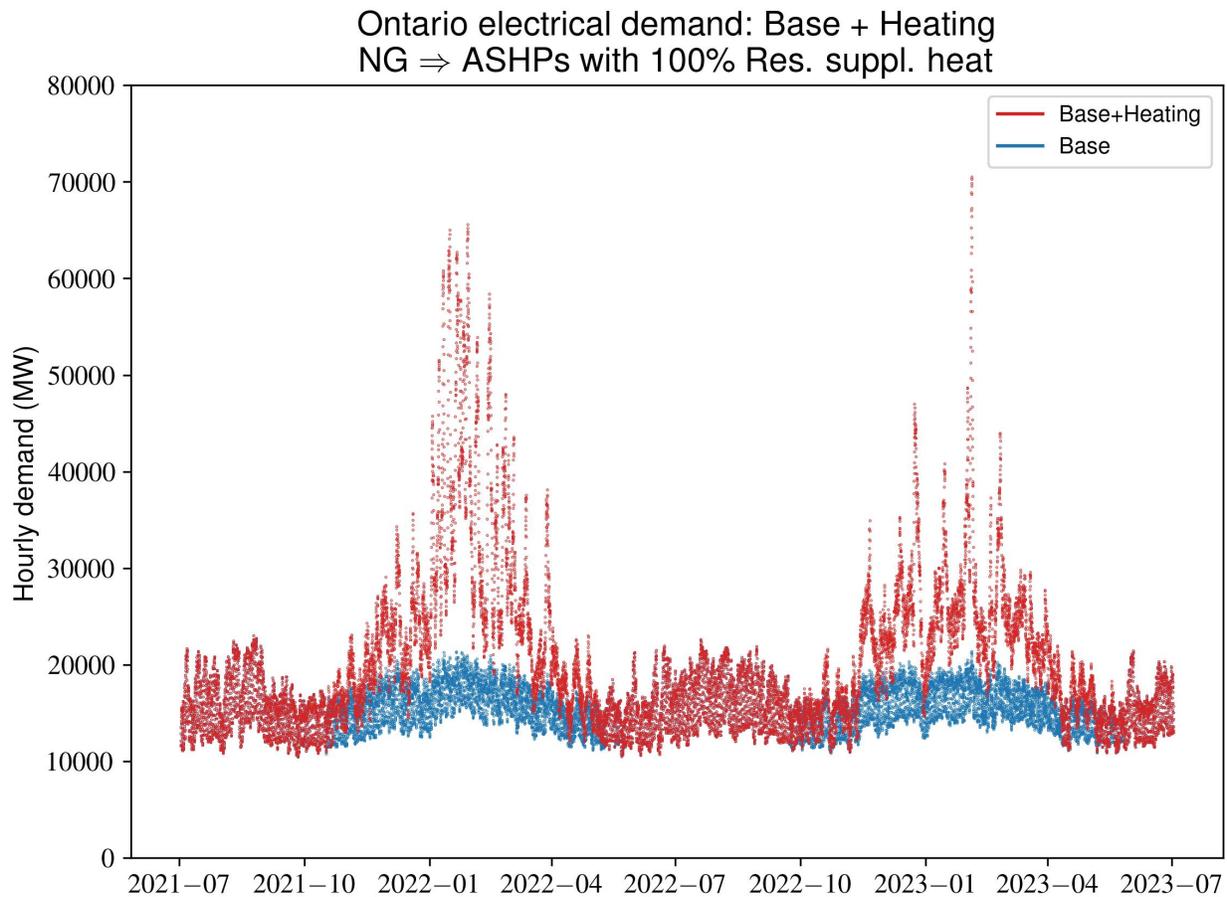


Figure 5.5. Actual (Base) hourly Ontario power demand (blue) and what the demand might have been if all natural gas heating had been converted to ASHPs with electric resistance supplementary heating (red). The overall magnitude of the heating demand is uncertain to $\pm 25\%$; the hourly fluctuations are much less uncertain.

- Wholesale electrification of heating, mostly with ASHPs, would dramatically lower the utilization of the electric power system.³ To cover costs, dominated by capital investments to meet peak demand, future electricity rates would need to rise well above the inflation rate.
- Electrification of heating, using an optimum mix of various zero-emission generation technologies, would result in more heat (produced at thermal power stations) being wasted than is currently produced by burning natural gas for all space and water heating.
- Building envelope improvements are unlikely to yield a major reduction of the cost of heating decarbonization via the electrification pathway. Inexpensive building envelope improvement measures (such as air sealing) are most likely to be worthwhile. Inadequate research, including real-world field studies, has been conducted to determine the likely uptake and net benefits, if any, of more ambitious envelope improvements.

³ Utilization means annual *mean load* as a percentage of the *peak load* during the same year.

- With Ontario's existing and planned use of natural gas for electricity generation, heating electrification with ASHP's will, until at least 2040, only reduce total GHG emissions by a small percentage relative to existing natural gas heating.
- Heating electrification with ground-source heat pumps (GSHPs) will be a good solution in low density, mostly rural, areas where thermal networks are not viable (~30% of buildings) and there is space for installation of ground heat exchangers. Despite the higher installation cost of GSHPs, because they add much less to the power system peak demand they impose significantly lower total societal cost when compared to ASHPs.

Following the thermal networks pathway should be both feasible and affordable for decarbonized heating of up to ~70% of Ontario's buildings:

- Thermal networks should be economically viable in most areas where natural gas service is available, and in other areas of comparable population/heat demand density. This includes detached homes, other existing buildings, and some compact small settlements and Indigenous communities.
- Thermal networks may use GHG emitting heat sources when first implemented but be converted in subsequent years, by their operators, to non-emitting sources with no service impacts or need for customer involvement.
- A great variety of affordable net-zero heat sources for thermal networks are, or can be made, available. For example: heat can be harvested from sewers, cooling systems and other community sources; about 200 km² of solar thermal collectors could provide sufficient heat for thermal networks to replace all Ontario natural gas heating; new/refurbished nuclear power plants configured for combined heat and power (CHP) could provide more heat than is needed for all Ontario buildings—energy efficiency would more than double. Providing both heat for buildings and electricity, with zero emissions, should increase the societal value and public acceptance of nuclear energy.
- Thermal energy storage (TES), at about 1% of the cost of battery electric storage, provides game-changing benefits. Multiple configurations and different scales of water- and ground-based TES can store heat for hours to years. Strategic TES deployment across a thermal network could achieve the energy capacity and charge/discharge rates needed to collect heat when available and ensure reliable heat supply to buildings when needed. Heat available year-round (such as from power generation and industry) or mainly during the summer (like solar thermal collectors and rejected heat from cooling systems) can be stored for use in the winter.
- Like electric power, water, sewage, communications, roads, and public transit systems, thermal networks are capital intensive infrastructure. The cost of implementing decarbonized heating for 70% of Ontario's buildings via the thermal networks pathway, using current technology and methodology, is estimated to be about half the cost of electrification with ASHPs. Careful planning and design optimization, greater use of TES, stra-

tegic integration of initially separate thermal networks, and use of heat from nuclear power plants configured for CHP will all help to lower consumers' energy costs.

- As is the case for electricity and water, thermal networks should have monopoly status within their specified service areas. Government policy could help motivate conversion from natural gas; with suitable motivation, connection should become the default within a short period after thermal network service becomes available in a community. Conversion and maintenance costs can be integrated into monthly rates to ensure equitable treatment and allow for better management by building owners of any financial impacts.
- With thermal networks, energy efficiency improvements through recovery, storage, and use of existing heat could often be more cost effective than investment of similar funds to improve building envelopes. This applies to existing and new buildings; strategic optimization could decrease costs and construction times for new buildings.

Transition to decarbonized heating will require strategic planning, investment in capability and capacity, and use of ASHPs sized for cooling until thermal networks can be established:

- Large-scale deployment of thermal networks, as is done in many other cold-climate countries, could be the only viable way to decarbonize heating for most Ontario buildings currently using natural gas. But thermal networks at the required scale will be a new category of critical infrastructure for which greater capability, capacity (industrial, workforce, R&D, etc.), and careful planning are required. Major government policy commitment and financial support will be needed, commensurate with the need to efficiently and reliably supply thermal energy comparable in magnitude to the energy delivered by the electric power infrastructure.
- Strategic planning should include sector coupling such as, but not limited to, coupling of electricity and heat sectors through CHP plants. With careful planning and design, sector coupling can improve the overall efficiency, reliability, resilience, economics, and environmental impact of the essential services delivered to society.
- Plans should ensure that near-term actions are consistent with expected long-term solutions, while avoiding actions with unwanted long-term implications, no realistic payback, or high risk of failure to achieve objectives.
- In low density areas where thermal networks will not be viable, heating should be electrified with a strong preference for GSHPs. This applies to both the electrification and thermal networks pathways. Installation of ASHPs and/or electric resistance elements sized for heating in cold weather would impose greater societal cost due to the significant grid upgrades required to meet their power demands at very low temperatures.
- To achieve full heating decarbonization by 2050, thermal networks should be planned and implemented as rapidly as possible in areas where they are deemed viable. A staged implementation approach would allow early projects to be used for demonstrations and learning opportunities.

- Since both planning and implementation of thermal networks will take years, building owners who need to replace existing air conditioning equipment could be encouraged to replace it with ASHPs sized to match the cooling load. Those ASHPs should provide adequate heating at temperatures above about +4 C, but be switched off in favour of existing heating equipment at lower temperatures. Such ASHPs will yield modest GHG reductions without increasing the peak demand on the power system. In the near term, until either a thermal network or other long-term solution becomes available, existing gas-fired heating equipment that reaches end of life could be replaced with new, higher-efficiency gas heating equipment, again achieving modest GHG reductions without increasing power system peak demand.
- As thermal networks become available, the greatest benefit will be achieved if buildings connect to them promptly for space and water heating, and for cooling if offered as a service. (If not available from the thermal network, then use of existing electric-powered cooling would continue.) Slow migration of buildings to the thermal network service(s) would delay decarbonization and create a situation akin to some buildings connecting to a newly installed municipal sewer system while others on the same street continue using septic fields.

Transformation to decarbonized heating will impact the lives of virtually every Canadian—and will have important repercussions for a wide range of stakeholders:

- The electrification pathway, with ASHPs for up to 70% of buildings, would require electric power system investment and development with unprecedented (in Ontario) scale, scope, and complexity and significant inflationary and fiscal impacts. Having reliable means to recover from prolonged power outages on very cold days would be a formidable challenge, possibly requiring central control over most individual heating systems.
- The thermal networks pathway would cost about half as much as the electrification pathway, with greater certainty of capacity matching demand. Buildings served by thermal networks could disconnect from natural gas service; heating reliability would remain at a similar level while risks of explosion, fire, and poisoning would be eliminated.
- Thermal networks would entail corresponding new expertise, jobs, innovation, and industrial development, and potential for international business development. The skills of many workers in the oil, gas, and underground infrastructure industries would make them well suited for redeployment to work on thermal networks. The elimination of at-building gas heating equipment will affect the HVAC industry, but many roles should be transferable to thermal networks and at-building heat transfer systems.
- The strategic leadership, expertise, planning, and resources needed to succeed with the contemplated transformational changes are daunting. But there are opportunities for major positive impacts on the national and provincial economies, including on growth, investment, productivity, employment, incomes, and new industries as well as important

benefits for life safety, health, wellness, social equity, national energy security, and the environment.

The legal and regulatory framework, strategic planning, and organizational and financing approaches to thermal networks warrant attention by all levels of government:

- The Two Pathways report provides an overview of the legal and regulatory framework within which thermal networks can be developed and maintained in Ontario, and how they can be financed. The federal context is briefly considered, but most focus is on provincial (Ontario) legislation, which constrains (or not) how municipalities can drive the local implementation of and transition to thermal networks. Ideally, an integrated strategic and regulatory approach to energy would treat thermal energy on par with electricity. Electricity planning and financing are mostly driven provincially.
- Since thermal networks will generally be implemented within the higher density areas of municipalities, it is natural that municipalities should lead. The only major barrier is financing (apart from willingness to act). Public-sector funding, while helpful, would likely be inadequate. Sufficient private-sector investment appears to be available, but needs government support to de-risk and work to secure (e.g., through requests for expressions of interest).
- Ontario and its municipalities could have stronger roles in planning for the use of thermal energy in buildings, and in implementing the plans, thereby facilitating attainment of net-zero objectives. The provincial government could support thermal energy planning by ensuring that municipalities have adequate resources and can access the data they require. Both federal and provincial governments could facilitate public/private financing and short- and long-term ownership models for thermal networks.
- Thermal energy planning entails: (i) detailed assessment of the average and peak demand for heat with fine geographic resolution within a district, (ii) inventory and characterization of potential heat sources (or ways to produce heat) and options to store and/or supply that heat, and (iii) analysis, simulation, and multi-factor optimization to devise a staged transition plan to achieve reliable, affordable, decarbonized heating for all buildings. Such planning, including consideration of sector coupling, should be recognized as a prerequisite for efficient, large-scale decarbonization. Plans would identify the required investments (including for electric power and thermal networks) and integration/coordination with electric power and/or other infrastructure.

Thermal networks can be a good alternative to fossil fuels for heating decarbonization in some Indigenous and remote communities that lack reliable grid connections with adequate capacity:

- Remote and Indigenous communities are very varied in size, density, building types and available energy options. The Two Pathways report discusses two communities.
- Oujé-Bougoumou Cree Nation (OBCN), which has operated a district heating system since 1992, is a source of many lessons learned and opportunities for improvement.

Given that Indigenous communities are very variable in density, building type and condition, and in the availability of skills and local energy source options, the analysis of the OBCN based example included a sensitivity analysis of the effect of i) building density, ii) the cost of competing fuels, and iii) the cost of biomass fuel options.

- Bingwi Neyaashi Anishinaabek (BNA), also known as Sand Point First Nation, is just starting the process to implement a thermal network. With negotiations for financing underway, it is still a useful example of the value of the biomass district heating option for northern and remote communities.
- Except for the smallest communities, Seasonal Thermal Energy Storage (STES) is emerging as an important, potentially game-changing technology. The winter peak heating loads are very high but of short duration. At a certain scale, when surplus heat production is available, including heat from solar panels during summer months or heat from diesel generators that is not needed when heat loads are low, large-scale STES units can store heat for months to meet peak demands. STES could displace oil boilers that might normally be used for the peak heating months and the installed heating capacity could be reduced.

The electrification pathway involves high peak power demands that could pose major capacity challenges for electricity local distribution companies (LDCs):

- The Two Pathways project produced custom reports for individual LDCs that collectively serve almost all of Ontario. The reports illustrate where thermal networks and GSHPs might be viable and show the hourly demand that might result if ASHPs were used instead of thermal networks.
- In LDCs that serve mostly urban areas, thermal networks could be viable for 80% to almost 100% of buildings. If, instead of using thermal networks in those LDCs, heating were to be electrified with ASHPs then the peak power demand could increase by factors of 3 to 5. Increasing the capacity of an LDC's entire distribution system to meet such increased peak demand would be extremely costly and difficult to achieve by 2050
- LDCs that serve mostly rural areas (where the modeling has most buildings heated with GSHPs) should expect their winter peaks to rise above summer peaks, but the need for capacity upgrades would be relatively minor. Use of ASHPs instead of GSHPs could triple the winter peak demands for heating.

Conclusions

It will be neither feasible nor affordable to supply the peak electric power needed to decarbonize building heating across Ontario using at-building heat pumps (with GSHPs where viable and ASHPs elsewhere). On the coldest days, the additional power needed just for ASHPs would be 2 to 3 times the current power system capacity. Research evidence indicates that, when reason-

ably expected technology improvements, building retrofits, and energy storage are all considered, the peak power demand for heating will not likely decrease by more than 20%.

For buildings in low density areas where thermal networks will not be viable, electrification of heating with GSHPs will be the most sensible decarbonization option when all factors are considered. Unlike ASHPs, whose performance depends on the outdoor temperature, the performance of GSHPs depends on the nearly-constant temperature of the ground from which they draw heat. Consequently, the peak power needed for GSHPs should be only about one third of the peak power needed for ASHPs. However, GSHPs that use borehole heat exchangers can suffer serious performance degradation, over a period of years, due to progressive cooling of the ground if more heat is extracted from the ground, for heating, than is restored when operated for cooling. To avoid such performance degradation, at-building solar thermal collectors are often installed to add heat to the system and maintain annual balance.

Deploying thermal networks, which would necessarily include large-scale seasonal thermal energy storage, should be viable, cost-effective, reliable, and equitable for about 70% of Ontario buildings. This includes buildings that currently have natural gas service and other significant clusters of buildings (e.g., towns, Indigenous communities) with comparably high heat demand density.

Significant effort and investment is needed, at federal, provincial and municipal levels, to develop the capability and capacity to plan, implement, and maintain decarbonized heating for all buildings. This will include increased investment in research, development, innovation and demonstrations, and it will include multi-factor optimization with consideration of many different options and stakeholder criteria.

A reasonable ambition would be to develop capability and capacity in the thermal energy sector comparable to what exists in the electric power sector, since the magnitude of energy delivered will be similar. The areas of capability and capacity are not only technical and industrial, but must also cover the diverse interests of many stakeholder groups, the coupling of heating (and cooling) with electricity and other sectors, and social, environmental, legal, regulatory, financial, organizational, human and other resources, and other aspects.

While the focus on the feasibility of thermal networks is often on financial aspects, governments should recognize that their major contribution includes setting a policy and regulatory or programs environment that significantly reduces perceived risk for investors; both public and private. The financial margins for thermal network systems are typically utility level returns and government action to minimize risk investment has proven critical in countries where thermal networks have become well established.

WHAT WE'LL SEE DOWN

TWO PATHWAYS

TO ZERO EMISSIONS FROM BUILDINGS

Annex for LDC:

Toronto Hydro-Electric System Limited

June 2025



To support the mandate of Canada's Net-Zero Advisory Body related to research, this project was undertaken with the financial support of the Government of Canada. Funding was provided through the Environmental Damages Fund's Climate Action and Awareness Fund, administered by Environment and Climate Change Canada.



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This report is an Annex to the main Two Pathways report:

“What We’ll See Down Two Pathways to Zero Emissions from Buildings”

The Boltzmann Institute, 2025.

doi : [10.5281/zenodo.15547372](https://doi.org/10.5281/zenodo.15547372)

1. Introduction

The Boltzmann Institute (BI), in the project “What We’ll See Down Two Pathways” (Two Pathways), has considered, compared, and made recommendations regarding two different approaches, or pathways, to (almost) eliminate GHG emissions from heating of buildings, at-scale, in communities – large and small, urban, suburban, rural and Indigenous – across Canada. For practical reasons, including data availability, most of the detailed analysis was focused on Ontario.

This Annex to the main report for the Two Pathways project presents findings and implications that are specifically relevant to the electricity local distribution company Toronto Hydro-Electric System Limited (LDC). Similar Annexes are available for 55 Ontario LDCs for which adequate data could be obtained. The Annexes are deliberately concise; full understanding of the content and implications of this Annex will depend on reading (much of) the main report, some of its references, and perhaps other Annexes (not specific to LDCs).

The information, specific to the LDC, presented here provides perspective on:

- the electrical demand that could result from electrification of building heating with air-source heat pumps (ASHP) and / or ground-source heat pumps (GSHP)
- the potential to reduce electrical demand for heating and reduce costs by implementing thermal networks (TNs) in high density areas and favouring GSHPs over ASHPs in low density areas.

The following Sections present LDC-specific data, plots, and explanations regarding:

- dwellings
- customers
- population and population density
- electrical demand by residential customers
- annual energy and peak power delivered by the LDC
- weather-related heating demand
- modeled electric power demand if heating were to be electrified.

The final Section provides discussion regarding interpretation, implications and use of the above.

2. Dwellings

Dwellings data for the LDC, derived from the 2021 Census, is shown in Table 1. Numbers were derived at the geographic level of Dissemination Blocks (DB) or postal Forward Sortation Areas (FSA) within the LDC geographic boundary published by the OEB.¹ The census divided Ontario into 137,867 DBs, with an average of 103 people per DB. There were 566, much larger, FSAs. LDC boundaries sometimes cross through an FSA, in which case the numbers shown include the total number in the FSA times the fraction of the FSA area that lies within the LDC; this can result in a minor discrepancy between the DB-level and FSA-level numbers at the LDC level due to nonuniform distribution across the FSA.²

¹ An FSA corresponds to the first three characters of a postal code.

² Statistics Canada derives FSA geometry from claimed postal codes on census responses. Because mailing

Table 1³

Dwelling type	Number	Geographic Level
Private dwellings - total	1252637	DB
Private dwellings - occupied by usual residents	1160347	DB
Occupied private dwellings - total	1160875	FSA
Single-detached houses	270470	FSA
Semi-detached houses	71915	FSA
Row-houses	62910	FSA
Apartments in a flat or duplex	47820	FSA
Apartments buildings with fewer than 5 storeys	162265	FSA
Apartments in buildings with 5 or more storeys	542595	FSA
Other single-attached houses	2770	FSA
Movable dwellings	75	FSA

3. Customers

Table 2 shows 2021 LDC customer counts in different rate classes from the Ontario Energy Board (OEB), and also the mean number of Residential customers in 2021 derived from FSA-level smart meter data published by the IESO.⁴

Table 2

Rate Class	Customers	Source
Residential (smart meters) –2021 mean	694337	IESO
Residential	702792	OEB
Seasonal	0	OEB
General Service < 50 kW	72672	OEB
General Service ≥ 50 kW	10158	OEB
Large User	45	OEB
Sub Transmission End Use	0	OEB

addresses sometimes differ from property location (e.g., PO boxes), the reported FSA geometries are not always accurate. That can result in errors of assignment of (parts of) FSAs to LDCs. These errors should be minor.

³ Table entries “N/A” indicate that no corresponding data was available from the standard sources.

⁴ <https://www.oeb.ca/sites/default/files/yearbook-General-Statistics-2021.xlsx>,
<https://reports-public.ieso.ca/public/HourlyConsumptionByFSA/>.

4. Population

A key challenge of the Two Pathways project was to estimate the hourly electric power demand that would result from different approaches to decarbonization of heating – various combinations of ASHPs, GSHPs, and TNs - for all buildings within each LDC. Most heating currently involves combustion of natural gas or other fuels at buildings, but the only reliable fuel consumption data that could be obtained was monthly natural gas for the whole province for the residential, commercial and industrial sectors. Data on dwellings has been presented above, but no reasonably comparable data could be obtained for commercial, institutional, or industrial buildings. As a consequence, it was necessary to make high-level approximations and develop models that use the census and other available data to best effect.

A key factor determining the viability of thermal networks in a given area is the density of heat demand (MW_{th}) per km of distribution pipe or per unit area (ha). A similar criterion applies also to natural gas distribution networks. From analysis of natural gas data (see the main Two Pathways report) it was determined that natural gas service is available to residential customers where the population density is, on average, at or above 24 people per hectare.

Recognizing that detailed analysis would be required in every case, and that different TN designs could be adopted at different densities, the simplifying assumption is made that TNs would generally be viable in the same areas that natural gas service is available. Non-residential buildings, for which data was not available, could increase the areas where TNs are viable. For specific numbers, $\rho = 24$ ppl/ha has been used as a density at which TNs are most likely viable, but low-temperature (5G) TN technology might make TNs viable at densities as low as $\rho = 10$ ppl/ha. (In some cases, a 5G TN is not much more than GSHPs with shared ground heat exchangers.)

Population data for Toronto Hydro-Electric System Limited, from the 2021 Census, is shown in Table 3. Figure 1 shows the percentage of population in the LDC living below any given density, calculated at the DB level.⁵ Figure 2 shows how the population density is distributed across the LDC, also at the DB level.

Table 3

LDC population	2793353
LDC population living at density ≥ 24 people/ha	2602891
Percentage in LDC of all people in Ontario living at density ≥ 24 people/ha	28.06%

⁵ The indicated area is for DBs with non-zero population, which can be less than the area of the LDC.

Population versus density for Toronto Hydro-Electric System Limited (LDC)
Totals: Population = 2793353, Area = 53736 ha

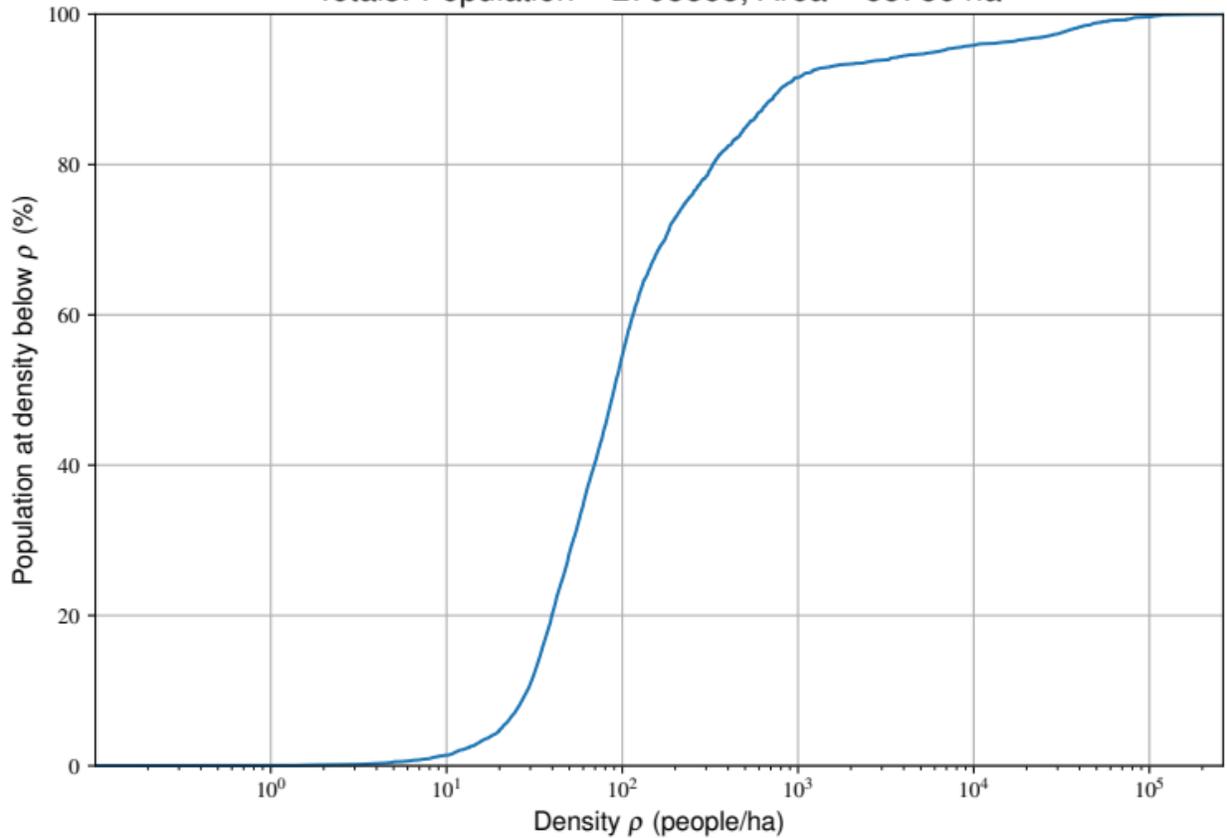


Figure 1. Percent of population in the LDC living below any given density ρ . Below $\rho = 10$ people/ha, properties should be large enough to install GSHPs. At $\rho = 24$ people/ha and above, TNs should be viable. Detailed analysis will be required to determine what zero-emissions heating technology would be best in the intermediate range.

People/ha - Toronto Hydro-Electric System Limited

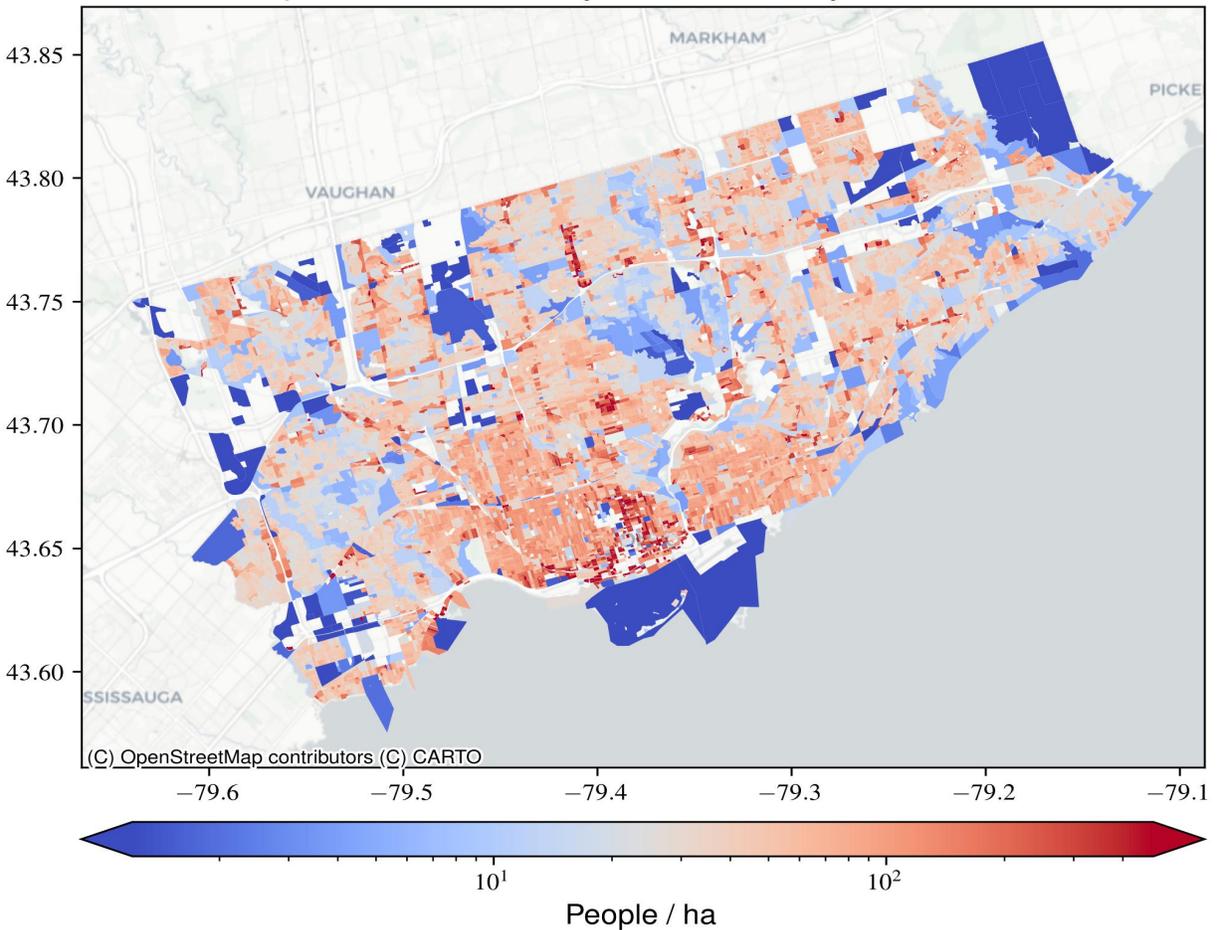


Figure 2. Population density in the LDC using data from the 2021 Census. Unfilled areas within the LDC have zero reported population. Gray corresponds to 24 people/ha. The polygon geometry provided for some census DBs may extend over water, which causes the indicated density of the adjacent waterfront neighbourhoods to be lower than if only the land area had been included.

5. Residential Electricity Demand

The most useful and extensive data regarding electricity demand in Ontario has been obtained from the IESO.⁶ The IESO does not provide data regarding power supplied to individual LDCs, nor does it give a breakdown by customer type or rate class, except for power delivered directly to large industrial customers. However, the IESO does make available hourly data consumption reported by smart meters, aggregated at the FSA level. The smart meter data also segregates the different residential and commercial rate classes. This smart meter data has been very informative.

In cases where the number of customers on a given retail rate plan was less than a minimum group size, required to meet privacy constraints, the aggregation area was increased to the first two characters of postal codes. This occurred frequently for commercial customers and rate plans other than time-of-use

⁶ <https://reports-public.ieso.ca/public/>

(TOU), often preventing reliable allocation of data to an LDC. Consequently, the present work only made use of data for residential customers on the TOU rate plan. Analysis was further restricted to mid-week days (Tuesday, Wednesday, Thursday) that were not holidays. With the use of geographic boundary files for FSAs and LDCs, it was determined which FSAs (or fractions thereof) are contained in the LDC.

Hourly temperature data was obtained from the closest weather stations to each FSA. The thermal mass of buildings causes their heat demand to be proportional to a moving average of past temperatures instead of the instantaneous outdoor temperature. Moving average temperatures were calculated for each weather station relevant to the LDC, with the weight of the temperature t hours in the past diminishing as $\exp(-t/tc)$ in the moving averages, where tc is a time constant (in hours).

Considering each hour of day separately, electricity consumption was fitted to a model curve for different trial values of tc , allowing identification of the tc that yields the best fit to the model. Both the hourly consumption observations and the best fit curves are shown in Figure 3. The last page of this report has plots showing the statistical deviations of observed values about the best fits for each hour.

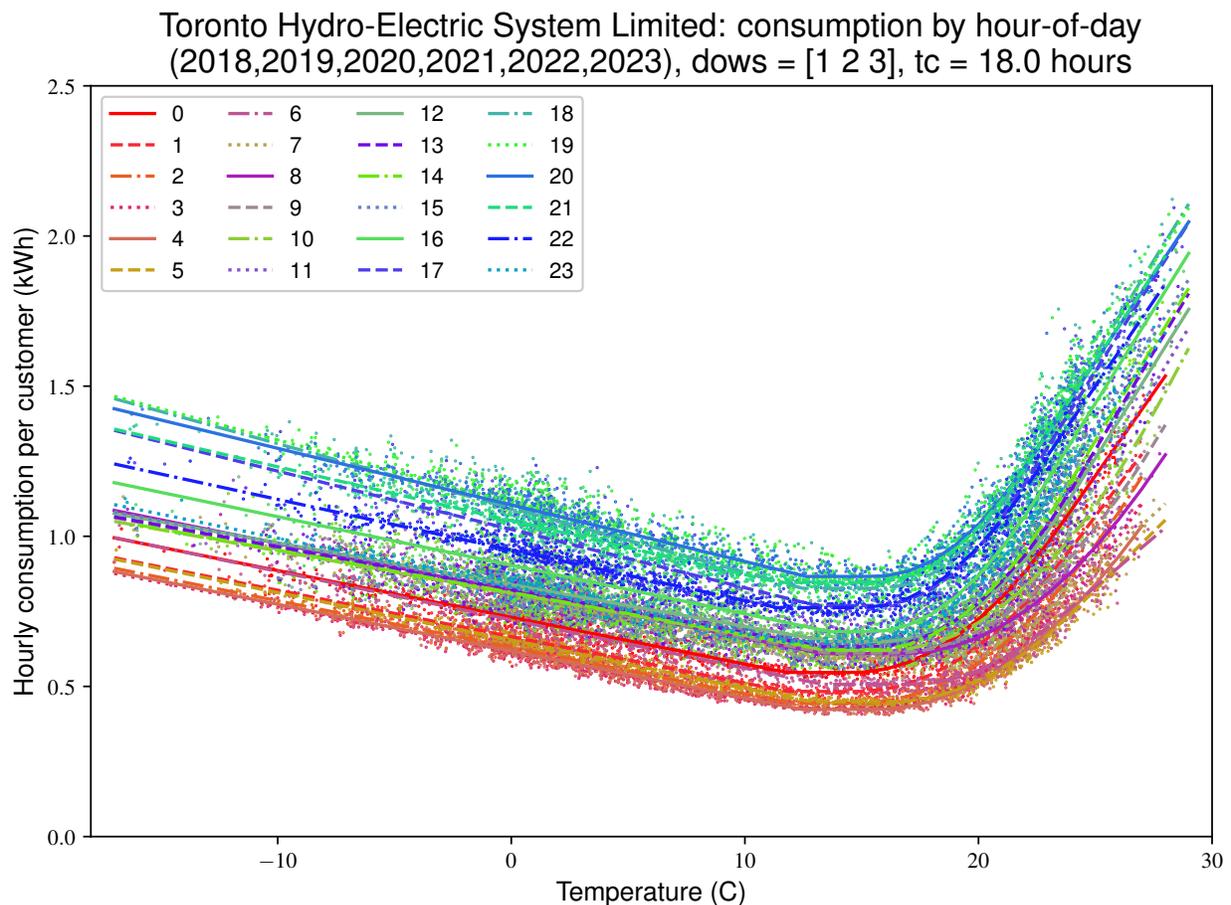


Figure 3. Average residential electricity consumption from hourly smart meter data as a function of temperature, in a different colour for each (just completed) hour of day (EST). The temperatures used are an exponential moving average as described in the text. Lines show fitted model curves.

The curves used to model electricity consumption (kWh) versus moving average temperature (T) have four segments:

- a linear (heating on) segment below a heating threshold temperature T_H , with negative slope m_H
- a short segment with constant power P_{base} (heating and cooling off) starting at T_H and extending until cooling begins at some higher temperature
- a growing quadratic segment above T_H that indicates gradual turning on of cooling
- a linear segment with positive slope m_C that begins with a smooth transition from the quadratic segment and continues at all higher temperatures.

Key parameters that characterize the linear segments of these fits are given in Table 4. The increase of power usage with dropping temperature in the heating segment will be due to an unknown combination of electric heating and electricity use by fuel-based heating systems (e.g., for blowers and pumps), plus some increment for more lighting use during the winter. The quadratic segments are believed to characterize human behaviour (personal desires for cooling) and are not relevant to the problem of heating buildings.

Table 4

Time constant of moving average temperature for best fit model of demand versus temperature	tc	18 h
Temperature below which heating is required	T_H	12.73 °C
Change in average demand per °C temperature increase when heating is needed	m_H	-0.016 kW/°C
Change in average demand per °C temperature increase when cooling is needed	m_C	0.115 kW/°C
Mean power when no heating / cooling is needed	P_{base}	0.63 kW

Variation of base power, P_{base} , through the day is indicative of daily patterns of residents and is highly consistent across the province. Even a slight lunchtime increase is evident. This is shown in Figure 4.

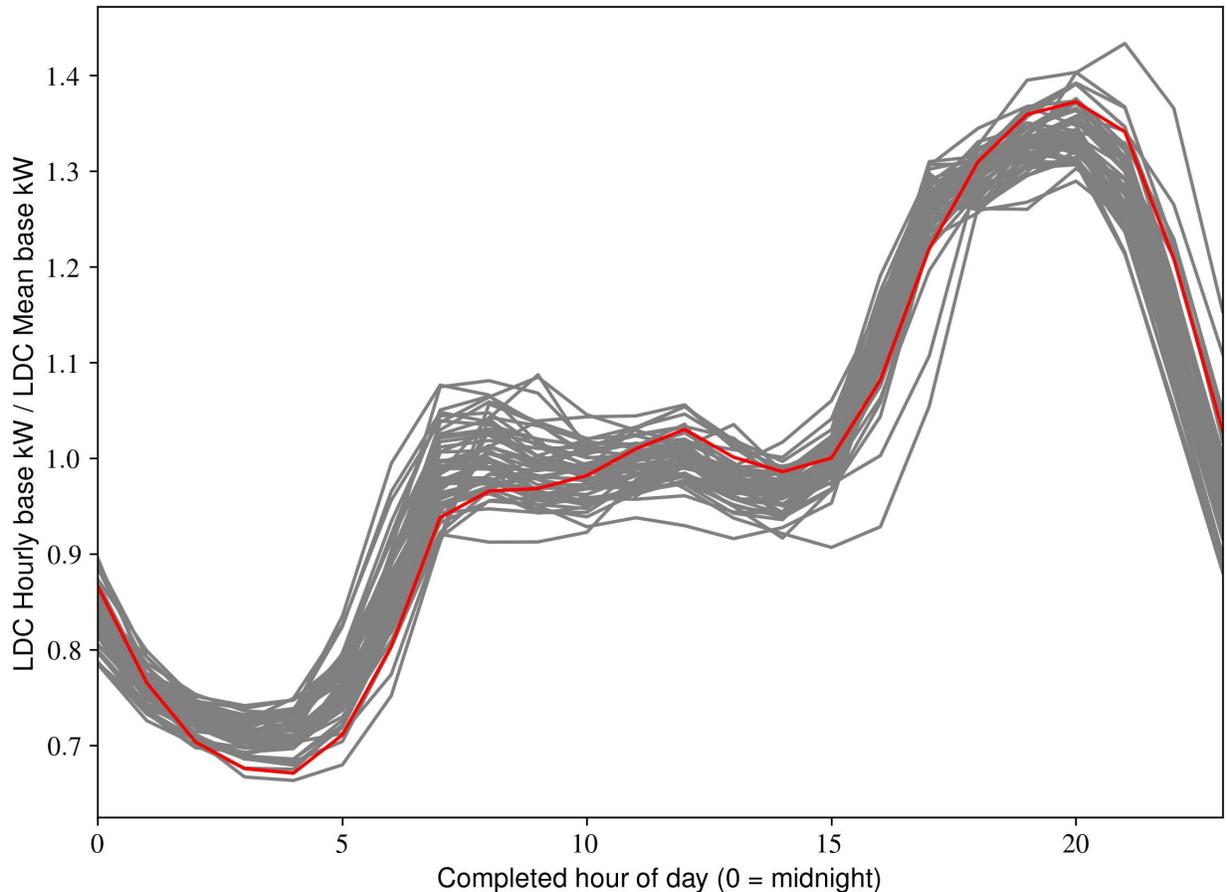


Figure 4. Hourly variation of mid-week base power, P_{base} , when the temperature is such that neither heating or cooling is needed. This LDC is shown in red and all the other LDCs across Ontario in grey.

6. Heating and Cooling Degree Hours

The demand for thermal power to heat buildings is proportional to the number of degrees the moving average temperature is below the heating threshold temperature, T_H . It is common to assume some value, such as 18 C, for the heating threshold temperature, but the analysis of Section 5 used LDC-specific data to determine that $T_H = 12.73$ C for residential customers with smart meters. Lacking evidence to the contrary, the same value is assumed valid for all buildings.

While it is also common to quantify the temperature factor of heating demand in Heating Degree Days (HDD), the analysis here employs hourly data and the temperature factor will be expressed in Heating Degree Hours (HDH). Similarly, the temperature factor for cooling is expressed in terms of Cooling Degree Hours (CDH), calculated using an effective $T_c > T_H$ derived from the above fits.

The hourly heating and cooling degrees over the six-year period for which smart meter data is available are shown in Figure 5. There is clearly far greater demand for heating than for cooling. There are also substantial annual variations in both the peak and cumulative HDH and CHD.

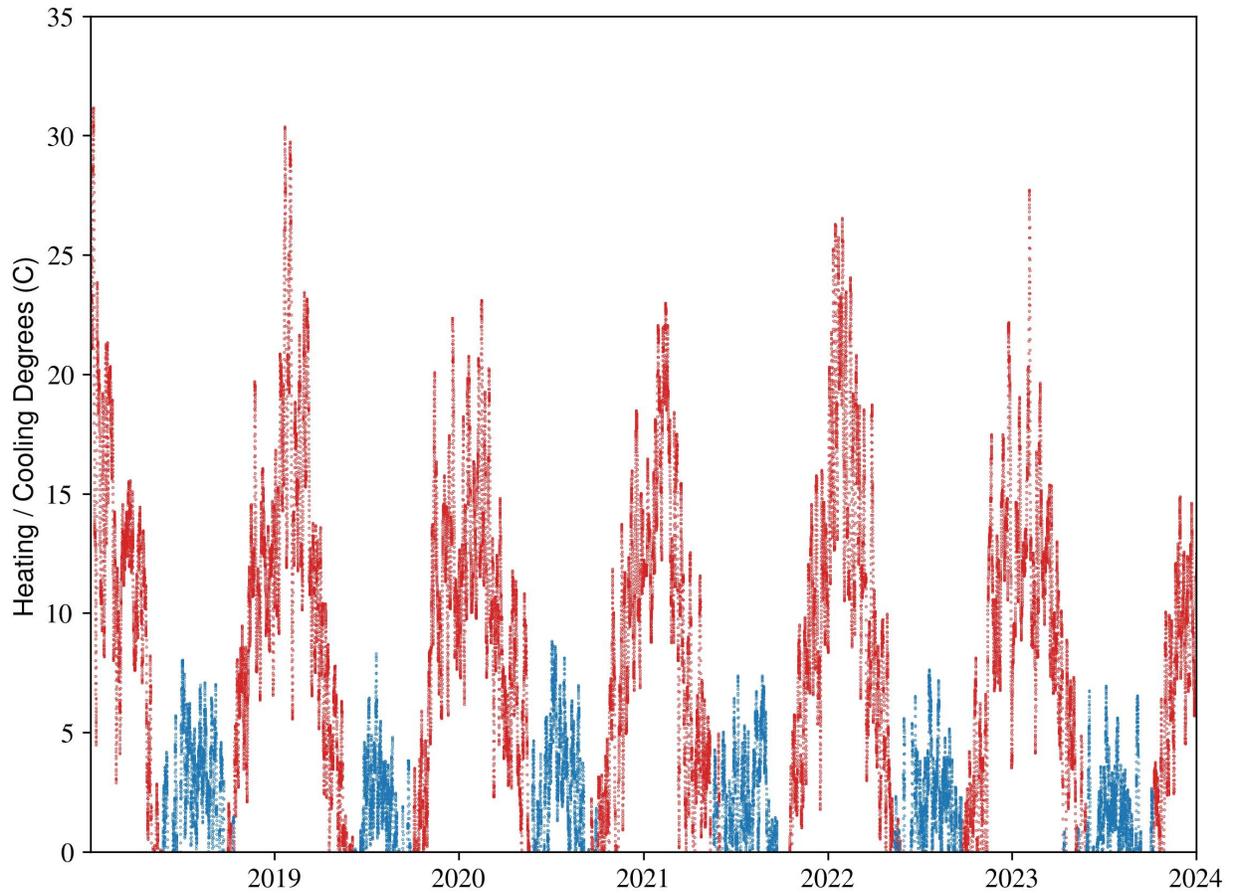


Figure 5. Hourly heating degrees (red) and cooling degrees (blue) for the LDC over a six year period. These are based on moving average temperatures, calculated as described in the main text. Use of moving average temperatures has the effect of smoothing hourly fluctuations without changing sums over intervals a week or longer.

Key data characterizing the HDH and CDH shown in Figure 5 are listed in Table 5, with all values in degrees C.

Table 5

Mean annual Heating Degree Hours	51308
Maximum hourly heating degrees	31.2
Mean hourly heating degrees (when heating required)	10.1
Mean annual Cooling Degree Hours	5687
Maximum hourly cooling degrees	8.8
Mean hourly cooling degrees (when cooling required)	2.8

7. Power Demand for Electrified Heating

Based on data presented in the Sections above, it is possible to estimate the additional electric power demand that could result from heating decarbonization for all buildings in the LDC. Almost all of that additional demand would be for heating electrification using either ASHPs or GSHPs; TNs might also be implemented, but their electricity needs would be much less. Strategic heating planning (discussed in the main Two Pathways report) will be needed to decide on the most appropriate mix of decarbonized heating solutions in each distinct area, along with a more reliable estimate of electricity demand.

The distribution of population density shown in Section 4 indicates the percentage of dwellings at densities likely too low for TNs to be viable and that would have sufficient land available to install GSHPs. The remainder of dwellings could decarbonize heating either by installing ASHPs or by connecting to TNs (if or when available). (A transition density of 24 ppl/ha was assumed; detailed analysis could indicate higher or lower percentages of dwellings suitable for GSHPs or TNs.) In areas where TNs are implemented instead of ASHPs, the peak power requirement for heating could be as low as 5% of what ASHPs would require, depending on choice or availability of heat sources and strategic design of thermal energy storage.

While Section 2 presented data on the numbers of dwellings of different types in the LDC, no comparable data was available for non-residential buildings. From province-wide natural gas consumption data, as noted in the main Two Pathways report, about 47% of natural gas used for space heating in Ontario is for the residential sector, with the remainder for other sectors (commercial (including institutional), industrial (including power generation)).

The simplifying assumption was made that residential buildings are responsible for 47% of heating demand in each LDC – not just province-wide – and that the temporal variation of heating demand is similar for dwellings with and without smart meters. The mix of customers shown in Section 3 may provide some indication regarding the validity of this assumption, but without an hourly (or monthly) breakdown it is not possible to know what portion of energy consumed for uses other than residential is for space heating. (The LDC will likely have the data needed to make that determination, as part of a local heating planning initiative.) If, for example, residential buildings are responsible for 70% of heating demand in the LDC instead of 47%, then the heating power demand estimate made here will be too high by a factor of $70/47 \approx 1.49$.

Supported by data from the Comprehensive Energy Use Database (CEUD),⁷ the average efficiency of conversion of natural gas energy to thermal energy (e.g., with gas furnaces) was assumed to be 85%. Combining population-weighted, province-wide HDH with monthly natural gas usage for space heating then allowed determination of the province-wide thermal energy (MWh) per HDH needed to heat all buildings. This was scaled down according to the LDC's population and local HDH to estimate the *thermal energy per HDH* (MW) needed within the LDC to heat buildings in any given hour. Using heat pumps to provide that much thermal power would require less electrical power, with the reduction factor being $1/\text{COP}$ where COP is the instantaneous effective COP of the GSHP or ASHP.

For GSHPs it has been assumed that $\text{COP} = 3$. Full decarbonization of heating with ASHPs generally

⁷ https://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/menus/trends/comprehensive_tables/list.cfm

requires the use of electric resistance supplementary heating, for when it is very cold and the ASHP cannot provide adequate heat. The effective COP is referred to as COP_{adj} in the main Two Pathways report, which describes the detailed model used for COP_{adj} .

Taking into account all of the above allowed estimation of the electricity demand that would have resulted if all buildings in the LDC (based on 2021 data) had been heated with heat pumps instead of fossil fuel during the years 2018 through 2023. The percentages of GSHPs and ASHPs are based on population density, as discussed above. The resulting hourly electric power demands – for space heating alone, since data for actual hourly demand was not available – are shown in Figure 6. No attempt has been made to project into the future; population growth and electrification of other sectors (transportation, industry) would cause further increases in power demand.

It must be emphasized that the approximations and assumptions involved, and discussed above, mean that the overall magnitude of the estimated power demand for the LDC is uncertain, perhaps at the $\pm 40\%$ level. But the hourly fluctuations should be much more reliable –perhaps $\pm 10\%$.

Data on actual 2021 electric energy consumption (including a breakdown by rate class or connection type) and summer and winter peak power are provided by the OEB in its General Statistics yearbook.⁸ For a small number of LDCs, there is limited or no data. Table 6 shows the data provided for Toronto Hydro-Electric System Limited, with N/A indicating “not available”. Where data is available, it may provide some insight into the validity or warranted adjustment to the assumption that residential building are responsible for 47% of the heat demand. Detailed (hourly) consumption data held by the LDC would be even more useful.

Table 6

Rate Class / Description	Units	Value (2021)
General Service < 50 kW	MWh	2267835
General Service >= 50 kW	MWh	13458667
Large User	MWh	1906653
Residential	MWh	5271578
Sentinel Lighting Connections	MWh	0
Street Lighting Connections	MWh	113578
Unmetered Scattered Load Connections	MWh	41389
Embedded Distributor(s)	MWh	0
Sub Transmission Customers	MWh	0
Total Consumption	MWh	23059700
Winter Peak	MW	3500.9
Summer Peak	MW	4385.6

⁸ <https://www.oeb.ca/sites/default/files/yearbook-General-Statistics-2021.xlsx>

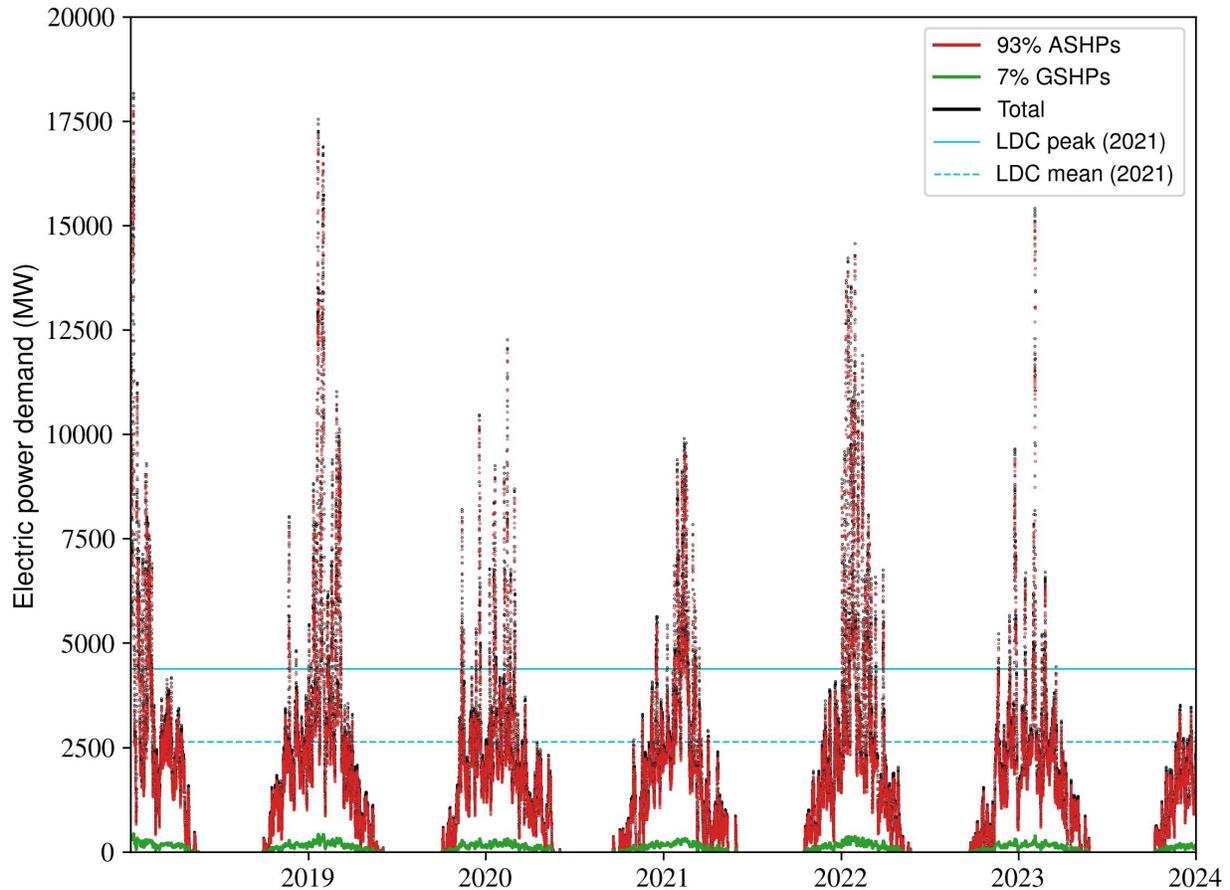


Figure 6. An estimate of what the hourly electric power demand for electrified heating with ASHPs and GSHPs would have been over a six year period if all existing buildings in the LDC had been converted from non-electric heating in the percentages indicated. Extreme peaks in power for ASHPs correspond to very cold weather, when the ASHP effective COP drops to close to 1. If available, actual (summer) peak and mean power for the LDC in 2021 are indicated by horizontal solid and dashed cyan lines.

8. Discussion

Through extensive analysis of available data, an estimate has been developed for the hourly electric power demand that might result from heating electrification of all buildings in the LDC. The model employs a mix of air-source and ground-source heat pumps, with GSHPs assumed wherever census data indicates that there should be sufficient space to install ground heat exchangers.

Due to use of approximations and reasonable assumptions in the modeling, necessitated by inadequate data, the overall magnitude of the estimated electric power demand in Figure 6 is uncertain at the $\pm 40\%$ level. Data held by the LDC, Enbridge, MPAC, etc. would be required to derive a less uncertain estimate. Nonetheless, more accurate modeling will not change the characteristics of power demand versus temperature for ASHPs, including extreme peaks.

Although it varies by LDC, the annual heating degree hours for buildings across Ontario are roughly 10 times the annual cooling degree hours. The maximum hourly heating degrees (in the coldest weather)

are about 3.5 times the maximum hourly cooling degrees.

Equipment used for cooling will generally have a COP of 3 (as high as 5) on hot days, while ASHPs have $COP_{adj} \sim 1$ on very cold days. This means that the peak electric power demand for heating buildings with ASHPs in the coldest weather will be about 10 times the peak electric power demand for cooling the same buildings. GSHPs maintain a fairly constant COP, independent of the outdoor temperature but dropping slightly as the ground temperature drops. Peak electric power demand for GSHPs in the coldest weather will be about 3.5 times the peak electric power demand for cooling the same buildings.

All the areas (census DBs) where ASHPs were assumed in the above modeling should have sufficiently dense heat demand for thermal networks to be viable. Providing decarbonized heating with TNs instead of ASHPs would avoid the modeled power demand for ASHPs (Figure 6). Electricity needed for TNs is relatively minor.

Of particular concern to the LDC will be the need to greatly increase the peak power capacity on the local distribution network if significant numbers of customers attempt to decarbonize their heating by converting to ASHPs. Utilization of capacity added to accommodate ASHPs could be as low as 8 percent.

Analysis in the main Two Pathways report indicates that, when the cost of providing peak power for ASHPs is properly included, the societal cost of heating with TNs will be far less than the societal cost of heating with ASHPs. The cost of additional power system capacity (generation, transmission and distribution) to provide reliable peak power for heating decarbonization with ASHPs (including electric resistance backup) is likely to be several times what building owners pay to install the ASHPs. Unless retail electricity rate structures are changed to charge separately for energy and peak capacity (whether used or not), rates per kWh will rise and customers who do not install ASHPs will end up subsidizing customers who do.

Given the great difference of their peak power requirements, installation of GSHPs instead of ASHPs should be strongly encouraged wherever TN service is not viable or unlikely to be available in the foreseeable future and there is sufficient land available for the ground heat exchangers.

Deployment of TNs in higher density areas, including for existing detached homes, warrants careful consideration to avoid the severe increased peak power demand and power system costs that would likely result from an attempt to achieve large-scale decarbonization with ASHPs.

In the short term, before TN service can be made available, customers who wish to install ASHPs should be encouraged to install units that are sized for cooling and to switch over to fuel-based heating systems at temperatures below about +4 C. See Section 7 of the main Two Pathways report for more on this strategy.

Toronto Hydro-Electric System Limited: statistical deviation of observed from fitted kWh
(2018,2019,2020,2021,2022,2023), dows = 123, tc = 18.0 hours

