TAF The Atmospheric Fund

Pumping Energy Savings:

Accelerating heat pump adoption in Ontario's electrically heated multi-residential buildings

RECOMMENDATIONS REPORT

July 2018

ABOUT THE ATMOSPHERIC FUND

Founded in 1991, The Atmospheric Fund (TAF) invests in urban climate solutions in the Greater Toronto and Hamilton Area to reduce carbon emissions and air pollution. TAF is supported by dedicated endowment funds provided by the City of Toronto (1991) and the Province of Ontario (2016) and has invested more than $50 million to date.

Visit www.taf.ca for more information or message us at info@taf.ca.

@AtmosphericFund

FB.com/AtmosphericFund

The Atmospheric Fund

The Atmospheric Fund
75 Elizabeth Street
Toronto, ON M5G 1P4

ABOUT PUMPING ENERGY SAVINGS

To reduce carbon emissions from buildings in the Greater Toronto and Hamilton Area (GTHA), we need to lower the energy consumption (natural gas, electricity) for heating and cooling. A substantial number of buildings in the region use highly inefficient, outdated electric resistance heaters for space heating – especially in multi-residential buildings. Heat pumps as ultra-efficient heating and cooling devices offer a promising technological alternative. The Atmospheric Fund started the Pumping Energy Savings project in 2015 to identify and help remove the barriers to the widespread uptake of heat pumps in Ontario. Our research shows the energy and emissions savings potential for heat pumps for electrically heated multi-residential buildings for the first time for Ontario. In addition to this recommendations report, the project team created a number of resources for home owners, contractors, and utilities that aim to accelerate the adoption of heat pumps.

- Project Director: Bryan Purcell, TAF Director of Policy & Programs; bpurcell@taf.ca
- Project Coordinator: Devon Calder, TAF Heat Pump Researcher; dcalder@taf.ca

ACKNOWLEDGMENTS

This project was made possible through the financial support of the Independent Electricity System Operator (IESO). Further in-kind support was provided by Alectra Utilities (formerly Horizon Utilities), Ontario Property Management Group (OPMG), and Toronto Hydro.

We thank our Advisory Group who gave their valuable time, insights, and feedback on many aspects of the project:

- Rob Edwards (IESO)
- Erik Janssen (Toronto and Region Conservation Authority)
- Kirk Johnson (Eco-Efficiency Consulting)
- Sunil Kumar (Kinross Gold)
- Mike Mulqueen (Toronto Hydro)
- Peter Ormond (Alectra Utilities)
- Kim Overbye (OPMG)
- Bill Willis (Thunder Bay Hydro)
- Suzanne Wiltshire (Mitsubishi Electric)

We also thank the property owners/operators who participated in our feasibility study:

- CAPREIT
- CityHousing Hamilton
- Crossbridge Condominium Services
- OPMG
- Starlight Investments
- Toronto Community Housing

We also engaged with an expert consulting team to collaborate on research, analysis, and development of content for this report. We thank Chris Neme (Energy Futures Group) and Judy Simons (ICF) for their valuable work on this project.

TORONTO Ontario

EXECUTIVE SUMMARY

Institutions such as the International Energy Agency increasingly recognize heat pumps as a key technology for achieving deep reductions in energy use and carbon emissions[1]. Conventional heating technologies are limited to efficiency levels below 100 per cent. Heat pumps, on the other hand, can achieve operating efficiencies between 200 to 400 per cent by leveraging renewable thermal energy from the outdoor air, ground, or water while using a small amount of electricity.

Heat pumps are increasingly common in markets such as the U.S. and Europe. However, uptake in Canada is limited. In Ontario, that's largely because of the relatively low cost of natural gas. Heat pumps are not currently seen as an economically viable retrofit solution for gas-heated buildings in the province. This is expected to change in the medium-term as carbon pricing increases the relative cost of natural gas. In the short-term, electrically heated buildings offer a viable market for heat pump technologies. Accelerating the development of this market will directly reduce energy use and carbon emissions, while also spurring the development of the industry capacity required to retrofit gas-heated buildings in the future.

Our research focused on the scale-up potential for heat pumps in electrically heated multi-residential buildings (EMURBs for short). With its 405,000 units, this sector represents 24 per cent of Ontario's existing multifamily dwelling stock. Due to the relatively high cost of electricity in Ontario, EMURBs have a strong business case for converting to heat pumps. Based on typical building age and physical condition, the EMURB stock in Ontario is also a candidate for comprehensive or multi-measure retrofits, which can generate an even stronger business case by blending the payback of multiple conservation measures with a heat pump retrofit. Research and experience have also shown that older multi-residential properties, including EMURBs, house a disproportionate share of economically-vulnerable population segments that may be challenged by high heating bills. Heat pumps offer a more cost-effective heating solution for all EMURB property owners and residents.

Multiple factors determine which heat pump system is technically and financially suited for an EMURB retrofit. Heat pump system types explored in this project include:

- CO_2 heat pumps – carbon dioxide is used as a refrigerant
- Cold climate ductless suite-by-suite mini/multi-split air-source heat pumps (cold climate ductless heat pumps for short)
- Distributed (in-suite) heat pumps supplied by air-or-ground source central plant
- Fan coil units supplied by air-or-ground source central plant
- Multi-split variable refrigerant flow system (air-or-ground source, with-and-without heat recovery)

Our multi-layered analysis of the energy conservation potential from retrofitting the EMURB stock in Ontario with heat pumps showed that a heat pump adoption rate of up to 70 per cent among EMURBs could be achieved within 10 years, saving 1.45 million tonnes of carbon emissions. That's equivalent to taking 31,522 cars off Ontario's roads for 10 years. However, this is only achievable if the first cost barrier is overcome, which could be addressed through provision of substantial new incentive programs. Current incentives for EMURB building owners are insufficient to significantly increase the uptake in heat pumps.

Uptake Scenario	% of EMURB Units Converted by 2027	# of EMURB Units Converted by 2027	Total Electricity Savings (MWh) by 2027	Total Carbon Emissions Savings (tCO_2eq) by 2027
Low Achievable	10%	40,500	800,000	210,000
Medium Achievable	30%	121,500	2.2 million	610,000
Max Achievable	70%	283,500	5.3 million	1,450,000

Table 1: Achievable Conservation Potential Scenarios - Ontario - 2018-2027

We analyzed three achievable conservation potential scenarios for the scale-up potential of heat pump adoption in EMURBs over a 10 year horizon based on different levels of incentives. The three scenarios were as follows:

1. **Low Achievable:** Assuming a new retrofit incentive for EMURBs equivalent to the current Save on Energy Heating & Cooling Incentive Program Cold Climate Ductless (and Multiport) air-source heat pump rebates for heat pump retrofits in single family homes (i.e. covering about one-third of the heat pump retrofit costs);
2. **Medium Achievable:** This scenario assumes the creation of one or more incentive programs which cumulatively cover about two-thirds of the heat pump retrofit costs (e.g. leveraging additional IESO and provincial funding);
3. **Maximum Achievable:** Based on a hypothetical efficiency program that provides financial incentives sufficient to cover 100 per cent of the cost of installing heat pumps. However, we don't recommend total cost coverage; this scenario is included simply as a point of reference.

As part of our conservation potential analysis, we assessed the cost-effectiveness of utilities offering the envisioned. We used several test methodologies, including the Program Administrator Cost Test (PACT). We applied PACT to the achievable potential scenarios using the IESO's Conservation Demand Management program energy efficiency cost-effectiveness tool.

Note: TAF used the IESO Conservation Demand Management Energy Efficiency Cost-Effectiveness tool as provided by IESO, but IESO did not review results/output nor did IESO staff evaluate/validate the cost-effectiveness tool testing results.

Both the Low Achievable and Medium Achievable scenarios passed the utility PACT test. The results are significant because they confirm the business case for extending existing generous IESO heat pump incentives from single-family-homes to EMURBs. Alternatively, a dedicated EMURB heat pump program, like the modelled Medium Achievable scenario, with incentive levels higher than what is currently offered to the sector could also be deployed cost-effectively.

Scenario	Cumulative Annual Electricity Savings (MWh) in Year 10	Net Present Value (NPV)	Benefit-Cost Ratio
Low Achievable	168,731	$84,716,951	2.11 *(Passed Test)*
Medium Achievable	506,142	$27,084,687	1.06 *(Passed Test)*

Table 2: EMURB Heat Pump Retrofit Incentives Cost-Effectiveness using PACT

In our research on the barriers to broad heat pump adoption, we relied on a framework developed by Natural Resources Canada and Navigant[2].

Barrier Category	Definition
Availability	Existence (or lack) of technologies, policies, resources or other factors affecting broader uptake of heat pumps.
Accessibility	Market participants' level of access to market channels, resources, or other factors blocking access to key elements required to realize adoption.
Affordability	Factors negatively impacting the cost effectiveness of a heat pump retrofit from the perspective of key market participants.
Awareness	The extent market participants are aware of heat pumps and the opportunity for retrofitting EMURBs, and factors preventing awareness.
Acceptance	How all preceding factors converge in relation to market acceptance and/or as yet unidentified factors affecting EMURB market acceptance.

Table 3: Critical Barriers to Market Uptake

The identified barriers touch upon financial aspects of heat pump retrofits, awareness (including perceived performance risk) and capacity. We also examined a number of opportunities including technology advancements, existing incentives, and support from key stakeholders ready to drive adoption (government, utilities, industry).

Barrier/Opportunity	Description
Financial Barriers	High upfront capital costs
	Extended paybacks
	Competing capital priorities
	Split incentives (for suite metered buildings)
	Rent controls (for rental buildings, especially suite metered buildings)
Awareness and Capacity Barriers	Building owners/operators' limited awareness of heat pump technology & savings potential
	HVAC contractors' and consulting engineers' limited capacity for, awareness of, and interest in heat pump retrofits
Opportunities	New high performing product.
	Well-established distribution channels
	Increased demand for efficient cooling in a warming climate
	Mandatory energy benchmarking and disclosure for MURBs can drive interest in efficient HVAC
	Financial incentives currently available
	Potential role for Gas Utilities to support implementation of geothermal heat pump loop infrastructure for customers
	New incentives and financing programs under development

Table 4: Identified Barriers and Opportunities for Heat Pump Market Uptake in Ontario

KEY RECOMMENDATIONS

The project team developed a set of recommendations to address each of the key barriers. However, while each of the recommendations generated can assist with increasing market adoption in some way on their own, realizing optimal conservation potential will require coordinated action across a number of the recommendations made in this report.

Here are some of the best ways that identified barriers could be addressed by utilities, government, and industry stakeholders:

Research, Development and Demonstration

Support demonstration projects to help kick-start the heat pump retrofit market.
Demonstration projects can build awareness and acceptance of heat pump retrofits in the EMURB market, while addressing perceived performance and reliability risks. Results could also improve future policies and programs by providing data on actual costs and savings, and any further barriers encountered.

Incentives and Financing

Provide enhanced incentives for heat pump retrofits and ensure building owners have access to suitable retrofit financing options.
A plan should be developed to offer a variety of financing options for heat pump retrofits, including public financing approaches (e.g. through new provincial incentives and/or the Canada Infrastructure Bank). Furthermore, current financial incentives available to EMURB property owners are not sufficient to spur widespread adoption of heat pump retrofits. Enhanced incentives would improve affordability and make heat pump retrofits acceptable to a wider range of property owners.

Capacity Building and Quality Assurance

Build industry knowledge, capacity, and interest for the EMURB heat pump retrofit opportunity.
Our research indicates limited industry capacity for and interest in designing and installing heat pump retrofits in EMURBs. Capacity building activities could improve accessibility, affordability, and awareness. Training should be targeted primarily at engineering services providers and mechanical contractors.

Establish a streamlined Measurement & Verification (M&V) protocol.
Formulate clear guidelines regarding the M&V practices for heat pump retrofits to alleviate uncertainty surrounding measurement of performance for these technologies. A clear M&V protocol will help owners/engineers/contractors understand what is required to be eligible for utility incentives. Such a protocol will inform development and refinement of conservation programs.

Regulatory

Explore options for new Ontario Building Code (OBC) renovation requirements to drive heat pump adoption.
The OBC is introducing energy efficiency requirements at time of renovation. There is potential with the next update to the OBC (2022) to include requirements that accelerate EMURB heat pump retrofits such as a ban on natural gas conversion.

Retrofitting EMURBs with heat pumps is a significant conservation opportunity that should be pursued to help Ontario meet its energy and climate goals under the Conservation Framework and the Climate Change Action Plan. It is imperative that action be taken now as the entire EMURB sector will need to be addressed in the long-run. And while the primary focus of this project has been on adoption of heat pumps in EMURBs, there is a much larger emissions and energy conservation opportunity in Ontario associated with heat pumps in gas-heated MURBs (GMURBS). At the present time, GMURB heat pump retrofits are not economically viable due to the relatively high cost of electricity compared to natural gas. However, this may change as carbon pricing and other market factors increase the cost of natural gas going forward. It is expected that efforts to accelerate deployment of heat pumps in EMURBs will help pave the way for widespread adoption in GMURBs once economic conditions are more favourable.

Outline of Next Steps

We will further explore and act on the findings of our research in the next phase of Pumping Energy Savings. We will continue to address barriers to heat pump adoption in EMURBs through:

- **Demonstration Projects:** Four archetypal EMURBs in the Greater Toronto and Hamilton Area (GTHA) will undergo deep retrofits; projects will showcase heat pumps as an alternative to conventional electric space heating and address perceived risks.
- **Measurement and Verification Guidelines:** Building on the International Performance Measurement and Verification Protocol (IPMVP) framework, develop guidelines for M&V for heat pump retrofits to support larger scale adoption efforts.
- **Financing Options:** Assess the business case for heat pump retrofits and identify and/or develop suitable financing options to support scale-up.
- **Scale-up Strategy:** Following the recommendations report, the strategy will draw on findings from the demonstration projects and incorporate new policy and program developments. We will investigate further capacity gaps, address stakeholder concerns, and expand methods to increase consumer confidence.

CONTENTS

TABLES

HEAT PUMPS FOR THE ONTARIO MARKET

Technology Overview

Heat pumps are energy efficient mechanical devices that extract heat from sources such as the air or ground (soil and/or water) and transfer it to a desired space. Conventional electric space heating technologies achieve 100 per cent efficiency. Heat pumps, on the other hand, can achieve operating efficiencies far greater, typically between 200 and 400 per cent. The technology, which has been around for decades (albeit with technology advancements over time), not only can heat spaces using a fraction of the energy a conventional natural gas or electric HVAC system requires, but can also provide space cooling and domestic hot water as well. Heat pumps are currently most widely used in Asia and Europe, with limited market penetration in North America.

A major component of the **Pumping Energy Savings** project was the undertaking of seven feasibility studies to ascertain the financial and technical viability for retrofitting EMURB properties with heat pumps. These studies revealed that heat pump selection should be determined by property characteristics. As part of the feasibility study, we reviewed multiple market ready heat pump options with an engineering team and evaluated the selection of a recommended heat pump option in each case using a suite of quantitative and qualitative criteria (see appendix F). We evaluated only electric powered air and ground source heat pumps.

Our findings showed that the following heat pump systems were the most financially and technically viable for the participating EMURB sites in our feasibility study:

- Cold climate ductless mini/multi-split air-source heat pumps (cold climate ductless heat pumps for short)
- Ground source heat pumps
- Centrally located air-source heat pumps

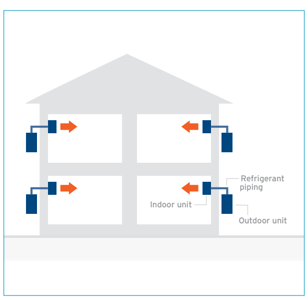
While the centrally located heat pump options offered high cost and energy savings, the cold climate ductless heat pump was scored as the recommended retrofit option in most cases due to ease of installation per suite and limiting property factors that affected selection of other options, such as central air-source or ground source systems that would require installation of a full building distribution system. In some cases, a central plant option was selected when existing equipment could be repurposed as part of a heat pump system, such as the potential for removing existing in-suite fan coils and reusing existing hydronic piping for an air-to-water or ground-to-water heat pump system. Ground source systems worked well when there were no impingements to drilling and installing a bore field.

Regardless of the solution, each of the above systems would require custom design and installation for a full building retrofit. The feasibility studies merely made recommendations on the best heat pump option for a particular site. And while cold climate ductless mini/multi-split systems were recommended in five of the seven sites that were evaluated, the evaluation results, shown in Appendix F, demonstrate that selection of an appropriate heat pump system depends on an evaluator’s decision making parameters, including how certain qualitative and quantitate criteria are weighted in terms of their importance for heat pump selection. Appendix F shows one recommended approach to evaluating a heat pump retrofit option, and while we agree with the recommendations, a property owner or contractor/engineer could choose to evaluate a selection of heat pump options very differently.

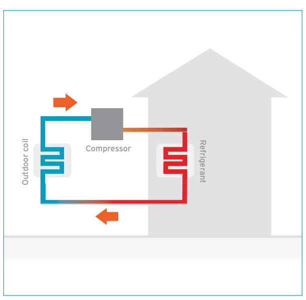
Here is a full list of the heat pump options considered in our seven feasibility studies:

- Cold climate ductless air-source heat pumps
- Distributed (in-suite) heat pumps supplied by air-or-ground source central plant
- Fan coil units supplied by air-or-ground source central plant
- CO_2 heat pumps that use carbon dioxide (R744) as a refrigerant. This solution is best suited for buildings that need high water temperatures to supply a hydronic system. This type of heat pump is a variation of an air-source central plant
- Multi-split variable refrigerant flow system, or VRF for short (air-or-ground source, with-or-without heat recovery)

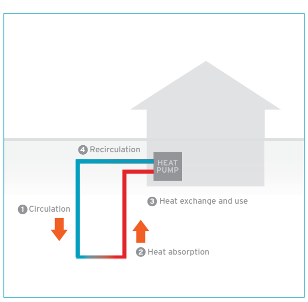
While the engineering team only recommended some of the above options, we stress that any of the heat pump systems could be viable for other EMURBs in Ontario. Ultimately, each building's characteristics and location will determine the appropriate heat pump solution, associated costs, and savings.



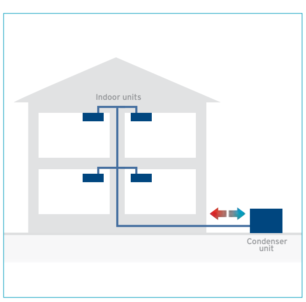
Cold climate ductless air-source heat pumps



Air-source central plant



Ground source central plant



Multi-split VRF system heat pump

Establishing the Business Case

Our seven pre-feasibility studies for EMURB properties in the GTHA yielded important insights into the economics of heat pump-only retrofits compared to retrofits that bundle heat pumps with other energy efficiency measures.

With a limited number of heat pump retrofit examples in Ontario for entire EMURB properties and virtually no publically available data of case studies to draw from, our work fills a crucial research gap. However, we acknowledge that our studies cover a small sample of a large, diverse building stock of over 400,000 units in Ontario.

A key finding of the study was that bundling a heat pump retrofit with other energy and water conservation measures significantly improves its business case. The market characterization study revealed that most EMURBs in Ontario are of an older vintage with energy inefficient and ageing equipment due for replacement. Assuming adequate access to capital for the retrofits, the old age and features of most EMURBS should increase the likelihood of implementing multiple measures. However, most EMURB properties are rental apartment buildings. Through stakeholder engagement, we found larger portfolio managers often conduct retrofits on a unit turnover basis and consider each measure in isolation as opposed to blended paybacks. Furthermore, rental apartment portfolio managers are generally not interested in any project that has a payback of greater than five years, despite the long-term benefits, to make it easier to sell properties should the opportunity arise. Bundling of measures for comprehensive retrofitting of properties could be more appealing to other rental apartment property owner types that have longer-term investment aspirations or that want to reduce operating costs.

Property owners of key EMURBs, such as condominiums, co-operative housing, and public housing agencies, could have different operational mandates and appetite for implementing larger scale retrofits. Co-operatives and condos for instance put aside capital each year for capital works – particularly with condos as a legal requirement. Additionally, social housing often receives lump sums of government funding for a bundle of measures that they can choose based on measurable eligibility requirements.

The table below summarizes the results of the feasibility study and showcases the business case for heat pump retrofits in a small sample of EMURB properties. The unique conditions heavily influence the economics of each opportunity.

		AVERAGE	LOWEST OBSERVED	HIGHEST OBSERVED
HEAT PUMPS ONLY	**Space Heating ENERGY Savings (%)**	61%	37%	87%
	Sizing Scenarios	100% (or less than w/backup from existing system)	50% of load meet 75% run hours w/existing backup	100% of load (oversized to meet peak below -20C) OR < 100% increasing complexity due to controls
	Total Energy Savings	19%	10%	29%
	Savings Per Unit (kWh/year)	3,723	2,050	8,929
	Retrofit Cost Intensity* ($/unit)	$10,804.04	$4,281	$34,643
	Simple Payback (years)	18.4	6.8	50.0
	WITH AVAILABLE INCENTIVES –			
	Retrofit Cost Intensity* ($/unit)	$9,894	$3,792	$32,937
	Simple Payback (years)	16.9	5.3	48.8
MULTI-MEASURE RETROFIT w/ HEAT PUMPS	**Total Energy Savings**	29%	15%	37%
	Savings Per Unit (ekWh/year)	5,695	3,250	10,912
	Retrofit Cost Intensity* ($/unit)	$11,986	$4,763	$34,960
	SIMPLE PAYBACK - Blended (years)	13.8	5.8	30.9
	WITH AVAILABLE INCENTIVES –			
	Retrofit Cost Intensity* ($/unit)	$10,892	$4,273	$33,214
	BLENDED Simple Payback (years)	12.6	4.5	30.0

**Retrofit Cost Intensity includes best estimate of the total required budget to complete the project, including, as required: further analysis, design, contract admin (eg: tender), materials and labour, construction review, commissioning, controls, project management, and contingencies, and HST.*

Table 5: Summary of Heat Pump Retrofit Pre-Feasibility Findings for Seven EMURB Properties

HEAT PUMP MARKET PENETRATION IN MURB SECTOR

Historic Market Penetration

Heat pumps have limited market penetration into the Ontario MURB sector. Estimates from Natural Resources Canada indicate that only 1.2 per cent of MURB units in Canada and 1.3 per cent of all MURBs in Ontario were equipped with heat pumps in 2015, the most recent year for which data is available from Natural Resources Canada's database on residential sector space heating system stock[3]. Despite the commercial availability and high level of efficiency that heat pumps offer, other forms of electric and natural gas powered systems continue to dominate the HVAC market.

Due to differences in energy infrastructure planning and market inertia in Ontario, the proportion of buildings that have natural gas or electricity for heating and cooling systems vary by city. For example, regions outside of the Greater Toronto and Hamilton Area (GTHA) have a higher proportion of EMURB properties due to differing access to natural gas.

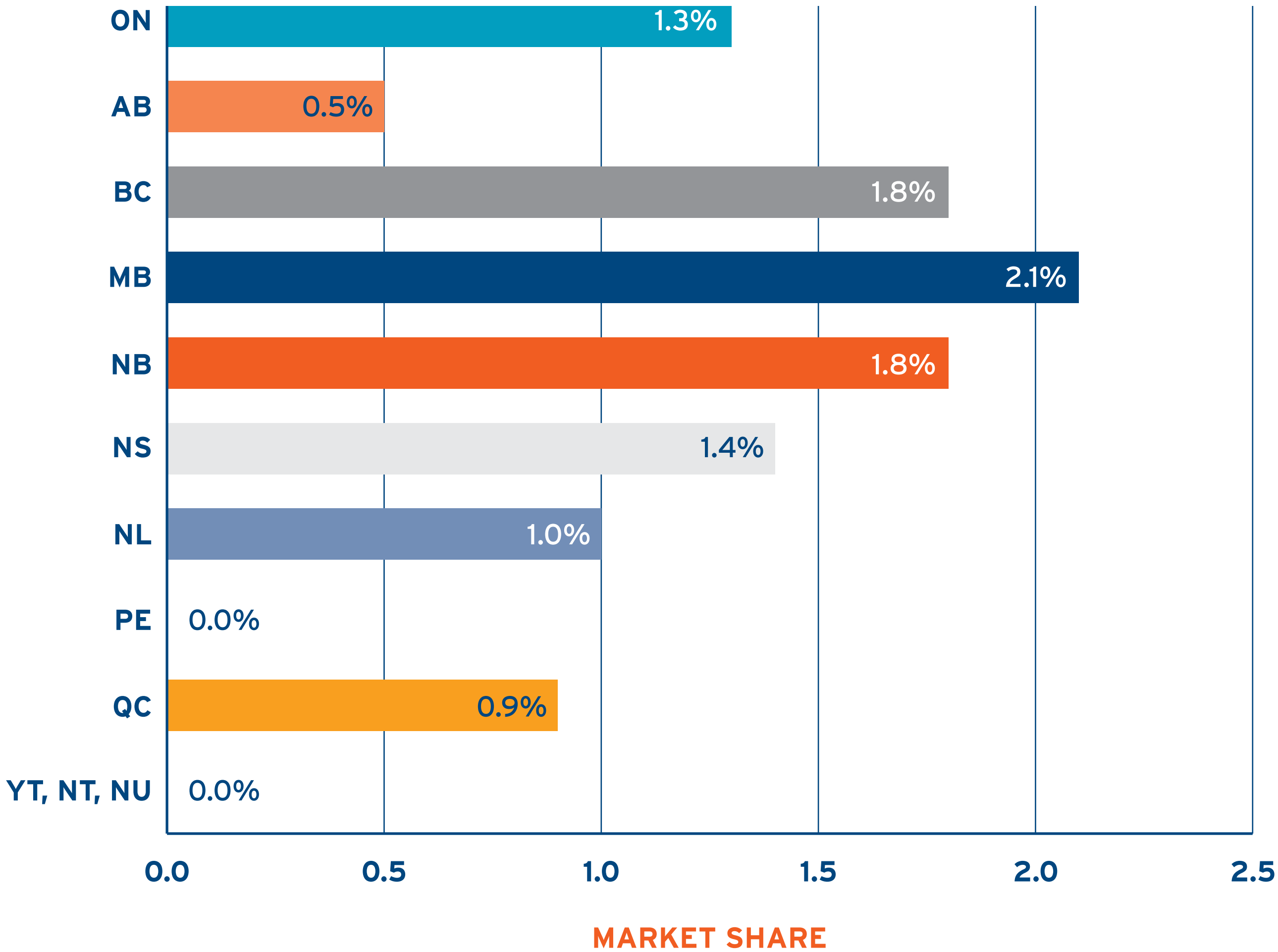


Figure 1: Proportion of Total Multi-Residential Units with Heat Pumps as Primary Source of Space Heating (2015)[4]

Ontario MURB dwellings with heat pumps as primary heating:

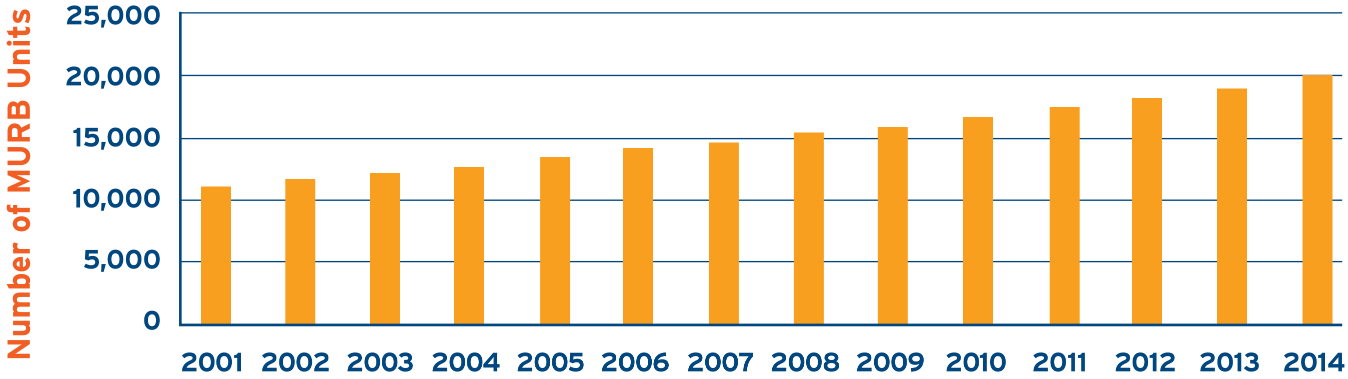


Figure 2: Annual Comparison of Ontario MURB Units Equipped with Heat Pumps[5]

While market penetration of heat pumps in the Ontario MURB sector, relative to other HVAC systems, has been low over the past 25 years, emerging market factors and institutional support could help accelerate adoption. Ontario energy and climate goals under the Conservation Framework, Climate Change Action Plan, and Ontario Fair Hydro Plan have increased support for lowering Ontario ratepayer space heating costs and finding near-term pathways to reduce building sector carbon emissions and find strategies for getting off natural gas.

Recent Green Ontario Fund Incentives

The Ontario Government's Climate Change Action Plan (CCAP) included a funding promise for property owners to purchase and install low carbon technologies including geothermal heat pumps and air-source heat pumps.[6] Established in August 2017, the Green Ontario Fund (GreenON) allocated cap-and-trade proceeds to energy efficiency programs. This included contributions to the Save on Energy Heating & Cooling Incentive Program, bringing rebates for homeowners up to $5,800 for air-source heat pumps and up to $20,000 for ground-source (geothermal) heat pumps, available from GreenON under the Rebates for Ground-Source Heat Pumps program[7]. The only form of EMURB eligible for these incentives were row townhomes. The incoming Ontario government announced the winding down of GreenON in June 2018, with all installations of approved applications to be finished by August 31, 2018.

IESO Incentives

Currently the only utility incentive programs available for heat pump retrofits for all EMURB types, regardless of structural type, are provided via the Independent Electricity System Operator (IESO) Save on Energy program. Incentive programs for multi-family heat pump retrofits include the Save on Energy Retrofit Custom Track program and the Save on Energy Process & Systems Program. The IESO also provided a redesign of the Save on Energy Heating & Cooling Program to include prescriptive incentives for air-source heat pumps. At present the only form of EMURB eligible for the Save on Energy Heating & Cooling Incentive program for air- source heat pumps are row townhomes. The IESO, which oversees operations of the provincial electricity system, has supported energy conservation in general for many years. More recently, it elevated its support for accelerating heat pump adoption in Ontario. IESO efforts to date include supporting local distribution companies in achieving conservation targets, supporting and administering incentive programs for building retrofit projects, pilot studies for heat pumps, and funding research. The IESO also released reports that emphasize the opportunity for heat pumps in Ontario.

ENERGY CONSERVATION POTENTIAL

Types of Conservation Estimates

Incentive Program	Rebate Amount	Eligible EMURBs
Save on Energy: Retrofit Program – Custom Track	$0.10/kWh of annual savings	All Types
Save on Energy: Process and Systems Program	$0.20/kWh of annual savings	All Types
Save on Energy - Pay for Performance (P4P) Program	$0.04/kWh/year – until 2020	Multiple EMURB properties must participate simultaneously
Save on Energy - Heating and Cooling Incentive Program	Up to $4,000 per suite for air-source heat pump retrofits – expires after 2018	Row Housing (at time of writing stacked townhomes not eligible)
NOTE: All eligibility criteria and program rules are available online at the Save On Energy website		

Table 6: Available Incentives for Ontario EMURB Heat Pump Retrofit

To understand the tremendous opportunity that heat pumps in the EMURB sector represent, it's crucial to estimate how much energy could be saved based on the adoption rate. Efficiency potential studies commonly estimate the energy savings potential from the following different perspectives:

Technical potential: This is the amount of energy savings that is technically possible, without regard to either the cost-effectiveness of the savings or the market barriers that may limit the willingness of building owners to make efficiency investments.

Economic potential: This is the portion of the technical potential that is cost-effective.

Achievable potential (based on TAF's research on marginal emissions factors in Ontario[8]): This is the portion of potential that could be achieved through market interventions – e.g. efficiency programs designed to overcome market barriers. Achievable potential is commonly, but not always, focused on the portion of economic potential that could be captured (i.e. economically achievable potential). Achievable potential is also often assessed at more than one level – e.g. maximum achievable, as well as what is achievable under different funding or program design constraints.

The project team developed an estimate of technical potential, as well as three different estimates of achievable potential, from heat pump retrofits in electrically-heated multi-unit residential buildings (EMURBs). In each case, our analysis focuses on a 10-year time horizon.

We did not explicitly develop an estimate of economic potential, which would have required segmenting the EMURB market by space heating consumption level, by presence or absence of cooling equipment, by climate zone, by building type or vintage, and/or by other variables that may affect cost-effectiveness. After careful analysis, we concluded that we did not have sufficient data of sufficient quality to confidently estimate or differentiate baseline heating and cooling electricity consumption levels – and therefore the cost-effectiveness of heat pump retrofits – for different segments of the multi-family market. However, we did assess the cost-effectiveness of the technical potential and three achievable potential scenarios we analyzed. We also performed cost-effectiveness analysis of the average heat pump retrofit into the average EMURB and provided some insights regarding the cost-effectiveness impact of the presence (or absence) for existing electric cooling.

This economic analysis was performed primarily using the IESO Conservation Demand Management Energy Efficiency Cost-Effectiveness tool. The tool is populated with the IESO's best current estimates of avoided electricity costs and was used to produce cost-effectiveness results under the Total Resource Cost test and the Program Administrator Cost test. As a sensitivity criterion, we also estimated the value of avoided carbon emissions to assess cost-effectiveness under a test more akin to the Societal Cost Test.

We focused our analysis on cold climate ductless air-source heat pumps. However, while these ductless mini/multi-split heat pumps will likely be the most cost-effective option for most EMURBs, ground source heat pumps may be an equally or even more attractive option for some buildings. It is difficult to predict which option is more cost-effective, let alone to characterize the cost and performance of those applications. In general, we would expect any ground source heat pump applications to provide similar electricity savings and be as cost-effective. Thus, our use of cold climate ductless air-source heat pumps as a proxy for all heat pumps is a somewhat conservative way to estimate savings potential.

The savings estimated in this report are the savings that customers would see on their bills (i.e. reductions in consumption recorded at customers' meters). They do not include additional reductions in losses resulting from less power being moved from power plants across power lines and other elements of the transmission and distribution system to customers. The IESO currently assumes that average transmission and distribution losses are equal to about 7 per cent of the volume of sales to customers (i.e. the amount of electricity that will no longer have to be generated at power plants as a result of heat pump retrofits will be about 7 per cent higher than the savings at the customers' meters estimated in this report).

TAF used the IESO Conservation Demand Management Energy Efficiency Cost-Effectiveness tool as provided by IESO, but IESO did not review results/output nor did IESO staff evaluate/validate the cost-effectiveness tool testing result.

Assumptions

Any analysis of efficiency potential requires a set of assumptions regarding the characteristics of both the potential market for the efficiency measure and the characteristics of the efficiency measure itself. The latter could include an efficiency measure's savings and load shape (i.e. how savings are distributed across hours of the day and months of the year, etc.). Our key core assumptions for each are summarized in Tables 19 and 20 in Appendix A.

Technical Potential

In this scenario, we looked at a hypothetical 100 per cent conversion rate. Since our analysis time horizon is ten years, our analysis of technical potential assumed that 10 per cent of all EMURB units – or 40,500 housing units – were retrofitted each year. The result would be cumulative annual energy savings of about 9.6 million MWh and 2.5 million tonnes of carbon dioxide (CO_2) avoided over a 10-year period.

Year	# Units Retrofitted	Incremental Annual Energy Savings (MWh)	Cumulative Annual Savings (MWh)	Cumulative Savings To Date (MWh)	TAF Marginal Emissions Factor (gCO_2eq/kWh)[9]	Incremental Annual Reductions (tCO_2)	Cumulative Reductions To Date (tCO_2)
2018	40,500	174,920	174,920	174,920	185.3	32,413	32,413
2019	40,500	174,920	349,839	524,759	198.6	34,739	101,891
2020	40,500	174,920	524,759	1,049,517	211.9	37,065	213,087
2021	40,500	174,920	699,678	1,749,195	225.2	39,392	370,654
2022	40,500	174,920	874,598	2,623,793	238.5	41,718	579,246
2023	40,500	174,920	1,049,517	3,673,310	251.7	44,027	843,409
2024	40,500	174,920	1,224,437	4,897,746	265	46,354	1,167,885
2025	40,500	174,920	1,399,356	6,297,102	278.3	48,680	1,557,326
2026	40,500	174,920	1,574,276	7,871,378	291.6	51,007	2,016,385
2027	40,500	174,920	1,749,195	9,620,573	304.9	53,333	2,549,714
TOTAL	405,000	1,749,195	1,749,195	9,620,573			2,549,714

Table 7: Technical Conservation Potential

Total cumulative lifecycle savings and carbon emission reductions (assuming each heat pump deployed over the 10 year time horizon has an 18 year service life) can be viewed in the detailed data tables on lifecycle savings and associated carbon reductions in Appendix E.

Achievable Potential

To determine the achievable potential, we analyzed three potential scenarios:

Scenario 1: Low Achievable – assuming incentives equal to the current Save on Energy Heating & Cooling Incentive Program Cold Climate Ductless (and Multiport) air-source heat pump rebates are made applicable to multi-family buildings (i.e. incentives would cover about one-third of the heat pump retrofit costs);

Scenario 2: Medium Achievable – assuming the current Save on Energy Heating & Cooling Incentive Program Cold Climate Ductless (and Multiport) air-source heat pump rebates are made applicable to multi-family buildings and rebates are either doubled or matched by another funding source (i.e. incentives would cover about two-thirds of the heat pump retrofit costs); and

Scenario 3: Maximum Achievable – assuming an efficiency program that provides financial incentives sufficient to cover 100 per cent of the cost of installing heat pumps. This scenario is for reference only: We do not recommend rebates that cover 100 per cent of costs as it would crowd out potential private capital.

For each scenario, we estimated market penetration rates over the next ten years. Our estimates were based on experience with leading HVAC efficiency programs implemented across North America over the past 20 years. Those assumptions were as follows:

	LOW ACHIEVABLE			MEDIUM ACHIEVABLE			MAXIMUM ACHIEVABLE		
YEAR	% of Market	# Units (htg)	# Units (clg)	% of Market	# Units (htg)	# Units (clg)	% of Market	# Units (htg)	# Units (clg)
2018	0.25%	1,013	709	1.00%	4,050	2,835	1.00%	4,050	2,835
2019	0.50%	2,025	1,418	3.00%	12,150	8,505	3.00%	12,150	8,505
2020	0.75%	3,038	2,126	5.00%	20,250	14,175	5.00%	20,250	14,175
2021	1.00%	4,050	2,835	7.00%	28,350	19,845	7.00%	28,350	19,845
2022	1.25%	5,063	3,544	8.00%	32,400	22,680	8.00%	32,400	22,680
2023	1.25%	5,063	3,544	9.00%	36,450	25,515	9.00%	36,450	25,515
2024	1.25%	5,063	3,544	10.00%	40,500	28,350	10.00%	40,500	28,350
2025	1.25%	5,063	3,544	10.00%	40,500	28,350	10.00%	40,500	28,350
2026	1.25%	5,063	3,544	9.00%	36,450	25,515	9.00%	36,450	25,515
2027	1.25%	5,063	3,544	8.00%	32,400	22,680	8.00%	32,400	22,680
Total	10.00%	40,504	28,352	70.00%	283,500	198,450	70.00%	283,500	198,450

Table 8: Achievable Potential Market Penetration Rate Assumptions

Although EMURB heat pump retrofits already qualify for Save on Energy commercial incentive programs (the Save on Energy Retrofit Program and the Save on Energy Process and Systems Program), the impact of these programs on achievable potential was not modelled. While there is opportunity to better promote the use of these programs for heat pump retrofits, our analysis suggests that the incentive amounts available ($0.10 to $0.20 per kWh) are too small to significantly increase uptake of this measure. Stakeholder engagement with EMURB property owners and managers revealed that project simple payback is the most widely used metric for evaluating efficiency investments; most operators require a simple payback of five years or less. For most EMURB properties, the simple payback on a heat pump retrofit will significantly exceed five years even with the existing commercial incentive programs. We recommend targeted marketing of the existing programs for EMURB properties, as a minority of early adopters can be expected to participate. However, widespread adoption of heat pumps in EMURBs will almost certainly require enhanced incentives.

Estimated Achievable Savings Potential (MWh)

The market penetration rates listed in Table 8 led to the estimates, provided in Tables 9, 10, and 11 below, of incremental and cumulative annual MWh savings, as well as cumulative savings to date and associated avoided carbon dioxide (CO_2) emissions for each scenario.

Total cumulative lifecycle savings and carbon emission reductions for each scenario (assuming each heat pump deployed over the 10 year time horizon has an 18 year service life) can be viewed in the detailed data tables on lifecycle savings and associated carbon reductions in Appendix E.

Year	Incremental Annual Savings (MWh)	Cumulative Annual Savings (MWh)	Cumulative Savings To Date (MWh)	TAF Marginal Emissions Factor (gCO_2eq/kWh)	Incremental Annual Reduction (tCO_2)	Cumulative Reductions To Date (tCO_2)
2018	4,220	4,220	4,220	185.3	782	782
2019	8,436	12,656	16,876	198.6	1,675	3,295
2020	12,656	25,312	42,188	211.9	2,682	8,659
2021	16,871	42,183	84,371	225.2	3,799	18,159
2022	21,091	63,274	147,645	238.5	5,030	33,250
2023	21,091	84,365	232,010	251.7	5,309	54,484
2024	21,091	105,456	337,466	265	5,589	82,430
2025	21,091	126,547	464,013	278.3	5,870	117,648
2026	21,091	147,638	611,651	291.6	6,150	160,699
2027	21,091	168,729	780,380	304.9	6,431	212,145
TOTAL	168,729	168,729	780,380			212,145

Table 9: Achievable Potential Low Achievable Scenario

Year	Incremental Annual Savings (MWh)	Cumulative Annual Savings (MWh)	Cumulative Savings To Date (MWh)	TAF Marginal Emissions Factor (gCO_2eq/kWh)	Incremental Annual Reduction (tCO_2)	Cumulative Reductions To Date (tCO_2)
2018	8,436	8,436	8,436	185.3	1,563	1,563
2019	16,871	25,307	33,743	198.6	3,351	6,589
2020	33,743	59,050	92,793	211.9	7,150	19,102
2021	50,614	109,664	202,457	225.2	11,398	43,798
2022	59,050	168,714	371,171	238.5	14,083	84,036
2023	67,486	236,200	607,371	251.7	16,986	143,488
2024	67,486	303,686	911,057	265	17,884	223,965
2025	67,486	371,172	1,282,229	278.3	18,781	327,262
2026	67,486	438,658	1,720,887	291.6	19,679	455,175
2027	67,486	506,144	2,227,031	304.9	20,576	609,498
TOTAL	506,144	506,144	2,227,031			609,498

Table 10: Achievable Potential Medium Achievable Scenario

Year	Incremental Annual Savings (MWh)	Cumulative Annual Savings (MWh)	Cumulative Savings To Date (MWh)	TAF Marginal Emissions Factor (gCO_2eq/kWh)	Incremental Annual Reduction (tCO_2)	Cumulative Reductions To Date (tCO_2)
2018	16,871	16,871	16,871	185.3	3,126	3,126
2019	50,614	67,485	84,356	198.6	10,052	16,529
2020	84,357	151,842	236,198	211.9	17,875	48,704
2021	118,100	269,942	506,140	225.2	26,596	109,495
2022	134,971	404,913	911,053	238.5	32,191	206,067
2023	151,843	556,756	1,467,809	251.7	38,219	346,202
2024	168,714	725,470	2,193,279	265	44,709	538,452
2025	168,714	894,184	3,087,463	278.3	46,953	787,303
2026	151,843	1,046,027	4,133,490	291.6	44,277	1,092,325
2027	134,971	1,180,998	5,314,488	304.9	41,153	1,452,411
TOTAL	1,180,998	1,180,998	5,314,488			1,452,411

Table 11: Achievable Potential Maximum Achievable Scenario

COST EFFECTIVENESS

We focused our cost-effectiveness analysis on results from the Total Resource Cost (TRC) test, the primary test currently used by the IESO. However, we also assessed results under both the Program Administrator Cost Test (PACT) and a version of the Societal Cost Test (SCT).

Total Resource Cost Test

The TRC test is nominally supposed to assess the combined effects of efficiency investments on the utility system and program participants. Conceptually, that should include all utility system costs and benefits, as well as any additional program participant costs and benefits. The value of non-energy benefits that efficiency program participants often receive from efficiency measures (e.g. improved comfort, improved health and safety, improved building durability and/or value, improved business productivity, etc.) is not accounted for in this conceptual construct. To address this challenge, the IESO currently uses a conservative 15 per cent "adder" in its version of the TRC to capture both participant non-energy benefits and the value of environmental benefits.

EMURB Heat Pump Measures

We analyzed the cost-effectiveness of an individual heat pump measure, using the assumptions noted above. We considered three scenarios: Our best estimate in which the heat pump was providing cooling savings in 70 per cent of EMURB units, as well as in two sensitivity scenarios – no cooling savings and cooling savings in 100 per cent of retrofitted units. The Total Resource Cost (TRC) test captures the combination of effects (costs and benefits) on both the utility system and program participants. Thus, for the first two scenarios in which cooling would effectively be added to at least some EMURB units (i.e. the best estimate scenario where 70 per cent of units assumed to have cooling in the baseline and 30 per cent do not, and the heating only/no cooling scenario), we did not treat the added cooling electricity consumption as a cost because we assumed that those utility system costs would be offset by the benefits participating customers would see in exchange (i.e. increased comfort). As noted above, we conducted our cost-effectiveness analysis with the IESO Conservation Demand Management Energy Efficiency Cost-Effectiveness tool, using its current avoided costs and other relevant assumptions for the Total Resource Cost test.

Year	Best Estimate (70% Cooling)	Heating Only (No Cooling)	Heating and 100% Cooling
2018	0.73	0.40	0.88
2019	0.75	0.41	0.90
2020	0.77	0.42	0.92
2021	0.79	0.43	0.94
2022	0.80	0.44	0.96
2023	0.81	0.44	0.97
2024	0.83	0.45	0.99
2025	0.84	0.46	1.01
2026	0.86	0.47	1.03
2027	0.88	0.48	1.05

Table 12: Heat Pump Measure TRC Benefit-Cost Ratios

The TRC cost-effectiveness of heat pumps is significantly affected by the degree to which they are providing cooling savings as well as heating savings. Also, heat pumps become more cost-effective over time. This is likely because the IESO forecast's avoided costs gradually increase over time, even in real (inflation-adjusted) terms.

The results are also sensitive to the assumed level of baseline heating consumption and therefore to assumed heating electricity savings. For example, the next table shows, heat pump retrofits would be cost-effective based on heating savings alone if installed in 2018 in a building with average annual baseline heating electricity consumption of about 15,000 kWh per apartment. The break-even point for cost-effectiveness on heating savings alone drops to about 12,500 kWh average annual baseline electricity consumption in 2027. In a building with 70 per cent of apartments using some form of air conditioning, heat pumps become cost-effective with average heating kWh of about 10,000 in 2018; the break-even point drops to about 7500 kWh by 2027. For buildings in which all apartments have air conditioning, heat pump retrofits are cost-effective in 2018 if annual space heating consumption is at least 8000 kWh; the break-even point drops to about 5300 kWh by 2027. While the average EMURB space heating baseline per suite is approximately 6,000 kWh/year, some EMURB properties have been found to have annual baseline electricity use for space heating as high as 17,000 kWh per suite per year.

Achievable Potential Cost-Effectiveness

In all three of these scenarios, we implicitly assumed that promotion of heat pumps into EMURBs would be done through the existing Save on Energy Heating & Cooling Incentive Program for single family customers extended to multi-family dwellings. This would leverage the existing program management infrastructure and minimize additional program costs. However, we did assume that there would be some additional program costs to cover significant marketing to trade allies and EMURB owners, training of trade allies, and other market development activities – starting at about $0.5 million in 2018 and ramping up to $2 million per year in 2020 and beyond. We also assumed some incremental additional overhead costs – about $75 per rebated heat pump – to account for costs associated with rebate processing, quality control inspections on five per cent of rebated units, handling with additional program inquiries/questions from trade allies and customers, etc. These assumptions had the effect of increasing program TRC costs by about two per cent for the maximum achievable scenario, eight per cent for the current IESO program (low) achievable scenario and four per cent for the medium achievable scenario.

Year	Baseline Heating (kWh): No AC	Baseline Heating (kWh): 70% AC	Baseline Heating (kWh): 100% AC
2018	14,978	9,950	7,796
2019	14,529	9,542	7,405
2020	14,157	9,197	7,072
2021	13,770	8,844	6,733
2022	13,608	8,649	6,523
2023	13,483	8,475	6,329
2024	13,251	8,234	6,084
2025	12,997	7,981	5,832
2026	12,789	7,755	5,598
2027	12,519	7,493	5,339

Table 13: EMURB Unit Heating kWh at which Heat Pump Retrofits Become Cost-Effective

Year	Low Achievable	Medium Achievable	Max Achievable
2018	0.68	0.71	0.72
2019	0.70	0.73	0.74
2020	0.71	0.74	0.75
2021	0.73	0.76	0.77
2022	0.74	0.77	0.78
2023	0.75	0.78	0.79
2024	0.77	0.80	0.81
2025	0.78	0.81	0.83
2026	0.79	0.83	0.84
2027	0.81	0.85	0.86

Table 14: TRC Benefit-Cost Ratios for Achievable Potential Scenarios

Program Administrator Cost Test

The Program Administrator Cost Test (PACT) considers only the utility system costs and benefits – it essentially subtracts both additional costs that program participants incur and additional benefits program participants receive from the TRC results. Sometimes called the Utility Cost Test (UCT), the PACT measures the cost-effectiveness of supply-side investments in programs. If avoided supply costs are shown to exceed costs incurred by the program, administrator average costs will decrease and a program is expected to be cost effective.

As with the TRC, we assessed PACT cost-effectiveness through the IESO's cost-effectiveness screening model. The results are shown below. Of the three achievable potential scenarios that we analyzed[10], both the "low potential" and the "medium potential" scenarios were cost-effective under the PACT. The "low potential" scenario was most cost-effective. As PACT results are largely a function of program rebate levels, these results are not surprising. Program rebates tend to be the largest portion of utility costs for most efficiency programs.

The Low and Medium scenario PACT results are significant because they confirm a cost effective business case for extending generous incentives to EMURBs for heat pump retrofits.

Scenario	Cumulative Annual Electricity Savings (MWh) - Yr 10	NPV Net Benefits	Benefit-Cost Ratio
Scenario 1: Low Achievable	168,731	$84,716,951	2.11
Scenario 2: Medium Achievable	506,142	$27,084,687	1.06
Scenario 3: Max Achievable	1,180,998	-$319,113,308	0.80

Table 15: PACT Cost Effectiveness

The Value of Avoided Carbon Emissions

As noted above, the IESO currently uses a 15 per cent non-energy benefits "adder" in its TRC test to account for both non-energy benefits for program participants and environmental benefits such as reduced carbon emissions. This is a rather conservative value as other jurisdictions (e.g. British Columbia, Colorado, Vermont) use adders of 15 per cent or more for just non-energy benefits (i.e. assigning a separate additional value to avoided environmental emissions)[11,12]. In addition, Ontario's 15 per cent adder was developed before the province's current carbon emission reduction commitment.

As a result, we developed an estimate of the value of avoided carbon emissions associated with EMURB heat pump retrofits. Our project team had the following set of assumptions regarding the **future value of avoided carbon emissions**:

We used "updated central" values developed by Environment and Climate Change Canada[13]. Those values start at $40.70 per tonne CO_2 (C$ 2012) in 2016 and increase gradually to $57.80 per tonne CO_2 (C$ 2012) by 2050. Other than for 2016, the estimates are only provided at five-year increments (e.g. 2020, 2025, 2030, etc.). The project team linearly interpolated values for years in between those increments. We also adjusted the numbers for inflation so that we could present results in 2017 dollars.

Scenario	Cumulative Annual Electricity Savings (MWh): Yr 10	NPV Net Benefits	Benefit-Cost Ratio
Scenario 1: Low Achievable	168,731	-$21,738,682	0.91
Scenario 2: Medium Achievable	506,142	-$30,970,740	0.96
Scenario 3: Max Achievable	1,180,998	-$54,991,970	0.97

Table 16: TRC + Carbon Cost-Effectiveness (adapted Societal Cost Test)

Caveats

Our cost-effectiveness results are based on current heat pump technology costs and performance. With a significant effort to promote heat pumps, retrofit costs will likely reduce over time due to economies of scale throughout the supply chain and increased familiarity by contractors. Also, recent innovative improvements have increased the efficiency and performance of heat pumps, with the prospect of more in the future.

BARRIERS AND OPPORTUNITIES

Critical Barrier Categories

Through research and stakeholder engagement, we identified multiple barriers to broad heat pump adoption and opportunities for overcoming market hurdles.

The table below describes the major barriers facing the adoption of heat pumps in EMURBs in Ontario.

In developing the table, we used the ***"Five A's: Barrier Classification and Market Transformation Program Design for Energy Efficient Technologies"*** methodology developed by Natural Resources Canada and Navigant to describe barrier & opportunity analysis findings.[14]

Number	Barrier Category	Definition
A1	**Availability**	Relates to existence (or lack thereof) of technologies, policies, resources or other factors affecting broader uptake of heat pumps.
A2	**Accessibility**	Current market participants' level of access to heat pump market channels, information resources related to heat pumps and retrofits, existence of supportive/preventative policies affecting access to heat pump retrofit opportunities, or other factors blocking access to key elements required to realize heat pump retrofit opportunities.
A3	**Affordability**	Factors negatively impacting the cost effectiveness of a heat pump retrofit from the perspective of key market participants.
A4	**Awareness**	The extent market participants (i.e. distributors, retailers, designers, electrical contractors, and end-users) are aware of heat pumps, knowledge of the opportunity for retrofitting EMURBs, and factors preventing increased awareness.
A5	**Acceptance**	How all preceding factors converge in relation to market acceptance and/or as yet unidentified factors related to form/fit of heat pump solutions affecting EMURB market acceptance (e.g. market, technology, and regulatory impediments).

Table 17: Barrier Categories

Financial Barriers

High Upfront Capital Costs

Retrofitting a building's entire heating system is a capital-intensive intervention. It involves not only heat pump equipment costs, but also other costs such as design, project management, other materials, and labour.

Historically, there has not been strong demand for heat pumps in Ontario. Competition among heat pump market contractors is limited, contributing to higher equipment costs relative to conventional system and service provision. While a full HVAC retrofit will continue to be a large expense, additional heat pump market penetration could help to bring upfront cost down over time.

Extended Payback Periods

Most MURB owners require quick paybacks (or high rates of return) for energy efficiency investments compared to other capital expenditures. A five-year payback is the longest timeframe most owners/operators will consider; many require no more than two or three years. Unfortunately, without financial incentives, payback periods for heat pumps often exceed these strict timelines.

Competing Capital Priorities

Even if building owners' desired payback criteria are met, there are often competing capital priorities. If these capital needs are essential to a building's continued operation (e.g. a roof replacement), or are perceived to offer higher or more certain financial returns, heat pump retrofits take a back seat. Competition for capital applies regardless of whether the owner is self-financing the project or borrowing against equity.

Split Incentives

In buildings where the tenants pay the electricity bills directly, there is even less incentive for the building owner to invest in energy efficiency, especially relatively expensive measures such as heat pumps, as the tenants reap most of the energy cost savings. Building owners mainly benefit from lower electricity costs for common areas and potentially lower tenant turnover (due to reduced cost of living).

Rent Control Limitations

The ability of building owners to recoup major capital investments is significantly restricted by rent controls in Ontario. All pre-1990 EMURBs are subject to rent control. In April 2017, the Ontario Legislature passed rent protection legislation applying to residential units first occupied on or after November 1, 1991. EMURB property owners may lack the knowledge to obtain "above guideline increases" for rent from energy efficiency upgrades such as a heat pump retrofit. Under the Ontario Residential Tenancies Act, 2006, a landlord may apply to the Landlord and Tenant Board of Ontario for an above guideline increase, which is an order permitting that rental charges be increased by more than the guideline permissible annual increase for any or all rental units in a premises if capital expenditures promote energy or water conservation, as per section 126(7)(e) but with some caveats outlined in 126(9).[15]

Awareness and Capacity

Limited Awareness among Building Owners and Operators

Because of the limited market penetration of heat pumps in Ontario's buildings, building owners, building managers and consumers are generally not aware of heat pumps or recent advancements in the technology. They are also probably unaware of the benefits the technology offers, such as electricity savings. Due to virtually no experience in EMURBs with the current generation of heat pump technology there are perceptions that claims of savings and other benefits are unrealistic. Perceptions of risk will be greater for the more expensive measures such as ground source heat pumps and newer technology advancements such as cold climate ductless air-source heat pumps.

In many parts of North America, particularly in colder climate regions, heat pumps installed by early adopters often have a reputation for not providing adequate comfort and for being more expensive to operate than expected. This historic experience, despite technology advancements, will likely exacerbate concerns about risk. High electricity rates compared to cheaper natural gas rates can also lower the perceived attractiveness of heat pumps in Ontario. The lack of awareness and perceived performance risks stalls market uptake.

Limited HVAC Contractor and Consulting Engineer Capacity and Interest

Through our extensive stakeholder engagement we learned that many HVAC contractors and consulting engineers are relatively unaware of recent advances in heat pump technology, particularly cold climate ductless air-source heat pumps. Although very common in Asia and other parts of the world, they have had very limited presence in the North American market until recently. Heat pumps represent a small percentage of total sales for most urban HVAC contractors, as they are unfamiliar with their performance characteristics and energy savings potential.

Some HVAC contractors and engineers may be aware and capable of implementing heat pump retrofits in EMURBs, but will only promote conventional HVAC systems unless directly asked about heat pump retrofits. In some instances, a property owner can have difficulty in finding a qualified contractor to bid on a full property heat pump retrofit for their EMURB.

HVAC contractors might also be unaware of the substantial retrofit opportunity in the EMURB sector due to limited public market intelligence on the size and characteristics of the sector.

And like property owners, engineers and contractors might avoid promotion of heat pumps for EMURBs because they too perceive heat pumps as not being able to perform optimally in Ontario due to the lack of proven examples of EMURB properties retrofitted with modern heat pump technology.

Stakeholder Engagement

For the **Pumping Energy Savings** project, TAF staff conducted a number of stakeholder engagement activities to inform the recommendations report. We engaged 31 stakeholder organizations across multiple sectors through questionnaires, telephone and in-person interviews. The results helped shape our barriers analysis and recommendations. We talked to:

- 7 HVAC industry companies (manufacturers, distributors, designers and installers)
- 6 Ontario Local Distribution Companies
- 5 Non-profits: industry and stakeholder associations and research institutes
- 4 Property management companies
- 3 Social housing providers
- 2 Municipal governments
- 2 HVAC and heat pump industry experts
- 1 Provincial government ministry
- 1 Federal government department

Opportunities

HVAC manufacturer competition driving performance of heat pump technology

Many of the major manufacturers are competing to outdo each other in terms of their system technology innovations for colder climates like Ontario, with the North American retrofit market as a whole being seen as a fertile market for future expansion. The new generation of cold climate ductless air-source heat pumps is very efficient (in both heating and cooling mode) and can function at very low temperatures. And ground source heat pumps, which have always benefitted from leveraging a stable thermal resource (i.e. the ground as a heat source and sink), are also benefitting from advancements in heat exchanger piping technology, drilling techniques, and distribution systems, such as variable refrigerant flow (with VRF being appropriate for air-source as well). This creates an opportunity to cost-effectively displace electric resistance heating that did not exist just five years ago. New improvements are offered every year.

Well-Established Distribution Channels

New heat pump technology will be sold and installed by a network of HVAC contractors in Ontario who have sold related products for decades and likely have established relationships with many multi-residential building owners and managers.

Increased Cooling Comfort

Experience in New England suggests many customers who buy cold climate ductless air-source heat pumps initially look only for cooling and were "sold up" on heat pump technology. A similar opportunity might exist in Ontario's EMURB sector – or at least that the offer of better cooling in addition to heating energy savings would make heat pumps more attractive. Such retrofits could increase electricity consumption in the summer in some buildings (i.e. where there was no pre-existing cooling). It is also likely that cold climate ductless heat pumps would displace much less efficient cooling in other buildings.

Mandatory Energy Reporting and Benchmarking

Ontario's new Energy and Water Reporting and Benchmarking disclosure program for large multi-residential buildings could generate interest in alternatives to existing expensive electric space heating systems.

As retrofits occur, disclosing information on the type of installed HVAC equipment will provide the public the opportunity to better understand the benefits of retrofitting buildings with conventional electric heating systems with heat pumps.

In addition to conservation benefits, energy reporting and benchmarking examples in the U.S. and Europe show positive correlations between energy efficiency and property values. This has been particularly effective when rating or labeling systems were mandatory.

While Canada has been slow to realize such benefits, the federal government has implemented the ENERGY STAR® certification for Commercial and Institutional buildings, and is pushing ahead with implementing an ENERGY STAR® Multi-Family Buildings Program, which would align with Energy and Water Reporting and Benchmarking, and would help Ontario and the rest of Canada with meeting carbon reduction targets.

Building efficiency labelling for MURBs would provide a simplified metric that could be easily promoted by the HVAC industry and real estate professionals. It could drive demand in the condominium and rental sector for properties with higher ratings, lead to higher property values, and increase property owner interest in implementing more energy efficient heating systems (e.g. heat pumps).

Gas Utility Support for Geothermal Heat Pump Loops

Enbridge Gas Distribution Inc. (Enbridge Gas), working with Ontario Geothermal Association, the Ministry of Energy, and Ministry of Environment and Climate Change (MOECC), have applied to the Ontario Energy Board (OEB) with their proposed utility framework for owning and maintaining geothermal loops while customers would own and maintain their own heat pump systems. In Enbridge's application they mention that the program may be expanded to multi-family customers in the future.[16] Both the Enbridge proposed geothermal program and a new provincial ground source heat pump rebate program, if expanded to EMURBs and gas-heated MURBs, would make retrofitting to a ground source heat pump system a viable alternative for many property owners.

On May 30, 2018 Enbridge Gas filed Procedural Order No. 3, an application with the Ontario Energy Board (OEB) titled "Application for approval of the cost consequences of the proposed Renewable Natural Gas Enabling Program and Geothermal Energy Service Program" in relation to file number EB-2017-0319, bringing the province one step closer to having a major utility model for ground source heat pump systems.[17] The application letter states: "Enbridge Gas Distribution Inc. (Enbridge Gas) filed an application with the Ontario Energy Board (OEB) seeking approval for the cost consequences of its proposed Renewable Natural Gas Enabling Program and Geothermal Energy Service Program. This includes approval of the methodology to set the service fees for each program and recording the annual sufficiency/deficiency of the programs within the Cap and Trade Compliance Obligation Variance Accounts."[18] Enbridge Gas has indicated recognition of the importance for reducing carbon emissions and legal obligations under Cap and Trade, including the promotion of fuel switching such as through geothermal.[19]

New Incentives and Financing Programs Under Development

Ontario's Climate Change Action Plan budgeted $300-$400 million for multi-unit residential building sector retrofits.[20] The federal government also announced that several billion dollars will be available for social housing retrofits, out of the new $13.2 billion National Housing Co-Investment Fund (NHCF), which could help to fund EMURB heat pump retrofits in Ontario.[21]

Categorization of Identified Barriers and Opportunities

No.		A1	A2	A3	A4	A5
		Availability	Accessibility	Affordability	Awareness	Acceptance
B1	High Upfront Capital Costs			X		X
B2	Extended Payback Periods			X		X
B3	Competing Capital Priorities			X		X
B4	Split Incentives			X		X
B5	Rent Control Limitations			X		X
B6	Building Owner/Operator Limitations	X	X		X	X
B7	Contractor/Consultant Limitations	X	X		X	X
O1	New High-Performance Products	X				X
O2	Well-Established Distribution Channels	X	X		X	X
O3	Increased Cooling Comfort		X			X
O4	Mandatory EWRB	X			X	X
O5	Gas Utility Support for Geothermal	X	X	X		X
O6	New Incentives and Financing Programs			X		X

Table 18: Categorization of Barriers and Opportunities

RECOMMENDATIONS

A key objective for this work was to develop recommendations that address barriers preventing scaled up adoption of heat pumps in the sector. While each of the following recommendations can assist with increasing market adoption in some way on their own, realizing optimal conservation potential will require coordinated action across a number of the recommendations.

Research, Development, and Demonstration

Support Demonstration Projects

Demonstration projects can build awareness and acceptance of heat pump retrofits in the EMURB market, while addressing perceived performance and reliability risks. All stakeholder groups consulted consistently flagged the need for demonstration projects. Results could also improve future policies and programs by providing a better understanding of actual costs, performance, and savings.

Demonstration projects can also act as 'living labs.' The lessons learned can inform strategies for lowering costs and improve savings in the future. Projects should be collaborative, including participation from local distribution companies, municipal governments, the Federation of Canadian Municipalities, federal infrastructure programs, real estate associations, and portfolio managers. TAF's TowerWise program team are already working on demonstrating the viability of heat pump retrofits in EMURBs in four archetypal EMURB properties in the Greater Toronto and Hamilton Area as part of a multi-year project contributing to scale-up of this conservation opportunity. The TowerWise team aims to release case study reports after post retrofit performance monitoring, which will be made available on the TAF website. However, as TAF's Ontario EMURB market study revealed, the EMURB sector has a diversity of property characteristics. Increasing the number of retrofit examples will help show the business case for different styles of EMURBs and reduce perceptions of risk.

Explore Program and Policy Options for Gas-Heated Buildings

While this project primarily focused on the adoption of heat pumps in EMURBs, heat pumps in gas-heated MURBs (GMURBS) pose a much larger energy conservation opportunity. Currently, GMURB heat pump retrofits are not economically viable due to the relatively high cost of electricity compared to natural gas. However, we should explore policy and program options that could make heat pumps viable for GMURBs.

Explore Development of an Automated Demand Response Program

Implementing an Automated Demand Response program such as Peaksaver for heat pumps could allow for opportunities such as 'supercharging' a retrofitted EMURB during early and later hours with space heating and scaling back during on-peak periods. Supercharging could entail ramping up the amount of heat being generated and creating a surplus of thermal energy in specific building areas (e.g. common areas) that could dissipate to other areas of the building. Supercharging would reduce the need for operating heat pumps during on-peak periods. Improving the thermal performance of a building envelope in some or all areas as part of a heat pump retrofit will help balance heating levels once 'supercharged'. The program could also ensure that the increased uptake in heat pumps does not significantly burden the grid during peak summer periods due to increased space cooling demand.

Incentives and Financing

Boost Marketing of Heat Pumps Through IESO and Local Distribution Companies

Many Ontario EMURB owner/operators are unaware of heat pump technologies, the opportunity for retrofitting, and existing Save on Energy commercial incentives for heat pump retrofits. Thus, targeted outreach is critical. Local distribution companies can identify EMURB buildings and direct targeted marketing materials and outreach activities directly at EMURB customers. A targeted approach can enable local distribution companies to identify the EMURB properties most likely to be cost-effective for retrofitting initially until costs decline and the climate change imperative (the need to lower carbon emissions) improves economics for retrofitting other buildings in their service area with heat pumps; either from increased carbon pricing or other carbon reduction strategies manifested as pricing mechanisms that drive the cost of energy conservation down. As part of the Pumping Energy Savings project, we developed a series of algorithms that can be replicated in MS Excel to identify EMURB sites out of an LDCs customer database with a high level of confidence (see Appendix C). Our project team tested this approach successfully with one local distribution company's customer database. Others could quickly and easily replicate this process with their own customer database.

Ensure EMURBs Have Access to Retrofit Financing Options

A plan should be developed and implemented to ensure all EMURB market segments have access to a range of attractive financing options for retrofits. This will require investigation of a variety of financing approaches and barriers. Possible options may include the provision of public financing, credit enhancements (e.g. through the Canada Infrastructure Bank), or other third party financing options. In addition to offering financing, alternative ownership models, such as equipment leasing/rental services or utility ownership models, should also be explored for their potential to accelerate adoption of heat pumps for EMURBs.

Based on the diversity of buildings and ownership structures in the EMURB sector, multiple options will likely need to be made available to owners to achieve the greatest conservation results. See Appendix D for a list of possible options EMURB owner/operators could use to implement a heat pump retrofit.

Financing agents would benefit from using the reporting and certification programs for Ontario MURB properties and retrofit projects to streamline the review and approval of retrofit project financing applications. Examples include:

- Ontario's new Energy and Water Reporting and Benchmarking (EWRB) disclosure program for large multi-family buildings can provide investors with rich open data to evaluate financing opportunities.
- Building sector stakeholders are considering the Investor Confidence Project's (ICP) Investor Ready Energy Efficiency™ (IREE) certification program for Ontario to increase investor confidence in energy efficiency building retrofits.[22] IREE certification, like LEED certification, is part of the Green Business Certification Inc.'s (GBCI) portfolio of official certifications. Developed in Europe, IREE signifies adherence to best practice technical standards and assurance of predictable energy savings. Retrofits must be approved by an ICP Quality Assurance Assessor to achieve IREE certification. GBCI in partnership with the Canada Green Building Council (CaGBC) have created GBCI Canada. In March 2018 GBCI Canada, CaGBC and the Advanced Energy Centre at MaRS Discovery District (MaRS) began recruitment of Canadian pilot property sites to participate in applying for IREE certification for their property's project.

Enhance EMURB Sector Incentives

While existing incentive programs available to EMURB property owners improve the financial feasibility of a heat pump retrofit, current incentive levels will not be sufficient to trigger accelerated widespread heat pump retrofits for EMURBs. Enhanced incentives will help bring down the high upfront cost of heat pump retrofits to appeal to a wider range of property owner types.

Here's a list of possible enhanced incentives:

- **Top-ups to existing incentive programs**: Provincial tax dollars could be used as a top-up to existing incentive programs.
- **Extending generous incentives available for retrofitting single family homes with cold climate ductless air-source heat pumps to multi-family buildings:** The IESO and the recent GreenON's residential HVAC programs already offered a substantial rebate for single family homes to install cold climate ductless air-source heat pumps. A prescriptive incentive such as the Save on Energy Heating & Cooling Incentive Program, could also work for EMURBs as single family homes arguably share the same contextual issues around diversity of property characteristics. This can also improve social equity, as a high proportion of MURB residents are low-income households.
- **Development of new programming specifically catering to heat pump retrofits in EMURBs:** We identified this as the least optimal solution; it would be more cost effective to leverage existing programming elements instead of developing brand new programs.

Target incentive levels should be at a threshold that allows projects to be realized within EMURB property owner existing decision-making parameters. Our research identified simple payback as a dominant metric used among EMURB property owners to measure viability of conservation measures – despite its severe shortcomings (see TAF's recent blog on the drawbacks of simple payback here: http://taf.ca/simple-payback-retrofit-decision/). Projects with paybacks of five years or less are given serious consideration and have a higher likelihood of implementation success. However, the volume of cash flow freed up by a retrofit project is also an important factor and could positively affect an owner's choice to advance a retrofit project with a payback longer than five years. In the case of heat pump retrofits, we would see significant cost savings for EMURBs.

While incentives are important, private capital is an important element in speeding up the adoption of heat pumps. Rebates should act only to supplement owners existing capital and/or private financing, with private capital given the opportunity to take a foothold in the sector as a viable financing source.

Promote Best In-Class Heat Pumps by Aligning Incentives with Efficiency

Higher incentives should be provided for higher performing heat pumps. Setting a minimum level of efficiency eligible for certain levels of incentives can maximize conservation potential by promoting heat pumps with features that make them the best suited for the Ontario context (e.g. cold climate ductless heat pumps).

Explore the Potential for Bulk Purchasing

As part of a new or enhanced incentive program, the IESO and/or a provincial entity could secure high volume bulk purchase pricing that could be extended to participating EMURB property owners. Fair conditions would allow all industry members the opportunity to participate and benefit from extension of bulk purchasing to EMURB market customers.

Based on market penetration assumptions, the IESO and the provincial government could secure high volume bulk purchase pricing that can be extended Ontario-wide to EMURB property owners via local distribution companies and distribution channel partners. Research shows that renewable energy bulk purchasing programs are an effective means to overcome market hurdles and transform local markets for installation of innovative low-carbon technologies. Pioneered successfully in Portland, Oregon with solar photovoltaic system purchases and installations, bulk purchasing programs now exist for heat pumps as well (e.g. the Solarize Freeport Mini-Split Heat Pump Bulk Purchase Program – Freeport, Maine).[23] Manitoba Hydro also piloted the Community Geothermal Program where a third-party carrying out feasibility studies for First Nations Communities offers a bulk purchase price for heat pump units.[24]

Capacity Building and Quality Assurance

Establish a Streamlined Measurement and Verification (M&V) Protocol

The IESO should work with stakeholders, including TAF, to formulate clear guidelines regarding the M&V requirements that are functional for the EMURB sector to increase accessibility for owners and channel partners applying for heat pump incentives. Optimal data results could also lead to development of prescriptive incentives for heat pump retrofits for EMURBs, accelerating uptake in the sector.

Incorporate Robust Quality Management in New Incentive Programs

Poorly installed heat pump systems can compromise energy savings, create maintenance challenges, and generate a range of nuisances for property owners. New incentives for heat pump retrofits should incorporate strong quality assurance/control processes to ensure that poor quality installations do not undermine market transformation.

The IESO, local distribution companies, distributors, industry associations (e.g. the Heating, Refrigeration and Air Condition Institute), consulting engineers, and/or individual contractors could assist with developing these protocols.

Regulatory

Explore new Ontario Building Code Renovation Requirements to Drive Adoption

The Province of Ontario is in the process of making the next update to the Ontario Building Code (scheduled for 2022). This update should include renovation requirements that accelerate EMURB heat pump retrofits. For example, electrically heated buildings undergoing HVAC renovations could be required to incorporate heat pumps, and/or prohibited from converting to natural gas heating.

Overview of Recommendations

Research, Development, and Demonstration

Recommendation	Barriers Addressed	Description
Support demonstration projects to help kick-start the heat pump retrofit market	B1, B2, B3, B4, B6, B7	More retrofit case studies are necessary to prove the application of heat pumps in Ontario EMURBs to reduce consumer perceptions of risk. Particularly, we need to address concerns of high upfront costs and uncertainty of the technical and financial feasibility of heat pump retrofits due to a lack of retrofit examples. Early adopters, with substantial financial assistance, can implement co-funded demonstration projects. This will accelerate the much-needed market intelligence gathering and increase public awareness of heat pump retrofit opportunities.
Explore program and policy options for heat pump retrofits of gas-heated buildings	B1, B2, B6, B7	Both gas-heated and electrically-heated multi-unit residential building owners in Ontario have limited awareness of heat pump retrofits. Engineers and mechanical contractors do not often promote the idea of heat pumps for the gas-heated sector, primarily due to the currently weak business case. Heat pump technology improvements continue to increase the efficiency of air-source and ground source heat pumps. However, more aggressive carbon pricing regimes and/or other market pricing mechanisms are needed to justify the high upfront incremental cost compared to conventional systems and balance the disparity between gas and electricity rates. One example is the United Kingdom's Renewable Heat Incentive tariff (RHI) program, which offers a fixed contract rate per kilowatt of renewable heat delivered. This program delivery model is similar to the Ontario solar feed-in tariff (FIT) program.
Explore the development of an Automated Demand Response program for heat pumps.	B2, B6	An automated demand response (ADR) program can help control costs and burden to the grid and for property owners by reducing electricity usage during peak periods. By utilizing the heat pump during off-peak periods and ramping down electricity consumption during on-peak periods, electricity costs can be reduced, which optimizes savings and helps maintain a shorter payback for a heat pump retrofit. By having utilities optimize the electricity consumption of a heat pump via an ADR program would also help to reduce the risk for property owners to have unanticipated rises in electricity usage associated with peak cooling, particularly if an EMURB had limited space cooling electricity use prior to a heat pump retrofit.

Incentives and Financing

Recommendation	Barriers Addressed	Description
Boost IESO/LCD marketing of heat pumps with a priority focus on EMURBs	B1, B6, B7	Targeted marketing and engagement directly to EMURB property owners can help raise the profile of heat pump retrofit opportunities and increase owner awareness of high performing technologies. The IESO can help connect distribution and contractor channel partners with property owners, which can increase speed up adoption and demonstration the effectiveness of heat pumps.
Ensure EMURBs have access to suitable retrofit financing options	B1, B2, B3, B4, B6, B7	In many cases, property owners cannot finance a full property heat pump retrofit on their own due to the high upfront cost. Financing and/or HVAC leasing can incentivize EMURB owners. The most appropriate solution will depend on property characteristics, such as ownership and metering type.
Provide enhanced incentives to the EMURB sector	B1, B2, B3, B4	Stakeholder engagement and research indicate that that high upfront capital costs and extended paybacks for heat pump retrofits continue to be major barriers to widespread adoption of heat pumps in the EMURB sector. Unfamiliar with the benefits from heat pump retrofits, most property owners will avoid the sizable investment. Greater financial assistance would help to alleviate concerns regarding financial risk and accelerate adoption.
Promote best in-class heat pumps by scaling/aligning incentives with heat pump efficiency	B6, B7	The best in-class heat pumps should be promoted with preferential treatment. This will help to increase positive perceptions of new and more efficient heat pumps for the Ontario market, leading to greater conservation results.
Explore the potential for bulk purchasing	B1, B2, B3, B6, B7	Current market price breaks offered by consulting engineers and contractors to individual EMURB property owners when retrofitting multiple suites will not be sufficient to overcome financial hurdles. If an EMURB undergoes a feasibility study to assess a full property conversion to heat pumps, there will already likely be price breaks identified based on the economies of scale from retrofitting multiple residential units. However, the business case for a single property may still not be enticing enough for a property owner to proceed. The cost of equipment could decrease for EMURB property owners, if volume bulk purchase pricing becomes available, e.g. via local distribution companies and well-established HVAC equipment distribution channels in Ontario. A bulk purchase program, developed with appropriate oversight from utilities, government, and/or industry associations, could create an even playing field for various size firms to participate. This would likely increase interest and support from Ontario HVAC industry players to help drive the opportunity for EMURB heat pump retrofits.

Capacity Building and Quality Assurance

Recommendation	Barriers Addressed	Description
Establish a streamlined Measurement & Verification (M&V) protocol for securing EMURB heat pump incentives	B3, B6, B7	There is a need to develop and demonstrate appropriate measurement & verification (M&V) procedures specifically associated with heat pump retrofits. Due to a lack of knowledge or interest in implementing rigorous measurement and verification methods, property owners and/or channel partners often consider other efficiency upgrades that are easy to implement, have shorter paybacks, and are easier to obtain incentives for. Stakeholder uncertainty of the appropriate M&V procedures for heat pump retrofits discourage local distribution companies and channel partners from promoting heat pumps as part of existing conservation programs. Clearer guidelines on how to implement high quality M&V on projects would help refine existing conservation programs.
Incorporate robust quality management strategies in any new incentive programs	B6, B7	Strong quality management protocols will help ensure proper savings are achieved with any EMURB heat pump retrofits, reduce concerns from building owners on the performance and operations of heat pumps post-retrofit, and improve the perception of heat pumps for potential market transformation.

Regulatory

Recommendation	Barriers Addressed	Description
Explore options for new Ontario Building Code renovation requirements to drive heat pump adoption	B6, B7	If the next version of the Ontario Building Code (slated for 2022 release) included mandatory requirements at time renovation and high-efficiency heat pumps were established as the minimum requirement, early EMURB participants could raise awareness of the multiple benefits from heat pump retrofits and reduce risk perceptions among building owners.

NEXT STEPS

Turning our recommendations into reality is a crucial step in speeding up the adoption of heat pumps in Ontario, but it's not the only one. In the next phase of **Pumping Energy Savings** will further explore and refine recommendations as well as address barriers to heat pump adoption in EMURBs through:

Demonstration Projects

Four archetypal EMURBs in the Greater Toronto Hamilton Area will undergo deep retrofits featuring heat pumps as part of TAF's TowerWise program. These buildings will as act as 'living labs' to test the economic and technical feasibility of heat pump retrofits and generate lessons learned and best practices to support scale-up. The demonstration projects will address perceived risks by showcasing heat pumps as an alternative to conventional electric space heating.

Measurement and Verification Guidelines

Building on the International Performance Measurement and Verification Protocol (IPMVP) framework, we will develop guidelines for M&V for heat pump retrofits (including basic and advanced options) to support large-scale adoption efforts.

Financing Options

Based on real cost and savings opportunities from demonstration sites, we will assess the business case for heat pump retrofits, identify and/or develop suitable financing options to support scale-up.

Scale-up Strategy

Following this report and drawing on findings from the demonstration projects, we will draft a scale-up strategy for heat pumps in Ontario. We will incorporate new policy and program developments, as well as refine and update our current recommendations. We will further investigate capacity gaps associated with designing, financing, measuring, verifying, and operating heat pumps as well as address stakeholder concerns and expand on methods for increasing building owner confidence.

CONCLUSION

Ontario should seize the opportunity to retrofit EMURBs with heat pumps to help achieve its energy and climate goals. Action must start now as the implementation of necessary interventions to transform the market requires a significant amount of time.

Given the current low adaptation rate for heat pumps in Ontario, the task might seem daunting, but it is feasible as our findings show. Our recommendations, based on an analysis of Ontario's EMURB market, detailed cost-effectiveness modelling, and thorough assessment of market barriers, will help capture this conservation potential. Ultimately, a number of market barriers need to be removed to unlock the substantial conservation potential of EMURB heat pump retrofits. These include gaps in awareness and capacity; lack of suitable financing; and perceived performance risks due to lack of experience in the market and poor historical perceptions of the technology.

Through the **Pumping Energy Savings** project, TAF already addresses several of the report recommendations with valuable information and tools to showcase the technical and economic feasibility of EMURB heat pump retrofits, e.g. through its Excel-based Business Case Analysis Tool (BCAT) for building owners. In the next phase of **Pumping Energy Savings**, we will implement a number of demonstration projects and create a more detailed scale-up strategy.

However, many recommendations require a targeted, comprehensive and ideally coordinated approach from other stakeholders, including local distribution companies, the IESO, the Ontario government, and the retrofit/HVAC industry:

Local distribution companies should begin by identifying the specific EMURB buildings within their service territory to determine the volume and location of EMURB stock. The TAF-developed BCAT tool and methodology outlined in Appendix C will be useful here. The project team tested this approach successfully with one local distribution company's customer database; other companies could quickly and easily replicate this process. From there, local distribution companies should direct targeted marketing materials and outreach activities directly at EMURB customers. Targeted outreach is critical as our research confirms that most EMURB owners have limited awareness of heat pump technology and its cost-saving potential.

IESO: Targeted marketing and outreach efforts need to be flanked by enhancements to the current incentive programs available to EMURBs for heat pump retrofits.

Our analysis of the barriers and opportunities confirmed the need for enhanced incentives to help scale up adoption of heat pumps in the sector. With regards to evaluating the need and capacity to administer dedicated programming, we assessed the cost-effectiveness of utilities offering enhanced incentive levels with several test methodologies, including the Total Resource Cost Test (TRC) and Program Administrator Cost Test (PACT) approaches currently used by the IESO to evaluate cost-effectiveness of Conservation Demand Management (CDM) programming. Our analysis showed a need for extension of an existing program, or creation of a dedicated CDM program, for greater uptake of heat pumps to occur in the Ontario EMURB sector. The PACT-supported provision of enhanced incentives, equivalent to the recent GreenON single family home rebates for heat pump retrofits, would be cost-effective if extended, or made as an equivalent dedicated program, to EMURBs. Our analysis also showed leveraging of IESO and provincial funds for an even greater incentive for EMURB heat pump retrofits would help to increase adoption of heat pumps in this sector.

Ontario government should also explore a number of actions, including the provision of low-cost financing options for property owners, continued delivery of grants programs for supporting early demonstration projects, regulatory reform to support heat pump retrofits (like the OBC updates), public awareness raising campaigns around the EMURB retrofit opportunity for property owners and retrofit professionals, and development of policies for making gas-heated MURBs viable candidates for heat pump retrofits.

Retrofit/HVAC industry stakeholders can provide assistance to government and utilities for developing policies and programs that would contribute to scaling up adoption of heat pumps in EMURBs. Support could take the form of steering committee participation, information sharing, pilot program development, testing, evaluation, and/or program administration. The IESO already has a relationship with the Heating, Refrigeration and Air Conditioning Institute (HRAI), with qualifying HRAI registered contractors being able to offer single family home owners the IESO heat pump retrofit incentives. Relationships like that between IESO and HRAI should continue to be leveraged to help identify ways to raise interest and capacity amongst retrofit professionals for EMURB heat pump retrofits. The retrofit/HVAC industry can also help drive the EMURB heat pump retrofit opportunity forward by engaging with LDCs on ways to conduct targeted outreach and promotion to inform EMURB property owners of the benefits of switching to heat pumps. To promote further interest amongst property owners, retrofit professionals and manufacturers should explore the potential for offering attractive heat pump retrofit financing in addition to available incentives. Further financial breaks to EMURB property owners could be realized if the retrofit/HVAC industry could work with utilities and/or government to offer a bulk purchasing program. This could be done in conjunction with incentive programming or as a standalone program.

Ontario has a relatively large concentration of EMURBs, most of which are at an age (30+ years) where major building retrofits are needed. Without dedicated effort to convert these buildings to heat pumps, increasing financial pressure and the disparity between lower gas prices versus electricity rates may cause EMURB owners to convert instead to natural gas heating, which would undermine Ontario's ability to meet its long-term carbon emissions reduction targets. Furthermore, the Ontario Government has tasked Local Distribution Companies (LDCs) with achieving a combined seven terawatt (TW) of conservation by December 2020. Retrofitting EMURBs across Ontario with energy efficient heat pumps could make a meaningful contribution to achieving that target. Accelerating the conversion of EMURBs to heat pumps will require multiple key interventions at critical junctures by key stakeholders. TAF has outlined pragmatic ways that those key stakeholders can work together and realize this tremendous energy conservation opportunity both cost effectively and in the near term. The accelerated uptake of EMURB heat pump retrofits and the deep decarbonisation of Ontario's space heating for MURBs are within reach.

APPENDICES

Appendix A: Conservation Potential Core Assumptions

Assumption	Share of Total EMURB Units	Estimated # of EMURB Units
0 bedrooms	6.7%	27,135
1 bedroom	38.7%	156,735
2 bedrooms	42.8%	173,340
3 bedrooms	11.7%	47,034
Total	100%	405,000

Table 19: Estimate of Ontario EMURB Market by Number of Bedrooms

Data for 0-1 bedroom, 2 bedroom and 3 bedroom units was taken from Statistics Canada's 2016 Census data for Ontario.[25]

Statistics Canada data for 0-1 bedroom units is further broken down into 0 bedrooms and 1 bedrooms based on Canada Mortgage and Housing Corporation's Rental Market Reports for Ontario cities which suggests that about that ratio of 1 bedroom to 0 bedroom is about 85:15.[26]

The number of total EMURB housing units in Ontario is based on TAF's recent market characterization study.[27]

	Assumption	Values Used	Basis or Source
1	Baseline heating kWh per EMURB housing unit	5948	TAF's analysis of monthly electric billing data for several hundred buildings. We assumed that buildings with an average December-February monthly electric consumption at least 1.5 times the average for May and September, which had at least 2000 kWh per year (weather-normalized) of estimated space heating consumption, were primarily heated with electricity.
2	Baseline seasonal average COP	1.0	Assumed to be electric resistance
3	Heat pump seasonal average COP	2.7	Mid-point of a range of 2.4 to 3.0 found in recent ductless heat pump meta-study.[28]
4	Average heating kWh savings per EMURB housing unit	3745	Calculation based on assumptions above: 5948 x [(2.7 - 1.0) / 2.7]
5	Baseline cooling kWh per EMURB housing unit (for those that have it)	1004	EnerGuide estimated consumption for two 8000 Btuh window air conditioners meeting minimum federal efficiency standards (EER 9.8) in Toronto.[29]
6	Baseline cooling EER	9.8	See above
7	Heat pump cooling SEER	22.9	Average for cold climate ductless heat pumps on the Northeast Energy Efficiency Partnerships' qualify list.[30]
8	Heat pump cooling kWh savings (for EMURB units with baseline cooling)	574	Calculation based on assumptions above: 1004 x [(22.9 - 9.8) / 9.8]

9	% of EMURB units with baseline cooling	70%	TAF's Market Characterization report found that 96 per cent of all EMURBs had some form of cooling – mostly window A/C or PTAC. We estimated an approximately 70 per cent value for baseline cooling based on available information. While not all units within those buildings had some form of cooling, there is no available definitive information on the portion that did. It is also likely that some units that do not currently have A/C will add it in the coming years, though it is impossible to precisely state how many.
10	Peak kW savings (for those EMURB units with cooling)	0.642	IESO Conservation Demand Management Energy Efficiency Cost-Effectiveness tool calculation based on estimated cooling kWh savings and IESO load shapes used in analysis.
11	Measure/Savings life (years)	18	Assumption for Residential Heating & Cooling program as per TAF consultant and IESO.
12	Savings load shapes	**Heating:** IESO Conservation Demand Management Energy Efficiency Cost Effectiveness tool's "Residential-Space_Heating_Room" module. **Cooling:** IESO Conservation Demand Management Energy Efficiency Cost-Effectiveness tool's "Residential-AC_Room" module.	
13	Heat pump average retrofit cost per EMURB unit	$6,332	Average cost to retrofit an EMURB suite with heat pumps based on five detailed TAF audits and project consultant assumptions from previous work on development of CDM programming; assuming a retrofit cost of $4,075 for a single head + $2,275 per additional head net of rebates equivalent to the current Save on Energy Heating & Cooling Incentive Program for Cold Climate Ductless (and Multiport) air-source heat pump retrofits; after discounting 18 per cent for savings from EMURB bulk purchase price TAF audit assumptions. Average cost reflects assumed average # of 2.6 heads per EMURB suite. Assumes heads needed equal to number of bedrooms plus 1 and related to a weighted average of estimated number of EMURB suites by size in Ontario (Used best available data from Statistics Canada on number of MURB units by number of bedrooms). 0 BRs 1 head $3,352 6.7% 1 BRs 2 heads $5,224 38.7% 2 BRs 3 heads $7,095 42.8% 3 BRs 4 heads $8,967 11.7%
14	Assumed Annual Operating Hours (Heating Mode)	2000	IESO Conservation Demand Management Energy Efficiency Cost-Effectiveness tool generated these numbers based on custom measure inputs provided by a TAF consultant. Please note that these numbers in reality will be context specific depending, but not limited to, system size, efficiency, and EMURB thermal envelope performance.
15	Assumed Annual Operating Hours (Cooling Mode)	615	IESO Conservation Demand Management Energy Efficiency Cost-Effectiveness tool generated these numbers based on custom measure inputs provided by TAF consultant. Please note that these numbers in reality will be context specific depending, but not limited to, system size, efficiency, and EMURB thermal envelope performance.
16	Heating Degree Days	10 year average: 2007 to 2016	TAF's analysis of monthly electric billing data for several hundred buildings to estimate space heating consumption, assumed to be heated primarily with electricity, was weather normalized to a 10 year average.

Table 20: Heat Pump Measure Assumptions

Appendix B: GMURB Retrofit Sensitivity Analysis

Gas prices will need to rise before electric powered heat pumps are a viable alternative to high efficiency gas heating systems for existing buildings already equipped with gas heating. Currently, there is no compelling business case in Ontario for gas-heated multi-unit residential building (GMURB) owners to switch from the status quo to electric powered heat pumps due to the higher cost of electricity over current gas prices. However, associated energy cost savings may be sufficient to warrant a retrofit with higher gas prices and/or cases where the existing gas HVAC system has a low enough operating efficiency compared to a prospective higher efficiency heat pump system.

This section looks at where the price of gas must go to make heat pumps more attractive economically than gas fired HVAC systems. Tables 21, 22, and 23 show forecasted carbon prices and associated natural gas rates based on information provided by ICF Consulting Canada to the Ontario Energy Board prior to the 2018 phase out of cap-and-trade.[31] Table 24 and 25 show gas and electricity price assumptions. Table 6 shows a comparison of the cost per equivalent-kilowatt-hour-thermal (CAD $/ekWh$_{th}$) for assumed natural gas and electricity prices based on specific gas and heat pump system efficiency scenarios.

Long-Term Carbon Price Forecast (LTCPF) and Natural Gas Rates in Ontario Prior to 2018 Cap-and-Trade Phase Out

	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Mid-Range LTCPF	$17	$18	$18	$19	$20	$21	$31	$36	$43	$50	$57
Minimum LTCPF	$17	$18	$18	$19	$20	$21	$22	$23	$24	$25	$27
Maximum LTCPF	$67	$70	$74	$77	$81	$85	$89	$94	$98	$103	$108

Table 21: Ontario Long-Term Carbon Price Forecast Scenario Results in Real 2017 CAD $/t$CO_2$e under Cap-and-Trade[32]

	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Mid-Range LTCPF	0.03	0.03	0.03	0.04	0.04	0.04	0.06	0.07	0.08	0.09	0.11
Minimum LTCPF	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.04	0.05	0.05	0.05
Maximum LTCPF	0.13	0.13	0.14	0.14	0.15	0.16	0.17	0.18	0.18	0.19	0.20

Table 22: Ontario Long-Term Carbon Price Forecast Scenario Results in Real 2017 CAD $/m under Cap-and-Trade[33]

	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Mid-Range LTCPF	0.003	0.003	0.003	0.003	0.004	0.004	0.005	0.006	0.008	0.009	0.010
Min. LTCPF	0.003	0.003	0.003	0.003	0.004	0.004	0.004	0.004	0.004	0.004	0.005
Max. LTCPF	0.012	0.012	0.013	0.013	0.014	0.015	0.016	0.017	0.017	0.018	0.019

Table 23: Ontario Long-Term Carbon Price Forecast Scenario Results in Real 2017 CAD $/ekWh under Cap-and-Trade[34]

Utility Rate Assumptions

Item	Rate
Delivery ($/m3)	$0.1413
Gas Supply Charge ($/m3)	$0.106499
Transportation ($/m3)	$0.053
Total ($/m3 - Not including tax or standard customer administration charge)	$0.3008
Conversion Factor (m3 to ekWh)	10.5567
Total Charge ($/ekWh)	$0.02849

Table 24: Gas Price Assumptions - January 1, 2018 (Enbridge)

Natural Gas rate includes delivery, transportation, and gas supply charges.

Item	Rate
Regulated Price Plan Upper Tier Rate ($/kWh) - price after first 750 kWh	$0.09
Other Charges (including regulatory, delivery and transmission)	$0.06
Total Charge ($/kWh)	$0.15

Table 25: Electricity Price Assumptions ($/kWh)

Other charges such as delivery and transmission charge are only estimates.

Heating Costs for Multi-Unit Residential Buildings by System Efficiency and Carbon Price

The following table shows where the cost of natural gas needs to go to make the cost of heating with a heat pump a viable alternative over conventional natural gas heating systems for multi-unit residential buildings. Three natural gas prices are calculated, using assumed carbon prices, and converted to dollars-per-kilowatt-hour-equivalent. Scenario 1 shows the Equivalent Kilowatt-Hour-Thermal Cost (CAD $\$/ekWh_{Th}$) for heating with different natural gas and electric heating systems, including heat pumps, under assumed market conditions prior to the cap-and-trade phase out. Scenario 2 assumes the cost of heating with an electric ground source heat pump (GSHP) that achieves a seasonal coefficient of performance (sCOP) of 3.7 becomes more cost effective than heating with a high efficiency condensing gas boiler that has an operating efficiency of 90 per cent when carbon prices in Ontario reach approximately $50 per tonne of carbon dioxide equivalent ($\$/tCO_2e$). Scenario 3 assumes the cost of heating with an air-source heat pump with 2.7 sCOP and GSHP with 3.7 sCOP both become more cost effective than heating with a high efficiency condensing natural gas boiler with 90 per cent operating efficiency when the price of carbon is approximately $\$150/tCO_2e$ or greater. Based on the analysis conducted by ICF Consulting Canada, carbon pricing under Ontario cap-and-trade had potential to reach $\$50/ tCO_2e$ or greater at any point over the next 10 years (see Table 21 in this appendix for long-term carbon price forecasts from ICF Consulting Canada). Since the newly elected Ontario Government's direction to exit cap-and-trade in 2018 there is an opportunity for the Federal Government to implement its own carbon tax in Ontario.[35] A much higher carbon price is also within the realm of reality when considering the potential of a national carbon price floor of $\$150/tCO_2e$ or greater for Canada to meet its 2030 objectives as laid out in the Pan-Canadian Framework.[36]

Scenario Assumptions				HVAC System Heating Equivalent Kilowatt-Hour-Thermal Cost (CAD $/ekWh$_{Th}$)				
				Natural Gas Atmospheric Boiler	Natural Gas Condensing Boiler	Air-source Heat Pump	Ground Source Heat Pump	Electric Resistance Baseboards
Carbon Price Forecast	**Carbon Price ($/t$CO_2$e)**	**Natural Gas incl. Carbon Price ($/ekWh)**	**Electricity Rate ($/kWh)**	65% operating efficiency	90% operating efficiency	sCOP 2.7	sCOP 3.7	100% operating efficiency or sCOP 1.0
Scenario 1: 2018 Cap-and-Trade Conditions (2018 Auction Reserve Price)	$14.68	$0.028	$0.15	$0.044	$0.032	$0.056	$0.041	$0.15
Scenario 2: GSHP become cheaper to operate than high efficiency condensing boilers ASHP become cheaper to operate than low efficiency atmospheric boilers	$50	$0.037	$0.15	$0.057	$0.042	$0.056	$0.041	$0.15
Scenario 3: ASHP & GSHP cheaper to operate than high efficiency condensing gas boiler	$150	$0.054	$0.15	$0.085	$0.061	$0.056	$0.041	$0.15

Table 26: Cost of Heating Comparison for Ontario Multi-Unit Residential Buildings by System Efficiency and Carbon Price

Appendix C: Methodology for Local Distribution Companies to Identify EMURBs in Their Service Areas

Identifying EMURBs by Establishing the WINTER/SHOULDER Season Electricity Use Threshold

With the help of Toronto Hydro, under a non-disclosure agreement, our project team compared seasonal electricity consumption data for all MURBs within the Toronto Hydro service area to identify which customers were electrically heated. We assumed that EMURBs would have higher winter electricity consumption than milder seasonal periods. After the data was cleaned, we generated a series of algorithms that would isolate usable from erroneous data records and compare the two months out of a year with the highest heating degree days (WINTER SEASON) to the two months with the lowest heating and cooling degree days (SHOULDER SEASON). Once reliable WINTER/SHOULDER ratios were calculated for MURBs within the Toronto Hydro dataset (2012 to 2014), we could estimate the quantity of EMURBs present in Toronto. Based on a rigorous analysis of confirmed EMURBs and Natural Gas-heated MURBs, our findings indicated that the majority of EMURBs have a WINTER to SHOULDER electricity consumption variance of 140 per cent and above. The 140 per cent ratio threshold was arrived at through analysis of confirmed EMURB and non-EMURB properties. A comparative analysis of TAF's EMURB and non-EMURB database records revealed that 95 per cent of natural gas-heated MURBs have a WINTER/SHOULDER electricity consumption variance of 139 per cent and below and 90 per cent of EMURBs have a WINTER/SHOULDER variance of 140 per cent and above. The results were reliable enough to utilize the 140 per cent threshold for the analysis of the Toronto Hydro dataset.

Applying the 140 per cent WINTER/SHOULDER threshold to the Toronto Hydro MURB dataset revealed that 19.2 per cent of MURBs in Toronto are assumed to be EMURBs. To ground-truth these findings, we checked to see how many of confirmed EMURBs found within the Toronto Hydro service area and dataset fell within the 140 per cent and above category. Our result: 80 per cent. Although this means that 20 per cent of the confirmed EMURBs were not captured in this approach, we can assume that the quantity of EMURBs that are not captured in the estimate will likely be complemented by captured Natural Gas MURB false positives. Alternatively, the 20 per cent margin of error could be shown as a range indicating the estimated number of MURBs in Toronto that are EMURBs is assumed to be 15.4 per cent to 23.0 per cent of total Toronto MURB stock.

Other local distribution companies in Ontario could utilize this approach to identify MURB customers in their respective service areas that are assumed to be EMURBs and target those with the highest conservation potential first to secure fast wins for EMURB heat pump retrofits.

Increasing EMURB Customer Targeting and Space Heating Electricity Use Estimation Accuracy via Linear Regression Analysis

This analysis can be further augmented with a Linear Regression Analysis of Energy Consumption Data in correlation with heating degree day data to improve your EMURB customer identification accuracy.

Instructions:

- Take 12 months of electricity consumption data (kWh) and 12 months of corresponding heating degree day (HDD) data.
- In an excel spreadsheet put all the monthly kWh data into one column, place the corresponding monthly HDD data to the right of the HDD data.
- In another cell use the INTERCEPT function. Example: =intercept(A1:A12,B1:B12) ; ***where all column A data are kWh's and all column B data are HDDs***. This function will generate the y-intercept.
- Taking the y-intercept value, subtract it from each of the monthly kWh values. If for one of the 12 months a negative value is returned, replace the negative value with zero.
- Add all the differences; the sum is the estimated kWh per year a building uses for electric space heating.
- Dividing that sum with the total annual electricity use will produce the estimated percentage of electricity an assumed EMURB customer uses for space heating.

Generating these ratios for all assumed EMURBs in a local distribution company's service area can aid in focusing customer outreach and conservation measure implementation efforts.

Appendix D: Financing Options for Retrofitting Ontario EMURBs with Heat Pumps

Here is a preliminary list of options that EMURB property owners can consider if they require financing to implement a heat pump retrofit:

FINANCING OPTIONS	DESCRIPTION
Local Improvement Charges	Municipal governments provide loans for property improvements, including energy efficiency measures, with repayment occurring through the property tax bill and onus to repay remaining with the property. On-property-tax-bill financing Administered via municipalities
APPLICABILITY	Multi-family Rental Multi-family Social Housing
STATUS	Currently only available in Toronto. See more information about City of Toronto's High-Rise Retrofit Improvement Support (Hi-RIS) program here: https://www.toronto.ca/community-people/community-partners/apartment-building-operators/hi-ris/
Energy Savings Performance Contractors (ESPC) **Or** **Energy Service Agreement (ESA)**	The service is typically provided by an energy service company which not only develops and implements the plan, but also provides the maintenance during a fixed period after completion. Providers of this type of financing will pay up to 100 per cent of all upfront project costs. ESPCs or ESAs is a building retrofit financing option developed in the private sector. ESPCs are typically performed by an Energy Services Company (ESCO) and include a comprehensive building energy audit, a financial analysis of upgrade options, arrangement of project financing, installation of building upgrades, and post-installation performance monitoring and equipment maintenance. ESPCs are typically designed to be cash-flow neutral, where the amount of monthly energy savings is at least equal to the amount of the monthly payment needed to finance the improvements. Most ESCOs guarantee the projected energy savings and will reimburse the customer if the savings are not realized.[37]
APPLICABILITY	Multi-family Condominium Multi-family Rental Multi-family Social Housing
STATUS	TAF developed the Energy Savings Performance Agreement (ESPA) program. More information here: http://taf.ca/publications/espa-brochure/

On bill utility financing/ repayment programs	Energy consumers can borrow money to carry out retrofits and then pay back the loan as a charge on their energy utility bills. Repayment is usually designed so that monthly payments are approximately equal to (or less than) the savings in energy costs resulting from energy efficiency measures.
APPLICABILITY	Multi-family Condominium Multi-family Rental Multi-family Social Housing
STATUS	Not broadly available in Ontario, although it is permitted. Ministry of Energy filed amendments to Ontario Regulation 161/99 and Ontario Regulation 160/99 on June 2, 2015. The amendments came into effect July 1, 2015. The purpose of the amendments is to clarify that on-bill financing for electricity conservation and demand management measures is an activity that electricity utilities can undertake.
Utility Ownership Model	Under the utility ownership model, the utility provides the necessary upfront costs for the project. In order to recuperate these costs, the utility companies generally charge an "access fee" on top of the residents existing energy bills. Unlike other financing models here, the customers have no ownership to the infrastructure; instead, they pay for the right to access the benefits of the energy produced by the system.[38] As such, in most instances, this type of financing model is used for renewable energy projects, such as solar or geo-exchange.
APPLICABILITY	Multi-family Condominium Multi-family Rental Multi-family Social Housing
STATUS	Examples include: Oakville Enterprises Corporation affiliation with Sandpiper Energy Solutions – Geo-Exchange: http://www.oecorp.ca/products-services/power-generation/ OEC Sandpiper Energy Solutions – Geo-Exchange Presentation to 2017 OGA Conference: http://www.ontariogeothermal.ca/assets/2016-02-05-oga-conference----mike-savel----sandpiper.pdf Town of Gibsons Geo-exchange Utility: http://gibsons.ca/services/geo-exchange-utility/ Fortis, BC: https://www.fortisbc.com/AlternativeEnergyServices/Pages/About-us.aspx

Government Loans	Governments may be able to offer low interest loans at favourable term lengths for energy efficiency upgrades. The Better Buildings Partnership (BBP) – Sustainable Energy Plan financing program below is an example of a municipal government loan program offered by the City of Toronto for energy efficiency retrofits for multi-unit residential social housing.
APPLICABILITY	Multi-family Condominium Multi-family Rental Multi-family Social Housing
STATUS	Examples include: Better Building Partnership (BBP) – Sustainable Energy Plan Financing Program [City of Toronto ONLY] Low interest loan (up to 20 years) Risk with Property Additional funding subject to City budget See info here: https://www.toronto.ca/services-payments/water-environment/environmental-grants-incentives-2/energy-retrofit-loans/
Private Lenders	A private lender is always an option that property owners can explore. It is recommended that a property owner work with a broker who has access to multiple lenders. A downside from pursuing this option is that interest and other fees associated with financing will likely be much higher than with any of the other options. However, this option could make the most sense for individual condo unit owners or smaller independent rental apartment owners depending on the characteristics of the property and estimated cost of the project.
Other	We will continue to explore and identify other viable options that could aid the EMURB sector with financing heat pump retrofits.

Table 27: Retrofit Financing Options

Appendix E: Lifecycle Savings and Greenhouse Gas Emissions Reductions for Technical and Achievable Conservation Potential Scenarios – Retrofitting EMURBs with Heat Pumps

Year #	Year	Marginal Coefficient (tCO_2eq/MWh)	Cumulative Heat Pump #Units in Operation To Date	Lifecycle Savings To Date (MWh)	Lifecycle Greenhouse Gas Reductions To Date ($MtCO_2eq$)
1	2018	0.1853	40,500	174,920	0.03
2	2019	0.1986	81,000	524,759	0.10
3	2020	0.2119	121,500	1,049,517	0.21
4	2021	0.2252	162,000	1,749,195	0.37
5	2022	0.2385	202,500	2,623,793	0.58
6	2023	0.2517	243,000	3,673,310	0.84
7	2024	0.265	283,500	4,897,746	1.17
8	2025	0.2783	324,000	6,297,102	1.56
9	2026	0.2916	364,500	7,871,378	2.02
10	2027	0.3049	405,000	9,620,573	2.55
11	2028	0.3181	405,000	11,369,768	3.11
12	2029	0.3314	405,000	13,118,963	3.69
13	2030	0.3447	405,000	14,868,158	4.29
14	2031	0.358	405,000	16,617,353	4.91
15	2032	0.3713	405,000	18,366,548	5.56
16	2033	0.3377	405,000	20,115,743	6.16
17	2034	0.3377	405,000	21,864,938	6.75
18	2035	0.3377	405,000	23,614,133	7.34
19	2036	0.3377	364,500	25,188,408	7.87
20	2037	0.3377	324,000	26,587,764	8.34
21	2038	0.3377	283,500	27,812,201	8.75
22	2039	0.3377	243,000	28,861,718	9.11
23	2040	0.3377	202,500	29,736,315	9.40
24	2041	0.3377	162,000	30,435,993	9.64
25	2042	0.3377	121,500	30,960,752	9.82
26	2043	0.3377	81,000	31,310,591	9.94
27	2044	0.3377	40,500	31,485,510	9.99

Table 28: Technical Potential - Lifecycle Electricity Savings & Greenhouse Gas Emission Reductions for Deployed Heat Pumps (18 Year Service Life)

Year #	Year	Marginal Coefficient (tCO_2eq/MWh)	Total heat pump Units in Operation To Date		Lifecycle Impacts To Date	
			Heating	*Cooling*	*Savings (MWh)*	*Emission Reductions ($MtCO_2eq$)*
1	2018	0.1853	1,013	709	4,220	0.001
2	2019	0.1986	3,038	2,127	16,876	0.003
3	2020	0.2119	6,076	4,253	42,188	0.009
4	2021	0.2252	10,126	7,088	84,371	0.018
5	2022	0.2385	15,189	10,632	147,645	0.033
6	2023	0.2517	20,252	14,176	232,010	0.054
7	2024	0.2650	25,315	17,720	337,466	0.082
8	2025	0.2783	30,378	21,264	464,013	0.118
9	2026	0.2916	35,441	24,808	611,651	0.161
10	2027	0.3049	40,504	28,352	780,380	0.212
11	2028	0.3181	40,504	28,352	949,109	0.266
12	2029	0.3314	40,504	28,352	1,117,838	0.321
13	2030	0.3447	40,504	28,352	1,286,567	0.379
14	2031	0.3580	40,504	28,352	1,455,296	0.439
15	2032	0.3713	40,504	28,352	1,624,025	0.502
16	2033	0.3377	40,504	28,352	1,792,754	0.558
17	2034	0.3377	40,504	28,352	1,961,483	0.615
18	2035	0.3377	40,504	28,352	2,130,212	0.672
19	2036	0.3377	39,491	27,643	2,293,973	0.727
20	2037	0.3377	37,466	26,225	2,449,336	0.780
21	2038	0.3377	34,428	24,099	2,592,102	0.828
22	2039	0.3377	30,378	21,264	2,718,073	0.870
23	2040	0.3377	25,315	17,720	2,823,049	0.906
24	2041	0.3377	20,252	14,176	2,907,030	0.934
25	2042	0.3377	15,189	10,632	2,970,015	0.955
26	2043	0.3377	10,126	7,088	3,012,006	0.970
27	2044	0.3377	5,063	3,544	3,033,001	0.977

Table 29: Low Achievable Potential - Lifecycle Electricity Savings & Greenhouse Gas Emission Reductions for Deployed Heat Pumps (18 Year Service Life)

			Total heat pump Units in Operation To Date		Lifecycle Impacts To Date	
Year #	**Year**	**Marginal Coefficient (tCO_2eq/MWh)**	*Heating*	*Cooling*	*Savings (MWh)*	*Emission Reductions ($MtCO_2eq$)*
1	2018	0.1853	2,025	1,418	8,436	0.002
2	2019	0.1986	6,075	4,253	33,743	0.007
3	2020	0.2119	14,175	9,923	92,793	0.019
4	2021	0.2252	26,325	18,428	202,457	0.044
5	2022	0.2385	40,500	28,351	371,171	0.084
6	2023	0.2517	56,700	39,691	607,371	0.143
7	2024	0.2650	72,900	51,031	911,057	0.224
8	2025	0.2783	89,100	62,371	1,282,229	0.327
9	2026	0.2916	105,300	73,711	1,720,887	0.455
10	2027	0.3049	121,500	85,051	2,227,031	0.609
11	2028	0.3181	121,500	85,051	2,733,175	0.770
12	2029	0.3314	121,500	85,051	3,239,319	0.937
13	2030	0.3447	121,500	85,051	3,745,463	1.110
14	2031	0.3580	121,500	85,051	4,251,607	1.291
15	2032	0.3713	121,500	85,051	4,757,751	1.478
16	2033	0.3377	121,500	85,051	5,263,895	1.648
17	2034	0.3377	121,500	85,051	5,770,039	1.818
18	2035	0.3377	121,500	85,051	6,276,183	1.988
19	2036	0.3377	119,475	83,633	6,771,622	2.156
20	2037	0.3377	115,425	80,798	7,250,267	2.317
21	2038	0.3377	107,325	75,128	7,695,322	2.468
22	2039	0.3377	95,175	66,623	8,089,994	2.601
23	2040	0.3377	81,000	56,700	8,425,885	2.714
24	2041	0.3377	64,800	45,360	8,694,598	2.805
25	2042	0.3377	48,600	34,020	8,896,132	2.873
26	2043	0.3377	32,400	22,680	9,030,489	2.918
27	2044	0.3377	16,200	11,340	9,097,667	2.941

Table 30: Medium Achievable Potential - Lifecycle Electricity Savings & Greenhouse Gas Emission Reductions for Deployed Heat Pumps (18 Year Service Life)

			Total heat pump Units in Operation To Date		Lifecycle Impacts To Date	
Year #	**Year**	**Marginal Coefficient (tCO_2eq/MWh)**	*Heating*	*Cooling*	*Savings (MWh)*	*Emission Reductions ($MtCO_2eq$)*
1	2018	0.1853	1,013	709	4,220	0.001
2	2019	0.1986	3,038	2,127	16,876	0.003
3	2020	0.2119	6,076	4,253	42,188	0.009
4	2021	0.2252	10,126	7,088	84,371	0.018
5	2022	0.2385	15,189	10,632	147,645	0.033
6	2023	0.2517	20,252	14,176	232,010	0.054
7	2024	0.2650	25,315	17,720	337,466	0.082
8	2025	0.2783	30,378	21,264	464,013	0.118
9	2026	0.2916	35,441	24,808	611,651	0.161
10	2027	0.3049	40,504	28,352	780,380	0.212
11	2028	0.3181	40,504	28,352	949,109	0.266
12	2029	0.3314	40,504	28,352	1,117,838	0.321
13	2030	0.3447	40,504	28,352	1,286,567	0.379
14	2031	0.3580	40,504	28,352	1,455,296	0.439
15	2032	0.3713	40,504	28,352	1,624,025	0.502
16	2033	0.3377	40,504	28,352	1,792,754	0.558
17	2034	0.3377	40,504	28,352	1,961,483	0.615
18	2035	0.3377	40,504	28,352	2,130,212	0.672
19	2036	0.3377	39,491	27,643	2,293,973	0.727
20	2037	0.3377	37,466	26,225	2,449,336	0.780
21	2038	0.3377	34,428	24,099	2,592,102	0.828
22	2039	0.3377	30,378	21,264	2,718,073	0.870
23	2040	0.3377	25,315	17,720	2,823,049	0.906
24	2041	0.3377	20,252	14,176	2,907,030	0.934
25	2042	0.3377	15,189	10,632	2,970,015	0.955
26	2043	0.3377	10,126	7,088	3,012,006	0.970
27	2044	0.3377	5,063	3,544	3,033,001	0.977

Table 31: Maximum Achievable Potential - Lifecycle Electricity Savings & Greenhouse Gas Emission Reductions for Deployed Heat Pumps (18 Year Service Life)

Appendix F - Feasibility Study Heat Pump Retrofit Option Selection Criteria and Evaluation Results

Below is the description of the qualitative and quantitative criteria used to select a recommended heat pump option as part of the Pumping Energy Savings heat pump retrofit feasibility assessment for EMURBs.

QUANTITATIVE CRITERIA

Utility Costs & Climate Change Emissions: The expected cost reductions in utility costs for operation of the building (accruing to either owner or tenant), and, the expected magnitude of climate change emissions which will be avoided by our proposed change over a typical operating year including impact of avoided utilities, and, likely magnitude of refrigerant fugitive emissions.

First Cost: The total cost (design and construction) of the proposed retrofit, after incentives (if any).

Required Design Effort: Level of due diligence and cost of detailed design for the proposed change (newer, less proven systems or very complicated retrofits score lower.

Physical Space Required: Loss of usable (occupied) floor area resulting from the retrofit due to installation of new systems, equipment, or services

Wasted Capital / Created Stranded Assets: Magnitude of equipment / services with remaining service life which will be prematurely abandoned or replaced as a result of this retrofit.

Maintenance Costs: Expected costs to operate the system due to materials required, frequency of maintenance requirements, ease of access and overall level of effort required to maintain a properly functioning system.

Net Present Value: First Cost, Expected Utility and Operating Costs, Maintenance, and Major Equipment Replacements, totaled over a given evaluation period, with future costs adjusted for inflation, interest, and utility cost escalation.

QUALITATIVE CRITERIA

Reliability: Likelihood of breakdown causing no-heat, no-cool, or urgent service requests throughout the year relative to the base-case system.

Flexibility: Ability of owner of system to adapt to changing utility costs or other issues by fuel switching, or, changing out components of the plant/system.

Longevity (15 years - 35 years): Expected life of equipment prior to replacement.

Vandal Resistance: Durability of fit and finish of components exposed to occupants and the public.

Install - Disruption to Residents: Assessing resident area noise, dust, required access to suites, volume of materials and length of installation process required to change the system.

Controllability & Metering: Inherent ability of system to be individually controlled and metered on a suite-by-suite basis.

Indoor Environmental Quality: Expected overall impact (positive or negative) on indoor environmental quality, including air filtration, fresh air volumes, and humidity control.

	Weighting	Option 1 Existing fan coils w/Hybrid Ground Source Central Plant	Option 2 Existing fan coils with Air-Source Central Plant	Option 3 New Ground Source In-Suite Water Source Heat Pumps	Option 4 New Suite-by-Suite Unitary Air-Source Heat Pumps	Option 5 New Air-Source Multi-split VRF (no heat recovery)	Option 6 New Water Loop Ground-Source Multi-split VRF
Utility Costs & GHG Emissions	27%	70%	70%	80%	80%	80%	100%
First Cost	13%	10%	40%	20%	70%	40%	10%
Install - Disruption to Residents	12%	0%	0%	0%	50%	20%	20%
Created Stranded Assets	8%	50%	50%	50%	80%	80%	50%
Reliability	8%	50%	50%	50%	100%	80%	60%
Maintenance Costs	6%	80%	80%	80%	60%	70%	60%
Vandal Resistance	6%	80%	100%	80%	30%	50%	60%
Indoor Environmental Quality	6%	70%	70%	30%	70%	80%	80%
Required Design Effort	4%	0%	0%	0%	90%	30%	0%
Physical space required	4%	30%	30%	20%	60%	80%	40%
Longevity (15 years - 35 years)	4%	100%	80%	80%	50%	60%	70%
Flexibility	2%	50%	50%	50%	0%	0%	50%
Controllability & Metering	2%	30%	30%	30%	100%	50%	50%
Total Score	100%	48%	52%	48%	**69%**	61%	57%

Table 32: Site 1 – Heat Pump Selection Evaluation Matrix

	Weighting	Existing fan coils w/ Ground-Source Central Plant Option 1	Existing fan coils w/ Air-Source Central Plant Option 2	New Ground-Source In-Suite Water Source Heat Pumps Option 3	Suite-by-Suite Unitary Air-Source Heat Pumps Option 4	Air-Source Multisplit VRF (no heat recovery) Option 5	Water Loop Ground-Source Multisplit VRF Option 6
Utility & Operating Costs/ Climate Change Emissions	27%	90%	70%	90%	N/A	80%	100%
First Cost	13%	40%	50%	30%	N/A	10%	10%
Install - Disruption to Residents	12%	65%	70%	20%	N/A	20%	10%
Indoor Environmental Quality	11%	60%	60%	50%	N/A	90%	90%
Reliability	10%	80%	70%	80%	N/A	60%	50%
Created Stranded Assets	8%	50%	50%	20%	N/A	20%	20%
Required Design Effort	4%	50%	10%	30%	N/A	30%	20%
Physical space required to Install	4%	80%	80%	30%	N/A	40%	40%
Longevity (15 years - 35 years)	4%	90%	80%	70%	N/A	70%	80%
Maintenance Costs	4%	80%	30%	80%	N/A	70%	50%
Controllability & Metering	2%	50%	50%	80%	N/A	80%	80%
Vandal Resistance	2%	100%	100%	100%	N/A	80%	90%
Total Score	100%	70%	62%	57%	N/A	54%	57%

Table 33: Site 2 – Heat Pump Selection Evaluation Matrix

	Weighting	Option 1 Existing fan coils w/ Ground-Source Central Plant	Option 2 Existing fan coils w/ Air-Source Central Plant	Option 3 New Ground-Source In-Suite Water-Source Heat Pumps	Option 4 New Suite-by-Suite Unitary Air-Source Heat Pumps	Option 5 New Air-Source Multisplit VRF (no heat recovery)	Option 6 New Water Loop Ground-Source Multisplit VRF
Utility Costs & GHG Emissions	27%	N/A	70%	N/A	80%	80%	N/A
First Cost	13%	N/A	40%	N/A	70%	40%	N/A
Install - Disruption to Residents	12%	N/A	0%	N/A	50%	20%	N/A
Created Stranded Assets	8%	N/A	50%	N/A	80%	80%	N/A
Reliability	8%	N/A	50%	N/A	100%	80%	N/A
Maintenance Costs	6%	N/A	80%	N/A	60%	70%	N/A
Vandal Resistance	6%	N/A	100%	N/A	30%	50%	N/A
Indoor Environmental Quality	6%	N/A	70%	N/A	70%	80%	N/A
Required Design Effort	4%	N/A	0%	N/A	90%	30%	N/A
Physical space required	4%	N/A	30%	N/A	60%	80%	N/A
Longevity (15 years - 35 years)	4%	N/A	80%	N/A	50%	60%	N/A
Flexibility	2%	N/A	50%	N/A	0%	0%	N/A
Controllability & Metering	2%	N/A	30%	N/A	100%	50%	N/A
Total Score	100%	N/A	59%	N/A	**69%**	61%	N/A

Table 34: Site 3 – Heat Pump Selection Evaluation Matrix

	Weighting	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6
		Existing fan coils w/ Hybrid Ground-Source Central Plant	Existing fan coils w/ Air-Source Central Plant	New Ground-Source In-Suite Water-Source Heat Pumps	New Suite-by-Suite Unitary Air-Source Heat Pumps	New Air-Source Multi-split VRF (no heat recovery)	New Water Loop Ground-Source Multi-split VRF
Utility Costs & GHG Emissions	26%	70%	70%	100%	80%	80%	100%
First Cost	13%	10%	40%	20%	70%	40%	10%
Install - Disruption to Residents	11%	0%	0%	0%	50%	20%	20%
Created Stranded Assets	8%	50%	50%	50%	80%	80%	50%
Reliability	8%	50%	50%	50%	100%	80%	60%
Vandal Resistance	8%	80%	100%	80%	30%	50%	60%
Maintenance Costs	6%	80%	80%	80%	60%	70%	60%
Indoor Environmental Quality	6%	70%	70%	30%	70%	80%	80%
Required Design Effort	4%	0%	0%	0%	90%	30%	0%
Physical space required	4%	30%	30%	20%	60%	80%	40%
Longevity (15 years - 35 years)	4%	100%	80%	80%	50%	60%	70%
Flexibility	2%	50%	50%	50%	0%	0%	50%
Controllability & Metering	2%	30%	30%	30%	100%	50%	50%
Total Score	**100%**	**48%**	**53%**	**54%**	**69%**	**60%**	**57%**

Table 35: Site 4 - Heat Pump Selection Evaluation Matrix

	Weighting	Option 1 Existing fan coils with Ground-Source Central Plant	Option 2A Existing fan coils with Air-Source Central Plant	Option 2B Existing fan coils w/ Air-Source CO_2 Heat Pump w/ Heat Recovery from garage	Option 3 New Ground-Source In-Suite Water-Source Heat Pumps	Option 4 Suite-by-Suite Unitary Air-Source Heat Pumps	Option 5 Air-Source Multisplit VRF (no heat recovery)	Option 6 Water Loop Ground-Source Multisplit VRF
Utility & Operating Costs/ Climate Change Emissions	27%	N/A	70%	80%	80%	N/A	80%	N/A
First Cost	13%	N/A	60%	50%	50%	N/A	50%	N/A
Install - Disruption to Residents	12%	N/A	90%	90%	90%	N/A	50%	N/A
Created Stranded Assets	8%	N/A	50%	50%	50%	N/A	0%	N/A
Reliability	8%	N/A	60%	60%	60%	N/A	100%	N/A
Maintainability	6%	N/A	50%	50%	50%	N/A	70%	N/A
Vandal Resistance	6%	N/A	80%	80%	80%	N/A	30%	N/A
Indoor Environmental Quality	6%	N/A	80%	80%	80%	N/A	80%	N/A
Required Design Effort	4%	N/A	0%	0%	0%	N/A	80%	N/A
Physical space required to Install	4%	N/A	80%	80%	80%	N/A	60%	N/A
Longevity (15 years - 35 years)	4%	N/A	80%	80%	80%	N/A	50%	N/A
Flexibility	2%	N/A	50%	50%	50%	N/A	0%	N/A
Controllability & Metering	2%	N/A	50%	50%	50%	N/A	100%	N/A
Total Score	100%	N/A	66%	**67%**	67%	N/A	61%	N/A

Table 36: Site 5 – Heat Pump Selection Evaluation Matrix

	Weighting	Option 1 Existing fan coils w/ Hybrid Ground-Source Central Plant	Option 2 Existing fan coils with Air-Source Central Plant	Option 3 New Ground-Source In-Suite Water-Source Heat Pumps	Option 4 New Suite-by-Suite Unitary Air-Source Heat Pumps	Option 5 New Air-Source Multi-split VRF (no heat recovery)	Option 6 New Water Loop Ground-Source Multi-split VRF
Utility Costs & GHG Emmissions	25%	70%	70%	80%	80%	80%	100%
First Cost	12%	10%	40%	20%	70%	40%	10%
Vandal Resistance	11%	80%	100%	80%	30%	50%	60%
Install- Disruption to Residents	11%	0%	0%	0%	50%	20%	20%
Created Stranded Assets	7%	0%	0%	0%	50%	30%	0%
Reliability	7%	50%	50%	50%	100%	80%	60%
Longevity (15 years - 35 years)	7%	80%	80%	80%	50%	60%	60%
Maintenance Costs	5%	80%	80%	80%	60%	70%	60%
Indoor Environmental Quality	5%	70%	70%	70%	70%	80%	80%
Required Design Effort	4%	0%	0%	0%	90%	30%	0%
Physical space required	4%	30%	30%	30%	60%	40%	40%
Flexibility	2%	50%	50%	50%	0%	0%	50%
Controllability & Metering	2%	30%	30%	30%	100%	50%	50%
Total Score	100%	46%	52%	50%	**65%**	55%	53%

Table 37: Site 6 – Heat Pump Selection Evaluation Matrix

	Weighting	Option 1 New fan coils with Ground-Source Central Plant	Option 2 New fan coils with Air-Source Central Plant	Option 3 New Ground-Source In-Suite Water-Source Heat Pumps	Option 4 Suite-by-Suite Unitary Air-Source Heat Pumps	Option 5 Air-Source Multisplit VRF (no heat recovery)	Option 6 Water Loop Ground-Source Multisplit VRF
Utility & Operating Costs/ Climate Change Emissions	27%	70%	70%	80%	80%	80%	100%
Install - Disruption to Residents	11%	0%	0%	0%	50%	20%	20%
First Cost	10%	10%	40%	20%	70%	40%	10%
Controllability & Metering	7%	30%	30%	30%	100%	50%	50%
Indoor Environmental Quality	7%	70%	70%	30%	70%	80%	80%
Created Stranded Assets	7%	50%	50%	50%	80%	80%	50%
Reliability	7%	50%	50%	50%	100%	80%	60%
Maintenance Costs	6%	80%	80%	60%	60%	70%	60%
Longevity (15 years - 35 years)	5%	100%	80%	80%	50%	60%	70%
Required Design Effort	4%	0%	0%	0%	90%	30%	0%
Physical space required to Install	4%	30%	30%	20%	60%	80%	40%
Vandal Resistance	4%	80%	80%	80%	30%	50%	60%
Flexibility	2%	50%	50%	50%	0%	0%	50%
Total Score	100%	49%	51%	47%	**71%**	61%	59%

Table 38: Site 7 - Heat Pump Selection Evaluation Matrix

REFERENCES

1. International Energy Agency. "Energy Efficiency 2017." Market Report Series, 2017. http://www.iea.org/publications/freepublications/publication/Energy_Efficiency_2017.pdf.
2. Delve, Katherine, Anne Wilkins, Federico Garcia-Lopez, and Michael Scholand. "Five A's: Barrier Classification and Market Transformation Program Design for Energy Efficient Technologies," Vol. 6. Market Transformation: Designing for Lasting Change. ACEEE, 2004. http://aceee.org/files/proceedings/2004/data/papers/SS04_Panel6_Paper10.pdf.
3. Natural Resources Canada. "Comprehensive Energy Use Database. Latest Update Completed May 29, 2018," 2018. http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/menus/trends/comprehensive_tables/list.cfm.
4. Natural Resources Canada. "Comprehensive Energy Use Database. Latest Update Completed May 29, 2018," 2018. http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/menus/trends/comprehensive_tables/list.cfm.
5. Natural Resources Canada. "Comprehensive Energy Use Database. Latest Update Completed May 29, 2018," 2018. http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/menus/trends/comprehensive_tables/list.cfm.
6. Ontario. "Ontario's Five Year Climate Change Action Plan 2016 - 2020," 2016. www.applications.ene.gov.on.ca/ccap/products/CCAP_ENGLISH.pdf.
7. Ontario. "Green Ontario Fund," 2017. https://www.greenon.ca/
8. The Atmospheric Fund. "A Clearer View on Ontario's Emissions: Practice Guidelines for Electricity Emissions Factors," 2017. http://taf.ca/wp-content/uploads/2017/08/TAF_Guide_Ontario_Emissions_Factors_Digital_2017-08-03.pdf.
9. TAF developed a methodology for calculating marginal emissions factors. See guide here: http://taf.ca/wp-content/uploads/2017/11/TAF_Guide_Ontario_Emissions_Factors_Digital_2017-08-03.pdf
10. The cost-effectiveness of technical potential is not analyzed under the PACT because, by definition, the PACT requires inclusion of assumed program costs. Thus, only achievable potential scenarios can be analyzed under the PACT.
11. Skumatz, Lisa A. "Non-Energy Benefits / Non-Energy Impacts (NEBs/NEIs) and Their Role & Values in Cost-Effectiveness Tests: State of Maryland." Prepared for Natural Resources Defense Council (NRDC), Superior, CO, March, 2014. https://energyefficiencyforall.org/sites/default/files/2014_%20NEBs%20report%20for%20Maryland.pdf.
12. BC Ministry Of Energy And Mines Electricity And Alternative Energy Division. "Guide To The Demand-Side Measures Regulation," 2014. https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/electricity-alternative-energy/energy-efficiency/guide_to_the_dsm_regulation_july_2014_c2.pdf.
13. Environment and Climate Change Canada. "Technical Update to Environment and Climate Change Canada's Social Cost of Greenhouse Gas Estimates," 2016. http://publications.gc.ca/collections/collection_2016/eccc/En14-202-2016-eng.pdf.

14. Delve, Katherine, Anne Wilkins, Federico Garcia-Lopez, and Michael Scholand. "Five A's: Barrier Classification and Market Transformation Program Design for Energy Efficient Technologies," Vol. 6. Market Transformation: Designing for Lasting Change. ACEEE, 2004. http://aceee.org/files/proceedings/2004/data/papers/SS04_Panel6_Paper10.pdf.

15. Ontario. Residential Tenancies Act, 2006, S.O. 2006, c. 17. https://www.ontario.ca/laws/statute/06r17.

16. Enbridge Gas Distribution Inc. "Ontario Energy Board File No. EB-2017-0319 Enbridge Gas Distribution Inc. Renewable Natural Gas Enabling Program and Geothermal Energy Service Program – Updated Exhibits. May 24, 2018 – EXHIBIT B," 2018.

17. Enbridge Gas Distribution Inc. "Application for Approval of the Cost Consequences of the Proposed Renewable Natural Gas Enabling Program and Geothermal Energy Service Program. PROCEDURAL ORDER NO. 3. May 30, 2018. EB-2017-0319," 2018.

18. Enbridge Gas Distribution Inc. "Application for Approval of the Cost Consequences of the Proposed Renewable Natural Gas Enabling Program and Geothermal Energy Service Program. PROCEDURAL ORDER NO. 3. May 30, 2018. EB-2017-0319," 2018.

19. Enbridge Gas Distribution Inc. "Ontario Energy Board File No. EB-2017-0319 Enbridge Gas Distribution Inc. Renewable Natural Gas Enabling Program and Geothermal Energy Service Program – Updated Exhibits. May 24, 2018 – EXHIBIT B," 2018.

20. Ontario. "Ontario's Five Year Climate Change Action Plan 2016 - 2020," 2016. www.applications.ene.gov.on.ca/ccap/products/CCAP_ENGLISH.pdf.

21. Canada Mortgage and Housing Corporation. "Federal Government Launches Multi-Billion Dollar National Housing Co-Investment Fund. May 2, 2018," 2018. https://www.newswire.ca/news-releases/federal-government-launches-multi-billion-dollar-national-housing-co-investment-fund-681514281.html

22. Investor Confidence Project. "Multifamily Protocols," 2018. http://www.eeperformance.org/multifamily-protocols.html.

23. Solarize Freeport. "MINI-SPLIT HEAT PUMP Bulk Purchase Program," 2016. http://www.solarizefreeport.com/mshp.htm#.WxFmqkxFy-p.

24. Manitoba Hydro. "Manitoba Hydro - Helping Manitobans Move Toward A More Energy Sustainable Future: 2016/17 Demand Side Management Plan," 2016. https://www.hydro.mb.ca/corporate/pdfs/demand_side_management_plan.pdf.

25. Statistics Canada. "2016 Census of Population, Statistics Canada Catalogue No. 98-400-X2016219. Release Date: October 25, 2017," 2017. http://www12.statcan.gc.ca/census-recensement/2016/dp-pd/dt-td/Rp-eng.cfm?LANG=E&APATH=3&DETAIL=0&DIM=0&FL=A&FREE=0&GC=0&GID=0&GK=0&GRP=1&PID=110564&PRID=10&PTYPE=109445&S=0&SHOWALL=0&SUB=0&Temporal=2017&THEME=121&VID=0&VNAMEE=&VNAMEF=.

26. For example, see CMHC, Rental Market Report: Greater Toronto Area, 2016, Table 1.1.3 (Number of Private Apartment Units in the Universe by Zone and Bedroom Type, Toronto CMA).

27. The Atmospheric Fund. "PUMPING ENERGY SAVINGS: Ontario EMURB Market Characterization Study," 2016. http://taf.ca/wp-content/uploads/2016/04/Pumping-Energy-Savings-Ontario-EMURB-Market-Characterization-Study_FINAL_compressed.pdf.

28. Faesy, Richard, Jim Grevatt, Brian McCowan, and Katie Champagne. "Ductless Heat Pump Meta Study. November 13, 2014." Northeast Energy Efficiency Partnership, 2014. http://www.neep.org/ductless-heat-pump-meta-study-2014.

29. Natural Resources Canada. "EnerGuide Room Air Conditioner Directory," 2012. http://publications.gc.ca/collections/collection_2012/rncan-nrcan/M141-13-2012.pdf.

30. Northeast Energy Efficiency Partnerships. "ColdClimateAir-SourceHeatPumpSpecificationListing-Updated 4.19.2017.Xlsx." CCASHP Test, 2017. http://neep.org/initiatives/high-efficiency-products/emerging-technologies/ashp/cold-climate-air-source-heat-pump2.

31. ICF Consulting Canada, Inc. "Long-Term Carbon Price Forecast Report. May 31, 2017. Updated on July 19, 2017." Submitted to: Ontario Energy Board, 2017. https://www.oeb.ca/sites/default/files/uploads/OEB-LTCPF-Report-20170531.pdf.

32. ICF Consulting Canada, Inc. 2017. "Long-Term Carbon Price Forecast Report. May 31, 2017. Updated on July 19, 2017." Submitted to: Ontario Energy Board. https://www.oeb.ca/sites/default/files/uploads/OEB-LTCPF-Report-20170531.pdf.

33. ICF Consulting Canada, Inc. 2017. "Long-Term Carbon Price Forecast Report. May 31, 2017. Updated on July 19, 2017." Submitted to: Ontario Energy Board. https://www.oeb.ca/sites/default/files/uploads/OEB-LTCPF-Report-20170531.pdf.

34. ICF Consulting Canada, Inc. 2017. "Long-Term Carbon Price Forecast Report. May 31, 2017. Updated on July 19, 2017." Submitted to: Ontario Energy Board. https://www.oeb.ca/sites/default/files/uploads/OEB-LTCPF-Report-20170531.pdf. Converting $/m3 to $/ekWh using conversion factor 10.5567

35. Rieti, J. "Doug Ford is officially ending Ontario's cap-and-trade plan, but what's next? CBC News. July 3, 2018," 2018. https://www.cbc.ca/news/canada/toronto/doug-ford-ending-cap-and-trade-1.4731954.

36. Sawyer, Dave, and Chris Bataille. "Policy Brief 2: The Pan-Canadian Framework on Clean Growth and Climate Change," 2017. https://www.enviroeconomics.org/single-post/2017/03/31/Taking-Stock-Opportunities-for-Collaborative-Climate-Action-to-2030.

37. U.S. Environmental Protection Agency. "Clean Energy Financing: Programs A Decision Guide for States and Communities," 2011. https://www.epa.gov/sites/production/files/2015-08/documents/financingprogramsresourceguide.pdf.

38. Coughlin, J, J Grove, J Jacobs, S Phillips, A Sawyer, and J Wiedman. "A Guide to Community Shared Solar: Utility, Private, and Nonprofit Project Development." U.S. Department of Energy, 2012.