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Heat Pump Pre-Screening Tool for New Commercial and Institutional Buildings

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Abstract

Heat pumps (HPs) provide significant advantages over conventional heating, ventilation and air conditioning (HVAC) systems. Nevertheless, they are rarely considered in new building design in Canada because they are perceived as (i) expensive and (ii) requiring detailed feasibility studies to determine whether the investment is worthwhile. This situation is compounded by the variety of HP systems available, which often makes it impractical to appropriately study all available options. However, without such studies, it is difficult to identify the best system for a particular building project.

This paper presents a user-friendly tool developed by CanmetENERGY to address this situation. The Heat Pump Assessment Tool (HPAC) is a free software that provides rapid assessments of HP systems for a specific set of building parameters with only minimal input requirements. The tool allows designers to rapidly assess a variety of heat pump systems at an early design stage, supporting the integration of these systems in buildings. HPAC's results are based on models developed for pre-defined building types, with a typical HVAC system for each building type used as a reference. The models allow for the rapid assessment of investment and operating costs, greenhouse gas reduction potential, net present value and simple payback period of selected HP systems for a variety of climate zones and utility rates across Canada. Although the tool focuses on the Canadian market, the methodology used is easily transferable to address the realities of other nations around the world.

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"Key Words: Heat Pump; Pre-Screening Tool; Renewable Energy"

1. Introduction

Space heating is one of the largest energy end uses in Canadian commercial/institutional buildings [1], representing 45% of all secondary energy use within the sector. While heat pump (HP) systems have been recognized as a key tool in effectively reducing heating related energy use [2], market uptake in Canada is still limited by higher initial costs and low utility rates. In addition, the integration of heat pump systems is often a complex process that involves carefully examining the indoor and outdoor environment, building envelope, and mechanical systems. This complexity often means that heat pumps are overlooked during early stage design, as it can be difficult to properly and quickly assess their impacts on building performance. The situation is made even more difficult by the variety of market available heat pump systems common in Canada, and the challenging Canadian climate.

To facilitate the uptake of HP systems within Canadian buildings, Natural Resources Canada has developed an early stage design tool to rapidly assess the feasibility of heat pump systems across a variety of building types. The Heat Pump Assessment Tool (HPAC) allows designers to quickly examine a variety of heat pump options (Air-source, ground-source, water loop, heat recovery chiller, variable refrigerant flow (VRF)) for new commercial/institutional buildings across Canada, providing a quantitative basis to support the selection and design of heat pump systems. This paper presents the overall approach and methodology used to develop HPAC tool. A description of the user interface is also provided using the example of a heat pump project analysis for a school located in Vancouver.

2. Tool Development Approach

The development of the tool was based on two main concepts:

- Ease of use by
    - Requiring minimal data inputs
    - Providing default values for almost all inputs
    - Using an Excel platform, and thus not requiring other software licences
    - Using built-in algorithms to adjust simulation results according to user inputs

- Reliability of assessment by
    - Using a database of energy simulation results developed by highly knowledgeable building simulation experts
    - Providing default values based on a strong knowledge and expertise of buildings/heat pump systems
    - Using an extensive and detailed cost database based on market costs

The structure of the software itself can be divided into three main components:

- Energy analysis module
    - Contains a database of pre-simulated results for eight building types, each with base case HVAC systems and pre-selected heat pump systems, in a variety of Canadian locations
    - Uses carefully examined results as a quantitative basis for system analysis
    - Provides the fundamental background for all analysis presented by the tool

- Economic analysis module
    - Contains detailed database of system costs derived from available market data
    - Uses built-in algorithms to compute the incremental cost of heat pump systems compared to base cases using the energy modeling results and the cost data base.

- User interface
    - Provides easy to navigate link between the database and user-desired assessment
    - Easily allows the user to quickly adjust key simulation parameters

3. Development of Energy Model Database

The energy simulation data base is comprised of simulations evaluating the energy use for eight commercial/institutional buildings covering a significant portion of the Canadian building stock:

- Large Office
- Small office
- School
- Hospital
- Multi-Unit Residential building
- Long Term care
- Small administration
- Detention Centre

All simulations were performed with EE4/DOE 2.1E using a one hour time step. Both heating and cooling energy use were evaluated for base case and selected HP systems. Simulations for the database were performed for eight different locations across Canada to examine the impact of climate and utility rate structure. Selected locations, and heating fuel sources, are summarized below in Table 1.

Table 1: Locations and primary heating fuel

Location	Predominant heating fuels

Halifax	Natural gas
Fredericton	Natural gas
Montreal	Natural gas, Electricity
Toronto	Natural gas
Winnipeg	Natural gas, Electricity
Regina	Natural gas
Calgary	Natural gas
Vancouver	Natural gas

3.1. Development of Reference Buildings and HVAC systems

The parameters of each reference buildings were derived from actual buildings in the Canadian market, and were selected to be representative of typical new constructions. A description of each reference building type is provided to the user, with key parameters including:

- Floor area and number of floors
- Insulation levels for major envelope components
- Presence of continuous cooling loads (e.g. those due to IT and communication equipment)

Reference HVAC systems were selected for each building type to provide a realistic depiction of typical new constructions, and are summarized below in Table 2. Some heating systems combine a central plant providing both space heating and domestic hot water (DHW). In these cases, the heating load from the program combines the space heating and hot water loads. Occupancy and operating schedules are derived from appropriate national energy codes in Canada [3].

Table 2: Summary of HVAC Performance

Building	Reference HVAC System
Hospital	Built-up VAV and CV with Reheat Coils (boiler/chiller)
Detention Center	Built-up VAV with Reheat Coils (boiler/chiller)
Large Office	Built-up VAV with Reheat Coils (boiler/chiller)
High School	Built-up VAV with Reheat Coils (boiler/chiller)
Multi Unit Residential building	Two-pipe fan coil (boiler/chiller)
Long Term care	Two-pipe fan coil (boiler/chiller)
Small administration	Packaged Constant Volume (DX/gas fired)
Small office	Packaged Constant Volume (DX/gas fired)

*VAV = Variable air volume
*CV = Constant volume
*DX = Direct expansion

Reference buildings were developed to provide a general idea of building energy performance. As such, results for the HPAC tool will be most reliable if the examined building is similar in size and geometry to the reference building. Options for user-input thermal loading is also provided in the tool for cases where the examined building represents a large departure from the reference case.

3.2. Development of Heat Pump Simulation Models

The HPAC tool examines a variety of market-available heat pump systems. Availability of each system is strictly dependent on the building type, and was pre-screened for applicability and economic viability. A summary of the systems and building type combinations is provided in Table 3.

Table 3: Heat Pump Systems evaluated by Building Type

Building Types	Heat Pump systems				
	Ground Source	Air source	Water Loop	Heat Recovery Chiller	Variable Refrigerant Flow
1-Hospital	X			X	
2-Detention Center					
3-Large Office	X		X	X	X
4-High School	X		X		X
5-Multi-Unit Residential building	X		X		X
6-Long Term care	X		X		X
7-Small administration	X	X	X		X
8-Small Office	X	X			X

All HP systems except the air-source unit are sized in the building energy simulations to meet the peak heating and cooling loads of the buildings, and as such do not require the use of an additional auxiliary system. Default equipment efficiencies are based on the minimum coefficient of performance (COP) standards in the Canadian marketplace. However, these values may be modified by the user to provide more appropriate estimations of performance. Key sizing and simulation details are provided by system type below.

Air-Source Heat Pumps

Air-source Heat pump (ASHP) units are common in the Canadian market. However, their integration is challenged by reduced heating capacities at low outdoor temperatures, posing a significant issue in cold climates. As such each ASHP integration includes a fully sized back-up system to ensure the building is appropriately heated.In the current generation of the tool, the maximum heating capacity for ASHP units is set to 106 kW, limiting the applicability of these systems to smaller buildings. Future iterations of the tool will increase this value, and also examine the potential of cold-climate air-source heat pumps, which offer improved heating capacities at low ambient temperatures.

Ground Source Heat Pumps

Ground source heat pumps (GSHP) use the ground as a thermal source/sink for the heat pump. This allows for more consistent heat pump source temperatures, especially in comparison to the air-source units described above. The HPAC tool focuses on vertical ground heat exchanger systems onlyt, as these are considered to be the most common installations in Canada.

Design of GSHP systems is often complex, and, as such, several simplifying assumptions have been used for energy modelling:

- Entering fluid temperatures to the heat pump are 4.4°C in heating mode and 26.7°C in cooling
- Borehole length calculations are performed for a single soil type. Currently, there is no method of modifying the soil parameters, although this could be implemented in future versions
- Borehole lengths are calculated using the maximum building thermal load, and an assumption of 15.6 m of borehole depth per kW of required heat pump capacity
- Distribution pump power use is based on an assumed required static pressure of 350 kPa. Air-based distribution systems use 1.0 W/L/s

Water Loop Heat Pump

Water loop heat pumps (WLHP) are effective systems in buildings where there is a frequent need for simultaneous heating and cooling (e.g. an office building). While they do not exhibit the same energy performance as ground-source units, they do offer lower capital costs while also potentially reducing required

boiler and cooling tower sizes. In the HPAC tool, water loop HP systems are simulated using a central boiler and cooling tower. For this type of system, the user also has the possibility to select a condensing boiler with a thermal efficiency of 90 % because of the low return temperatures. Default Coefficients of Performance (COP)s of 3.5 and 4.2are used in cooling and heating mode, respectively.

Variable Refrigerant Flow

Variable refrigerant flow (VRF) systems are a newer addition to the market, and use inverter driven variable capacity compressor technology, combined with sophisticated control devices, to manage multiple heat pump indoor units connected to a single main outdoor unit. They are particularly effective at managing simultaneous heating and cooling situations, and generally do not require the central equipment that the water loop heat pump systems use. Default COPs of 3.5 are used for the cooling and heating mode, respectively.

DOE2.1 does not fully facilitate the detailed modelling of VRF systems. However, many manufacturers do provide performance curves and detailed guidelines in order to estimate system energy performance, with similar procedures used in models developed for the HPAC tool. It will be possible to improve VRF system modelling for future versions of HPAC As new tools and simulation methodologies become available.

Heat Recovery Chillers

Heat recovery chillers (HRC) are ideal for buildings with continuous cooling loads, and allow for the recovery of heat rejected during the production of cooling energy by the chiller. Proper integration of heat recovery can allow for improved payback periods. However, careful planning is required, as the low grade thermal energy obtained during heat rejection must be carefully matched to its planned use (For this tool, low temperature heating systems).For building energy simulations, the heat recovery chiller is modelled with a COP of 2.6, and a leaving water temperature of 54°C. Whenever there is demand for both heating and cooling, the heat recovery chiller is used to recover thermal energy for space heating and DHW (up to the maximum space cooling load). Should heating not be required, centrifugal chillers are used instead, with thermal energy rejected to the ambient via a cooling tower.

3.3 Life Cycle Costing Analysis

A life cycle costing (LCC) analysis is undertaken for each heat pump system to determine its cost effectiveness relative to the base case system. The incremental capital cost for each heat pump system is taken from RSMeans [4] and stored in a detailed data base. Operating cost savings for each heat pump system are taken from the building energy simulation results. The LCC analysis is performed over a 20 year lifecycle, assuming a discount rate of 7%, and utility cost escalation rates of 2.0% per year. In addition to NPV values, both simple “real” payback periods are calculated. The user has the option to adjust many of the financial variables as appropriate, except for the operation costs which are derived from the energy simulation result.

3.4 GHG analysis

The HPAC tool computes total quantities of greenhouse gas (GHG) in tons of CO_2 eq. for the base case and each heat pump system evaluated, using the marginal electricity generation emission factors and the associated distribution loss factors specific to each regions covered by the tool. A natural gas combustion emission factor of 191g/e kwh is also used, including a leakage rate of 0.33%.

4. User Interface

The user interface includes one input sheet and one output/results sheet. They are described below, using an example of a potential heat pump project in a High School located in Vancouver.

4.1. Input Sheet

Completing the Input sheet is the first task when using the Heat Pump Screening Tool. The input sheet is divided in three sections: Building inputs, HP inputs, and economic inputs, with minimal entry data. In the Building Inputs section, the user has to provide only 3 parameters to initiate the analysis: the building type, location and, in the case of a project in Montreal and Winnipeg, the predominant energy source for heating. After entering these parameters, default values populate the rest of the input sheet based on the simulation results stored in the energy modelling data base.

With the selection of building type, a description of the building parameters appears on the screen and the user can decide to adjust:

a) the floor area default values, assuming that the all other characteristics of the school in which the user wishes to evaluate a HP project are similar to the reference case, or,

b) the heating and cooling loads of the building if it is already known to the user

A screen capture of the Input sheet for the evaluation of a heat pump system in a high school in Vancouver is provided in Figure 1. The reference building description available to the user is shown in Figure 2. The screen capture of the input sheet shows that three pre-screened heat pump system options are evaluated by the tool: GSHP, VRF, and WLHP. Since no 24X7 cooling load is typically present in this type of building, the option of HRC is not available, and because of the size of the building, the ASHP system is not available either.

4.2. Output and Results Sheet

Once all of the relevant input information is entered, the user clicks at the bottom of the input sheet ***Go to Result*** , which automatically opens the Output and Results sheet. The majority of the outputs are self-explanatory, and are divided in three main sections that provide computed data for the base case and each heat pump options relevant to : Annual Energy and GHG Emission Results, Annual Operating Costs results (include energy and maintenance costs) and Economics. At the bottom of the output page result, one section also provides the preferred HP systems on the basis of economic criteria and reduction of GHG emissions. Figure 3 and Figure 4 summarize presented results for the school example in Vancouver. In this example, HPAC tool identified the WLHP system as the prevailing heat pump system based on the economic criteria, with an immediate return on investment. It also identified the GSHP system as the preferred option in terms of GHG emissions reductions.

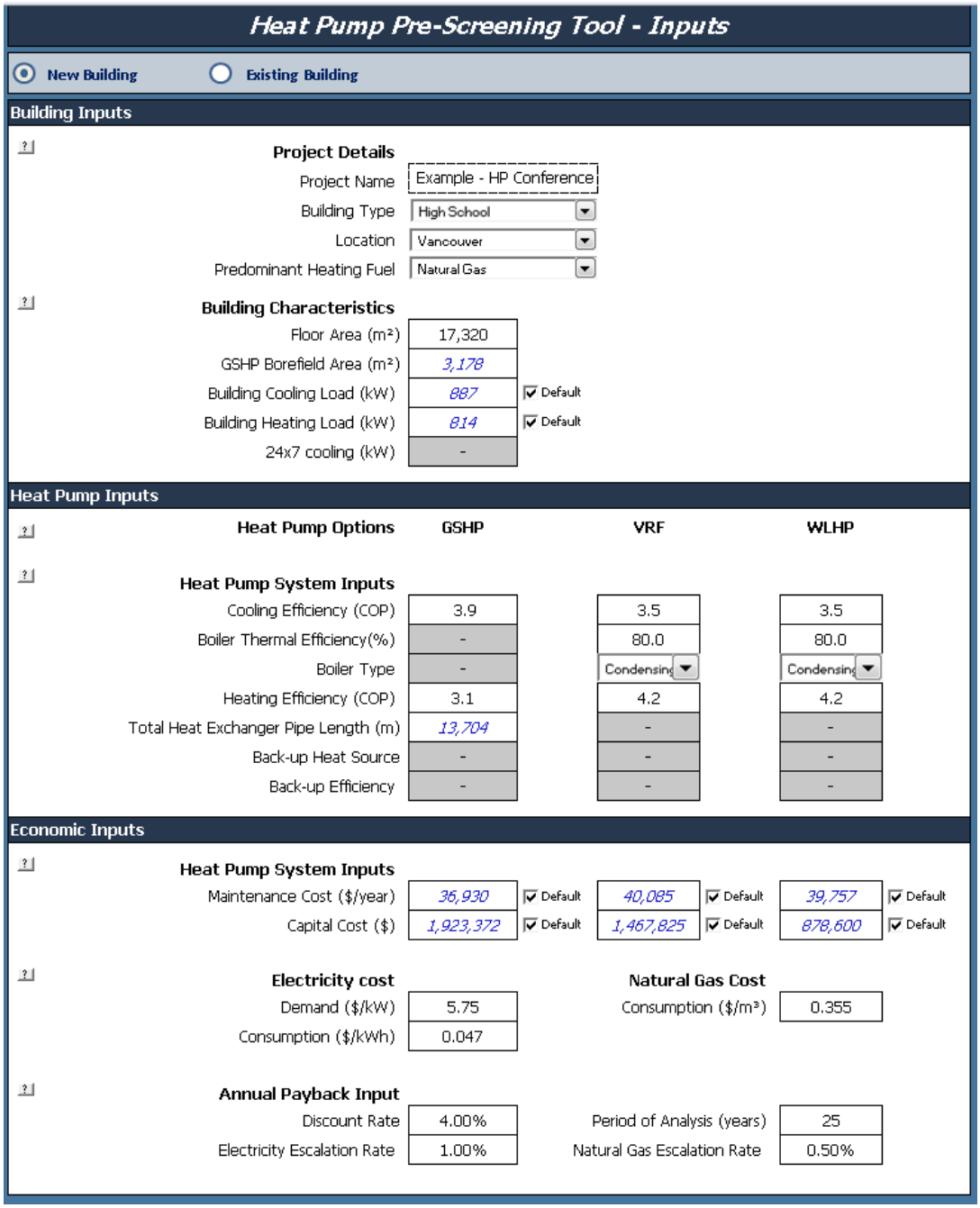


Fig. 1. Input Page of the HPAC Tool – High School in Vancouver example

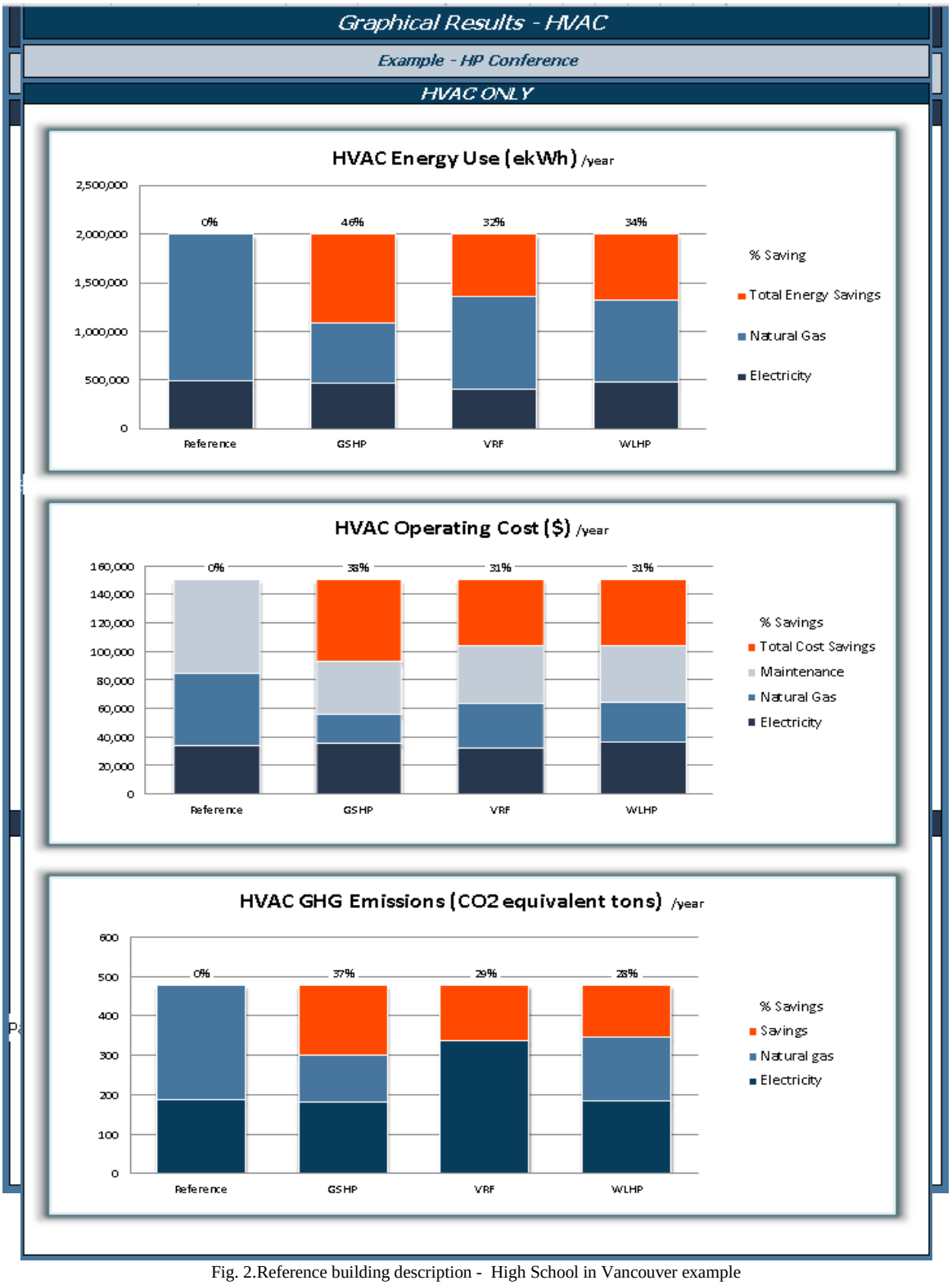


Fig. 2.Reference building description - High School in Vancouver example

Fig. 3. Numerical results – High School in Vancouver example

Fig. 4. Graphical representation of results - High School in Vancouver example

5. Conclusion and future work

This paper presents the approach that Natural Resources Canada took for the development of an early stage design tool supporting the implementation of heat pump systems in Canadian commercial/institutional buildings.

The tool uses detailed energy simulation and pricing databases to quickly examine a variety of heat pump options for different building types and Canadian regions. A simple, easy to use interface links to each database, allowing designers to quickly assess the energy and economic performance of different market available heat pump systems. While the HPAC tool is specific to Canada, the methodology used during development can be adapted to the realities of other cold climate countries.

Future work is planned to expand the functionality of the HPAC tool. First, additional development will focus on expanding the number of heat pump systems examined, and improving the simulation models used for more complex systems such as the VRF. The costing database will also be updated as appropriate to reflect changes in the market, and the introduction of new heat pump products. Finally, development of an equivalent tool for existing buildings is also under consideration. This market represents both a significant opportunity for heat pump systems, while also presenting a higher degree of complexity for system integrations.

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