HYBRID 2 HUNDRED

UNDERSTANDING PATHWAYS & PERFORMANCE OF RETROFITTED HYBRID HEATING SYSTEMS IN DETACHED HOMES

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Executive Summary

The Hybrid 2 Hundred project was commissioned to support BC residents, the province, and local municipalities in the increasingly wide adoption of heat pumps in the residential sector. The intent of this project is to evaluates the performance of residential heat pumps and hybrid heating systems using modelled scenarios and practical implementation considerations to support improved system design, performance evaluation, and energy efficiency.

There are a wide variety of dwellings and HVAC equipment to serve BC residents. The retrofit industry presents unique challenges due to the variety of systems available. A project might involve the replacement of electric baseboards with mini-split heat pumps in a multi-unit residential building. Alternatively, an owner of a single-family home might replace an ageing furnace with a new air handler and an air to air heat pump. Hydronic systems also hold a significant portion of the market and present unique challenges with the inclusion of air to water heat pumps.

Historically, when discussing HVAC systems, the focus has been on the efficiency rating of the equipment. This only provides a partial picture as there is typically a distribution system attached to the appliance. The efficiency of a hybrid system cannot be determined without a considerable amount of modeling to determine when each heat source is active. An Average Annual Efficiency (AAE) calculator was created as part of this project to provide some insights on hybrid system efficiency.

The AAE calculator contains a model of a midsized 1980s home with weather data from Vancouver (climate zone 4), Kelowna (climate zone 5), and Prince George (climate zone 6). The detailed heat pump performance specifications were included in the calculator to reflect the varying COP based on outdoor temperatures. The calculator has several variables that can be modified, including three heat pump sizes, two gas appliance efficiencies, the switchover temperature, and three different cities. Modifying these variables affects the running hours, the fuel consumed, and greenhouse gas emission (GHG) information of each appliance. This highlights the importance of equipment selection and the switchover temperature.

Future projects could expand on the AAE calculator to add more cities, additional equipment, and other dwellings.

The Hybrid 2 Hundred project also seeks to define the evaluation protocol for hybrid systems. A critical component of a performance based evaluation is proper design information to confirm that the design assumptions are reflected in the installed dwelling. Measurements on the systems must be focused on the mechanical room because the majority of the distribution systems are not visible in a finished home. Although forced air and hydronic systems appear quite different, similar parameters can be checked against design documents, such as flow rates, pressures, and temperatures.

Background

Many owners of existing dwellings are upgrading their heating systems to include cooling which has increased the prevalence of heat pumps and dual fuel HVAC systems. The Province of BC and several municipalities are supporting the adoption of heat pumps and increased reliance on electric fuel sources through Highest Efficiency Equipment Standards (HEES) and the implementation of regulations for the time of replacement of specific appliances.

Measuring the installed efficiency of dual fuel or dual source HVAC systems is challenging. The energy consumption of each appliance must be calculated using the regional temperatures, equipment performance specifications, and a heat loss & heat gain calculation unique to the dwelling. The installed distribution system must also be considered as the programmed switchover temperature between energy sources and the distribution system must be considered for an accurate model.

As the industry moves towards higher efficiency standards, new processes must be developed to properly credit dual fuel systems with an appropriate overall efficiency rating to ensure that stated targets are met. When discussing efficiency targets that are greater than 100%, the definition is a goal of a Coefficient of Performance (COP) that is greater than 1.

This project seeks to support BC residents in achieving 100% or greater efficiency for their heating and cooling systems by:

1. Identifying the current efficiency of common configurations of heating systems, and
2. Defining transition pathways and performance metrics for integrated or retrofitted heat pumps or hybrid systems

Although certain standards currently in development for hybrid heating systems are looking to combine metrics between gas efficiency and heat pump efficiency, items such as controls and performance must be addressed for an accurate representation of the system.

Project Objectives & Deliverables

A series of interviews were conducted with contractors and specialists that work in BC in the residential HVAC industry. The intent of the interviews was to determine the most common combinations of equipment and system types. This information will be used to generate an evaluation protocol for year-round performance of heating and cooling systems that use more than one energy source.

This work will support the creation of effective processes for determining testing standards of installed systems to optimize efficiency and ensure that performance targets meet the intended metrics outlined in government regulation and policy.

Scenario Matrix

There are many system configurations that are common in BC, their popularity varies depending on the region and climate zone. The type of heating system that was originally installed heavily influences the cooling device that is likely selected in large part due to cost and ease of installation.

Forced air systems are very common in all parts of the province, they are often paired with an air to air heat pump and use the existing duct system to distribute conditioned air. The common forced air equipment pairs that were discussed were:

- Existing gas furnace with a dual-fuel air to air heat pump added
- Existing electric furnace with a dual-fuel air to air heat pump added
- Existing gas furnace where the homeowner relies on portable air conditioning for cooling
- Existing furnace with an independent mini-split system installed

Electric baseboards are another common heating source, but do not provide an opportunity to incorporate cooling, which requires a separate heating and/or cooling system to be installed. The most common variations that were anticipated are:

- Existing electric baseboards with an independent mini-split system added
- Existing electric baseboards, an independent furnace & air to air heat pump system added
    - Natural gas furnaces are more common than electric furnaces

Hydronic systems are not as popular as forced air but still represent a significant portion of the market. Often, the heat emitters are radiant piping that is run throughout the dwelling. This heat emitter is poorly suited for cooling, although some contractors will do in-floor cooling, it is extremely uncommon. The more common cooling options are to either install an independent system or to install an air to water heat pump with alternative heat emitters, such as a fan coil unit. The systems that were discussed:

- Hydronic system with an independent mini-split system installed
- Hydronic system with an air to water heat pump installed

The contractors interviewed were also asked if they frequently installed any other system types. There are some instances where combi systems are installed, which are a type of hydronic system, but in very low numbers so they were not considered further as the hydronic systems would yield similar results and processes.

Scenario Prevalence

Methodology

To establish the prevalence of the HVAC system types that are being installed in BC, six HVAC companies that have a significant presence in the residential market were contacted for an interview over the phone. To avoid regional bias, one company from the Victoria, Mid-island, Northern, Interior, and two from the Greater Vancouver regions were interviewed.

The Average Annual Efficiency model cannot differentiate between styles of the heating and cooling appliances other than the efficiencies and fuel sources used.

To capture the most common systems based on interview responses, a mini-split heat pump was modeled as an approximation for all heat pumps. Similarly, with the electrical and gas backup heaters, an approximation for other common backup energy sources can be attained. The model was designed to demonstrate trends, it requires alterations to more accurately model specific projects, which is outside the scope of the project.

Refer to the appendix section Average Annual Efficiency (AAE) Resources for additional information.

Results

The most common retrofits across all regions were to add mini-split systems to an existing baseboard system, adding a mini-split system to an existing hydronic system, and adding an air to air heat pump to an existing furnace system.

An estimate of the quantity of retrofits completed by each company was collected. Using weight adjusted values based on the number projects completed, the top three responses remained as the most popular systems. The replacement of furnaces without adding a heat pump decreased because this option was more popular with some of the smaller companies.

The results of the interviews match the expectations of the interviewer and the other subject matter experts that were consulted.

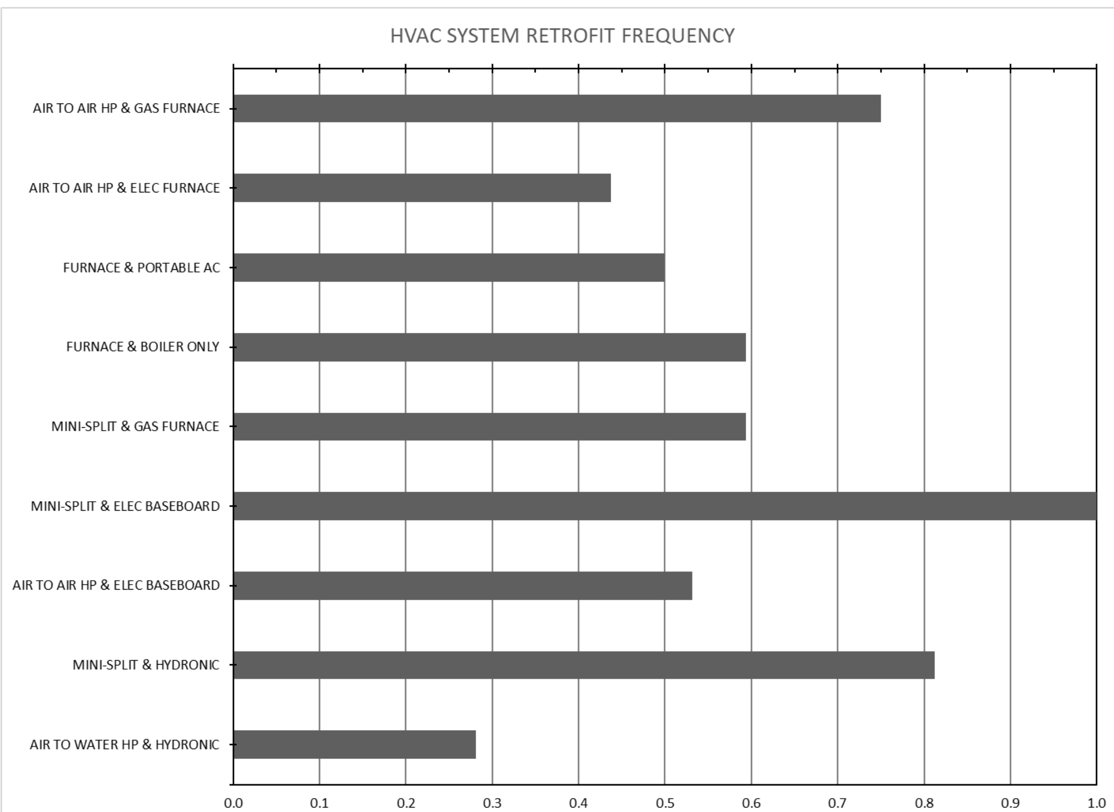


Figure 1. HVAC System Retrofit Frequency Graph

Table 1. HVAC Retrofit Prevalence Matrix

Rate the following retrofit installations in terms of how frequently you perform them: Often = 3, Sometimes = 2, Rarely = 1, Never = 0	**Vancouver #1**	**Vancouver #2**	**Mid-Island**	**Interior**	**Victoria**	**North**	**TOTALS**
Existing gas furnace & add an electric heat pump	1	3	1	3	3	1	12
Existing electric furnace & add an electric heat pump	2	1	1	1	2	0	7
Existing furnace & add portable AC	2	0	0	3	2	1	8
Replace gas furnaces (or boilers) without adding a heat pump	3	1	1	3	1	1	10
Existing gas furnace & add a mini-split	3	2	2	1	1	1	10
Existing electric baseboards & add mini-split	3	3	3	2	2	3	16
Existing electric baseboards & add centrally ducted heat pump	1	3	3	1	1	0	9
Existing gas hydronic system & add mini-split	3	3	3	1	2	1	13
Adding an air to water heat pump to a hydronic system	2	1	1	0	1	0	5
Roughly how many HVAC retrofits does your company do annually?	30	100	600	200	400	45	1375

COP Modelling of Hybrid Systems

Modelling Assumptions

The assumptions used in the efficiency modelling are based on CSA F280 which contains plans used for testing compliance and their design parameters specific to a 1980's vintage home.

Key assumptions are included in the appendix with the CSA F280 heat loss and heat gain calculations of all three locations that were modelled. Initially, only the Vancouver location was to be modeled, but the inclusion of Prince George and Kelowna were deemed to be of interest because of the significant differences in climate and heating/cooling requirements.

Methodology

To limit the scope of the project, a single dwelling was analyzed. Refer to the appendix for the assemblies that were used to represent a medium sized, 1980's single family home. The accuracy of the energy model was checked against a CSA F280 calculation.

An hourly energy model of the dwelling is required to accurately determine the varying loads that it will experience throughout each day, using the annual weather data from the three different cites. The temperature data used is Canadian Weather Year for Energy Calculation (CWEC) 2016.

Modeling the dwelling with an electric resistance heating system allows for a baseline to be established. The switchover temperature is a variable that can be edited by the user. The switchover temperature determines at what outdoor temperature the secondary heating systems will activate, which is significant to the overall energy consumption and GHG emissions.

The secondary heating system can be modeled as either a natural gas appliance or an electric resistance heater. The equipment data tab contains the values for the heat pumps and the backup appliances, which can be modified to match specific equipment. The Condensing Furnace and Gas Boiler are by default, 95% efficient appliances. The Standard Furnace, commonly referred to as a mid-efficient furnace is set by default to 80% efficient, which represents a natural draft furnace or boiler from the 1990s.

The Average Efficiency section includes editable variables for equipment type and switchover temperature. The primary output is the average heating efficiency, but there is additional data on annual energy demand and consumption. These key assumptions and the average COP is also presented in the Results table at the top of the Dashboard tab and is split for the 3 different cities.

Average Efficiency		
	Primary	Supplementary
Type	Heat Pump	Condensing Furnace
Model	AM036	
Run Hours (hours)	8518	242
Switchover Temperature (°C)	0	
Peak Heat Loss as per TECA (MBH)	44.73	
Peak Heating Demand as per Model (MBH)	48.20	
Annual Energy Demand (kWh/yr)	20493	1696
Annual Energy Consumption (kWh/yr)	5625	1785
Average Annual Efficiency	**3.64**	**0.95**
Average Heating Efficiency	**2.99**	

Figure 2. Average Efficiency Table

The Energy End-Use Breakdown table displays the modeled energy consumption of the dwelling. The natural gas emissions are assumed to be at 0.18 $kgCO_2e/kWh$ and electricity at 0.011 $kgCO_2e/kWh$. These ratios are multiplied by energy consumed by the energy end-use values to determine the performance metrics, including total GHG emissions. It is assumed that the domestic hot water is provided by a natural gas appliance, this could be another variable added to the calculator in the future.

Energy End-Use Breakdown			
End-Use	Elec (kWh)	NG (kWh)	Total (kWh)
Heating	5625	1785	7410
Cooling	500	0	500
Interior Equipment	8514	0	8514
Fans	435	0	435
Water Systems	0	3553	3553
Total	**15074**	**5339**	**20413**

Figure 3. Energy End-Use Breakdown Table

A pie chart of the energy breakdown is included to help visualize the energy consumption.

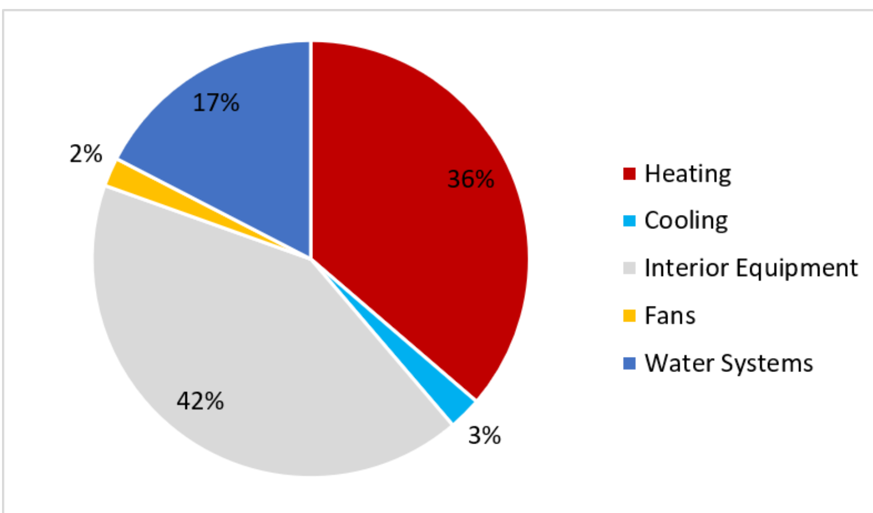


Figure 4. Energy End-Use Breakdown Chart

The Performance Metrics table displays the energy intensity metrics and the total GHG emissions based on the modeling data.

Perfomance Metrics		
Mechanical Energy Use Intensity (Max.)	40	kWh/m².yr
Adjusted TEDI (Max.)	74	kWh/m².yr
Air Tightness in ACH @ 50Pa (Max.)	6.8	Ach @ 50 Pa
Total GHG	1127	kgCO2e/yr
Total GHGI	3.7	kgCO2e/yr.m²

Figure 5. Performance Metrics Table

Observations

The graph below shows a single day in January's hourly demand. The black dots are the dwelling load that is required to maintain the indoor setpoint temperature. The red dots are the output of the high-efficient furnace, and the blue dots are the outputs from the nominally 3-ton heat pump to meet the dwelling loads. The switchover temperature was arbitrarily set to 0°C. Outdoor temperature callouts are noted adjacent to the appliance outputs.

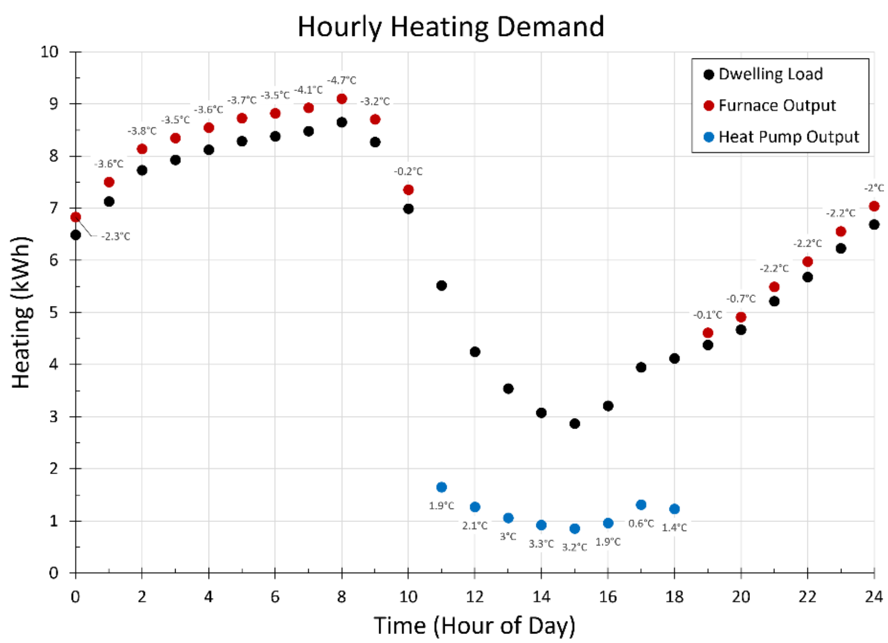


Figure 6. Hourly Heating Demand Graph

Adjustments to the heat pump sizing and the switchover temperature will have a significant impact on the average efficiency and the performance metrics. For example, in Kelowna, the lowest outdoor temperature recorded did not reach the 2.5% winter design temperature noted in the 2024 BCBC, the AM060 heat pump, which is nominally 5-tons would have easily satisfied the heating demands of the dwelling and the backup furnace would not have turned on if the switchover temperature was set to the heat pump capacity. If the switchover was set to 0°C, which is a common, but outdated design decision, the performance metrics shift dramatically. The average heating efficiency reduces from a COP of 2.84 to 1.52 and the total GHG emissions increase by 385%.

Climate Zone 5_Kelowna

Average Efficiency	Primary	Supplementary
Type	Mini Split HP	Condensing Furnace
Model	AM060	
Run Hours (hours)	8760	0
Switchover Temperature (°C)	-17	
Peak Heat Loss as per TECA (MBH)	60.28	
Peak Heating Demand as per Model (MBH)	61.44	
Annual Energy demand (kWh/yr)	28450	0
Annual Energy Consumption (kWh/yr)	10001	0
Average Annual Efficiency	**2.84**	**No Heating**
Average Heating Efficiency	**2.84**	

End-Use	Elec (kWh)	NG (kWh)	Total (kWh)
Heating	10001	0	10001
Cooling	1267	0	1267
Interior Equipment	8514	0	8514
Fans	330	0	330
Water Systems	0	3553	3553
Total	**20112**	**3553**	**23666**

Perfomance Metrics		
Mechanical Energy Use Intensity (Max.)	50	kWh/m².yr
Adjusted TEDI (Max.)	95	kWh/m².yr
Air Tightness in ACH @ 50Pa (Max.)	6.8	Ach @ 50 Pa
Total GHG	861	kgCO2e/yr
Total GHGI	2.9	kgCO2e/yr.m²

Figure 7. Kelowna Model with 17°C Switchover

Climate Zone 5_Kelowna

Average Efficiency	Primary	Supplementary
Type	Mini Split HP	Condensing Furnace
Model	AM060	
Run Hours (hours)	6986	1774
Switchover Temperature (°C)	0	
Peak Heat Loss as per TECA (MBH)	60.28	
Peak Heating Demand as per Model (MBH)	61.44	
Annual Energy demand (kWh/yr)	15201	13250
Annual Energy Consumption (kWh/yr)	4809	13947
Average Annual Efficiency	**3.16**	**0.95**
Average Heating Efficiency	**1.52**	

End-Use	Elec (kWh)	NG (kWh)	Total (kWh)
Heating	4809	13947	18756
Cooling	1267	0	1267
Interior Equipment	8514	0	8514
Fans	330	0	330
Water Systems	0	3553	3553
Total	**14920**	**17501**	**32421**

Perfomance Metrics		
Mechanical Energy Use Intensity (Max.)	79	kWh/m².yr
Adjusted TEDI (Max.)	95	kWh/m².yr
Air Tightness in ACH @ 50Pa (Max.)	6.8	Ach @ 50 Pa
Total GHG	3314	kgCO2e/yr
Total GHGI	11.0	kgCO2e/yr.m²

Figure 8. Kelowna Model with 0°C Switchover

The addition of a wider variety of heat pumps and cities would greatly improve the AAE calculator, but that is outside the scope of this project. The ability to alter design parameters and instantly see the change in metrics can support design decisions and provide insights to potential operating costs.

Evaluation Protocols

Efficiency & Effectiveness

A complication in the discussion of efficiency is the consideration of the effectiveness of the HVAC system. Effectiveness relates to indoor air quality and thermal comfort. If indoor air quality is poor, often from insufficient ventilation, occupants will open windows. When thermal comfort is poor, some areas of the dwelling will be over-conditioned or use supplemental heating and cooling appliances to compensate for distribution system deficiencies. This behavior will not be represented in a model because it is assumed that the HVAC equipment is delivering the required heating, cooling, and ventilation to satisfy the occupant's needs.

The variance introduced by occupants can never be fully removed, but minimum standards for the HVAC systems must be in place to yield a reasonable approximation to the model. Following the approved standards in the BCBC 9.33.4.1. is critical to ensuring that effective HVAC systems are installed.

General Evaluation Criteria:

- Equipment capacity at design conditions meet CSA F280 heat loss & heat gain calculations
    - Per BCBC 2024, 9.33.5.1
- Commissioning report is complete and left onsite
    - Must note switchover temperature
- Thermostats are not located in the supply air discharge path or on outside walls
- Primary heating/cooling systems have thermostats interconnected with supplemental heating/cooling systems to prevent one system cooling while the other is heating
    - Per BCBC 2024, 9.36.3.6. (2)

To achieve a hybrid system average efficiency, limitations on the gas backup equipment are not impactful because most of the mid-efficient systems have been replace with high-efficient equipment. The switchover temperature is the most critical component, as long as the heat pump has been properly sized to the dwelling loads, it will be responsible for the majority of the heating, easily attaining a COP greater than 1.

Mini-Split Systems

Typical mini-split systems use wall or ceiling mounted cassettes. These styles do not have a distribution system, making them easier to evaluate in terms of an acceptable installation. If the mini-split system includes fan coil units, which are typically smaller air handling units, the attached ducting distribution system must be evaluated in the same way as an air handling unit.

Poor thermostat location is a common issue with mini-split systems. Typically, each indoor unit will have a dedicated thermostat. To reduce wiring, these thermostats are often located too close to the supply air discharge of the unit, resulting in short cycling of the equipment.

Condensate drains are also a common deficiency. Where possible, use gravity drainage and connect indirectly to the sanitary system. Condensate pumps should be avoided; they increase the maintenance requirements and add a significant failure point.

Centrally Ducted Air Handling Units (AHU)

The most common air handling units (AHU) are centrally ducted furnaces with air to air heat pumps. If several AHUs are used in combination, they might be referred to as fan coil units (FCU). The challenge of evaluating an AHU is with its distribution system. The efficiency rating of an appliance is generated in lab conditions that will differ from installed conditions, especially if the duct design has been compromised in some way.

External static pressure (ESP) measurements of the duct system are a quick and straight forward way to test the airflow rates and indicate the quality of the duct distribution system. Measuring ESP is accomplished by drilling a small hole in the ductwork and placing a static pressure probe at that point, while the other port is open to atmospheric pressure, giving a pressure differential. The graphic below reflects actual ESP measurements taken on site.

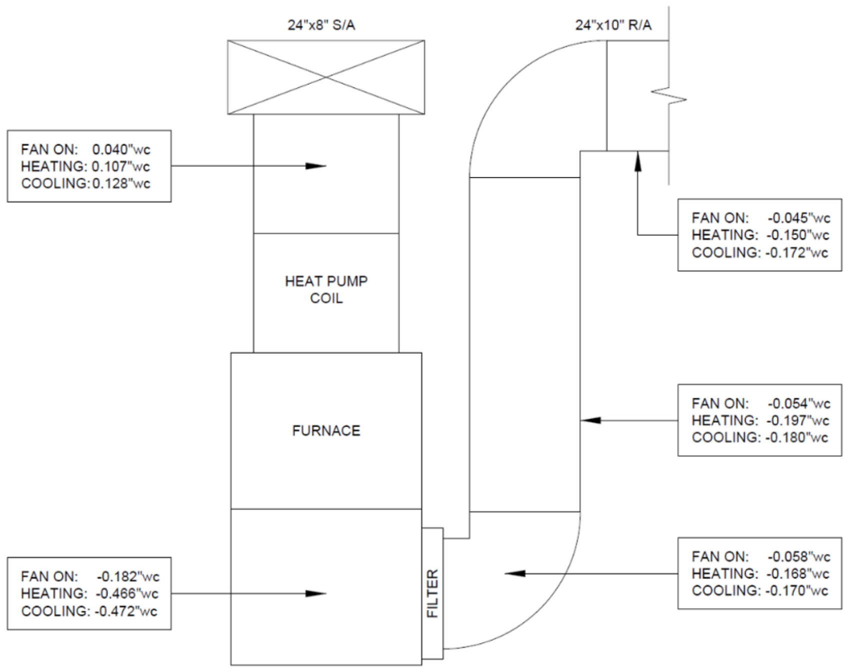


Figure 9. External Static Pressure Measurements

The cooling speed generates the highest ESP, which is due to the controls of the furnace turning the air handler fan to maximum speed (RPM) in this mode. This is common in many furnaces and air handlers but does need to be checked based on the specific make and model. The table below shows the expected air delivered based on the ESP of the duct system and a light filter that adds 0.1 inches of water column ("wc). A more restrictive filter will add additional ESP and must be included to estimate airflow. The airflow rates can be confirmed with a flow hood, but this is time consuming and rarely done onsite. Leakage should be minimized to ensure that the air moved by the fan blower arrives at the intended location. Leakage can be measured by using one of several existing standards.

Table 9 – Air Delivery - CFM (With Filter)												
FURNACE SIZE	SPEED TAPS	Function	EXTERNAL STATIC PRESSURE (IN.W.C.)									
			0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
0401410	Gray	Cooling. Do not use for heating	1120	1085	1055	1015	985	950	915	880	850	815
	Yellow	Cooling. Do not use for heating	925	885	850	810	775	735	695	660	620	580
	Blue [3]	Heating or alt Cooling	765	725	685	640	605	565	525	475	430	375
	Orange [3]	Alt Cooling or alt Heating	750	710	665	625	585	545	500	455	405	350
	Red [3, 7]	Alt Cooling. Do not use for heating	510	435	400	345	290	230	190	145	–	–

Figure 10. Air Delivery Table Based on ESP

For retrofit applications, the ESP of the ducting must be measured before the existing equipment is decommissioned and the new equipment is selected. The existing distribution system is likely hidden behind finished drywall and therefore cannot be visually inspected. It is common for oversized heating and cooling appliances to be installed during retrofit applications because heat loss & heat gain calculations are not performed and/or the existing distribution system is not properly verified that it can handle the airflow rates required. In the case where a distribution system cannot be properly modified, it is better to size the equipment to the existing duct, rather than oversize the equipment and have insufficient airflow.

Return air grilles must be provided for each floor as per the BCBC-2024, clause 9.33.6.12. (2) and the doors shall be undercut per 9.33.6.12. (3). These two items are critical to ensure proper circulation throughout the dwelling.

Hydronic Systems

Hydronic systems have similar challenges to the centrally ducted forced air systems; they rely on their distribution systems to perform as intended. There is a massive number of acceptable piping arrangements for a residential application. Similarly, there are many fundamental errors that occur when designing these systems.

A system schematic must be provided to ensure that the system is piped in an acceptable way. This schematic can come from the manufacturer, TECA's piping handbooks, or another referenced standard in the BCBC 9.33.4.1. The schematic should note the pipe sizes, the major equipment, water temperatures, and flow rates. The schematic should also include information on the domestic hot water, pools/spas, and snow melt if those systems are incorporated into the domestic heating system.

Fluid flow rates, inlet and outlet water temperatures, and system pressures can be quickly measured onsite to verify that a hydronic system is operating as intended. This does require proper design documentation for comparison as these values will differ between projects.

Existing HVAC Testing Protocol: ANSI/RESNET/ACCA 310-2020

The ANSI/RESNET/ACCA 310-2020 Standard for Grading the Installation of HVAC Systems (ACCA 310) has growing support in industry as a performance-based standard that best assesses the quality of energy distribution systems in a clear, methodical, and non-invasive method. It's adoption as the default testing standard in the BCBC is one path towards performance-based testing.

The ANSI/RESNET/ACCA 310-2020 standard and an excel compliance tool are available online.

The ACCA 310 standard includes tools and checklists that facilitate the verification process for the tester and Authorities Having Jurisdiction (AHJ). This is a significant advantage to adopting a mature standard. Inclusions such as Canadian climate data would be required as an external reference, which is already included in the building code.

The ACCA 310 Standard contains a 5-step process to evaluate the installed performance of the heating and cooling system. The testing must be completed in order and cannot proceed to the next step without addressing deficiencies.

1. Evaluation of the design
2. Evaluation of the total duct leakage
3. Evaluation of the blower fan airflow
4. Evaluation of the blower fan watt draw
5. Evaluation of the refrigerant charge

A large component of the standard is based on design review, which aligns with TECA's recommendations. Room by room load calculations must be provided to support the equipment selection and the distribution system design. In Canada, the load calculations must be CSA F280 complaint per BCBC Section 9.33.5.1.

Duct leakage is critical to test prior to assessing the airflow rate of the blower to ensure that the air the blower is moving is delivered to its intended location.

The wattage of the blower fan can easily be measured with a multimeter. The standard grades the blower fan efficiency by comparing the watts used divided by the airflow (CFM) produced by the blower. High watts/cfm indicates constricted or undersized ductwork.

Duct leakage and blower fan watt draw can be testing during rough-in or final inspection, but it is preferable to test during rough-in, where modifications to the system are still practical.

The final step is to verify the refrigerant charge, which is critical for proper commissioning and system operation. The standard accepts a geotagged and stamped photograph to show that the total anticipated refrigerant charge is equal to or less than 5% of the installed charge.

The ACCA 310 standard is a comprehensive system to verify that the distribution system and the heating and cooling appliances have been properly commissioned. Adoption of this standard will ensure that the equipment operates as the manufacturer intended and will identify systems that that do not meet reputable installation and design guidelines.

Recommendations

The British Columbia Building Code (BCBC) has shifted towards a focus on energy efficiency and performance-based metrics for installed appliances and the building assemblies. The inclusion of HVAC systems into a performance model aligns with the direction of the province's code development.

Technical Safety BC does not require refrigeration permits on most residential heat pump installations or replacements. The focus of municipal inspections on HVAC systems has largely been on natural gas and electrical work because they were viewed as the primary concerns for safety. Municipalities often do not require a mechanical permit or assess the effectiveness of HVAC distribution systems.

The collection of design data for residential HVAC systems varies between municipalities which creates confusion for mechanical contractors and a barrier to training building officials. Standardizing the document submission process is a critical first step towards performance-based metrics. Without design information that outlines the project assumptions, there is no baseline to measure against.

The importance of the switchover temperature in hybrid systems is supported by the testing in the AAE calculator. Switchover temperature is often overlooked as an important design parameter, and contractors frequently apply some arbitrary number rather than a calculated balance point. Section 9.36.3.6.(6) of the BCBC notes that the heat pump should operate to its full capacity, if the mechanical documentation is incomplete, this will likely not be known and therefore cannot be inspected.

Mechanical design documentation to be submitted for a performance-based HVAC system are:

- Ventilation Compliance Checklist
  - Shows compliance with BCBC 9.32.
- CSA F280 Heat Loss & Heat Gain Report
  - Required for equipment selection to meet BCBC 9.33.5.1.
- Heating & Cooling Equipment Selection Worksheet
  - Notes the manufacturers and the models of installed appliances
  - Records design assumptions such as pressure losses due to distribution systems and additional accessories
- Design Summary
  - Notes information on items such as heat emitters, fan coil units, and radiant panels
  - Control strategy with switchover temperature noted
- System Drawings and/or Schematics
  - Single line drawings of the distribution system
  - Hydronic systems require a schematic to show component placement and piping strategy
- Commissioning Worksheets
  - Ideally provided by the manufacturer for the specific installed model

  - Required for heat pumps, air handlers, boilers, water heaters, ventilation fans, and any other major equipment
  - Commissioning worksheets must be signed by a qualified contractor and left on site

There is no single trade that is qualified for a complete residential heat pump installation. There is not a consensus in the industry as to the ideal path forward to address the common problems that are found in BC. To complete a typical project, often four different trades are required, a refrigeration technician, a sheet metal worker, an electrician, and a gas fitter. In practice, there can be as few as two contractors completing a project. It is unlikely that they will have a trade qualification in all areas.

Many associations have supported a trade within the Refrigeration and Air Conditioning Mechanic (RACM) program that would specifically train residential HVAC contractors. This is not universally supported, which is an additional barrier to adoption, especially when the cost to the province to develop a new trade is also considered.

An air to air heat pump microcredential has been created in partnership between BCIT and TECA, with the support of the Home Performance Stakeholder Council (HPSC) and the Heating, Refrigeration and Air Conditioning Institute of Canada (HRAI). HPSC has recently announced a requirement for mechanical contractors on their network to complete the air to air microcredential. Since access to most rebates is through the HPSC contractor network, an incentivized upskilling process has been introduced, giving a competitive advantage to companies that comply. This also introduces another type of inspection process as they have the ability to respond to customer complaints and potentially remove contractors that are not meeting code requirements. An air to water heat pump microcredential is currently under development.

The City of Vancouver has adopted a mechanical permit, which other municipalities could emulate. This would formalize the HVAC document submission process, which could be supported by the Construction Standards and Digital Solutions Branch at the BC Ministry of Housing and Municipal Affairs. The framework for residential mechanical document submissions is already in place but has not seen widespread adoption because it is voluntary. A requirement of the mechanical permit applicant to hold the appropriate microcredential would ensure that the contractors have sufficient training to complete the required mechanical design documentation.

There are many factors driving the adoption of heat pumps including BCBC requirements in new construction, to the desire of homeowners for greater thermal comfort when adding heat pumps to existing heating only systems. There are significant barriers to adoption, in particular, there is a skepticism of the capability of heat pumps to heat at low outdoor temperatures. Although these concerns are unfounded, they are reinforced by anecdotal stories of failed installations. Proper design documentation submission is the first step towards performance-based metrics, which will allow for temperature and pressure measurements to be taken in the mechanical room to verify the system is operating as intended.

The ANSI/RESNET/ACCA 310-2020 Standard for Grading the Installation of HVAC Systems is an existing standard that is already being used in industry to perform non-invasive testing on heating and cooling systems. It could be adopted into the BCBC with minor additions.

Key Findings & Talking Points

A COP of greater than 1 is a low target for systems that include a heat pump.

- Hybrid systems will outperform electric resistance heaters even if they are not optimized.
- Heat pumps are far more efficient than both electric resistance and gas appliances, they should not be held to the same standard.

To minimize GHG emissions in hybrid systems, the switchover temperature should be based on the heat pump capacity and the heating load of the dwelling.

- The BCBC requires that the full capacity of the heat pump is used during normal operation.
    - **BCBC: Section 9.36.3.6. Temperature Controls**
      6) Heat pumps equipped with supplementary heaters shall incorporate controls to prevent supplementary heater operation when the heating load can be met by the heat pump alone, except during defrost cycles.
- Picking arbitrary switchover temperatures often underutilizes the heat pump, switchover temperature should be specific to each project.
- The switchover temperature greatly impacts the COP.
- There is a popular misconception that heat pumps do not operate well below 0°C, which is false, especially with cold climate heat pumps. Units that operate down to -30°C are available.

The Average Annual Efficiency (AAE) calculator is a flexible tool that simulates year-round hybrid heating system performance.

- Users can test 3 different climate zones, 3 heat pump capacity, gas or electric backup heaters, and specific switchover temperatures.
- The outputs are COP, energy use, run hours, and GHG emissions.
- The AAE allows for comparison of design decisions and their impact on energy metrics.
- Only one single family home with 1980s assemblies is modeled, but other dwellings could be imported into the AAE with an appropriate energy model.

A clear evaluation protocol is needed so the installed system matches the model.

- The ACCA 310 Standard is an acceptable approach to measure installed systems.
- Proper ductwork, system sizing, control strategies, and complete design documents are critical to assess the quality of a system.
- Standards help maintain comfort and efficiency, improving project outcomes.
- Future implementation efforts should prioritize standardized design documentation, performance verification procedures, and contractor training to improve consistency between modeled and installed performance.

Modelling Assembly Values:1980s Vintage Dwelling

Description of Assembly	R-Value
Above Grade Wall - Typical	12.62
Above Grade Wall - Garage	11.75
Interior Foundation Wall	8.03
Ceiling	17.66
Exposed Floor	20.64
Exposed Header - Typical	11.28
Exposed Header - Garage	10.00

Description of Assembly	Values
Windows	USI: 2.7 & SHGC: 0.49
Doors	USI: 1.41

Foundation Description:

Basement Concrete Slab & Walls, insulation: interior wall = 1.41RSI (configuration #3), first storey brick veneer placed directly on basement's concrete walls, interior surface of wall insulated from top of wall to 0.6 m below grade.

- Area: 972ft^2
- Full Perimeter: 153ft
- Exposed Perimeter: 153ft

Vancouver: Design Temperatures

- January 2.5%: -7°C
- July 2.5% DB: 28°C

Kelowna: Design Temperatures

- January 2.5%: -17°C
- July 2.5% DB: 33°C

Prince George: Design Temperatures

- January 2.5%: -32°C
- July 2.5% DB: 28°C

Vancouver Heat Loss & Heat Gain Summary

PROJECT #: 1980 Vancouver Home. TC-STD-80-VN-S

HEAT LOSS & HEAT GAIN SUMMARY, (BTUH)

imperial

ROOM NAME	FLOOR LEVEL	FL AREA (ft^2)	**HEAT LOSS** TOTAL	**HEAT GAIN** SENS.	**TOTAL (sensible + latent)**
(#1)BASEMENT AREA 1	1	547	8005	289	**375**
(#2)BASEMENT AREA 2	1	425	5891	84	**109**
(#3)FAMILY ROOM	2	252	5015	3693	**4801**
(#4)NOOK	2	78	1834	712	**925**
(#5)KITCHEN	2	153	261	1310	**1703**
(#6)POWDER	2	41	307	6	**8**
(#7)FOYER/ENTRY	2	70	1777	398	**517**
(#8)LIVING ROOM	2	185	3128	3523	**4580**
(#9)STAIRS	2	104	1623	1134	**1474**
(#10)DINING ROOM	2	142	2215	2076	**2699**
(#11)WIC	3	55	951	152	**198**
(#12)MASTER BEDROOM	3	305	4433	2262	**2940**
(#13)ENSUITE	3	100	1191	864	**1123**
(#14)BEDROOM 2	3	180	3176	2371	**3082**
(#15)BEDROOM 3	3	140	2056	836	**1087**
(#16)BATH	3	64	767	289	**375**
(#17)LAUNDRY	3	88	317	181	**236**
(#18)BEDROOM 4	3	140	1792	664	**863**
		AREA	HEAT LOSS	GAIN (sens.)	GAIN (total)
OVERALL BUILDING		3069	44737	20843	**27096**

Prince George Heat Loss & Heat Gain Summary

PROJECT #: 1980 Prince George Home. TC-STD-80-VN-S

HEAT LOSS & HEAT GAIN SUMMARY, (BTUH)

imperial

ROOM NAME	FLOOR LEVEL	FL AREA (ft^2)	**HEAT LOSS** TOTAL	**HEAT GAIN** SENS.	**TOTAL (sensible + latent)**
(#1)BASEMENT AREA 1	1	547	16687	285	**371**
(#2)BASEMENT AREA 2	1	425	12172	83	**107**
(#3)FAMILY ROOM	2	252	10343	3662	**4761**
(#4)NOOK	2	78	3783	703	**913**
(#5)KITCHEN	2	153	538	1310	**1702**
(#6)POWDER	2	41	633	6	**8**
(#7)FOYER/ENTRY	2	70	3665	418	**544**
(#8)LIVING ROOM	2	185	6452	3494	**4542**
(#9)STAIRS	2	104	3347	1120	**1455**
(#10)DINING ROOM	2	142	4568	2066	**2686**
(#11)WIC	3	55	1910	150	**195**
(#12)MASTER BEDROOM	3	305	8908	2269	**2950**
(#13)ENSUITE	3	100	2393	881	**1145**
(#14)BEDROOM 2	3	180	6382	2367	**3078**
(#15)BEDROOM 3	3	140	4131	825	**1073**
(#16)BATH	3	64	1540	285	**370**
(#17)LAUNDRY	3	88	636	179	**233**
(#18)BEDROOM 4	3	140	3600	656	**852**
		AREA	HEAT LOSS	GAIN (sens.)	GAIN (total)
OVERALL BUILDING		3069	91688	20758	**26985**

Kelowna Heat Loss & Heat Gain Summary

PROJECT #: 1980 Kelowna Home. TC-STD-80-VN-S

HEAT LOSS & HEAT GAIN SUMMARY, (BTUH)

imperial

ROOM NAME	FLOOR LEVEL	FL AREA (ft^2)	**HEAT LOSS** TOTAL	**HEAT GAIN** SENS.	**TOTAL (sensible + latent)**
(#1)BASEMENT AREA 1	1	547	10497	410	533
(#2)BASEMENT AREA 2	1	425	7684	130	168
(#3)FAMILY ROOM	2	252	6859	4271	5552
(#4)NOOK	2	78	2509	943	1226
(#5)KITCHEN	2	153	357	1327	1725
(#6)POWDER	2	41	420	26	34
(#7)FOYER/ENTRY	2	70	2430	564	733
(#8)LIVING ROOM	2	185	4279	3945	5129
(#9)STAIRS	2	104	2219	1320	1716
(#10)DINING ROOM	2	142	3030	2336	3037
(#11)WIC	3	55	1295	221	288
(#12)MASTER BEDROOM	3	305	6037	2755	3581
(#13)ENSUITE	3	100	1622	1030	1338
(#14)BEDROOM 2	3	180	4325	2810	3653
(#15)BEDROOM 3	3	140	2800	1070	1390
(#16)BATH	3	64	1044	369	480
(#17)LAUNDRY	3	88	431	209	272
(#18)BEDROOM 4	3	140	2440	852	1107
		AREA	HEAT LOSS	GAIN (sens.)	GAIN (total)
OVERALL BUILDING		3069	60279	24588	**31964**

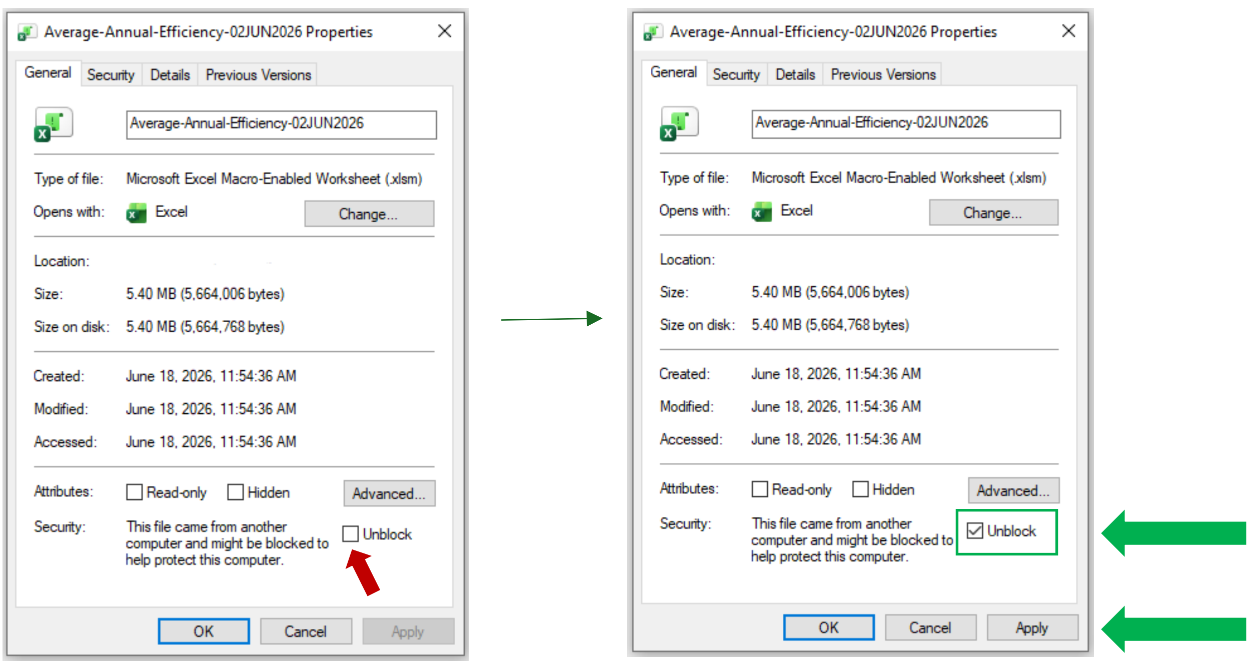
Average Annual Efficiency (AAE) Resources

AAE Activation

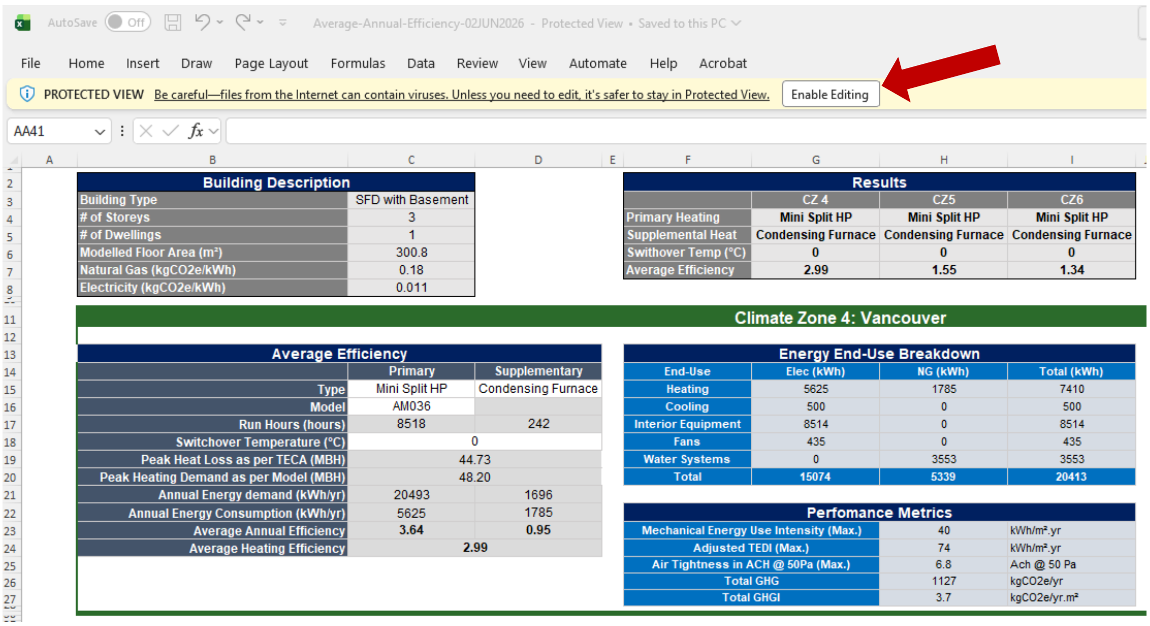
The AAE is available for free on TECA's website. The download link is provided in the Reference Material & Links section on the following page.

1. Download the file to your computer
    a. The following items must be addressed to enable the macros of the calculator.

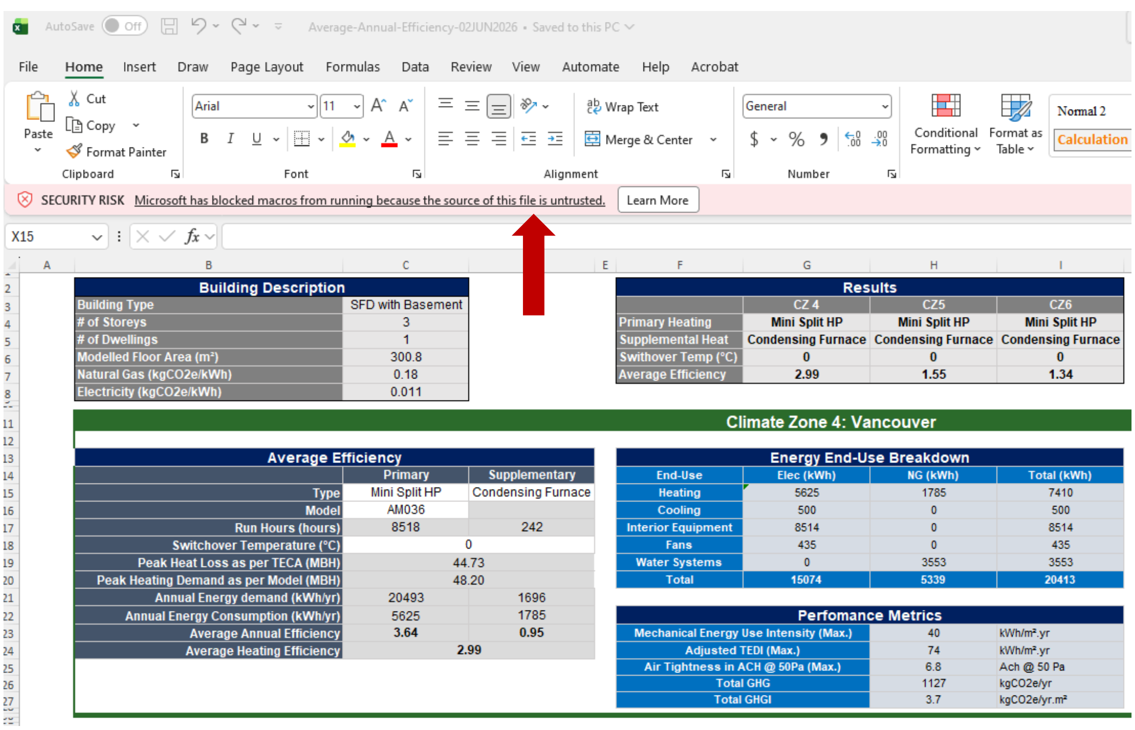
2. Right click on the file and select "Properties", click the "Unblock" button in the low right corner of the General tab, in the Security section. Click "Apply".



3. Excel will typically open the file in “protected view”, which is noted in a yellow band across the top of the page. The “Enable Editing” button must be clicked to make alterations to the file.



NOTE: If after clicking “Enable Editing”, a pink band is displayed, the Security section in the file properties has not been unblocked, refer to the line #2 to unblock the macros.



AAE Equipment Modifications

To modify the performance specifications of the equipment in the model, use the "Equip. Data" tab.

The backup system efficiencies can be changed by altering the cell value in the Efficiency column.

Equipment Type	Efficiency
Condensing Furnace	0.95
Elec Baseboard	1
Gas Boiler	0.95
Standard Furnace	0.8

Figure 11. Backup Efficiency Table

To change the heat pump data, alter the following columns to match the desired performance specifications from the manufacturers' capacity table of the new heat pump.

- OAT (°F): Outdoor Air Temperature
  - The outdoor dry bulb air temperature in Fahrenheit for the heating capacities
- Equipment Size
  - Use the first few digits of the model, which should indicate the nominal capacity
- Total Capacity (MBH)
  - The heating output at the OAT in MBH (which is 1,000s of BTUH)
  - Indoor dry bulb temperature should be take at 72°C
- Power Input (kW)
  - Power that is delivered to the heat pump

Note: The Coefficient of Performance (COP) of a heat pump will change depending on outdoor and indoor conditions.

Heat Pump Data						
Equipment Type	OAT (°F)	OAT (°C)	Equipment Size	Total Capacity (MBH)	Power Input (kW)	COP
Heat Pump	-21.8	-29.9	AM036	24.2	4.35	1.63
Heat Pump	-17.8	-27.7	AM036	25.8	4.42	1.71
Heat Pump	-12.6	-24.8	AM036	28	4.52	1.82
Heat Pump	-7.1	-21.7	AM036	30.3	4.61	1.93
Heat Pump	-4.0	-20.0	AM036	31.8	4.68	1.99
Heat Pump	1.0	-17.2	AM036	34.1	4.78	2.09
Heat Pump	5.0	-15.0	AM036	35.6	4.85	2.15
Heat Pump	10.0	-12.2	AM036	37.9	4.94	2.25
Heat Pump	14.0	-10.0	AM036	39.3	5.01	2.30
Heat Pump	19.0	-7.2	AM036	39.9	5.01	2.33
Heat Pump	23.0	-5.0	AM036	40.2	4.73	2.49
Heat Pump	27.0	-2.8	AM036	40.2	4.38	2.69
Heat Pump	32.0	0.0	AM036	40.2	3.92	3.01
Heat Pump	37.0	2.8	AM036	40.2	3.53	3.34
Heat Pump	44.0	6.7	AM036	40.2	3.2	3.68
Heat Pump	47.0	8.3	AM036	40.2	3.1	3.80
Heat Pump	51.0	10.6	AM036	40.2	2.77	4.25
Heat Pump	54.0	12.2	AM036	40.2	2.7	4.36
Heat Pump	57.0	13.9	AM036	40.2	2.58	4.57
Heat Pump	60.0	15.6	AM036	40.2	2.47	4.77

Figure 12. Heat Pump Data Table

Dwelling Load & Location Modifications

To alter the AAE to model a specific dwelling, an hourly energy model is required. The model must include the outdoor temperature and the heating load of the dwelling. The remaining fields will auto-fill because they are equations based off the weather data and the equipment information.

It is recommended to use the CWEC 2016 dataset for the temperatures of your project. Ensure that the same number of cells are output, otherwise some adjustments to the calculator will be required to capture the correct cells.

The AAE calculator is set by default to take the dwelling heating load in kilowatts per hour, under the column header "Heating (kW/h)". If you're output is in MBH, use that column and determine the kW/h by a conversion equation.

					Primary Heating							Supplementary Heating				
	Timestamp	OAT (°C)	Heating (kW/h)	Heating (MBH)	Equipment Type	Heat Pump Name	Equip. Capacity	Min Demand (MBH)	Min Demand (KW)	Efficiency	kWH/h	Equipment Type	Furnace Demand (kW)	Eqp. Efficiency	kWh/hr	Average Efficiency
Heating (Electricity)	2011-01-01 1:00	-1.8	6.86	23.41			0	0.00	0.00	0.00	0.00	Condensing Furnace	6.86	0.95	7.22	0.95
Heating (Electricity)	2011-01-01 2:00	-3	7.45	25.42			0	0.00	0.00	0.00	0.00	Condensing Furnace	7.45	0.95	7.84	0.95
Heating (Electricity)	2011-01-01 3:00	-4	7.86	26.82			0	0.00	0.00	0.00	0.00	Condensing Furnace	7.86	0.95	8.27	0.95
Heating (Electricity)	2011-01-01 4:00	-4.7	8.24	28.11			0	0.00	0.00	0.00	0.00	Condensing Furnace	8.24	0.95	8.67	0.95
Heating (Electricity)	2011-01-01 5:00	-5.2	8.53	29.10			0	0.00	0.00	0.00	0.00	Condensing Furnace	8.53	0.95	8.98	0.95
Heating (Electricity)	2011-01-01 6:00	-5.6	8.77	29.92			0	0.00	0.00	0.00	0.00	Condensing Furnace	8.77	0.95	9.23	0.95
Heating (Electricity)	2011-01-01 7:00	-5.4	8.9	30.37			0	0.00	0.00	0.00	0.00	Condensing Furnace	8.9	0.95	9.37	0.95
Heating (Electricity)	2011-01-01 8:00	-5.4	8.96	30.57			0	0.00	0.00	0.00	0.00	Condensing Furnace	8.96	0.95	9.43	0.95
Heating (Electricity)	2011-01-01 9:00	-4	8.52	29.07			0	0.00	0.00	0.00	0.00	Condensing Furnace	8.52	0.95	8.97	0.95
Heating (Electricity)	2011-01-01 10:00	-1.4	6.88	23.47			0	0.00	0.00	0.00	0.00	Condensing Furnace	6.88	0.95	7.24	0.95
Heating (Electricity)	2011-01-01 11:00	1	5.14	17.54	Heat Pump	AM036	40.2	17.54	5.14	3.01	1.71		0		0.00	3.01
Heating (Electricity)	2011-01-01 12:00	2	3.83	13.07	Heat Pump	AM036	40.2	13.07	3.83	3.34	1.15		0		0.00	3.34
Heating (Electricity)	2011-01-01 13:00	2.7	3.1	10.58	Heat Pump	AM036	40.2	10.58	3.10	3.34	0.93		0		0.00	3.34
Heating (Electricity)	2011-01-01 14:00	2.4	2.8	9.55	Heat Pump	AM036	40.2	9.55	2.80	3.34	0.84		0		0.00	3.34
Heating (Electricity)	2011-01-01 15:00	3.1	2.64	9.01	Heat Pump	AM036	40.2	9.01	2.64	3.34	0.79		0		0.00	3.34
Heating (Electricity)	2011-01-01 16:00	1.6	2.98	10.17	Heat Pump	AM036	40.2	10.17	2.98	3.34	0.89		0		0.00	3.34
Heating (Electricity)	2011-01-01 17:00	0.1	3.71	12.66	Heat Pump	AM036	40.2	12.66	3.71	3.01	1.23		0		0.00	3.01
Heating (Electricity)	2011-01-01 18:00	-0.3	4.07	13.89			0	0.00	0.00	0.00	0.00	Condensing Furnace	4.07	0.95	4.28	0.95
Heating (Electricity)	2011-01-01 19:00	-0.1	4.16	14.19			0	0.00	0.00	0.00	0.00	Condensing Furnace	4.16	0.95	4.38	0.95
Heating (Electricity)	2011-01-01 20:00	-0.7	4.41	15.05			0	0.00	0.00	0.00	0.00	Condensing Furnace	4.41	0.95	4.64	0.95
Heating (Electricity)	2011-01-01 21:00	-0.5	4.74	16.17			0	0.00	0.00	0.00	0.00	Condensing Furnace	4.74	0.95	4.99	0.95
Heating (Electricity)	2011-01-01 22:00	-1.9	5.31	18.12			0	0.00	0.00	0.00	0.00	Condensing Furnace	5.31	0.95	5.59	0.95
Heating (Electricity)	2011-01-01 23:00	-1.7	5.91	20.16			0	0.00	0.00	0.00	0.00	Condensing Furnace	5.91	0.95	6.22	0.95
Heating (Electricity)	2011-01-01 0:00	-2.3	6.49	22.14			0	0.00	0.00	0.00	0.00	Condensing Furnace	6.49	0.95	6.83	0.95
Heating (Electricity)	2011-01-02 1:00	-3.6	7.13	24.33			0	0.00	0.00	0.00	0.00	Condensing Furnace	7.13	0.95	7.51	0.95
Heating (Electricity)	2011-01-02 2:00	-3.8	7.73	26.37			0	0.00	0.00	0.00	0.00	Condensing Furnace	7.73	0.95	8.14	0.95
Heating (Electricity)	2011-01-02 3:00	-3.5	7.93	27.06			0	0.00	0.00	0.00	0.00	Condensing Furnace	7.93	0.95	8.35	0.95
Heating (Electricity)	2011-01-02 4:00	-3.6	8.12	27.71			0	0.00	0.00	0.00	0.00	Condensing Furnace	8.12	0.95	8.55	0.95
Heating (Electricity)	2011-01-02 5:00	-3.7	8.29	28.29			0	0.00	0.00	0.00	0.00	Condensing Furnace	8.29	0.95	8.73	0.95
Heating (Electricity)	2011-01-02 6:00	-3.5	8.38	28.59			0	0.00	0.00	0.00	0.00	Condensing Furnace	8.38	0.95	8.82	0.95
Heating (Electricity)	2011-01-02 7:00	-4.1	8.48	28.93			0	0.00	0.00	0.00	0.00	Condensing Furnace	8.48	0.95	8.93	0.95
Heating (Electricity)	2011-01-02 8:00	-4.7	8.65	29.51			0	0.00	0.00	0.00	0.00	Condensing Furnace	8.65	0.95	9.11	0.95
Heating (Electricity)	2011-01-02 9:00	-3.2	8.27	28.22			0	0.00	0.00	0.00	0.00	Condensing Furnace	8.27	0.95	8.71	0.95
Heating (Electricity)	2011-01-02 10:00	-0.2	6.99	23.85			0	0.00	0.00	0.00	0.00	Condensing Furnace	6.99	0.95	7.36	0.95
Heating (Electricity)	2011-01-02 11:00	1.9	5.52	18.83	Heat Pump	AM036	40.2	18.83	5.52	3.34	1.65		0		0.00	3.34
Heating (Electricity)	2011-01-02 12:00	2.1	4.25	14.50	Heat Pump	AM036	40.2	14.50	4.25	3.34	1.27		0		0.00	3.34
Heating (Electricity)	2011-01-02 13:00	3	3.54	12.08	Heat Pump	AM036	40.2	12.08	3.54	3.34	1.06		0		0.00	3.34

Figure 13. AAE Dwelling Load & Location Table

Ensure that all modifications are correctly reflected in the Dashboard tab, such as the title of the summary section to avoid confusion.

Reference Material & Links

Average Annual Efficiency Calculator Download:
teca.ca/contractor-resources/teca-resources/average-annual-efficiency-calculator

ANSI/RESNET/ACCA 310-2020 Standard for Grading the Installation of HVAC Systems
acca.org/qa/ansi-standard-310

ASHRAE Homepage:
ashrae.org

British Columbia Building Code (BCBC) Homepage:
gov.bc.ca/gov/content/industry/construction-industry/building-codes-standards/bc-codes/2024-bc-codes

BCBC 2024 PDF:
gov.bc.ca/assets/gov/farming-natural-resources-and-industry/construction-industry/building-codes-and-standards/revisions-and-mo/bcbc-revision-3/bcbc-revision-4/bcbc_2024_web_version_20240409.pdf

Canadian Weather Year for Energy Calculation (CWEC)
https://open.canada.ca/data/en/dataset/55438acb-aa67-407a-9fdb-1cb21eb24e28

National Building Code (NBC) Homepage:
nrc.canada.ca/en/certifications-evaluations-standards/codes-canada/codes-canada-publications/national-building-code-canada-2025

NBC 2025 PDF Download:
nrc-publications.canada.ca/eng/view/object/?id=adf1ad94-7ea8-4b08-a19f-653ebb7f45f6

TECA Homepage:
teca.ca