Air-Source Heat Pump Sizing and Selection

Course No: M05-029
Credit: 5 PDH

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This course was adapted from Natural Resources Canada (NRCan), Cat. No. M154-138/2020E-PDF - ISBN 978-0-660-36713-2 and posted on our website with prior permission from NRCan.

Acknowledgements:

The Air Source Heat Pump Sizing and Selection Guide was developed in response to industry requests for consistent guidance in the process of sizing air source heat pumps according to the design heating or cooling load and intended use ("Sizing") as well as identifying the appropriate system according to the installation and application ("Selection").

Technical content of this Guide was developed by Terry Strack of Strack & Associates Ltd. and Jeremy Sager of NRCan / CanmetENERGY.

NRCan wishes to thank all those who assisted with the review, editing and final development of this Guide, including: Bruce Harley Energy Consulting LLC., Bfreehomes Design Ltd. (and partner Service Organisations across Nova Scotia), Cross Heating & Air Conditioning Ltd., Bowser Technical, Yukon Department of Energy, NRCan / Office of Energy Efficiency - Equipment Division, as well as Jérémie Leger, Sébastien Brideau, Amr Daouk, Martin Kegel and Justin Tamasauskas of NRCan / CanmetENERGY. The development of this Guide was managed by Jeremy Sager of NRCan / CanmetENERGY.

Funding for this work was provided by Natural Resources Canada through the Program of Energy Research and Development as well as through the Office of Energy Efficiency, Equipment Division.

Cat. No. M154-138/2020E-PDF (On-line)
ISBN 978-0-660-36713-2
Aussi disponible en français sous le titre :
« Guide de sélection et de dimensionnement des thermopompes à air » au Canada

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GLOSSARY

Add-on system: Adding HVAC equipment to a pre-existing system.

AFUE: Annual Fuel Utilization Efficiency. Dimensionless ratio used to indicate the fuel conversion efficiency of a furnace as a percentage. A 96% AFUE furnace will output 96 Btu of useful heat for 100 Btu of fuel consumption. A 96% AFUE, 50,000 Bth/h gas furnace will have a heat output of 48,000 Btu/h (i.e., 50,000 x 0.96 = 48,000).

AHRI: Air-Conditioning, Heating & Refrigeration Institute

ANSI: American National Standards Institute

ASHP: Air source heat pump

ASHRAE: American Society of Heating, Refrigerating and Air Conditioning Engineers.

Auxiliary back-up heating system: A backup heating system needed if/when the heat pump cannot provide enough heat for the building (i.e., furnace, electric baseboard, etc.)

Balance point temperature (BPT): See “Thermal balance point”.

Btu: British Thermal Unit equivalent to 0.293 watt-hours, or 1,055 Joules of energy content.

Btu/h: British Thermal Unit per hour (sometimes written as Btuh), used to rate the output or capacity of heating or cooling equipment. One Btu/h is equivalent to 0.293 watts of capacity.

CC-ASHP: See “Cold-Climate” ASHP

Centrally Ducted ASHP: A system that uses an outdoor and indoor evaporator/condenser unit to transfer heat from outside to the inside of a building, and vice-versa, via a forced air distribution system.

CEE: Consortium for Energy Efficiency

Climate Zones: Regions that have a similar number of heating degree days (HDD) in the heating season. Canada is subdivided into six climate zones (i.e., Zones 4, 5, 6, 7A, 7B and 8) with HDD values range from < 3000 HDD (Zone 4) to ≥ 7,000 HDD (Zone 8). These climate zones are developed and managed by ANSI/ASHRAE Standard 169 and are widely referenced in energy performance ratings procedures and standards.

Climate Zones for ASHPs: Climate zones developed specifically for the CSA EXP-07 “Load-based climate-specific testing and rating procedures for heat pumps and air conditioners”. Canada is subdivided into five ASHP climate zones described as: Marine, Cold/dry, Cold/humid, Very cold, and Subarctic. These climate zones are referenced throughout this Guide.

Cold-climate ASHP: An alternative to traditional air source heat pump heating/cooling systems that is effective (i.e., maintains capacity and COP) even at cold ambient temperatures. (For further details, refer to NEEP’s *Cold Climate Air-Source Heat Pump Specification* https://neep.org/ASHP-Specification). Note that the ability of the system to maintain capacity at cold outdoor temperature should also be considered when determining if a system is a suitable “cold-climate ASHP”. See NEEP’s *Cold Climate Air-Source Product List* to assist in this regard available at the link above.

COP: Coefficient of Performance. The COP is a measure of a heat pump's efficiency. It is determined by dividing the energy output of the heat pump by the electrical energy needed to run the heat pump, at a specific temperature. The higher the COP, the more efficient the heat pump. This number is comparable to the steady-state efficiency of oil- and gas-fired furnaces.

CSA: Canadian Standards Association

CSA F280 Load Analysis: Provides a calculation method for determining the heat loss and heat gain of residential buildings for selecting the appropriate output capacity of a space heating / cooling appliance or group of appliances.

Cut-off Control: A control device that restricts the operation of a heat pump or backup heating system to a predetermined range of outdoor temperatures.

Cut-off Temperature: The outdoor temperature, below which the operation of an air source heat pump is restricted by an outdoor temperature control, and full backup heating is used to heat the building or target zone. The cut-off temperature value can be determined by either a "low-temperature cut-off limit" of the heat pump equipment, or by an "economic cut-off temperature" that is determined by energy prices and equipment efficiencies.

For backup heating systems, the cut-off temperature is the outdoor temperature above which the backup heating system is restricted from operating, usually set at the balance point temperature for the ASHP installation.

Design cooling load (DCL): Is the amount of heat to be removed from the house to maintain its desired indoor temperature (i.e. 75°F or 25°C) at the CSA F280 design conditions for cooling at the house location. DCL includes both the sensible and latent cooling loads.

Design heating load (DHL): Is the amount of heat required for the house to maintain its desired indoor temperature (i.e. 72°F or 22°C) at the CSA F280 design conditions for heating at the house location.

Dip-switch: Manual electric switches in a standard Dual In-line Package (DIP) located on an electronic control board to select different options or control settings.

Distribution/Branch box: Component that divides the refrigerant from the outdoor unit to the multi-zone indoor units.

Dry-bulb Temperature (DBT): DBT is the temperature of air measured by a thermometer freely exposed to the air, but shielded from radiation and moisture. DBT is the temperature that is usually thought of as air temperature.

Dual-fuel ASHP system: A central system which combines an electric heat pump and a fuel-based furnace to provide heating/cooling to a building.

Ductless Mini-Split ASHP: A system that uses an outdoor evaporator/condenser unit to transfer heat from outside to the inside of a building, and vice-versa, via an indoor air handling unit. A single-zone ductless mini-split ASHP uses one indoor air handling unit to heat/cool one room or zone. A multi-zone ductless mini-split ASHP uses multiple indoor air handling units to heat/cool multiple rooms or zones. The maximum number of indoor units that can be connected is determined by the specific outdoor unit specification, and can range from 2 to 8.

Economic Balance Point Temperature (e-BPT): Outdoor temperature at which it is economically desirable to switch from the air source heat pump to a back-up heating source. It is determined based on estimated costs of heat delivery by the air source heat pump versus the back-up system. Calculation of the economic cut-off temperature requires the cost of electricity, cost of backup system fuel, heat pump COP, backup system efficiency and outdoor temperature.

Economic Cut-off Temperature: See Economic Balance Point Temperature (e-BPT)

Economic Switch-Over Temperature: See Economic Balance Point Temperature (e-BPT)

EER: Energy Efficiency Ratio. The EER is the ratio of Btu of cooling delivered to watt-hours of electricity consumed at a specific temperature. It is used to indicate the steady-state cooling efficiency of a heat pump or air-conditioner. Nominal EER ratings are quoted at 95°F (35°C). Higher EERs indicate higher cooling efficiency.

Energy Audit: A systematic evaluation of the energy needs of a building.

Forced-air Distribution System: A system of supply and return air ductwork used to distribute conditioned air throughout the building.

Fraction of Total Annual Heating: An estimate of the amount of heating that the ASHP will deliver without the use of back-up heating. The fraction of annual heating above a given outdoor temperature is calculated for each climate zone by first referencing the fraction of heating degree days occurring in a given temperature bin (Refer to "Climate Zones for ASHPs). These "bin fractions" are multiplied by the heating hours to arrive at heating degree hours for a given temperature bin. The heating degree hours occurring in each temperature bin are then divided by the total heating degree hours for that climate zone to arrive at the fraction of total annual heating. The fraction of total annual heating above a given outdoor temperature is calculated by summing the annual heating fractions starting from 0 at 60F to the total heating degree hours at -23F and below (the lowest temperature bin). A curve of total annual heating above a given outdoor temperature is then created for each climate zone (Figure 22). A vertical line associated with an ASHP's balance point temperature can then be charted against the total annual heating above a given outdoor temperature curve to estimate the fraction of total annual heating that system will accomplish for that climate zone.

Heat/Energy Recovery Ventilator: A heat exchange system that exchanges heat between the stale exhaust air (from the building) and the outdoor fresh supply air (to the building) to reduce heating/cooling demands associated with ventilation needs of the building.

Heating Degree Days (HDD): HDD are the number of degrees of temperature difference between a base temperature (usually 18.3°C) and the mean daytime outside temperature on any given day. For example, if the mean temperature for the day is 12°C, 6 HDD (18°C – 12°C = 6 HDD) will be recorded. The total number of HDD over the heating season indicates the relative severity of the winter for a specific location.

HSPF: Heating Seasonal Performance Factor. The HSPF is the ratio of Btu of heating delivered to watt-hours of electricity consumed over the heating season. It is used to characterise the performance of electric heating equipment over a typical heating season. A higher HSPF rating indicates a higher efficiency. HSPF ratings for ASHPs vary by "Climate Zone".

HOT2000: Energy simulation and design tool for low rise residential buildings.

HRAI: The Heating, Refrigeration and Air Conditioning Institute

HVAC: Heating, Ventilation and Air Conditioning

Hybrid ASHP system: see Dual-fuel ASHP System.

Hydronic heating system: A heating/cooling system that uses water as a medium for heat transfer.

Kilowatt or kW: One kW is equivalent to 3,413 Btu/h.

Kilowatt-hour or kWh: One kWh is equivalent to 3,413 Btu or 3,600 kJ

Load line: A representation of the heating/cooling load of a building as a function of outdoor temperature.

Low-temperature cut-off: Outdoor temperature below which the air source heat pump is restricted from operating.

Low-stage Performance: Performance of a two-stage/variable capacity air source heat pump at its lowest capacity.

LPG/Propane: Liquefied petroleum gas. Propane is classified as LPG along with butane, isobutane and mixtures of these gases.

NEEP: Northeast Energy Efficiency Partnerships

Performance curve: A representation of the output capacity of a heat pump as a function of outdoor temperature.

Retrofit: Modernising the HVAC system of a building

SEER: Seasonal Energy Efficiency Ratio. The SEER rating is the ratio of Btu of cooling delivered to watt-hours of electricity consumed over the cooling season. It is used to characterise the performance of electric cooling equipment over a typical cooling season. A higher SEER rating indicates a higher efficiency.

Single-stage ASHP: An ASHP that has a single-stage compressor, which can only operate at full capacity.

Switch-over point: The point at which a hybrid/dual-fuel system switches from using the air source heat pump to using the backup heating system.

Target area load: Heating or cooling load for a specific area of a building required to meet a desired temperature.

Target output capacity: The output capacity required from a heat pump to meet heating or cooling requirements of a building.

Thermal boundary: The physical barrier that separates the interior and exterior of the building and controls its heat transfer.

Thermal Balance Point Temperature (t-BPT): The temperature at which the heating load line intersects the air source heat pump capacity curve. (i.e., point where heating load of the building matches the heat pump's output capacity). Above the t-BPT, the heat pump is capable of meeting the buildings heating requirements. Below the t-BPT, the heat pump may not be capable of meeting the buildings heating requirements and a backup heating system will be required.

Total Cooling Load: The total cooling load is the sum of the sensible and latent cooling loads for the building or target area under consideration.

Turn-down Ratio: In a two stage, multi-stage or variable capacity ASHP, this is the ratio of maximum capacity to minimum capacity (e.g., 3:1). ASHPs with higher turn-down ratios will operate without cycling for a greater proportion of the heating season, increasing their seasonal efficiency.

Two-staged ASHP: An ASHP that has a two-stage compressor, which can operate at two different levels, low-stage or high-stage, depending on the capacity needed.

Variable-capacity ASHP: An ASHP that has a compressor which can operate at different levels, depending on the capacity needed. CC-ASHPs are often equipped with variable capacity driven compressors.

Watt or W: One W is equivalent to 3.413 Btu/h.

Wet-bulb Temperature (WBT): WBT is the temperature read by a thermometer covered in water-soaked cloth (wet-bulb thermometer) over which air is passed, and is used to measure the relative humidity or moisture content of the air. At 100% relative humidity (RH), the WBT is equal to the dry-bulb temperature (DBT). At lower RH values the WBT is lower than the DBT of the air.

INTRODUCTION

Purpose

The **Air Source Heat Pump Sizing and Selection Guide** is intended for use by mechanical system designers / renovation contractors to assist them in selecting and sizing air source heat pumps (ASHP) for Canadian climates in both new and existing residential (i.e., retrofit) applications.

Scope

The focus of this Guide is on air source heat pumps (ASHP) for space heating and/or cooling applications.

This guide covers the following applications of ASHPs:

- New home (or major new addition) installations.
- Full heating system replacement where existing HVAC equipment is removed.
- Add-on ASHP applications to displace heating energy or provide supplemental heating where existing heating equipment remains functional.

This guide covers the following technologies:

- Ducted and ductless ASHPs
- Single-zone and multi-zone centrally ducted ASHPs
- Single-zone and multi-zone ductless mini-split ASHPs
- Single-zone and multi-zone ducted mini-split ASHPs
- Single stage ASHPs
- Staged and variable-capacity ASHPs
- Cold-climate ASHPs.

Exclusions:

- Installation best practices and requirements are outside the scope of this Guide.

OVERVIEW OF THE AIR-SOURCE HEAT PUMP SIZING AND SELECTION PROCESS

An overview of the ASHP sizing and selection process is shown graphically in Figure 1.

The process consists of seven steps which can be grouped into four major parts:

I. Define key ASHP requirements (STEPS 1 to 4);
   - *Define ASHP Configuration.*
   - *If required, choose mini-split indoor unit types.*
   - *Determine heating and cooling loads.*
   - *Determine sizing approach and ASHP target capacity requirements.*

II. Identify candidate ASHPs matching key requirements, and make final ASHP choice (STEP5);

III. Define system control strategy (STEP 6); and,

IV. Define back-up heating requirements (STEP 7).

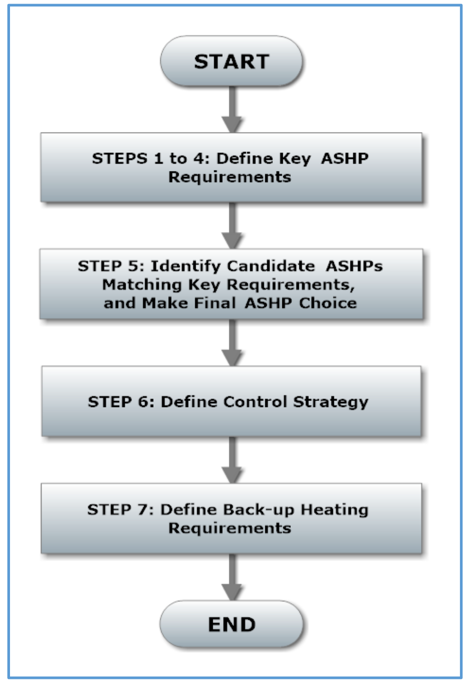


Figure 1: Overview of the ASHP Selection and Sizing Process

Components of the ASHP Sizing and Selection Process

The **ASHP Sizing and Selection Process** is supported by the:

1. **ASHP Sizing and Selection Guide**, also referred to as the "Guide" (i.e., this document);
2. **ASHP Key Specifications Summary Worksheet**, also included with the Guide (as Appendix B), or available as a separate PDF download;
3. **ASHP spreadsheet tool** to assist users in completing the step-by-step guide process, available as an Excel workbook download; and,
4. **Worked examples** of using the Guide to select either centrally ducted or ductless mini-split ASHPs for various installation scenarios, available as a separate PDF download.

Users can complete the guide process by using one or more of these components. Short descriptions of each are provided on the following pages.

NOTE TO DESIGNERS AND CONTRACTORS: "Fast-tracking" ASHP Selection and Sizing

Experienced designers / contractors can quickly complete the ASHP selection and sizing process by using:

- The "**ASHP Key Specifications Summary Worksheet**" to direct the process and record information and option selected, and
- The "**ASHP Spreadsheet Tool**" as a calculating and plotting aid.

The full **ASHP Guide** can consulted on an as-needed basis to provide additional information as required.

1. ASHP Sizing and Selection Guide

This seven-step Guide provides sizing and sizing instructions, and information on various options for both centrally-ducted and mini-split ASHPs.

- Complete each step of the Guide in the order shown to select and size an ASHP for a specific application.
  - Each STEP provides the user with 3 to 4 options.
  - Short descriptions of each option help users select which one "best fits" specific application requirements.
  - Chosen options are recorded on the **ASHP Key Specifications Summary Worksheet** (see 2 below).
- Use the information recorded in Steps 1 to 4 to identify a short list of commercially available ASHP models that are suitable for the specific application.
- Final ASHP selection can be based on such items as:
  - Staging or modulation capabilities,
  - Efficiency ratings,
  - Noise ratings, and
  - Equipment cost.
- In the final two steps, define:
  - The ASHP system control strategy, and
  - The backup heating requirements.

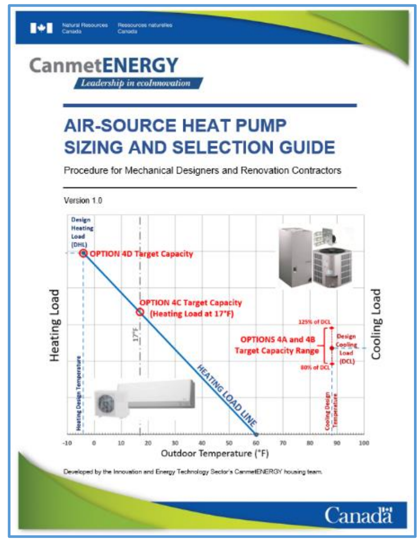
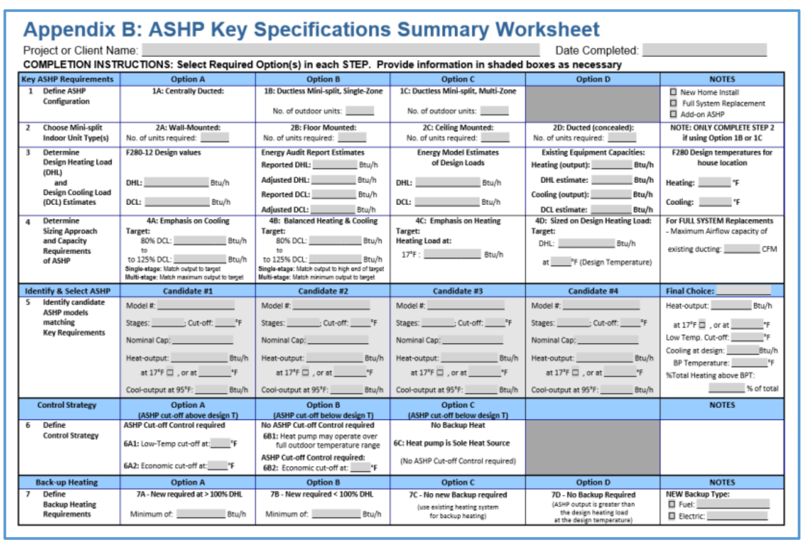


Figure 2: Air-Source Heat Pump Selection and Sizing Guide

2. ASHP Key Specifications Summary Worksheet

The **ASHP Key Specifications Summary Worksheet** can be used in one of two ways:

- Together with the **ASHP Guide** as a summary sheet that records decisions made while working through the seven steps using the full Guide documentation; or,
- As a stand-alone worksheet that experienced users can complete to select and size an ASHP, referring to the full Guide documentation only when additional information is required.



Appendix B: ASHP Key Specifications Summary Worksheet

Project or Client Name: ____ Date Completed: ____

COMPLETION INSTRUCTIONS: Select Required Option(s) in each STEP. Provide information in shaded boxes as necessary

Key ASHP Requirements	Option A	Option B	Option C	Option D	NOTES
1 Define ASHP Configuration	1A: Centrally Ducted:	1B: Ductless Mini-split, Single-Zone No. of outdoor units: ____	1C: Ductless Mini-split, Multi-Zone No. of outdoor units: ____		☐ New Home Install ☐ Full System Replacement ☐ Add-on ASHP
2 Choose Mini-split Indoor Unit Type(s)	2A: Wall-Mounted: No. of units required: ____	2B: Floor Mounted: No. of units required: ____	2C: Ceiling Mounted: No. of units required: ____	2D: Ducted (concealed): No. of units required: ____	NOTE: ONLY COMPLETE STEP 2 if using Option 1B or 1C
3 Determine Design Heating Load (DHL) and Design Cooling Load (DCL) Estimates	F280-12 Design values DHL: ____ Btu/h DCL: ____ Btu/h	Energy Audit Report Estimates Reported DHL: ____ Btu/h Adjusted DHL: ____ Btu/h Reported DCL: ____ Btu/h Adjusted DCL: ____ Btu/h	Energy Model Estimates of Design Loads DHL: ____ Btu/h DCL: ____ Btu/h	Existing Equipment Capacities: Heating (output): ____ Btu/h DHL estimate: ____ Btu/h Cooling (output): ____ Btu/h DCL estimate: ____ Btu/h	F280 Design temperatures for house location Heating: ____ °F Cooling: ____ °F
4 Determine Sizing Approach and Capacity Requirements of ASHP	4A: Emphasis on Cooling Target: 80% DCL: ____ Btu/h to to 125% DCL: ____ Btu/h Single-stage: Match output to target Multi-stage: Match maximum output to target	4B: Balanced Heating & Cooling Target: 80% DCL: ____ Btu/h to to 125% DCL: ____ Btu/h Single-stage: Match output to high end of target Multi-stage: Match minimum output to target	4C: Emphasis on Heating Target: Heating Load at: 17°F : ____ Btu/h	4D: Sized on Design Heating Load: Target: DHL: ____ Btu/h at ____°F (Design Temperature)	For FULL SYSTEM Replacements - Maximum Airflow capacity of existing ducting: ____ CFM
Identify & Select ASHP	**Candidate #1**	**Candidate #2**	**Candidate #3**	**Candidate #4**	**Final Choice:** ____
5 Identify candidate ASHP models matching Key Requirements	Model #: ____ Stages: ____; Cut-off: ____°F Nominal Cap: ____ Heat-output: ____ Btu/h at 17°F ☐ , or at ____°F Cool-output at 95°F: ____ Btu/h	Model #: ____ Stages: ____; Cut-off: ____°F Nominal Cap: ____ Heat-output: ____ Btu/h at 17°F ☐ , or at ____°F Cool-output at 95°F: ____ Btu/h	Model #: ____ Stages: ____; Cut-off: ____°F Nominal Cap: ____ Heat-output: ____ Btu/h at 17°F ☐ , or at ____°F Cool-output at 95°F: ____ Btu/h	Model #: ____ Stages: ____; Cut-off: ____°F Nominal Cap: ____ Heat-output: ____ Btu/h at 17°F ☐ , or at ____°F Cool-output at 95°F: ____ Btu/h	Heat-output: ____ Btu/h at 17°F ☐ , or at ____°F Low Temp. Cut-off: ____°F Cooling at design: ____ Btu/h BP Temperature: ____°F %Total Heating above BPT: ____ % of total
Control Strategy	**Option A (ASHP cut-off above design T)**	**Option B (ASHP cut-off below design T)**	**Option C (ASHP cut-off below design T)**		**NOTES**
6 Define Control Strategy	ASHP Cut-off Control required 6A1: Low-Temp cut-off at: ____°F 6A2: Economic cut-off at: ____°F	No ASHP Cut-off Control required 6B1: Heat pump may operate over full outdoor temperature range ASHP Cut-off Control required: 6B2: Economic cut-off at: ____°F	No Backup Heat 6C: Heat pump is Sole Heat Source (No ASHP Cut-off Control required)		
Back-up Heating	**Option A**	**Option B**	**Option C**	**Option D**	**NOTES**
7 Define Backup Heating Requirements	7A - New required at > 100% DHL Minimum of: ____ Btu/h	7B - New required < 100% DHL Minimum of: ____ Btu/h	7C - No new Backup required (use existing heating system for backup heating)	7D - No Backup Required (ASHP output is greater than the design heating load at the design temperature)	NEW Backup Type: ☐ Fuel: ____ ☐ Electric: ____

Figure 3: The "ASHP Key Specifications Summary Worksheet"

3. ASHP Spreadsheet Tool

This Excel-based tool examines the Guide steps to assist designers or contractors in selecting and sizing air-source heat pumps (ASHP) in Canadian climates.

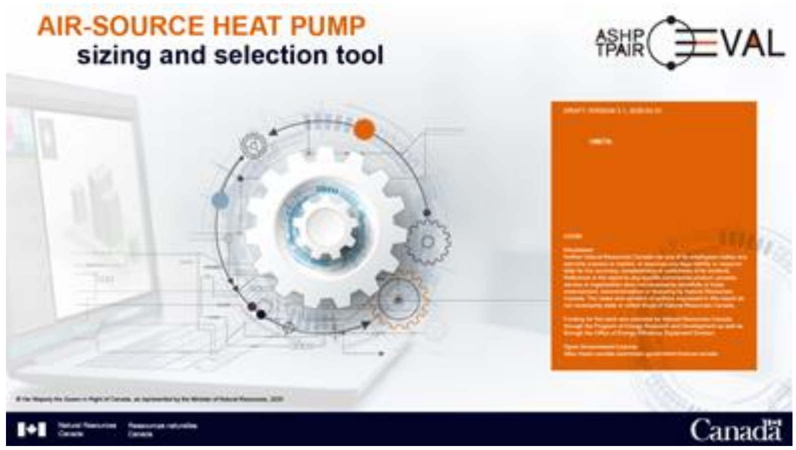


Figure 4: ASHP Selection and Sizing Spreadsheet Tool

The ASHP spreadsheet tool will perform various calculations and charting functions that can be used to help select and size ASHPs. These include:

- Plotting of heating load lines, and estimating the target output capacity of ASHP equipment needed for an application based on:
  - *load values entered, and*
  - *sizing approach selected.*
- Plotting of ASHP output characteristics versus outdoor temperature, and estimating thermal balance point temperatures (t-BPTs) for up to four candidate ASHPs for an application.
- Estimating the annual fraction of total space heating load provided by the different candidate ASHPs above their t-BPTs to help with final selection.
- Calculating the minimum backup heating requirement for the application.
- For dual-fuel applications, calculating the “economic cut-off temperature” for the ASHP based on:
  - *local cost of electricity and fuel, and*
  - *the efficiency characteristics of the ASHP and the backup heating system.*

4. Worked Examples of Using the ASHP Guide

Worked examples have been completed for both centrally-ducted and ductless mini-split ASHPs using various sizing and selection scenarios.

- These example cases illustrate how the Guide process works and have been prepared to help users better understand the various decision steps when selecting ASHPs for different applications.

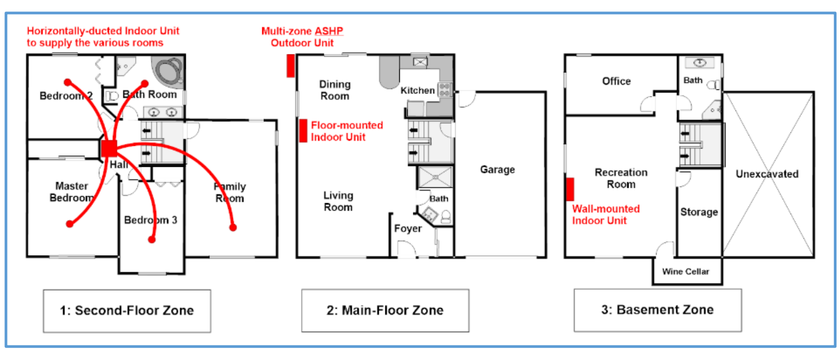


Figure 5: "Worked Example" – Mini-split, Multi-zone, Add-on ASHP

STEP 1: DEFINE ASHP CONFIGURATION

In this step you will define the most appropriate air-source heat pump (ASHP) configuration based on:

- The planned application for the ASHP, and
- The heating / cooling system configuration in the house or area being considered.

Common types of ASHP configurations include:

- Option 1A: Centrally ducted ASHP,
- Option 1B: Ductless mini-split, single-zone ASHP, and
- Option 1C: Ductless mini-split, multi-zone ASHP.

The following pages provide brief descriptions of the three ASHP options, while Table 1 provides an overview of typical uses for the different options.

Table 1: Typical Air-Source Heat Pump Options for Different Applications and Heating System Configurations

Application Description	Heating System Configuration	Option 1A: Centrally Ducted	Option 1B: Ductless Single-zone	Option 1C: Ductless Multi-zone
Full-house Heating system replacement or new installation	Central forced-air	✓		
	Baseboard or hydronic (no central duct system)		✓ (multiple ASHPs)	✓
Full-house Cooling system replacement or new installation	Central forced-air	✓		
	Baseboard or hydronic (no central duct system)		✓ (multiple ASHPs)	✓
Heating Displacement with an Add-on ASHP to reduce use of an existing heating system	Central forced-air	✓		
	Baseboard or hydronic (no central duct system)		✓ (one or more ASHPs)	✓
Isolated zone, supplemental heating / cooling with an Add-on ASHP	Central forced-air		✓ (one or more ASHPs)	✓
	Baseboard or hydronic (no central duct system)		✓ (one or more ASHPs)	✓

Option 1A: Centrally Ducted ASHP

Centrally ducted ASHP are almost always installed to provide the entire heating load of a home or major section of a home. Installers typically ensure that the heating load can be met by the ASHP capacity and auxiliary backup heating at the outdoor design temperature for the house location.

Figure 6: Centrally ducted ASHP

- In retrofit installations, the available breaker rating in the main electrical panel as well as the maximum airflow capacity of existing ductwork may limit the maximum size and heating capacity of the central ASHP that can be installed.
  - In these installations central furnaces are replaced by central ASHP systems equipped with auxiliary backup or dual-fuel heating.
  - In add-on central ASHP applications, the existing central furnace may function as the backup heating system (in a dual-fuel configuration).
- In low-energy new construction, or existing homes that have had major energy upgrades to the building envelope, it may be possible to meet the design heating load using cold-climate variable capacity ASHP technology without the use of auxiliary heating, subject to approvals by building officials and / or home insurance providers.

In all applications, this type of ASHP delivers heating / cooling to the conditioned space via a forced-air distribution system.

Option 1B: Ductless Mini-split, Single-Zone ASHP

Ductless systems, commonly known as "mini-splits," are often used to heat an area of a new or an existing home with no pre-existing ductwork.

Ductless mini-split systems are often installed as add-on systems to provide only a portion of the heating load for the entire home.

- For heating there is most often an existing heating system left in place that is capable of fully meeting the heating load of the home when needed during the coldest weather. The existing heating system mitigates the risk of under-sizing the add-on ASHP system.

More than one ductless mini-split system can be installed to provide heating to multiple areas of a house as part of a whole-house conditioning system.

Figure 7: Ductless mini-split ASHP

Option 1C: Ductless Mini-split, Multi-Zone ASHP

Ductless multi-zone systems, often called "multi-splits," use a single outdoor unit with multiple indoor units to heat / cool two to eight separate rooms or zones in a home.

These multi-zone systems can be installed to provide heating /cooling to multiple areas of a house as part of a whole-house conditioning system.

Figure 8: Ductless mini-split, multi-zone ASHP

- Careful sizing and controls are especially important with ductless multi-zone systems in order to maintain high efficiency.
- Multi-zone ASHPs may require the installation of a separate distribution box as per manufacturer instructions. Extra consideration on installation may be required when designing these systems to accommodate the location of the distribution box.

ASHP Installation Type

ASHP Installation types include:

- New home installations,
- Full system replacements, where the existing HVAC system is removed, and
- Add-on ASHP installations where the existing heating system remains operational.

Record the type of installation by checking the appropriate box in the “notes column” on the **“ASHP Key Specifications Summary Worksheet”.**

Once you have decided on the most appropriate configuration of ASHP, circle the chosen option, and indicate the type of installation (i.e., new install / full HVAC replacement / Add-on ASHP) on the **“ASHP Key Specifications Summary Worksheet”.**

- A copy of this worksheet is available at the end of this Guide as Appendix B

If you have chosen: Option 1A – Centrally Ducted ASHP, skip ahead to STEP 3.

If you have chosen: Option 1B – Ductless Single-Zone ASHP, or
Option 1C – Ductless Multi-zone ASHP, proceed with STEP 2.

Upon completing Step 1, you will have:

- ☐ Selected the type of ASHP most suited for the application.
- ☐ For ductless ASHP applications, estimated the number of units required.
- ☐ Recorded the type of installation: New home / Full HVAC replacement / Add-on ASHP.

STEP 2: Choose Indoor Unit Type(s) for use with Ductless Mini-split ASHP

NOTE TO DESIGNERS AND CONTRACTORS: When to complete STEP 2.

Complete STEP 2 ONLY if you have selected either:

- Option 1B – Ductless Mini-split, Single-Zone ASHP, or
- Option 1C – Ductless Mini-split, Multi-Zone ASHP in STEP1.

If in STEP 1, you have selected Option 1A – Centrally Ducted ASHP, proceed to STEP 3.

In STEP 2 you will choose the indoor unit type(s) to be used with the ductless single-zone or multi-zone ASHP(s) chosen in STEP 1.

Common types of indoor units for ductless ASHPs include:

- Option 2A: Wall mounted,
- Option 2B: Floor mounted,
- Option 2C: Ceiling mounted, and
- Option 2D: Ducted (concealed).

The following sections provide brief descriptions of these different indoor unit options.

Once you have decided on the most appropriate indoor unit option(s) for the application, record the option(s) chosen and number of indoor units required on the **"ASHP Key Specifications Summary Sheet".**

Option 2A: Wall Mounted Indoor Unit

The wall mounted indoor unit is the type that is most often used in ductless ASHP installations.

These indoor units:

- Are installed on the wall, typically a few inches down from the ceiling;
- Require available wall space and clearance from other objects on the wall;
- Can have high airflow, sensors and oscillating vanes to disburse air over large living areas; and
- Have a higher visual impact than some other types of indoor units.

Figure 9: Wall Mounted Indoor Unit

Option 2B: Floor Mounted Indoor Unit

Floor mounted units can be ideal in basement areas and/or areas that lack available wall space.

Floor-mounted indoor units:

- Will work under large windows that prohibit wall-mounted units from being used;
- Can have high airflow ratings in order to cover large living areas;
- May be more effective at distributing heat than high-wall units; and
- Have a higher visual impact than some other types of indoor units.

Figure 10: Floor Mounted Indoor Unit

Option 2C: Ceiling Mounted Indoor Unit

The ideal location for in-ceiling units are hallways and landings as these indoor units can distribute air in four different directions when running.

Ceiling mounted indoor units:

- Are usually installed on the uppermost floor of the home when retrofitting ductless ASHPs;
- Require no available wall space;
- Have lower airflow ratings than wall or floor mounted units, which limits the coverage area somewhat;
- Can require more invasive installation depending on the nature of the ceiling cavity; and
- may have less visual impact than some other types of indoor units.

Figure 11: Ceiling-mounted Indoor unit

Ceiling mounted units are most often installed as part of a multi-zone system where a wall or floor mounted unit is used in the main living area and the ceiling mounted unit is installed upstairs for conditioning hallways and central locations in open floorplans.

Option 2D: Ducted (concealed) Indoor Unit

A ducted indoor unit can serve one or more rooms with less visual impact than other types of indoor units. Supply air is ducted from the indoor unit to outlet grilles using compact ducting that is installed with the indoor unit.

Ducted indoor units:

- Provide more reliable airflow distribution to separate rooms than a ceiling-mounted unit.
- May be easier to size for high efficiency operation than using multiple ductless heads when servicing several small, isolated rooms (e.g., several small bedrooms).

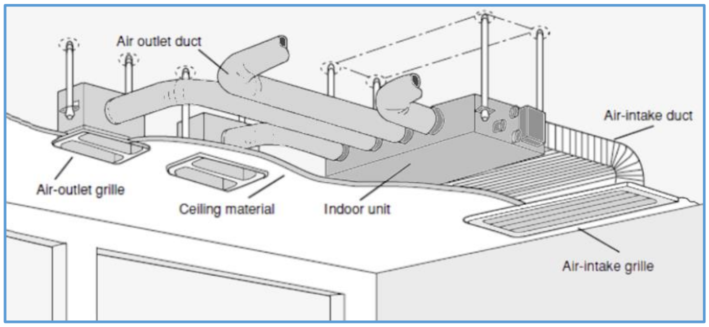


Figure 12: Ducted Indoor Unit

Ducted indoor units are most often installed as part of a multi-zone system where a wall or floor mounted unit is used in the main living area and a ducted indoor unit is installed upstairs for conditioning separate bedrooms and hallways.

Upon completing Step 2, you will have:

☐ Estimated the number of indoor units required for the ductless ASHP application.

☐ Selected the type of indoor unit(s) most suited for the application.

STEP 3: DETERMINE DESIGN HEATING AND COOLING LOAD ESTIMATES

In STEP 3 you will estimate the heating and cooling loads for the house or the target area of the house being considered for the ASHP installation. Common ways of estimating heating and cooling loads include:

- Option 3A: CSA F280 Load Analysis,
- Option 3B: Energy Audit Load Estimates,
- Option 3C: Energy Modelling of Design Loads, and
- Option 3D: Existing Equipment Capacities.

Table 2 matches different ASHP applications to the most likely load estimating options available. Brief descriptions and examples of using these four load estimating options are provided on the following pages.

Table 2: Different Types of ASHP Applications and Corresponding Load Estimating Options

ASHP Application	Option 3A: CSA F280 Load Analysis	Option 3B: Energy Audit Load Estimates	Option 3C: Energy Modelling of Design Loads	Option 3D: Existing Equipment Capacities
ASHP installation in a new house, or in a house with significant envelope upgrades	✓		✓	
ASHP retrofit or add-on installation in an existing house with an Energy Audit		✓	✓	
ASHP retrofit or add-on installation in an existing house without an Energy Audit			✓	✓

Other factors to consider in retrofit and add-on installations

Maximum Airflow Capacity of Existing Ductwork: In retrofit applications of centrally-ducted ASHPs, the maximum size of ASHP that can be installed in the house may be determined by the maximum airflow capacity of the existing supply ducts. A simple procedure for estimating this maximum airflow capacity is described on page 16.

Target Area Load Estimates: In retrofit installations of add-on ductless mini-split ASHP, sizing will be based on the thermal loads of the target area within the house that is being conditioned by the add-on ASHP. A simple procedure of estimating target-area loads from whole-house loads is described on page 17.

Once you have decided on the load estimating option, and calculated the heating and cooling loads for the house or target area,

- Record the load information on the **"ASHP Key Specifications Summary Sheet".**
- If the installation involves retrofitting a centrally-ducted ASHP, also record the maximum airflow capacity of the existing duct system.

Option 3A: CSA F280 Load Analysis

New National and Provincial Building Codes require capacities of heating appliances be determined in accordance with CSA F280 *"Determining the Required Capacity of Residential Space Heating and Cooling Appliances"* for all new residential construction.

The F280 Load Analysis Standard can also be used for existing houses which have undergone extensive envelope upgrades to improve energy efficiency.

Figure 13: CSA F280 Load Analysis determines design loads based on building envelope characteristics

EXAMPLE - Option 3A: CSA F280-12 Load Analysis

CSA F280 load analysis of a new-construction, three-storey townhome, built to ENERGY STAR® for New Home requirements, has calculated design loads of:

Heating: 15,800 Btu/h at a design temperature of -4°F (-20°C);

Cooling: 19,200 Btu/h at a design temperature of 88°F (31°C).

Option 3B: Energy Audit Load Estimates

For houses that have a completed energy efficiency evaluation audit, design loads can be estimated based on information contained in the Audit Report.

- If the building envelope retrofits defined in the report <u>have been implemented</u>, design load values can be taken directly from the audit report.
- If the building envelope retrofits defined in the report <u>have not been implemented</u>, design load values can be estimated from the reported information in the audit report (see example for calculation details).

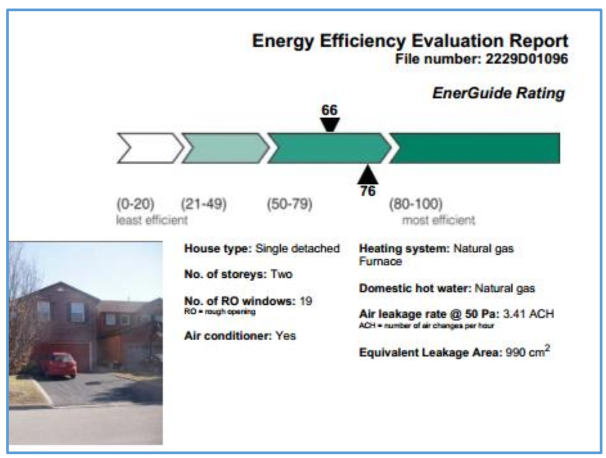


Figure 14: Energy Efficiency Evaluation (Audit) Report (circa 2012) used to estimate design loads

Note: More recent EnerGuide Rating System evaluation reports (not shown) may have estimated design heating and design cooling loads for the home included on page 2 of the House Report (under "Mechanical Systems"). If that is the case, use these values directly.

EXAMPLE - Option 3B: Energy Audit Load Estimates

The audit report for a two-storey house, situated in an area with design conditions of -4°F (-20°C) for heating and 88°F (31°C) for cooling, states:

If you were to implement ALL of the building envelope retrofits recommended …, it is estimated that your home's design heating load would be 43,641 Btu/h (12,790 W) and its design cooling load would be 23,519 Btu/h (2.0 tons). If you are considering replacing your space heating and/or cooling system, provide this information to your heating/cooling contractor to help ensure a properly-sized system.

If all building envelope retrofits were implemented, design loads for the house are as reported:

Post-Retrofit Design Heating Load (DHL): 43,641 Btu/h at a design temperature of -4°F (-20°C);

Post-Retrofit Design Cooling Load (DCL): 23,519 Btu/h at a design temperature of 88°F (31°C).

If building envelope retrofits were NOT implemented, the design cooling load would still be a reasonable estimate, but the design heating load will need to be adjusted.

The report also states:

- *You could save up to 12 percent by performing all of the recommended non-space heating system upgrades.*

This means the reported design heating load is 88% (i.e. 100% minus the 12% savings shown above). Therefore, the actual design heating load for the house is estimated as:

Pre-Retrofit DHL = 43,641 Btu/h / 0.88 = 49,592 Btu/h (14,530 W)

Based on the audit report, this particular example house has pre-retrofit design loads of:

Pre-Retrofit DHL: 49,592 Btu/h at a design temperature of -4°F (-20°C);

Pre-Retrofit DCL: 23,519 Btu/h at a design temperature of 88°F (31°C).

Option 3C: Energy Model Estimates of Design Loads

Design heating and cooling loads for a house or target areas within a house can be estimated by creating an energy model of the house to determine the heating and cooling requirements at the summer and winter design conditions for the house location.

Figure 15: HOT2000 Energy Modelling software can estimate design loads for both new and existing houses

Energy modelling software such as HOT2000 can be used to estimate design heating and cooling loads for the whole house or individual rooms or zones within a house based on construction details of the building envelope. These load estimates can be used to help size and select the appropriate ASHP equipment, whether it is:

- A centrally ducted ASHP system, used to condition the whole house, or
- A ductless mini-split ASHP system targeting a particular area within the home.

NOTE TO DESIGNERS AND CONTRACTORS: HOT2000 Energy Simulation

Consider having a HOT2000 Energy Model created by someone experienced with the simulation software. Natural Resources Canada's searchable listing of service organisations can assist with this. The *New House Wizard* option in the simulation software can be used to create a model for an existing house. Once the HOT2000 model has been created, it can be used to generate design heating and cooling loads.

The HOT2000 model is available for free download from NRCan: http://www.nrcan.gc.ca/energy/efficiency/housing/home-improvements/17725.

Option 3D: Estimate Design Loads from Existing Equipment Capacities

NOTE: This approach does not apply when the intention is to offset a portion of the heating load (i.e., heating displacement or supplemental / isolated zone applications, as shown in Table 1). In those cases, a load calculation should be done only on the part of the home intended to be conditioned by the heat pump.

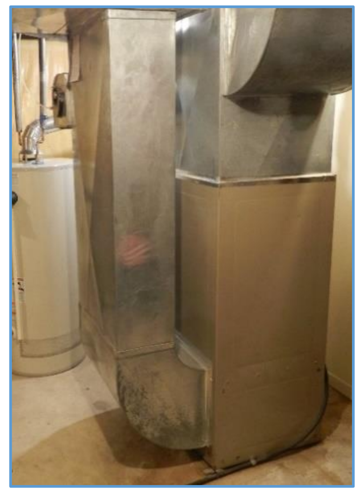


Figure 16: Using existing equipment to estimate Design Loads

There is no precise way of estimating design heating and cooling loads from installed equipment capacities.

However, as a last resort, rough estimates of design heating/cooling loads can be based on the installed capacities of existing HVAC equipment conditioning the home in cases where:

- No historic comfort issues have existed (if comfort issues have existed, see below);
- No significant energy performance upgrades have been made to the home since the current heating system was installed; and,
- Some evidence that reasonable sizing practices were used for specifying the existing equipment (e.g. furnace runs for extended periods of time when the weather is very cold).

Bracketing Design Heating Loads Based on Existing Equipment Capacity:

- Heating appliance output is always greater than the design heat loss (DHL),
- Most mechanical designers will add a cushion to the calculated DHL; 125% of DHL is a reasonable amount to assume as a minimum size;
- Historically, 140% of DHL was set as the upper limit for heating appliance capacity in CSA F280. Although this maximum capacity restriction has been removed from the latest version of CSA F280 (as of 2012), the 140% of DHL value can still be used when assessing older installations.

Bracketing Design Cooling Loads Based on Existing Equipment Capacity:

- The Heating, Refrigeration and Air Conditioning Institute's (HRAI) design training (often referenced in Building Codes) allows cooling appliance output to be sized with outputs ranging from 80% to 125% of the design cooling load (DCL).
- However, to prevent undercooling and client call-backs, it is common field practice to size cooling appliance output at between 100% and 125% of DCL. Use these values to estimate DCL values.

EXAMPLE – Option 3D: Estimating Design Loads from Existing Equipment Capacities

For example, a 1987 vintage, tract-built house has the original heating and cooling equipment installed with the following nameplate information:

Heating: Natural gas furnace, Input = 90,000 Btu/h, Output = 68,400 Btu/h

Cooling: Central A/C Condenser, Model number: HS18**-31**1

> NOTE: When using model numbers to determine existing capacities, use the manufacturer's model number nomenclature to determine the corresponding capacity value.
>
> A web search of the manufacturer's coding of model numbers indicates that **-31** in the model number designates a cooling capacity of 31,000 Btu/h (2.6 tons). Rated capacity in cooling is commonly reported at 95°F (35°C).

The design temperature conditions are: -4°F (-20°C) for heating and 88°F (31°C) for cooling.

Applying the Bracketing statements to this example installation:

Existing heating output = 68,400 Btu/h

If sized: at 140% of DHL, then DHL = 48,860 Btu/h; If sized at 125% of DHL, then DHL = 54,720 Btu/h

Existing cooling output = 31,000 Btu/h at 95°F (35°C)

NOTE: To obtain the cooling capacity at the design temperature of 88°F (31°C), designers should consult the manufacturers expanded performance tables (then select the output at the temperature closest to the design cooling temperature). If these are not available, approximate with the nominal rated capacity.

If sized at: 125% of DCL, then DCL ~ 24,800 Btu/h; at 100% of DCL, then DCL ~ 31,000 Btu/h (these are approximate because the capacity of the system at the design cooling temperature of 88°F (31°C) would be slightly higher than the nominal rated capacity at 95°F (35°C).

Based on the existing equipment capacities, design loads are estimated to be:

DHL: 48,860 to 54,720 Btu/h at a design temperature of -4°F (-20°C),

DCL: 24,800 to 31,000 Btu/h at a design temperature of 88°F (31°C).

Cases where historic comfort issues exist

If comfort issues exist in the home, or a recent upgrade to the energy performance of the home has been undertaken, an energy audit and/or heating/cooling load calculation should be conducted for the home prior to sizing and selection of the heat pump.

Also note that comfort issues may be a result of items other than undersized equipment, such as defects in the thermal boundary (e.g. air leakage, lack of insulation), in the mechanical equipment (e.g. leaky, disconnected or undersized ducts, low air flow caused by clogged evaporator coil, clogged air filters) or both.

Estimating Maximum Airflow Capacity of Existing Supply Ducts

In retrofit applications of centrally-ducted ASHPs, the maximum size of ASHP that can be installed may be determined by the maximum airflow capacity of the existing supply ductwork.

- For low-velocity duct systems found in most homes, the maximum airflow capacity can be estimated by measuring the cross-sectional area of the supply trunk(s) near the equipment, before any branch take-offs.
- The total cross-sectional area (in square feet) is then multiplied by an airflow velocity of 900 feet per minute, which is the maximum recommended by the Heating, Refrigeration and Air-conditioning Institute of Canada (HRAI Canada) for low velocity duct systems.

The following equations can be used to calculate the maximum airflow rating of a duct system in cubic feet per minute (CFM).

The equation for rectangular ducts, with dimensions measured in inches is:

Maximum Airflow Capacity (CFM) = (Trunk1depth x Trunk1width + Trunk2depth x Trunk2width + etc.) x 0.00694 x 900,

or simplifying,

Maximum Airflow Capacity (CFM) = (Trunk1depth x Trunk1width + Trunk2depth x Trunk2width + etc.) x 6.25
(Equation 1a)

The equation for rectangular ducts, with dimensions measured in centimetres is:

Maximum Airflow Capacity (m^3/s) = (Trunk1depth x Trunk1width + Trunk2depth x Trunk2width + etc.) x 0.0001 x 4.57,

or simplifying,

Maximum Airflow Capacity (m^3/s) = (Trunk1depth x Trunk1width + Trunk2depth x Trunk2width + etc.) x 0.000457
(Equation 1b)

The equation for round ducts, with dimensions measured in inches is:

Maximum Airflow Capacity (CFM) = ($Trunk1diameter^2$ + $Trunk2diameter^2$ + etc.) x π / 4 x 0.00694 x 900,

or simplifying,

Maximum Airflow Capacity (CFM) = ($Trunk1diameter^2$ + $Trunk2diameter^2$ + etc.) x 4.91 (Equation 2a)

The equation for round ducts, with dimensions measured in centimetres is:

Maximum Airflow Capacity (m^3/s) = ($Trunk1diameter^2$ + $Trunk2diameter^2$ + etc.) x π / 4 x 0.0001 x 4.57,

or simplifying,

Maximum Airflow Capacity (m^3/s) = ($Trunk1diameter^2$ + $Trunk2diameter^2$ + etc.) x 0.000359 (Equation 2b)

Where: 0.00694 is the conversion factor between square-inches and square-feet.
0.0001 is the conversion factor between square-centimetres and square-meters
900 feet/minute (4.57 metres/second) is the maximum recommended velocity by HRAI for low velocity, residential ducts.
π (pi) is a constant, with a value of approximately 3.14.

EXAMPLE CALCULATION: - maximum airflow capacity of an existing duct system

An existing HVAC system has three supply trunks:

- One measures 8 inches deep and 22 inches wide.
- The other two are 6 inches in diameter.

Estimate the maximum airflow capacity of the duct system.

Using equations 1a and 2a:

Maximum Airflow Capacity = (8 x 22) x 6.25 + (6^2 + 6^2) x 4.91 = 1,453 CFM

The maximum airflow capacity of the existing duct system is estimated as 1,453 CFM.

Estimating Target Area Loads for Add-on Mini-split ASHPs

In retrofit installations of add-on ductless mini-split ASHP, sizing will be based on the thermal loads of the target area within the house that is being conditioned by the add-on ASHP. Target area loads can be estimated using one of the following approaches:

- If detailed room-by-room heating and cooling loads are available from either: *Option 3A: CSA F280 Load Analysis*, *Option 3B: Energy Audit Load Estimates*, or *Option 3C: Energy Model Estimates* use the room values to estimate target area loads for ASHP sizing.
- If only whole-house heating and cooling loads are available, target area loads can be estimated by proportioning the load values by the floor area of the target area to that of the whole house.

NOTE TO DESIGNERS AND CONTRACTORS: Load Estimates for Add-on ASHPs

In add-on ASHP applications designed for heating displacement where the existing heating equipment (e.g., electric baseboard) is left in place to handle heating in the coldest weather, the risk of under-sizing the ASHP is largely mitigated. In these situations, a conservative estimate of heating loads is a safe and acceptable approach. Note, however, that in an add-on situation, it is often possible to meet some portion of heating loads beyond just the room in which a ductless indoor unit is located: for example, a living room system can partially heat the upstairs in a house with an open plan and open stairway.

EXAMPLE CALCULATION: Target area heating and cooling loads

An add-on ductless mini-split ASHP is being considered to condition part of the second floor in a two-storey house with a finished basement as shown in Figure 17. Estimate the heating and cooling loads for the target area on the second floor

Heating and cooling loads for the whole house have been estimated from a previous energy audit as:

- Heating: 49,600 Btu/h at a design temperature of -4°F (-20°C); and
- Cooling: 23,500 Btu/h at a design temperature of 88°F (31°C).

Other information:

- Finished floor areas on all three levels total about 3,310 square-feet.
- Target area size is about 1,130 square-feet.

Therefore, target area loads are estimated as:

- Heating: 49,600 x 1,130 / 3,310 = 16,900 Btu/h at a design temperature of -4°F (-20°C);
- Cooling: 23,500 x 1,130 / 3,310 = 8,000 Btu/h at a design temperature of 88°F (31°C).

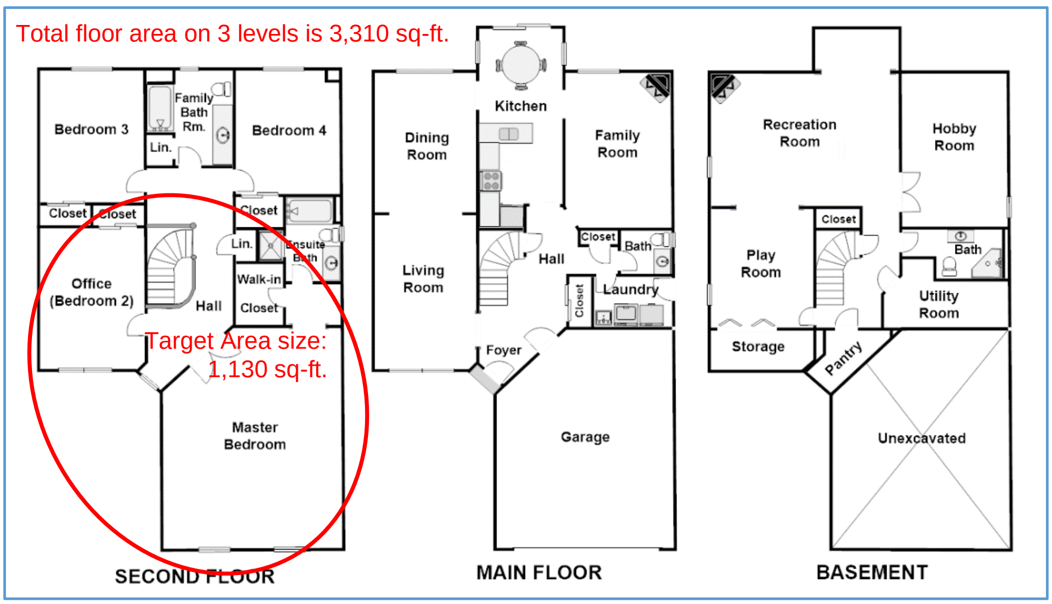


Figure 17: Two-storey house floor plans with Second-Floor Targeted Areas circled

Heating Load Line Chart and Cooling Load

After the heating and cooling design loads have been estimated for the house or targeted area, it is possible to create a heating load line chart. Do this by plotting the following two points on the chart:

- The first point is the estimated design heating load at the heating design temperature.
- The second point is zero (0) heating load at an outdoor temperature of 60°F (16°C)
  - *Note: the temperature chosen as the zero-load point is based on field observations. Due to internal and solar gains and thermal lag, most homes, with thermostats set to 70°F (21°C), do not require heating at outdoor temperatures above 60°F (16°C).*
- The design cooling load can be plotted at the cooling design temperature.

An example of a heating load line chart for a house with a design heat load of 49,600 Btu/h at an outdoor design temperature of -4°F (-20°C) is shown in Figure 18.

The design cooling load of 23,500 Btu/h at an outdoor design temperature of 88°F (31°C) has also been added on the right-hand side of the chart.

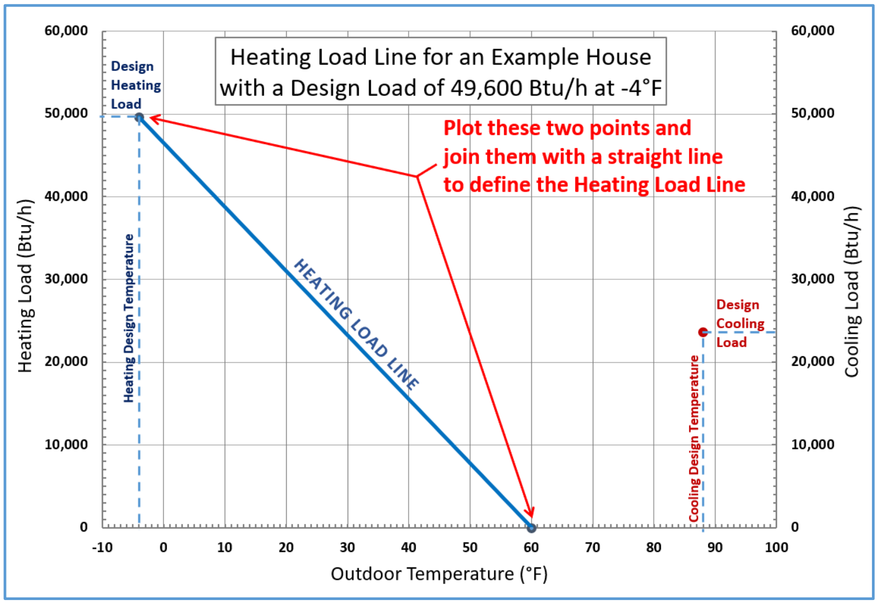


Figure 18: Example of a Plotting a Heating Load Line and Design Cooling Load for a House

These thermal load characteristics will be used in STEP 4 to establish target capacity values for the ASHP.

Upon completing Step 3, you will have:

- ☐ Estimated the design heating and cooling loads for the overall house or targeted space.
- ☐ For centrally-ducted retrofit applications, estimated the maximum airflow capacity of the existing ductwork in the house.
- ☐ Created a heating load curve for the overall house or targeted space to assist with ASHP equipment selection.

STEP 4: DETERMINE SIZING APPROACH AND CAPACITY REQUIREMENTS OF ASHP

In STEP 4 you will:

- Choose a sizing option that fits with the client's objectives / goals for the ASHP installation,
- Determine the target output capacity of an ASHP that is needed for the application being considered, that is consistent with the client's goals.

There is no single sizing approach that is applicable to all ASHP applications.

- The "best-fit" sizing approach will depend on the client's expectations for the ASHP installation.
- A productive conversation with the client should determine their expectations, and will help ensure that you meet their objectives for the ASHP installation.
- Use the descriptions in Table 3 to help gauge client expectations and link their expectation to a specific sizing option (i.e., 4A, 4B, 4C or 4D).
- Document the choice made by the client by recording the sizing option on the **"ASHP Key Specifications Summary Sheet".**
- Calculate the target output capacity of the ASHP needed for the application using the specific instructions for the sizing option chosen, and record the value(s) on the **"ASHP Key Specifications Summary Sheet".**

Table 3: Mapping Primary Client Objectives / ASHP Applications to the Sizing Options

Main Client Objectives / Goals for the ASHP Installation	Option 4A: Emphasis on Cooling	Option 4B: Balanced Heating and Cooling	Option 4C: Emphasis on Heating	Option 4D: Sized on Design Heating Load
Client is primarily interested in cooling. The ASHP is seen as an alternative for a new or existing A/C unit; The backup / existing heating system is seen as the primary heating source for most of the heating season.	✓			
Client is interested in both cooling and ASHP heating. The backup/existing heating system is used primarily during colder weather.		✓		
Client sees the ASHP primarily as a heating source. The backup / existing heating system is used during the coldest periods. Cooling performance is of secondary interest to the client. A CC-ASHP is suggested.			✓	
Client is interested in an ASHP that is sized to provide all or nearly all of the heating at design conditions with little or no use of backup heating. Cooling performance of secondary interest to the client. A CC-ASHP is suggested.				✓

Target Capacity Values Used with Different Sizing Options

The four different sizing options are illustrated in Figure 19 and summarized below.

- **Options 4A and 4B** target capacities are based on the design cooling load;
- **Option 4C** target capacity is based on heating load at 17°F (-8.3°C);
- **Options 4D** target capacity is based on the design heating load at the heating design temperature for the installation site.

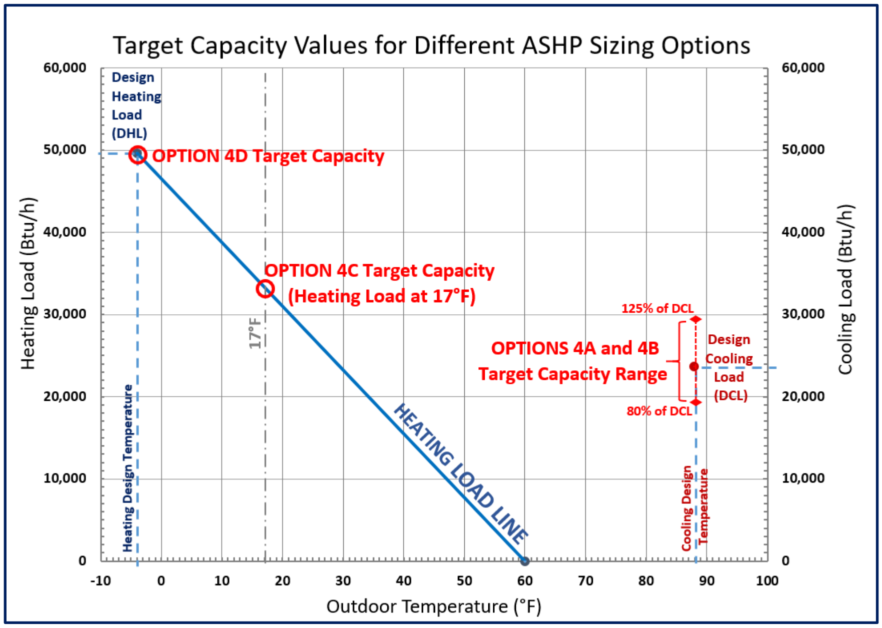


Figure 19: An Example of defining Target Capacities for different ASHP Sizing Options

SIZING APPROACHES BASED ON COOLING REQUIREMENTS – Options 4A and 4B

Typical Applications

Option 4A: Client interest is primarily on cooling.

Option 4B: Installations where both cooling and heating are important.

Option 4A or 4B Target Cooling Capacity

In each case, the Target Capacity for the house or targeted area is:

Target Cooling Capacity Range = 80% to 125% x the Design Cooling Load (equation 3)

When using sizing option 4A or 4B Record the Target Cooling Capacity Range for the specific application on the **"ASHP Key Specifications Summary Sheet"**.

Table 4 provides sizing criteria for each of the sizing options that are based on cooling loads. Use the **Sizing Criteria** shown in Table 4 together with the **Target Cooling Capacity Range** to identify "best fit" ASHP equipment in STEP 5.

Table 4: Sizing Options 4A and 4B and Sizing Criteria for Selecting ASHP Equipment

SIZING OPTION	Relative amount of Heating by the ASHP	Sizing Criteria for Selecting ASHP Equipment
OPTION 4A: Emphasis on Cooling	ASHP sized for cooling Some heating in mild weather	When sizing single-stage ASHPs: Match ASHP cooling output to the **Target Cooling Capacity** at design temperature. When sizing two-stage or variable capacity ASHPs: Match high-stage cooling output to the **Target Cooling Capacity Range.**
OPTION 4B: Balanced Cooling and Heating	Ranges from most of the heating in mild weather to most of the heating over the heating season	When sizing single-stage ASHP's: Match ASHP cooling output to the high end of the **Target Cooling Capacity Range** (i.e. 100% to 125% of design load). For further enhancements to heating output: Use two-stage or variable capacity equipment and match low-stage cooling output to the **Target Cooling Capacity Range (where possible without exceeding 125% limit)**.

EXAMPLE: Calculating Target Capacity Range for Options 4A and 4B:

From STEP 3, the example house has a design cooling load of:

- **Cooling:** 23,600 Btu/h at a design temperature of 88°F (31°C).

Using equation 3, **Target Cooling Capacity Range** is:

= 0.80 x 23,600 Btu/h to 1.25 x 23,600 Btu/h,

= 18,880 to 29,500 Btu/h at an outdoor temperature of 88°F

Use this **Target Cooling Capacity Range** to select an appropriate ASHP from commercially available models (*See Table 4 and STEP 5 for additional details*).

NOTE TO DESIGNERS AND CONTRACTORS: OPTION 4B Sizing of Multi-Stage ASHPs:

When selecting 2-stage or variable-capacity ASHPs using OPTION 4B sizing, use the minimum or low-stage cooling output to match the required **Target Cooling Capacity Range** for the application, where possible. Note that some variable capacity ASHPs, particularly ductless units, may have turn-down ratios of 3:1 or even greater. The designer will need to address potential cooling oversizing concerns by ensuring the 125% maximum cooling capacity is not exceeded when matching minimum cooling output to the Target Cooling Capacity Range.

Rationale: This sizing approach will increase the size of the ASHP in order to boost the heating output, while still matching the cooling requirements needed for the application. Minimum cooling capacities are available from manufacturers' extended performance data.

If you are selecting a multi-stage ASHP using summary performance data, it is likely that only maximum cooling capacities at 95ºF are provided.

In these cases, estimate low-stage cooling values for SELECTION PURPOSES ONLY as follows:

- Estimate a minimum cooling output by multiplying the published maximum cooling output by the minimum / maximum heating ratio (i.e., minimum heating capacity / maximum heating capacity for a given outdoor temperature), and use this lower cooling capacity for selection purposes

Designers should also review "Selection Tips for Multi-stage and CC-ASHPs" on page 27.

SIZING APPROACHES BASED ON HEATING REQUIREMENTS – Options 4C and 4D

Typical Applications

Option 4C: Sites where heating performance is important and the ASHP is sized to provide a major portion of the heating required, with some assistance from either a new or an existing backup heating system during colder periods of the heating season. Depending on the climate zone, a CC-ASHP may be required.

Option 4D: Sites where the ASHP is the principal heating source, because the application is:

- in a location where propane, fuel oil and electricity are the available fuel types (i.e., low cost natural gas is not available);
- a new, energy-efficient home;
- an existing home with deep energy retrofits;
- another low-load installation, such as:
  - *uses in mild heating climates;*
  - *small condo or house; or*
  - *single-zone system serving an individual room or new addition in an existing home*.

For most climate zones in Canada, a CC-ASHP will be required with Option 4D.

Note: Option 4D sizing may not be feasible when retrofitting centrally ducted ASHPs to existing duct systems designed for traditional furnaces. These duct systems will have a maximum airflow capacity which may limit the size of ASHP to a value below the Option 4D sizing requirement, unless significant energy improvements have been made to the thermal envelope of the house. A simple procedure for estimating maximum airflow capacity of existing duct systems is described on page 16.

Table 5 provides suggested ASHP sizing criteria for each of the sizing options that are based on heating loads. It is strongly recommended to use manufacturers' extended performance data for the product line(s) being considered for Option 4C or Option 4D. Extended performance data will provide information on ASHP heating performance at low outdoor temperatures, as well as performance values over the range of staging or modulation available for multi-stage equipment.

Table 5: Sizing Options 4C and 4D and Sizing Criteria for Selecting ASHP Equipment

SIZING OPTION	Relative Amount of Heating by ASHP	Sizing Criteria for Selecting ASHP Equipment
OPTION 4C: Emphasis on Heating	Most of the heating in mild to cold weather in most climate regions.	Select an ASHP with heating output that is close to the **Target Heating Capacity** at 17ºF (-8.3°C). A CC-ASHP should be considered. **For increased heating output (preferred):** Select an ASHP with heating output that is greater than the **Target Heating Capacity** at 17ºF (-8.3°C)
OPTION 4D: Sized to Design Heating Load (DHL)	All or nearly all of the heating requirements over the full heating season	Select an ASHP with heating output that is close to the **Target Heating Capacity** at the heating design temperature for the location. A CC-ASHP should be considered. **For ASHP systems requiring NO Backup Heating:** Select an ASHP with heating output that is greater than the **Target Heating Capacity** at the heating design temperature for the location.

For the specific sizing option selected for the application under consideration, use the **Target Heating Capacity** to identify "best fit" ASHP equipment in STEP 5.

Option 4C Target Heating Capacity

For Option 4C the **Target Heating Capacity** is:

Target Heating Capacity = Heating Load of the House or Target Zone at 17°F (-8.3°C)

The following equation can be used to calculate the target heating capacity at 17°F based on the design heating load and design temperature for the specific application under consideration.

Target Heating Capacity at 17°F = Design Heating Load x (60 - 17) / (60 - Design Temperature), or simplifying

Target Heating Capacity at 17°F = Design Heating Load x 43 / (60 - Design Temperature) *(Equation 4)*

Where: Design heating load is heating requirement of the house or target area at the design temperature.
Design temperature is the outdoor temperature (°F) specified for the location for design heating calculations.

When using Option 4C, calculate and record the **Target Heating Capacity** value for the application under consideration on the **"ASHP Key Specifications Summary Sheet".**

EXAMPLE: Target Capacity for Option 4C:

A house has a design heating load of 49,600 Btu/h at a design temperature of -4°F (-20°C).

Using equation 4, the heating load value at an outdoor temperature of 17°F (-8.3°C) is calculated as:

Target Heating Capacity at 17°F = 49,600 x 43 / (60 – (– 4)) = 33,325 Btu/h

The **Target Heating Capacity** is therefore 35,524 Btu/h at 17°F (-8.3°C), and will be used to select an appropriate ASHP from commercially available models *(See Table 5 and Step 5 for additional details)*.

Option 4D Target Heating Capacity

For Option 4D, the **Target Heating Capacity** is:

Target Heating Capacity = Design Heating Load at design temperature *(Equation 5)*

When using Option 4D, record the **Target Heating Capacity** value for the application under consideration on the **"ASHP Key Specifications Summary Sheet".**

EXAMPLE: Target Capacity for Option 4D:

From STEP 3, an example house has a DHL of 15,800 Btu/h at a design temperature of -4°F (-20°C).

The **Target Heating Capacity** is therefore 15,800 Btu/h at -4°F (-20°C), and will be used to select an appropriate ASHP from commercially available models *(See Table 5 and Step 5 for additional details).*

Upon completing Step 4, you will have:

- Defined a Target Capacity for heating or cooling at specific outdoor conditions for the application under consideration.
- Defined criteria for selecting the most suitably sized ASHP models from commercially available equipment to match basic client objectives.

STEP 5: IDENTIFY AND SELECT ASHP MATCHING KEY REQUIREMENTS

In STEP 5 you will:

- Create a short list (e.g., 3 or 4) of candidate ASHP systems that matches with the ASHP options and Target Capacity that have been developed in STEPS 1 through 4.
- Review specific performance features, and other factors such as cost, of the different candidate ASHP with the client in order to identify a "best-fit" ASHP for the application which will satisfy client's expectations.

In order to identify a short list of candidate-ASHPs that satisfy design requirements:

1) **Use manufacturers' performance data to identify possible ASHP systems**
   i) Use on-line database listings of available systems *(web-links are provided below)*,
   ii) Use manufacturers' performance summary sheets, or
   iii) Use manufacturers' extended performance data tables.
2) **Create a short-list** of candidate ASHPs using the ASHP options and Target Capacity that have been developed in STEPS 1 though 4 of the Guide Process.
   (e.g., "Good" / "Better" / "Best" equipment choices).

In order select a best-fit ASHP system which will satisfy client's expectations:

3) **Compare performance of the candidate ASHP models** to one another and to client requirements. Possible factors to consider and compare could include:
   i) Stage or modulating capabilities,
   ii) Turn-down ratio (maximum to minimum capacity),
   iii) Low-temperature performance capabilities and low-temperature operating limits,
   iv) Thermal balance point temperature (t-BPT) for the application and Fraction of Total Annual Heating provided above the t-BPT for the climate zone under consideration *(see details on how to estimate the "Fraction of Total Annual Heating" value later in STEP 5),*
   v) Efficiency ratings (e.g., COP, EER, etc.) and how they vary over the operating range,
   vi) Noise ratings of outdoor units,
   vii) Cost of the equipment.
4) **Make any final adjustments** to ASHP sizing and staging-modulation, if necessary, to match client requirements.
5) **Record the "best fit" ASHP** on the **"ASHP Key Specifications Summary Sheet".**

On-line Equipment Database Listings

There are three main databases of ASHP equipment at the time of publication:

- Air-Conditioning, Heating & Refrigeration Institute (AHRI) equipment directory (also accessible through the Consortium for Energy Efficiency (CEE) website), and
- Northeast Energy Efficiency Partnerships (NEEP) listing of cold-climate ASHPs.
- Nova Scotia Approved Heat Pump List of ductless mini-split ASHPs

Air-Conditioning, Heating & Refrigeration Institute (AHRI) and Consortium for Energy Efficiency (CEE)

The AHRI directory of certified products is located here:
https://www.ahridirectory.org/Search/SearchHome?ReturnUrl=%2f#

The CEE provides a useful front-end user interface for the AHRI directory. It is located here:
http://www.ceedirectory.org/site/1/Home

The CEE/AHRI database has test data with:

- Cooling capacity data is available at 95°F (35°C). This will be suitable for screening **Target Cooling Capacity** for Sizing Options 4A and 4B, from STEP 4.
  - Only maximum or high-stage cooling values are provided for two-stage and variable capacity equipment, which may limit the use with Sizing Option 4B in STEP 4 when considering minimum or low-stage cooling capacities. *(See "Note to Designers and Contractors" for details on how to estimate minimum cooling output when using Sizing Option 4B" with multi-stage ASHPs).*
- Heating capacity and efficiency measurements down to 17°F (-8.3°C), which will be sufficient when **Target Heating Capacity** values are referencing outputs at 17°F (-8.3°C) (e.g., Sizing Option 4C from STEP 4).
  - Only maximum or high-stage heating values are provided for two-stage and variable capacity equipment.

Northeast Energy Efficiency Partnerships

An Excel spreadsheet list of cold-climate ASHP products is maintained by the Northeast Energy Efficiency Partnerships (NEEP), a non-profit organization in the United States. It is located here: http://www.neep.org/ASHPInstallerResources

The NEEP List shows both high-stage and low-stage heating and high-stage cooling output values for two-stage and variable capacity equipment, and has manufacturer-reported data with heating capacity and efficiency values down to 5°F (-15°C).

- The NEEP list is useful when ASHP sizing is being based on minimum or low-stage cooling capacity *(See "Note to Designers and Contractors" for details on how to estimate minimum cooling output when using Sizing Option 4B with multi-stage ASHPs).*
- The NEEP list is useful for screening and initial selection of ASHPs based on heating performance when performance data below 17°F (-8.3°C) is relevant (e.g., Sizing Option 4D from STEP 4).

Nova Scotia Approved Heat Pump List

A PDF list of qualified ductless mini-split cold-climate ASHP products is maintained by Efficiency Nova Scotia at: https://www.efficiencyns.ca/guide/minisplits/

Listed products qualify for Nova Scotia's Green Heat and Home Energy Assessment incentives, and include both single-zone and multi-zone units.

The Nova Scotia Approved Heat Pump List shows rated heating capacity at 47°F (8°C), HSPF rating for Region 4 and Region 5, and Coefficient of Performance (COP) values at 5°F (-15°C).

Selection Tips for Two-Stage, Multi-Stage and VC-ASHPs

NOTE TO DESIGNERS AND CONTRACTORS: The Importance of ASHP Turn-down Ratio in Minimizing Equipment Cycling

When selecting two-stage, multi-stage and/or variable capacity equipment, selecting a system with the highest turn-down ratio will be important to ensuring client satisfaction. This is particularly important in relation to **Sizing Options 4B, 4C and 4D**. For example, Figure 20 depicts two variable capacity CC-ASHPs with maximum (high stage) and minimum (low stage) capacity curves. These curves intersect the heating load line of the home at two points (the high stage capacity curve intersects at a point higher on the heating load line and the low stage capacity curve intersects at a point lower on the heating load line). The duration of the heating load line that is between these two intersecting points indicates the amount of the heating load that the ASHP will operate at without cycling. As cycling degrades performance and results in comfort swings within the home, the designer's objective should be to minimize cycling by selecting equipment with a high turn-down ratio. In Figure 20, CC-ASHP #2 has a turn-down ratio of 2.2:1 and will operate without cycling between outdoor temperatures of 12°F (-11°C) and 34°F (1°C), while CC-ASHP#1 has a turn-down ratio of 1.4:1 and will operate without cycling between outdoor temperatures of 20°F (-7°C) and 30°F (-1°C). CC-ASHP#2 will cycle much less often for this heating load.

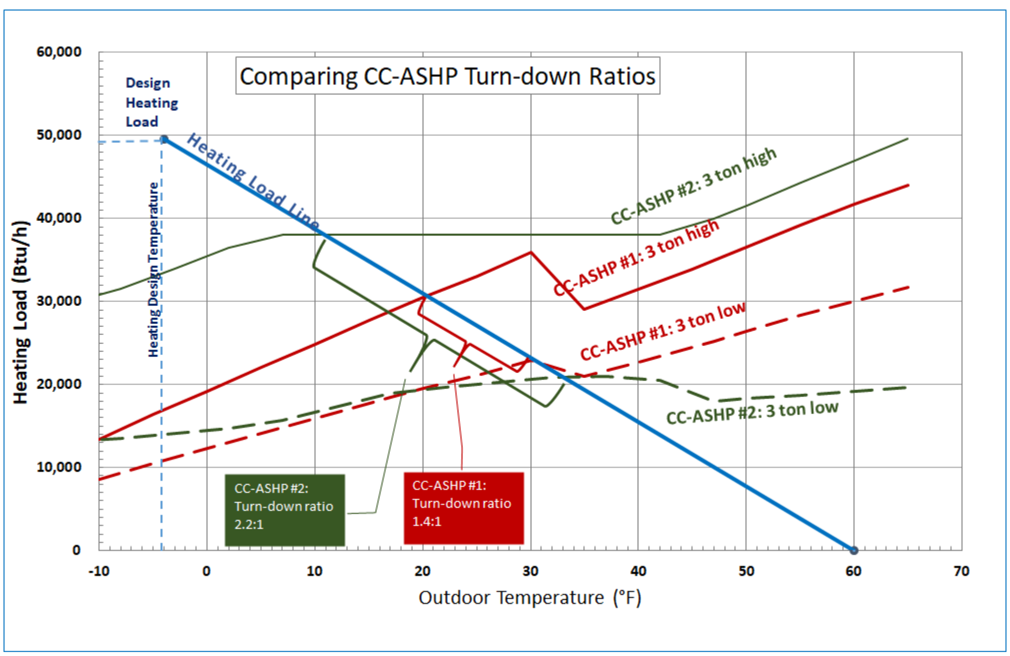


Figure 20: Comparing CC-ASHP Turn-down Ratios

Finding the Thermal Balance Point Temperature for an ASHP

The thermal balance point temperature (t-BPT) can be estimated by superimposing a plot of the ASHP heating capacity(ies) curve (using information from the manufacturer's extended performance tables at different outdoor temperatures) onto the heating load line chart from Step 3 as shown in Figure 21. Use the maximum capacity information whenever it is available. The t-BPT is the temperature at which the heating load line intersects the ASHP performance curve.

For example:

- The ASHP with the green capacity curve has a t-BPT of about 33°F (0.6°C);
- The ASHP with the orange capacity curve has a t-BPT of about 28°F (-2°C); and,
- The ASHP with the red capacity curve has a t-BPT of about 21°F (-6°C);

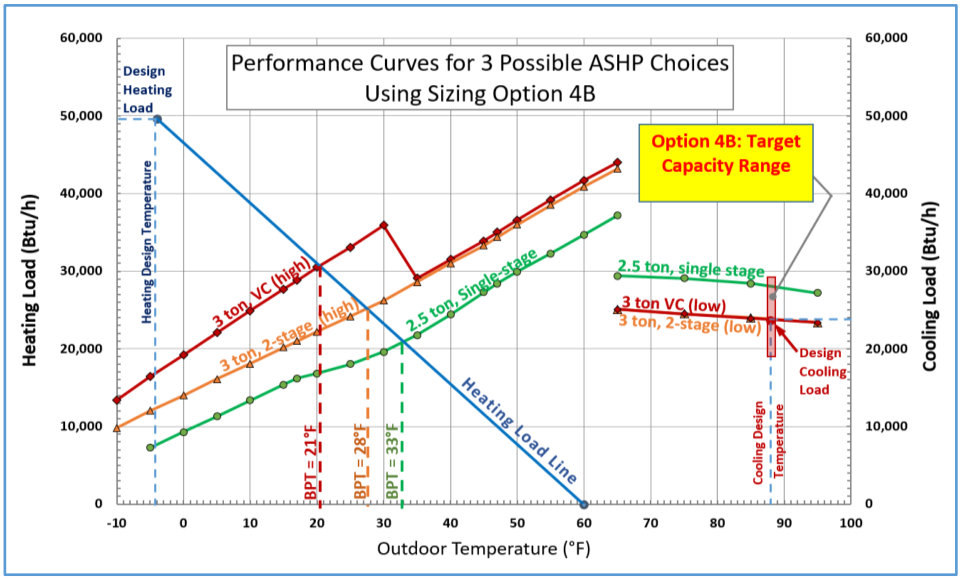


Figure 21: Performance Curves and Balance Point Temperatures for 3 Possible ASHP Choices

Estimating the Fraction of Annual Heating Provided

Choosing the ***"best fit" ASHP*** for an application invariably involves trading off heating capabilities against different ASHP options. The following simplified procedure provides a quick estimation of the relative amount of heating provided by different ASHP systems to assist designer, contractors and their clients make informed decisions on which heat pump system is the "best one" for the particular application. The steps involved are:

- For each ASHP being compared, determine the thermal balance point temperature (t-BPT) by developing a performance curve for each ASHP and the load line for the house (or area of the house being considered) as illustrated in the example in Figure 21;
- Data from the on-line equipment databases and/or extended performance data from the manufacturer is used to guide the development of the ASHP performance curve as illustrated in Figure 20;
- Using the *"Total Annual Heating Fraction"* chart provided in Figure 22, determine the fraction of total heating delivered by each ASHP option above their t-BPT for the climate zone of the installation site;

- Use this information with other data (e.g. capacity, equipment cost, efficiency rating, etc.) to help make the final decision on the ASHP model for the particular application.

Total Annual Heating Fractions for Different Climate Zones in Canada

The fraction of total annual heating that occurs above a given outdoor temperature is modelled for five different climate zones in Canada and is shown graphically in Figure 22.

- Starting from the right-hand side (i.e., warmer outdoor temperatures), these plots accumulate, or integrate the heating degree-day loads for a typical year as you move left towards colder outdoor temperatures, and display the percentage of Total Annual Heating load that has been accumulated on the vertical axis.
- The rate of rise of the curve depends on the climate zone:
    - *Marine-climate locations have most of the annual heating load (~100%) occurring at outdoor temperatures of 15°F or warmer.*
    - *In contrast, in the subarctic-climate, only about 45% of the annual heating load occurs at outdoor temperatures of 15°F or warmer.*
    - *Other Canadian climate-zones fall in between these two extremes.*

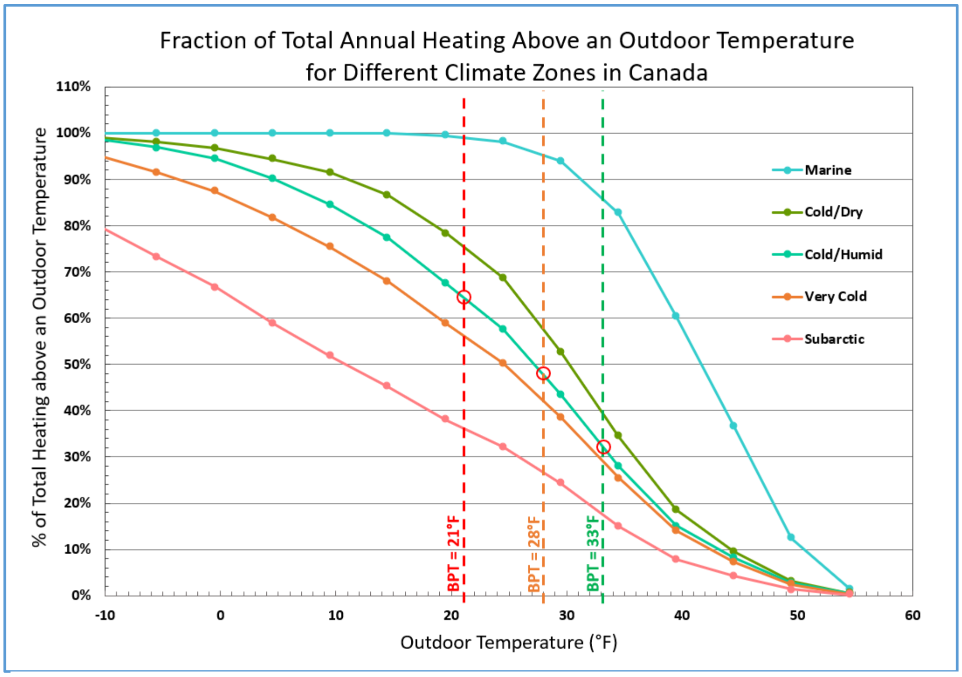


Figure 22: Fraction of Total Annual Heating Curves for Five Climate Zones in Canada

By plotting the t-BPT of an ASHP installation as a vertical line on the outdoor temperature axis, these curves will estimate the fraction of total annual heating that the ASHP will deliver without the use of backup heating.

- The fraction of total annual heating provided is indicated by the intersection of the t-BPT line with the climate-zone curve for the house location. Red circles indicate the heating fractions for the three ASHPs shown in Figure 22 in "Cold-Humid" climate zone locations.
- You can determine the climate zone for house locations in Canada by examining the map of Climate Zone Assignments shown in Figure 23.

Note that there are a number of factors that will affect the actual heating fraction compared to the value estimated using Figure 22:

- Defrost and oil pan heater operation (that is typically not accounted for in the AHRI or manufacturer extended performance tables) will reduce the available capacity somewhat and decrease the actual heating fraction slightly.
- Controls such as a standard 2-stage heat pump thermostat that allows the heat pump to operate below the t-BPT will increase the actual heating fraction.
- Heat pumps with higher capacities at low temperatures and allow lower temperature operation, will have a higher actual heating fraction than heat pumps with steeper capacity curves that drop off quickly or simply don't operate in cold temperatures, even when they have similar t-BPT values.

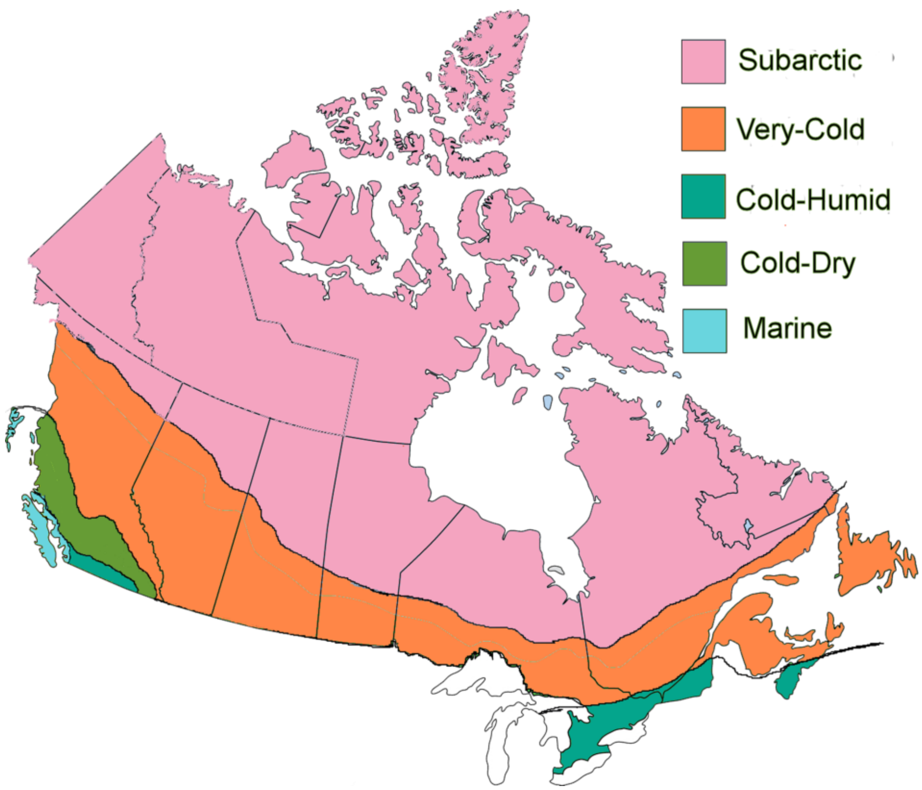


Figure 23: Climate Zone Assignments for Heat Pump Applications

Most Canadian population centres fall into three climate zones:

- Cold-Humid,
- Cold-Dry, and
- Very-Cold.

The exceptions are the coastal areas of British Columbia which has a "Marine" climate, and the northern region of Canada which has a "Subarctic" climate.

EXAMPLE: Estimating Annual Heating Fractions for ASHP Systems:

Three ASHP systems (i.e., single-stage, two-stage and variable capacity models) have been short-listed using *"Sizing Option B: Balanced Heating and Cooling"* for a house located in the "Cold-Humid" climate zone. The heating and cooling performance curves for the three systems are shown in Figure 21 for reference. The following analysis provides estimates of the relative heating performance of each ASHP under consideration.

Using the thermal balance point temperature (t-BPT) for each system (see Figure 21), the "Fraction of Total Annual Heating" that can be delivered above the t-BPT can be estimated using the Chart in Figure 22 for the "Cold-Humid" climate zone. The results are summarized below:

2.5-ton, single-stage ASHP	t-BPT = 33°F (0.6°C)	Fraction of Annual Heating above the t-BPT = 33%
3.0-ton, two-stage ASHP	t-BPT = 28°F (-2°C)	Fraction of Annual Heating above the t-BPT = 48%
3.0-ton, variable capacity ASHP	t-BPT = 21°F (-6°C)	Fraction of Annual Heating above the t-BPT = 64%

Use this information together with other data (e.g., equipment costs, efficiency ratings, etc.) to help choose the "best ASHP" for the application.

Fine-tuning the ASHP Sizing and Selection

The fraction of total heating provided can also be used to fine-tune the ASHP sizing and selection.

1. If the ASHP heating fraction is perceived as too low, consider:

- *Using an ASHP with better low-temperature performance which will lower the thermal balance point temperature and increase the ASHP heating fraction.*
- *Using a slightly larger capacity ASHP while maintaining other key performance requirements, such as cooling capacity limits and cost objectives.*

2. If the ASHP heating fraction is perceived as too high, consider:

- *Using an ASHP with somewhat reduced capacity and/or cold-weather performance, while maintaining other key performance requirements such as cooling capacity.*

Examples of Choosing ASHP models based on Specification Summary Characteristics

Using the ASHP options and the target capacity ranges defined in STEPS 1 to 4, and other factors that are important to the client, it is possible to choose specific ASHP equipment to "Best Fit" an application's requirements.

Centrally Ducted ASHP Examples

Table 6 provides a summary of examples of ASHP choices for different sizing scenarios using centrally-ducted heat pump equipment.

- The first three examples are retrofits of centrally ducted ASHPs to the same detached house using an existing supply duct system, but selecting different sizing options, chosen in STEP 4. This existing duct system does not have the airflow capacity needed for the 4D sizing option.
- The fourth example (i.e., 4D sizing) is an installation of a ducted ASHP in a new-build, energy-efficient, semi-detached house. In this example, the duct system would be sized and designed to accommodate the airflow requirements of the ASHP system chosen.

Table 6: Examples of Possible Centrally-ducted ASHP Equipment Choices Using Different Sizing Options

Design Loads (STEP 3)	Sizing Option, (STEP 4)	ASHP: Staging; Rated Capacity	Cooling Output at Design Temperature (% of design)	Thermal Balance Point Temperature (t-BPT)	Fraction of Annual Heating above t-BPT	Turn-down Ratio
Heating: 49,600 Btu/h at -4°F (-20°C) Cooling: 23,600 Btu/h at 88°F (31°C) (Cold-Humid Climate Zone)	4A Emphasis on cooling	1-stage; 2.0 ton	23,100 Btu/h (98%)	37°F (3°C)	22% of total heating	N/A
Heating: 49,600 Btu/h at -4°F (-20°C) Cooling: 23,600 Btu/h at 88°F (31°C) (Cold-Humid Climate Zone)	4B Balanced heating & cooling	2-stage; 3.0 ton	Maximum: 32,700 Minimum: 23,800 Btu/h (101% to 139%)	28°F (-2°C)	48% of total heating	1.37:1
Heating: 49,600 Btu/h at -4°F (-20°C) Cooling: 23,600 Btu/h at 88°F (31°C) (Cold-Humid Climate Zone)	4C Emphasis on heating	Variable capacity; 4.0 ton	Maximum: 43,900 Btu/h Minimum: 30,300 Btu/h (128% to 186%)	17°F (-8°C)	72% of total heating	1.45:1
Heating: 18,500 Btu/h at -13°F (-25°C) Cooling: 11,800 Btu/h at 86°F (30°C) (Cold-Humid Climate Zone)	4D Sized on design heating load	Variable capacity; 3.0 ton	Maximum: 32,000 Btu/h Minimum: 11,500 Btu/h (98% to 270%)	(below design temperature)	100% of total heating	2.78:1

Details on the sizing and selection process for these four centrally-ducted ASHP cases are provided in a **"ASHP Sizing and Selection Worked Examples"** addendum to the Guide which is available as a separate PDF download.

Mini-split ASHP Examples

Table 7 provides a summary of examples of ASHP choices for different sizing scenarios using mini-split heat pump equipment.

- The first three examples, are retrofits of mini-split ASHPs into two targeted areas of the same house that was used in the previous ducted examples (4A through 4C).
- The 4D example is an installation of a multi-zone ASHP that is retrofitted to a smaller detached house with a lower overall heating load.

Table 7: Examples of Possible Mini-split ASHP Equipment Choices Using Different Sizing Options

Design Loads (STEP 3)	Sizing Option, (STEP 4)	ASHP: Staging; Rated Capacity	Cooling Output at Design Temperature (% of design)	Thermal Balance Point Temperature (t-BPT)	Fraction of Annual Heating above t-BPT	Turn-down Ratio
Two target areas: Heating: 2 x 17,000 Btu/h at -4°F (-20°C) Cooling: 2 x 8,000 Btu/h at 88°F (31°C) (Cold-Humid Climate Zone)	4A Emphasis on cooling	2 x single-zone mini-splits; Variable capacity; 8,100 Btu/h cooling each	Maximum: 2 x 8,100 Btu/h; Minimum: 2 x ~4,900 Btu/h* (61% to 101%)	28°F (-2°C)	48% of target area heating	1.65:1
Two target areas: Heating: 2 x 17,000 Btu/h at -4°F (-20°C) Cooling: 2 x 8,000 Btu/h at 88°F (31°C) (Cold-Humid Climate Zone)	4B Balanced heating & cooling	2 x single-zone mini-splits; Variable capacity; 12,000 Btu/h cooling each	Maximum: 2 x 12,000 Btu/h Minimum: 2 x ~7,200 Btu/h* (90% to 150%)	25°F (-4°C)	56% of target area heating	1.67:1
Two target areas: Heating: 2 x 17,000 Btu/h at -4°F (-20°C) Cooling: 2 x 8,000 Btu/h at 88°F (31°C) (Cold-Humid Climate Zone)	4C Emphasis on heating	2 x single-zone mini-splits; Variable capacity; 14,000 Btu/h cooling each	Maximum: 2 x 14,000 Btu/h* Minimum: 2 x ~8,400 Btu/h* (105% to 175%)	10°F (-12°C)	84% of target area heating	1.67:1
Whole house as the target area: Heating: 30,740 Btu/h at -13°F (-25°C) Cooling: 23,104 Btu/h at 86°F (30°C) (Cold-Humid Climate Zone)	4D Sized on design heating load	Multi-zone mini-split, with 3 indoor units; Variable capacity; 28,400 Btu/h cooling	Maximum: 28,400 Btu/h Minimum ~11,400 Btu/h** (49% to 123%)	-4°F (-20°C)	96% of total heating	2.49:1

Notes:
* Minimum cooling output is an estimated value, based on 0.6 times the maximum cooling rating.
** Minimum cooling output is an estimated value; based on the published minimum / maximum heating output ratio.

Details on the sizing and selection process for these four ductless mini-split ASHP cases are provided in a **"ASHP Sizing and Selection Worked Examples"** addendum to the Guide which is available as a separate PDF download.

Upon completing Step 5, you will have:

☐ Selected a specific model and size of ASHP(s) that "Best Fits" the application requirements and client expectations as defined by the options selected in STEPS 1 through 4.

STEP 6: DEFINE THE ASHP CONTROL STRAGEGY

In STEP 6 you will define the control strategy needed to coordinate operation of the ASHP and new or existing backup heating system. The needed control strategy will be determined by three factors:

1. The low-temperature cut-off limit of the ASHP relative to the design temperature,
2. Cost of heat from the ASHP relative to the cost of heat from the backup heating system, and
3. Sizing of the ASHP heating output relative to the design heating load.

A decision tree using these factors is provided in Figure 24 and maps the results to five different control strategies (C/S).

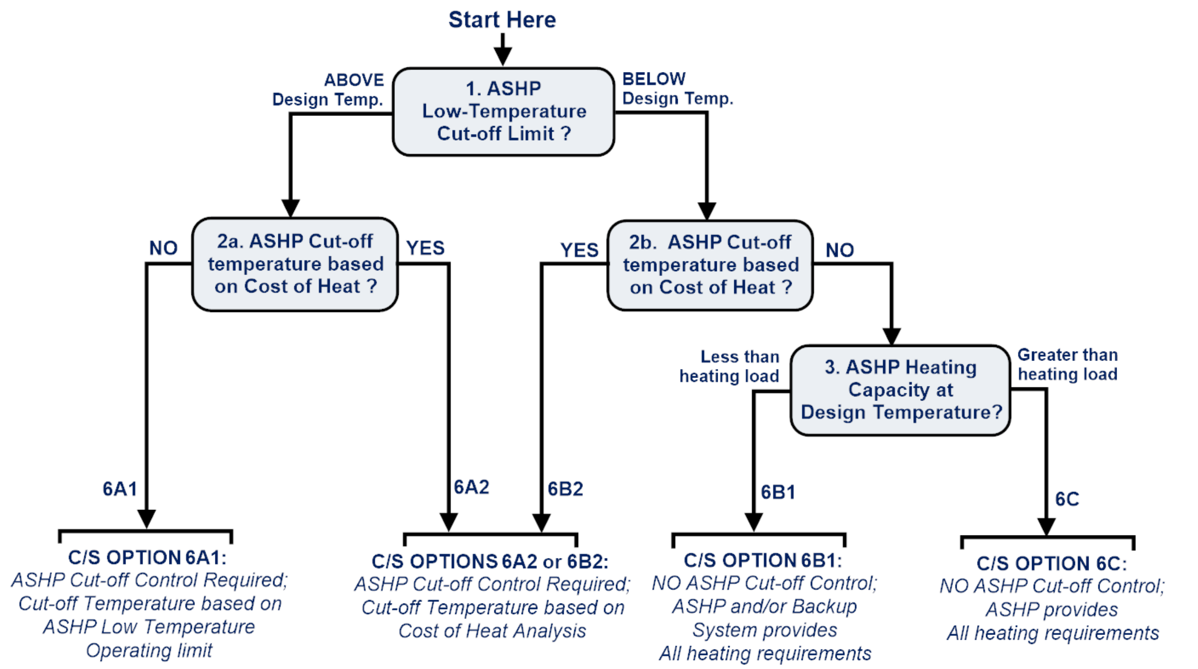


Figure 24: Decision Tree to determine the most appropriate ASHP Control Strategy Option

NOTE TO DESIGNERS AND CONTRACTORS: Low-Temperature Cut-off Limits:

Low-temperature cut-off limits may not be explicitly stated in the manufacturer's literature.

- When not provided, use the lowest outdoor temperature shown in extended performance tables, or equivalent information from the specifications such as the *"heating outdoor temperature operating range*" to provide an indication of **"low-temperature cut-off limit"** for the equipment.

It is important that installers follow manufacturer's recommendations on outdoor temperature operating limits in order to prevent fault conditions from occurring during operation.

- Low-temperature faults may require manual intervention to reset the ASHP equipment and return it to operation.

Once you have determined the most appropriate Control Strategy, circle the chosen option, and indicate a switch-over temperature to full backup heating if required on the **"ASHP Key Specifications Summary Worksheet".**

The five different control strategy options are described in the following sections.

- Factors to consider when implementing the different options are listed at the end of STEP 6.
- Types of ASHP installations covered by these control strategy options include:
    - Integrated ASHP / backup systems (e.g., "hybrid" or "dual-fuel" systems);
    - Add-on ASHP systems; and,
    - Ductless ASHP systems.

Option 6A Control Strategies: For ASHPs with low-temperature cut-off limits ABOVE the heating design temperature

Control Strategy 6A1: ASHP Cut-off Temperature Based on ASHP Low-Temperature Cut-off Limit

The ASHP has a low-temperature cut-off limit that is above the design temperature. This can result in restrictions in ASHP operation at lower outdoor temperatures.

- Field selection of a switch-over temperature to full backup heating may be needed.
- The outdoor cut-off temperature is set to a value slightly above low-temperature cut-off limit for the heat pump.
- The outdoor cut-off temperature may be above, or below (as shown in the example), the thermal balance point temperature.

An example of the various heating modes with Control Strategy 6A1 are shown in Figure 25.

- At outdoor temperatures above the thermal balance point temperature, all heating will be provided by the ASHP.
- At outdoor temperatures between the thermal balance point temperature and the cut-off temperature, heating will be provided by both the ASHP and backup system (i.e., in sequence of operation, the details of which will depend on the thermostat or equipment control logic). Refer to **Implementation of Controls** at the end of this STEP for additional details on control sequencing.

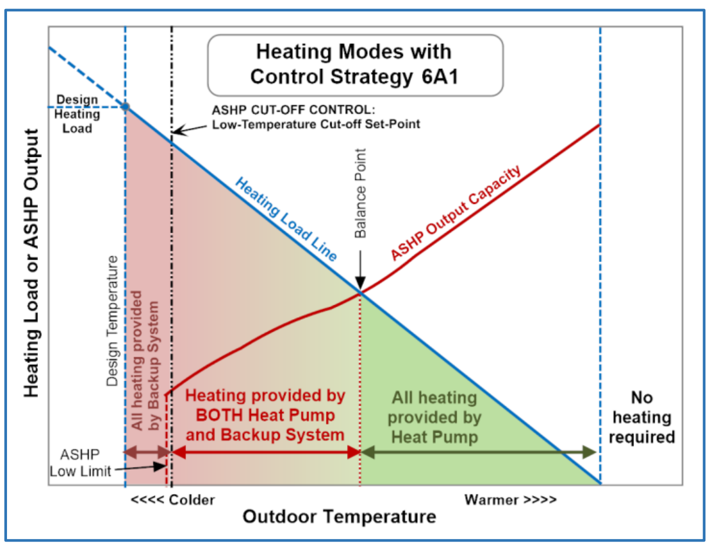


Figure 25: Example of Heating Modes with Control Strategy 6A1

- At outdoor temperatures below the cut-off temperature, ASHP operation will be disabled and all heating will be provided by the backup heating system.

Control Strategy 6A2: ASHP Cut-off Temperature Based on Cost-of-Heat Analysis (i.e., Economic Balance Point or "Economic cut-off")

The ASHP low-temperature cut-off specification is above the design temperature, and it is normally restricted from operating at the lowest outdoor temperatures. However, ASHP operation is further restricted to higher outdoor temperatures based on estimated costs of heat delivered by the ASHP versus the backup system.

- Field selection of a cut-off temperature to full backup heating may be needed.
- The outdoor cut-off temperature is set based on the cost of heat delivered from the ASHP versus the backup heating source. Refer to Appendix A for details on how to determine this economic cut-off temperature.
  - *This economic balance point temperature (e-BPT) can be above or below the thermal balance point temperature (t-BPT).*
  - *This type of control is most applicable to installations where a low-cost fuel is used for backup heating, whether integrated into a single system or with an add-on heat pump using an independent backup heating system.*

An example of the various heating modes with Control Strategy 6A2 are shown in Figure 26. In this instance, the e-BPT is above the t-BPT.

- At outdoor temperatures above the e-BPT, all heating will be provided by the ASHP.
- At outdoor temperatures below the e-BPT, ASHP operation will be disabled and all heating will be provided by the backup heating system (i.e., in sequence of operation, the details of which will depend on the thermostat or equipment control logic). Refer to **Implementation of Controls** at the end of this STEP for additional details on control sequencing.
- For regions with time-of-use electricity rates, the e-BPT may have two or more values based on time-of-day and day-of-week settings.

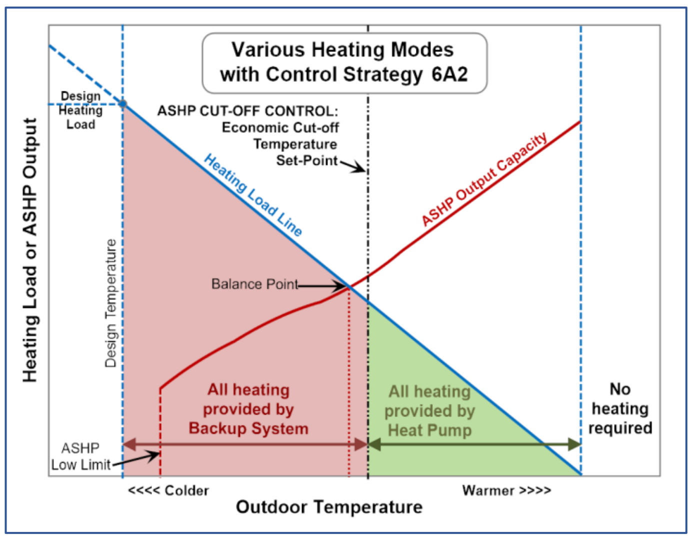


Figure 26: Example of Heating Modes with Control Strategy 6A2

Option 6B and 6C Control Strategies:

For ASHPs with low-temperature cut-off limits BELOW the heating design temperature

Control Strategy 6B1: ASHP is allowed to operate over the full outdoor temperature range; No temperature cut-off required.

The ASHP has a low-temperature cut-off limit that is below the design temperature and is allowed to operate over the full range of outdoor temperatures expected at the installation site (i.e., no restrictions in operation).

- No field-specified outdoor temperature cut-off control is required.

An example of the various heating modes with Control Strategy 6B1 are shown in Figure 27. The ASHP will contribute to the space heating requirements over the full range of outdoor temperatures.

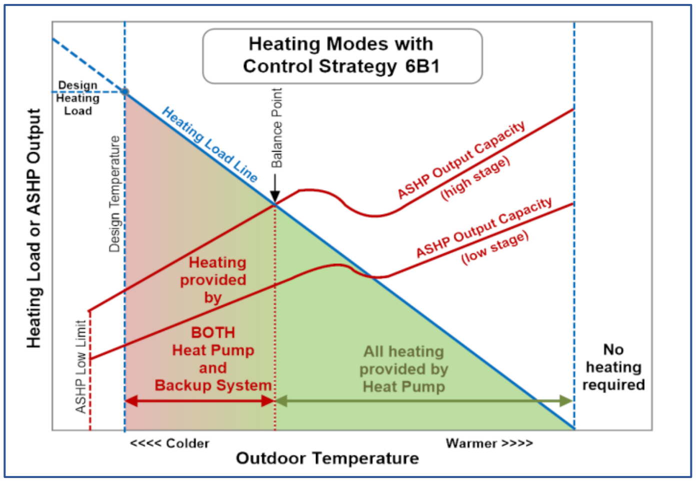


Figure 27: Example of Heating Modes with Control Strategy 6B1

- At outdoor temperatures above the thermal balance point temperature, all heating will be provided by the ASHP.
- At outdoor temperatures below the thermal balance point temperature, heating will be provided by both the ASHP and backup system (i.e., in sequence of operation, the details of which will depend on the thermostat or equipment control logic). Refer to **Implementation of Controls** at the end of this STEP for additional details on control sequencing.

Control Strategy 6B2: ASHP Cut-off Temperature Based on Cost-of-Heat Analysis (i.e., Economic Balance Point or "Economic cut-off")

The ASHP low-temperature cut-off specification is below the design temperature, and the ASHP is technically capable of operating over the full range of outdoor temperatures expected at the installation site. However, the ASHP operation is restricted to higher outdoor temperatures based on estimated costs of heat delivered by the ASHP versus the backup system.

- Field selection of a cut-off temperature to full backup heating may be needed.
- The outdoor cut-off temperature is set based on the cost of heat delivered from the ASHP versus the backup heating source. Refer to Appendix A for details on how to determine this economic cut-off temperature.
  - *This economic balance point temperature (e-BPT) can be above or below the thermal balance point temperature (t-BPT).*

- *This type of control is most applicable to installations where a low-cost fuel is used for backup heating, whether integrated into a single system or with an add-on heat pump using an independent backup heating system.*

An example of the various heating modes with Control Strategy 6B2 are shown in Figure 28. In this instance, the e-BPT is below the t-BPT.

- At outdoor temperatures above the t-BPT, all heating will be provided by the ASHP.
- At outdoor temperatures between the t-BPT and the switch-over temperature, heating will be provided by both the ASHP and backup system (i.e., in sequence of operation, the details of which will depend on the thermostat or equipment control logic). Refer to **Implementation of Controls** at the end of this STEP for additional details on control sequencing.
- At outdoor temperatures below the e-BPT, ASHP operation will be disabled and all heating will be provided by the backup heating system.

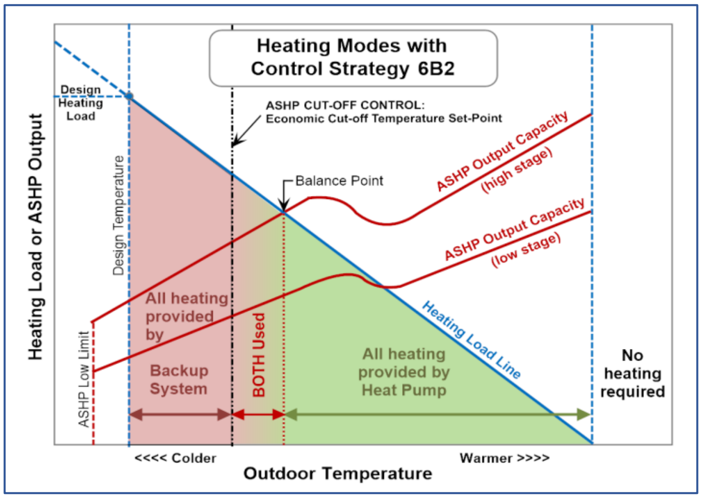


Figure 28: Example of Heating Modes with Control Strategy 6B2

- For regions with time-of-use electricity rates, the e-BPT may have two or more values based on time-of-day and day-of-week settings.

Control Strategy 6C: ASHP Heating Capacity is greater than the Design Heat Loss; No Backup Heating required

The ASHP has no low-temperature cut-off or the cut-off temperature limit is below the design temperature, and the ASHP output capacity at the heating design temperature is greater than the design heat loss.

- No field-specified outdoor temperature cut-off control is required and none should be installed/enabled.

An example of the heating mode with Control Strategy 6C is shown in Figure 29.

- The ASHP has the heating capacity to match the space heating requirements over the full range of outdoor temperatures and no backup heating is required.

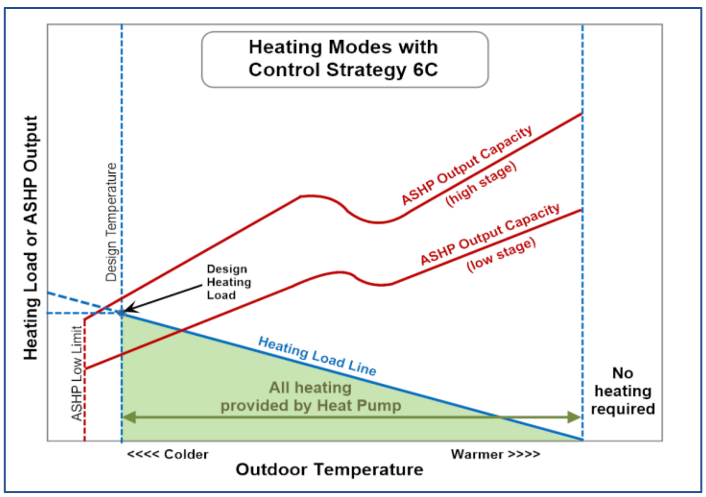


Figure 29: Example of Heating Modes with Control Strategy 6C

Implementation of Control Strategies

Additional factors to consider when implementing the five control strategies are provided in the following sections for different ASHP system configurations such as: Integrated ASHP and backup systems; Add-on ASHP systems; and, Ductless ASHP systems.

Factors when Implementation Control Strategies 6A1, 6A2, 6B1 and 6B2

Integrated ASHP and backup heating system:

- A single, multi-stage indoor thermostat sequences the operation of both the ASHP and back-up heating system above the outdoor temperature cut-off set-point (Note: Control Strategy 6B1 does not have an outdoor temperature cut-off control).
  - *For system using fuel-based furnaces (e.g., “hybrid” or “dual-fuel” systems), the thermostat will first bring on the ASHP to satisfy a “heating call”, and only turn off the ASHP and bring on backup heating if the “heating call” cannot be satisfied by the ASHP.*
  - *For ducted systems using backup heating that can operate simultaneously with the ASHP (e.g., downstream electric resistance heating elements) the ASHP may continue to operate simultaneously with the backup heating in order to satisfy the “heating call”.*
  - *For ductless systems with controls that can be integrated with backup heating (e.g., mini-split / multi-split systems with auxiliary heat relay to electric baseboard backup), the thermostat will first bring on the ASHP to satisfy a “heating call”, and only bring on the backup heating if the “heating call” cannot be satisfied by the ASHP.*

ASHP add-on to an existing heating system:

- Separate indoor thermostats controlling the ASHP and existing heating system (used for backup heating).
- The set-point temperature on the backup heating system thermostat(s) should be set below the ASHP set-point values to ensure operation of the ASHP when it is able to operate.
  - *For installation with existing central heating systems used as backup, it may be desirable to install an “outdoor temperature cut-off control” on the existing heating system to disable operation above a given outdoor temperature (e.g., above the thermal balance point temperature) to prevent the backup heat from running unnecessarily in mild weather when the ASHP is capable of meeting the heating demands. This can also be accomplished with many web-enabled thermostats.*
  - *In the case of ductless systems where a central backup heating system covers a larger area of the house than the ductless ASHP, it may be beneficial to (re)locate the backup heating thermostat in an area that is not served directly by the ASHP.*

Additional Factors when Implementing Control Strategies 6A1, 6A2 and 6B2 only

- An outdoor temperature cut-off control disables ASHP operation at outdoor temperatures below the cut-off set-point, and all heating is provided by the backup system.
  - *For control strategy 6A1, the ASHP low-temperature cut-off specification determines the cut-off temperature; For control strategies 6A2 and 6B2 the cost of heat analysis determines the switch-over point (see APPENDIX A: "Determining the Economic Cut-off Temperature (e-BPT)", for additional details).*
  - *The outdoor cut-off temperature will likely be set on the thermostat directly, or on the equipment via dip-switches or setup menus, depending on the manufacturer.*
  - *When using control strategies 6A2 or 6B2 in regions with time-of-use electricity rates, choosing a control offering multiple cut-off temperatures that are based on time-of-day and day-of-week is preferable.*

Factors when Implementing Control Strategy 6C

Central ASHP or ASHP add-on to an existing system:

- Indoor thermostat controls are generally provided by the ASHP manufacturer and control the ASHP over the full range of outdoor temperature conditions.
- Supplemental or backup heat is not necessary.
- An alternate source of heat (such as a wood or pellet stove) is optional and not considered in the design heating capacity calculation.

Ductless Mini-Split / Multi-Split ASHP:

- As ductless systems do not provide a method of circulating conditioned air to spaces where there is no indoor ASHP unit, a method of circulating air through the home to ensure all occupied spaces are receiving conditioned air may be beneficial. A "fully ducted" heat recovery ventilator / energy recovery ventilator (or some other method of circulating air between rooms) can assist in this regard.

Upon completing Step 6, you will have:

- ☐ Defined heat pump system control requirements and set-point values for the application.

STEP 7: DEFINE BACKUP HEATING REQUIREMENTS

In STEP 7 you will define the type of backup and the heating capacity required for the installation. The backup heating requirements for an ASHP installation are determined by four factors:

1. Whether or not the ASHP has been added-on to an existing heating system.
2. Whether or not the ASHP operation is restricted by either low-temperature cut-off limits or control strategies / settings (i.e., in STEP 6);
3. Whether or not the heating output of the ASHP is greater than the design heating load at the design temperature; and,
4. Whether or not the ASHP and backup heating system can operate simultaneously, or must operate in sequence, one at a time;

A decision tree based on these factors is provided in Figure 30 and maps the results to four different control strategies.

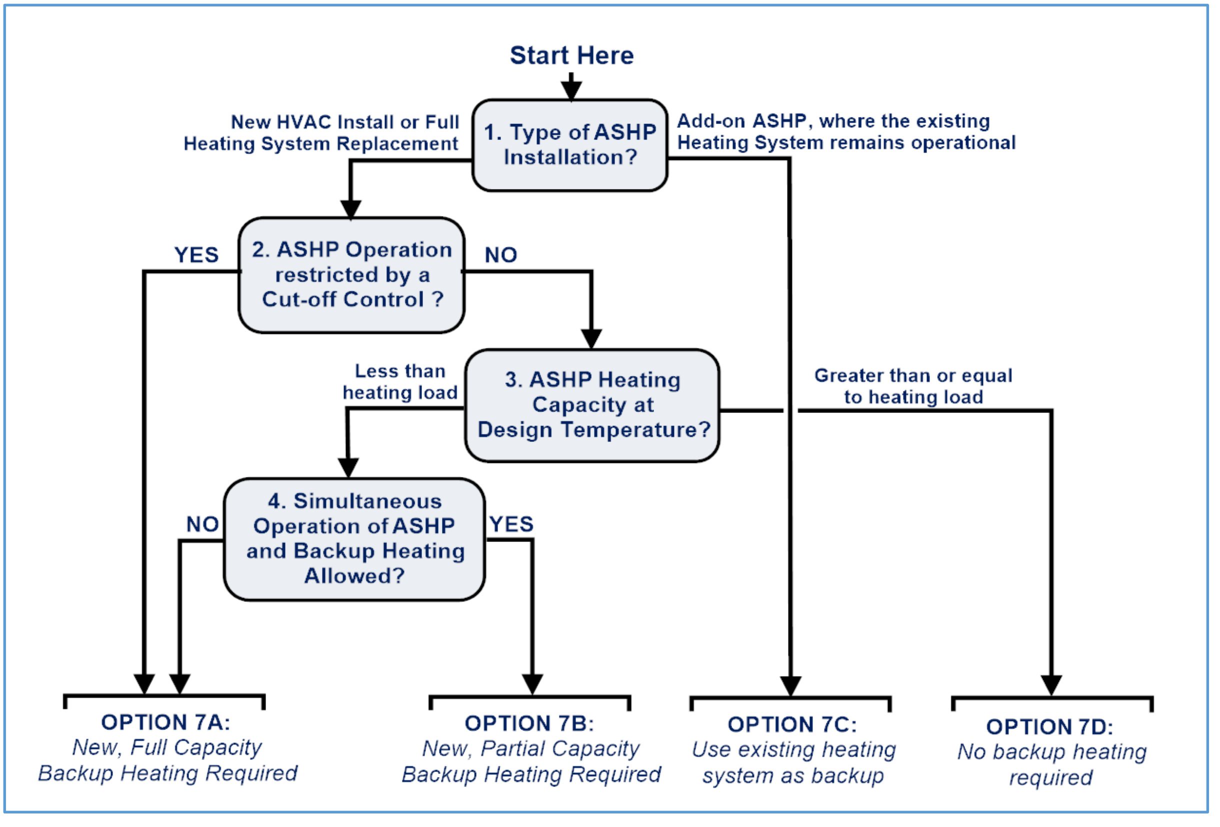


Figure 30: Decision Tree to determine the Backup Heating Requirements

Once you have determined the most appropriate backup option, circle the chosen option, and if new backup is required, indicate the minimum capacity and type of new backup heating needed (i.e., fuel or electric) on the **"ASHP Key Specifications Summary Worksheet".**

Option 7A: New, Full Backup Heating System Required

Typical Applications

New construction installations and full heating system replacements using:

- ASHPs with operating restrictions above the design temperature; or
- Unrestricted ASHPs sized to less than the design load, or backup heating that cannot operate simultaneously with the ASHP, for example:
  - *Centrally-ducted ASHP with fossil-fuel furnace backup.*

Option 7A Backup Capacity Requirements:

- Installation of new backup heating is required,
- Heating output of the backup system should equal or exceed 100% of the heating load of the house or targeted area at the design temperature.

Option 7B: New, Partial Backup Heating System Required

Typical Applications

New construction installations and full heating system replacements using:

- An unrestricted ASHP using control strategy 6B1, sized to less than the design load, and with backup heating that can simultaneously operate with the ASHP, for example,
  - *Centrally-ducted ASHP with electric resistance auxiliary heaters; or*
  - *A new installation of a ductless or ducted mini-split ASHP with supplemental hydronic or electric baseboard heaters.*

Option 7B Backup Capacity Requirements:

- Installation of new backup heating is required,
- Heating output of the ASHP plus the backup system should equal or exceed 100% of the heating load of the house or targeted area at the design temperature.

Option 7C: Use Existing Heating System as Backup; No New Backup System Required

Typical Applications

ASHP installations, where the original full capacity heating system remains intact and operational, that use:

- Restricted or unrestricted ASHPs sized to less than the design load, for example,
  - *Ductless or mini-ducted add-on ASHP installations using one or more indoor units.*
  - *Centrally ducted ASHP replacing an air conditioner with fossil-fuel furnace backup (e.g., “hybrid” or “dual-fuel” systems)*

Option 7C Backup Capacity Requirements:

- No new backup heating is required,
- The existing, full capacity heating system will function as backup heating for the ASHP below the thermal balance point temperature or other control point defined by the system control strategy (see STEP 6).

Option 7D: No Backup Heating Required

Typical Applications

An installation using an unrestricted ASHP with a heating output greater than the design heating load. This can include:

- New construction installations or replacement systems using ductless or ducted mini-split ASHPs, and
- New construction installations of centrally-ducted ASHPs
- Replacement HVAC installations using centrally-ducted ASHPs where the heating capacity is less than the original system in order to stay within the maximum airflow limits of the existing duct system.
  - *The ASHP may not be less capacity than the design heat loss, if the original system was oversized, or if the home has been upgraded with energy retrofits, or both.*
  - *Design heat-loss calculations are recommended.*

Option 7D Backup Capacity Requirements:

- No backup heating installation is required.

Upon completing Step 7, you will have:

- ☐ Defined the backup heating capacity needed to supplement the ASHP equipment in order to satisfy the design heating load of the house or targeted area.

Appendix A: Determining the "Economic Cut-off Temperature" to Switch from ASHP Heating to Full Backup Heating

In applications where backup heating is supplied by a low-cost, fuel-based heating source, there may be times during the heating season when it is economically beneficial to switch to full backup heating even though the ASHP is still capable of delivering heating. In these situations the cost of heat delivered by the backup heating system is lower than the cost of heat delivered by the ASHP. This appendix gives you the necessary information to determine the outdoor temperature at which this *"economic cut-off" or "economic balance point temperature" (e-BPT)* should take place.

The e-BPT is determined by four factors:

1. **Consumption-based cost of electricity,** including energy, delivery and taxes, but excluding any fixed monthly customer and regulatory charges and other levies that do not vary with the amount of electricity used.
    a. Use a recent electricity bill to calculate the *consumption-based cost of electricity* in one of the following ways:
        i. For utilities with a single electricity rate ($/kWh) covering both energy and delivery, use this rate plus any applicable taxes and additional charges (e.g., rate riders) that are based on usage to calculate a consumption-based cost of electricity.
        ii. For utilities with multiple steps / tiers of electricity rates ($/kWh) covering both energy and delivery, use the highest rate-step / tier that will most likely apply when the ASHP is operating, plus any applicable taxes and additional charges (e.g., rate riders) that are based on usage to calculate a consumption-based cost of electricity.
        iii. For utilities where electricity delivery and regulatory costs are shown separately (such as in the province of Ontario), and include "distribution system loss-factor adjustments" and fixed costs that vary from utility to utility, it may be easier to calculate the consumption-based delivery and regulatory costs based on "kWh usage" and add this rate to the energy commodity rates, that are shown on the bill, together with any applicable taxes. This will require going to the utility website to determine the value of fixed charges (*Customer Charge ($ per billing period); Standard Supply Service Rate ($ per month)*) that apply to the particular utility (see example for details).
2. **Consumption-based cost of fuel,** including energy, delivery and taxes, but excluding any fixed monthly charges that do not vary with the amount of fuel used.
    a. Fixed customer charges normally appear on the fuel bill (e.g., *Customer Charge of $20.00; Basic Charge of $14.00*)
    b. Use a recent fuel bill to calculate the consumption-based cost of fuel by subtracting the fixed charges (including any applicable taxes) from the bill and then dividing the remaining balance (including taxes) by the total number of fuel units used (e.g., m^3 or GJ) in the billing period to get a fuel cost rate (see example for details).
3. **Efficiency of the backup heating system** (e.g. AFUE), and
4. **Coefficient of performance (COP**) of the ASHP, which decreases with outdoor temperature.

EXAMPLE: Calculating Consumption-based Electricity Costs for Utilities in Ontario

Your Electricity Charges

Electricity
Electricity provided by Alectra Utilities as Standard Supply Service

Time of Use - Winter	
On-peak 218.000 kWh at $0.132 per kWh	28.78
Mid-peak 199.000 kWh at $0.095 per kWh	18.91
Off-peak 720.000 kWh at $0.065 per kWh	46.80
Delivery	67.75
Regulatory	5.09
Debt Retirement Charge	0.00
Your Total Electricity Charges	**167.33**
H.S.T. (Reg#728604299 RT0001)	**21.75**
8% Provincial Rebate	13.39CR
Total Current Bill (for information only)	**$175.69**

Compare your daily usage

Read Date	kWh Usage
09 FEB 18	1,137
10 DEC 17	982
10 OCT 17	1,032
09 AUG 17	1,138
08 JUN 17	852
10 APR 17	1,004
08 FEB 17	1,156
09 DEC 16	942
11 OCT 16	1,244
09 AUG 16	1,305
08 JUN 16	897
10 APR 16	1,088
08 FEB 16	1,146
08 DEC 15	981
08 OCT 15	1,042

kWh / day: 0 5 10 15 20 25 30

From the Utility Website, fixed costs are: **Delivery** - *Customer Charge ($40.56 per month); and* **Regulatory** - *Standard Supply Service Rate ($0.25 per month)*.

Over the 2-month billing period, the consumption-based delivery and regulatory costs are:

= ($67.75 – $40.56) + ($5.09 – ($0.25 x 2)) = $31.78

The Consumption-based Delivery and Regulatory rate is: $31.78 / 1,137 kWh used = $0.028 / kWh

Consumption-based time of use (TOU) Electricity Rates, including delivery & regulatory charges are:

On-Peak: ($0.132 + $0.028) plus 13% HST, minus 8% Provincial Rebate = $0.160 x 1.05 **= $0.168 / kWh**

Mid-Peak: ($0.095 + $0.028) plus 13% HST, minus 8% Provincial Rebate = $0.123 x 1.05 **= $0.129 / kWh**

Off-Peak: ($0.065 +$ 0.028) plus 13% HST, minus 8% Provincial Rebate = $0.093 x 1.05 **= $0.098 / kWh**

EXAMPLE: Calculating Consumption-based Natural Gas Costs

Charges For Natural Gas

Feb 09, 2018 - Mar 12, 2018

Customer Charge	$20.00
Delivery to You	45.90
Transportation to Enbridge	18.43
Gas Supply Charge	34.22
Cost Adjustment	1.39
Charges for Natural Gas	**119.94**

Meter Reading Information

Meter Number		**123456**
Estimated Reading	Mar 12,18	7594
Previous Reading	Feb 09,18	7256
Gas used this period (m³)		338
PEF Value		1.00400
Adjusted m³		339

Your bill is based on either actual metered consumption or estimated consumption.

Consumption-based Natural Gas Cost:

= ($119.94 - $20.00) plus 13% HST divided by 339 m^3 = $99.94 x 1.13 / 339 **= $0.333 / m^3**

Determining the e-BPT is a two-step process:

a. **Determine the minimum required coefficient of performance (COP_{min})** for the cost of heating from the ASHP to equal the cost heating from the backup system, and
b. **Determine the outdoor temperature corresponding the COP_{min} value** for the specific ASHP system being used. This outdoor temperature will be defined as the *"economic cut-off temperature"*.

a. Determining the minimum required COP

The minimum coefficient of performance (COP_{min}) occurs when the cost of heat from the ASHP and the backup heating system are equal as described by the following relationship.

$$\frac{Variable\ Cost\ of\ Electricity}{COP_{min}} = \frac{Variable\ Cost\ of\ Fuel}{Efficiency_{backup}}$$

Rearranging and isolating COP_{min}, results in:

$$COP_{min} = \frac{Variable\ Cost\ of\ Electricity \times Efficiency_{backup}}{Variable\ Cost\ of\ Fuel} \times Conversion\ Factor$$ *[Equation 6]*

Cost of fuel units, energy content and associated conversion factors are provided in Table 8. The conversion factor is needed to convert the fuel units into kWhs, and is numerically the higher heating value of the fuel in kWh per unit of fuel (e.g., Natural Gas: 10.36 kWh/m^3)

Table 8: Common Backup Fuels with Conversion Factors for use in the COP_{min} Equation

Backup Fuel	Higher Heating Value	Cost of Fuel Units	Conversion Factors for Equation 6 (kWh per unit of fuel)
Natural Gas	37.3 MJ / m^3	$ / m^3	10.36
Natural Gas	37.3 MJ / m^3	$ / GJ	277.8
LPG / Propane	25.3 MJ / litre	$ / litre	7.03
Heating Oil	38.2 MJ / litre	$ / litre	10.61

EXAMPLE: Calculating COP_{min} for an installation using natural gas for backup heating.

Consumption-based Cost of Electricity is $0.10 / kWh

Consumption-based Cost of Natural Gas is $0.333 / m^3 (equivalent to $8.93 / GJ);

(NOTE: Both the electricity and fuel prices include energy and delivery costs and taxes, but exclude fixed monthly charges that do not vary with the amount of electricity or natural gas consumed).

The natural gas furnace has an efficiency (AFUE) rating of 95%.

Conversion Factor is 10.36 kWh / m^3 *(from Table 8)*

Using equation 6:

COP_{min} = 0.10 x 0.95 / 0.333 x 10.36
= 3.0

In this example, the minimum COP for the ASHP to provide lower cost heating than the backup heating system is about 3.0.

A graphic alternative to determining COP_{min} in provided in Figure 31 for natural gas. To use this chart, project the consumption-based cost of electricity, shown on the vertical axis, as a horizontal line, and the consumption-based cost of natural gas divided by the furnace efficiency (i.e., AFUE), shown on the horizontal axis, as a vertical line. Where the two lines cross will indicate the COP_{min} value shown by the sloped lines on the chart.

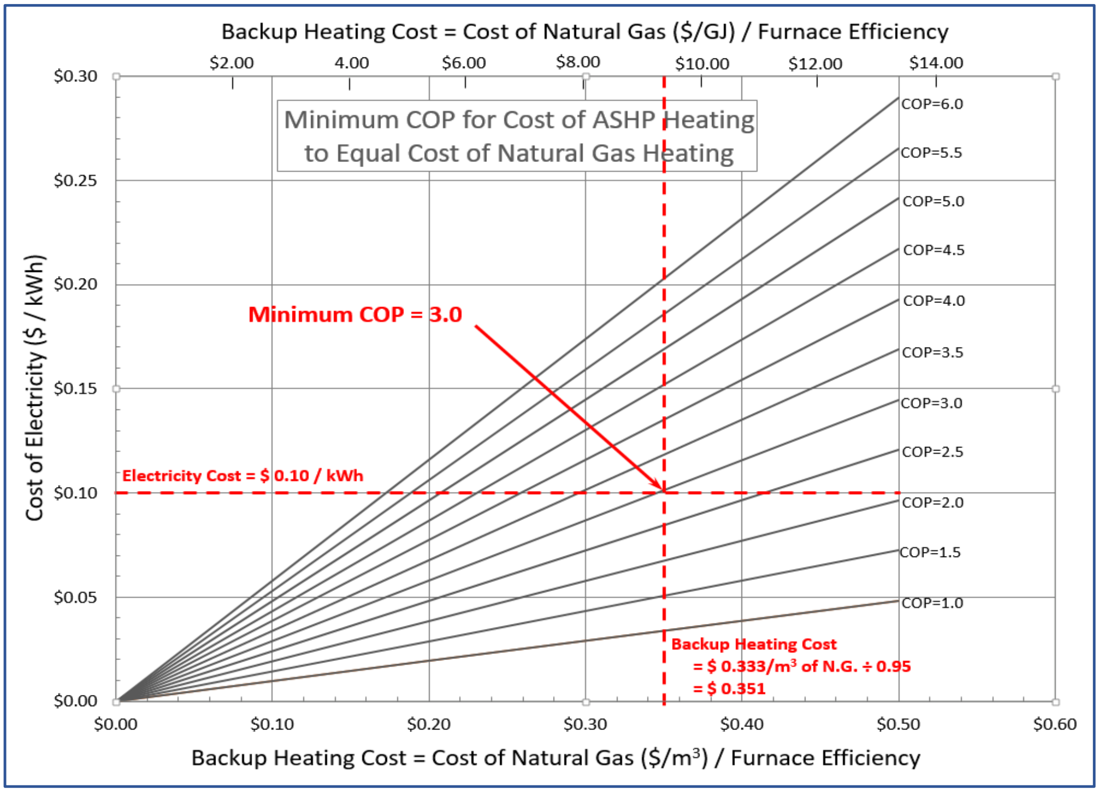


Figure 31: Chart for determining Minimum COP for ASHP Heating Cost to Equal Natural Gas Heating Cost

The example shown in Figure 31 estimates a COP_{min} value of 3.0 which is the same as the value calculated using equation 6.

NOTE TO DESIGNERS AND CONTRACTORS: Use of LPG/propane or Fuel Oil for Backup

In most instances, the cost of LPG/propane or fuel oil is high enough to result in backup heating costs that are higher than ASHP heating costs even at relatively low outdoor temperatures.

Switching to LPG / propane or fuel oil heating will typically be based on the need for additional heating capacity rather than the cost of heat from the ASHP.

As a result, no economic cut-off control is normally required when using LPG/propane or fuel oil for backup heating. Switching from ASHP heating to backup heating will be handled by the normal staging controls of the heating system.

Example: Electricity cost of $0.17 / kWh; LPG / propane cost of $0.90 / L; Furnace AFUE of 95%.
Conversion Factor for LPG/ Propane is 7.03 kWh / L *(from Table 8)*

Using Equation 6:

$$\mathbf{COP_{min}} = \$0.17 \times 0.95 / \$0.90 \times 7.03 = \mathbf{1.3}$$

An ASHP will provide lower cost heating than the propane furnace down to a COP of 1.3

Time of Use Electricity Rates

In region of the country with time-of-use electricity rates, the required minimum COP for ASHP heating to equal the cost of Natural Gas heating will vary with the electricity rate periods as illustrated in Figure 32.

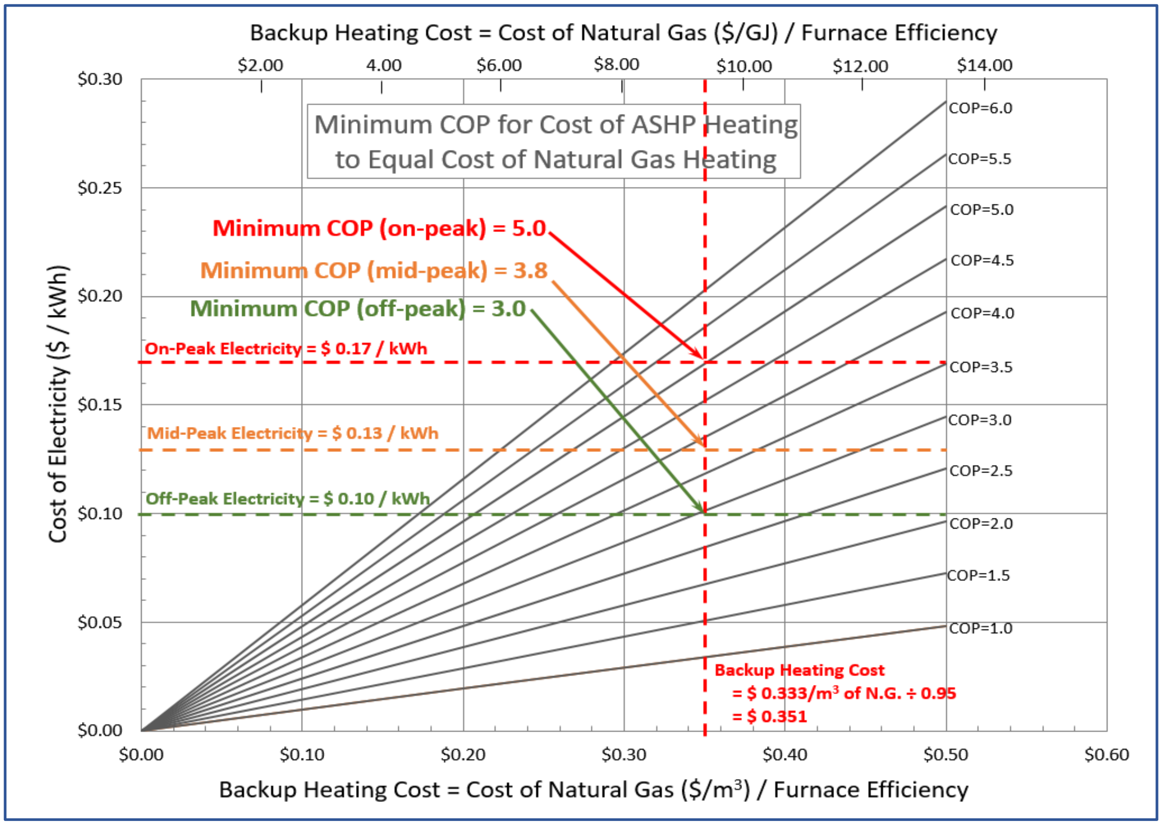


Figure 32: Example of determining Minimum COP for ASHP Heating Cost to Equal Natural Gas Heating Cost with Time-of-Use (TOU) Electricity Rates

In this example the electricity rates vary with the time-of-day and day of week with on-peak, mid-peak and off-peak electricity cost so $0.17, $0.13 and $0.10 per kWh respectively. These prices include energy and delivery costs and taxes, but exclude fixed monthly charges that do not vary with the amount of electricity consumed. The cost of natural gas is $0.333 per cubic metre which includes energy and delivery costs and taxes, but excludes fixed monthly charges that do not vary with the amount of fuel consumed. The natural gas furnace has an AFUE (efficiency) of 95%.

The minimum ASHP COP values needed to product heating at a cost equal to that of the natural gas backup furnace are:

- On-peak periods, COP_{min} = 5.0;
- Mid-peak periods, COP_{min} = 3.8;
- Off-peak periods, COP_{min} = 3.0.

b. Determine the Outdoor Temperature when COP_{min} occurs

Once the COP_{min} value has been determined, refer to either a chart or table of COP values versus outdoor temperature from the heat pump manufacturer for the model of ASHP being used to determine the outdoor temperature corresponding to the COP_{min} value. The ASHP will deliver heating that is lower cost than the cost of heat from the backup heating system at outdoor temperatures that are above this value.

Table 9 shows an example of an extended performance table for a 2-ton, single-stage, centrally ducted air source heat pump. Do not use “Rated” values of COP as they are typically higher than actual performance data indicates.

Table 9: Example of Extended Performance Data for an ASHP Showing COP versus Outdoor Temperature

	OUTDOOR AMBIENT TEMPERATURE															
	65	60	55	50	47	45	40	35	30	25	20	17	15	10	5	0	-5
MBh	30.74	28.63	26.55	24.50	**23.20**	22.20	19.70	17.43	15.59	14.20	13.16	12.60	11.89	10.13	8.36	6.59	4.83
T/R	32.7	30.5	28.3	26.1	24.7	23.6	21.0	18.6	16.6	15.1	14.0	13.4	12.7	10.8	8.9	7.0	5.1
kW	1.97	1.93	1.88	1.84	**1.81**	1.79	1.75	1.70	1.66	1.61	1.57	1.54	1.52	1.48	1.43	1.39	1.34
Amps	9.1	8.4	7.8	7.2	6.9	6.7	6.3	5.9	5.6	5.3	5.0	4.8	4.7	4.4	4.1	3.7	3.3
COP	4.57	4.36	4.14	3.91	3.76	3.63	3.31	3.00	2.76	2.58	2.46	2.40	2.29	2.01	1.71	1.39	1.05

Economic Cut-off Temperature (e-BPT)

For ASHP systems using Control Strategies 6A2 or 6B2 in STEP 6, the outdoor temperature corresponding to the COP_{min} value is also the e-BPT.

Using the example of a COP_{min} value equal to 3.0, the e-BPT is 35°F (2°C) for this particular ASHP model.

- The cut-off control installed in the system would be set to restrict ASHP operation to outdoor temperatures above 35°F (2°C).

Economic Cut-off Temperature (e-BPT) with time-of-use rates

With time-of-use electricity rates there will be multiple COP_{min} values, each corresponding to a different e-BPT.

Using COP values for the example ASHP shown in Table 9:

- **On-peak periods, COP_{min} = 5.0,**
  Restrict ASHP operation at all outdoor temperatures (i.e., do not operate during on-peak);
- **Mid-peak periods, COP_{min} = 3.8,**
  Restrict ASHP operation to outdoor temperatures above 47°F (8°C) during mid-peak;
- **Off-peak periods, COP_{min} = 3.0,**
  Restrict ASHP operation to outdoor temperatures above 35°F (2°C) during off-peak.

The cut-off control installed in this system would be set to restrict ASHP operation to these outdoor temperatures and times-of-day and days-of-week corresponding to the different rate periods.

Economic Cut-off Temperature (e-BPT) with a 2-stage or Variable Capacity ASHPs

Table 10 shows an example of an extended performance tables for a 3-ton, variable capacity, centrally ducted heat pump. The top half of the table shows performance values for the ASHP operating at the highest capacity / stage, while the bottom half of the table show performance values when operating at the lowest capacity / stage.

Table 10: Example of Extended Performance Data for a Variable-Capacity ASHP Showing COP versus Outdoor Temperature

Expanded Heating Data – High Stage

	Outdoor Ambient Temperature																	
	65	60	55	50	47	45	40	35	30	25	20	17	15	10	5	0	-5	-10
MBh	44.0	41.7	39.2	36.6	35.0	33.9	31.5	29.1	35.9	33.1	30.5	28.8	27.7	24.9	22.1	19.2	16.4	13.4
T/R	35.0	33.2	31.2	29.2	27.9	27.0	25.1	23.1	28.6	26.4	24.3	22.9	22.1	19.8	17.6	15.3	13.1	10.7
kW	2.66	2.61	2.56	2.51	2.48	2.46	2.41	2.36	3.97	3.87	3.77	3.72	3.68	3.58	3.48	3.39	3.29	3.19
Amps	10.8	10.5	10.3	10.1	10.0	9.9	9.7	9.4	16.4	16.0	15.6	15.3	15.2	14.7	14.3	13.9	13.5	13.1
COP	4.84	4.67	4.49	4.28	4.14	4.04	3.83	3.61	2.65	2.51	2.37	2.27	2.21	2.04	1.86	1.67	1.46	1.24
HI PR	389	373	358	343	335	328	316	303	290	277	266	260	255	245	236	226	218	210
LO PR	146	136	127	117	110	106	98	87	78	70	62	57	55	47	40	34	30	23

Expanded Heating Data – Low Stage

	Outdoor Ambient Temperature																	
	65	60	55	50	47	45	40	35	30	25	20	17	15	10	5	0	-5	-10
MBh	31.7	30.0	28.3	26.4	25.2	24.5	22.7	21.0	22.9	21.1	19.5	18.4	17.7	15.9	14.1	12.3	10.5	8.6
T/R	35.8	33.9	31.9	29.9	28.5	27.6	25.7	22.1	24.1	22.2	20.5	19.3	18.6	16.7	14.8	12.9	11.0	9.0
kW	1.53	1.50	1.47	1.45	1.43	1.42	1.40	1.37	2.01	1.97	1.92	1.90	1.88	1.84	1.79	1.75	1.70	1.66
Amps	6.3	6.2	6.1	6.0	5.9	5.9	5.8	5.6	8.3	8.1	8.0	7.8	7.8	7.6	7.4	7.2	7.0	6.8
COP	6.10	5.87	5.62	5.35	5.16	5.04	4.77	4.48	3.34	3.15	2.97	2.84	2.76	2.54	2.30	2.06	1.80	1.52
HI PR	377	361	347	332	324	318	306	293	281	268	258	252	247	238	229	219	211	204
LO PR	144	133	125	115	108	104	96	85	77	69	60	56	54	46	40	33	29	23

Since economic cut-off points will commonly occur at warmer temperatures, when the ASHP is primarily operating on the lowest capacity, it is suggested that the “low-stage” performance table be used to determine the e-BPT when using 2-stage or variable capacity ASHPs.

Using the example of a COP_{min} value equal to 3.0, the e-BPT is about 25°F (-4°C) for this particular variable capacity ASHP model.

- The cut-off control installed in the system would be set to restrict ASHP operation to outdoor temperatures above 25°F (-4°C).

Appendix B: ASHP Key Specifications Summary Worksheet

Project or Client Name: ______ Date Completed: ______

COMPLETION INSTRUCTIONS: Select Required Option(s) in each STEP. Provide information in shaded boxes as necessary

Key ASHP Requirements	Option A	Option B	Option C	Option D	NOTES
1 Define ASHP Configuration	1A: Centrally Ducted:	1B: Ductless Mini-split, Single-Zone No. of outdoor units: ______	1C: Ductless Mini-split, Multi-Zone No. of outdoor units: ______		☐ New Home Install ☐ Full System Replacement ☐ Add-on ASHP
2 Choose Mini-split Indoor Unit Type(s)	2A: Wall-Mounted: No. of units required: ______	2B: Floor Mounted: No. of units required: ______	2C: Ceiling Mounted: No. of units required: ______	2D: Ducted (concealed): No. of units required: ______	NOTE: ONLY COMPLETE STEP 2 if using Option 1B or 1C
3 Determine Design Heating Load (DHL) and Design Cooling Load (DCL) Estimates	F280-12 Design values DHL: ______ Btu/h DCL: ______ Btu/h	Energy Audit Report Estimates Reported DHL: ______ Btu/h Adjusted DHL: ______ Btu/h Reported DCL: ______ Btu/h Adjusted DCL: ______ Btu/h	Energy Model Estimates of Design Loads DHL: ______ Btu/h DCL: ______ Btu/h	Existing Equipment Capacities: Heating (output): ______ Btu/h DHL estimate: ______ Btu/h Cooling (output): ______ Btu/h DCL estimate: ______ Btu/h	F280 Design temperatures for house location Heating: ______ °F Cooling: ______ °F
4 Determine Sizing Approach and Capacity Requirements of ASHP	4A: Emphasis on Cooling Target: 80% DCL: ______ Btu/h to to 125% DCL: ______ Btu/h **Single-stage:** Match output to target **Multi-stage:** Match maximum output to target	4B: Balanced Heating & Cooling Target: 80% DCL: ______ Btu/h to to 125% DCL: ______ Btu/h **Single-stage:** Match output to high end of target **Multi-stage:** Match minimum output to target	4C: Emphasis on Heating Target: Heating Load at: 17°F : ______ Btu/h	4D: Sized on Design Heating Load: Target: DHL: ______ Btu/h at ____°F (Design Temperature)	For FULL SYSTEM Replacements - Maximum Airflow capacity of existing ducting: ______ CFM
Identify & Select ASHP	**Candidate #1**	**Candidate #2**	**Candidate #3**	**Candidate #4**	**Final Choice:** ______
5 Identify candidate ASHP models matching Key Requirements	Model #: ______ Stages: ______; Cut-off: ____°F Nominal Cap: ______ Heat-output: ______ Btu/h at 17°F ☐ , or at ______°F Cool-output at 95°F: ______ Btu/h	Model #: ______ Stages: ______; Cut-off: ____°F Nominal Cap: ______ Heat-output: ______ Btu/h at 17°F ☐ , or at ______°F Cool-output at 95°F: ______ Btu/h	Model #: ______ Stages: ______; Cut-off: ____°F Nominal Cap: ______ Heat-output: ______ Btu/h at 17°F ☐ , or at ______°F Cool-output at 95°F: ______ Btu/h	Model #: ______ Stages: ______; Cut-off: ____°F Nominal Cap: ______ Heat-output: ______ Btu/h at 17°F ☐ , or at ______°F Cool-output at 95°F: ______ Btu/h	Heat-output: ______ Btu/h at 17°F ☐ , or at ______°F Low Temp. Cut-off: ______°F Cooling at design: ______Btu/h BP Temperature: ______°F %Total Heating above BPT: ______ % of total
Control Strategy	**Option A (ASHP cut-off above design T)**	**Option B (ASHP cut-off below design T)**	**Option C (ASHP cut-off below design T)**		**NOTES**
6 Define Control Strategy	ASHP Cut-off Control required 6A1: Low-Temp cut-off at:____°F 6A2: Economic cut-off at:____°F	No ASHP Cut-off Control required 6B1: Heat pump may operate over full outdoor temperature range ASHP Cut-off Control required: 6B2: Economic cut-off at: ____°F	No Backup Heat 6C: Heat pump is Sole Heat Source (No ASHP Cut-off Control required)		
Back-up Heating	**Option A**	**Option B**	**Option C**	**Option D**	**NOTES**
7 Define Backup Heating Requirements	7A - New required at > 100% DHL Minimum of: ______ Btu/h	7B - New required < 100% DHL Minimum of: ______ Btu/h	7C - No new Backup required (use existing heating system for backup heating)	7D - No Backup Required (ASHP output is greater than the design heating load at the design temperature)	NEW Backup Type: ☐ Fuel: ______ ☐ Electric: ______