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Addendum to the AIR-SOURCE HEAT PUMP SIZING AND SELECTION GUIDE

8 Worked Examples of Ducted and Ductless ASHP Applications

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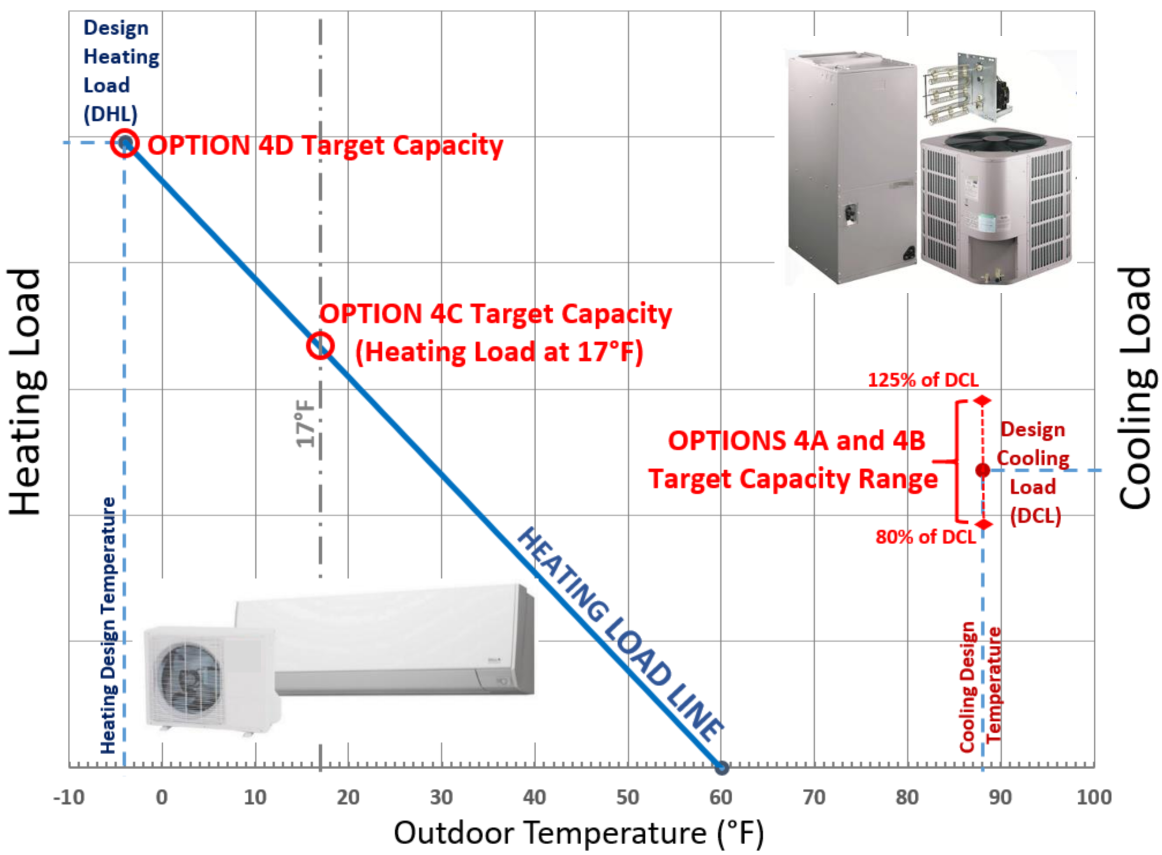

Canada

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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: 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-capacity 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 SIZING 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).

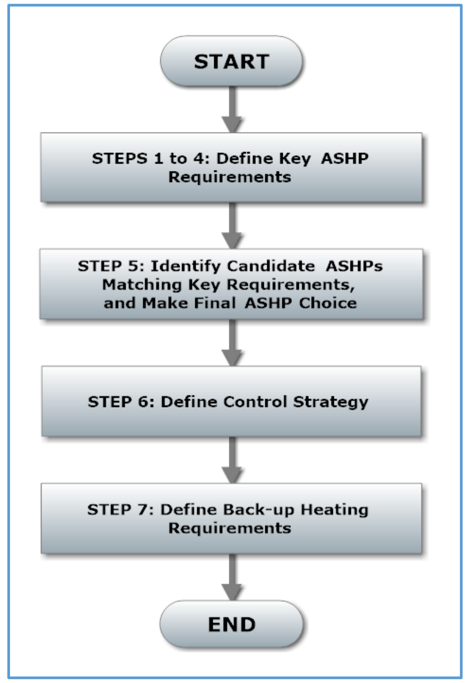


Figure 1: Overview of the ASHP Selection and Sizing Process

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”, available as a separate PDF download;
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, (i.e., this document).

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.

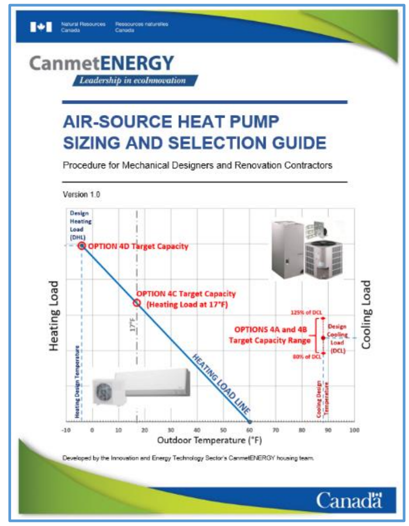
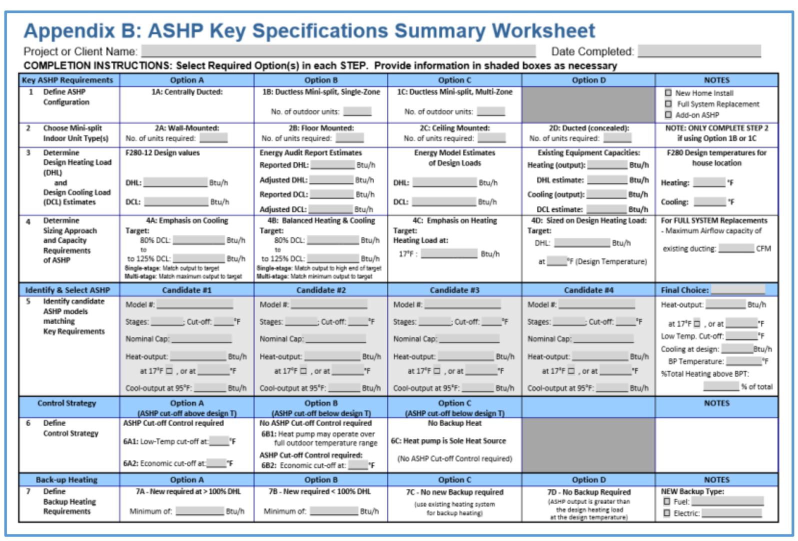


Figure 2: Air-Source Heat Pump Selection and Sizing Guide

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.

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

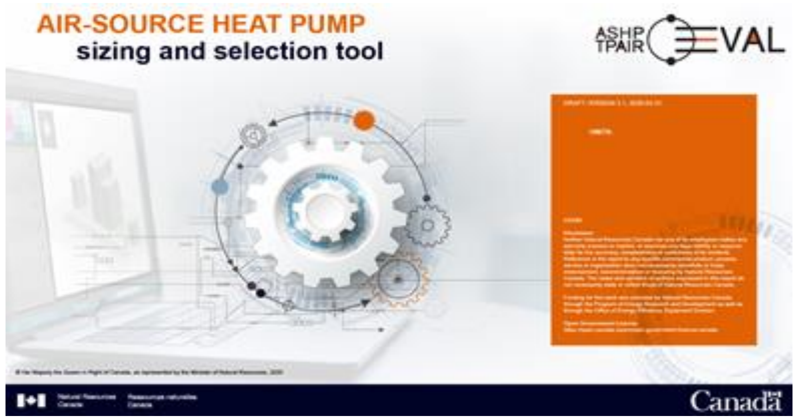


Figure 4: ASHP Selection and Sizing Spreadsheet Tool

- 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.

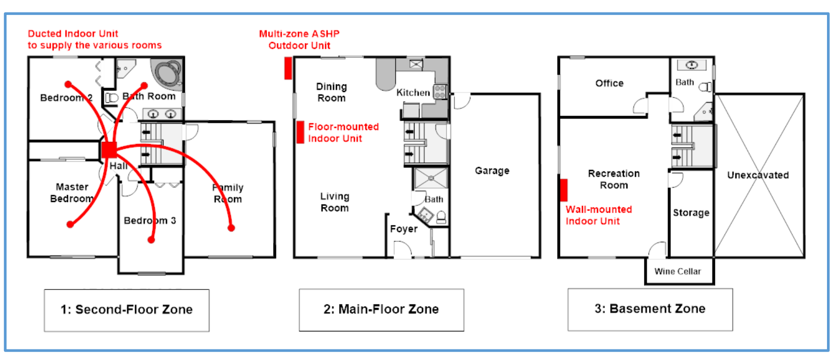


Figure 5: "Worked Example" – Mini-split, Multi-zone, Add-on ASHP

Example A1: Full System Replacement: Replacing a Furnace and A/C with a Furnace and ASHP ("Hybrid / Dual-Fuel" System) using "Sizing Option A" (Sized for Cooling)

Background

An existing house has a central forced-air heating system that consists of a standard efficiency natural gas furnace and a central air conditioner. Both need to be replaced.

The client is interested in installing a high-efficiency natural gas furnace with an air-source heat pump to primarily provide cooling and allow some heating in shoulder seasons when the cost of heat from the heat pump is lower than the cost of heat from the natural gas furnace.

The house location has design temperature conditions of -4°F (-20°C) for heating and 88°F (31°C) for cooling.

STEP 1: Define ASHP Configuration

Use **OPTION 1A: Centrally Ducted ASHP**

STEP 2: Skip Step 2 when using **OPTION 1A: Centrally Ducted ASHP**

STEP 3: Determine Design Heating and Cooling Load Estimates

The house has had an Energy Audit completed and the report is available from the homeowner. None of the recommended upgrades have been made to the home or HVAC system since the audit was done.

Use **Option 3B: Energy Audit Load Estimates.**

The audit report 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 and its design cooling load would be 23,519 Btu/h (2.0 tons).*

Since the upgrades were not implemented, the reported design heating load (DHL) will need to be adjusted to back out the assumed building envelope improvements. The reported design cooling load (DCL) will not need to be adjusted. The report also states:

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

This means the reported design heating load in the audit report is 88% of the actual value (i.e. 100% minus the 12%). Therefore, the actual design heat loss for the house is equal to:

Design Heating Load = 43,641 Btu/h / 0.88 = 49,592 Btu/h

Based on the audit report, the house has estimated design loads of about:

Heating (DHL): 49,600 Btu/h at a design temperature of -4°F (-20°C);

Cooling (DCL): 23,500 Btu/h at a design temperature of 88°F (31°C).

Calculated maximum airflow capacity of existing duct system:

The existing supply ducting has four supply trunks / ducts off the furnace plenum:

- One rectangular at 8 inches deep by 22 inches wide.
- Two round at 6-inch diameter, and
- One round at 5-in diameter.

Using equations 1a and 2a from the Guide:

$$\textbf{Maximum Airflow Capacity (CFM)} = (8 \times 22) \times 6.25 + (6^2 + 6^2 + 5^2) \times 4.91 = 1576 \textbf{ CFM}$$

The maximum airflow capacity of the existing duct system is estimated as 1,576 CFM.

STEP 4: Determine Sizing Approach and Capacity Requirements of ASHP

The most appropriate option is:

- **OPTION 4A: Emphasis on Cooling**, and
  Sizing Criteria: 80% to 125% of design cooling load; (DCL is 23,500 Btu/h at 88°F (31°C))
- **Target Cooling Capacity Range** is cooling of 18,800 Btu/h to 29,400 Btu/*h* *[equation 3]*

STEP 5: Identify and Select ASHP Matching Key Requirements

The contractor has screened a number of possible ASHP systems and has identified three centrally ducted heat pumps for the application, with cooling capacities that fall within the **Target Cooling Capacity Range**. These are listed in Table 1 with the manufacturer's data showing cooling capacities at an outdoor temperature of 95°F (35°C).

Note that cooling capacities at 95°F (35°C) outdoor temperature may be used for initial screening purposes as this information is commonly available in manufacturers' summary listings. If extended performance data is available, use capacity ratings at an outdoor temperature close to the design temperature for the site.

Table 1: Manufacturers' Performance Data for Candidate Centrally-ducted Heat Pumps using "Sizing Option A"

Model	Number of Stages	Nominal Capacity (tons)	High / Low Cooling Capacity at 95°F (Btu/h)	High / Low Heating Capacity at 47°F (Btu/h)	High / Low Heating Capacity at 17°F (Btu/h)	High / Low Cooling Airflow (CFM)
ASHP1-CD-24-1	1-stage	2.0	22,400	23,200	12,600	800
ASHP2-CD-24-2	2-stages	2.0	High: 22,200 Low: 16,700	High: 24,000 Low: 16,600	High: 15,000 Low: 10,500	High: 875 Low: 637
ASHP3-CD-24-V	Variable capacity	2.0	High: 22,300 Low: 14,700	High: 23,600 Low: 13,700	High: 15,200 Low: 8,800	High: 720 Low: 540

Note: Indoor Conditions: 75ºF (24°C) dry bulb temperature and 63°F (17°C) wet bulb temperature

Using manufacturers' extended performance data, heating and cooling performance curves for the three possible ASHP systems are plotted in Figure 6 versus outdoor temperature together with the house load characteristics.

- The maximum cooling characteristics are very similar for the three different ASHPs.
- Airflow requirements for the three ASHP are well below the maximum airflow capacity of the existing duct system (i.e., 1,576 CFM).
- The heating characteristics for the 2-stage and variable capacity units are almost identical, with the single-stage unit output slightly less at outdoor temperatures below about 47°F (8°C)
- The thermal balance point temperatures (t-BPT) for the three 2-ton ASHPs are:
  - ASHP1: 37°F (3°C);
  - ASHP2: 35°F (2°C); and,
  - ASHP3: 34°F (1°C).

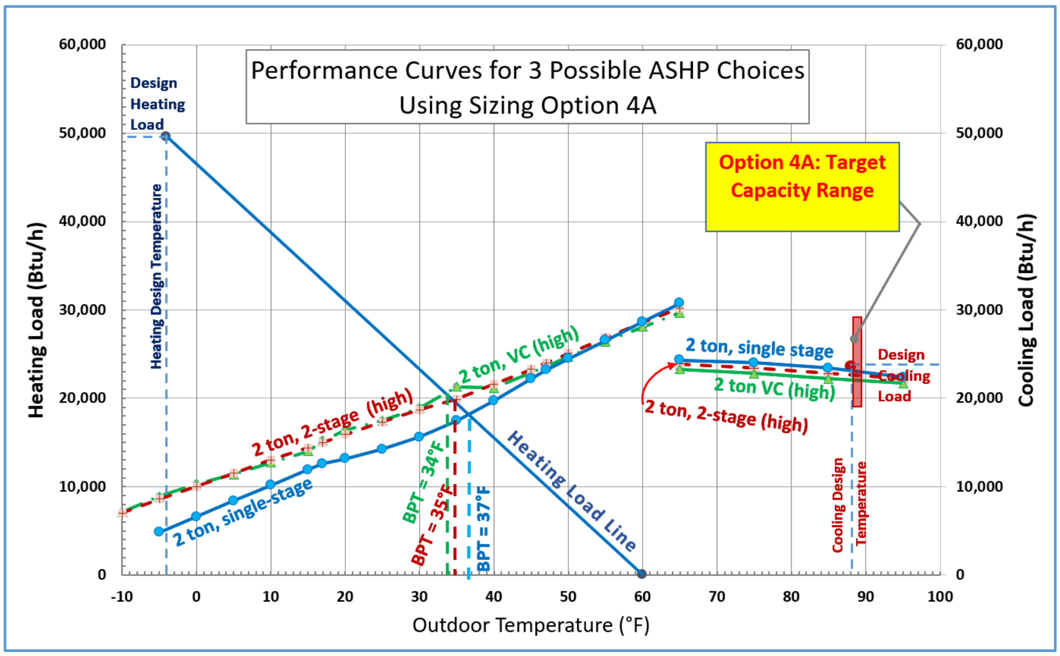


Figure 6: Performance Curves & Balance Point Temperatures for 3 ASHP Choices for Sizing Option 4A

Estimated Turn-down Ratios

The following analysis provides estimates of the turn-down ratios of the ASHPs being considered.

Using the high stage and low stage cooling capacities specified in the manufacturer's performance tables, the turn-down ratios for the ASHPs considered are:

- ASHP 1: N/A (single stage)
- ASHP 2: 22,200 / 16,700 = 1.33:1
- ASHP 3: 22,300 / 14,700 = 1.52:1

Estimated Annual Heating Fractions provided by the Candidate ASHPs

The following analysis provides estimates of the relative annual heating performance of each of the ASHPs under consideration.

- From the climate zone map (see Appendix 1 of this document) it is determined that the house is located in the “Cold-Humid” climate zone.

Using the thermal balance point temperature (t-BPT) for each system shown in Figure 6 the *“Fraction of Total Annual Heating”* that can be delivered above the t-BPTs were estimated for the “Cold-Humid” climate zone.

The results are summarized below:

ASHP1: 2.0-ton, single-stage;	t-BPT = 37°F (3°C)	Fraction of Annual Heating above t-BPT = 22%
ASHP2: 2.0-ton, two-stage;	t-BPT = 35°F (2°C)	Fraction of Annual Heating above t-BPT = 27%
ASHP3: 2.0-ton, variable capacity;	t-BPT = 34°F (1°C)	Fraction of Annual Heating above t-BPT = 30%

The fraction of total heating expected to be delivered above the thermal balance point temperatures ranges from 22% and 30%.

The client decided on **ASHP1,** the **2 ton, single-stage heat pump** on the basis of its lower first cost.

Heat Pump Performance Summary for the chosen model, ASHP1-CD-24-1

Cooling:

- Cooling output at design temperature is about 23,100 Btu/h, or 98% of the design load.

Heating:

- Thermal balance point temperature is about 37°F (3°C)
- Low-temperature cut-off is -5°F (-21°C), which is below the design temperature.
- The Fraction of Total Annual Heating provided by ASHP above the thermal balance point temperature is estimated at 22%.

STEP 6: Define the ASHP Control Strategy

Following the decision tree shown in Figure 7:

1. The chosen heat pump is shown as capable of operating to -5°F (-21°C), which is just below the design temperature of -4°F (-20°C).

2. The client has asked that the system control switch from ASHP heating to 100% backup heating whenever the cost of heat from the ASHP exceeds the cost of heat from the new high-efficiency natural gas furnace.

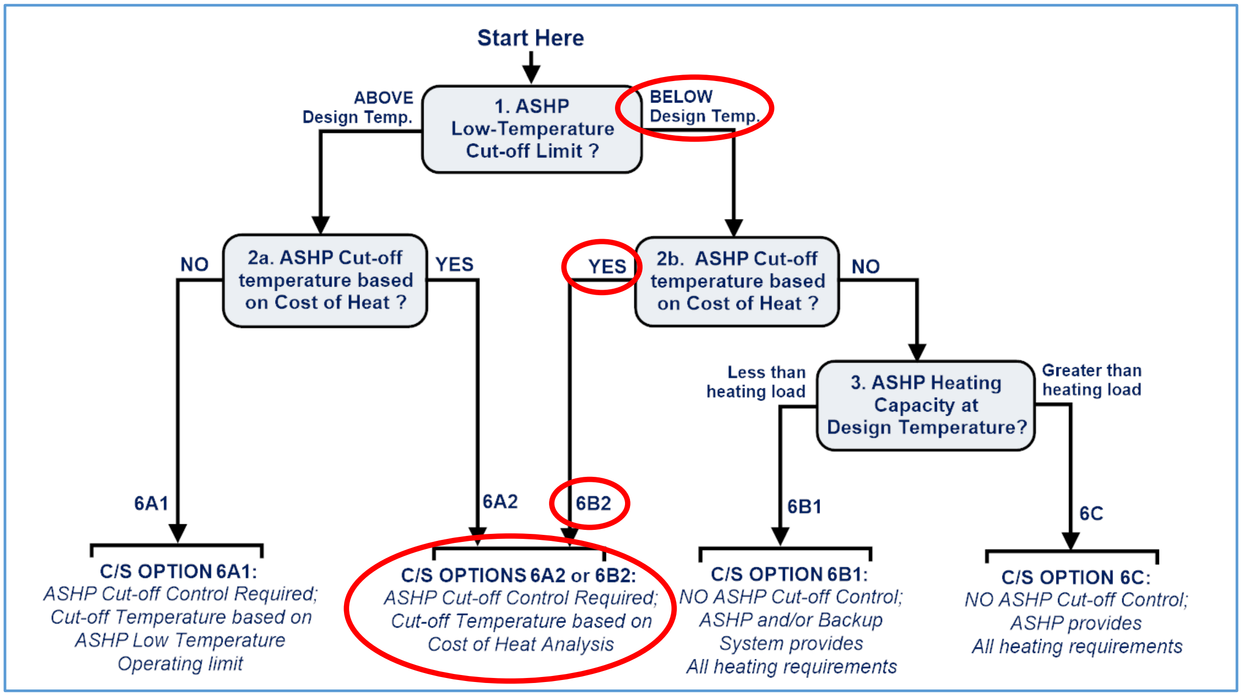


Figure 7: Decision Tree to Determine ASHP Control Strategy Option for Example A1

Control Strategy 6B2 is chosen with an *"economic cut-off"* or *"economic balance point temperature"* (e-BPT) to full backup heating based on an outdoor temperature. Refer to ***Appendix A*** *of the* ***"Air-Source Sizing and Selection Guide"*** for a full description of how to determine the *e-BPT*.

The following summarizes the information for this example:

- The variable cost of electricity delivered to the site is \$0.10 / kWh;
- The variable cost of natural gas delivered to the site is \$0.333 / m^3;
- The efficiency (i.e., AFUE) of the new natural gas furnace is 95%; and,
- The conversion factor for natural gas is 10.36 kWh / m^3.

Using Equation 6 from the Guide, a COP_{min} value is determined for the ASHP as:

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

COP_{min} equals \$0.10 / kWh times 0.95 divided by \$0.333 / m^3 times 10.36 kWh / m^3

COP_{min} equals 3.0

Using the manufacturer's extended performance tables for the 2-ton ASHP selected in STEP 5, it is determined that the ASHP will have a COP of 3.0 or more at outdoor temperatures of 35°F (2°C) or warmer. (Refer to Appendix A in the Guide for details).

The "economic balance point temperature (e-BPT)" would be set within the ASHP controls to disable ASHP operation at outdoor temperatures below 35ºF (2°C). Below this temperature all heating will be provided by the natural gas furnace.

- With a centrally ducted "hybrid" or "dual-fuel" system, the ASHP and fuel-based furnace cannot operate simultaneously, but rather are operated in sequence, one at a time.
- A single, multi-stage indoor thermostat sequences the operation of both the ASHP and natural-gas furnace.
    - *At outdoor temperatures above the e-BPT, the thermostat will first bring on the ASHP to satisfy a "heating call", and only turn off the ASHP and bring on natural gas furnace backup heating if the "heating call" cannot be satisfied by the ASHP.*
    - *At outdoor temperatures below the e-BPT, ASHP operation is disabled, and the thermostat will bring on the natural gas furnace to satisfy the heating call.*

STEP 7: Define Back-up Heating Requirements

Since the old HVAC system is being removed, a NEW backup heating system is required.

Backup heating will be provided by a high efficiency, natural gas furnace that will be controlled by a multi-stage thermostat which will turn the heat pump OFF when the furnace is operating.

Following the decision tree shown in Figure 8:

1. **Type of Installation**: Full heating system replacement;
2. **ASHP Operation Restricted at Low Temperature:** Yes, ASHP restricted by chosen control strategy *(i.e., Option 6B2).*

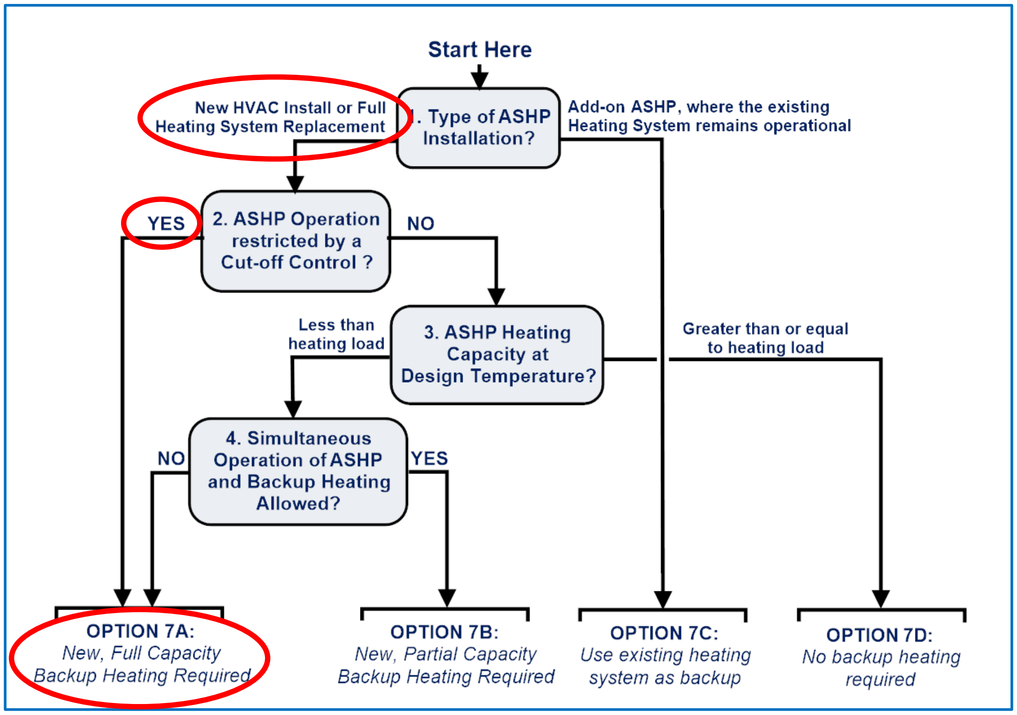


Figure 8: Decision Tree to Determine the Backup Heating Requirements for Example A1

Back-up Heating Option 7A is required.

- The output capacity of the furnace must equal or be greater than 100% of the design heat load (DHL) value of 49,600 Btu/h, and be capable of supplying an airflow of 800 CFM needed by the ASHP at the operating static pressure of the existing duct system.

The natural gas furnace chosen is a 60,000 Btu/h input furnace with an AFUE of 95%. Output capacity is 57,000 Btu/h, or 115% of the design heating load of the house. The furnace has a maximum airflow rating of 1,200 CFM which will be able to deliver the airflow required by the chosen ASHP.

Example A2: ASHP Add-on: Single-Zone Ductless Add-On to an Electric Baseboard & Wood Stove Heating System using “Sizing Option A” (Sized for Cooling)

Background

An existing 2-storey house has an electric baseboard heating system and no air conditioning. Some space heating is also provided by a wood stove, which is used during the coldest periods of the heating season.

The client is interested in installing one or more ductless air-source heat pumps (ASHP) to primarily provide cooling and allow for some heating in shoulder seasons when the wood stove is not being used. The baseboard heating system will remain functional and provide backup heating for the ASHP.

The house location has design temperature conditions of -4°F (-20°C) for heating and 88°F (31°C) for cooling.

STEP 1: Define ASHP Configuration

The house floor plan is shown below. The key occupied areas within the home are the main floor kitchen and family room, and the master suite/on-suite bath room and office on the second floor. These two areas are the target areas for the ASHP installation.

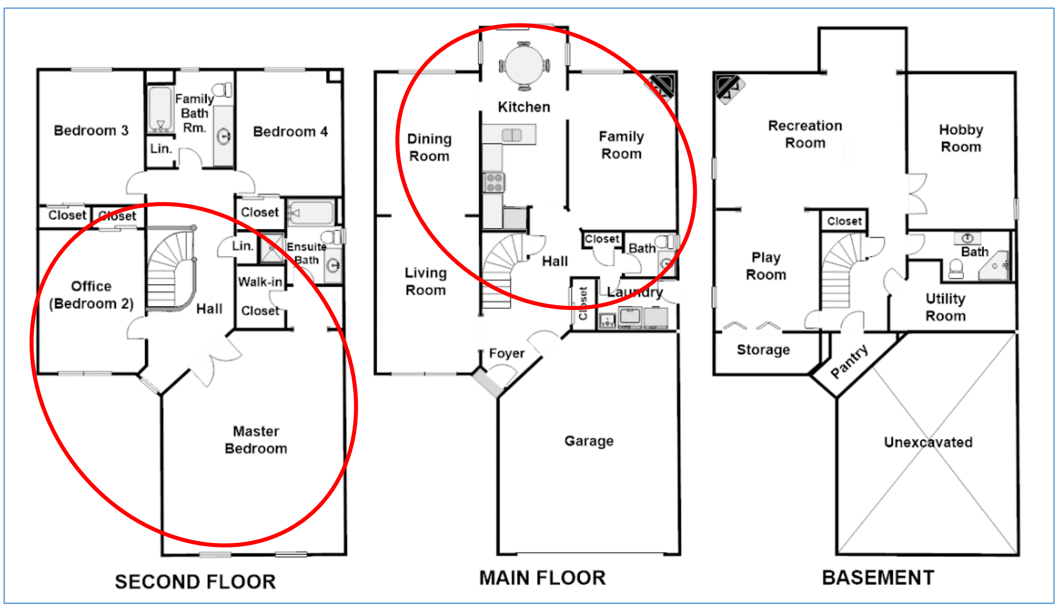


Figure 9: Two-storey house floor plans with Targeted Areas circled

Use **OPTION 1B**: Ductless Mini-split, Single-zone, Add-on ASHPs

- **Two units required:** one for the main-floor target area and another for the second-floor target area.

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

The indoor unit types selected to service the two target areas are:

- The second-floor area will use a compact ducted unit (Option 2D) installed in the attic space near the attic access hatch and will be ducted to the various rooms as shown in Figure 10.
- The main-floor area will use a wall-mount unit (Option 2A) installed on the exterior wall of the family room to service primarily the family room and kitchen. Some heat will circulate to the dining room and living room through the open doorways that link the rooms.

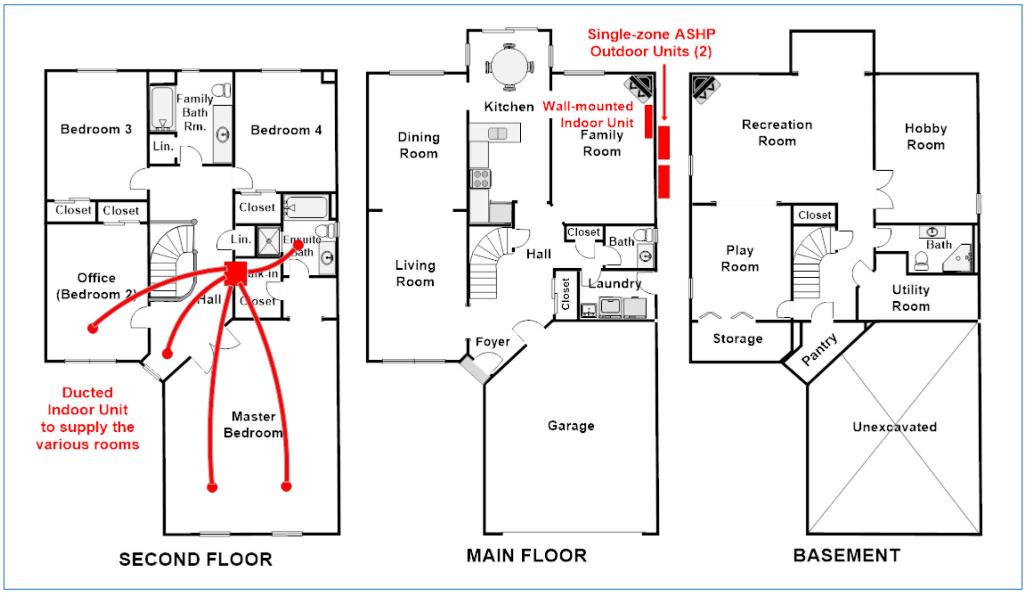


Figure 10: Type and location of the Indoor units in the two Targeted Areas

STEP 3: Determine Design Heating and Cooling Load Estimates

The house has had an Energy Audit completed and the report is available from the homeowner. None of the recommended upgrades have been made to the home or HVAC system since the audit was done.

Use **Option 3B: Energy Audit Load Estimates.**

The audit report 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 and its design cooling load would be 23,519 Btu/h (2.0 tons).

Since the upgrades were not implemented, the reported design heating load (DHL) will need to be adjusted to back out the assumed building envelope improvements. The reported design cooling load (DCL) will not need to be adjusted. The report also states:

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

This means the reported design heating load in the audit report is 88% of the actual value (i.e. 100% minus the 12%). Therefore, the actual design heat loss for the house is equal to:

Design Heating Load = 43,641 Btu/h / 0.88 = 49,592 Btu/h

Based on the audit report, the whole house has estimated design loads of about:

Heating: 49,600 Btu/h at a design temperature of -4°F (-20°C);

Cooling: 23,500 Btu/h at a design temperature of 88°F (31°C).

Target Area Load Estimates

Room-by-room heat loss / heat gain values were not available. Also, because the existing heating system sized to meet the DHL is remaining in place, target area load estimates based on floor area are acceptable. Target area loads are estimated here by proportioning the whole house load values by the floor area of the target areas as follows:

- Second-floor target area consisting of master bedroom, on-suite bath, hall and office has a floor area of about 1,130 square-feet
- Main-floor target area consisting of family room, kitchen, living room and dining room, has a floor area of about 1,130 square-feet
- The total finished area of the house, including the basement is about 3,300 square-feet.

Since the two target areas are the same size, each will have similar load values. The target area loads are estimated as:

Heating (DHL): 49,600 x 1,130 / 3,300 = 17,000 Btu/h at a design temperature of -4°F (-20°C);

Cooling (DCL): 23,500 x 1,130 / 3,330 = 8,000 Btu/h at a design temperature of 88°F (31°C).

STEP 4: Determine Sizing Approach and Capacity Requirements of ASHP

The most appropriate option is:

- **OPTION 4A: Emphasis on Cooling**, and
  Sizing Criteria: 80% to 125% of design cooling load; (DCL is 8,000 Btu/h at 88°F (31°C))
- **Target Cooling Capacity Range** is cooling of 6,400 Btu/h to 10,000 Btu/h *[equation 3]* for each of the two target areas within the house.

STEP 5: Identify and Select ASHP Matching Key Requirements

The contractor has screened a number of possible ASHP systems and has identified three ductless mini-split heat pumps for the application, with cooling capacities that fall within the **Target Cooling Capacity Range**. These are listed in Table 2 with the manufacturer's data showing rated cooling capacities at an outdoor temperature of 95°F (35°C), and rated heating capacities at 47°F (8°C) and 17°F (-8°C).

Note that cooling capacities at 95°F (35°C) outdoor temperature may be used for initial screening purposes as this information is commonly available in manufacturers' summary listings. If extended performance data is available, use capacity ratings at an outdoor temperature close to the design temperature for the site.

Table 2: Manufacturer's Performance Data for Candidate Ductless Heat Pumps using "Sizing Option A"

Model	Number of Stages	Rated Cooling Efficiency (SEER)	Rated Cooling Capacity at 95°F (Btu/h)	Max / Min Cooling Capacity at 95°F (Btu/h)	Rated Heating Efficiency (HSPF)	Turn-down Ratio at 95°F	Rated Heating Capacity at 47°F (Btu/h)	Rated Heating Capacity at 17°F (Btu/h)
ASHP1-MS-09-V	Variable capacity	15.00	9,000	Max: 10,200 Min: 4,100	10.0	2.48	10,200	9,000
ASHP2-NS-09-V	Variable capacity	19.40	9,000	Max: 12,100 Min: 3,800	12.0	3.18	15,000	10,800
ASHP3-LS-09-V	Variable capacity	28.20	9,000	Max: 12,200 Min: 3,600	11.8	3.39	15,900	10,200

Using the Air-conditioning, Heating and Refrigeration Institute (AHRI) published performance data, heating and cooling performance for the three candidate ASHP systems are plotted in Figure 11 together with estimated load characteristics for the two target areas within the house.

- The rated cooling characteristics are 9,000 Btu/h for all three ASHPs.
- The max cooling characteristics are 10,200 Btu/h for ASHP1, 12,100 Btu/h for ASHP2 and 12,200 for ASHP3
- The heating characteristics for all ASHP models 2 and 3 are fairly similar, while ASHP1 has a much lower heating output at 47°F (8°C) than the other two models.
- The thermal balance point temperatures (t-BPT) for the three ASHP options operating in the second floor and the main floor target areas are:
  - ASHP1: 28°F (-2°C);
  - ASHP2: 28°F (-2°C); and,
  - ASHP3: 27°F (-3°C).

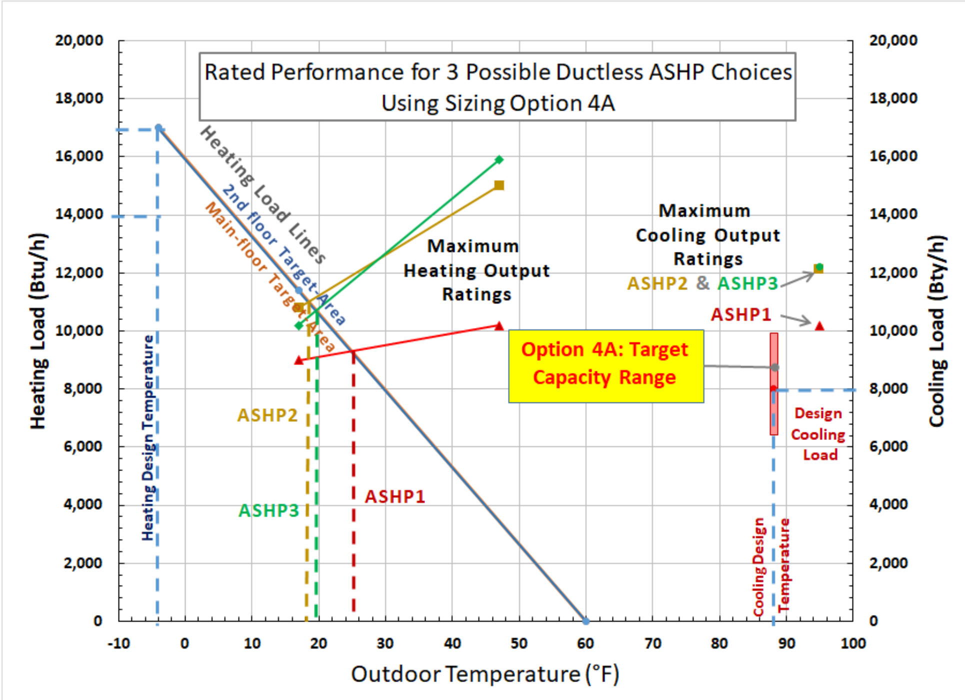


Figure 11: Performance Curves & Balance Point Temperatures for 3 ductless ASHP Choices using Sizing Option 4A

Estimated Turn-down Ratios

The following analysis provides estimates of the turn-down ratios of the ASHPs being considered.

Using the high stage and low stage cooling capacities specified in the manufacturer's performance tables, the turn-down ratios for the ASHPs considered are:

- ASHP 1: 10,200 / 4,100 = 2.48:1
- ASHP 2: 12,100 / 3,800 = 3.18:1
- ASHP 3: 12,200 / 3,600 = 3.39:1

Estimated Heating Fractions provided by the ASHP

The following analysis provides estimates of the relative heating performance of each of the ASHPs under consideration.

- From the climate zone map (see Appendix 1 of this document) it is determined that the house is located in the "Cold-Humid" climate zone.

Using the thermal balance point temperature (t-BPT) for each system shown in Figure 19 the *"Fraction of Total Annual Heating"* that can be delivered above the t-BPTs were estimated for the "Cold-Humid" climate zone using the chart in Appendix 1 of this document.

The results are summarized below:

ASHP1: t-BPT = 25°F (-4°C); Fraction of Annual Heating above the t-BPT = 62% of the target area
ASHP2: t-BPT = 18°F (-8°C); Fraction of Annual Heating above the t-BPT = 68% of the target area
ASHP3: t-BPT = 20°F (-7°C); Fraction of Annual Heating above the t-BPT = 66% of the target area

The client decided on ASHP1 on the basis of its lower first cost and more appropriate sizing to the target cooling capacity range.

Heat Pump Performance Summary for the chosen model, ASHP1-MS-09-V

Cooling:

- Maximum cooling output at 95°F (35°C) is 10,200 Btu/h, or 128% of the design load of each of the two target areas within the house. Minimum cooling output at 95°F (35°C) is 4,100 Btu/h.
- The target cooling capacity range of 6,400 to 10,000 Btu/h is within the operating range of this ASHP.

Heating:

- Thermal balance point temperature is about 25°F (-4°C) for each of the target areas.
- Low-temperature cut-off is -15°F (-26°C).
- The fraction of target area heating provided by the ASHP above the thermal balance point temperature is estimated at about 62% of the heating required in each of the target areas within the house.

STEP 6: Define the ASHP Control Strategy

Following the decision tree shown in Figure 12:

1. Manufacturer's data indicates that the chosen mini-split ASHP can operate at outdoor temperatures below the design temperature of -4°F (-20°C), so there is no requirement to restrict the ASHP operation based on low outdoor temperature.
2. The ASHP's are add-ons to an electric baseboard heating system, both operating on electricity, so there is no requirement for economic switch-over to backup heating.
3. ASHP heating output capacity is less than the design heating load at the design temperature.

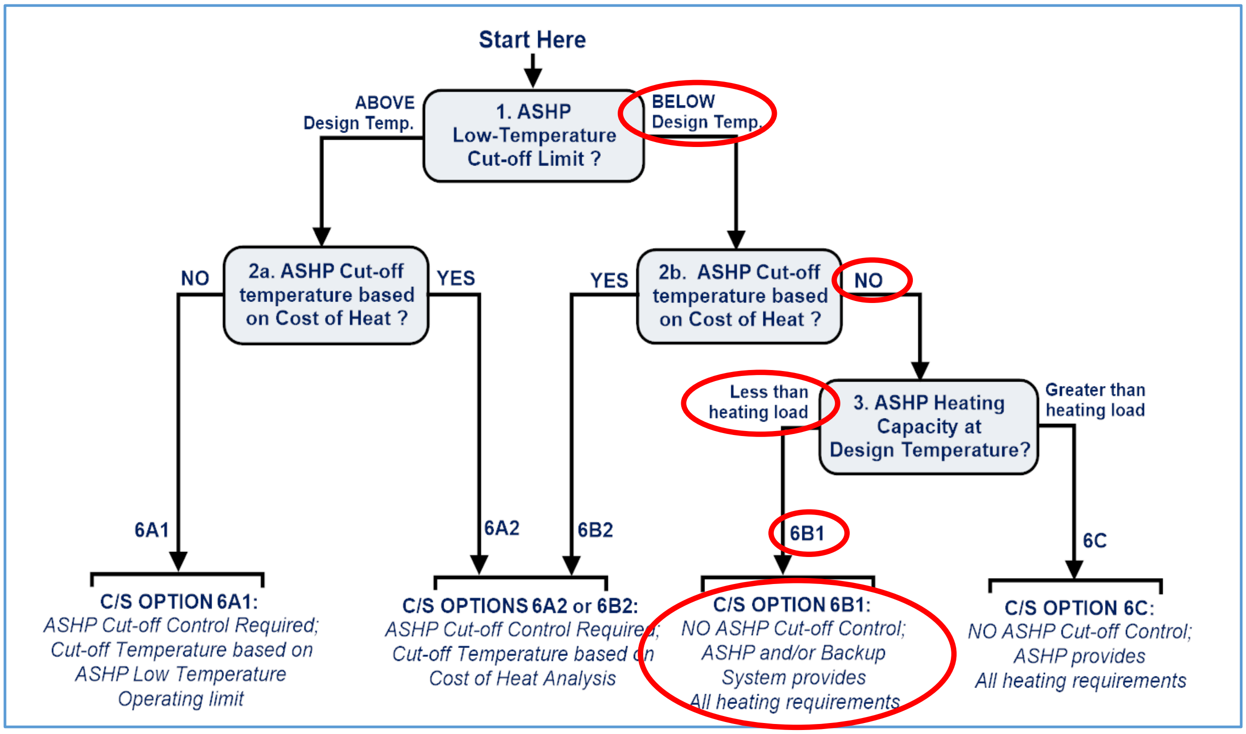


Figure 12: Decision Tree to Determine ASHP Control Strategy Option for Example A2

Control Option 6B1 is chosen with the add-on ASHP's and the original baseboard heating system operational over the full outdoor temperature range.

- Controls that integrated the ASHP and existing electric baseboard heating system were not available for this ASHP model. As a result, separate indoor thermostats will be controlling the ASHPs and existing baseboard heating system independently.
- The set-point temperature on the baseboard heating system thermostats must be set below the low end of the ASHP dead band for the desired temperature set-point values to ensure operation of the ASHP independent of the electric baseboards.

STEP 7: Define Back-up Heating Requirements

The two ductless ASHPs are add-ons to the original electric baseboard heating system, which remains intact and functional and has the capacity to meet the design heating load of the home.

Following the decision tree criteria shown in Figure 13:

1. **Type of Installation:** Add-on ASHP, where the existing heating system remains operational.

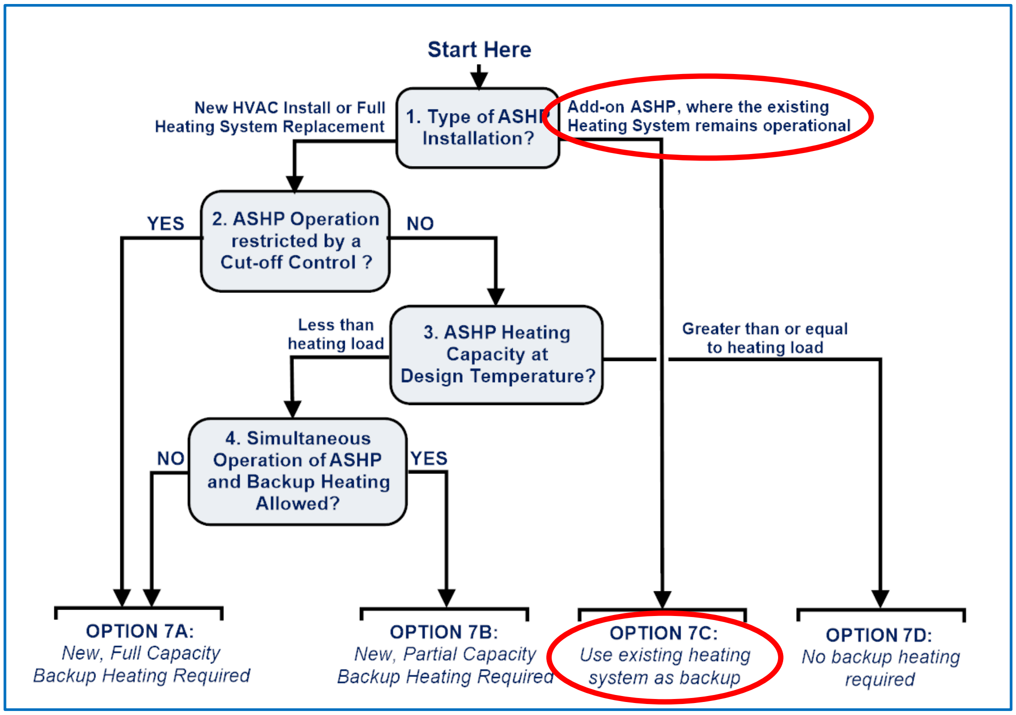


Figure 13: Decision Tree to Determine the Backup Heating Requirements for Example A2

Back-up Heating Option 7C is the most appropriate.

- Use the existing baseboard heating system as backup;
- No new backup system required.

Example B1: Full System Replacement: Converting a Furnace and A/C to a Furnace and ASHP ("Hybrid / Dual-Fuel" System) using "Sizing Option B" (Balanced Heating & Cooling)

Background

An existing house has a central forced-air heating system that consists of a standard efficiency propane furnace and a central air conditioner. Both need to be replaced.

The client is interested in installing an air-source heat pump to provide a portion of the heating in winter and cooling in summer. During the coldest periods, additional heating will be provided by a new high-efficiency propane furnace.

The house location has design temperature conditions of -4°F (-20°C) for heating and 88°F (31°C) for cooling.

STEP 1: Define ASHP Configuration

Use **OPTION 1A: Centrally Ducted ASHP**

STEP 2: Skip Step 2 when using **OPTION 1A: Centrally Ducted ASHP**

STEP 3: Determine Design Heating and Cooling Load Estimates
(same as Example A1)

The house has had an Energy Audit completed and the report is available from the homeowner. None of the recommended upgrades have been made to the home or HVAC system since the audit was done.

Use **Option 3B: Energy Audit Load Estimates.**

The audit report 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 and its design cooling load would be 23,519 Btu/h (2.0 tons).*

Since the upgrades were not implemented, the reported design heating load (DHL) will need to be adjusted to back out the assumed building envelope improvements. The reported design cooling (DCL) load will not need to be adjusted. The report also states:

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

This means the reported design heating load in the audit report is 88% of the actual value (i.e. 100% minus the 12%). Therefore, the actual design heat loss for the house is equal to:

Design Heating Load = 43,641 Btu/h / 0.88 = 49,592 Btu/h

Based on the audit report, and the house has estimated design loads of about:

Heating: 49,600 Btu/h at a design temperature of -4°F (-20°C);

Cooling: 23,500 Btu/h at a design temperature of 88°F (31°C).

The existing supply ducting has four supply trunks / ducts off the furnace plenum:

- One rectangular at 8 inches deep by 22 inches wide.
- Two round at 6-inch diameter, and
- One round at 5-in diameter.

Using equations 1a and 2a from the Guide:

Maximum Airflow Capacity (CFM) = (8 x 22) x 6.25 + (6^2 + 6^2 + 5^2) x 4.91 = 1576 CFM

The maximum airflow capacity of the existing duct system is estimated as 1,576 CFM.

STEP 4: Determine Sizing Approach and Capacity Requirements of ASHP

The most appropriate option is:

- **OPTION 4B: Emphasis on Balanced Cooling and Heating**, and
  Sizing Criteria: 80% to 125% of design cooling load; (DCL is 23,500 Btu/h at 88°F (31°C)).
- **Target Cooling Capacity Range** is cooling of 18,800 Btu/h to 29,400 Btu/h *[equation 3]*

STEP 5: Identify and Select ASHP Matching Key Requirements

The contractor has screened a number of possible ASHP systems and has identified three centrally ducted heat pumps for the application that have cooling capacities that fall within the **Target Cooling Capacity Range**. These are listed in Table 3 with the manufacturer's data showing rated cooling capacity at an outdoor temperature of 95°F (35°C).

Note that cooling capacities at 95°F (35°C) outdoor temperature may be used for initial screening purposes as this information is commonly available in manufacturers' summary listings. If extended performance data is available, use capacity ratings at an outdoor temperature close to the design temperature for the site.

Table 3: Manufacturer's Performance Data for Candidate Centrally-ducted Heat Pumps using "Sizing Option B"

Model	Number of Stages	Nominal Capacity (tons)	Cooling Capacity at 95°F (Btu/h)	Airflow (CFM)
ASHP1-CD-30-1	1-stage	2.5	27,000	870
ASHP2-CD-36-2	2-stages	3.0	32,100 (high-stage); 23,400 (low-stage)	1,150 (high-stage); 800 (low-stage)
ASHP3-CD-36-V	Variable capacity	3.0	32,800 (high-stage); 23,400 (low-stage)	1,160 (high-stage); 895 (low-stage)

Note: Indoor Conditions: 75ºF (24°C) dry bulb temperature and 63°F (17°C) wet bulb temperature

Using the extended performance data, heating and cooling performance curves for the three possible ASHP systems are plotted in Figure 14 versus outdoor temperature together with the house load characteristics.

- The cooling capacity of the low-stage outputs of the 3-ton, 2-stage and variable capacity ASHPs are identical, at 23,400 Btu/h, and are equal to the design cooling load of the house at the design conditions.
- The cooling capacity of the 2.5-ton single-stage ASHP is 27,000 Btu/h and is higher than the design load but is still within the target capacity range for the application.
- Airflow requirements for all three ASHPs are below the maximum airflow capacity of the existing duct system (i.e., 1,576 CFM).
- The heating characteristics for the 2-stage and variable capacity units are almost identical at outdoor temperature above 34°F (1°C), but diverge at lower temperatures, with the variable capacity ASHP having significantly higher output capacity than both the 2-stage and single-stage ASHPs at lower temperatures.
- The thermal balance point temperature for the three ASHPs are estimated at:
    - ASHP1: 33°F (0.6°C);
    - ASHP2: 28°F (-3°C); and,
    - ASHP3: 21°F (-6°C).

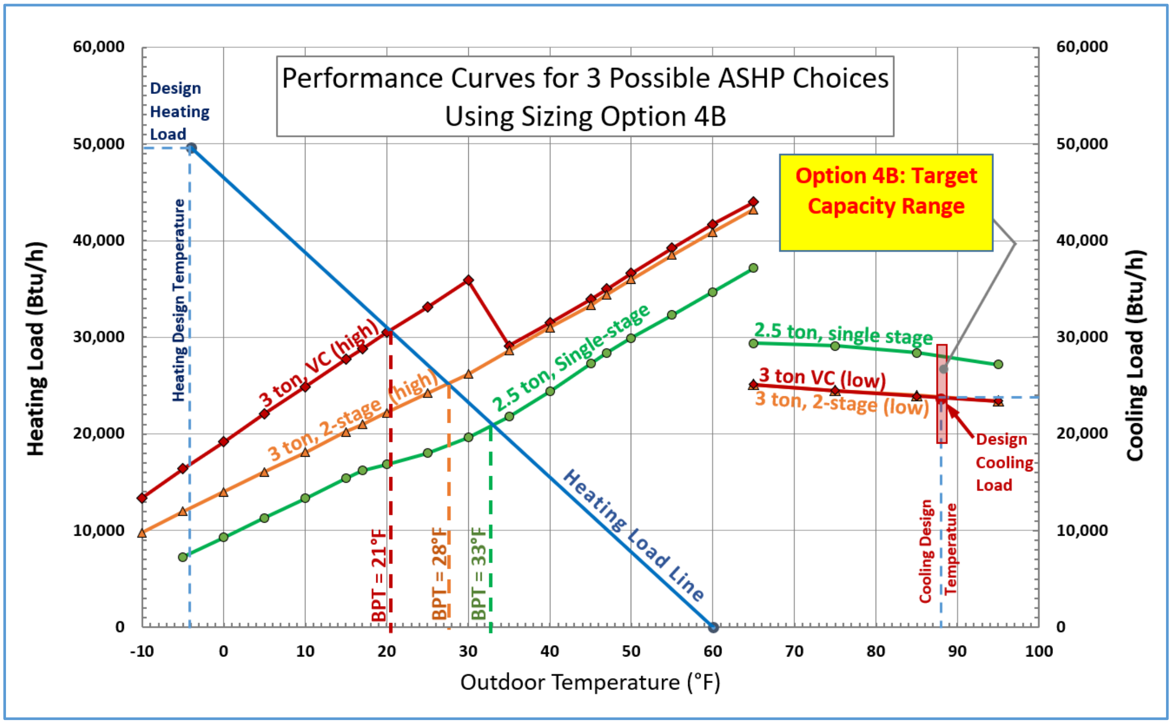


Figure 14: Performance Curves & Balance Point Temperatures for 3 ASHP Choices for Sizing Option 4B

Estimated Turn-down Ratios

The following analysis provides estimates of the turn-down ratios of the ASHPs being considered.

Using the high stage and low stage cooling capacities specified in the manufacturer's performance tables, the turn-down ratios for the ASHPs considered are:

- ASHP 1: N/A (single stage)
- ASHP 2: 32,100 / 23,400 = 1.37:1
- ASHP 3: 32,800 / 23,400 = 1.4:1

Estimated Heating Fractions provided by the ASHP

The following analysis provides estimates of the relative heating performance of each of the ASHPs under consideration.

- From the climate zone map (see Appendix 1 of this document) it is determined that the house is located in the "Cold-Humid" climate zone.

Using the thermal balance point temperature (t-BPT) for each system shown in Figure 14 the *"Fraction of Total Annual Heating"* that can be delivered above the t-BPTs were estimated for the "Cold-Humid" climate zone using the chart in Appendix 1 of this document.

The results are summarized below for the "Cold/Humid" climate zone:

ASHP1: 2.5-ton, single-stage	t-BPT = 33ºF (0.6°C) Fraction of Annual Heating above the t-BPT = 33%
ASHP2: 3.0-ton, two-stage	t-BPT = 28ºF (-3°C) Fraction of Annual Heating above the t-BPT = 48%
ASHP3: 3.0-ton, variable capacity	t-BPT = 21ºF (-6°C) Fraction of Annual Heating above the t-BPT = 64%

In this instance, the client decided that **ASHP2, the 3-ton, 2-stage ASHP** fitted best with their overall goals for the project.

Heat Pump Performance Summary for the chosen model, ASHP2-CD-36-2

Cooling:

- High-stage cooling output at design temperature (i.e., 88°F) is about 32,700 Btu/h, or 139% of the design cooling load.
- Low-stage cooling output at design temperature (i.e., 88°F) is about 23,800 Btu/h, or 101% of the design cooling load.

Heating:

- Balance point temperature is about 28°F (-3°C)
- Low-temperature cut-off is -10°F (-23°C) (i.e., below the design temperature)
- The Fraction of Total Heating provided by ASHP above the thermal balance point temperature is estimated at 48%.

STEP 6: Define the ASHP Control Strategy

Following the decision tree shown in Figure 15:

1. The chosen heat pump is shown as capable of operating to -10°F (-23°C), which is well below the design temperature of -4°F (-20°C).
2. The client wants to displace as much propane usage as possible with the ASHP, so the unit will be unrestricted and allowed to operate over the full range of outdoor conditions. (i.e., No low-temperature or economic cut-off control required).
3. ASHP heating output capacity is less than the design heating load at the design temperature.

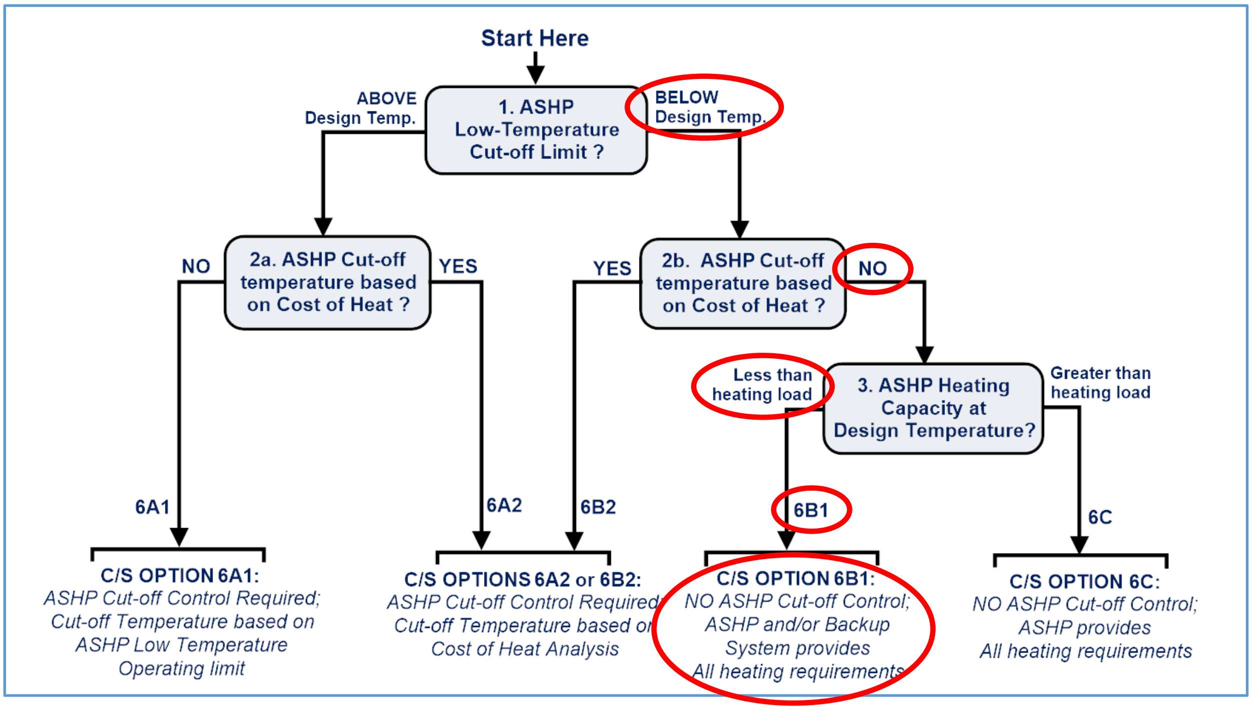


Figure 15: Decision Tree to Determine ASHP Control Strategy Option for Example B1

Control Option 6B1 is chosen, which allow the ASHP to operate over the full outdoor temperature range. No low-temperature ASHP cut-out control is required.

- A single, multi-stage indoor thermostat sequences the operation of both the ASHP and propane furnace used for back-up.
- With a centrally ducted “hybrid” or “dual-fuel” system, the ASHP and fuel-based furnace cannot operate simultaneously, but rather are operated in sequence, one at a time.
  - *The thermostat will first bring on the ASHP to satisfy a “heating call”, and only turn off the ASHP and bring on propane furnace if the “heating call” cannot be satisfied by the ASHP.*

STEP 7: Define Back-up Heating Requirements

Since the old HVAC system is being removed, a NEW backup heating system is required.

Backup heating will be provided by a high efficiency, propane gas furnace that will be controlled by a multi-stage thermostat which will turn the heat pump OFF when the furnace is operating.

Following the decision tree shown in Figure 16:

1. **Type of Installation:** Full heating system replacement;
2. **ASHP Operation Restricted at Low Temperature:** No, ASHP is not restricted by chosen control strategy *(i.e., Option 6B1)* or by ASHP low temperature cut-off.
3. **ASHP Heating Capacity at Design Temperature:** Less than heating load.
4. **Simultaneous operation of ASHP and Backup Heating**: No, not allowed.

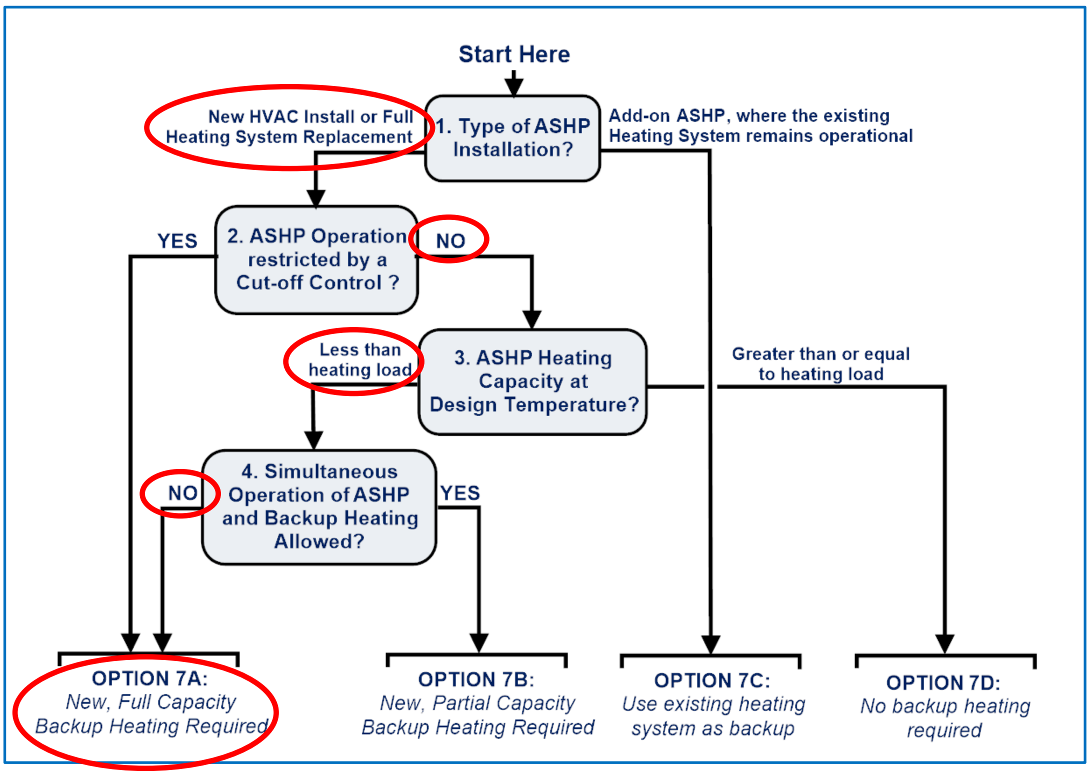


Figure 16: Decision Tree to Determine the Backup Heating Requirements for Example B1

Back-up Heating Option 7A is required.

- The output capacity of the new furnace must equal or be greater than 100% the design heat loss value of 49,600 Btu/h, and be capable of supplying an airflow of 1,150 CFM needed by the ASHP at the operating static pressure of the existing duct system.

The propane furnace chosen is a 60,000 Btu/h input furnace with an AFUE of 95%. Output capacity is 57,000 Btu/h, or 115% of the design heating load of the house. The furnace has a maximum airflow rating of 1,200 CFM which will deliver the airflow required by the chosen ASHP.

Example B2: ASHP Add-on: Single-Zone Ductless Add-on to an Existing Electric Baseboard Heating System using "Sizing Option B" (Balanced Heating and Cooling)

Background

An existing 2-storey house has an electric baseboard heating system and no air conditioning.

The client is interested in installing one or more ductless air-source heat pumps (ASHP) to provide a portion of the heating in winter and cooling in summer. The baseboard heating system will remain functional and will provide backup heating for the ASHP.

The house location has design temperature conditions of -4°F (-20°C) for heating and 88°F (31°C) for cooling.

STEP 1: Define ASHP Configuration

The house floor plan is shown below. The key occupied areas within the home are the main floor kitchen and family room, and the master suite/on-suite bath room and office on the second floor. These two areas are the target areas for the ASHP installation.

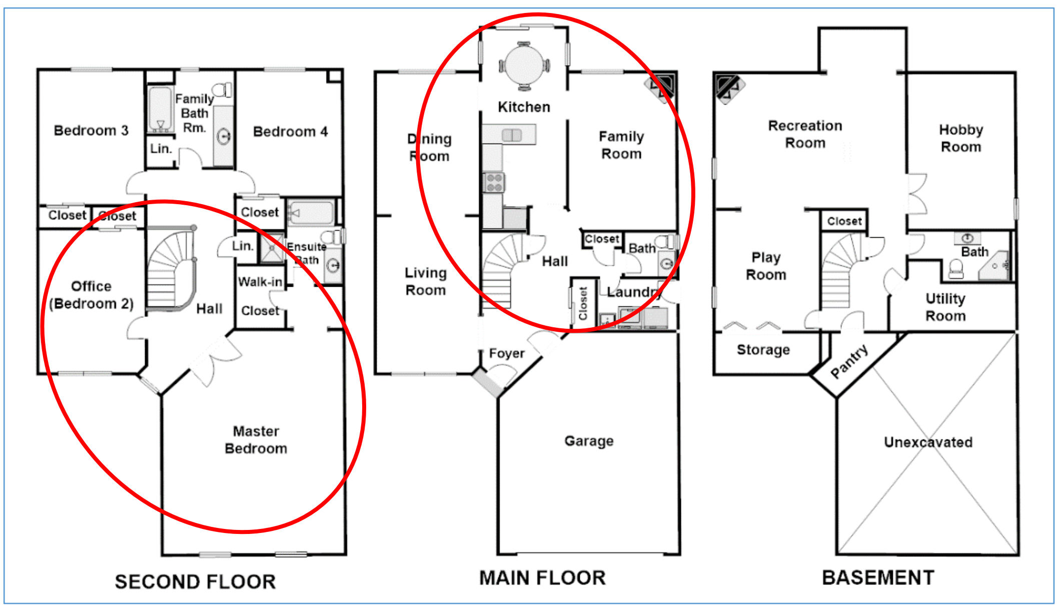


Figure 17: Two-storey house floor plans with Targeted Areas circled

Use **OPTION 1B: Ductless Mini-split, Single-zone, Add-on ASHPs**

- **Two units required:** one for the main-floor target area and another for the second-floor target area.

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

The indoor unit types selected to service the two target areas are:

- The second-floor area will use a ducted unit (Option 2D) installed in the attic space near the attic access hatch and will be ducted to the various rooms as shown in Figure 18.
- The main-floor area will use a wall-mount unit (Option 2A) installed on the exterior wall of the family room to service primarily the family room and kitchen. Some heat will circulate to the dining room and living room through the open doorways that link the rooms.

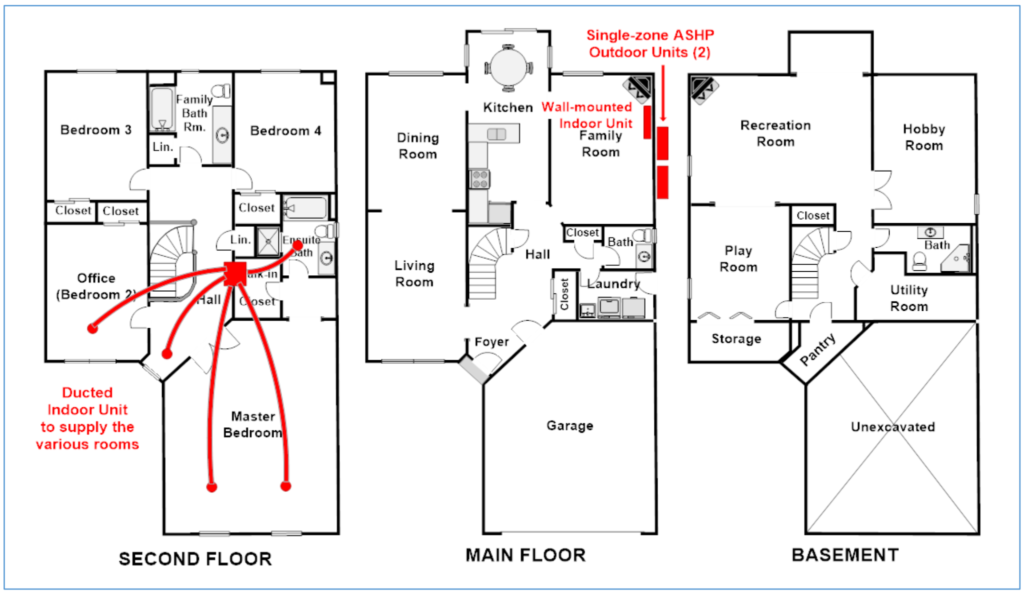


Figure 18: Type and location of the Indoor units in the two Targeted Areas

STEP 3: Determine Design Heating and Cooling Load Estimates

The house has had an Energy Audit completed and the report is available from the homeowner. None of the recommended upgrades have been made to the home or HVAC system since the audit was done.

Use **Option 3B: Energy Audit Load Estimates.**

The audit report 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 and its design cooling load would be 23,519 Btu/h (2.0 tons).

Since the upgrades were not implemented, the reported design heating load will need to be adjusted to back out the assumed building envelope improvements. The reported cooling load will not need to be adjusted. The report also states:

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

This means the reported design heating load in the audit report is 88% of the actual value (i.e. 100% minus the 12%). Therefore, the actual design heat loss for the house is equal to:

Design Heating Load = 43,641 Btu/h / 0.88 = 49,592 Btu/h

Based on the audit report, and the whole house has estimated design loads of about:

Heating: 49,600 Btu/h at a design temperature of -4°F (-20°C);

Cooling: 23,500 Btu/h at a design temperature of 88°F (31°C).

Target Area Load Estimates

Target area loads were estimated by proportioning the whole house load values by the floor area of the target areas as follows:

- Second-floor target area consisting of master bedroom, on-suite bath, hall and office has a floor area of about 1,130 square-feet
- Main-floor target area consisting of family room, kitchen, living room and dining room, has a floor area of about 1,130 square-feet
- The total finished area of the house, including the basement is about 3,300 square-feet.

Since the two target areas are the same size, each will have the same load values. The target area loads are estimated as:

Heating (DHL): 49,600 x 1,130 / 3,300 = 17,000 Btu/h at a design temperature of -4°F (-20°C);

Cooling (DCL): 23,500 x 1,130 / 3,330 = 8,000 Btu/h at a design temperature of 88°F (31°C).

STEP 4: Determine Sizing Approach and Capacity Requirements of ASHP

The most appropriate option is:

- **OPTION 4B: Emphasis on Balanced Cooling and Heating**, and

  Sizing Criteria: 80% to 125% of design cooling load; (DCL is 8,000 Btu/h at 88°F (31°C))
- **Target Cooling Capacity Range** is cooling of 6,400 Btu/h to 10,000 Btu/h *[equation 3]* for each of the two target areas within the house.

STEP 5: Identify and Select ASHP Matching Key Requirements

The contractor has screened a number of possible ASHP systems and has identified three ductless mini-split heat pumps for the application, with cooling capacities that fall within the **Target Cooling Capacity Range**. These are listed in Table 4 with the manufacturer's data showing rated cooling capacities at an outdoor temperature of 95°F (35°C), and rated heating capacities at 47°F (8°C) and 17°F (-8°C).

Note that cooling capacities at 95°F (35°C) outdoor temperature may be used for initial screening purposes as this information is commonly available in manufacturers' summary listings. If extended performance data is available, use capacity ratings at an outdoor temperature close to the design temperature for the site.

Table 4: Manufacturer's Performance Data for Candidate Ductless Heat Pumps using "Sizing Option B"

Model	Number of Stages	Rated Cooling Efficiency (SEER)	Rated Cooling Capacity at 95°F (Btu/h)	Max Cooling Capacity at 95°F (Btu/h)	Min Cooling Capacity at 95°F (Btu/h)	Min Cooling < 125% of DCL	Turn-down Ratio	Rated Heating Efficiency (HSPF)	Max Heating Capacity at 47°F (Btu/h)	Max Heating Capacity at 17°F (Btu/h)
ASHP1-MS-9-V	Variable capacity	20.50	9,000	10,200	4,100	Yes	2.49:1	10	10,200	9,000
ASHP2-MS-9-V	Variable capacity	23.5	9,000	12,100	3,800	Yes	3.18:1	12	15,000	10,800
ASHP3-MS-9-V	Variable capacity	24.6	9,000	12,200	3,600	Yes	3.39:1	11.8	15,900	10,200
ASHP4-MS-12-V	Variable capacity	23	12,000	14,680	4,100	No	3.58:1	11	19,800	13,120

Using the NEEP CC-ASHP Product Listings published performance data, heating and cooling performance for the three candidate ASHP systems are plotted in Figure 19 together with estimated load characteristics for the two target areas within the house.

For multi-stage or variable capacity equipment, **Sizing Option 4B** matches minimum cooling capacities to the Target Cooling Range (i.e., 6,400 to 10,000 Btu/h in this example), where possible (without exceeding the 125% limit).

The low stage or minimum cooling capacities at 95°F (35°C) range from 4,100 Btu/h for ASHP1 to 3,600 Btu/h for ASHP3. This is below the low end of the Target Capacity Range (6,400 Btu/h), so an upsized fourth ASHP was identified that has a rated cooling capacity of 12,000 Btu/h. This rated cooling capacity exceeds the 125% limitation of DCL. The designer thus concludes that the 9,000 BTU/h rated cooling capacity systems are the right sized systems. The three systems at 9,000 Btu/h cooling capacity ratings had the following characteristics:

- The rated cooling capacities are identical for all three variable-capacity ASHP, each with an output of 9,000 Btu/h at 95°F (35°C).
- The maximum heating output at 47°F (8°C) range from 15,900 Btu/h for ASHP3 to 10,200 Btu/h for ASHP1. Maximum heating outputs at 17°F (-8°C) range from 10,800 Btu/h for ASHP2 to 9,000 Btu/h for ASHP1.
- The thermal balance point temperatures (t-BPT) for the three ASHP options operating in the second floor and the main floor target areas are:
    - ASHP1: 25°F (-4°C);
    - ASHP2: 18°F (-8°C); and,
    - ASHP3: 20°F (-7°C).

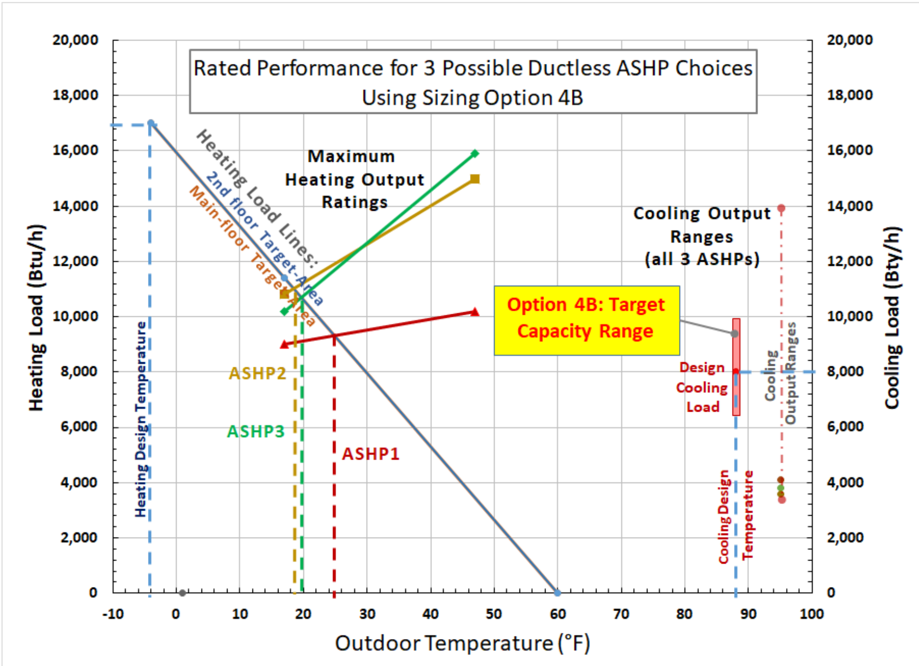


Figure 19: Performance Curves & Balance Point Temperatures for 3 ductless ASHP Choices using Sizing Option 4B

Estimated Turn-down Ratios

The following analysis provides estimates of the turn-down ratios of the ASHPs being considered.

Using the high stage and low stage cooling capacities specified in the manufacturer's performance tables, the turn-down ratios for the ASHPs considered are:

- ASHP 1: 10,200 / 4,100 = 2.48:1
- ASHP 2: 12,100 / 3,800 = 3.18:1
- ASHP 3: 12,200 / 3,600 = 3.39:1

Estimated Heating Fractions provided by the ASHP

The following analysis provides estimates of the relative heating performance of each of the ASHPs under consideration.

- From the climate zone map (see Appendix 1 of this document) it is determined that the house is located in the "Cold-Humid" climate zone.

Using the thermal balance point temperature (t-BPT) for each system shown in Figure 19 the *"Fraction of Total Annual Heating"* that can be delivered above the t-BPTs were estimated for the "Cold-Humid" climate zone using the chart in Appendix 1 of this document.

The results are summarized below:

ASHP1: t-BPT = 25°F (-4°C); Fraction of Annual Heating above the t-BPT = 62% of the target area
ASHP2: t-BPT = 18°F (-8°C); Fraction of Annual Heating above the t-BPT = 68% of the target area
ASHP3: t-BPT = 20°F (-7°C); Fraction of Annual Heating above the t-BPT = 66% of the target area

The client decided on ASHP2 on the basis of its higher heating output at low outdoor temperatures and higher estimated annual heating fraction as well as its relatively high turn-down ratio.

Heat Pump Performance Summary for the chosen model, ASHP2-MS-9-V

Cooling:

- Rated cooling capacity at 95°F (35°C) is 9,000 Btu/h, which is within the Target Capacity Range of each of the two target areas within the house.

Heating:

- Balance point temperature is about 18°F (-8°C) for each of the target areas.
- Low-temperature cut-off is -15°F (-26°C) (i.e., below the design temperature).
- The fraction of target area heating provided by the ASHP above the thermal balance point temperature is estimated at 68% of the heating required in each of the two target areas within the house.

STEP 6: Define the ASHP Control Strategy

Following the decision tree shown in Figure 20:

1. Manufacturer's data indicates that the chosen mini-split ASHP can operate at outdoor temperatures <u>below the design temperature</u> of -4°F (-20°C), so there is no requirement to restrict the ASHP operation based on low outdoor temperature.
2. The ASHP's are add-ons to an electric baseboard heating system, both operating on electricity, so there is no need for an economic switch-over to full backup heating.
3. ASHP heating output capacity is less than the design heating load at the design temperature.

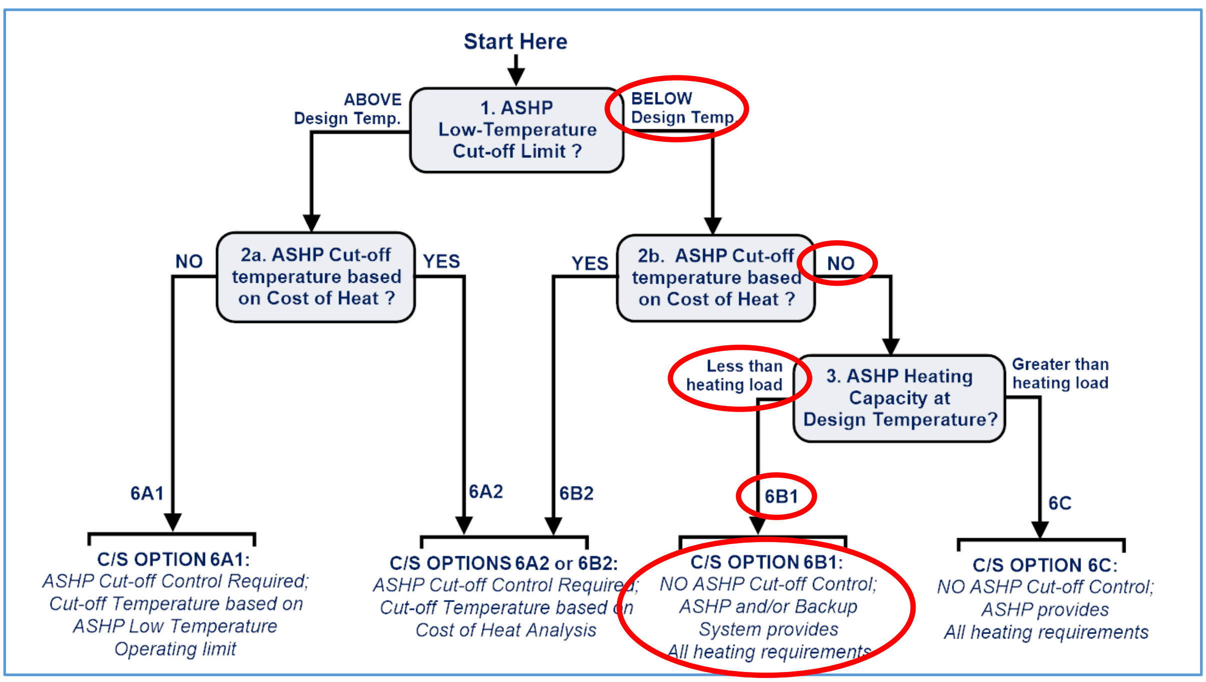


Figure 20: Decision Tree to Determine ASHP Control Strategy Option for Example B2

Control Option 6B1 is chosen with the add-on ASHP's and the original baseboard heating system will be operational over the full outdoor temperature range.

- Controls that integrated the ASHP and existing electric baseboard heating system were not available for this ASHP model. As a result, separate indoor thermostats will be controlling the ASHPs and existing baseboard heating system independently.
- The set-point temperature on the baseboard heating system thermostats must be set below the low end of the ASHP dead band for the desired temperature set-point values to ensure operation of the ASHP independent of the electric baseboards.

STEP 7: Define Back-up Heating Requirements

The two ductless ASHPs are add-ons to the original electric baseboard heating system, which remains intact and functional and has the capacity to meet the design heating load of the home.

Following the decision tree criteria shown in Figure 21:

1. **Type of Installation:** Add-on ASHP, where the existing heating system remains operational.

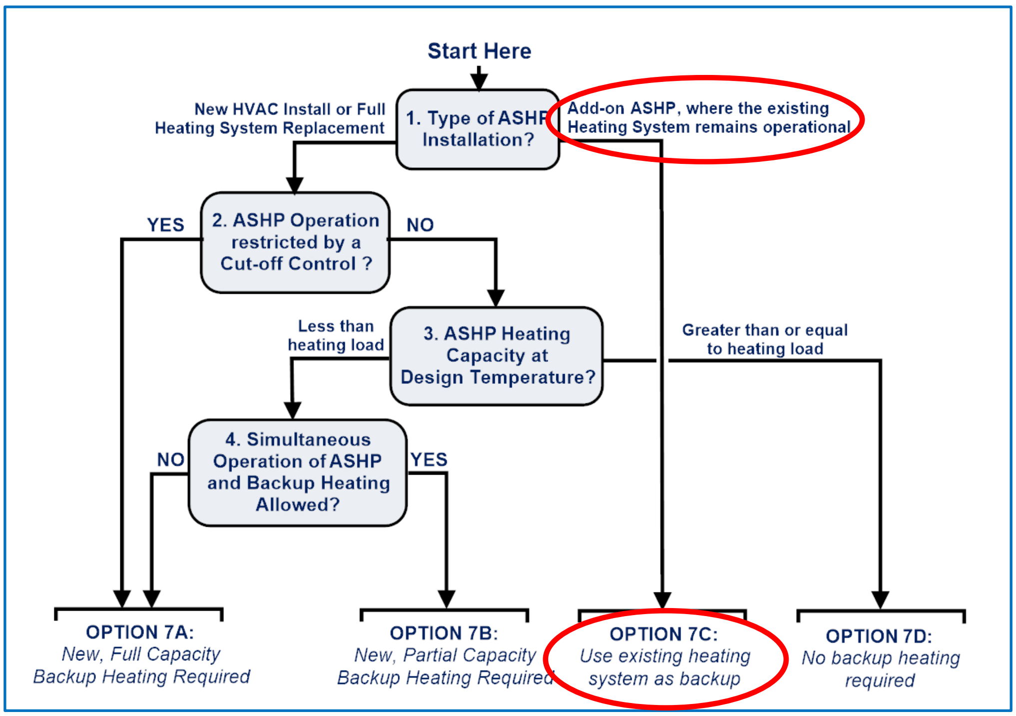


Figure 21: Decision Tree to Determine the Backup Heating Requirements for Example B2

Back-up Heating Option 7C is the most appropriate.

- Use the existing baseboard heating system as backup;
- No new backup system required.

Example C1: Full System Replacement: Converting a Furnace and A/C to a Furnace and ASHP (“Hybrid / Dual-Fuel” System) using “Sizing Option C” (Emphasis on Heating)

Background

An existing house has a central forced-air heating system that consists of a standard efficiency propane furnace and a central air conditioner. Both need to be replaced.

The client is interested in installing an air-source heat pump to provide most of the heating in winter and cooling in summer. During the coldest periods, any additional heating will be provided by a new high-efficiency propane furnace.

The house location has design temperature conditions of -4°F (-20°C) for heating and 88°F (31°C) for cooling.

STEP 1: Define ASHP Configuration

Use **OPTION 1A: Centrally Ducted ASHP**

STEP 2: Skip Step 2 when using **OPTION 1A: Centrally Ducted ASHP**

STEP 3: Determine Design Heating and Cooling Load Estimates (same as Example A1)

The house has had an Energy Audit completed and the report is available from the homeowner. None of the recommended upgrades have been made to the home or HVAC system since the audit was done.

Use **Option 3B: Energy Audit Load Estimates.**

The audit report 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 and its design cooling load would be 23,519 Btu/h (2.0 tons).*

Since the upgrades were not implemented, the reported design heating load (DHL) will need to be adjusted to back out the assumed building envelope improvements. The reported design cooling load (DCL) will not need to be adjusted. The report also states:

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

This means the reported design heating load in the audit report is 88% of the actual value (i.e. 100% minus the 12%). Therefore, the actual design heat loss for the house is equal to:

Design Heating Load = 43,641 Btu/h / 0.88 = 49,592 Btu/h

Based on the audit report, and the house has estimated design loads of about:

Heating (DHL): 49,600 Btu/h at a design temperature of -4°F (-20°C);

Cooling (DCL): 23,500 Btu/h at a design temperature of 88°F (31°C).

Calculated maximum airflow capacity of existing duct system:

The existing supply ducting has four supply trunks / ducts off the furnace plenum:

- One rectangular trunk at 8 inches deep by 22 inches wide.
- Two round ducts at 6-inch diameter, and
- One round duct at 5-in diameter.

Using equations 1a and 2a:

$$\textbf{Maximum Airflow Capacity (CFM)} = (8 \times 22) \times 6.25 + (6^2 + 6^2 + 5^2) \times 4.91 = 1576 \text{ CFM}$$

The maximum airflow capacity of the existing duct system is estimated as 1,576 CFM.

STEP 4: Determine Sizing Approach and Capacity Requirements of ASHP

The most appropriate option is:

- **OPTION 4C: Emphasis on Heating**, and

  <u>Sizing Criteria:</u> Heating output that falls close to the house heating load at 17°F (-8.3°C); (Design heating load is 49,600 Btu/h at -4°F (-20°C))

Target Heating Capacity:

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

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

Target Heating Capacity is ASHP heating output of about 33,325 Btu/h at 17°F (-8.3°C)

STEP 5: Identify and Select ASHP Matching Key Requirements

The contractor has screened a number of possible ASHP systems and has identified three, centrally ducted heat pumps for the application that have heating capacities that fall close to the **Target Heating Capacity**. These are listed in Table 5 with the manufacturer's data showing rated heating capacities at an outdoor temperature of 17°F (-8.3°C).

Table 5: Manufacturer's Performance Data for Candidate Centrally Ducted Heat Pumps using "Sizing Option C"

Model	Number of Stages	Rated Cooling Capacity at 95°F (35°C) (Btu/h)	Min Cooling Capacity at 95°F (35°C) (Btu/h)	Min Cooling less than 125% of DCL ?	Heating Capacity at 17°F (-8.3°C) (Btu/h)	Turn-down Ratio at 17°F (-8.3°C)	Heating Airflow (CFM)
ASHP1-CD-60-1	1-stage	55,300	N/A	No	36,000	N/A	1,800
ASHP2-CD-48-2	2-stages	44,000	31,900	No	33,000 (high stage) 20,600 (low stage)	1.6:1	1,550 (high stage)
ASHP3-CD-48-V	Variable capacity	42,000	19,000	Yes	48,000 (high stage) 26,000 (low stage)	1.85:1	1,440 (high stage)

Using the extended performance data, heating and cooling performance curves for the three possible ASHP systems are plotted in Figure 22 versus outdoor temperature together with the house load characteristics.

- The heating output of all three ASHP choices matches closely with the heating load of the house at 17°F (-8°C); However the 5-ton, single-stage unit has significantly higher output at milder temperatures compared to the 2-stage and variable capacity units due to the lack of capacity control.
- The cooling capacity of the 5-ton single-stage unit has more than two times the design cooling load and is well outside the normal capacity range for cooling. This will result in very poor dehumidification performance.
- The larger 5-ton unit also requires an airflow of 1,800 CFM, which exceeds the maximum airflow capacity of the existing duct system by over 200 CFM.
- The 4-ton, 2-stage and 4-ton, variable capacity ASHP have airflow requirements of 1,550 and 1,485 CFM which both fall below the maximum airflow capacity rating of the existing duct system of 1576 CFM.
- The high stage heating capacity for the 2-stage system at 17°F (-8°C) is much lower than the variable capacity system and the variable capacity system shows a superior turn-down ratio over the full operating range.
- The cooling capacity of the variable capacity unit is lower than the 2-stage unit, and again the variable capacity has a superior turn-down ratio in cooling
- The thermal balance point temperatures for the three ASHPs are estimated at:
    - ASHP1: 15°F (-9°C);
    - ASHP2: 17°F (-8°C); and,
    - ASHP3: 3°F (-16°C).

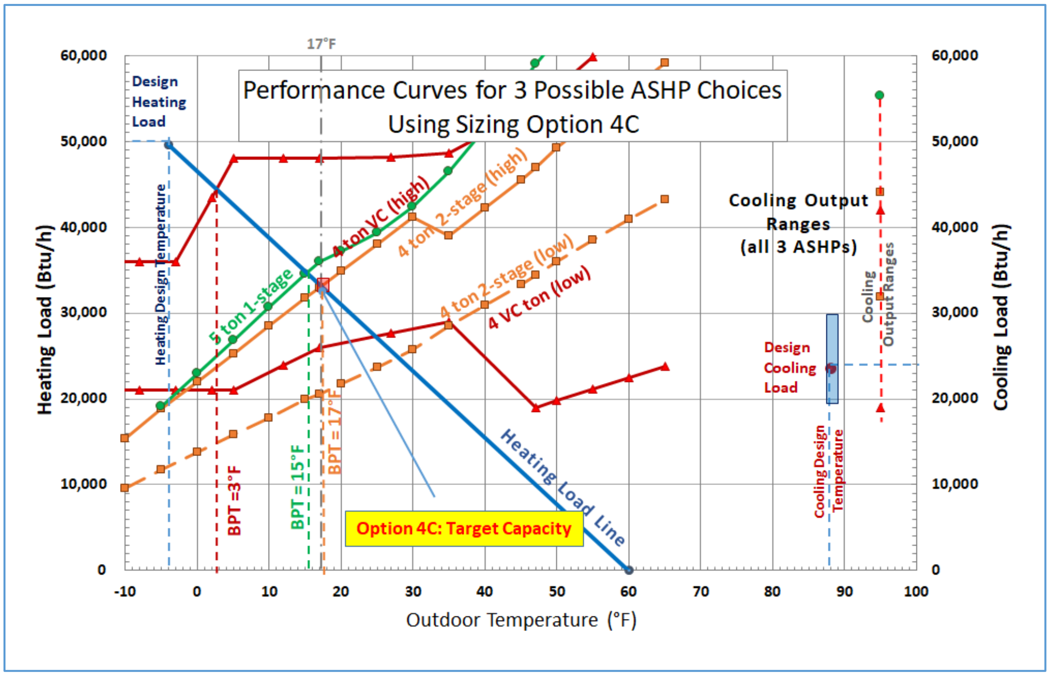


Figure 22: Performance Curves & Balance Point Temperatures for 3 ASHP Choices for Sizing Option 4C

Estimated Turn-down Ratios

The following analysis provides estimates of the turn-down ratios of the ASHPs being considered.

Using the high stage and low stage cooling capacities specified in the manufacturer's performance tables, the turn-down ratios for the ASHPs considered are:

- ASHP 1: N/A
- ASHP 2: 33,000 / 20,600 = 1.6:1
- ASHP 3: 48,000 / 26,000 = 1.85:1

Estimated Annual Heating Fractions provided by the ASHP

The following analysis provides estimates of the relative heating performance of each of the ASHPs under consideration.

- From the climate zone map (see Appendix 1 of this document) it is determined that the house is located in the "Cold-Humid" climate zone.

Using the thermal balance point temperature (t-BPT) for each system shown in Figure 22 the *"Fraction of Total Annual Heating"* that can be delivered above the t-BPTs were estimated for the "Cold-Humid" climate zone using the chart in Appendix 1 of this document.

The results are summarized below:

ASHP1: 5.0-ton, single-stage	t-BPT = 15ºF (-9°C) Fraction of Heating above the t-BPT = 76%
ASHP2: 4.0-ton, two-stage	t-BPT = 17ºF (-8°C) Fraction of Heating above the t-BPT = 72%
ASHP3: 4.0-ton, variable capacity	t-BPT = 3ºF (-16°C) Fraction of Heating above the t-BPT = 84%

The fraction of heating expected to be delivered by the 4-ton variable capacity unit is the highest, its turn-down ratio is superior, and its minimum cooling capacity is the lowest. The Variable capacity unit thus offers the maximum range of performance for this application.

The client has decided on the **4-ton, variable capacity ASHP**.

Heat Pump Performance Summary for the chosen model, ASHP3-CD-48-V

Heating:

- Balance point temperature is about 3°F (-16°C)
- Low-temperature cut-off is -13°F (-25°C)
- The turn-down ratio at 17ºF (-8°C) is 1.84:1
- The Fraction of Total Heating provided by ASHP above the thermal balance point temperature is estimated at 84%.

Cooling:

- Rated cooling capacity at 95°F (-8.3°C) is about 42,000 Btu/h, or 178% of the design cooling load.
- Low-stage or minimum cooling capacity at 95°F (-8.3°C) is about 19,000 Btu/h, or 81% of the design cooling load.

STEP 6: Define the ASHP Control Strategy

Following the decision tree shown in Figure 23:

1. The chosen heat pump is shown as capable of operating to -10°F (-23°C), which is well below the design temperature of -4°F (-20°C).
2. The client wants to displace as much propane usage as possible with the ASHP, so the unit will be unrestricted and allowed to operate over the full range of outdoor conditions. (i.e., No economic switch-over)
3. ASHP heating output capacity is less than the design heating load at the design temperature.

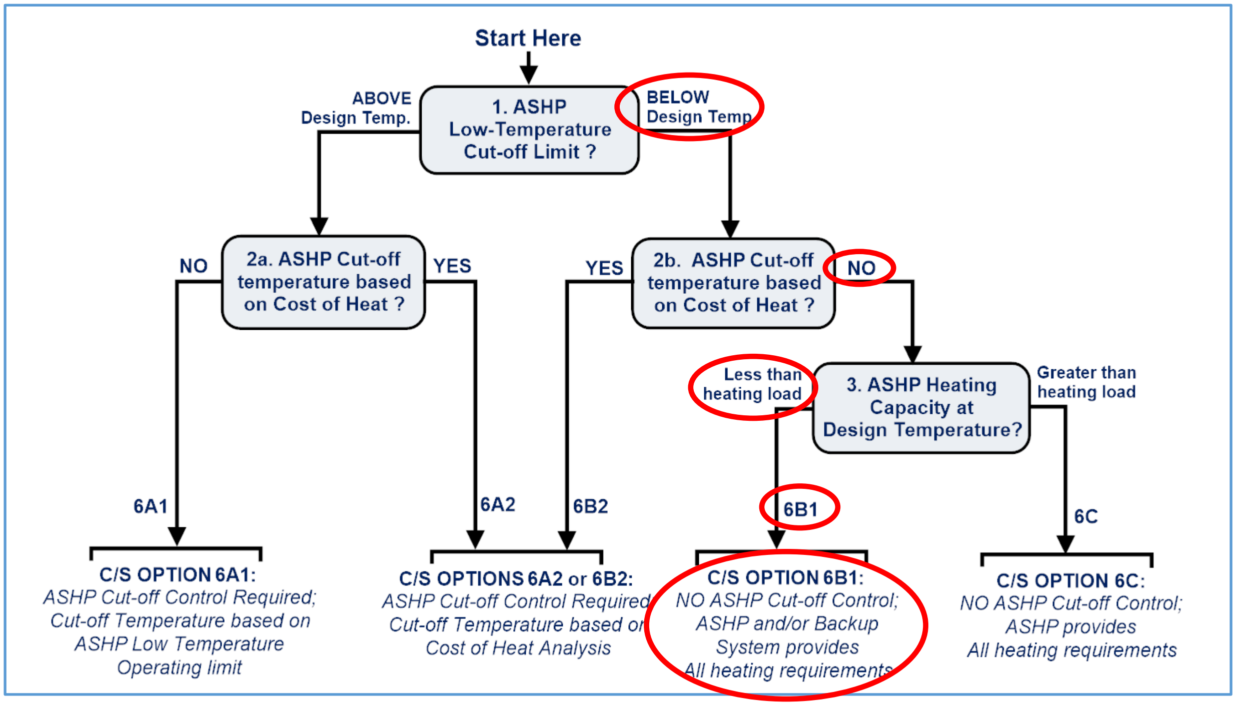


Figure 23: Decision Tree to Determine ASHP Control Strategy Option for Example C1

Control Option 6B1 is chosen, which allow the ASHP to operate over the full outdoor temperature range. No low-temperature ASHP cut-out control is required.

- A single, multi-stage indoor thermostat sequences the operation of both the ASHP and propane furnace used for back-up.
- With a centrally ducted “hybrid” or “dual-fuel” system, the ASHP and fuel-based furnace cannot operate simultaneously, but rather are operated in sequence, one at a time.
  - *The thermostat will first bring on the ASHP to satisfy a “heating call”, and only turn off the ASHP and bring on propane furnace if the “heating call” cannot be satisfied by the ASHP.*

STEP 7: Define Back-up Heating Requirements

Since the old HVAC system is being removed, a NEW backup heating system is required.

Backup heating will be provided by a high efficiency, propane gas furnace that will be controlled by a multi-stage thermostat which will turn the heat pump OFF when the furnace is operating.

Following the decision tree shown in Figure 24:

1. **Type of Installation:** Full heating system replacement;
2. **ASHP Operation Restricted at Low Temperature:** No, ASHP is not restricted by chosen control strategy *(i.e., Option 6B1)* or by ASHP low temperature cut-off.
3. **ASHP Heating Capacity at Design Temperature:** Less than heating load.
4. **Simultaneous operation of ASHP and Backup Heating**: No, not allowed.

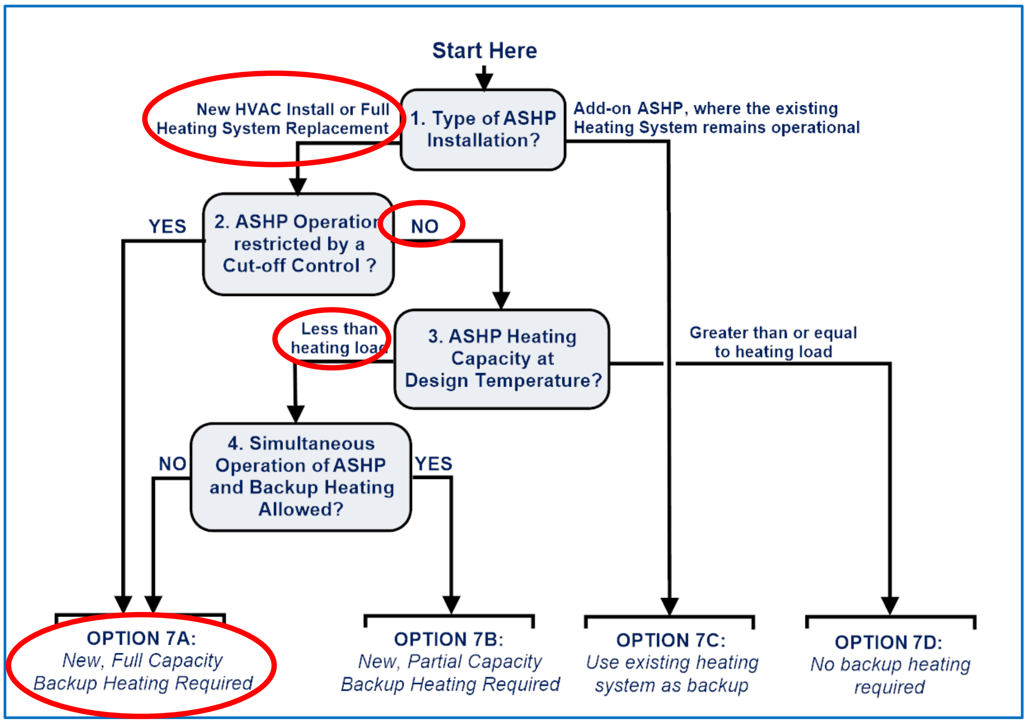


Figure 24: Decision Tree to Determine the Backup Heating Requirements for Example C1

Back-up Heating Option 7A is required.

- The output capacity of the new furnace must equal or be greater than 100% the design heat loss value of 49,600 Btu/h, and be capable of delivering the up to 1,440 CFM require by the 4-ton, variable capacity ASHP at the operating static pressure of the existing duct system.

The propane furnace chosen is an 80,000 Btu/h input, 2-stage furnace with an AFUE of 95%. Maximum output capacity is 76,000 Btu/h, or 153% of the design heating load of the house. This larger capacity furnace was selected based on its maximum airflow rating of 1,500 CFM, which is need to satisfy the airflow requirements of the 4-ton ASHP selected for the application.

Example C2: ASHP Add-on: Single-Zone Ductless Add-on to an Existing Electric Baseboard Heating System using "Sizing Option C" (Emphasis on Heating)

Background

An existing 2-storey house has an electric baseboard heating system and no air conditioning.

The client is interested in installing one or more ductless air-source heat pumps (ASHP) to provide most of the heating in winter and cooling in summer. The baseboard heating system will remain functional and will provide any additional heating during the coldest periods.

The house location has design temperature conditions of -4°F (-20°C) for heating and 88°F (31°C) for cooling.

STEP 1: Define ASHP Configuration

The house floor plan is shown below. The key occupied areas within the home are the main floor kitchen and family room, and the master suite/on-suite bath room and office on the second floor. These two areas are the target areas for the ASHP installation.

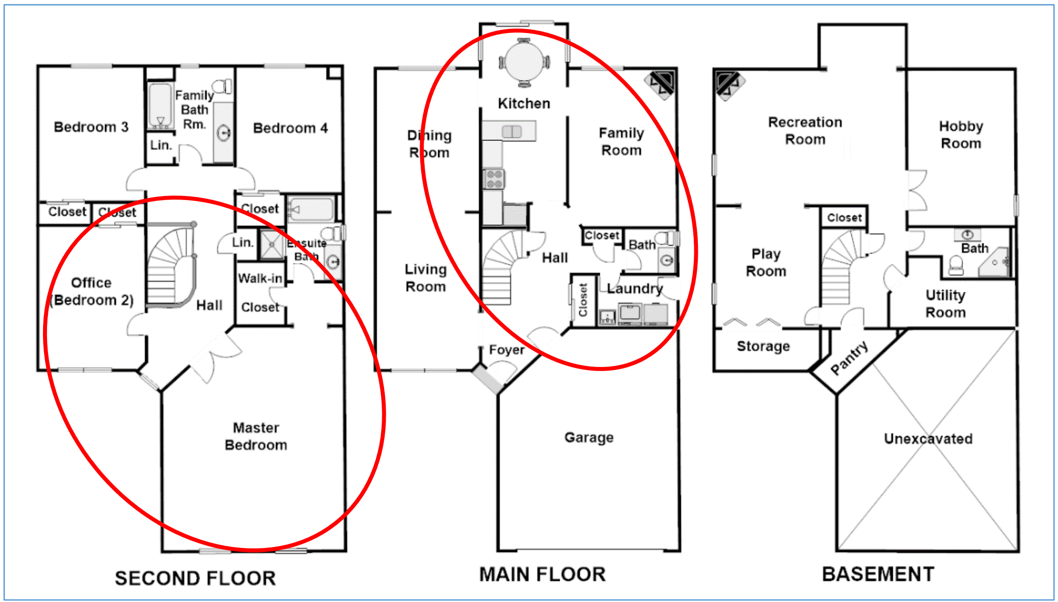


Figure 25: Two-storey house floor plans with Targeted Areas circled

Use **OPTION 1B: Ductless Mini-split, Single-zone, Add-on ASHPs**

- **Two units required:** one for the main-floor target area and another for the second-floor target area.

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

The indoor unit types selected to service the two target areas are:

- The second-floor area will use a ducted unit (Option 2D) installed in the attic space near the attic access hatch and will be ducted to the various rooms as shown in Figure 31.
- The main-floor area will use a wall-mount unit (Option 2A) installed on the exterior wall of the family room to service primarily the family room and kitchen. Some heat will circulate to the dining room and living room through the open doorways that link the rooms.

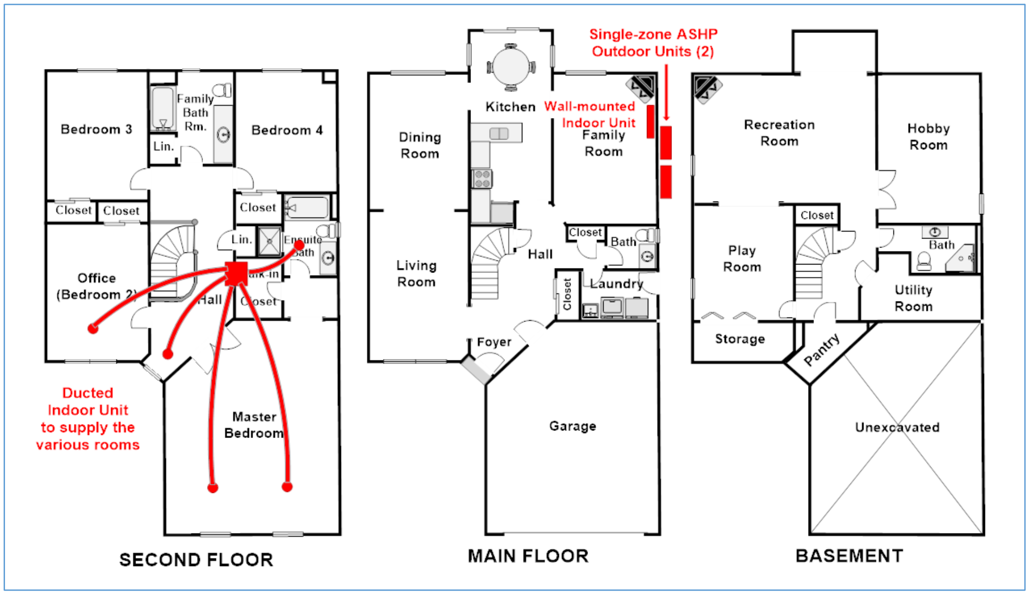


Figure 26: Type and location of the Indoor units in the two Targeted Areas

STEP 3: Determine Design Heating and Cooling Load Estimates

The house has had an Energy Audit completed and the report is available from the homeowner. None of the recommended upgrades have been made to the home or HVAC system since the audit was done.

Using **Option 3B: Energy Audit Load Estimates.**

The audit report states:

> *If you were to implement ALL of the building envelope retrofits recommended …, it is estimated that your home's design heat loss would be 43,641 Btu/h and its design cooling load would be 23,519 Btu/h (2.0 tons).*

Since the upgrades were not implemented, the reported design heat loss will need to be adjusted to back out the assumed building envelope improvements. The reported cooling load will not need to be adjusted. The report also states:

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

This means the reported design heating load in the audit report is 88% of the actual value (i.e. 100% minus the 12%). Therefore, the actual design heat loss for the house is equal to:

Design Heating Load = 43,641 Btu/h / 0.88 = 49,592 Btu/h

Based on the audit report, and the whole house has estimated design loads of about:

Heating: 49,600 Btu/h at a design temperature of -4°F (-20°C);

Cooling: 23,500 Btu/h at a design temperature of 88°F (31°C).

Target Area Load Estimates

Target area loads were estimated by proportioning the whole house load values by the floor area of the target areas as follows:

- Second-floor target area consisting of master bedroom, on-suite bath, hall and office has a floor area of about 1,130 square-feet
- Main-floor target area consisting of family room, kitchen, living room and dining room, has a floor area of about 1,130 square-feet
- The total finished area of the house, including the basement is about 3,300 square-feet.

Since the two target areas are the same size, each will have the same load values. The target area loads are estimated as:

Heating (DHL): 49,600 x 1,130 / 3,300 = 17,000 Btu/h at a design temperature of -4°F (-20°C);

Cooling (DCL): 23,500 x 1,130 / 3,330 = 8,000 Btu/h at a design temperature of 88°F (31°C).

STEP 4: Determine Sizing Approach and Capacity Requirements of ASHP

The most appropriate option is:

- **OPTION 4C: Emphasis on Heating**, and

  Sizing Criteria: ASHP heating output that falls close to the target area heating load at 17°F (-8°C);
  (Design heating loads for each of target areas is about 17,000 Btu/h at -4°F (-20°C)).

Target Heating Capacity (estimated using Equation 4):

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

Target Heating Capacity at 17°F = 17,000 x 43 / (60 – (– 4)) = 11,400

Target Heating Capacity is ASHP heating output of about 11,400 Btu/h at 17°F (-8.3°C) for each of the two target areas within the house.

STEP 5: Identify and Select ASHP Matching Key Requirements

The contractor has screened a number of possible ASHP systems and has identified three ductless mini-split heat pumps for the application, with heating outputs that fall close to the **Target Heating Capacity**. These are listed in Table 6 with the manufacturer's data showing rated cooling capacities at an outdoor temperature of 95°F (35°C), and rated heating capacities at 47°F (8°C) and 17°F (-8°C).

Table 6: Manufacturer's Performance Data for Candidate Ductless Heat Pumps using "Sizing Option C"

Model	Number of Stages	Rated Cooling Efficiency (SEER)	Rated Cooling Capacity at 95°F (Btu/h)	Rated Heating Efficiency (HSPF)	Rated Heating Capacity at 47°F (Btu/h)	Max/Min Heating Capacity at 47°F (Btu/h)	Max/Min Heating Capacity at 17°F (Btu/h)	Turn-down Ratio at 17°F (-8.3°C)
ASHP1-MS-12-V	Variable capacity	23.1	12,000	12.5	14,400	18,100 / 2,000	12,000 / 1,150	10.4:1
ASHP2-EL-18-V	Variable capacity	20	18,000	10.3	18,000	18,465 / 7,458	12,000 / 2,589	4.6:1
ASHP3-TO-18-V	Variable capacity	20.5	19,000	11.5	18,800	27,600 / 3,100	16,400 / 1,900	8.6:1

Using the NEEP CC-ASHP Product Listings published performance data, heating and cooling performance for the three candidate ASHP systems are plotted are plotted in Figure 27, together with the estimated load characteristics for the two target areas within the house.

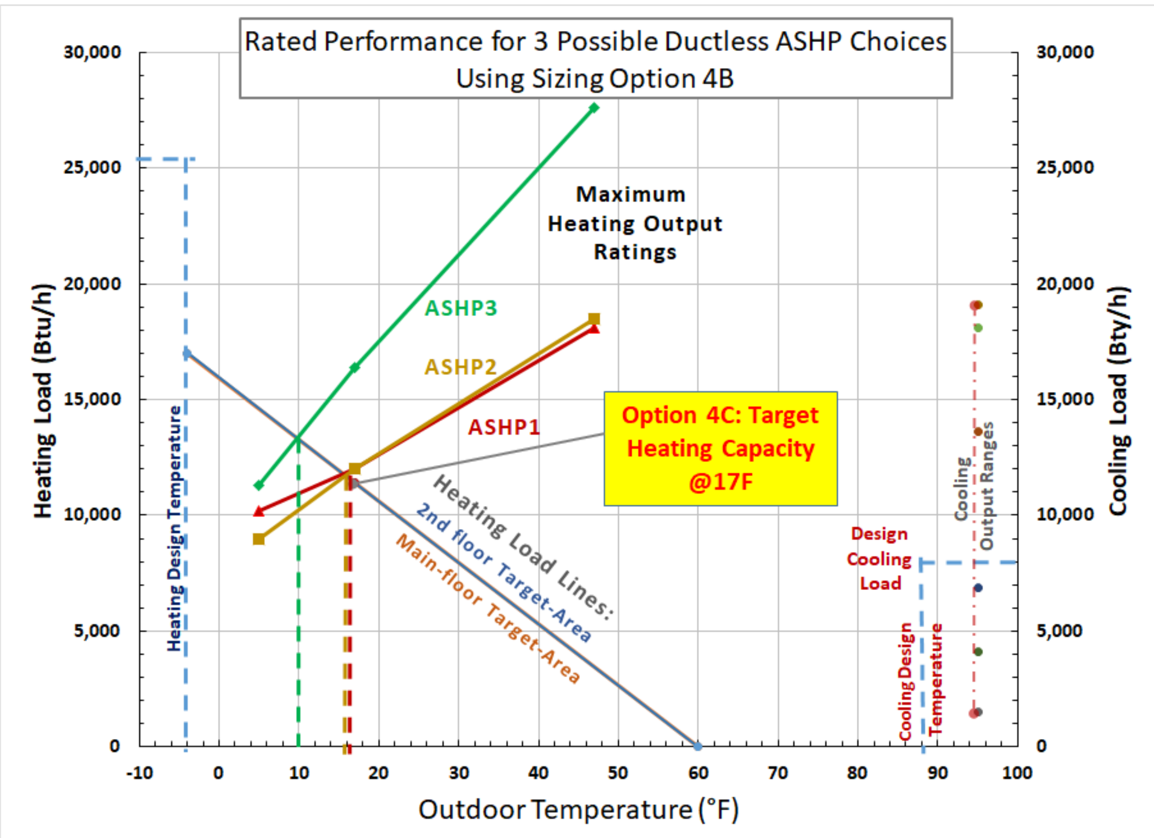


Figure 27: Performance Curves & Balance Point Temperatures for 3 ductless ASHP Choices using Sizing Option 4C

The heating characteristics of the three ASHP candidate units are somewhat different:

- ASHP1 has a rated heating capacity of 14,400 Btu/h at 47°F (8°C), but a maxcimum capacity of 18,100 Btu/h at this same temperature. It's capacity curve crosses the heating load line at very close to the target heating temperature and its turn-down ratio is superior to the other ASHPs. It also has the highest SEER and HSPF rating of the three systems. ASHP 3 is right-sized for the target heating load.

- ASHP2 is similar to ASHP 1 but has a lower turn-down ratio, lower HSPF and lower SEER than ASHP 1. ASHP 2 is right-sized for the target heating load, but is lower performing than ASHP 1.
- ASHP3, although having a high turn-down ratio as well as high HSPF and SEER ratings, is simply over-sized for the intended application.

The thermal balance point temperatures (t-BPT) for the three ASHP options operating in the two target areas are:

- ASHP1: 17°F (-8°C);
- ASHP2: 17°F (-8°C);
- ASHP3: 10°F (-12°C).

The rated cooling capacity for ASHP 1 is 12,000 Btu/hr at 95°F (35°C), however ASHP 1 has a cooling capacity range from 1,500 – 13,600 Btu/h @ 95°F (35°C). The design cooling load of 8,000 Btu/h at 88°F (31°C) is well within its operating range. ASHP1 is therefore not over-sized for the cooling load.

Estimated Turn-down Ratios

The following analysis provides estimates of the turn-down ratios of the ASHPs being considered.

Using the high stage and low stage heating capacities specified in the manufacturer's performance tables at 17F (-8°C), the turn-down ratios for the ASHPs considered are:

- ASHP 1: 12,000 / 1,150 = 10.4:1
- ASHP 2: 12,000 / 2,589 = 4.6:1
- ASHP 3: 16,400 / 1,900 = 8.6:1

Estimated Heating Fractions provided by the ASHP

The following analysis provides estimates of the relative heating performance of each of the ASHPs under consideration.

- From the climate zone map (see Appendix 1 of this document) it is determined that the house is located in the "Cold-Humid" climate zone.

Using the thermal balance point temperature (t-BPT) for each system shown in Figure 27 the *"Fraction of Total Annual Heating"* that can be delivered above the t-BPTs were estimated for the "Cold-Humid" climate zone using the chart in Appendix 1 of this document.

The results are summarized below:

ASHP1:	t-BPTs = 17°F (-8°C);	Fraction of heating above t-BPT = 72%
ASHP2:	t-BPTs = 17°F (-8°C);	Fraction of heating above t-BPT = 72%
ASHP3:	t-BPTs = 10°F (-12°C);	Fraction of heating above t-BPT = 84%

The amount of heating expected to be delivered by the 3 different systems is similar. The client decided on ASHP3 on the basis of its flatter heat output characteristic and higher heating output at low outdoor temperatures.

Heat Pump Performance Summary for the chosen model, ASHP3-MS-18-V

Heating:

- Balance point temperature is about 10°F (-12°C) for both target areas.
- Low-temperature cut-off is -15°F (-26°C).
- The fraction of target area heating provided by the ASHP above the thermal balance point temperature is estimated at about 84% heating required by each of the target areas within the house.

Cooling:

- The cooling output ranges from 1,500 to 13,600 Btu/h at 95°F (35°C) and the DCL is 8,000 Btu/h at 88°F (351°C). The units chosen are variable capacity heat pumps and should be capable of reducing cooling output to match closely to the design cooling loads of the target areas within the house.

STEP 6: Define the ASHP Control Strategy

Following the decision tree shown in Figure 28:

1. Manufacturer's data indicates that the chosen mini-split ASHP can operate at outdoor temperatures <u>below the design temperature</u> of -4°F (-20°C), so there is no requirement to restrict the ASHP operation based on low outdoor temperature.
2. The ASHP's are add-ons to an electric baseboard heating system, both operating on electricity, so there is no need for an economic switch-over to full backup heating.
3. ASHP heating output capacity is less than the design heating load at the design temperature.

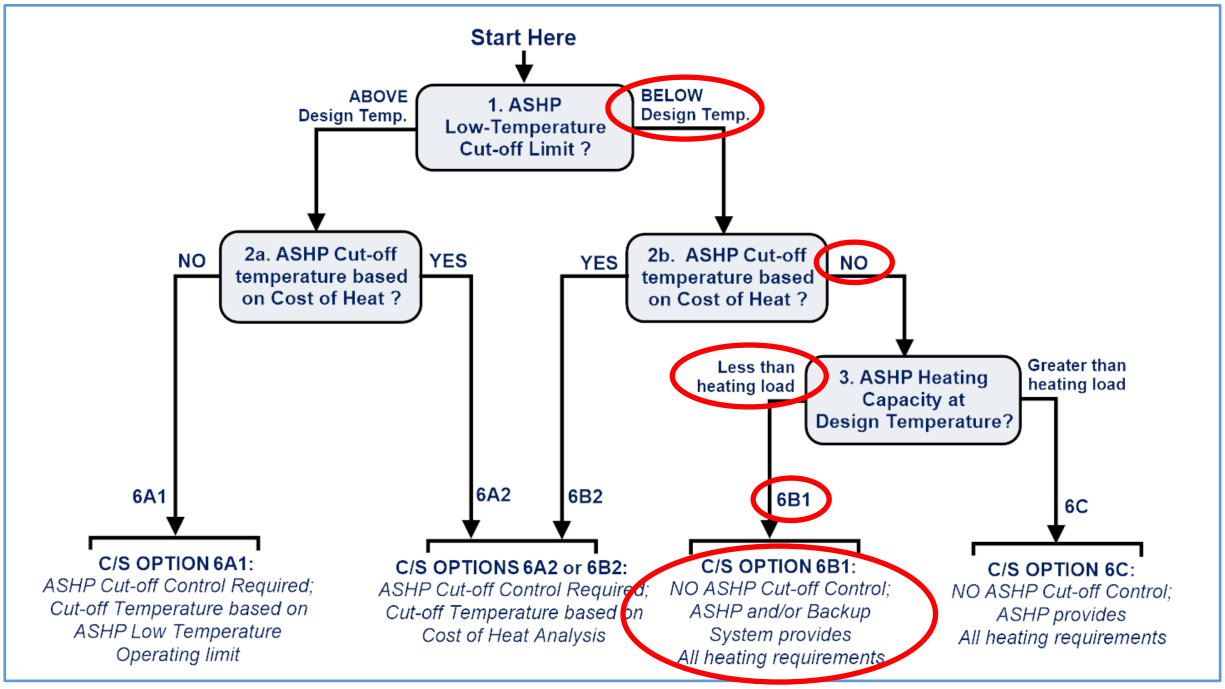


Figure 28: Decision Tree to Determine ASHP Control Strategy Option for Example C2

Control Option 6B1 is chosen with the add-on ASHPs and the original baseboard heating system operational over the full outdoor temperature range.

- Controls that integrate the ASHP and existing electric baseboard heating system were available for this ASHP model.
  - *Each ASHP indoor unit will control the existing baseboard heating system such that the baseboards provide heating only when the ASHP is unable to provide the heating requirements.*
  - *This controls-approach requires an auxiliary heat call connection to a wireless baseboard thermostat located in the target areas serviced by the ASHP. The wireless baseboard thermostat relays the auxiliary heat call signal to wireless receivers mounted in or beside the electric baseboards installed in the target areas serviced by the ASHP indoor unit. Only the baseboards occurring in the target areas being conditioned by the ASHP would require such controls.*

STEP 7: Define Back-up Heating Requirements

The two ductless ASHPs are add-ons to the original electric baseboard heating system, which remains intact and functional and has the capacity to meet the design heating load of the home.

Following the decision tree criteria shown in Figure 29:

1. **Type of Installation:** Add-on ASHP, where the existing heating system remains operational.

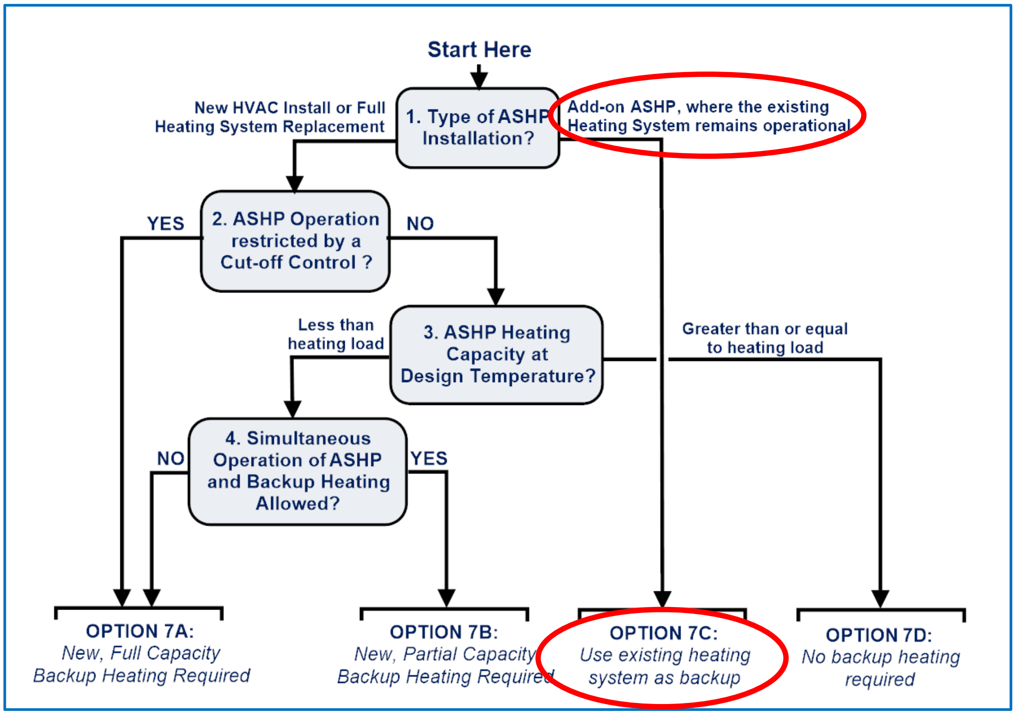


Figure 29: Decision Tree to Determine the Backup Heating Requirements for Example C2

Back-up Heating Option 7C is the most appropriate.

- Use the existing baseboard heating system as backup;
- No new backup system required.

Example D1: New HVAC System: A Centrally Ducted Cold Climate Air Source Heat Pump as the only Heating System using "Sizing Option D" (Sized on Design Heating Load)

Background

The client of a new home and is interested in installing a cold-climate, variable capacity air-source heat pump to do all of the space heating in their energy efficient home. Cooling is also of interest but is secondary to heating. The house is being designed with a central forced-air duct system.

The design temperature conditions for the location are: -13°F (-25°C) for heating and 86°F (30°C) for cooling.

STEP 1: Define ASHP Configuration

Use **OPTION 1A: Centrally Ducted ASHP**

STEP 2: Skip Step 2 when using **OPTION 1A: Centrally Ducted ASHP**

STEP 3: Determine Design Heating and Cooling Load Estimates

Use **Option 3A: CSA F280 Load Analysis.**

Being a new home, the designer has completed a F280 analysis, to determine the required heating and cooling loads. The design loads for the new house are:

Heating: 18,500 Btu/h at a design temperature of -13°F (-25°C);

Cooling: 11,800 Btu/h at a design temperature of 86°F (30°C).

STEP 4: Determine Sizing Approach and Capacity Requirements of ASHP

The appropriate option is:

- **OPTION 4D: Sized on the Design Heating Load**, and

  Sizing Criteria: ASHP heating output that falls at or close to the target heating capacity at the design temperature;

- **Target Heating Capacity** is ASHP heating of 18,500 Btu/h at -13°F (-25°C). *[equation 5]*

STEP 5: Identify and Select ASHP Matching Key Requirements

The contractor has identified two possible centrally ducted, variable capacity heat pumps for the application, in which the manufacturer has provided data at outdoor temperatures low enough to evaluate their effectiveness. Manufacturer's performance data for the two systems are provided in Table 7.

Table 7: Manufacturer's Performance Data for Candidate Centrally-ducted Heat Pumps using "Sizing Option D"

Model	Number of Stages	Max / Min Cooling Capacity at 95°F (Btu/h)	HSPF (Region IV)	Max / Min Heating at 47°F (Btu/h)	Max / Min Heating at 17°F (Btu/h)	Maximum Heating at 5°F (Btu/h)	Maximum Heating at -13°F (Btu/h)	Turn-down Ratio at 17°F (-8.3°C)
ASHP1-CD-030-V	variable capacity	Max: 30,000 Min: 18,000	9.7	Max: 34,000 Min: 18,000	Max: 32,000 Min: 16,000	32,000	25,000	2:1
ASHP2-CD-036-V	variable capacity	Max: 36,000 Min: 18,000	11	Max: 40,000 Min: 18,000	Max: 38,000 Min: 19,000	38,000	29,000	2:1

The two candidate ASHPs have maximum heating capacities at -13°F (-25°C) that exceed the design heat loss value of 18,500 Btu/h, so both have sufficient capacity at the target heating capacity. ASHP 1, while having a lower HSPF than ASHP 2, has a lower minimum heating capacity and will therefore run longer without cycling than ASHP 2. For this reason, it is preferred for this application. Both ASHP 1 and ASHP 2 have cooling capacities that exceed the upper limit of the design cooling load (125% of the DCL), but this is of lesser concern to the client.

Performance curves (based on performance as reported in manufacturer's extended performance tables) showing maximum and minimum heating characteristics for the two ASHP system are plotted in Figure 30 versus outdoor temperature together with the house heating load characteristic.

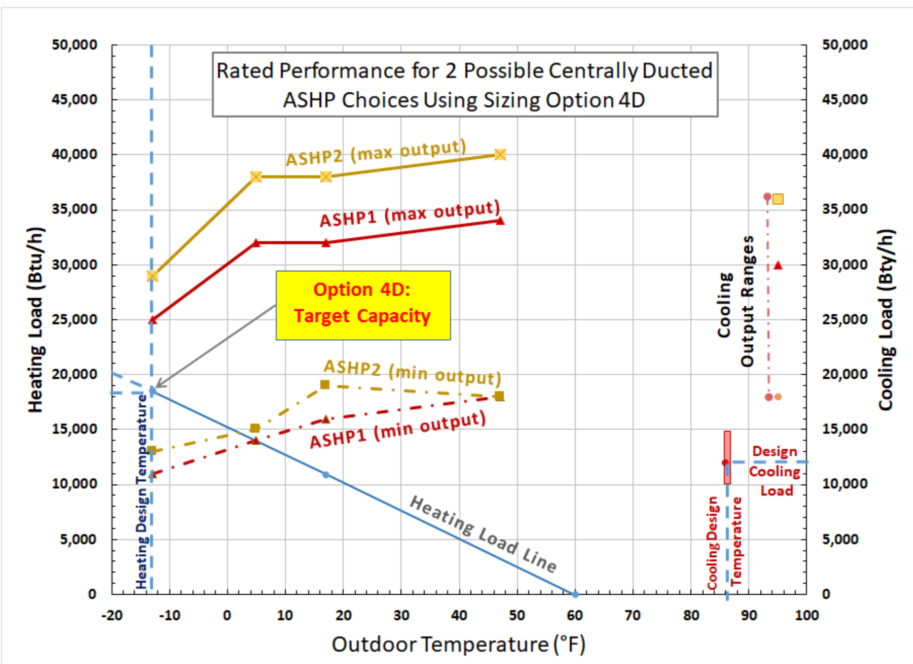


Figure 30: Variable-Capacity ASHP Performance with Sizing Option 4D (Sized on Design Heating Load)

The thermal balance point temperatures (t-BPT) for the two ASHP options are:

- ASHP1: t-BPT is below the design temperature of -13°F (-25°C);
- ASHP2: t-BPT is below the design temperature of -13°F (-25°C).

Estimated Turn-down Ratios

The following analysis provides estimates of the turn-down ratios of the ASHPs being considered.

Using the high stage and low stage heating capacities specified in the manufacturer's performance tables at 17F (-8°C), the turn-down ratios for the ASHPs considered are:

- ASHP 1: 32,000 / 16,000 = 2:1
- ASHP 2: 38,000 / 19,000 = 2:1

Estimated Heating Fractions provided by the ASHP

The two candidate ASHPs have t-BPT's that are below the design temperature and both will be able to satisfy 100% of the heating requirements of the house.

In this case, ASHP 1 was chosen as it matches the design heating load line of the house slightly better than ASHP 2.

Heat Pump Performance Summary for the chosen model, ASHP1-CD-30-V

Heating:

- Balance point temperature is below the design temperature of -13°F (-25°C).
- Low-temperature cut-off is below the design temperature of -13°F (-25°C).
- Maximum heating output at design temperature is about 32,000 Btu/h, or 173% of the design load. The ASHP has variable output, with the minimum output ranging from 44% to 53% of maximum output over the operating temperature range, which will extend ASHP runtimes.
- The fraction of total heating provided by the ASHP is 100% over the full heating season.

Cooling:

- Maximum cooling output is about 30,000 Btu/h, or 250% of the design cooling load.
- Minimum cooling output is about 18,000 Btu/h, or 150% of the design cooling load.

STEP 6: Define the ASHP Control Strategy

Following the decision tree shown in Figure 31:

1. The chosen heat pump is capable of operating below the design temperature of -13°F (-25°C).
2. There are no plans to restrict the operation of the ASHP, and it will be operational over the full range of outdoor temperatures.
3. The heating capacity of the ASHP exceeds the design heat loss of the house at the outdoor design temperature.

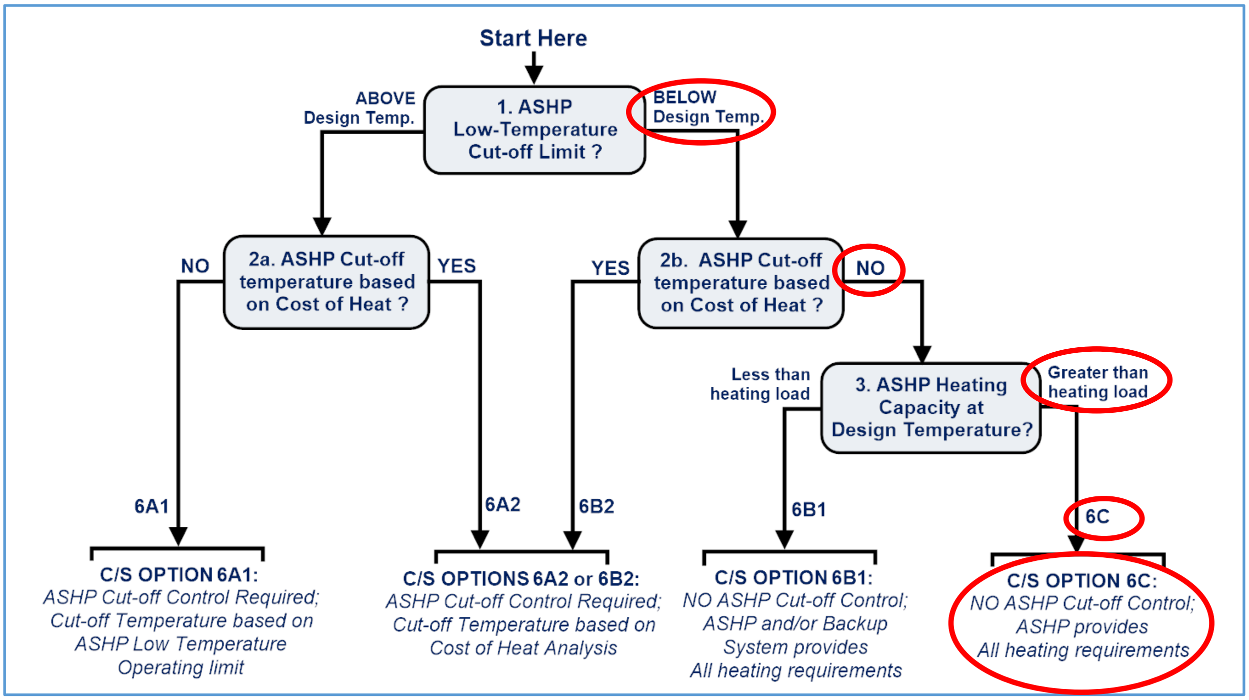


Figure 31: Decision Tree to Determine ASHP Control Strategy Option for Example D1

Control Strategy Option 6C is chosen; NO supplemental heating is needed.

STEP 7: Define Back-up Heating Requirements

Following the decision tree criteria in Figure 32:

1. **Type of Installation:** New HVAC installation;
2. **ASHP Operation Restricted at Low Temperature:** No, ASHP is not restricted by chosen control strategy *(i.e., Option C)* or by ASHP low temperature cut-off.
3. **ASHP Heating Capacity at Design Temperature:** Greater than design heating load.

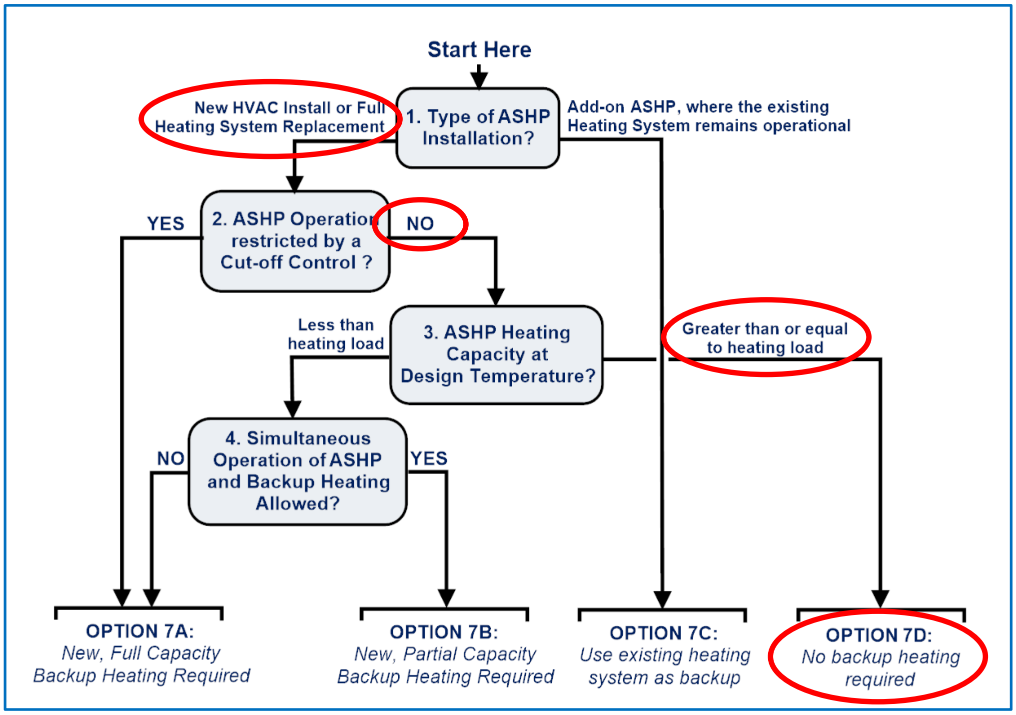


Figure 32: Decision Tree to Determine the Backup Heating Requirements for Example D1

Back-up Heating Option 7D is most appropriate; NO backup heating is required.

Example D2: ASHP Add-on: Multi-Zone Ductless Add-on to an Existing Electric Baseboard Heating System using "Sizing Option D" (Sized on Design Heating Load)

Background

The client is interested in installing an add-on, cold-climate, multi-zone air-source heat pump to provide most, if not all of the space heating in the home that is currently equipped with electric baseboard heating. Cooling is also of interest but is secondary to heating.

The design temperature conditions for the location are: -13°F (-25°C) for heating and 86°F (30°C) for cooling.

STEP 1: Define ASHP Configuration

Use **OPTION 1C: Mini-split, Multi-zone, Add-on ASHP**

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

The house floor plan is shown below. It was decided to treat each floor as a separate zone or target area.

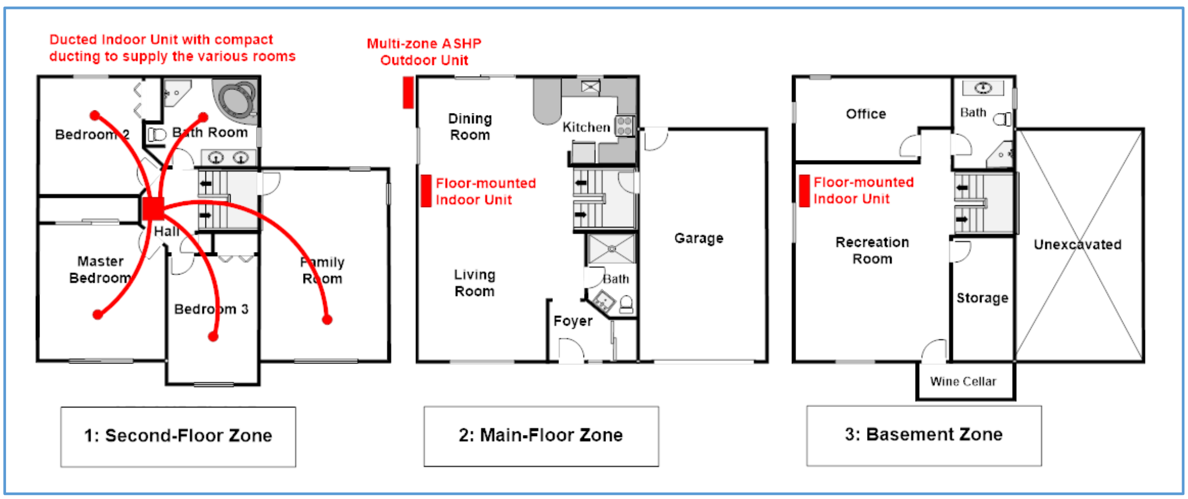


Figure 33: Floor plans for House with location and type of indoor unit shown

The indoor unit types selected to service each of the target areas are shown in Figure 33 and described below.

- The second-floor area will use a ducted unit (Option 2D) installed in the attic space above the hall and ducted to the various rooms as shown in Figure 33.
- The main-floor area will use a floor-mount unit (Option 2B) installed on the exterior wall of the dining room to service the open concept main floor.

- The basement area will be serviced by a wall-mounted unit (Option 2A) installed on the exterior wall of the recreation room.

STEP 3: Determine Design Heating and Cooling Load Estimates

Use **Option 3C: Modelling of the House Energy Requirements**

Since a zoned heating solution is being considered, the client and designer have agreed that developing an energy model of the house heating and cooling loads is the most appropriate approach to ensure proper sizing of the AHSP equipment.

An energy model was created for this house and produced the heating and cooling loads at the design conditions for each of major areas or zones within the home as summarized in Table 8.

Table 8: Energy Model values of Heating and Cooling Loads for various areas, or zones within the home

Area Name	Heating Loads (Btu/h)	Cooling Loads (Btu/h)
Second Floor - Family Room above the garage	2,277	2,900
Second Floor - Bedroom Zone (includes 3 bedrooms, bath room and hall)	13,783	8,574
Second Floor subtotal	***16,060***	***11,474***
Main Floor (includes kitchen, dining room, living room, bath room and foyer)		
Main Floor subtotal	***9,300***	***8,527***
Basement Area (includes rec room, office and bath room and storage room)		
Basement subtotal	***5,380***	***3,103***
Total whole house totals	***30,740***	***23,104***

The design loads for the house are:

Heating: 30,740 Btu/h at a design temperature of -13°F (-25°C);

Cooling: 23,104 Btu/h at a design temperature of 86°F (30°C).

STEP 4: Determine Sizing Approach and Capacity Requirements of ASHP

The appropriate option is:

- **OPTION 4D: Sized on the Design Heating Load**, and
  <u>Sizing Criteria:</u> ASHP heating output that falls at or close to the target heating capacity at the design temperature;

  Target Heating Capacity is ASHP heating of 30,740 Btu/h at -13°F (-25°C) *[equation 5]*

STEP 5: Identify and Select ASHP Matching Key Requirements

When selecting a suitable add-on multi-zone ASHP system, it is necessary to consider both the performance of the outdoor unit as well as the location and number of indoor units required in order to condition the priority target areas of the home under consideration.

Some multi-zone ASHPs may require the installation of a separate distribution box between the indoor and outdoor units. Extra consideration of installation may be required when designing these systems to accommodate the location of the distribution box.

Note that the selection process for multi-zone systems requires additional care and attention. Depending on the target heating capacity (and therefore the capacity of the outdoor unit), the designer may be limited to a minimum number of indoor units. Furthermore, indoor unit capacities may be too large for individual rooms or zones to be conditioned. When dividing the house into zones, it is therefore advised to follow the approach of determining “roughly equal sized zones”. This is in-line with Step 2 of NRCan’s Zoning Duct Design Guide [NRCan, 2017].

Multi-zone Outdoor Units Performance

The contractor has identified three possible multi-zone ductless, cold climate heat pumps for the application. Multi-zone, ductless ASHPs consist of a single outdoor unit that is connected to two or more indoor units.

Performance data for the three systems identified are provided in Table 9 for the outdoor units.

Table 9: Manufacturer’s Performance Data for Candidate Multi-zone Ductless Heat Pumps using “Sizing Option D”

Model	Number of Stages	Maximum Number of Indoor Units	Max / Min Cooling Capacity at 95°F (Btu/h)	Max / Min Heating at 47°F (Btu/h)	Max / Min Heating at 17°F (Btu/h)	Maximum Heating at 5°F (Btu/h)	Maximum Heating at -13°F (Btu/h)
ASHP1-MZ-030-V	variable capacity	3	Max: 28,400 Min: 12,500	Max: 28,600 Min: 11,400	Max: 28,600 Min: 13,100	28,600	25,200
ASHP2-MZ-036-V	variable capacity	4	Max: 36,000 Min: 9,600	Max: 45,000 Min: 22,500	Max: 45,000 Min: 22,500	45,000	34,200
ASHP3-MZ-042-V	variable capacity	5	Max: 42,000 Min: 11,200	Max: 48,000 Min: 24,000	Max: 48,000 Min: 24,000	48,000	36,500

Performance curves showing maximum and minimum heating characteristics for the three candidate ASHP systems are plotted in Figure 33 versus outdoor temperature together with the whole house heating load characteristic.

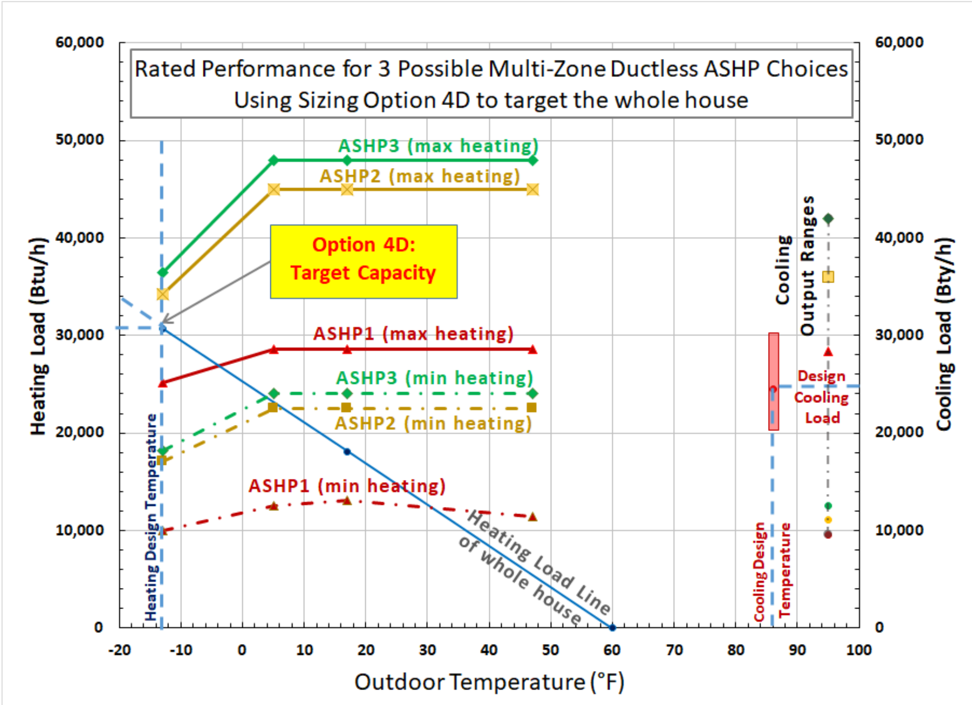


Figure 34: Add-on Multi-zone ASHP Performance using Sizing Option 4D targeting the full house load

Two of the three candidate ASHPs have maximum heating capacities that exceed the design heating requirement of the house of 30,740 Btu/h at an outdoor temperature of -13°F (-25°C).

- ASHP2 and ASHP3 have maximum heating outputs of 34,200 Btu/h and 36,500 Btu/h respectively, which exceed the total heating requirement of the house at the design temperature.
  - *The minimum heating outputs for ASHP2 and ASHP3 cross the house load line at about 5°F (-15C) and they will be capable of variable capacity operation at outdoor temperatures at or below this value. As a result, these larger heat pumps will operate on minimum output and be forced to cycle ON and OFF in order to control capacity for much of the heating season.*
  - *The ASHP2 outdoor unit can support up to 4 indoor units, while the larger ASHP3 can support up to 5 indoor units.*
- ASHP1 has a maximum output of 25,200 Btu/h at -13°F (-25°C), which is slightly below (i.e., 82%) the design heating requirement.
  - *The minimum heating output for ASHP1 crosses the house load line at about 30°F (-1°C) and will be capable of variable capacity operation at outdoor temperatures at or below this value. As a result, ASHP1 will be able to operate within its variable capacity range for much of the heating season.*
  - *The ASHP1 outdoor unit can support up to 3 indoor units.*
- The thermal balance point temperatures (t-BPT) for the three ASHP options are:
  - *ASHP1: t-BPT is -4°F (-20°C);*

- *ASHP2: t-BPT is below the design temperature of -13°F (-25°C); and,*
- *ASHP3: t-BPT is below the design temperature of -13°F (-25°C).*

Estimated Turn-down Ratios

The following analysis provides estimates of the turn-down ratios of the ASHPs being considered.

Using the high stage and low stage heating capacities specified in the manufacturer's performance tables at 17F (-8°C), the turn-down ratios for the ASHPs considered are:

- ASHP 1: 28,600 / 13,100 = 2.2:1
- ASHP 2: 45,000 / 22,500 = 2:1
- ASHP 2: 48,000 / 24,000 = 2:1

Estimated Heating Fractions provided by the ASHP

The following analysis provides estimates of the relative heating performance of each of the ASHPs under consideration.

- From the climate zone map (see Appendix 1 of this document) it is determined that the house is located in the "Cold-Humid" climate zone.

Using the thermal balance point temperature (t-BPT) for each system shown in Figure 27 the *"Fraction of Total Annual Heating"* that can be delivered above the t-BPTs were estimated for the "Cold-Humid" climate zone using the chart in Appendix 1 of this document.

The results are summarized below:

ASHP1: t-BPT = -4°F (-20°C); Fraction of Annual Heating provided above the t-BPT is about 96%

ASHP2: t-BPT is below design temperature; Fraction of Annual Heating provided is 100%

ASHP3: t-BPT is below design temperature; Fraction of Annual Heating provided is 100%

In spite of the balance point differences, the amount of heating expected to be delivered by the three different systems is very similar.

In this case, ASHP1 is chosen by the client as it follows the heating load line of the house much better than the other two alternatives. ASHP1's lower cooling capacity will also match the cooling requirements better than the other two candidate heat pumps.

The selection of ASHP1 outdoor unit does impose some limitation on the number of indoor units, as this model of multi-zone heat pump is restricted to a maximum of 3 indoor zones. Indoor unit considerations are discussed further in the following section.

Indoor Unit Capacities

The system configuration decided on by the client is a three-zone system (one zone per floor), as described in Table 10. The three-zones will be conditioned by individual indoor units that are connected to the single "multi-split" outdoor unit selected previously.

This particular model of multi-zone heat pump does not require a distribution box to be installed.

Different styles and capacities of indoor units were selected to best satisfy the thermal requirements of each of the zones as described in STEP 2 and shown in Figure 33.

Table 10: Indoor unit Types and Capacities used in the mini-split, multi-zone ASHP application

Zone No.	Indoor Unit Model	Indoor Unit Type	Nominal Rated Heating Capacity at 47°F (Btu/h)	Maximum Available Heating* Capacity at 47°F (Btu/h)	Maximum Available Heating* Capacity at -13°F (Btu/h)
1	IDU-D-15	Compact-ducted unit	18,000	14,260	12,550
2	IDU-F-09	Floor-mount unit	10,900	8,635	7,600
3	IDU-F-06	Wall-mount unit	7,200	5,708	5,020
All		**Total**	**36,100**	**28,600***	**25,170***

* Maximum Available heating outputs at 47°F and -13°F from the outdoor unit selected.

The rated heating capacity of the three connected indoor units exceeds the output capacity of outdoor unit chosen. The estimated available heating capacity for each of the zones at 47°F and -13°F is shown in the last two columns on the right side of Table 10, based on the total heating output available from the outdoor unit at these outdoor temperatures.

Heat Pump Performance Summary for the chosen outdoor model, ASHP1, connected to three indoor units

Heating:

- Balance point temperature is -4°F (-20°C).
- Low-temperature cut-off is below the design temperature -13°F (-25°C).
- Maximum heating output at design temperature is about 25,170 Btu/h, or 82% of the design load.
- The ASHP has variable output and turn-down ratio of 2.2:1, with the minimum heating output ranging from 10,000 Btu/hr to 13,100 Btu/hr over the operating temperature range. This variable capacity will extend ASHP runtimes during milder weather and when fewer than three indoor zones are calling for heat.
- The fraction of total heating provided by the ASHP is estimated to be about 96% over the full heating season.

Cooling:

- Maximum cooling output is about 28,400 Btu/h, or 123% of the design cooling load, while minimum cooling output is 12,500 Btu/h. The design cooling load of 23,140 Btu/h is therefore well within the operating range of the ASHP.

STEP 6: Define the ASHP Control Strategy

Following the decision tree shown in Figure 35:

1. Manufacturer's data indicates that the chosen mini-split ASHP can operate at outdoor temperatures below the design temperature of -13°F (-25°C), so there is no requirement to restrict the ASHP operation based on low outdoor temperature.
2. The ASHP's are add-ons to an electric baseboard heating system, both operating on electricity, so there is no need for an economic switch-over to full backup heating.
3. ASHP heating output capacity is less than the design heating load at the design temperature.

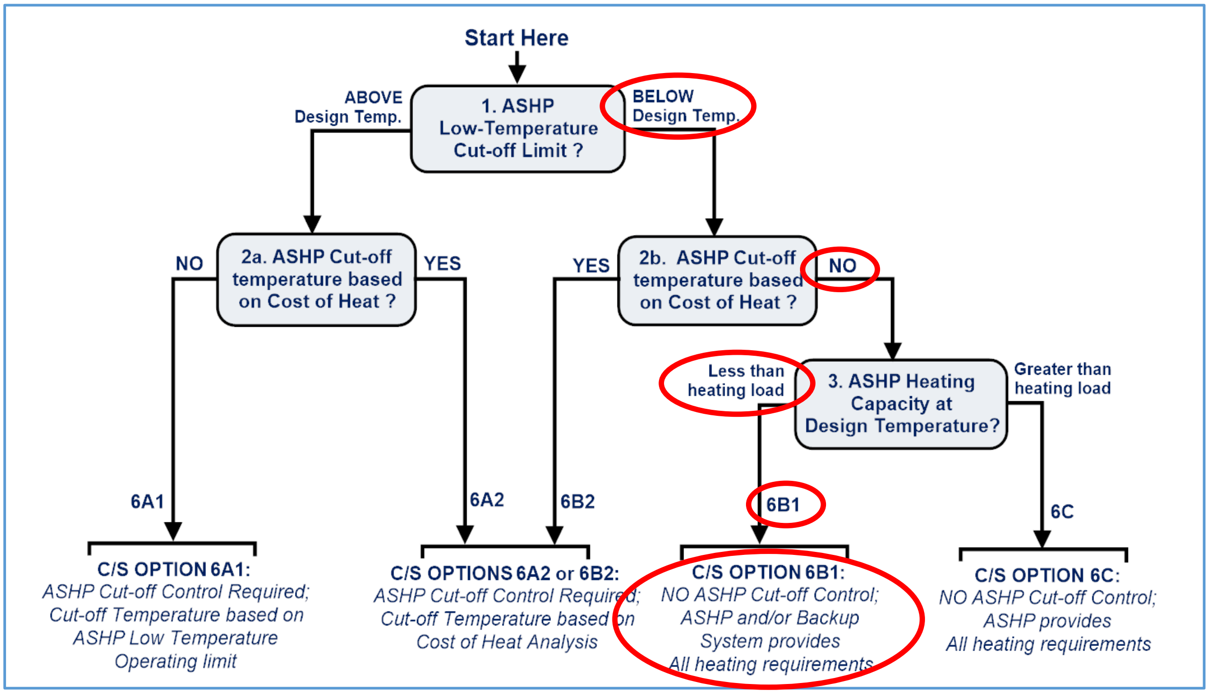


Figure 35: Decision Tree to Determine ASHP Control Strategy Option for Example D2

Control Option 6B1 is chosen with the add-on ASHPs and the original baseboard heating system operational over the full outdoor temperature range.

- Controls that integrate the ASHP and existing electric baseboard heating system were available for this ASHP model.
  - *Each ASHP indoor unit will control the existing baseboard heating system such that the baseboards provide heating only when the ASHP is unable to provide the heating requirements.*
  - *This controls approach requires an auxiliary heat call connection to a wireless baseboard thermostat located in the target areas serviced by the ASHP. The wireless baseboard thermostat relays the auxiliary heat call signal to wireless receivers mounted in or beside the electric baseboards installed in the target areas serviced by the ASHP indoor unit. Only the baseboards occurring in the target areas being conditioned by the ASHP would require such controls.*

STEP 7: Define Back-up Heating Requirements

The ductless multi-zone ASHP is an add-on to the original electric baseboard heating system, which remains intact and functional and has the capacity to meet the design heating load of the home, should the need arise.

Following the decision tree criteria shown in Figure 36:

1. **Type of Installation:** Add-on ASHP, where the existing heating system remains operational.

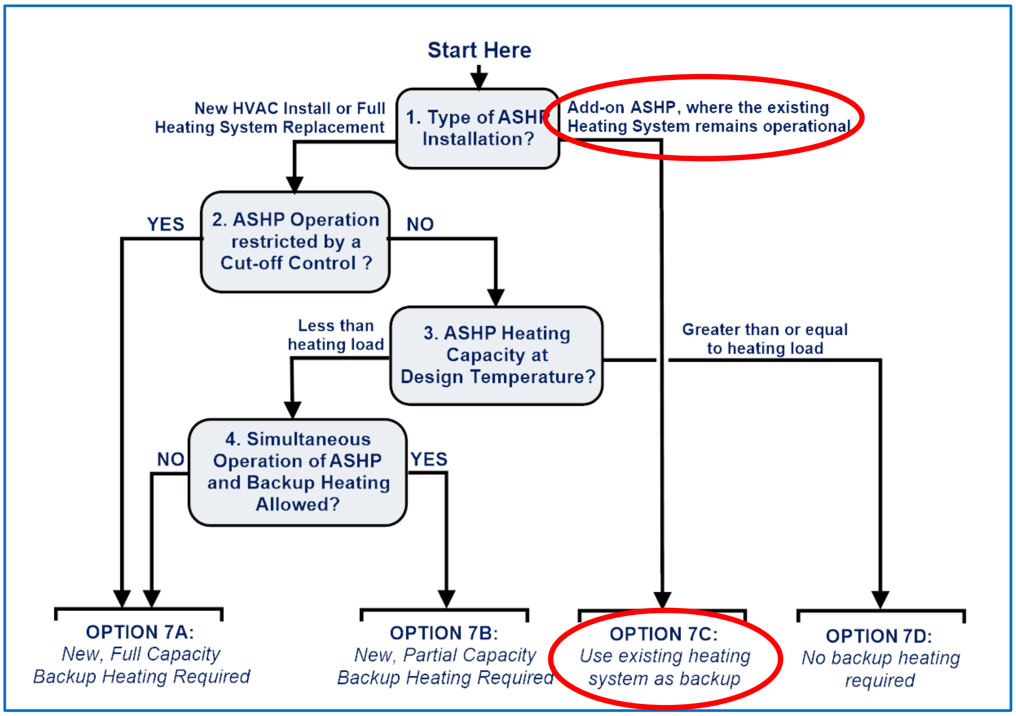


Figure 36: Decision Tree to Determine the Backup Heating Requirements for Example D2

Back-up Heating Option 7C is the most appropriate.

- Use the existing baseboard heating system as backup;
- No new backup system required.

APPENDIX 1 – Fraction of Total Annual Heating Above an Outdoor Temperature for Climate Zones in Canada

Use the following Chart to estimate total annual heating fraction that an Air-Source Heat Pump can deliver above a given outdoor temperature (e.g., Balance Point Temperature; Economic Cut-off Temperature, etc.).

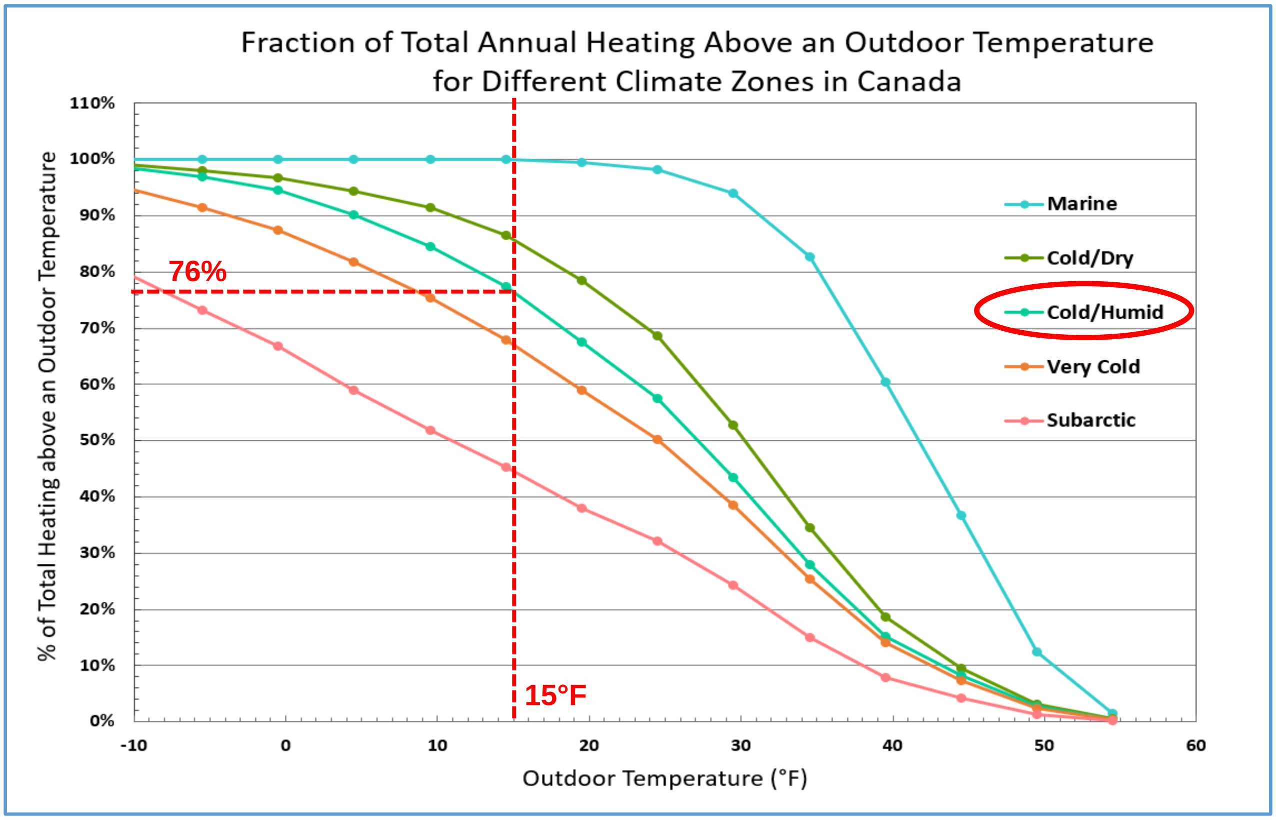


Figure 37: Fraction of Total Annual Heating Curves for Five Climate Zones in Canada

Example of how to use the chart:

1. **An ASHP, installed in a house has a heating thermal balance point temperature of 15°F.**
    a. *Plot a vertical line at 15°F on the horizontal axis.*
2. **The house is located in the Cold/Humid Climate Zone of Canada;**
   The climate zone for your location can be determined from the Map on the next page.
    a. *Mark the intersection of the vertical line with the appropriate climate-zone curve.*
    b. *Project a horizontal line from the marked point to the vertical axis*
3. **The Fraction of Total Annual Heating above the given temperature is read off the vertical axis of the chart.**

a. In this example, the fraction of Total Annual Heating delivered above 15°F is about 76%.

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.

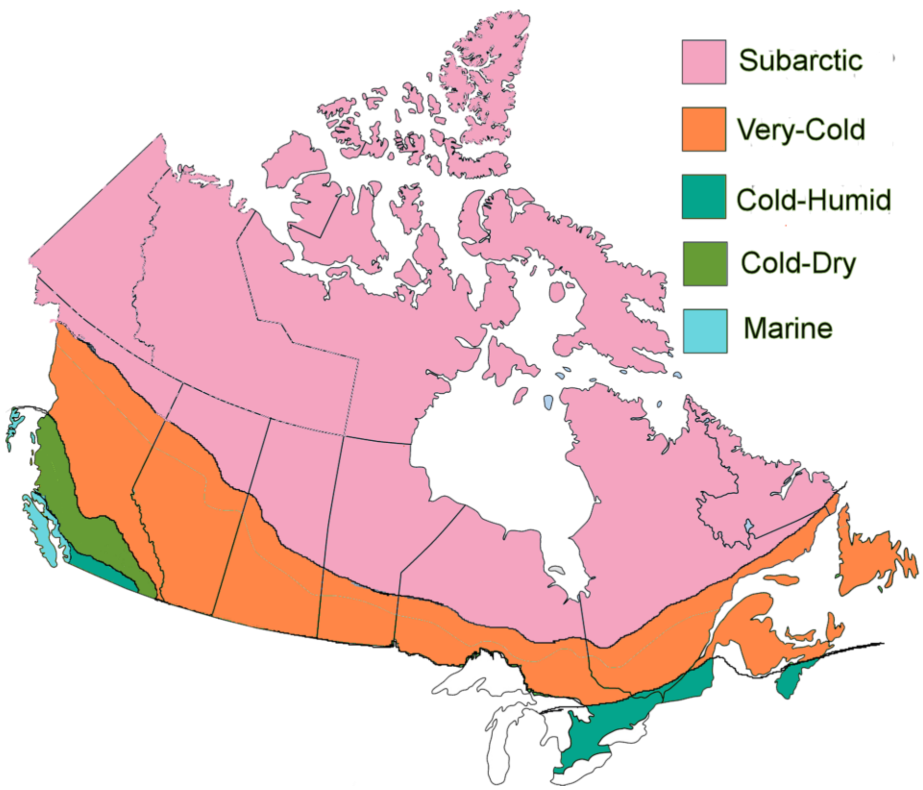


Figure 38: Climate Zone Assignments for Heat Pump Applications

APPENDIX 2 – References

Natural Resources Canada (NRCan). *Zoning Duct Design Guide.* Version 1.0. 2017. Available on-line.