September 4, 2025

REPORT#E25-347

Dual-Fuel Heat Pump Systems Analysis

Prepared For NEEA:
Noe Contreras, Senior Product Manager

Prepared By:
Ben Larson, Principal Consultant

Larson Energy Research
1932 Boulder Dr.
Menomonie, WI 54751

Northwest Energy Efficiency Alliance
PHONE
503-688-5400
EMAIL
info@neea.org

Table of Contents

Figures

Tables

Preface

This research examined current and emerging systems to identify those with lower operating costs, reduced energy use, and emissions. The initial list was narrowed down to a few promising combinations. The work began before NEEA established guidelines for dual-fuel measurement and market transformation reporting, so source energy, peak impacts, and load flexibility benefits were not included in the original scope. However, these elements present opportunities for future studies.

Executive Summary

Gas and electric systems can be combined in multiple ways to provide residential space conditioning. Referred to as dual fuel systems (DFS), different combinations and control schemes will lead to different operating costs, energy use, and emissions. Under contract to the Northwest Energy Efficiency Alliance (NEEA), Larson Energy Research (LER) conducted an exploratory analysis to identify dual fuel systems with lower operating costs, reduced energy use, and reduced emissions. LER considered a range of equipment types, sizes, control points, and climates. The analysis used hourly calculations of house load, by climate, over an entire year (8,760 hours). The main analysis outputs were annual energy use by fuel, consumer annual operating costs, and annual greenhouse gas emissions.

The analysis tool used in the project was an updated version of the Variable Capacity Heat Pump (VCHP) Levelized Cost Tool created by the Center for Energy and Environment (CEE). The tool was used for a previous NEEA project, the "Variable Speed Heat Pump Product Assessment and Analysis." [1] LER revised the tool to meet the specific analytic needs of the dual fuel system exploration.

The base case for analysis is assumed to be a gas furnace for heating with a central air conditioner for cooling.

LER explored a wide range of dual fuel system combinations. The gas component of each combination was either a furnace or a tankless water heater with a hydronic water-to-air heat exchanger in the air handler unit (TWH+AHU). These two gas systems were paired with heat pumps of different characteristics including single speed, average variable speed, low-load efficient, and cold climate. The distinctions are discussed in this report. Additional special cases of a single-zone ductless heat pump paired with the gas system and a central gas heat pump were considered.

Across these systems, the analysis examined different ways to control when the gas and electric heating systems are used. Those included "switchover," "supplement," and "smart dual fuel switching." Switchover controls are those that use only the gas system below a specified outdoor air temperature and only the heat pump above it. Supplement uses the gas system only when the electric heat pump cannot meet the heating load. This control applies only to the TWH+AHU systems. Smart dual fuel switching (SDFS) controls make real-time decisions about whether to heat with gas or electricity depending on an input signal like a time-of-use rate, utility price, or greenhouse gas emission schedule.

[1] Smith, Isaac. *Variable Speed Heat Pump Product Assessment and Analysis*. Prepared for NEEA. April 20, 2024. https://neea.org/resources/variable-speed-heat-pump-product-assessment-and-analysis

The major findings from this analysis include:

- **Natural gas use will decrease** with any dual fuel system compared to a furnace. The control type and switchover temperature are the largest determinants of use. In the scenarios analyzed, gas use was reduced by 50 to 88 percent.

- The **optimum size** for the heat pump in dual fuel systems **is around a 30 ºF balance point**. The balance point is the temperature above which the heat pump has enough output capacity to completely heat the house. Below that, additional heat sources are needed.
  - Smaller heat pumps, at a 40 ºF balance point for example, failed to meet the cooling load in most climates. It is not likely that a contractor would install an air conditioner that missed a significant portion of the cooling load. Therefore, a minimum reasonable size can be expected for heat pumps in dual fuel systems.
  - Efficiency gains diminish when sizing larger than a 30 ºF balance point. The lower efficiency of heat pumps at colder temperatures reduces their relative advantage over gas.
  - **Switchover temperature** should be set close to the heat pump balance point to make the most use of the investment in the equipment. Restated, for a heat pump with a balance point size of 30 ºF, a switchover temperature of 45 ºF fails to make use of the heat pump equipment over a 15-degree range. Having equal switchover and balance point temperatures will use the full capacity of the heat pump. In practice, it may make sense to set the switchover temperature two to five degrees above the balance point as a comfort margin.

- **Supplement/Simultaneous Systems** have lower operating costs than switchover systems in some cases. In mild heating climates, the benefit of being able to run the heat pump at lower outdoor temperatures is small since there are so few heating hours at temperatures below the balance point. Moderate heating climates like Spokane offer more opportunity to use the heat pump below the balance point, producing a larger reduction to the load on the gas equipment.
- The differences between electricity and gas rates matter. The consumer value proposition is strong in Washington and Oregon, but total cost benefits are harder to realize in Idaho and Montana where gas rates are lower compared to electricity rates.
- Any given set of electric and gas rates and gas heat system efficiencies establishes a "breakeven COP" for the electric system, the efficiency point the heat pump must exceed in order to decrease operating cost. That breakeven point depends largely on the relative rate differences.

- The heat pump type matters.
  - All heat pump types saved on operating costs in WA and OR. Some types of heat pump saved more than other types (for example see Table 9, under annual operating cost column).
    - Low-load efficient heat pumps appear to almost always have the optimum characteristics to pair with a dual fuel switchover system. Cold climate heat pumps may have an edge in colder climates like eastern WA and OR. In any climate, the

efficiency at low and minimum load appears to be the single most important characteristic. Thus, a cold-climate capable heat pump that also possessed this characteristic would be an outstanding choice. Ultimately, the best choice will depend on the upfront, initial cost differences and their comparison vs. operating cost.

- Better-performing heat pumps can save on operating costs in ID and MT where single-speed heat pumps cannot.

The project demonstrated that **smart dual fuel switching strategies can be extremely effective** at minimizing consumer costs, greenhouse gas emissions, or other values when operating in response to real-time signals. This benefit can offer additional value to the consumer if they are on time-of-use rate plans, and could be beneficial to the electric utility when seeking to minimize peak electric grid impacts. Implementing such a strategy to the utmost requires real-time data transmission from electricity and gas service providers to the system controller and end use equipment.

While this report covers neither source energy nor co-incident peak impacts, those elements do represent future study opportunities.

1 Introduction

The drive to limit greenhouse gas emissions in the face of climate change presents a clear opportunity to "add a four-way switching valve" to air conditioners and turn them into heat pumps. In practice, that may not be so simple. Certain heat pumps may be more advantageous than others and, likewise, certain gas heating systems may interact more or less favorably with the electric heating system. Larson Energy Research (LER) devised an analysis to explore a range of dual fuel systems and control schemes for those systems. Gas and electric systems can be combined in multiple ways to provide space heating. Different combinations and control schemes will lead to different costs, energy use, and emissions. This research explored systems that exist today and those that might exist soon to identify those with lower operating costs, reduced energy use, and reduced emissions.

To start, LER established the baseline system to be a condensing gas furnace and a central air conditioner. 2019 distributor data implies a current practice baseline of approximately 0.905 annualized fuel utilization efficiency (AFUE).[2] Those furnaces are paired with central air conditioners in all but the mildest cooling climates.

Working in conjunction with NEEA, LER identified the dual fuel system archetypes of interest. For gas heating, those included a furnace or a tankless water heater with a hydronic water-to-air heat exchanger in the air handler unit (TWH+AHU). These two gas systems were paired with heat pumps of different characteristics including single speed, average variable speed, low-load efficient, and cold climate. Additional special cases of a single-zone ductless heat pump, paired with the gas system, as well as a central gas heat pump were considered.

Across these systems, the analysis examined different ways to control when the gas and electric heating systems are used: "switchover" and "supplement." Switchover controls are those that use only the gas system below a specified outdoor air temperature and only the heat pump above it. Supplement uses the gas system only when the electric heat pump cannot meet the heating load. This control applies only to the TWH+AHU systems. Supplement controls allow the gas and heat pump components to run simultaneously.

The analysis tool used in the project was an updated version of the Variable Capacity Heat Pump (VCHP) Levelized Cost Tool created by the Center for Energy and Environment (CEE). The tool was used for a previous NEEA project, the "Variable Speed Heat Pump Product Assessment and Analysis."[3] LER revised the tool to meet the specific analytic needs of the dual fuel system exploration.

[2] Regional Technical Forum - Residential Gas Furnace UES

[3] Smith, Isaac. *Variable Speed Heat Pump Product Assessment and Analysis*. Prepared for NEEA. April 20, 2024. https://neea.org/resources/variable-speed-heat-pump-product-assessment-and-analysis

The tool calculates an hourly house heating or cooling load, in a variety of climates, over an entire year (8,760 hours) and then calculates the input energy required to meet that load depending on the equipment selection. The tool allows the user to define equipment efficiency with detailed heat pump performance curves. Gas system efficiency may also be defined. The tool also has adjustable parameters to control how and when the two heating systems run or interact.

The main analysis outputs are annual energy use (both gas and electricity), consumer annual operating costs, and annual greenhouse gas emissions. The analysis used utility costs for each state derived from U.S. Energy Information Administration (EIA) data.

Throughout this report, LER refers to “optimum” system types, sizing, and controls. These seek to minimize operating costs and energy use all while keeping first costs low. The analysis focused on the operational outputs of the equipment: energy use, utility costs to the consumer, and greenhouse gas emissions. The team then uses an inductive approach when considered first costs in assessing the optimum values. The term “operating cost” refers to the energy costs only, excluding maintenance costs.

The project scope excluded analyzing the equipment first cost; however, any decision about which system to install would include that cost. Some rules of thumb about first cost are useful when considering the analysis outputs. For instance, the variable speed equipment costs more than single speed, and cold climate heat pumps may cost even more. Additionally, larger equipment sizes will cost thousands of dollars more per ton. This information can be used to evaluate the scenarios. For example, if one system combination saves $200 per year in operating cost over another, it would accrue $3,600 over the 18-year equipment life. Thus, to be a positive value proposition to the consumer, the install cost needs to be less than $3,600. This information can be used to set the incremental cost limits a more “advanced” system can cost. Specific first cost inputs could lead to more precise statements about optimum systems; however, it is possible to make useful observations when the incremental operating cost differences between equipment types are small (tens of dollars per year). Incremental first costs are not likely to be low enough to justify the system upgrade. Further, the analysis frequently shows diminishing gains from progressive system upgrades. Eventually it makes sense to stop pursuing those gains due to the likelihood of increased first costs.

2 Methods

2.1 Variable Capacity Heat Pump (VCHP) Tool

The central analysis tool used throughout the project, the VCHP Levelized Cost Tool, is a spreadsheet created by the Center for Energy and Environment from an earlier NEEA project. The original tool development and its use is described in the "Variable Speed Heat Pump Product Assessment and Analysis" report.[4] The tool is a spreadsheet that calculates hourly house heating/cooling loads, and the energy input of the equipment needed to meet those loads. The hourly loads are calculated based on weather files (TMY3 data[5]) and account for temperature differences between inside and out, solar heat gains, internal heat gains, infiltration, thermal mass, and duct losses. The tool allows the user to define multiple house characteristics, such as heat loss (UA), and to schedule thermostat operation. On the equipment size, the tool allows the user to define heat pump performance curves (input power and output capacity as functions of outdoor temperature). The tool also contains calculations to allow equipment sizing to a user-specific, pre-determined size (like 2.5 tons) or sizing specification based to a user-input balance point.

LER expanded the tool's capabilities to meet the specific needs of the dual fuel analysis project.

Changes included:

- Altering or adding control points and logic relevant to dual fuel systems: gas system lockout temperature, gas system switchover temperature, backup heat setback recovery fraction.
- Calibration parameters that limit when heating may occur: first month of fall heating, last month of spring heating, and an average daily outdoor temperature below which heating will occur despite being in the "non-heating" season.
- Equipment-specific modifications: adding two types of gas systems and a ductless heat pump model capability.
- Accounting changes for the separate tabulation of gas and electric site input energy
- Adding weather data for five Northwest climates: Seattle; Spokane; Redmond, OR; Idaho Falls; and Missoula. These five are in addition to the existing Portland, Boise, and Bozeman data.
- Adding visualizations such as daily total energy consumption, labeled by fuel use, over the entire year bar graph.
- Creating the ability to define and run multiple scenarios at once to conduct the parametric analysis needed for this project. LER implemented this through a combination of tables which define labels and parameter values, and Visual Basic scripting. This was necessary to explore the hundreds of scenarios in which the team was interested.

[4] Smith, Isaac. *Variable Speed Heat Pump Product Assessment and Analysis*. Prepared for NEEA. April 20, 2024. https://neea.org/resources/variable-speed-heat-pump-product-assessment-and-analysis

[5] https://www.nrel.gov/docs/fy08osti/43156.pdf

The tool has numerous outputs. The most salient of those were collected in an output table for this project. The output table can be manipulated by filtering parameters to explore and compare all the scenarios modeled. Both the output table and the VCHP Levelized Cost Tool spreadsheet are provided separately from this report. The rest of this section describes detailed aspects of the calculations and tool usage.

2.2 Equipment

2.2.1 Gas Systems and Efficiency

For the gas-fired portion of the dual fuel system, LER considered two equipment types: a condensing furnace and a tankless water heater with air handler unit (TWH+AHU). The condensing furnace had a nominal efficiency of 95 AFUE and the TWH+AHU had a nominal efficiency of 97% at full load. Both systems were assumed to be modulating—that is, they could match their input and output rates to the demand. NEEA provided lab test data from other work which showed that the efficiency decreased as the equipment modulated down. The slope of a performance curve is not constant and varies as the percent of load changes. These slopes are different between the traditional furnace and a TWH + AHU configuration. The gas furnace efficiency decreases at higher part loads than the TWH+AHU. LER translated this data to a form that could be implemented in the calculation tool. Figure 1 graphs the efficiency equations used.

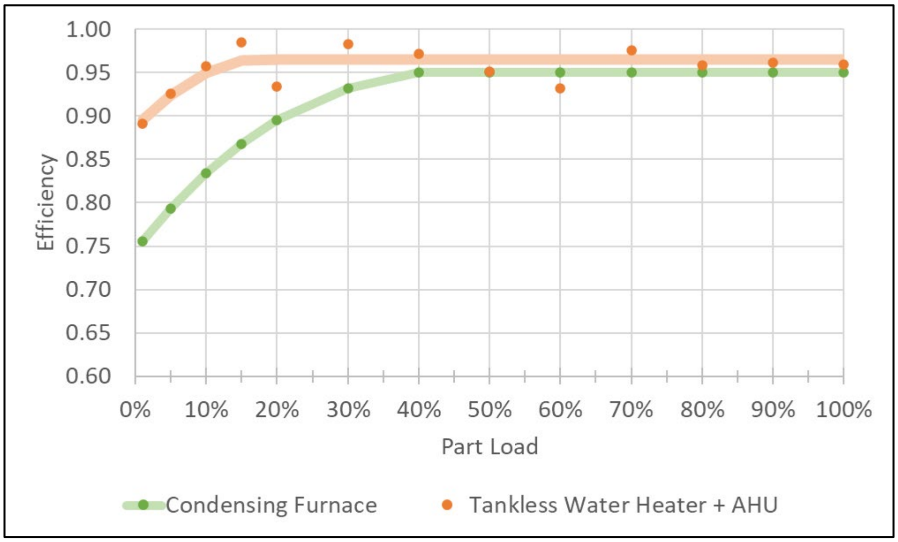

Figure 1. Gas System Efficiency by Part Load

The calculations are implemented as follows:

- For the furnace, part loads at 40% and above are fixed at 95%. Otherwise, efficiency equals:
  - $0.7438 + 1.7537*PL - 4.7687*PL^2 + 5.4413*PL^3 - 2.2034*PL^4$ where PL is part-load fraction

- For the TWH+AHU, part loads above 15% are fixed at 96.5%. Otherwise, efficiency equals:

- $0.8871 + 0.8919*PL - 3.0668*PL^2 + 3.956*PL^3 - 1.7117*PL^4$ where PL is part-load fraction

The part-load value was determined from the hourly model by calculating the runtime for the gas system every hour. If it runs for the entire hour, PL is set to 1. If it runs for one-quarter of the hour, PL is set to 0.25. This is a necessary simplification compared to how actual systems run because LER is working with an hourly calculation, not a sub-hourly one. The veracity of the simplification is best evaluated by looking at the calculation outputs. Figure 2 is a histogram of fractional runtime per hour (aka part load) for a gas furnace-only heating system. It shows that for more than 97% of all heating, the furnace runs at less than 50% part load. This matches the understanding the NEEA team and LER have of gas furnace operation (unpublished). Effectively, gas furnaces are oversized relative to the heating load for most operating hours. This can result in reduced efficiency.

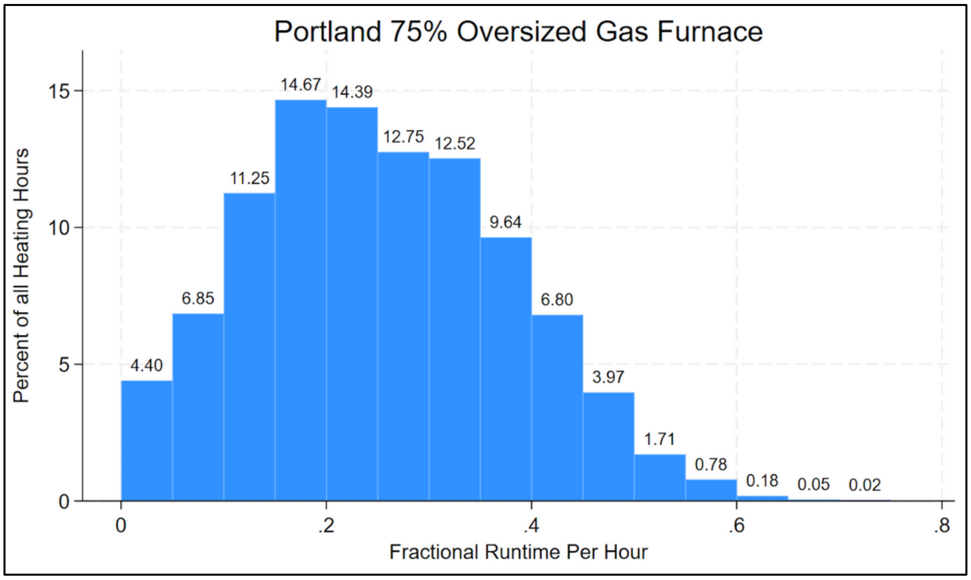

Figure 2. Gas System Load by Hour Runtime

2.2.2 Heat Pump Archetypes and Efficiency

The gas systems are paired with a range of heat pump equipment. LER worked with NEEA to define archetypes that represent a variety of different heat pump design and operational characteristics. This builds directly on the previously-mentioned 2022 “Variable Speed Heat Pump Product Assessment and Analysis” conducted by CEE.[6] An overwhelming body of work has suggested that SEER/SEER2, EER, and HSPF/HSPF2 are insufficient for predicting performance across a range of conditions. Instead, the actual input power and output capacity of the equipment at different temperatures (accounting for variable speed operating choices) is necessary to calculate energy use. This becomes even more important when combined with a gas backup system. LER deemphasizes the traditional metrics of SEER and HSPF; as a result, those metrics are provided only for some of the equipment.

[6] https://neea.org/resource/variable-speed-heat-pump-product-assessment-and-analysis/

Heat pump types include:

- **Single Speed Normal EER.** Meets the federal minimum for SEER2, 13.4, EER2, 9.0, and HSPF2, 7.5.
- **Single Speed "Good" EER**. A federal minimum compliant heat pump for hot climates. Has an EER2 of 11.2. Otherwise, the same heating performance as the other single speed heat pump.
- **Average Variable Speed HP**. A heat pump with a variable speed compressor. It is meant to reflect the market average. It is the same as the "Average One" archetype from the 2022 "Variable Speed Heat Pump Product Assessment and Analysis" study.
- **Low-Load Efficient HP**. A variable speed heat pump that has relatively higher efficiency at low part load. This product will perform well in mild heating conditions of ~30 ºF and above. At colder temperatures, it does not maintain its heating output capacity as well as a cold climate heat pump would. It is patterned after the Daikin Fit product line.
- **Cold Climate HP**. A variable speed heat pump that maintains output capacity at colder conditions, especially down to 5 ºF. This comes at the expense of relatively poor low load efficiency. It is patterned after the Mitsubishi Hyper M-Series product line.
- **Super Heat Pump**. A variable speed heat pump with both low load efficiency and cold climate capability. This is a hypothetical product merely to explore "what-if" scenarios.
- **Ductless Heat Pump**. A variable speed heat pump with a single indoor head serving the main zone of the house. Represents a middle-market efficiency. It uses the same implementation as the Regional Technical Forum "DHP2."
- **Gas Heat Pump**. This heat pump type uses the performance curves for the Anesi heat pump from Stone Mountain.

2.2.3 Heat Pump Sizes

In the analysis, the heat pumps were sized to four different balance points (the outdoor temperatures below at which the heat pump does not have enough output capacity to maintain the thermostat setpoint of the house on its own). The balance points used were 5 ºF, 20 ºF, 30 ºF, and 40 ºF. A lower balance point implies a larger heat pump size (tons). The heat pump performance curves define exactly what size is needed for a given balance point. For example, at a 20 ºF balance point, the single speed heat pump needs a nominal size of 4.7 tons while the cold climate heat pump needs only 2.7 tons nominal (because its performance curves show it maintains heating output to colder temperatures better). The four different heat pump sizes were modeled for both gas system types: the switchover with the condensing furnace and the supplement with the TWH+AHU.

While this report's analysis is focused on operating costs rather than total costs, including equipment purchase, the first costs of up-sizing equipment does inform the direction of investigation. The operating cost savings found in the simulations are on the scale of hundreds of dollars per year. Heat pump costs are on the scale of thousands per ton. LER chooses, therefore, not to investigate scenarios that would require very large heat pumps. While greater efficiency and lower operating costs could be achieved with such systems, the diminishing incremental benefits make them impractical and they are excluded from this discussion.

2.3 Controls

2.3.1 Switchover

In the switchover control, the system switches between electric and gas at a given outdoor temperature. Only one system is allowed to operate at a time. The values explored are 20 ºF, 30 ºF, 35 ºF, and 40 ºF. Below those temperatures, the gas system runs exclusively.

This control is used with the gas furnace cases; the control is also commonly available today on dual fuel systems. An outdoor temperature sensor is installed with the system and setting by the installer determines the temperature at which the switch occurs.

2.3.2 Supplement

With the supplement control, the gas system supplements the heat pump output when needed. This control allows both heat pump and gas furnace to operate simultaneously. Above the heat pump balance point the heat pump has enough capacity to heat the house by itself. Below the balance point the heat pump will continue to run (down to its operating limit temperature) but the gas system is needed to add supplemental heating. In the analysis, the gas system makes up the exact shortfall needed.

Due to the interacting heat transfer between heat exchange coils inside an air handler unit, this system can be tricky to build and operate. One company, iFlow, has demonstrated a tankless water heater with hydronic coil combination that can operate simultaneously with the heat pump.[7]
In the analysis, this control is paired with the gas TWH+AHU system option.

[7] https://www.iflowhvac.com/iflow-hybrid-heating-systems/

2.3.3 Ductless Heat Pump

The ductless heat pump (DHP) is a special control case because it directly heats a single zone in the house while the gas furnace provides heat to the whole house through the central duct system. The control scheme uses findings from NEEA's 2013 field study of ductless heat pumps, which shows a single zone DHP carrying a fraction of the house load that depends on the house heat loss rate and the outdoor temperature.[8] This fraction is usually not the full heating need of the house; the rest of the need is met by the gas furnace.

This control is more of a hypothetical demonstration of the likely upper end of DHP capability. This analysis assumes a system controlled by a single thermostat that prioritizes DHP heating, using its full capacity before supplementing with the gas furnace. In the field, orchestrating the operation of the two components can be difficult. In practice, the gas furnace is likely to provide some (or most) of the heat that could have been provided by the DHP compared to the hypothetical control strategy modeled here.

2.4 Utility Prices and GHG Emissions

2.4.1 Prices

The gas and electric utility consumer prices for the analysis were sourced from the U.S. Energy Information Administration (EIA).[9] The project team analyzed prices over the past 20+ years in Oregon, Washington, Idaho, and Montana. While electricity rates are similar in all four states, natural gas prices have been substantially lower in recent years in ID and MT than in OR and WA. In conjunction with NEEA, the team decided to treat the two pairs of states separately and use 2023 average rates for cost analysis. Those rates are shown in Table 1.

Table 1. Utility Prices

Location	Electricity $ / kWh	Gas $ / therm
OR, WA	0.1157	1.507
ID, MT	0.1161	0.953

2.4.2 GHG Emissions

The greenhouse gas emission factors used in the analysis are:

- Natural Gas: 11.7 lbs CO_2 / therm
- Electricity: 0.606 lbs CO_2e / kWh

[8] https://neea.org/resources/ductless-heat-pump-impact-process-evaluation-field-metering-report

[9] https://www.eia.gov/electricity/ and https://www.eia.gov/naturalgas/

The factor for natural gas is simply the chemistry of direct combustion of methane. It excludes distribution system CH_4 leakage and CH_4 & N_20 combustion emissions. The electricity factor is sourced from the Environmental Protection Agency's eGRID data.[10] The value is for the Northwest power grid average from 2022, the latest year for which data is available. The value represents the state of the grid in that year, which is quite similar to other recent years.

2.5 House Heat Loss Rate and Calculation Parameters

With the study goal of understanding the relative performance of different DFS combinations and controls, the project team chose to model a house with average heating and cooling loads. The house characteristics were held constant across all scenarios while equipment parameters varied. The team set the heat loss rate (UA) in the calculations to be 640 Btu/hrºF. This matches the average single family conductive UA from the 2022 Residential Building Stock Assessment (RBSA).

To ground the calculation tool in realistic results, LER performed a calibration exercise. As a reference point, the team referred to the RBSA Metering and RBSA I reports, which contained clear data on house characteristics and gas furnace usage. Several calculation tool parameters were altered until the tool produced 620 therms/yr for a 2,000 ft^2 house in heating zone 1 (Portland). These data come from RBSA I. The calculation tool parameters are "knobs" the team adjusts to get the tool to better match reality. The calculation approximates actual physics and heat transfer and not a perfect reflection. Therefore, the values on these knobs should not be interpreted literally but rather as adjustments necessary to get the imperfections in calculation to result in more accurate output. The following are the values found to give the best fit and then held constant throughout the rest of the work. They are documented here for future reproducibility.

- Heating enabled below 55 ºF outside air temperature (OAT)
- Cooling enabled above 80 ºF outside air temperature
- Heating setpoints 66 ºF/60 ºF (occupied / setback)
- Cooling setpoints 76 ºF/85 ºF
- Heating season of October through May unless daily average OAT outside that period is below 55 ºF.
- This prevents extraneous heating and cooling within the same day in the shoulder months.

The above parameters may seem somewhat extreme, especially the implied house balance point of 55 ºF for heating and 80 ºF for cooling. Without these values, however, the tool was predicting far more energy use than observed in regional baseline studies.

[10] https://www.epa.gov/egrid/summary-data. This analysis uses the average emissions value, not the marginal rate, because the new electric load from the DFS does not occur on peak. The gas equipment provides heating under the peak grid conditions.

Additional relevant calculation and control parameters include:

- The gas system is not allowed to run (locked out) above 40 ºF for DFS.
- For recovery from setback, the gas furnace is used to provide 100% of needed load (unless OAT is above 40 ºF). Given that a major advantage of a DFS is having the large output capacity of gas heating, it is rational to use it when significant output is needed. That happens when recovering from setback. Further, it is likely that even if the thermostat started recovery with the heat pump, it would inevitably switch to the gas system to recover the indoor temperature quickly enough.
- The heat pumps defrost according to an algorithm devised and implemented by CEE in a prior project using the tool. In this project, that defrost approach is used identically across all the heat pump archetypes.

2.6 Smart Dual Fuel Switching

The project also explored a system control concept sometimes referred to as smart dual fuel switching. This concept uses a dynamic signal – such as a utility rate schedule or grid-level GHG emissions – to prioritize the use of one fuel over another. To compare, the switchover control selects fuel based solely on outdoor temperature, and a supplement control always prioritizes electric fuel. Smart switching creates the possibility to prioritize specific goals such as consumer cost, GHG emissions, or utility marginal cost.

To demonstrate the smart switching concept, the project team simulated two approaches: One to optimize consumer energy costs based on a TOU (time of use) electricity rate schedule and another to reduce overall GHG emissions based on electricity generation GHG emissions. Smart switching could also be used for other goals by using different inputs (such as utility marginal cost) to select fuel.

2.6.1 Schedules

2.6.1.1 TOU Schedule

To simulate a dynamic time-of-use (TOU) signal, the team used the schedule from Puget Sound Energy's TOU pilot program.[11] The schedule is as follows:

- Winter Peak: $0.312776 / kWh Oct-Mar 7-10am, 5-8pm Weekdays
- Summer Peak: $0.1969 / kWh Apr-Sep 5-8pm Weekdays
- Off Peak: $0.063558 / kWh All other times

The schedule has winter peak rates nearly five times the off-peak rate for three hours in the morning and three in the evening. The summer peak rate is three times the off-peak and for only three hours in the evening.

[11] https://www.pse.com/en/account-and-billing/time-of-use

2.6.1.2 GHG Schedule

For the GHG emissions, the team used data from the EIA Grid Monitor platform, which provides the historic hourly GHG emissions for several utilities, balancing authorities, and regions.[12] The team selected the Puget Sound Energy data from 2023. The emissions averaged 0.34 lbs CO_2/kWh and ranged as shown in Figure 3. Note that this average is less than the Pacific Northwest grid average used in other parts of the analysis.

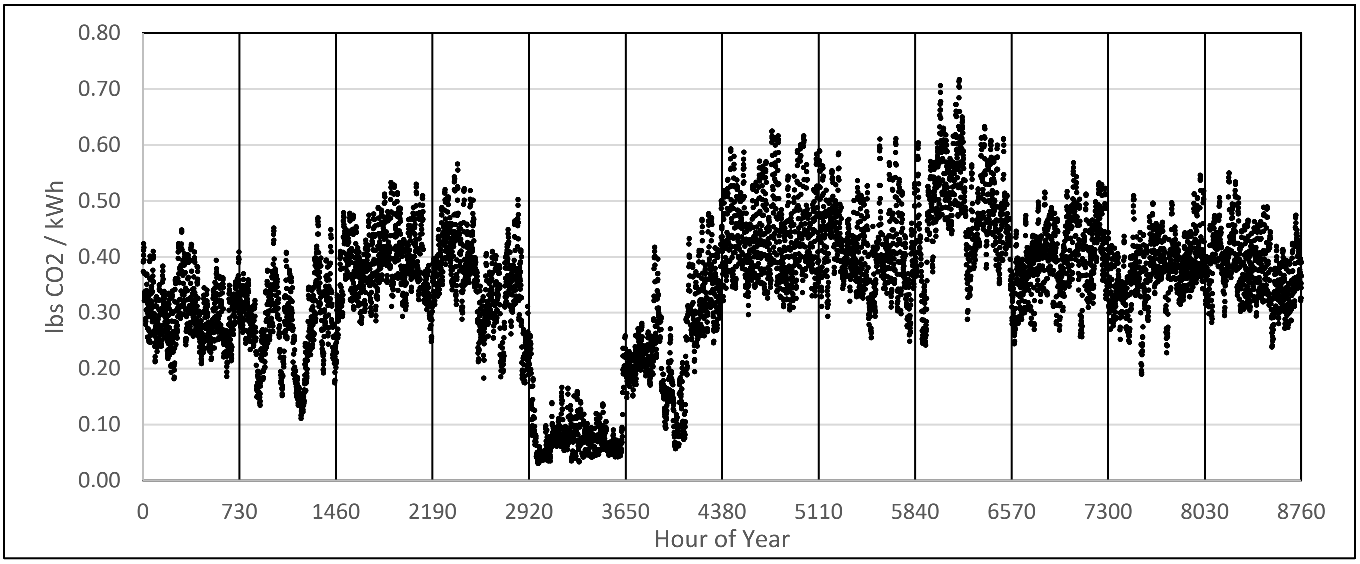

Figure 3. Puget Sound Energy 2023 GHG Emissions by Hour of Year

2.6.2 Control Optimizer

2.6.2.1 TOU Control

To optimize for consumer cost, the controller compares the cost of delivered heat for both fuel types during each hour of the year and prioritizes the fuel with the lower cost. Cost is the product of energy price and COP. Energy price varies based on the TOU schedule. COP is determined in the calculation based on operating conditions and equipment performance curves.

As an example, the COPs for gas and electric equipment over a given hour might be 0.95 and 3.0. If gas prices are $1.50 per therm and electricity is $0.06 per kWh, the cost of delivered heat per MMBtu is $15.79 for gas or $5.86 for electricity. In this situation, the controller will prioritize the heat pump. If, however, the electricity price were $0.31 per kWh, the delivered heat cost via electricity would increase to $30.26 per MMBtu. In that situation, the controller would use gas heating.

[12] https://www.eia.gov/electricity/gridmonitor/dashboard/electric_overview/US48/US48

For situations in which the controller prioritizes electric heating, but the heat pump does not have sufficient capacity, the system will use gas. For a gas furnace, this means switching to gas-only heating; for a TWH+AHU, gas supplements the heat pump. In our models all heating for recovery from setback was simulated with gas heating regardless of fuel prices.

2.6.2.2 GHG Control

To optimize for GHG emissions, the controller compares the CO_2 emissions for both fuel types during each hour and prioritizes the fuel with lower emissions. Gas-fuel emissions are based on the equipment's emissions for the heating load. Electric-fuel emissions are based on the grid emission levels from the GHG schedule and the electrical energy required to meet the heating load in that hour.

As with the simulation of a TOU control, the GHG control uses gas for setback recovery and when heating load exceeds heat pump capacity.

3 Findings

This section focuses on the highlighted findings and provides specific example scenarios to demonstrate each major conclusion. All the scenario output from the analysis is available in a large table in the accompanying spreadsheet (“DF Outputs 2024-11-22.xlsx”). In that spreadsheet, the user can filter based on different parameters to compare cases. The range of possible values for each parameter is shown below.

Equipment	Weather
<u>Tankless WH + AHU with AC</u> TWH+AHU with Cold Climate Heat Pump Gas HP with Variable Speed AC TWH+AHU with Single Speed Heat Pump Normal EER TWH+AHU with Single Speed Heat Pump Good EER TWH+AHU with Low-Load Efficient Heat Pump TWH+AHU with Average Variable Speed Heat Pump TWH+AHU with Super Heat Pump TWH+AHU with Ductless Heat Pump <u>Furnace with AC</u> Furnace with Cold Climate Heat Pump Gas HP with Variable Speed AC Furnace with Single Speed Heat Pump Normal EER Furnace with Single Speed Heat Pump Good EER Furnace with Low-Load Efficient Heat Pump Furnace with Average Variable Speed Heat Pump Furnace with Super Heat Pump Furnace with Ductless Heat Pump	Portland Seattle Spokane Boise Bozeman Redmond Idaho Falls Missoula **Heat Pump Size (Balance Point)** 5 ºF, 20 ºF, 30 ºF, 40 ºF **Switchover Temperature** -88 ºF, 20 ºF, 30 ºF, 35 ºF, 40 ºF **Special Control** None, TOU Optimized, GHG Optimized **Rate Schedule** None, PSE-TOU **GHG Schedule** None, PSE-2023

3.1 Daily Energy Use

Before discussing numerical results, a review of graphical output from the tool would be helpful. In the three graphs of Figure 4, each point represents the energy use, by system, corresponding to the daily average outside temperature. Red is the gas energy use, green is the heat pump in heating, and blue is the space cooling energy. All three graphs are for the Portland climate.

The first graph is for a gas furnace and single speed heat pump combination with the switchover temperature at 40 ºF and the heat pump sized to 30 ºF. The graph shows substantial gas energy use in the heating season. This happens when the hourly outside temperature drops below 40 ºF. Also apparent is heat pump energy use throughout the heating season. The HP even runs on the days when the gas furnace runs (this is for days with hours both above and below 40 ºF).

The second graph changes only one parameter compared to the first: the switchover temperature is lowered to 35 ºF. The result is an obvious decrease in gas heating use over the course of the season. Portland has a substantial number of load hours between 35 ºF and 40 ºF. The heat pump can heat the house for these because it is sized to a 30 ºF balance point. Interestingly, although not shown, the analysis also reveals that lowering the switchover to 30 ºF makes further reductions in gas usage but, in the Portland climate, they are not as dramatic as the change between 35 ºF– 40 ºF. Other climates will have slightly different results due to their temperature bin profiles.

The third graph changes both the equipment and control strategy. It shows a TWH+AHU paired with a single speed heat pump (sized to 30 ºF balance point as before). This scenario has no hard switchover point. Instead, the control runs the gas system to supplement the heat pump whenever the heat pump cannot meet the house heating load by itself.

Close examination of the graphs shows some gas usage above the heat pump balance point of 30 ºF. This is the gas system being used in recovery from nighttime setback or when the heat pump is defrosting.

These graphs clearly show several important, recurring findings: the switchover temperature has a large impact on gas usage, and the supplemental control strategies lead to the lowest gas use of any controls considered. The graphs also show that for the Portland climate, the cooling input energy need on the hottest days is relatively smaller than the heating input need on the coldest days.

30 °F Balance Point
40 °F Switchover

30 °F Balance Point
35 °F Switchover

30 °F Balance Point
Supplement

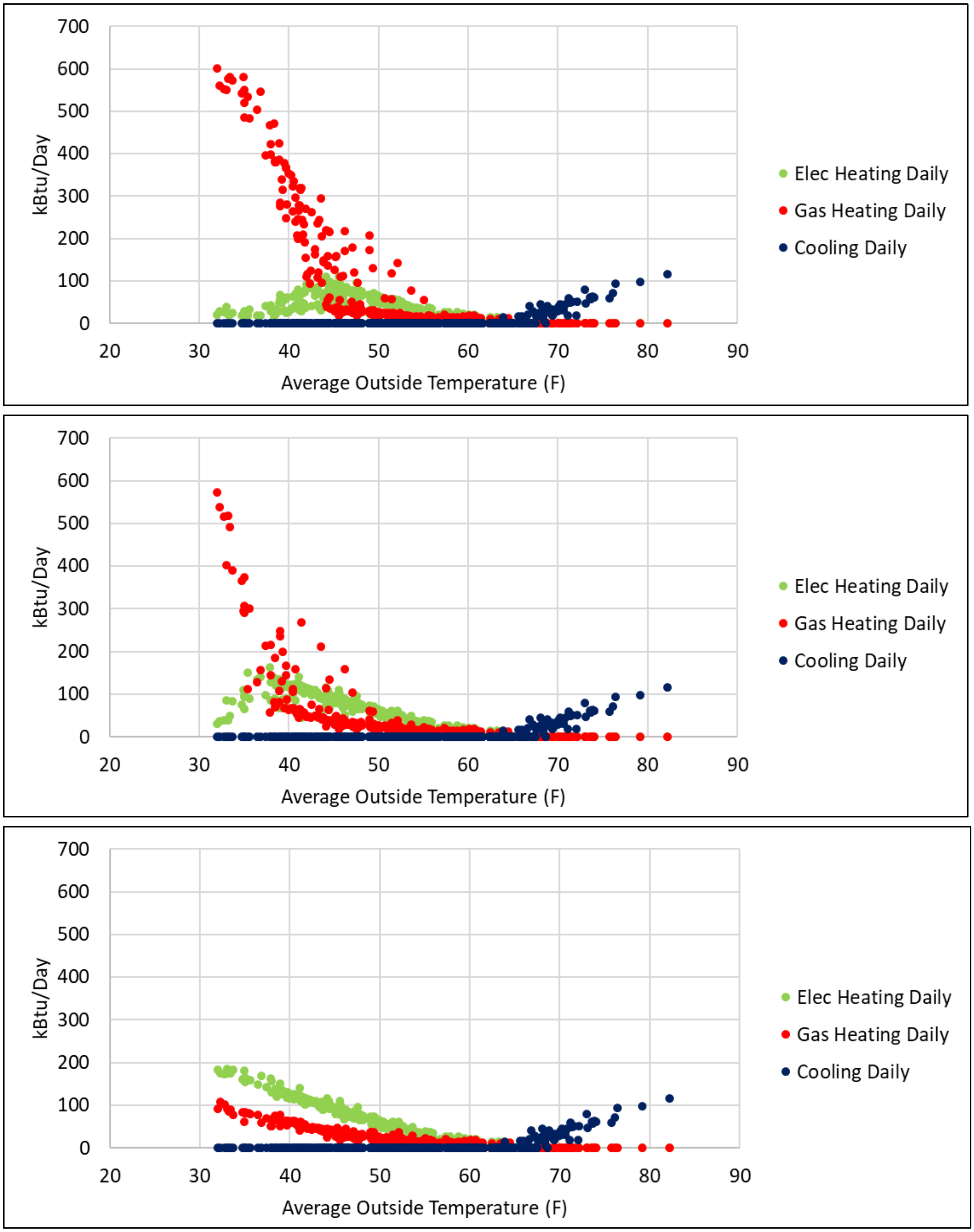

Figure 4. Daily Energy Use by Type vs. Average Outdoor Temperature

3.2 Fuel Use Impacts

Compared to a gas furnace, dual fuel systems will decrease gas use and increase electricity use on site. The largest lever determining gas use is neither the gas system efficiency nor the heat pump archetype, but the decision of when to use the gas. In the switchover control, this is the decision about which outdoor temperature value to switch between fuels. In the supplement system decision, this is largely the decision about the heat pump size. Table 2, for the Portland climate and a single speed heat pump (SSHP) sized to 30 ºF, shows gas consumption in the dual fuel cases can decrease 50% to 88% compared to the furnace-only case. Electricity use increases as gas use decreases. Greenhouse gas emissions drop in all cases compared to the base case.

Table 2. Fundamental Changes in Heating Fuel Use in Portland, OR

Heating System*	Control	Gas therms/yr	Electricity kWh/yr	GHG lbs. CO_2 / yr	Annual Operating Cost†
Portland					
Furnace		631	668	8,127	$1,093
TWH+AHU, Single Speed HP	Supplement	80	5,346	4,523	$806
Furnace, Single Speed HP	30 ºF Switchover	105	5,178	4,699	$821
Furnace, Single Speed HP	35 ºF Switchover	154	4,726	4,994	$842
Furnace, Single Speed HP	40 ºF Switchover	309	3,310	5,953	$912

*Heat pump sizes to 30 ºF balance point in all cases which equates to 3 tons. Air conditioner also 3 tons.

†Includes cooling cost of $65/yr

3.3 Heat Pump Size

The analysis explores heat pump sizes from 5 ºF to 40 ºF balance point. It revealed that the smallest heat pumps, the 40 ºF balance point, will not meet the cooling load. A contractor would be unlikely to size an air conditioner, or the heat pump replacing that air conditioner, too small to meet the cooling load. Further, consumers would be unlikely to accept such an installation. Therefore, somewhat oddly, the cooling load sets a lower bound on the heat pump size. In most climates across the Northwest, that size corresponds to a 30 ºF balance point.

Table 3 shows the total cooling load (cooling need), total cooling input energy, unmet load at the 40 ºF size, and unmet load at 30 ºF size across eight Northwest climates. The energy use is for the single speed heat pump. For reference, for the project's test house, the 30 ºF balance point is 2.7 tons and the 40 ºF balance point is 1.5 tons. The table shows that 20%–40% of the cooling need is unmet at the smaller size. The larger size works everywhere (except Boise, where an additional half ton is needed for the extra hot summers).[13]

Table 3. Cooling Loads and Sizing

Climate	Cooling Need MMBtu / yr	Cooling Energy MMBtu / yr	Unmet need at 40 °F Size MMBtu / yr	Unmet need at 30 °F Size MMBtu / yr
Portland	5.0	1.7	1.1	0.0
Boise	15.1	5.3	5.8	0.7
Bozeman	8.7	3.0	2.9	0.2
Seattle	1.5	0.5	0.3	0.0
Spokane	7.4	2.5	2.2	0.1
Redmond	8.1	2.8	2.6	0.1
Missoula	7.0	2.4	2.3	0.1
Idaho Falls	9.2	3.1	3.3	0.1

Larger heat pumps (i.e., lower balance points) mean more of the house load can be carried by electricity to lower temperatures. The analysis explored lower balance points and found that 30 ºF appears to be the "sweet-spot" size that offers the most consumer cost benefit, GHG reductions, while minimizing likely equipment costs.

First, the maritime Northwest climates like Seattle and Portland have very few load-hours below 30 ºF. If gas is going to be installed as part of the heating system, it certainly makes sense to use it in these cold hours instead of spending extra money on a larger heat pump.

Second, colder climates experience notable load hours between 30 ºF and 20 ºF. Table 4 compares variations in heat pump size for Spokane and Bozeman. The table is for a single speed heat pump switching over to the gas furnace below the balance point. In Spokane, however, the operating cost decreases only slightly. In Bozeman, with a different gas to electric rate ratio, the operating cost increases as the heat pump takes on the heating load at lower temperatures. This is explored in more detail in Section 3.5. Each additional ton of heat pump size is likely to cost thousands of dollars more on the initial install so, even in the case of the small operating cost savings in Spokane, the increased first cost is likely not to be recouped over the life of the product.

[13] Heating and cooling systems are traditionally designed to meet 99.6% of the heating and cooling hours in a year. Therefore, by definition, some of the load will be unmet. In practice, this means a part or all the dwelling will not be maintained exactly at setpoint under the hottest or coldest hours.

To conclude the sizing recommendation, the cooling needs determine a minimum size while the analysis shows few advantages to systems larger than the 30 ºF point. Therefore, the analysis yields an optimal size for dual fuel systems. These conclusions on sizing generally hold for all heat pump archetypes. Section 3.6.3 further discusses cold climate heat pumps.

Table 4. Heat Pump Size Variation Comparison

Balance Point	Heat Pump Size Tons	Heating Electricity MMBtu	Heating Gas MMBtu	Annual Operating Cost .	GHG Emissions .
Spokane					
20 °F	4.5	32.1	28.8	$1,626	9,613
30 °F	2.7	18.7	61.9	$1,657	11,034
40 °F	1.4	5.2	109.5	$1,513	13,814
Bozeman					
20 °F	4.5	30.4	70.4	$1,832	14,299
30 °F	2.7	15.8	108.2	$1,669	15,989
40 °F	1.4	4.2	151.7	$1,607	18,588

3.4 Gas System Type and Controls

3.4.1 Furnaces and Outdoor Switchover Temperature

The main determinant of gas and electricity consumption in DFS with furnaces is the switchover temperature. Which temperature to use when setting up a system is best determined by the heat pump balance point. This is because the capital cost of a heat pump, and the heating output capacity associated with it, is so much greater than that of a gas furnace. It does not make economic sense to purchase a heat pump larger than needed. Once that size is established, using the heat pump as much as possible is desirable. Stated another way, if the heat pump is sized to 30 ºF and the switchover is set at 40 ºF, there is 10 degrees of heat pump capability simply sitting idle. The most rational strategy is to set the switchover near the heat pump balance point. In practice, it may be useful to add a small comfort margin and set the switchover 2–5 degrees F above the balance point.

Taken together with Section 3.3, the analysis shows an optimal configuration for gas furnace dual fuel systems is to size the heat pump to 30 ºF and set the switchover to 35 ºF. Setting the switchover to a higher temperature not only fails to use the output capacity that the consumer paid for from the heat pump; it also increases the annual operating cost. Table 2 shows the cost increases when switchover is moved from 35 ºF to 40 ºF. The efficiency for all types of heat pumps is still high in this temperature range, which makes the heat pump outperform the gas furnace on a cost per unit heat delivered basis.

3.4.2 TWH+AHU – Supplemental Heating Control

The TWH+AHU system concept enables not switching over exclusively to gas based on outdoor temperature. Products such as those from iFlow have solved the engineering challenge to allow simultaneous gas and heat pump operation. This allows the gas system to supplement the heating output of the heat pump while the heat pump continues running. It also means no switchover points to explore. Overall, the system design maximizes heat pump use.

Table 5 shows the supplemental control can result in more operating cost savings than the furnace/switchover system. While the cost advantage in Portland is slight, it is substantial in colder climates like Spokane. The difference across climates is due to the heat pump still being able to offer a lower cost way to heat, below 35 ºF, even though it is not able to carry the house heating load by itself. Portland has few heating load hours below this switchover temperature, so the supplement DFS combination does not have the ability to make a difference.

Table 5. Supplemental Systems: TWH+AHU

System	Electric Heating Input MMBtu/yr	Gas Heating Input MMBtu/yr	Total Heating Input MMBtu/yr	Electric Heating Cost	Gas Heating Cost	Total Heating Cost
Portland						
Furnace with AC	2.3	63.1	65.4	$77	$951	$1,093
TWH+AHU, SSHP Supp.	18.2	8.0	26.2	$619	$120	$806
Furnace, SSHP Switch at 35F	16.1	15.4	31.5	$547	$232	$842
Spokane						
Furnace with AC	2.4	115.3	117.7	$82	$1,737	$1,916
TWH+AHU, SSHP Supp.	31.3	25.5	56.8	$1,061	$384	$1,543
Furnace, SSHP Switch at 35F	14.2	75.7	89.9	$482	$1,142	$1,713

3.5 Utility Rates

Overall, the analysis output showed the consumer value proposition depends on the gas and electric rates and the ratio between them. Idaho, Montana, Oregon, and Washington all have about the same electricity rates, but there is a split when it comes to gas prices. Table 6 shows the price of the fuel at the site on a per million Btu basis, the cost of input energy to the equipment. Gas is clearly less expensive than electricity and more so in ID+MT.

Table 6. Site Cost per Unit Energy

Location	Electricity $/MMBtu	Gas $/MMBtu
OR, WA	33.90	15.10
ID, MT	34.00	9.50

Therefore, to reduce consumer heating costs an electric heat pump must overcome not just the efficiency of a gas option, but also the higher price of electric energy. Table 7 shows that in OR+WA a heat pump must have a COP over 2.1 to reduce operating costs over gas. In ID+MT, that COP increases to 3.4 because the gas price is lower. Note that this calculation also depends on the gas system efficiency. If that efficiency decreases, to 80% for example, the breakeven electric COP would drop to 1.8 in OR+WA and 2.9 in ID+MT.

Table 7. Breakeven Electric COP

Location	Gas COP	Breakeven Electric COP
OR, WA	0.95	2.1
ID, MT	0.95	3.4

Applying the above discussion to annual system operation, it becomes clear that in order for the cost to heat a house to be lower with an electric system, the average heat pump COP must be above the breakeven point. This can be achieved with high efficiency heat pumps and operating them in temperature ranges where they perform well, i.e., in warmer conditions.

Table 8 compares output for single speed heat pump scenarios in Portland and Missoula. In all cases, the heat pump is sized to the 30 ºF balance point. Despite effectively the same COP in either climate, the cases in Missoula cost more to operate compared to a furnace system because the heat pump efficiency is below the breakeven COP. Section 3.6 shows cases in which a higher performing heat pump can yield lower operating costs.

Table 8. Impact of Utility Rates

System	Heat Pump COP	Gas COP	Overall Heating COP	Heating Electricity MMBtu/yr	Heating Gas MMBtu/yr	Total Heating Input MMBtu/yr	Annual Operating Cost	Annual CO_2 lbs.
Portland								
Furnace with AC	-	0.93	0.9	2.3	63.1	65.4	$1,093	8,127
TWH+AHU, SSHP Supp.	3.1	0.95	2.2	18.2	8.0	26.2	$806	4,523
Furnace, SSHP Switch at 35F	3.1	0.93	1.9	16.1	15.4	31.5	$842	4,994
Missoula								
Furnace with AC	-	0.92	0.9	2.6	129.8	132.5	$1,420	16,138
TWH+AHU, SSHP Supp.	3.0	0.96	1.7	34.0	34.9	68.9	$1,583	10,606
Furnace, SSHP Switch at 35F	3.1	0.94	1.1	13.2	94.6	107.8	$1,434	13,845

3.6 Heat Pump Types

3.6.1 Switchover Control with Heat Pump Types

Dual fuel systems with switchover controls increased efficiency over gas furnaces in all cases considered. The type of heat pump used for the system has a strong influence on the size of that increase. Table 9 shows the heating performance of different heat pump types in two different climates, Bozeman and Portland. All systems in the table are sized to a 30 °F balance point and use a 35 °F switchover. In both climates the different heat pumps rank in the same order of efficiency: the low-load efficient heat pump is most efficient, followed by the cold climate, the average variable speed, and then the single speed heat pumps.

The Bozeman cases demonstrate how a colder climate mutes the relative benefits of different heat pump types. Because a much larger share of heating occurs below the switchover temperature, heat pump efficiency has a smaller relative effect on total heating efficiency. The reduction in total heating energy use ranges from 15 to 17 percent across the different cases.

Table 9. Switchover Control with Heat Pump Types in Two Climates

System	Heat Pump COP	Gas COP	Overall Heating COP	Heating Electricity MMBtu/yr	Heating Gas MMBtu/yr	Total Heating Input MMBtu/yr	Annual Operating Cost
Portland							
Furnace with AC		0.93	0.90	2.3	63.1	65.4	$1,093
Furnace, Single Speed HP Good EER	3.1	0.93	1.9	16.1	15.4	31.5	$842
Furnace, Average Variable Speed HP	3.7	0.92	2.0	14.2	15.5	29.7	$768
Furnace, Low Load Efficient HP	4.6	0.93	2.2	12.0	15.2	27.3	$688
Furnace, Cold Climate HP	4.2	0.90	2.1	12.6	18.5	31.1	$731
Bozeman							
Furnace, AC		0.91	0.89	2.1	153.3	155.4	$1,645
Furnace, Single Speed HP Good EER	3.1	0.92	1.1	11.7	121.3	132.9	$1,652
Furnace, Average Variable Speed HP	3.5	0.92	1.1	9.8	121.7	131.5	$1,579
Furnace, Low Load Efficient HP	4.4	0.92	1.1	8.4	120.8	129.2	$1,521
Furnace, Cold Climate HP	3.9	0.91	1.1	8.7	128.0	136.8	$1,549

3.6.2 Supplement Control with Heat Pump Types

Heat pump types in supplement control dual fuel systems follow the same efficiency patterns as the switchover control: All cases show efficiency improvements, with the degree of improvement varying by heat pump type. The rank order of improvement is the same: The low-load efficient heat pump produced the greatest increase, followed by the cold climate, the average variable speed, and then the single speed heat pumps.

As with the switchover cases, a colder climate reduces variation in efficiency between different heat pumps with supplement controls, but to a lesser degree and for a different reason. In the case of the supplement system, the heat pumps continue to operate below 35 °F, into temperature ranges where they are less efficient. Types with higher capacity at these colder temperatures, like the cold climate heat pump, will produce a greater share of the heating in these challenging conditions than a basic single speed heat pump. When a larger share of the heating season has colder weather, the cold climate heat pump system takes a greater hit to its overall efficiency because it has higher heat pump output. The effect on total system efficiency, however, is positive.

Table 10. Supplement Control with Heat Pump Types in Two Climates

System	Heat Pump COP	Gas COP	Overall Heating COP	Heating Electricity MMBtu/yr	Heating Gas MMBtu/yr	Total Heating Input MMBtu/yr	Annual Operating Cost
Portland							
Furnace with AC		0.93	0.9	2.3	63.1	65.4	$1,093
TWH+AHU, Single Speed HP Good EER	3.1	0.95	2.2	18.2	8.0	26.2	$806
TWH+AHU, Average Variable Speed HP	3.6	0.95	2.4	16.5	8.0	24.5	$736
TWH+AHU, Low Load Efficient HP	4.5	0.95	2.7	13.9	8.0	21.9	$645
TWH+AHU, Cold Climate HP	4.1	0.95	2.6	14.9	8.4	23.3	$674
Bozeman							
Furnace with AC		0.91	0.89	2.1	153.3	155.4	$1,645
TWH+AHU, Single Speed HP Good EER	2.9	0.96	1.5	34.7	55.7	90.5	$1,827
TWH+AHU, Average Variable Speed HP	3.0	0.96	1.6	33.4	54.9	88.2	$1,762
TWH+AHU, Low Load Efficient HP	3.6	0.96	1.6	29.7	54.2	83.9	$1,622
TWH+AHU, Cold Climate HP	3.2	0.95	1.7	34.4	49.9	84.3	$1,717

3.6.3 Cold Climate Heat Pumps in Cold Places

The preceding sections note that low-load efficient heat pumps achieve higher efficiencies than cold climate heat pumps. This finding holds across climates but does not account for the comparative advantage of cold climate heat pumps: They have higher output capacities at low temperatures compared to other types.

Table 11 compares DFS systems sized to a 30 °F balance point in cold climates. The table includes the control schemes that result in the lowest annual operating cost for both cold climate heat pumps and low-load efficient heat pumps. While low-load efficient heat pumps lead to lower operating costs, they require nearly one more ton of nominal capacity to achieve the same balance point. The lower initial cost of a two-ton cold climate heat pump, compared to a three-ton low-load efficient heat pump, may outweigh the energy costs savings.

Table 11. Cold Climate vs. Low-Load Efficient Heat Pumps in Cold Climates

	Lowest Operating Cost DFS with Cold Climate Heat Pump			Lowest Operating Cost DFS with Low-Load Efficient Heat Pump		
	Control	Tons	Operating Cost	Control	Tons	Operating Cost
Bozeman	30 °F Switchover	1.9	$1,562	30 °F Switchover	2.8	$1,517
Spokane	Supplement	1.9	$1,420	Supplement	2.8	$1,342

Given the cold climate heat pump's advantage over other types down to a 30 °F balance point, LER also considers the effect of increasing the heat pump size, allowing it to run in even colder conditions. Table 12 compares the sizes and operating costs of different cold climate heat pump systems sized to both 30 °F and 20 °F balance points. This increases the nominal capacity size of the heat pump by 0.8–0.9 tons. It raises operating costs in Bozeman and lowers them in Spokane. When operating savings exist, the first costs will again likely outweigh them. This matches the point of diminishing returns seen with other heat pump types.

Table 12. Larger Cold Climate Heat Pumps for Cold Climates

	Cold Climate HP DFS sized to 30 °F			Cold Climate HP DFS sized to 20 °F		
	Control	Tons	Operating Cost	Control	Tons	Operating Cost
Bozeman	30 °F Switchover	1.9	$1,562	20 °F Switchover	2.7	$1,631
	Supplement	1.9	$1,717	Supplement	2.7	$1,761
Spokane	30 °F Switchover	1.9	$1,584	20 °F Switchover	2.8	$1,439
	Supplement	1.9	$1,420	Supplement	2.8	$1,395

A cold climate heat pump is effectively a tradeoff between capacity at lower temperatures and efficiency overall. In a dual fuel system this tradeoff can pay off by increasing the amount of heat delivered by the heat pump at efficiencies above the electric breakeven COP without increasing the nominal size of the heat pump. This makes cold climate heat pumps preferable to other types in climates dominated by temperatures that are cold, but not so cold as to depress efficiency below the breakeven COP. In milder climates, a cold climate heat pump will end up operating relatively more on the downside of the capacity/efficiency tradeoff, making other types a more cost-effective choice.

3.7 Smart Dual Fuel Switching

Overall, the analysis demonstrated that controlling the DFS according to a dynamic signal, or "smart switching," can effectively alter the system's operation.

Table 13 shows the results of the TOU-optimized control in a Seattle climate. In all cases the heat pumps are sized to a 30 ºF balance point, and the furnace systems use a 35 ºF switchover under the standard control. Compared to the standard control, the TOU-optimized control reduced annual operating costs by $66 to $125.

To optimize cost, the controller shifts heating load from electric to gas during electricity rate peaks. As a result, TOU-optimized operation uses more gas than standard controls.

Table 13. TOU-Optimized Fuel Switching Results

	Annual Heating Operating Cost		Electric share of heating input energy	
	Standard Control	TOU Control	Standard Control	TOU Control
Furnace with AC	$1,078		3%	
Furnace, Single Speed HP Good EER	$765	$640	51%	44%
Furnace, Low Load Efficient HP	$635	$552	44%	37%
TWH+AHU, Single Speed HP Good EER	$717	$608	70%	49%
TWH+AHU, Low Load Efficient HP	$581	$515	64%	43%

Table 14 shows the results of the GHG-optimized control for the same equipment and climate. Interestingly, this control had no significant effect on the operation of the TWH+AHU systems. This is because the standard controls for those systems are already effectively optimized for emissions reductions by maximizing heat pump use.

For the gas furnace systems, the GHG-optimized control shifts some of the heating load from gas to electric. In both cases this led to an 11% decrease in GHG emissions.

Table 14.GHG-Optimized Fuel Switching Results

	Annual Heating Emissions lbs. CO_2		Electric share of heating input energy	
	Standard Control	GHG Control	Standard Control	GHG Control
Furnace with AC	7,996		3%	
Furnace, Single Speed HP Good EER	3,593	3,215	51%	61%
Furnace, Low Load Efficient HP	3,152	2,794	44%	53%
TWH+AHU, Single Speed HP Good EER	2,892	2,905	70%	70%
TWH+AHU, Low Load Efficient HP	2,439	2,444	64%	64%

This example considers the cases of TOU and GHG optimization. Other optimizations are clearly possible, like one for utility marginal costs, or a control that balances multiple inputs. Last, the team observes that different schedules will lead to different numerical results; however, the concept demonstrated in this example still holds. DFS can be controlled in ways other than in response to the outdoor temperature (a simple switchover) that offer additional benefits through lower cost, GHG emissions, or peak load avoidance.

4 Conclusions

A dual fuel system uses less gas than a gas furnace.

- Control type and switchover temperature have the largest influences on the size of the reduction. In the cases analyzed, it ranged from 50 to 88 percent.
- Switchover controls limit the temperature range in which the heat pump can operate. If a larger share of heating demand occurs above the switchover temperature, the heat pump can carry a larger share of the load. Thus, lower switchover temperatures reduce gas use.
- Supplement controls, in combination with the right gas system, permit the heat pump to operate down to its operating limit, allowing it to carry a greater share of the load than in a switchover system.

All climates reported in this study have dual fuel system options that will decrease total energy use and operating cost. Control type, heat pump type, and heat pump size are all significant factors in the size of the reduction.

- Because the heat pump component of a dual fuel system is more energy efficient than the gas component, total system site efficiency increases with the heat pump's share of the load. Lower switchover temperatures increase site efficiency, as does a supplement control type vs. a switchover. Supplement systems show the greatest relative advantage in climates like eastern WA and OR, which experience a larger share of heating demand below a switchover system's cutoff but still above the coldest temperatures that would depress COP—in other words, climates with substantial load hours between ~15 ºF and ~35 ºF.
- Selecting a heat pump type with higher efficiencies in the temperature ranges where the heat pump is most used will increase overall efficiency. Of the types analyzed, the low-load efficient variable speed heat pump produced the greatest efficiencies, regardless of climate or control type. The cold-climate heat pump came in second, followed by average variable speed heat pump and then the good single speed heat pump.
- Sizing heat pumps to around a 30 °F balance point appears to be the optimal choice. For switchover control types, the switchover temperature should be set to no more than a few degrees higher than the balance point. Smaller heat pumps will not have sufficient capacity to take full advantage of the temperature ranges where they can contribute most to system efficiency. In many climates, they will also lack sufficient capacity for the cooling season. Larger heat pumps will be able to meet a larger portion of the total heating load, but this gain occurs in the temperature ranges where they are least efficient. It also means they will run at lower part loads during moderate weather, further depressing their COP. The greater initial equipment costs of these larger systems are likely to overwhelm the relatively small decreases in operating cost.

The extent to which a dual fuel system will affect the consumer's operating costs is dependent on utility rates as much as on system design. Increases in energy efficiency that result from the use of electric heating equipment do not necessarily produce operating cost savings.

- While electric heat pumps are significantly more energy efficient than gas heating, electricity is significantly more expensive than gas on a utility-rate basis. For a given gas efficiency level, the difference between electric and gas rates defines a minimum "breakeven COP" that the heat pump must surpass in order to reduce operating costs. For a gas COP of 0.95 under recent utility rates, that breakeven COP is around 2.1 in OR and WA, and 3.4 in ID and MT.
- The analysis showed a strong consumer value proposition for dual fuel systems in OR and WA, especially for single speed heat pumps (which have the lowest first cost) and low-load efficient heat pumps (which have lowest electric operating costs). In ID and MT, the rate structure favors gas more of the time, so only products like the low-load efficient heat pump produce operating savings, and those are modest.

The project demonstrated that smart dual fuel switching strategies can be extremely effective at minimizing consumer costs, greenhouse gas emissions, or other values when operating in response to real-time signals. This can offer additional value to the consumer if they are on time-of-use rate plans and could be beneficial to the utility when seeking to minimize peak electric grid impacts. These additional benefits could easily increase the consumer value proposition to install a dual fuel system.