Improving Savings Estimates of Cold Climate Air Source Heat Pumps (ccASHP) in TREAT

A Simplified Method for Adjusting the Rated HSPF of ccASHPs

July 2022

Prepared by:

Performance Systems Development
Ithaca, NY 14850

Executive Summary

The purpose of this memo is to provide guidance to improve the accuracy of savings estimates from installing cold climate air source heat pumps (ccASHP) in single and multifamily residential buildings when using engineering calculations or energy simulation software tools such as TREAT. Most calculation methods for savings of replacing existing heating systems with ccASHP do not account for its varying efficiency and capacity with outdoor temperature. In cold climates, the actual average efficiency over the entire heating season is generally lower than the manufacturer's rated heating seasonal performance factor (HSPF), which results in greatly overestimated savings.

This memo provides a simplified HSPF adjustment method that can be applied to the rated HSPF used in any engineering calculation, saving estimate from a technical resource manual (TRM), or energy simulation tool. TREAT, like most software simulation tools, uses a single input of the rated Region IV HSPF. While TREAT does use an algorithm to adjust the rated HSPF to the climate zone of the given weather location, it is using this same HSPF for all temperatures of the heating season and not accounting for the varying efficiency with outside temperature. Additionally, the actual performance of ccASHPs depends on the unit's ducting configuration type, which TREAT handles all types the same. The analysis for this memo found that generally ducted ccASHPs had larger reduction adjustments of the rated HSPF than the ductless systems. To improve the accuracy of TREAT when modeling ccASHP, users should follow the Modeling ccASHP in TREAT procedure given below.

Statement of Problem

Cold climate air source heat pumps (ccASHP) use variable speed compressors and fans. Their output capacity and efficiency vary with outside temperature, making it much more complex to accurately estimate the true energy performance. TREAT, like most residential simulation software tools and utility technical resource manuals (TRM), uses the single rated HSPF input as the efficiency of the equipment for all temperatures. This results in underestimating the energy consumption of these equipment, especially in cold climates, and therefore grossly over-estimating the savings from replacing an existing heating system with a ccASHP. What is more, the rated HSPF is a seasonal efficiency based on Climate Zone 4, which further contributes to the variation of rated versus actual performance.

The actual seasonal efficiency of ccASHP in the typical cold climates where these equipment are being installed can vary as much as 15% better to 35% worse than the rated HSPF, directly affecting the savings estimates by the same percentage. See the Figures 1 and 2 below.

Scope

The scope of this memo provides a simple method for adjusting the manufacturer rated heating seasonal performance factor (HSPF) of ccASHP to account for the change in efficiency and capacity with outdoor temperature across the entire heating season. While the seasonal energy efficiency ratio (SEER) also varies with outdoor temperature, this memo is focused on heating dominated climates not addressing a similar adjustment needed for the SEER.

The HSPF adjustment should only be used for ccASHPs where the following conditions are true:

- Full displacement of the existing heating system(s) with ccASHP(s)
- Integrated control of supplemental backup heat
- Equipment is sized to meet the full load of the building at the design outdoor temperature

HSPF Adjustment Methodology

The methodology of the determining the HSPF adjustment factors is based on the white paper[1] prepared for NYSERDA and the NYS Department of Public Service by Hugh Henderson of Frontier Energy, Inc. This paper is also the basis for the improved heat pump savings calculations in the NY State TRM Version 9.

The method uses a one-degree temperature bin analysis to calculate the average coefficient of performance (COP) for the heating season of the given location. The adjustment was calculated separately for all 27,696 ducted and 3,462 ductless equipment from the NEEP ccASHP Product List from April 2022 across all 17 IECC climate zones. Approximately 240 heat pumps were excluded from this analysis due to missing sufficient manufacturer data in the NEEP database. The adjusted COP values were then divided by the rated COP yielding a normalized percentage adjustment factor. The average was then taken across all COP adjustment factors by duct configuration, IECC climate zone, and binned rated HSPF. The results of the COP adjustment factors are given in Tables 1 and 2 below.

Following the methods of the white paper referenced above, for each ccASHP in the NEEP database:

1. The heating seasonal average heating COP was calculated weighted by the hours in each bin for all hours where the outdoor temperature was less than the assumed building heating balance point temperature of 57.5 F
2. It was assumed that the ccASHP will be correctly sized to meet the full heating design load of a building at the 99% heating dry-bulb temperature as listed by the 2021 ASHRAE Handbook of Fundamentals for the representative weather location of each IECC climate zone
3. Supplemental heat was not included in the average seasonal COP

Further research is underway, and an updated version of the memo and HSPF adjustment tables may be published in the future.

Seasonal Average Adjusted HSPF

Energy simulation software tools such as EnergyPlus have the capability to simulate the hourly changes in heat pump performance based on a more complex input set of heat pump performance data curves from the product manufacturer. For most other energy simulation tools that take a simple HSPF input, the following adjustment procedure should be used into to properly account for the heat pump's efficiency and capacity changing with outside temperature.

1. Look up the adjustment factor in the HSPF Adjustment tables below based on:
    - Ducting Configuration as given by the product manufacturer, also listed in the NEEP Product List for the AHRI number of the selected equipment
    - IECC Climate Region of the building
    - The "HSPF Region IV" value given by the product manufacturer
2. Multiply the manufacturer's rated HSPF by this adjustment factor, this is the HSPF that should be entered into the simulation software.

[1] Henderson, Hugh. "Savings Calculations for Residential Air Source Heat Pumps - The Basis for Modifying EFLH and Seasonal Efficiency Factors for Whole House and Displacement Applications". June 16, 2020. https://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId=%7B7BC5CE9D-B4F8-4164-96E0-9D6D110E2491%7D

Ductless and Compact Duct Configurations

For all ducting configurations listed in the NEEP ccASHP Product List except “Multizone All Ducted” and “Singlezone Ducted, Centrally Ducted”, use the table below.

	Manufacturer Rated HSPF Region IV				
IECC Climate Region	**>= 9 < 10**	**>= 10 < 11**	**>= 11 < 12**	**>= 12 < 13**	**>= 13 <= 14**
3A - Atlanta,GA	112%	103%	99%	95%	90%
3AWH - Montgomery,AL	114%	105%	101%	97%	92%
3B - ElPaso,TX	115%	106%	102%	99%	93%
3C - SanDiego,CA	108%	102%	98%	96%	91%
4A - NewYork,NY	112%	102%	98%	94%	89%
4B - Albuquerque,NM	114%	104%	100%	95%	91%
4C - Seattle,WA	115%	107%	102%	100%	94%
5A - Buffalo,NY	105%	93%	89%	85%	82%
5B - Denver,CO	103%	90%	86%	82%	79%
5C - PortAngeles,WA	116%	107%	103%	100%	95%
6A - Rochester,MN	87%	74%	70%	66%	65%
6B - GreatFalls,MT	90%	77%	73%	69%	68%
7 - InternationalFalls,MN	79%	66%	62%	58%	58%
8 - Fairbanks,AK	72%	59%	55%	52%	52%

Table 1: Adjustment factors for ccASHP having ductless or compact duct configurations

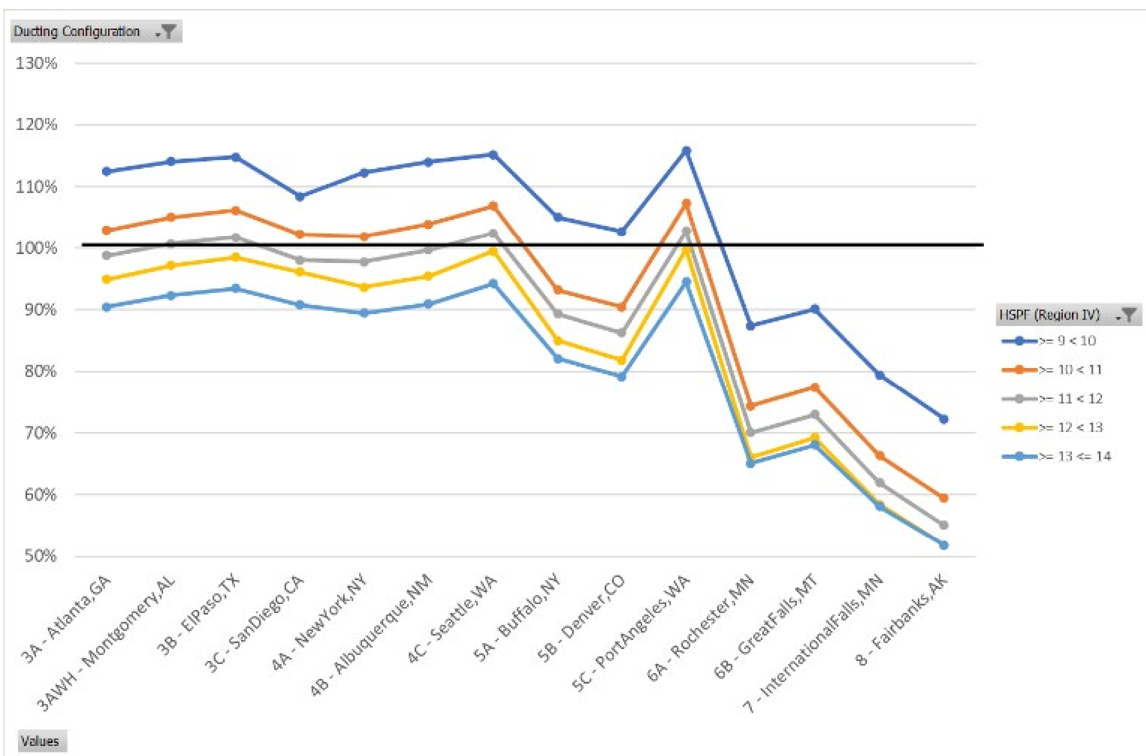

Figure 1: Adjustment factors for ccASHP having ductless or compact duct configurations. The black line at 100% represents no adjustment.

Ducted Configurations

For “Multizone All Ducted” and “Singlezone Ducted, Centrally Ducted” ducting configurations only, use the table below.

	Manufacturer Rated HSPF Region IV				
IECC Climate Region	**>= 9 < 10**	**>= 10 < 11**	**>= 11 < 12**	**>= 12 < 13**	**>= 13 <= 14**
3A - Atlanta,GA	104%	104%	98%	72%	87%
3AWH - Montgomery,AL	105%	106%	99%	70%	89%
3B - ElPaso,TX	106%	107%	99%	69%	89%
3C - SanDiego,CA	107%	107%	96%	59%	89%
4A - NewYork,NY	102%	103%	98%	75%	86%
4B - Albuquerque,NM	104%	104%	99%	75%	87%
4C - Seattle,WA	107%	107%	99%	67%	90%
5A - Buffalo,NY	96%	95%	93%	77%	80%
5B - Denver,CO	94%	93%	90%	74%	78%
5C - PortAngeles,WA	106%	107%	100%	69%	90%
6A - Rochester,MN	81%	78%	77%	66%	67%
6B - GreatFalls,MT	83%	81%	79%	65%	69%
7 - InternationalFalls,MN	73%	70%	69%	60%	61%
8 - Fairbanks,AK	67%	63%	62%	55%	55%

Table 2: Adjustment factors for ccASHP having ducted configurations

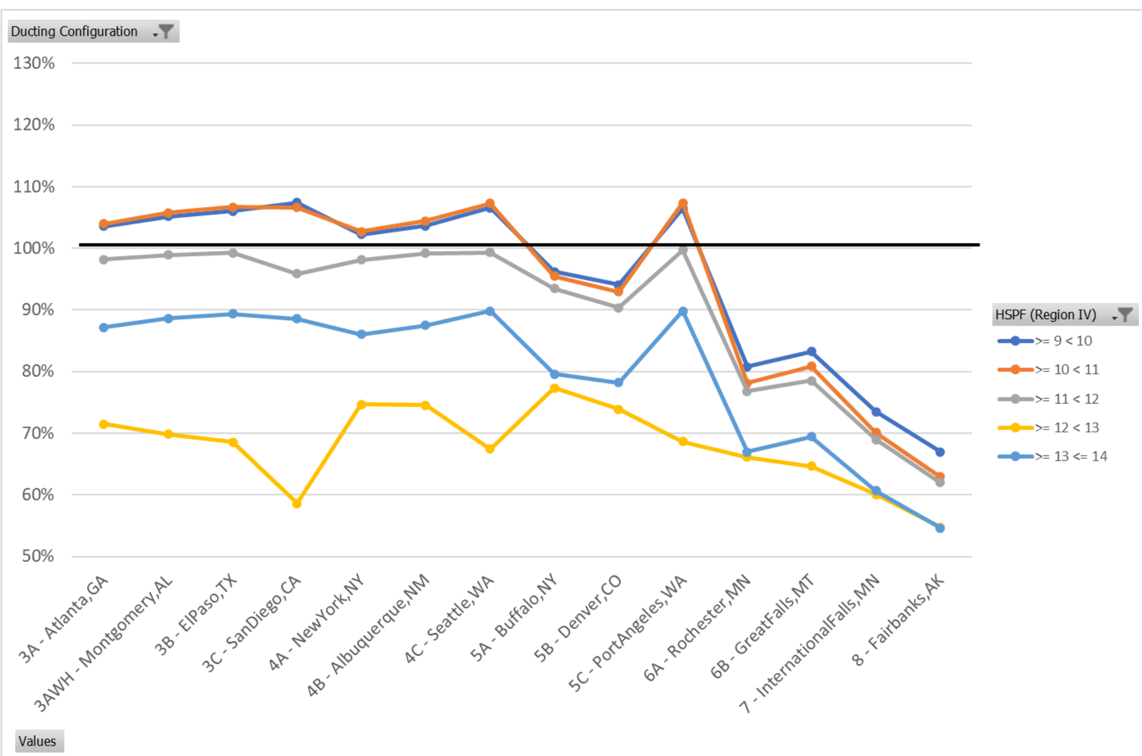

Figure 2: Adjustment factors for ccASHP having ducted configurations. The black line at 100% represents no adjustment.

Sample Results

To aid the user in understanding the potential impact, two sets of cases are presented below to understand the impact of location and the manufacturer's rated HSPF on the adjustment factor. The user would go to the NEEP ccASHP Product List and enter the AHRI # for their selected ccASHP to retrieve the HSPF (Region IV) value.

Impact of Rated HSPF

Assuming the same design heating load of 24,000 Btu/hr for a building located in Buffalo, NY and installing a multizone non-ducted ccASHP, a contractor compares the two units shown below. The contractor would use Table 1 above since this example is for a non-ducted ccASHP.

AHRI #	HSPF (Region IV)	Location	Adjustment Factor	HSPF for Savings Calculation
207517162	12.5	Buffalo, NY	85%	10.6
205123813	9.75	Buffalo, NY	105%	10.2

Impact of Location

Assuming the same single zone, centrally ducted ccASHP for the same design heating load of 24,000 Btu/hr for two different buildings, one located in New York, NY and other in International Falls, MN. The contractor would use Table 2 above since this example is for a ducted ccASHP.

AHRI #	HSPF (Region IV)	Location	Adjustment Factor	HSPF for Savings Calculation
10525696	10.75	New York, NY	103%	11.1
10525696	10.75	International Falls, MN	70%	7.5

Modeling ccASHP in TREAT

When modeling cold climate air source heat pumps (ccASHP) in TREAT, the following procedures should be followed.

Modeling Steps for all Air Source Heat Pumps

This section gives information about certain settings that should be used to model heat pumps, and calculations for adjustments and conversions needed for inputs into TREAT.

Calculating the Adjusted HSPF

Heating Season Performance Factors (HSPF) and Seasonal Energy Efficiency Rating (SEER) are seasonal efficiencies often used to predict performance over an entire year. The actual performance of variable speed heat pumps changes climate in which the equipment is being operated.

1. When modeling heat pumps following this protocol, it is now recommended that the user NOT check the "Account for Climate Impact on HSPF and SEER" option in the Weather/Defaults page within the Advanced section. While this option enables the TREAT climate efficiency degradation algorithms, this impact as well as the impact of the heat pump's variable speed compressor is being more accurately accounted for using the procedure above.
2. Follow the procedure in the Seasonal Average Adjusted HSPF section above to calculate the seasonal average HSPF. This is the HSPF value that will be entered into the "Annual Efficiency" input field in TREAT.

Modeling Existing Air Source Heat Pumps

Please note that when modeling existing heat pump equipment, it is up to the modeler to enter the SEER or HSPF that accurately describes the efficiency at which the equipment operates. Due to age, improper charge, improper sizing, and operating conditions, you may need to make further adjustments to the HSPF beyond the adjustment tables above. Additionally, the efficiency should be bounded by the calibration process and/or real-world performance constraints such as those listed in the ANSI/BPI-2400 standard.

Input vs. Output Capacity

Heat pump specifications typically list the rated output capacity for the heating and/or cooling, however, TREAT requires input capacity for the heating system input.

To convert the rated output capacity to input capacity:

1. Convert the adjusted HSPF to a COP: COP = HSPF / 3.412

2. Divide the “Rated Heating Capacity (Btu/hr) @47°F” given in the NEEP ccASHP product information for your selected heat pump by the COP calculated above.

Input Capacity = Rated Output Capacity / calculated COP

3. Enter the calculated input capacity into TREAT.
4. Double check your calculations by viewing the Design Heating and Cooling Loads Report after running the model with these inputs. The **Available Heating Equipment Output Capacity** should match the output capacity with which the calculations for this step began.

Converting EER to SEER

Seasonal Energy Efficiency Rating (SEER) efficiency values must be entered for all cooling systems in TREAT. Packaged ASHP units are typically rated in Energy Efficiency Rating (EER).

To convert EER to SEER:

SEER = EER / 0.875

Modeling Instructions for Specific Heat Pump Types

This section gives specific instructions for modeling each of the most common types of heat pumps. Before proceeding, please follow the instructions in the “Modeling Steps for all Air Source Heat Pumps” section to understand how to convert output to input capacity, SEER versus EER, and adjustments to the HSPF heating efficiency. If the equipment being modeled has a backup heating system, also follow instructions in the Modeling Backup Heat section below. The initial steps below apply to all air source heat pumps.

1. Select “Air Source Heat Pump” as the Primary Heating system and set Fuel to “Electricity”
2. Enter the calculated heating input capacity as given by the procedure above.
3. Enter the adjusted HSPF as given in the procedure above.
4. If this ccASHP will also be used for cooling, select the check box for “Air Conditioning” below the Heating section
5. Enter the “Rated Cooling Capacity (Btu/hr) @95°F” given by the product manufacturer, or as given in the NEEP ccASHP product information for the selected heat pump.

Ductless / Mini-Split Heat Pump

1. Set Air Conditioning Type to: Room Air Conditioner
2. Click the **Edit Primary Distribution System** button and change the Duct Test Leakage and Total Duct Surface Area to zero for Supply and Return, and change Estimated Total Distribution Efficiency to 100% to account for no ductwork.
3. For multiple mini-splits, please see the section on Combining Multiple HVAC Equipment for Entry into TREAT

Central Air Source Heat Pump

1. Set Air Conditioning Type to: Central Air Conditioner
2. Click the **Edit Primary Distribution System** button to change the inputs to ensure that the entries match the data from the audit or duct testing. Best practice is to only model the ductwork in unconditioned spaces (e.g. attic, basement, crawlspace).
3. Check the **Shared with Cooling** box to apply these setting to the cooling system.
4. Adjust the Heating Design Supply Temp to that specified by the product manufacturer
5. Adjust the Air Conditioning Design Supply Temp to that specified by the product manufacturer

Window / Sleeve Heat Pump

1. Set Air Conditioning Type to: Room Air Conditioner
2. If the equipment provides heating, create a primary or secondary heat plant, as appropriate and select type Air Source Heat Pump.
3. Click the **Edit Primary Distribution System** button to change the Duct Test Leakage and Total Duct Surface Area to zero for Supply and Return, and change Estimated Total Distribution Efficiency to 100% to account for no ductwork.

Modeling Back-Up Heating System

This section describes how to model the back-up heating system(s) that operate with the heat pump system.

As a starting point, set this to **Operate when primary capacity insufficient**. During calibration process, if the primary and secondary heating energy consumption between the Building Model and Billing Data are not in agreement in the feedback pane, change the secondary system control to **Fixed Percentage of Monthly Energy Use**. Then iteratively change this percentage and re-calculate results to calibrate the model within your desired bounds.

If the secondary heating system runs in tandem with the primary, set the Secondary System Control to **Fixed Percentage of Monthly Energy Use** and use the best available information to estimate the percentage of monthly heating energy consumption.

The capacity and efficiency of the backup systems should be entered based on the real specifications of the equipment. The following are some of the most common backup heating systems and how they should be entered.

Ducted Gas Backup: Create a natural gas furnace as a secondary heating system. Edit the Secondary Distribution System to reflect the properties of this duct system. If it is shared with the Primary Distribution System or the Cooling Distribution System, check the box the applies.

Ducted Electric Backup: Create an electric furnace and enter an efficiency of 100% as the secondary heating system. Edit the Secondary Distribution System to reflect the properties of this duct system. If it is shared with the Primary Distribution System or the Cooling Distribution System, check the box the applies.

Electric Baseboard Backup: Create an electric baseboard backup heating system.

Combining Multiple Pieces of HVAC Equipment for Entry into TREAT

Modeling buildings with multiple distributed HVAC systems, such as multifamily buildings with in-unit heating systems, requires that multiple pieces of equipment must be combined for entry into TREAT.

1. Sum the capacities of the equipment.
2. Create an average of the efficiencies. If possible, create a weighted average of the efficiencies using the best data available. Assuming the runtimes of all equipment are similar, use the output capacity for determining this weighted average.

Example:

There are three room air conditioners in the building with output capacities of Q1, Q2 and Q3 Btu/hr and efficiencies of E1, E2 and E3.

The total output capacity Q = Q1+Q2+Q3

The capacity-weighted efficiency E = (Q1xE1 + Q2xE2 + Q3xE3) / (Q1+Q2+Q3)