White Paper

Savings Calculations for Residential Air-to-Water Heat Pumps for Space Heating

Guidance for AWHP systems that use Hydronic Distribution.

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Prepared for

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Overview of AWHPs

A new class of air source heat pump systems can provide heating pulling energy from the ambient (or outdoor) air to provide hot water. These air to water heat pump (AWHP) units distribute heat in the home using hydronic or hot water systems instead of ductwork. These heat pumps also can be reversible and provide chilled water by rejecting heat to ambient (as known as an air-cooled chiller). AWHP are not considered a drop-in replacement for fossil fuel boilers since significant hydronic system modifications are usually required.

In many retrofit applications in existing homes the hydronic distribution system, or hot water baseboards, that were installed with the fuel-fired boiler must be adapted to use an AWHP. AWHPs generally can NOT provide hot water at the same temperatures as boilers. Therefore, in order to keep hot water temperatures low, the house can be retrofitted to use additional heat emitters such as additional/larger baseboard heaters or hydronic air handler units (AHUs). Alternatively, buildings where the envelope or shell has been significantly improved so that the heating loads are much smaller (e.g., a deep retrofit), it may be possible to use existing heat emitters to meet the heating load at lower hot water temperatures.

In new construction, homes often use in-floor radiant heating that circulate low temperature water in hydronic systems. AWHPs are an especially good fit in these applications.

The white paper describes how to predict the performance of AWHPs and recommends typical operating temperatures for various hydronic applications. The discussion addresses single stage AWHPs that are installed with a buffer tank on the load-side of the heat pump unit to reduce compressor cycling rates, as well as variable speed AWHPs that may or may not require a buffer tank.

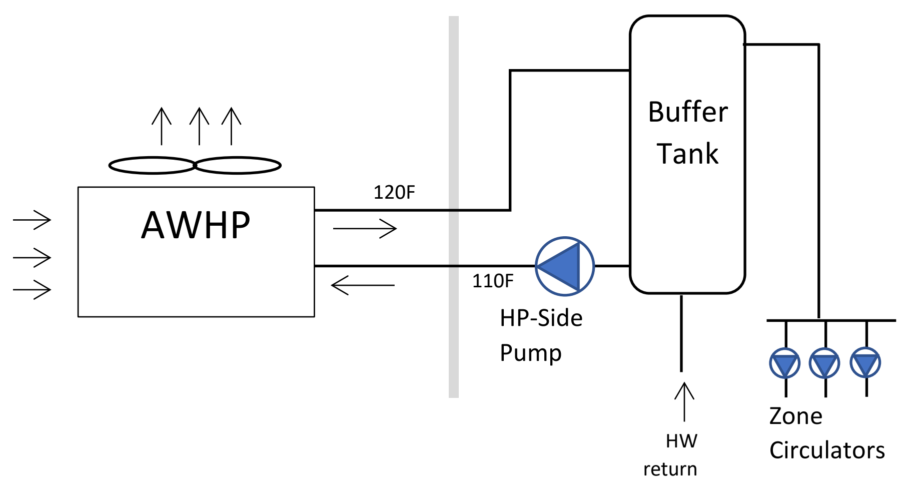

Figure 1. Typical Schematic for an Air-to-Water HP System for Space Heating

AWHP products appropriate for space heating applications typically can operate over a range of leaving water temperatures (LWTs) from 90°F to 140°F. These units operate at flow rates to provide a water-side temperature rise in the range of 10 to 15°F. The efficiency and capacity of these systems are strongly affected by the LWT, as well as ambient air temperatures.

Other AWHP products – such as those using CO_2 as a refrigerant – can efficiently provide LWTs over 160°F. However, these products typically have a much lower flow rate and provide a much higher temperature rise (e.g., over 80°F). Therefore, these units usually apply in Domestic Hot Water (DHW) applications where inlet temperatures stay below 80°F – limiting their application for residential space heating[1]. This white paper does NOT address these products aimed at DHW applications, which are usually rated under AHRI 1300.

In theory, the rating standard for air-to-water heat pump equipment is AHRI-550/590-2015. This "Chiller" standard also includes rating conditions for air-cooled heating, which are shown in Table 1. However, a search of the AHRI directory (www.ahridirectory.org) in late 2021 revealed that no products appear to be using this standard for product certification (Nordic states in their literature that there currently is no AHRI product certification program). Only a few manufacturers appear to use these rating conditions in their product literature.

Table 1. Test Conditions and Certified Data from AHRI 550/590-2021 Standard, Air-Cooled Heating

Air-Cooled Rating Conditions	Entering Air Temperature (EDB / EWB)	Leaving Water Temperature	AHRI Data
Heating High – Low	47°F / 43°F	105°F	COP_{H-L} QH_{H-L}
Heating High – Med	47°F / 43°F	120°F	COP_{H-M} QH_{H-M}
Heating High – High	47°F / 43°F	140°F	COP_{H-H} QH_{H-H}
Heating Low – Low	17°F / 15°F	105°F	COP_{L-L} QH_{L-L}
Heating Low – Med	17°F / 15°F	120°F	COP_{L-M} QH_{L-M}
Heating Low – High	17°F / 15°F	140°F	COP_{L-H} QH_{L-H}

Notes: The heating capacity and efficiency on the 2021 standard appear to not include defrost impacts (unlike the 2015 version of the standard).

AWHP Performance Details Affecting Seasonal Efficiency

Efficiency Vermont publishes a list of qualified air-to-water heat pump products that are eligible for rebates in their programs[2]. That list is shown as Table 2. They list heating COPs corresponding to "A5W110", at 5°F ambient temperature with a 110°F LWT. The COPs at this condition range from 1.75 to 2.55 – a surprising amount of variation. The nominal capacity (in tons) in their list appears to be related to the heating capacity. NEEP is considering developing a specification and database for AWHP products that may adopt the A5W110 rating point.

[1] Except in applications where some space heating is provided using an indirect heat exchanger in the DHW tank
[2] https://www.efficiencyvermont.com/Media/Default/docs/rebates/qpls/efficiency-vermont-awhp-qpl.pdf

Table 2. List of Qualified AWHP Products from the Efficiency Vermont List

Manufacturer	Model #	Model/Series Name	System Type	Nominal Capacity	COP @ A5W110*	Product Incentive
Aermec	ANK030H	ANK	Mono-bloc	2.5	1.85	$2,500
	ANK030HP			2.5	1.85	$2,500
	ANK030HA			2.5	1.85	$2,500
	ANK045H			3	1.95	$3,000
	ANK045HP			3	1.95	$3,000
	ANK045HA			3	1.95	$3,000
	ANK050H			4	2.07	$4,000
	ANK050HP			4	2.07	$4,000
	ANK050HA			4	2.07	$4,000
Arctic Heat Pumps	020A	EVI - Cold Climate	Mono-bloc	2.5	2.26	$2,500
	040A			4	2.18	$4,000
	060A			5	2.26	$5,000
Chiltrix	CX34-ODU	CX34	Mono-bloc	3	2	$3,000
Enertech Global	EAV030A1AAABTSS	Advantage	Mono-bloc	2.5	2.25	$2,500
	EAV060A1AAABTSS			5	2.55	$5,000
Nordic	ATW-45-HACW	ATW Series	Split	3	1.8*	$3,000
	ATW-55-HACW			4	1.8*	$4,000
	ATW-65-HACW			5	1.8*	$5,000
	ATW-75-HACW			6	1.8*	$6,000
SpacePak	45SIM-036A4	Solstice Inverter	Mono-bloc	3	1.93	$3,000
	45SIM-060A4			5	1.75	$5,000
	45SIS-060A4		Split	5	1.9	$5,000
	LAHP48A4	Solstice Extreme	Mono-bloc	4	2.55	$4,000
Taco Comfort Solutions	SystemM-1	System M	Mono-bloc	3	2.2	$3,000

* Equivalent value. Equipment automatically reduces outlet water temperature to 105F when ambient conditions drop to 5F

Table 3 shows the published performance data for the Solstice Extreme LAHP48 air-to-water heat pump, which was part of the 5-site pilot field test for NYSERDA (2021). The heating COP is plotted as a function of ambient temperature and LWT in Figure 2 . Only two points correspond to the rating conditions from ARHI 550/590. We presume the published performance data correspond to steady-state, frost-free operation with a clean coil, just following a defrost cycle.

Table 3. Published Performance Data for Solstice Extreme

LAHP48

Heating						Cooling					
Water Temp °F	Ambient Temp °F	Capacity BTU/hr	Water DP ft WC	Watts	COP	Water Temp °F	Ambient Temp °F	Capacity BTU/hr	Water DP ft WC	Watts	COP
110	-5	37,500	14.6	3,880	2.30	42	70	41,100	15.0	4,298	2.80
	17	44,800	14.6	3,970	2.70		82	39,950	15.0	4,414	2.65
	47	60,580	14.6	4,263	3.75		95	38,800	15.0	4,897	2.32
120	-5	38,500	14.6	4,513	2.00	44	70	42,500	15.0	4,190	2.97
	☆ 17	46,440	14.6	5,790	2.35		82	41,250	15.0	4,238	2.85
	☆ 47	66,480	14.6	5,963	3.26		95	40,000	15.0	4,820	2.43
130	-5	40,425	14.6	5,249	1.86	47	70	44,600	15.0	4,240	3.08
	17	48,762	14.6	5,371	2.18		82	43,200	15.0	4,274	2.96
	47	69,804	14.6	5,768	3.04		95	41,800	15.0	4,708	2.60

All data based upon pure water @ 11.0 GPM

Note: Performance data from Bulletin LAHP2-1018. The “stars” mark conditions aligned with AHRI 550/590 heating points.

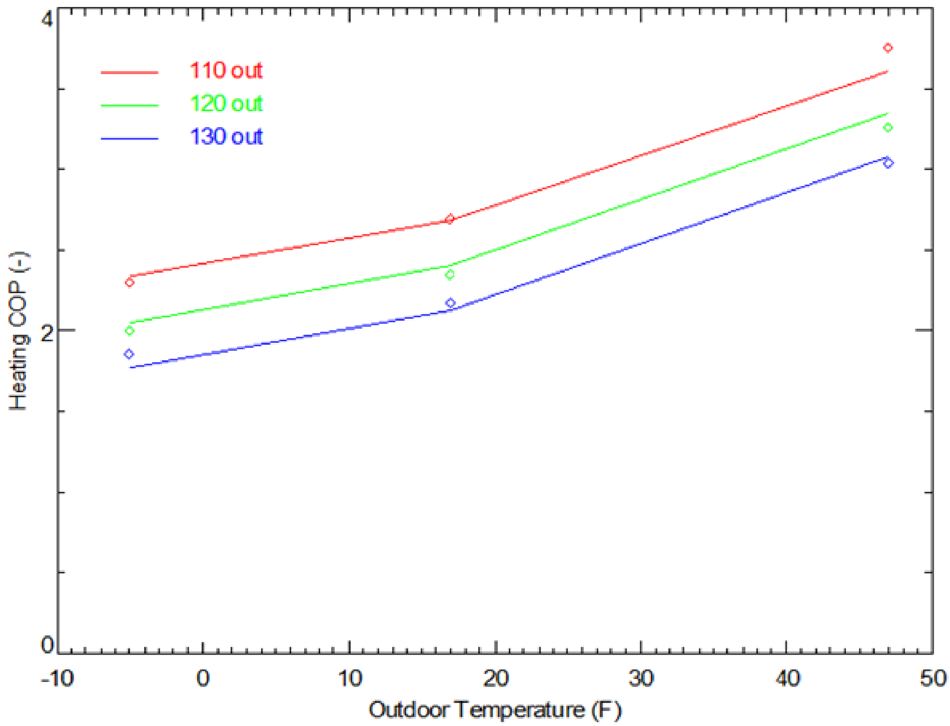

Figure 2. Plot of Published Performance Data for SpacePak Solstice Extreme Unit (from Table 3, lines are best fit)

Table 4 compares the A5W110 COP from Efficiency Vermont to the other ratings that the various manufacturers include in their literature. The lack of a uniform test and rating standard for this type of equipment provides uncertainty in how these systems will perform in the field.

Table 4. Comparing Published COPs and Rating Conditions for Various AWHP Products

				Heating COPs									
Manufacturer	**Model**	**System Arrangement**	**Nominal Capacity (tons)**	**Efficiency Vermont A5W110**	**Measured Seasonal (rad flr)**	**A47W95**	**A17W95**	**AHRI A47W105**	**AHRI A17W105**	**ISO?? A45W113**	**AHRI A47W120**	**AHRI A17W120**	**Notes**
Aermec ANK	ANK030H	Monoblock	2.5	1.85						3.62			
	ANK030HP	Monoblock	2.5	1.85									
	ANK030HA	Monoblock	2.5	1.85									
	ANK045H	Monoblock	3	1.95						3.81			
	ANK045HP	Monoblock	3	1.95									
	ANK045HA	Monoblock	3	1.95									
	ANK050H	Monoblock	4	2.07						3.89			
	ANK050HP	Monoblock	4	2.07									
	ANK050HA	Monoblock	4	2.07									
Arctic HPs EVI	020A	Monoblock	2.5	2.25									
	040A	Monoblock	4	2.18									
	060A	Monoblock	5	2.26									
Chiltrix	CX34-ODU	Monoblock	3	2				3.53	2.45		2.99	2.03	LWT is actually 104F and 122F
EnerTech	EAV030A1AAABTSS	Monoblock	2.5	2.25		5.12	3.24						
	EAV060A1AAABTSS	Monoblock	5	2.55		4.83	3.44						
Nordic	ATW-45-HACW	Split	3	1.8									rated according to 550/590-2017
	ATW-55-HACW	Split	4	1.8	2.4			4.25	2.46		3.39	2.02	
	ATW-65-HACW	Split	5	1.8									
	ATW-75-HACW	Split	6	1.8									
SpacePak Inverter (SCM)	45SIM-036A4	Monoblock	3	1.93							2.65		
	45SIM-060A4	Monoblock	5	1.75							2.65		
	45SIS-060A4	Split	5	1.9									
Solstice Extreme	LAHP48 (2019)	Monoblock	4	2.48	2.1						3.26	2.35	2019 data says 2.48 instead of 2.55
Solstice Extreme	LAHP48A4	Monoblock	4	2.55							3.26	2.35	
Taco Comfort Solutions	SystemM-1	Monoblock	3	2.2									

The implied slope or rate of change in COP with ambient temperature is about 1.5 % per degree °F for several products listed in the table above. Similarly, the implied slope for COP with LWT is about -1.1% per degree °F, for all products where performance is given at multiple water temperatures. These slopes are in good agreement with regression models shown as lines in Figure 2 for the Solstice Extreme unit. Therefore, we will use the Solstice Extreme regression models to represent a generic AWHP for some of the analysis given below.

<u>Accounting for Defrost and Cycling Losses</u>

Field testing of the Solstice Extreme unit at four residential test sites (NYSERDA 2021) in Upstate NY showed that the actual average COPs – over a day – were systematically lower than the published (steady state) heating COPs. The published values for that unit reflect steady-state, frost-free operation while the daily average measured values include the impact of defrost and cycling. Table 5 compares the measured heating COPs to the published values, after accounting for the different LWTs for each site. The measured COPs are daily averages after removing pumping power as well as crankcase heater (CCH) power. The ratio of measured to published COPs range from 65% to 78%, with an average of 73%. The differences between the measured and published COPs are most-likely due to defrost and cycling losses.

Table 5. Comparing Published COPs to Measured COPs for Solstice Extreme

Site	Average LWT (°F)	Published COP at 20°F Ambient	Measured COP at 20°F Ambient (w/o pumps & CCH)	Ratio Measured-to-Published
S2	135	2.0	1.3	65%
S3	117	2.5	1.9	76%
S4	115	2.7	2.1	78%
S5	130	2.1	1.5	71%

Notes: CCH – crankcase heater

In a conversation with the factory engineers for the Solstice Extreme unit in November 2021, they acknowledged that defrost and cycling losses were significant for the single speed, monobloc Solstice extreme (LAHP48). However, they noted that the new variable speed version of the Solstice unit has addressed many of the issues that were found in the NYSERDA field testing. They expected defrost and cycling penalties to be much smaller with the newer unit.

Efficiency Vermont completed a field test of the Nordic ATW-series AWHP near Burlington, VT (Just 2020). This field study estimated a seasonal average efficiency of 2.4. Though it appears they did not integrate across the day to determine the overall average COP, accounting for the impact of defrost and cycling losses. They found that the instantaneous, measured COPs were consistent with the manufacturer's data.

The 2018 TRM for Vermont (Efficiency Vermont 2018) used the manufacturer's published data in a bin analysis for Burlington and come up with a seasonal average COP of 2.83. This seasonal COP takes into account the benefit of supply temperature reset, from 110°F to 130°F, but does not appear to account for cycling or defrost losses. If we apply a conservative factor of 20% the Vermont TRM, the predicted seasonal efficiency becomes 2.3.

The discussion above shows that the combined impact of cycling and defrost can be as high as 30% for AWHP systems. The defrost degradation curves from the ASHP White Paper (Henderson 2020) used an empirical degradation factor for defrost, from an ASHP manufacturer, that is zero at or above 47°F, peaks at 11% just below freezing, and then plateaus at 7.5% at lower temperatures. A bin analysis for Albany shows that the impact of this relation is to reduce seasonal efficiency by 8.3%.

Cycling losses typically decrease efficiency by 5% to 15% for constant speed systems, and often less for variable speed systems since these units modulate to the meet the load (and cycle less often). Based on all this input we recommend that the adjustment factors in Table 6 be used.

Table 6. Recommended Adjustment Factors to Adjust for Defrost and Cycling

Type of AWHP	Recommended COP Adjustment Factor (Actual/Published)
Constant Speed AWHP	0.80
Variable Speed AWHP	0.85
Variable Speed AWHP, Adaptive Defrost	0.90

Typical Load-Side Supply Temperatures

Table 7 summarizes some common hydronic arrangements used with hydronic HPs and lists the typical hot water supply temperatures used with each arrangement. The hydronic arrangement listed in the table are described in more detail below.

- Radiant Floor Premium Design. Underfloor tubes have recommended spacing (e.g., 6 inches). Hydronic fins or heat transfer plates are used to thermally couple tubing to floor (or in the wall). No carpets. Supply water temperatures of 90-100°F are possible.
- Radiant Floor Low-Cost Design. Underfloor tubes have wider spacing. Limited or no heat transfer fins. Floors are carpeted. Higher supply temperatures are needed (e.g., 110-120°F)
- Baseboard with Hydronic AHU. In some retrofit applications the hydronic baseboard heaters are supplemented by adding an air handler unit with hydronic coil and the associated ductwork. In many cases the AHU can be selected to use lower temperature water temperatures (e.g., 120 to 130°F supply) and provide the extra heating required to make up for the reduced heating capacity provided by the baseboards operating at lower temperatures. This arrangement also can allow for cooling operation by using chiller water from the AWHP unit in the AHU coil.
- Modified Baseboard. In some retrofit applications, more heat emitters (baseboards, radiators, or European style/white heat emitters) can be added to the home so that the hydronic system can meet the home heating load at lower supply temperatures (e.g., 140 to 150°F).
- Conventional Baseboard. This hydronic arrangement was typically sized to use a fuel-fired boiler supplying 160 to 180°F hot water. Most HPs are unable to supply water at this temperature. Therefore, conventional baseboard systems can not normally work with HPs without some level of modification, as discussed above.

For each application, use actual load-side leaving/supply temperature or choose one of the recommended values from Table 7.

Table 7. Typical Supply Temperatures for Various Hydronic Designs

Hydronic Application	**Approximate Load-Side Leaving/Supply Temperature (F)**
Radiant Floor (premium design)	90
	100
Radiant Floor (low-cost design)	110
Baseboard w/ Hydronic AHU	120
	130
Modified Baseboard (some additional emitters)	140
	150
Conventional Baseboard	160+

Adapted from: Presentation by John Siegenthaler for EnerTech, "Part 2: System Design Details for Air-to-Water Heat Pumps", February 2021 (youtube.com).

In buffer tank arrangements, the load supply temperature is often 5°F to 10°F lower than the AWHP LWT. The section below discusses piping arrangements that can minimize this penalty.

Direct-to-Load Piping

One improvement to hydronic heat pumps systems is to use “Direct-to-Load” piping as shown in Figure 3. This concept for hydronic heat pumps has been presented by Manning and Ponikau (2015) at the NYGeo conference and Manning (2017) at IGSHPA. They reported the arrangement resulted in the hottest water leaving the heat pump directly reaching the zones. In more standard piping arrangements with 4-port buffer tanks, the temperature of water reaching the zones can be as much 10°F lower than the heat pump leaving temperature. They report that to achieve the best performance, a variable speed circulator should be used on the zone side of the buffer tank.

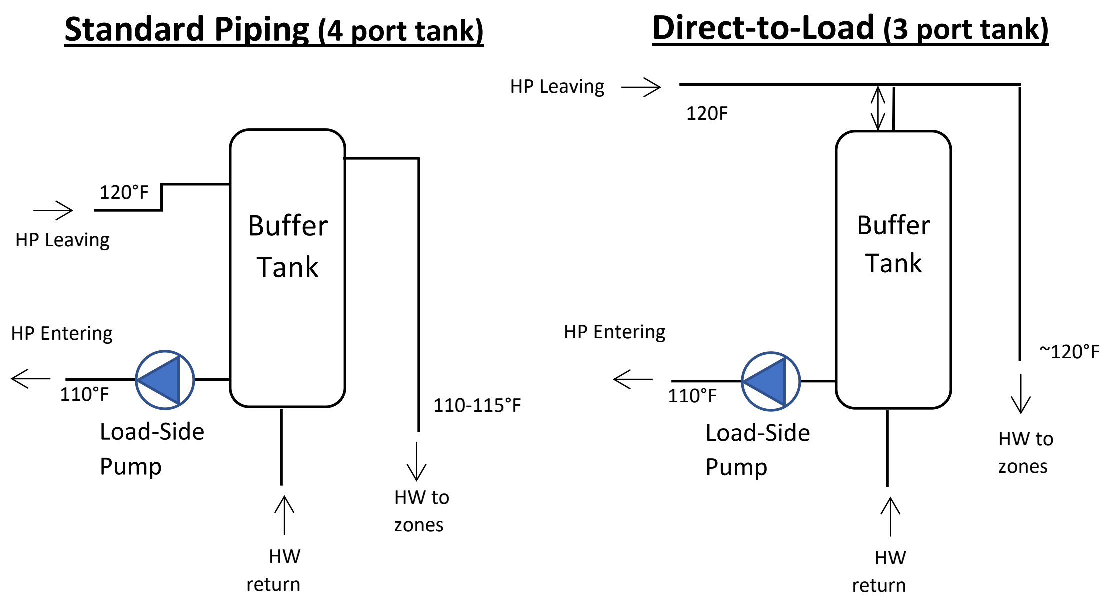

Figure 3. Schematic of Standard and Direct-to-Load Piping Arrangements for a Hydronic HP System

For prescriptive measures we conservatively recommend that a benefit of 5°F be assumed for direct-to-load piping, regardless of the type of circulator flow control method implemented on the zone side of the buffer tank.

Impact of Load-Side Temperature Reset

A key strategy to reduce energy use in hydronic systems is to provide lower temperature water to the heat emitters as the outdoor temperature gets warmer. A more moderate hydronic leaving water temperature (LWT) is still able to meet the heating load when outdoor conditions are mild, since the heating loads are smaller. This strategy is especially important for HPs since the heating COP is a strong function of the LWT. A bin analysis was developed using the TMY weather data for the NY cities. The COP curves for the Solstice Extreme were used in the analysis. Figure 4 shows a reset schedule that assumes a load supply temperature near 130°F at design is reduced by 40°F (reset range) by the time the outdoor reaches 57.5°F. In this case the seasonal average COP is increased by 16% compared to the seasonal COP without reset.

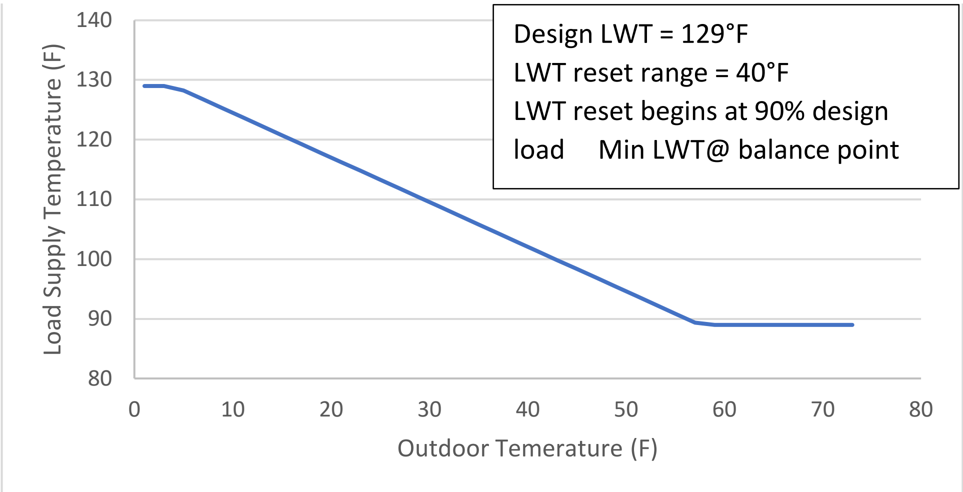

Figure 4. Reset of the Hydronic Supply Temperature with Outdoor Temperature (Albany)

Table 8 shows the results for various design leaving/supply temperatures and reset ranges in Albany (similar results are expected for other Upstate cities). The boost in COP ranges from 6 to 22% over the range of assumptions. Reset provides the most benefit when the design supply temperature is hottest, and the reset range is widest.

For prescriptive measures we recommend a 10% efficiency boost be assumed for most applications of supply temperature reset based on outdoor temperature, or a reset factor of 1.1. Like every control measure, proper implementation will require that the details of supply temperature reset control parameters be properly defined and documented.

Table 8. COP Adjustment Factor for Supply Temperature Reset Based on Outdoor Air for Albany with an AWHP

	Leaving Water Temperature at Design (°F)		
Supply Reset Range (°F)	**150**	**130**	**110**
60	1.32	-	-
40	1.22	1.16	-
20	1.12	1.09	1.07

Impact of Pumping on System Efficiency

AWHPs require pumps on the load-side of the unit. Flows are relatively high compared to boilers (approximately 3 gpm per installed ton of heating capacity), so the impact of pumping power can be significant. AWHPs normally are installed with a buffer tank, as shown in Figure 1. Then separate hydronic circulators are controlled by zone thermostats that draw from the buffer tank to deliver heat to the space load. To determine the pumping adjustment factor for efficiency you need to determine the pumping power for the load-side pump between the buffer tank and the HP unit (see Figure 1)

The load-side pumps run whenever the AWHP operates. The zone circulators are controlled to run based on space thermostats – similar to a boiler system. Since this power is approximately the same for the base case boiler and the HP case, this zone circulator power is neglected in the savings calculations below.[3] Table 9 provides a correction factor for efficiency based on the load-side pumping power.

Table 9. Pumping Adjustment Factor to Modify Heating and Cooling Efficiency (Excluding zone-side circulators)

	Nominalized Power for Load-Side Pump (Watts per nominal ton of heating output)			
	20	**40**	**60**	**80**
Heating Pumping factor ($F_{pmp,h}$)	99.4%	98.9%	98.4%	97.8%

Notes: Assuming an operating COP for HP in the range of 1.8 to 2.2.

Most of Solstice Extreme units in NYSERDA AWHP demonstration project (NYSERDA 2021) used about 160 Watts, or 40 Watts per nominal heating ton. When a heat exchanger was added the power increased to about 80 Watts per nominal heating ton.

<u>Estimating Seasonal Efficiency from the Reported A5W110 COP</u>

Table 10 shows how the seasonal efficiency relates to the COP at 5°F and 110°F reported by Efficiency Vermont. The Seasonal Efficiency Factors were determined using a bin analysis similar to the ASHP White Paper (Henderson 2020) based on TMY3 weather data. The variation of COP with ambient temperature and leaving water temperature were based on Solstice Extreme efficiency curve in Figure 2. The HP is sized to be 100% at the ACCA design conditions. The analysis is based on published steady state performance and does not account for defrost or cycling losses.

Table 10. Factor Relating Seasonal COP to the COP at A5W110 (from Efficiency Vermont Table)

	Seasonal Efficiency Factor: Seasonal / A5W110					
	Leaving Water Temperature (°F)					
City	**100**	**110**	**120**	**130**	**140**	**150**
Albany	1.32	1.20	1.09	0.97	0.86	0.74
Binghamton	1.33	1.21	1.10	0.98	0.86	0.75
Buffalo	1.33	1.22	1.10	0.99	0.87	0.76
Massena	1.27	1.15	1.04	0.92	0.80	0.69
New York	1.42	1.30	1.19	1.07	0.96	0.84
Poughkeepsie	1.33	1.21	1.10	0.98	0.87	0.75
Syracuse	1.33	1.21	1.10	0.98	0.87	0.75

[33] An alternative approach for retrofit applications might be to assume zone circulator energy use increases by 50-75% in the hydronic HP case, relative to the boiler case, because lower HW temperatures result in longer circulator runtimes. Circulator energy use in boiler systems is on the order of 150 kWh per year. Variable speed zone circulators might save energy but must overcome the impact of lower water temperatures increasing runtime. Because of all these competing factors, the impact of zone circulators is not considered here.

Calculating Seasonal Efficiency

Summary of the calculation process. First determine the following data:

- The COP for the unit at A5W110 conditions
- the pumping power per nominal heating ton
- the maximum leaving water temperature, accounting for impact of the piping arrangement
- the weather city

Calculate the seasonal efficiency

Seasonal COP $= COP_{A5W110} \times SEF \times F_{adj} \times F_{reset} \times F_{pump}$

Where:

COP_{A5W110}	Efficiency at 5°F and 110°F published by Efficiency Vermont or from manufacturer. https://www.efficiencyvermont.com/Media/Default/docs/rebates/qpls/efficiency-vermont-awhp-qpl.pdf
SEF	Seasonal efficiency factor from Table 10, depending on leaving water temperature and the weather city. Reduce LWT by 5°F for direct-to-load piping.
F_{adj}	Adjustment factor for defrost and cycling from Table 6, depending on AWHP unit characteristics
F_{pump}	Factor from Table 9, based on normalized pumping power.
F_{reset}	Use generic factor of 1.1 or pull an appropriate value from Table 8, depending on the temperature reset details. Use 1.0 for no reset.

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