# Ductless Mini-Split Heat Pump Systems: The Answers to Questions about Efficiency You Didn't Know You Had

### John Walczyk, Cadmus Antonio Larson, National Grid

## ABSTRACT

People choose to install ductless mini-spilt heat pumps (DHP) for the high-rated efficiency, ease of installation, cold weather heating ability, and ability to eliminate duct losses. Many positive attributes of DHPs seem easy to quantify; however, their actual efficiency, performance, and savings are less straightforward. To determine certified efficiency ratings, manufacturers comply with the American National Standards Institute (ANSI)/Air Conditioning, Heating and Refrigeration Institute (AHRI) Standard 210/240 (denoted as the AHRI standard; AHRI 2012). The certified efficiency ratings may not represent actual seasonal efficiency because DHPs rarely operate at the test conditions required by the AHRI standard. Furthermore, the AHRI standard does not require testing below 17°F; the verified performance below this temperature is not available.

This paper first provides technical background information about DHPs, then explains the DHP testing and analytical methodology defined in the AHRI standard. There are several realworld examples from long-term meter data included to support these concepts. Additionally, we compare nameplate efficiency ratings to the actual measured average efficiency from 90 DHPs for a full cooling season. The variance of actual to rated efficiency will support the paper concepts about the AHRI standard; we include a comprehensive explanation of rated efficiency and performance to describe how AHRI standard ratings may be misleading. The paper explains which specification data are important and how to use these data to select a DHP system that meets the needed criteria and maximizes energy savings.

## Introduction

When a homeowner decides to purchase HVAC equipment, they generally rely on their HVAC contractor to select equipment that:

- Aligns with their budget
- Offers the features they want
- Reduces operating cost (through reduced maintenance or high-efficiency operation)
- Heats and cools the space adequately

To select equipment capable of conditioning the space, contractors estimate the heating and cooling load of a home or the conditioned space and choose equipment with sufficient heating and cooling capacity<sup>1</sup> to meet the load.

Figure 1 shows examples of several Mitsubishi DHP efficiency and capacity ratings. To illustrate the concepts in this paper, we specifically chose a Mitsubishi DHP because Mitsubishi

<sup>&</sup>lt;sup>1</sup> Capacity is the amount of heat (added or removed) that a DHP is capable of providing, usually measured in Btus or tons.

publishes extensive and detailed technical information and performance specifications.<sup>2</sup> We explain the calculation of seasonal energy efficiency ratio (SEER), rather than the heating seasonal performance factor (HSPF) because, although both follow the same general principles, the calculation of SEER requires fewer steps.

# **Ductless Heat Pumps: Technical Information**

The majority of central air conditioners (CACs) use a single-speed compressor to move refrigerant to reject heat from inside a building to the outdoor environment. Increasing the surface area of the heat rejection surface (the outdoor condensing coil) effectively increases the efficiency. An 18 SEER 3-ton CAC, for example, is usually larger than a 13 SEER, 3-ton unit. Unlike common CACs, most DHPs use variable-refrigerant flow technology to vary the capacity (tonnage) to meet the building cooling load. A variable speed DHP may run for more hours in a season than a CAC, because the DHP is capable of operating at a lower average capacity. Low-speed operation effectively increases the surface area of the DHP, thus increasing operating efficiency.

A DHP's rated cooling capacity and efficiency (circled in blue in Figure 1) are certified values, determined by certified tests following the AHRI standard. The rated heating capacity and efficiency are also certified values (circled in red in Figure 1). For the DHPs in Figure 1, the manufacturer provides the range of capacity (minimum and maximum), but, unlike rated values, these values are not AHRI-certified.

				R	ated Maximum
Outdoor unit model			MUZ-FH09NA	MUZ-FH12NA	MUZ-FH15NA
Capacity	Cooling <del>%</del> 1	Btu/h	9,000 (1,700 ~ 12,000)	12,000 (2,500 ~ 13,600)	15,000 (6,450 ~ 19,000)
Rated (Minimum~Maximum)	Heating 47 <b></b> ∦1	Btu/h	(1,600 ~ 18,000)	13,600 (3,700 ~ 21,000)	18,000 (5,150 ~ 24,000)
Capacity Rated (Maximum)	Heating 17 <del>∦</del> 2	Btu/h	6,700 (12,200)	8,000(13,600)	11,000 (18,000)
Power consumption	Cooling *1	W	560 (100 ~ 1,000)	870 (170 ~ 1,150)	1,200 (410 ~ 2,200)
Rated (Minimum~Maximum)	Heating 47 <del>∦</del> 1	W	710 (110 ~ 1,470)	950 (280 ~ 2,300)	1,300 (430 ~ 3,360)
Power consumption Rated (Maximum)	Heating 17 <del>∦</del> 2	W	600 (1,440)	720 (1,900)	1,020 (2,480)
EER *1 [SEER] *3	Cooling		16.1 [30.5]	13.8 [26.1]	12.5 [22.0]
HSPF IV ₩4	Heating		13.5	12.5	12.0
COP	Heating <b></b> *1		4.50	4.20	4.06

NOTE: Test conditions are based on AHRI 210/240.

 #1: Rating conditions (Cooling) — Indoor: 80°FDB, 67°FWB, Outdoor: 95°FDB, (75°FWB) (Heating) — Indoor: 70°FDB, 60°FWB, Outdoor: 47°FDB, 43°FWB

 #2:
 (Heating) — Indoor: 70°FDB, 60°FWB, Outdoor: 17°FDB, 15°FWB

Figure 1. Mitsubishi M-Series performance data (Mitsubishi 2014)

According to the information in Figure 1, the MUZ-FH15NA model can provide between 6,450 Btu/h and 19,000 Btu/h of cooling capacity when the outdoor dry-bulb temperature is 95°F, and up to 18,000 Btu/h of heating capacity when the outdoor dry-bulb temperature is 17°F. Note that the figure does not provide efficiency estimates, but these can be calculated for each

<sup>&</sup>lt;sup>2</sup> Example available online: <u>http://meus1.mylinkdrive.com/index.html</u>

capacity using the following algorithms for the energy efficiency ratio (EER; a cooling metric) and coefficient of performance (COP; a heating metric) and the values in Figure 1:

$$EER = \frac{Capacity (BTU/h)}{Power (Watts)} = \frac{15,000 (BTU/h)}{1,200 (Watts)} = 12.5$$

$$COP = \frac{Capacity (BTU/h)}{Power (Watts) \times 3.412 \frac{(BTU/h)}{Watt}} = \frac{18,000 (BTU/h)}{1,300 (Watts) 3.412 \frac{(BTU/h)}{Watt}} = 4.06$$

Other efficiency values for the minimum and maximum speeds can be calculated in the same manner. However, the calculation of SEER, described in the next section, is not as straightforward.

By controlling (limiting) speed, a manufacturer can de-rate the size of a DHP to boost the efficiency rating. They do this because some consumers value extreme cold weather performance over efficiency, while others value efficiency over capacity. Figure 2 shows a comparison of the performance and physical specifications of the MUZ-FH15NA model to the MUZ-FH18NA model. Although these two DHPs are physically identical (as shown in the Compressor specifications), they employ different control algorithms to achieve different rated capacity, EER, and SEER (compare values pointed out by red arrows).

Outdoor unit model			MUZ-FH15NA	MUZ-FH18NA	
Capacity	Cooling #1	Btu/h	15,000 (6,450 ~ 19,000)	17,200 (6,450 ~ 21,000)	
Rated (Minimum-Maximum)	Heating 47 ±1	Btu/h	18,000 (5,150 ~ 24,000)	20,300 (5,150 ~ 30,000)	
Capacity Rated (Maximum)	Heating 17 +2	Btu/h	11,000 (18,000) 🗲	13,700 (20,300)	
Power consumption	Cooling #1	W	1,200 (410 ~ 2,200)	1,430 (410 ~ 2,220)	
Rated (Minimum-Maximum)	Heating 47 ±1	W	1,300 (430 3,360)	1,720 (430 ~ 3,390)	
Power consumption Rated (Maximum)	Heating 17 #2	w	1,020 (2,480)	1,320 (3,180)	
EER +1 [SEER] +3	Cooling		12.5 [22.0]	12.0 [21.0]	
HSPF IV #4	Heating		12.0	12.0	
COP	Heating #1		4.06	3.46	
Power supply	V, phase, Hz			208/230, 1, 60	
Max. fuse size (time delay) A		20	20		
Min. circuit ampacity A		A	16	16	
Fan motor			0.93	0.93	
	Model		SNB172FQKMT	SNB172FQKMT	
	RLA		12.0	12.0	
Compressor	LRA		15.0	15.0	
	Refrigeration oil L (Model)		0.40 (FV50S)	0.40 (FV50S)	
Refrigerant control			Linear expansion valve	Linear expansion valve	
Sound level #1	Cooling	dB(A)	51	52	
	Heating	dB(A)	55	55	
Defrost method				Reverse cycle	
Log to the log of the log of	W	in.	33-1/16	33-1/16	
Dimensions	D	in.	13	13	
	н	in.	34-5/8	34-5/8	
Weight		Ib,	124	124	
External finish	3			Munsell 3Y 7.8/1.1	
Remote controller				Wireless type	

Figure 2. Comparison of identical DHPs with different ratings

The actual seasonal operating efficiency of a DHP system depends on how it operates. For example, if the MUZ-FH15NA model (rated SEER 22) only operated at its rated speed at an outdoor temperature of 95°F during the cooling season, its actual average efficiency for the season would be 12.5. The AHRI standard requires performance testing at various conditions and uses the test results to calculate certified efficiency values. SEER is meant to represent the average operating efficiency of a system for a cooling season, which can differ from the test conditions and the assumptions used to define the calculation methodology. Although seasonal operation varies by climate and by usage patterns, studies have revealed that the SEER rating, on average, may reasonably estimate the average operating efficiency for a single-speed CAC (Hirsch 2003).

The next section provides an overview of the AHRI standard SEER calculation methodology and results of a large DHP metering study to explain why actual DHP seasonal efficiency can be significantly different from rated SEER.

# **ANSI/AHRI Standard 210/240: Testing Procedures**

To determine a certified SEER value, the AHRI standard specifies five required tests (labeled #1 through #5) and two optional tests,<sup>3</sup> summarized in Figure 3.

Test Description	Indoo	ntering r Unit erature	Outd	Entering oor Unit perature	Compressor Speed	Cooling Air Volume Rate
	Dry-Bulb °F °C	Wet-Bulb ⁰F °C	Dry-Bulb °F °C	Wet-Bulb °F °C	speed	
$A_2 \text{ Test} - \text{required} $ (steady, wet coil) <b>1</b>	80.0 26.7	67.0 19.4	95.0 35.0	$75.0^{(1)}$ $23.9^{(1)}$	Maximum	Cooling Full- load <sup>(2)</sup>
$B_2$ Test – required (steady, wet coil) #2	80.0 26.7	67.0 19.4	82.0 27.8	$65.0^{(1)}$ $18.3^{(1)}$	Maximum	Cooling Full- load <sup>(2)</sup>
E <sub>v</sub> Test - required <b>#3</b> (steady, wet coil)	80.0 26.7	67.0 19.4	87.0 30.6	$69.0^{(1)}$ $20.6^{(1)}$	Intermediate	Cooling Intermediate <sup>(3)</sup>
B <sub>1</sub> Test – required #4 (steady, wet coil)	80.0 26.7	67.0 19.4	82.0 27.8	$65.0^{(1)}$ $18.3^{(1)}$	Minimum	Cooling Minimum <sup>(4)</sup>
F <sub>1</sub> Test – required #5 (steady, wet coil)	80.0 26.7	67.0 19.4	67.0 19.4	53.5 <sup>(1)</sup> 11.9 <sup>(1)</sup>	Minimum	Cooling Minimum <sup>(4)</sup>
G <sub>1</sub> Test - optional (steady, dry coil)	80.0 26.7	(5)	67.0 19.4	_	Minimum	Cooling Minimum <sup>(4)</sup>
I <sub>1</sub> Test - optional (cyclic, dry coil)	80.0 26.7	(5)	67.0 19.4	—	Minimum	(6)

Figure 3. AHRI standard cooling mode test conditions for units having a variable speed compressor

To determine certified efficiency and capacity (nameplate values), manufacturers send a system to an AHRI testing facility (denoted as a test center) capable of conducting tests in accordance with the standard and calculating a SEER value using a series of equations. These tests are summarized next.

**Test 1:** The test center conducts the first test in Figure 3 (Test A<sub>2</sub>) at full capacity (maximum compressor speed) and at a 95°F outdoor air temperature, with the airflow of the indoor unit set to high speed. This test determines the AHRI-certified EER value. Note that the MUZ-FH15NA model (Figure 1) shows both a rated capacity (15,000 Btu/h) and a maximum capacity (19,000 Btu/h). Although the AHRI standard prescribes a maximum compressor speed for this test, the rated speed, not the maximum speed, is used to calculate EER. At these test conditions, the DHP could actually operate at a lower efficiency than the rated EER value.

<sup>&</sup>lt;sup>3</sup> The primary purpose of the two additional optional tests shown in Figure 3 is to determine efficiency losses due to the DHP cycling on and off. This is a necessary consideration if the startup efficiency is less than the steady-state operating efficiency. Most manufacturers omit these tests, using a default value for the cycling degradation coefficient.

**Test 2:** The second test (Test B<sub>2</sub>) is also performed at full capacity and at high-speed indoor airflow, but at a lower outdoor temperature (82°F).

**Test 3:** The third test (Test  $E_v$ ) is performed at an intermediate compressor speed at outdoor temperature 87°F. Section 3.2.4 of the AHRI standard defines intermediate speed with the following equation:

 $Intermediate speed = Minimum Speed + \frac{Maximum Speed - Minimum Speed}{3}$ 

The maximum speed in this test is the rated speed, not necessarily the actual maximum speed. The AHRI standard does not specify an indoor fan speed for this test; the indoor fan operates at the speed selected by the DHP controls.

**Test 4:** The test center performs the fourth test (Test B<sub>1</sub>) under the same conditions as the second test (outdoor air temperature of 82°F), but with the compressor speed set to minimum and an indoor fan set to the lowest speed.

**Test 5:** The fifth test (Test  $F_1$ ) is performed at minimum compressor speed with outdoor air temperature set to 67°F and an indoor fan set to the lowest speed.

The SEER calculation methodology defined in the AHRI standard appears relatively complex, using algorithms that include the impact of compressor speed on efficiency. Unlike single-speed HVAC systems, the efficiency of a variable speed system changes with both temperature and compressor speed. The only inputs required are the results from the five tests described above. SEER is calculated using bin temperature analysis and a series of linear and polynomial equations.

The next section outlines and, when possible, visually plots the function of the equations used to determine SEER.

## **ANSI/AHRI Standard 210/240: SEER Calculation Methodology**

The general form of the SEER calculation is a ratio of total seasonal capacity to seasonal energy consumption, as follows:

$$SEER = \frac{\sum_{j=1}^{8} q_c(T_j)}{\sum_{j=1}^{8} e_c(T_j)} = \frac{\sum_{j=1}^{8} \frac{q_c(T_j)}{N}}{\sum_{j=1}^{8} \frac{e_c(T_j)}{N}} \quad \begin{array}{l} \text{Where:} \\ q_c = \text{cooling capacity in bin temperature} \\ e_c = \text{energy consumption in bin temperature} \\ T = \text{bin temperature} \\ N = \text{total hours in cooling season} \end{array}$$

Equation 4.1-1 from AHRI standard

This equation is simply a cooling run-time weighted average of eight discrete EER values. Figure 4 shows the eight temperature bins and proportional number of hours in each temperature bin.

Bin Number, j	Bin Temperature Range °F	Representative Temperature for bin °F	Fraction of Total Temperature Bin Hours, N <sub>r</sub> /N
1	65-69	67	0.214
2	70-74	72	0.231
3	75-79	77	0.216
4	80-84	82	0.161
5	85-89	87	0.104
6	90-94	92	0.052
7	95-99	97	0.018
8	100-104	102	0.004

Figure 4. Temperature bins (AHRI standard, Table 16: Distribution of Fractional Hours within Cooling Season Temperature Bins)

The proportion of hours represents the Region IV climate. Different proportional hours for different climates results in a different SEER value. Figure 5 shows the heating (left) and cooling (right) load hours. Specific regions are not defined for cooling in this figure; rather, the AHRI standard uses the weather data from the 800-hour line on the right figure, which is generally coincident with Region IV heating hours.

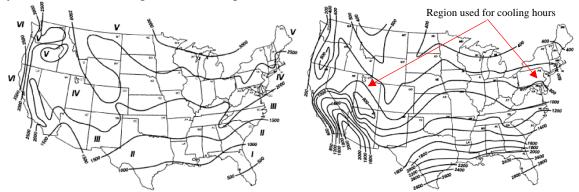


Figure 5. AHRI standard heating (left) and cooling (right) load hours

In summary, the certified SEER value is based on efficiency (which varies with temperature) and the amount of time the DHP operates at eight different temperatures that represent one climate region in the United States. The following concepts are the basis of, and provide rationale for, the SEER calculation methodology:

- As outdoor temperature increases, the cooling load of conditioned space increases
- As outdoor temperature increases and compressor speed is constant, DHP efficiency decreases
- As compressor speed increases, efficiency decreases
- As outdoor temperature increases, compressor speed increases to meet the increasing cooling load of the conditioned space

The AHRI standard calculations are based on these concepts and use the results of the five required tests to calculate SEER.

#### **Application of Results from Test 1**

The capacity (Btu/h) result of test 1 serves as the basis for a building cooling load function (shown below, where k=2 denotes maximum compressor speed). This function (cooling required versus outdoor temperature) is based on DHP cooling performance at 95°F. The assumption is that DHPs are sized to adequately cool the space at this temperature. The equation includes a factor of 1.1 to account for equipment oversizing.<sup>4</sup>

$$BL(T_{j}) = \frac{(T_{j} - 65)}{95 - 65} \cdot \frac{\dot{Q}_{c}^{k=2}(95)}{1.1}$$

Equation 4.1-2 from AHRI standard

For the example system MUZ-FH15NA model, the building load at 95°F is given by:

$$BL = \frac{95 - 65}{95 - 65} \times \frac{15,000}{1.1} = 13,636 \, Btu/h$$

The building load at 65°F is 0 Btu/h. Figure 6 shows the building load curve and examples of test results (colored points) for the MUZ-FH15NA model.<sup>5</sup> The purpose of creating a building load curve is to first determine the capacity required at each temperature bin, then to determine the energy consumption needed to provide that capacity (additional details are provided below and in Figure 7). The orange region line in Figure 6 was determined from manufacturer data for the MUZ-FH15NA model.

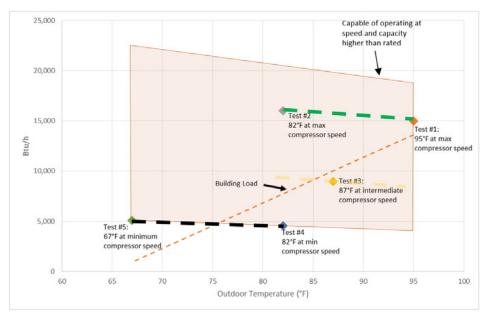


Figure 6. Building load curve and example of five test results required by the AHRI standard

 <sup>&</sup>lt;sup>4</sup> Contractors typically oversize a DHP system so it is capable of supplying more capacity than required at peak temperatures. For example ACCA Manual J suggests an oversizing factor of one-half ton (ACCA 2008).
 <sup>5</sup> The figure does not show actual test results, but values that were estimated using published capacity and power correction factors for variable speed operation.

#### Maximum Capacity Function from Test 1 and Test 2

The AHRI standard uses the cooling capacity and electrical power consumption determined from tests 1 and 2 (at 95°F and 82°F, respectively) to determine a linear function for capacity and power at maximum compressor speed (k=2). The green dotted line in Figure 6 shows this function for capacity,<sup>6</sup> described mathematically as:

$$\dot{Q}_{c}^{k=2}(T_{j}) = \dot{Q}_{c}^{k=2}(82) + \frac{\overset{\text{Test } 2 \text{ Result}}{\dot{Q}_{c}^{k=2}(95)} - \dot{Q}_{c}^{k=2}(82)}{95 - 82} \cdot (T_{j} - 82)$$

Eq. 4.1.3-3 from AHRI/ANSI 210/240

#### Minimum Capacity Function from Test 4 and Test 5

The AHRI standard uses the cooling capacity determined from tests 4 and 5 (at 82°F and 67°F, respectively) to determine a linear function for capacity at minimum compressor speed (k=1). The black dotted line in Figure 6 shows this function, described mathematically as:

$$\dot{Q}_{c}^{k=l}(T_{j}) = \dot{Q}_{c}^{k=l}(67) + \frac{\dot{Q}_{c}^{k=l}(82) - \dot{Q}_{c}^{k=l}(67)}{82 - 67} \cdot (T_{j} - 67)$$

Equation 4.1.3-1 from AHRI standard

Using these functions, the minimum and maximum capacity at any temperature can be calculated.

### **Application of Capacity Determined by Test 3**

Because a DHP is able to operate at a range of speeds, the standard includes a methodology to calculate the capacity at intermediate speed (k=v) for any temperature, as follows:

$$\dot{Q}_c^{k=\nu}(T_j) = \overbrace{\dot{Q}_c^{k=\nu}(87)}^{rad} + M_{\mathcal{Q}} \cdot \left(T_j - 87\right)$$

Equation 4.1.4-1 from AHRI standard

The  $M_Q$  term represents the slope of the intermediate speed capacity versus temperature function. This slope, in terms of capacity per degree Fahrenheit, is calculated by interpolating capacity values from the minimum and maximum capacity functions. With this slope, the DHP capacity at a variable intermediate speed for any temperature can be determined (the yellow hashed line in Figure 6 shows an example of the capacity function based on compressor speed for test 3).

<sup>&</sup>lt;sup>6</sup> For the sake of brevity, only capacity is shown. The AHRI standard uses the same approach for power functions.

### **Additional SEER Calculations**

The equations above provide linear temperature-dependent capacity and power functions for three discrete speeds: minimum, intermediate, and maximum. Variable speed DHPs are capable of operating at any speed between the minimum and maximum,<sup>7</sup> so the next step in the SEER calculation process is to determine the speed at which the DHP needs to operate to meet the building load. The AHRI standard provides conditional equations to determine whether the DHP is running at minimum speed, and whether it is cycling on and off at intermediate or maximum speed. Figure 7 shows these conditions along the building load curve.

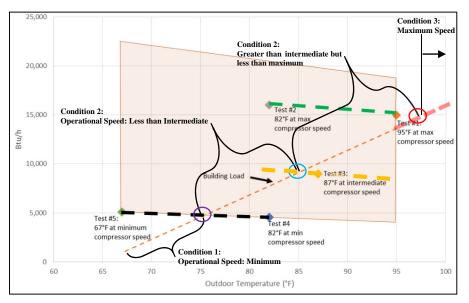


Figure 7. Determination of DHP speed from building load

### **Condition 1**

The AHRI standards uses a conditional equation to determine the intersection of the building load with the minimum compressor speed curve (circled purple in Figure 7). For this example, we calculated the intercept at approximately 75°F outdoor temperature. Below this temperature, the DHP runs only at its minimum speed and does not operate continuously because the capacity at the lowest speed exceeds the building load (it would cycle on and off). Because the required capacity is relatively low below 75°F, the calculated efficiency has a relatively minimal impact on the final SEER estimate. This is the only condition for which a cyclic degradation factor is applied; this may be one reason some manufacturers' choose to skip the optional tests.<sup>8</sup>

## **Condition 2**

When the outdoor temperature reaches 75°F, the DHP runs continuously at less than the intermediate speed to satisfy the building load. At 85°F, the DHP operates precisely at intermediate speed. Above 85°F and up to approximately 98°F (see red hashed line in Figure 7),

<sup>&</sup>lt;sup>7</sup> Or, as shown in Figure 1, some DHPs can operate at higher than the maximum rated speed.

<sup>&</sup>lt;sup>8</sup> The optional tests shown in Figure 3 are used to estimate an efficiency degradation factor due to a unit cycling on and off.

the DHP operates at the speed necessary to deliver cooling capacity to meet the building load. Section 4.1.4.2 of the AHRI standard provides a sequence of equations to determine capacity and energy consumption for all bin temperatures in this range (bins 3 through 7 for this example). Simply stated, these calculations interpolate a value from the minimum and maximum speed EER estimates to determine EER along the building load curve. Functionally, this creates a polynomial relationship of EER and temperature.

## **Condition 3**

The AHRI standard uses a conditional equation to determine the intersection of the building load with the maximum compressor speed capacity curve (circled red in Figure 7). When the outdoor temperature exceeds approximately 98°F, the DHP operates continuously at maximum speed and, above this temperature, would not provide sufficient cooling to the space.<sup>9</sup> For this reason, capacity above 98°F is no longer based on the building load capacity curve, but on the DHP capacity from the maximum compressor speed capacity curve (green hashed line in Figure 7).

# **HSPF and Efficiency Overview**

The AHRI standard estimates the HSPF of a DHP for the heating season using an approach similar to the SEER calculation method. The most notable differences are:

- Use of a defrost factor to account for efficiency loss because of frost buildup on the outdoor coil
- Specification of additional weather regions, although Region IV is commonly used
- Tests are performed at outdoor temperatures of 62°F, 47°F, 35°F, and 17°F

Although approximately 6% of the Region IV heating hours are below 17°F, the AHRI standard does not require performance testing below 17°F, presumably because air-source heat pump operation at very cold temperatures is relatively new. Figure 8 shows an example of published performance of a MUZ-FH DHP model.

<sup>&</sup>lt;sup>9</sup> The DHP in this example is actually capable of providing more cooling capacity than the rated capacity (see Figure 6).

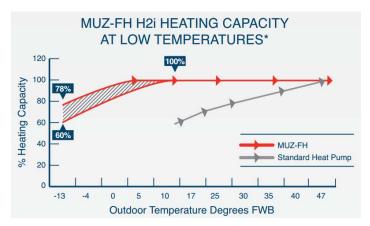


Figure 8. Mitsubishi performance curve for MUZ-FH H2i series DHP (Mitsubishi 2015)

At temperatures above 17°F, the capacity curve in Figure 8 is flat. However, this DHP should be capable of increasing heating capacity as outdoor temperature increases.<sup>10</sup>

Manufacturers are constrained by testing outlined in the AHRI standard. For this reason, they could be motivated to set the rated speed at the temperature test points to maximize the efficiency rating. By altering the rated speed, they could alter the capacity and power curves estimated by the AHRI standard functions. Alternatively, they might sacrifice efficiency by increasing speed to maximize capacity at cold conditions; whichever conditions will meet their customer's needs. Figure 2, which compares two identical heat pumps, shows evidence of this. The concepts described in the previous sections outline how the capacity curve in Figure 8 is maximizing both HSPF and the capacity below 17°F.

The AHRI standard does not require a test below 17°F; therefore, the DHP can operate at any efficiency below this temperature with no impact on the HSPF or COP rating. To produce the flat capacity curve shown in Figure 8, the actual rated speed needs to be reduced as temperature increases. As outdoor temperature increases, this strategy effectively increases efficiency at a greater rate than if the DHP maintained a constant compressor speed.

## **Summary and Field Results**

The methodology outlined in the AHRI standard does not accurately estimate DHP performance and efficiency. Some of the reasons for this are:

- Some DHPs operate in a different weather region than that defined in the AHRI standard (Region IV)
- Some DHPs operate at a higher speed and, consequently, have a lower efficiency than rated
- A DHP's actual performance in cooling mode can be lower than the rated performance because DHPs have the ability to operate at a higher speed than the rated speed
- The actual performance of DHPs at low temperatures (below 17°F) is not tested, yet many DHP models are designed to operate at temperatures well below 17°F
- Some DHPs do not operate to provide capacity at precisely the Btu/h rate of the building load (any condition above 75°F; see Figure 7).

<sup>&</sup>lt;sup>10</sup> For DHPs in heating mode, as outdoor temperature increases, both capacity and efficiency increase.

We analyzed the usage patterns and seasonal operating efficiency of DHPs installed in 90 homes in Massachusetts.<sup>11</sup> Figure 9 (DHP1) and Figure 10 (DHP2) show examples of identical DHPs with substantial differences in actual operating efficiency. Each figure shows metered power (red) and outdoor temperature (blue) from June 1 through August 31, 2015. The nameplate efficiency rating for these units (both Mitsubishi MUZFE18NA) is 20.2 SEER. The average metered efficiencies were 19.5 for DHP1 and 11.2 for DHP2.

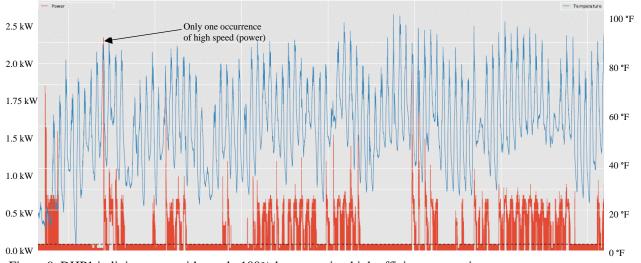
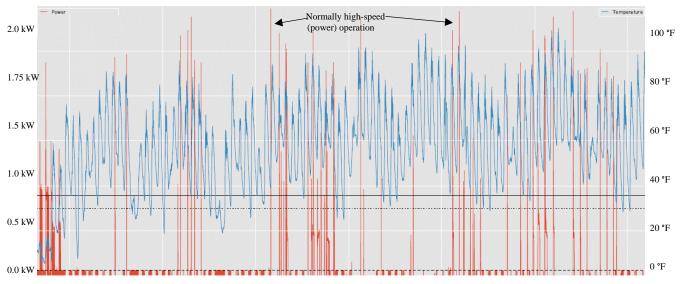


Figure 9. DHP1 in living room with nearly 100% low-capacity, high-efficiency operation



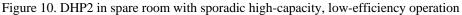


Figure 9 shows that the average power of DHP1 was relatively low, operating around 600 watts for the majority of the cooling season. Figure 10 shows that when DHP2 operated, it operated at a much higher power than DHP1. DHP1 was in a living room and was controlled to maintain a constant temperature most of the time. DHP2 was in a spare room, used sporadically.

<sup>&</sup>lt;sup>11</sup> Final publically available results are expected in August 2016.

When DHP2 was used, it is likely that the homeowner set the thermostat significantly lower than the indoor temperature, which eventually caused the DHP to operate at a high cooling capacity. Operational strategies can severely impact performance. If the homeowner wanted to improve the operating efficiency of DHP2, they could have attempted to slowly cool the space to avoid high-speed, low-efficiency operation.

Figure 11 shows the average COP in 2°F temperature bins for a DHP metered in Vermont.<sup>12</sup> This system ran almost continuously for the entire winter. We estimated the COP curves (red and green lines) using manufacturer data (NEEP 2016).

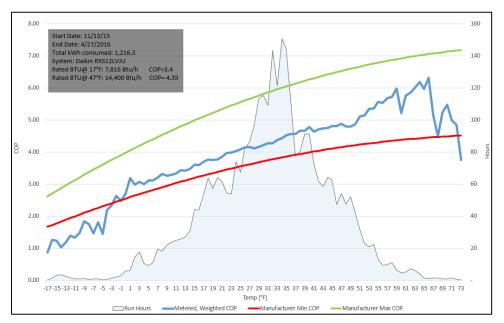


Figure 11. Performance of DHP during heating season

Figure 11 shows that, at very cold temperatures, actual COP may be lower than the lowest published COP.<sup>13</sup> The meter data indicated that the DHP entered defrost mode approximately 13% of the time when the outdoor temperature was lower than -12°F, which contributed to the decrease in efficiency.<sup>14</sup>

Figure 12 shows the distribution of the ratio of metered average seasonal efficiency to nameplate SEER for 90 DHPs.

<sup>&</sup>lt;sup>12</sup> This study is ongoing. Results will be published in December 2016.

<sup>&</sup>lt;sup>13</sup> These results are for illustration purposes only. Field metering methods are less accurate than laboratory controlled experiments. Additionally, a relatively small proportion of hours were observed at the coldest temperatures, which decreases the accuracy of the average measurement.

<sup>&</sup>lt;sup>14</sup> The DHP may go into defrost mode or reverse cycle for some other reason. One-minute temperature data of indoor supply and return air revealed that the supply air temperature was colder than return air.

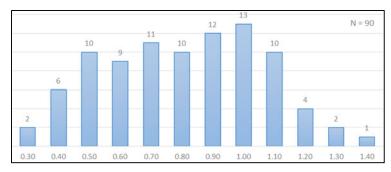


Figure 12. Count of DHPs by ratio of metered average efficiency to rated SEER

The average SEER of the metered DHPs was 22.1. The average metered efficiency of all DHPs was 17.9, approximately 20% less than the nameplate rating. Figure 12 shows that 13 of 90 DHPs (14%) operated within 5% of the nameplate SEER, and 17 DHPs (19%) operated at a higher efficiency than the nameplate SEER.

## Conclusions

Meter data revealed that the primary reason some DHPs have lower seasonal efficiency than nameplate SEER is because many homeowners operate their DHP sporadically (example shown in Figure 10). Many of the metered DHPs were installed in spaces that do not require continuous conditioning, such as a spare bedroom, office, or area of the home that could not be adequately cooled by the CAC. Consequently, these homeowners are more likely to switch the DHP on or off and use it more like an appliance than a central cooling system that conditions a space to a constant temperature, which is the basis for the AHRI standard SEER calculations.

However, the average DHP operating efficiency was not always lower than the nameplate SEER value. The following are examples of when a DHP may operate at a higher average efficiency than its nameplate SEER:

- *It is oversized.* A DHP that is oversized for the space has a lower building load curve than assumed by the AHRI standard. The load curve (see Figure 7) would decrease (shift downward) and the DHP could operate at a lower speed and higher efficiency than assumed by the AHRI standard. Oversizing for cooling may be common in a heating-dominated climate.
- *The AHRI bin temperatures do not represent weather or usage patterns.* If the AHRI bin temperature hours are, on average, warmer for cooling or cooler for heating than the actual bin temperature hours, the DHP could operate more efficiently than estimated by the AHRI standard.
- *It is operated as a supplemental heat source.* A savvy operator may know the outdoor temperature at which a DHP is more expensive to operate than an alternate fuel source (such as oil). If a DHP is turned off when the outdoor temperature drops below 25°F, for example, the average heating efficiency may be higher than estimated by the AHRI standard.

Many DHPs have features that help improve their average efficiency. Manufacturers like Mitsubishi use proprietary energy-savings control algorithms that limit the compressor speed and capacity to maximize efficiency. For this type of energy-saving strategy to work, a homeowner needs to accept that heating or cooling to their desired temperature may take a long time.

The application (e.g., heating/cooling needs of the space) and operational strategy clearly have a large impact on DHP performance and efficiency. The following details are important for estimating the efficiency and potential savings of a DHP:

- *Physically bigger is generally better*. Oversized systems have an increased average operating efficiency because the larger coil surface areas have a greater ability to transfer heat per Btu/h of rated capacity.
- Avoid large temperature swings or volatile operation. A DHP system should operate at partial load as often as possible. For example, do not set the indoor temperature setpoint to 60°F when the space temperature is 80°F.
- *Do not rely on SEER and HSPF ratings.* These ratings may only be reasonable for a space that is precisely conditioned and maintaining a constant indoor temperature throughout the year.
- *Do not rely on peak performance ratings (e.g., COP, EER).* Review all available technical details to determine both peak performance and rated performance. Most variable speed DHPs are able to operate at higher speed and lower efficiency than the certified value. Undersized DHPs result in much less efficient operation than expected.
- *Other advantages.* Central HVAC systems can be inefficient because they may condition unnecessary rooms or experience air leakage, entrainment, or conductive losses through the duct system. DHPs condition a specific zone and do not lose efficiency because of duct losses—two potentially major advantages.

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