

# ***HVAC***

## ***Efficiency Definitions***

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## **Energy Efficiency Ratio (EER)**

The energy efficiency ratio is used to evaluate the equipment's efficiency while in the cooling mode. EER is defined as the net cooling capacity (in Btuh) divided by the total electrical power input (in watts), as shown in EQ – 1. EER is calculated at a single very specific operating point and is typically only applied for commercial equipment  $\geq 6$  nominal tons.

$$\mathbf{EER = \frac{NetCapacity(Btuh)}{PowerInput(kW)}} \quad \text{(see supplemental equations EQ 3-6)} \quad \mathbf{EQ-1}$$

For applicable units, manufacturers must rate their units per the ARI defined operating conditions. This must officially be determined EER from actual laboratory test measurements, and results in an  $EER_{ARI}$ . The ARI defined EER conditions are:

- Evaporator Entering Air (EAT) = 80/67°F
- Ambient air (condenser air) = 95°F
- Specific static pressure requirements that vary with the tonnage.
- No outside ventilation air is specified.
- No specific indoor airflow rate.

However, the same equation can be applied at any other specific operating condition. In this case the resulting value is an application specific EER value, or  $EER_{App}$ . Care must be taken not to confuse the two...any application specific conditions which incur a larger load on the unit than what the ARI conditions impose, will result in a lower energy efficiency ratio value.

Since the value for EER is expressed in Btuh/watts, it is not dimensionless, and is an “efficiency ratio” – not a value of efficiency. Since the units are typically not mentioned when quoting EER values, it is important not to interpret this as a “percentage” or “actual efficiency”. For example, a 9.7 EER value does not mean that the unit is 9.7% efficient. In order to obtain an actual value for efficiency, the units must be converted so they are similar terms in both the numerator and denominator.

For example, if a unit produces 220,000 Btuh of cooling with 22 kW of power input:

$$\mathbf{ex: \quad \% \text{ Energy Efficiency} = \frac{220,000Btuh}{22,000(watts) \times 3.414(Btuh / watt)} = 2.9 \%} \quad \mathbf{EQ-2}$$

This means that for every Btuh of electrical energy supplied, 2.9 Btuh of heat can be absorbed.

**The EER rating evaluates how a unit will perform at one specific point. A higher value for EER represents a higher efficiency at standard conditions.**

$$\mathbf{Net \ Capacity = Gross \ Capacity - indoor \ fan \ motor \ heat} \quad \mathbf{EQ-3}$$

$$\mathbf{Indoor \ fan \ motor \ heat = \left( \frac{Bhp * 746(watts / Bhp)}{motor \_ efficiency} \right) \times (3.414Btuh / watt)} \quad \mathbf{EQ-4}$$

$$\mathbf{Total \ Power \ Input = compressor \ watts + Indoor \ fan \ motor \ watts + condenser \ fan \ motor \ watts} \quad \mathbf{EQ-5}$$

$$\mathbf{Fan \ motor \ input \ (watts) = \left( \frac{actual \_ power(Bhp) \times 746(watts / Bhp)}{motor \_ efficiency} \right) \times (number \_ of \_ fans)} \quad \mathbf{EQ-6}$$

## Seasonal Energy Efficiency Ratio (SEER)

The Seasonal Energy Efficiency Ratio is similar to the EER in that its purpose is to represent the efficiency of the unit while in the cooling mode. However, there are two major differences between them. First, the SEER attempts to take into account the energy consumption due to the cycling of the fan motors and compressors. Second, EER is calculated only at one point (the ARI standard conditions) where SEER is calculated at two different points that simulate operation at higher and lower humidity levels for entering conditions.

According to the industry definition, the SEER rating is only defined for units 5 tons and less that operate on single phase current. Nonetheless, it is industry convention to apply the SEER rating to single and three phase equipment that are  $\leq 5$  tons. Also, just like an  $EER_{App}$  the SEER formula is sometimes calculated for larger equipment.

The SEER calculation requires performance testing and measurements at two different points, as outlined below. The first point is intended to simulate dry coil conditions and is evaporator entering air (EAT) of 80/57°F and ambient air of 82°F. The unit is operated at this point and performance measurements are taken. Next, the unit is cycled on and off and power measurements are taken. Then, the same procedure is done at EAT = 80/67°F with 82°F ambient, to simulate wet coil conditions.

Calculating SEER involves laboratory testing, in a similar manner to all other rating values, with the exception that SEER requires power measurements to be recorded while the unit is in steady state operation, upon start-up and while the unit is at rest (there can still be some amp draw even while the compressors are not running due to potential operation of the fan motor, crankcase heaters, etc). SEER is *impossible* to calculate without a considerable amount of specific test data. Similarly to EER, the SEER is not a dimensionless value, but is always quoted as a pure number (i.e. no units).

$$\mathbf{SEER} \approx \text{weighted average of EER values at all four measurement conditions} \quad \mathbf{EQ-7}$$

Many times people try to derive the SEER value from the EER value. However, this is *impossible* without laboratory test data. To do so requires calculating of a Degredation Factor ( $C_D$  as shown in EQ-8), which can only be determine from laboratory testing at the various SEER defined operating conditions.

$$\mathbf{SEER} = EER ( 1 - C_D/2 ) \quad \text{where } C_D = \text{the Degredation Factor} \quad \mathbf{EQ-8}$$

**The SEER evaluates a unit's performance under two different conditions ; high and low humidity with less than design ambient conditions. A higher value of SEER represents a higher cooling efficiency.**

### **Coefficient of Performance (COP)**

The coefficient of performance is used to measure the unit's efficiency while in the heating mode and is applied to heat pumps, of any nominal cooling capacity, that operates on three phase current. To evaluate a heat pump's efficiency while in cooling mode, EER or SEER must be used. The COP is a dimensionless value defined as the energy produced by the heat pump (in watts) divided by the energy consumed by the heat pump (in watts). In an air to air heat pump, the evaporating refrigerant moves heat from the outside air (when in heating mode) and this heat plus the heat equivalent of the work of compression is rejected to the recirculated air flowing over the condenser coil and to the space to be heated. There is always heat energy in the outside air, however, at lower temperatures, it becomes more difficult to extract.

Therefore the COP decreases at lower ambient and the ARI COP rating is calculated at two different ambient temperatures (47°F and 17°F). The formula for calculating COP is shown below in EQ-9.

$$\mathbf{COP = \frac{Net\ Capacity\ (watts)}{Power\ Input\ (watts)} = \frac{(Gross\ Cooling\ capacity) - (Supply\ fan\ heat)}{supply\ fan + compressor(s) + condenser\ fan(s)}} \quad \mathbf{EQ-9}$$

Thus, a heat pump with a COP = 2.5 would produce two and a half times as much heat than the heat equivalent of the watts input. If electrical resistance heat is used to condition the space, it is by definition, 100% efficient. In this case only 1 watt of heat would be obtained for every watt input, and the resulting COP would be equal to 1.

**COP represents the efficiency of a heat pump while in the heating mode. A higher value of COP reflects a higher heating efficiency.**

## Heating Seasonal Performance Factor (HSPF)

The Heating Seasonal Performance Factor is used to measure a unit's efficiency while in the heating mode and applies only to heatpumps. It is defined as the total heating output (including supplementary electric heat) divided by the total electric power necessary to maintain building heating requirements for its normal annual usage period. The units are Btuh divided by Watt-hours for the same period. The HSPF is only applied to heat pumps (in heating mode) that operate on single phase current and have a nominal cooling capacity of less than 5.5 tons.

Since HSPF represents a seasonally corrected heating efficiency, the first step in the calculation involves the hours of operation for different geographic locations and different modes of operation. To accomplish this, the country has been broken up into different regions reflecting the amount of time spent in a particular mode of operation. The heating regions map is shown in Figure 1, and a similar map exists that represents hours spent in cooling mode.

By factoring in the total hours of operation in each mode, as well as the design conditions for each area, the HSPF can be calculated using EQ-10.

$$\text{HSPF} = \frac{\text{(total heating output during normal usage period)}}{\text{(total electric power input during normal usage period)}} \quad \text{EQ-10}$$

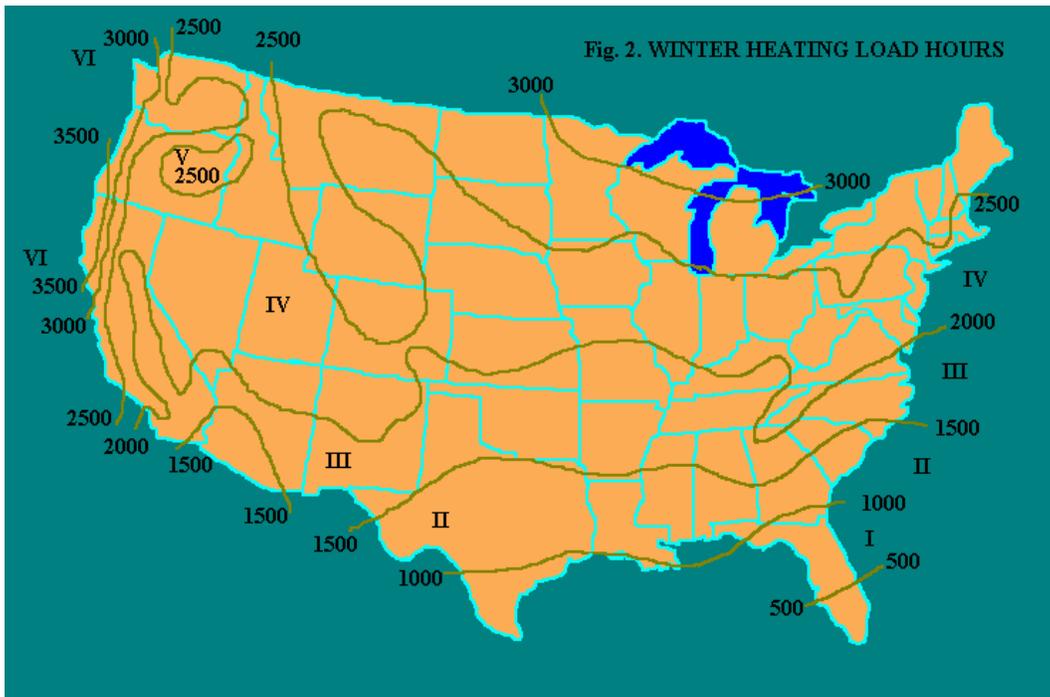


Fig. 1 – HSPF Heating Zones

## Integrated Part Load Value (IPLV)

The Integrated Part Load Value was developed to evaluate the equipment's energy consumption in the cooling mode while it is operating at less than full capacity. The IPLV can essentially be described as a weighted average of the energy efficiency ratio (EER) calculated at each stage of unloading at which the unit can operate.

Thus, the IPLV is similar to EER and SEER in that all three are intended to represent the unit's cooling efficiency. The significant difference between them is that the EER is calculated at one very specific point while IPLV is calculated over the unit's entire range of unloading operation. One major difference between the SEER and IPLV values is that SEER takes into account the cycling of the equipment, but does not actually unload the compressors like IPLV does. The IPLV can be of significant importance since a unit typically operates at full capacity only a small fraction of the time it is in use.

In order to properly integrate IPLV, it is important to understand how the value is calculated. IPLV is a function of two independent variables; Part-Load-EER and the Part-Load-Factor (PLF). IPLV is mathematically represented by the formula shown in EQ-11 and EQ-12.

$$\text{PLF} = \text{A0} + (\text{A1} \times \text{Q}) + (\text{A2} \times \text{Q}^2) + (\text{A3} \times \text{Q}^3) + (\text{A4} \times \text{Q}^4) + (\text{A5} \times \text{Q}^5) + (\text{A6} \times \text{Q}^6) \quad \text{EQ-12}$$

Where:

Q = % of full-load capacity at part-load rating conditions

A0 through A6 are constants given by the part-load curve

$$\text{IPLV} = (\text{PLF}_1 - \text{PLF}_2)[(\text{EER}_1 + \text{EER}_2)/2] \quad \text{EQ-11}$$

$$+ (\text{PLF}_2 - \text{PLF}_3)[(\text{EER}_2 + \text{EER}_3)/2]$$

$$+ (\text{PLF}_{n-1} - \text{PLF}_n)[(\text{EER}_{n-1} + \text{EER}_n)/2]$$

$$+ (\text{PLF}_n)(\text{EER}_n)$$

Where:

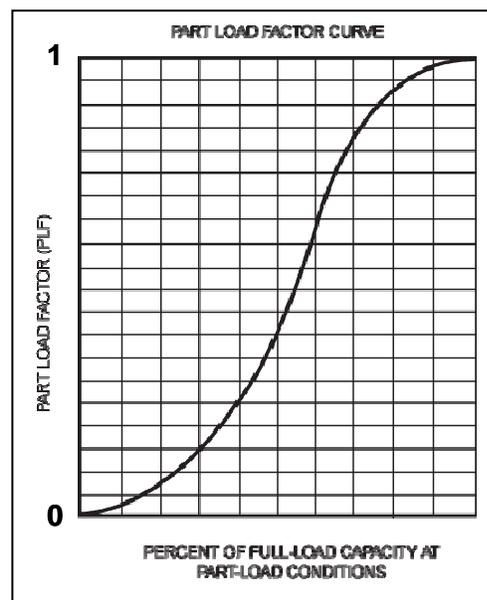
PLF = Part Load Factor from EQ-12

n = total number of capacity steps

subscript 1 = 100% capacity and EER at part-load conditions

subscript 2 through n = Specific capacity steps

Since the IPLV is a function of the PLF, it is important that the PLF curve is representative of how the unit will actually perform. Otherwise, the IPLV value is meaningless. See Figure 2. Note that at at ~ 80% of full load, the PLF is nearly equal to 1.0, while at ~ 20% of full load, the PLF is only equal to ~ 0.07. Thus, the PLF is a value that represents the percentage of the time a unit typically spends operating at a given step of capacity. The exact values of the PLF greatly determine the single IPLV value. Also, the EER value for each step of capacity is dependent on the load that is on the unit. The summation of all these values (as shown in EQ-11) yields the single IPLV value that is published.



**Figure 2**

A unit that has few steps of unloading will have a higher Part Load Factor (which results in a higher IPLV, all other factors being equal) than one that has many steps of unloading. This is true regardless of whether or not the unit ever uses these steps of unloading. A higher IPLV does not mean that the unit is

more energy efficient. It is important to recognized that more stages of unloading will result in a lower IPLV...which means it is more closely matched to the cooling load, will result in less over-cooling of the conditioned space, and better humidity control. Additionally, more stages of unloading will result in less cycling of the equipment. Continuous cycling of the equipment will typically lead to premature wear and excessive current draw on start-up. Therefore, a unit with a lower IPLV is usually preferable unless the unit will always operate near its full load value 100% of the time.

**IPLV represents the cooling efficiency of a unit operating over its entire range of unloading. Unless the unit will operate at or near its full load value 100% of the time, a lower IPLV is more desirable for better overall performance.**

**NOTE:** As of the date of this document, the current IPLV methodology is flawed because it does not properly represent all the aspects of part load. ARI has defined a new procedure that is predicted to be released in 2006. The levels will be about the same, but will also show credit for variable speed fans and other part load improvements that the prior procedure does not properly consider.