

The Efficacy of SEER as a Seasonal Performance Measure for Different Climates

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ABSTRACT

The SEER (Seasonal Energy Efficiency Ratio) Test and Rating procedure was adopted by the US Department of Energy in 1979 to provide consumers with a relative indication of seasonal air conditioner efficiency. A quarter century later, experience suggests that SEER is not an adequate measure or metric for meeting the regional needs of homeowners and utilities. For instance, in hot-dry climates SEER does not provide an adequate prediction of seasonal energy costs for consumers or peak demand impacts on electric utilities. Similarly, in hot, humid climates, SEER does not consider the dehumidification performance of a cooling system, which is critically important to customers. New testing and rating procedures may be required to address these market changes.

This paper evaluates one potential improvement to the SEER procedure: a regional SEER that could incorporate weather data to better predict seasonal performance. The bin-calculated SEER is calculated for various TMY2 locations and compared to the seasonal efficiency predicted by a detailed hourly simulation model. The nominal SEER for the modeled air conditioning unit was 11.7 Btu/Wh. The seasonal efficiencies predicted by the simulation model for 19 US locations ranged from 10.3 to 11.9 Btu/Wh. The bin-calculated SEER that uses location-specific bin data accounts for about half of the SEER variation. The remaining portion of the SEER variation is due to different humidity conditions entering the indoor coil in various climates.

The concept of the regional SEER would provide consumers with a better indication of the energy efficiency and could be calculated using the same set of test data that manufacturers now collect on their systems (i.e., no additional test burden for manufacturers).

INTRODUCTION

In the United States, the energy efficiency of single-phase, central air conditioners and heat pumps

up to 65,000 Btu/h is measured by the Seasonal Energy Efficiency Ratio (SEER) test and rating procedure (Federal Register 1979). Over the years the test and rating procedure has been revised several times to account for multi-speed air conditioning systems and other product improvements. In 1992, a SEER of 10 Btu/Wh was set by the federal law to be the minimum allowable efficiency for products sold in the US. On January 2006, the minimum efficiency increased to 13 Btu/Wh. SEER is a single national standard, intended to provide a representative ranking or measure of seasonal performance for typical US climate conditions.

A quarter century later, experience suggests that SEER may not an adequate measure or metric for meeting the regional needs of homeowners and utilities. For instance, in hot-dry climates SEER does not provide an adequate prediction of seasonal energy costs for consumers or peak demand impacts on electric utilities. Similarly, in hot, humid climates, SEER does not consider the dehumidification performance of a cooling system, which is critically important to customers. Also, default assumptions and test conditions, such as the fan static pressure, may no longer represent actual field operating conditions. New testing and rating procedures may be required to address these market changes in order to ensure that SEER provides a reasonably indication of seasonal efficiency. Sachs and Henderson (2006) describe many of the ways in which SEER fall short of representing seasonal performance.

This paper evaluates ways that the SEER *rating* procedure could be modified to provide better and more meaningful predictions of seasonal efficiency and performance in the key US regions. The overall goal is to determine how the calculation procedures could be modified to use the current set of laboratory test data to meet the needs of different US regions. The premise is that climate-specific SEER values could be calculated for each region, while still retaining the current typical SEER for compatibility and compliance with current federal minimum efficiency standards.

SEER was designed as a metric for consumers to compare systems in terms of seasonal energy

consumption. Today, utilities and consumers are also concerned about peak electric demand and performance at high temperature, since residential air conditioning is a significant contributor towards the need for new generation (and transmission-distribution) assets. Utility incentives (rebates) now focus on demand reduction through high efficiency at high temperatures. As time-of-day pricing becomes important in the residential market, peak performance will also matter greatly to consumers.

The paper first reviews the history of the how the SEER Test and Rating Procedure was originally developed and simplified for single speed equipment. Then we use weather data from 238 TMY2 locations to evaluate how well the current simplified SEER procedure represents different climates. Finally the climate specific SEER calculations are compared to predictions of seasonal efficiency determined from detailed hourly simulations.

THE SEER RATING PROCEDURE

The Current SEER Rating Procedure

The test and rating procedure to determine the seasonal energy efficiency ratio (SEER) was developed at National Institute of Standards and Technology (NIST) by a team of researchers (Parken et al 1977; Kelly & Parken 1978; Parken et al 1985). The SEER calculation procedures were originally developed based upon a bin analysis that calculated the cooling load, capacity and efficiency over a range of ambient temperatures. Temperature bin data were used to assign the number of hours to each temperature bin and effectively weight the AC operating hours based on the time spent at each operating condition. The following table summarizes the SEER calculation procedure.

Table 1. Summary of Original Bin-Based Methods to Calculate SEER: Single Speed

$SEER_{bin} = \frac{Annual_Cooling}{Annual_Energy_Use} = \frac{\sum q(T_j) \cdot n_j \cdot CLF}{\sum e(T_j) \cdot n_j \cdot PLF}$								
<p>where:</p> <ul style="list-style-type: none"> $q(T_j)$ - trend for AC cooling capacity as a function of ambient temperature $e(T_j)$ - trend for AC cooling energy use as a function of ambient temperature T_j - ambient temperature in the j^{th} bin n_j - number of hours in the j^{th} bin 								
<p>and where:</p> $CLF = \frac{BL(T_j)}{q(T_j)}$ $BL(T_j) = \frac{q(95)}{1.1} \cdot \frac{(T_j - 65)}{(95 - 65)}$ $PLF = 1 - C_d \cdot (1 - CLF)$								
<ul style="list-style-type: none"> CLF - cooling load fraction PLF - part load fraction (degrades efficiency at part load) $BL(T_j)$ - building cooling load line (assuming the AC unit is 10% oversized at 95°F and the load goes to zero at 65°F) C_d - cooling degradation factor (assumed to be 0.25 by default) 								
<p>Temperature Bin Data "Typical" Cooling Season (N can be arbitrarily set to 1000 hrs, then fraction = 0.214, results in n = 214)</p>								
Temp - T_j (°F)	67.5	72.5	77.5	82.5	87.5	92.5	97.5	102.5
Fraction - n_j/N	0.214	0.231	0.216	0.161	0.104	0.052	0.018	0.004

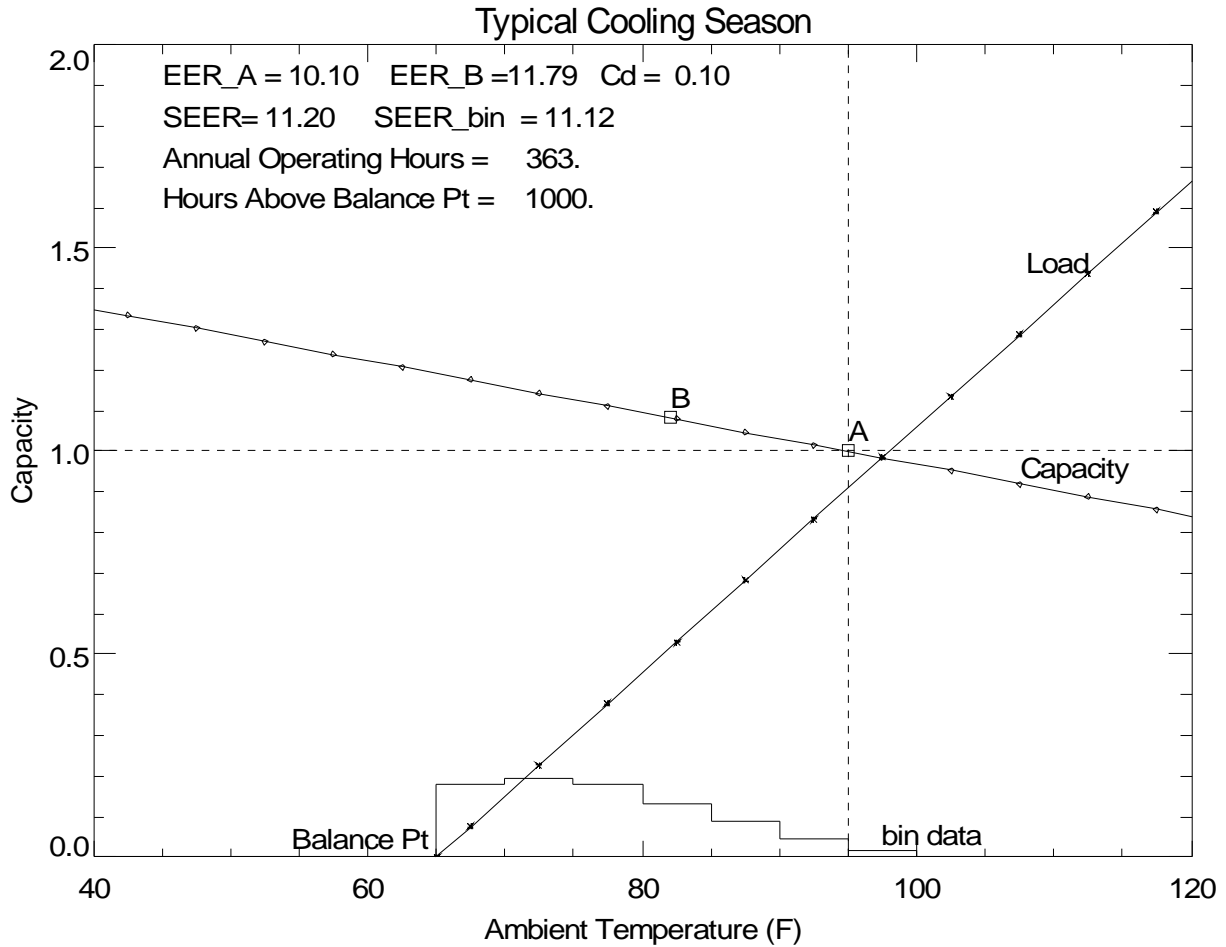


Figure 1. Graphical Description of Original Bin-Based Calculation Procedures for SEER

This bin-method was computationally intensive and therefore the following simplified method was eventually adopted for single-speed units as an approximation:

$$SEER = EER(82) \cdot (1 - C_d \cdot (0.5)) \quad \text{Equation. (1)}$$

This much simpler approximation for SEER was found to closely match the value determined from bin procedure in Table 1 and therefore was adopted into all current versions of the standards that describe the SEER calculation procedure (ARI 210/240-203; Federal 2005). While, the bin-based method has been dropped for single speed units, it has been retained for the SEER calculations for two-speed and variable speed units. The greater complexity of analyzing these units has justified retaining the more complex bin-based calculation methods.

Figure 1 graphically shows the results of bin calculation procedure using a hypothetical single

speed unit with an EER of 10.1 Btu/Wh at 95°F and 11.79 Btu/Wh at 82°F (or a cooling COP of 2.96 W/W at 35°C and 3.45 W/W at 27.8°C). The bin data on the plot are the temperature data for a “Typical” cooling season (from Table 1 above). They indicate the relative number of hours spend in each temperature bin. On the plot the bin data are normalized to a fractional value so that all the values sum to one. The bin calculation method predicts the SEER to be 11.12 Btu/Wh, which is within 1% of the nominal SEER of 11.20 Btu/Wh predicted by the simplified method.

The simplified equation for SEER works well because test condition B at 82°F closely corresponds to the load-weighted seasonal average temperature using the temperature bin data, which is define as:

$$T_{wt} = \frac{\sum BL(T_j) \cdot n_j \cdot T_j}{\sum BL(T_j) \cdot n_j} \quad \text{Equation (2)}$$

Where BT is the building load line defined in Table 1 and shown on Figure 1. T_{wt} equals 82.4°F using the outdoor temperature bin data from Table 1. Similarly the value of 0.5 used for CLF in equation 1 approximately corresponds to ratio of BL(82) and q(82) shown in Figure 1. Since the equations for capacity $q(T_j)$, building load BL(T_j), and power $e(T_j)$ are all linear, the simple SEER calculation given by equation 1 provides a close approximation of the more detailed bin analysis.

Determining Seasonal Efficiency for Different Climates

The original SEER development work recognized that temperature bin data for specific climates would yield more accurate predictions of seasonal efficiency. However DOE ultimately opted for a single typical climate to represent the “average” seasonal performance for the nation. This seasonal average efficiency ultimately became known as SEER. This temperature bin data from Table 1 is referred to as the DOE-bin data in the subsequent plots.

Figure 2 shows the distribution of SEER values determined using temperature bin data for the 238 US locations in the TMY2 weather data. The calculations use the same nominal performance parameters shown in Figure 1. The bin-calculated SEER for the variation locations ranged from 10.3 to 12.7 Btu/Wh, or from 92% to 113% of the nominal SEER of 11.2 Btu/Wh calculated from equation 1. The average SEER for 238 locations is 11.43 Btu/Wh¹, or within 2% of the nominal SEER. This analysis confirms that the nominal SEER calculated with equation 1 is fairly close to average seasonal efficiency determined for all US locations. However, the SEER for individual climates can be far from the nominal SEER.

Figure 3 shows how the bin-calculated SEER for each location varies with the cooling load hours. Locations with a small number of full load cooling hours can deviate significantly from the nominal SEER, but these locations are typically in Alaska or other locations that do not normally use cooling equipment. Cooling is most important in locations with more full load cooling hours. Therefore the focus of our analysis is on those locations.

The six locations with the lowest bin-calculated SEER are identified on the plot (i.e., where the nominal SEER over predicts seasonal performance). They are all hot dry climates in the Southwestern states of Arizona, California, and Nevada. Other researchers (Horowitz 2004; SCE 2003) have also recently completed studies showing that the nominal SEER is not a good predictor of seasonal efficiency in these locations. Figure 3 also identified other locations with hot, humid climates with high cooling loads such as coastal Florida, Southeastern Texas, Hawaii, Puerto Rico, and Guam. The Texas and Florida locations all are fairly close to the nominal SEER of 11.2. The locations with calculated SEERs that are most different from the nominal value are all in Hawaii. Hilo and Lihue are the two humid climates where the seasonal efficiency is significantly under predicted by the nominal SEER.

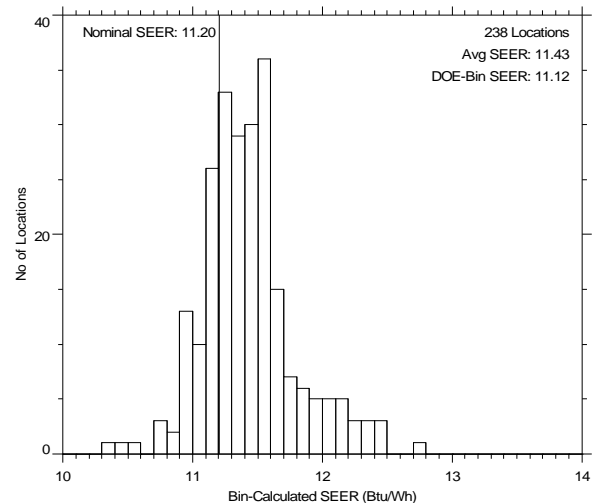


Figure 2. Histogram of Bin-Calculated SEERs Using TMY2 Data for 238 US Locations

¹ We also developed temperature bin data from the 232 TMY locations. The average SEER for those 232 locations was very similar at 11.40 Btu/Wh.

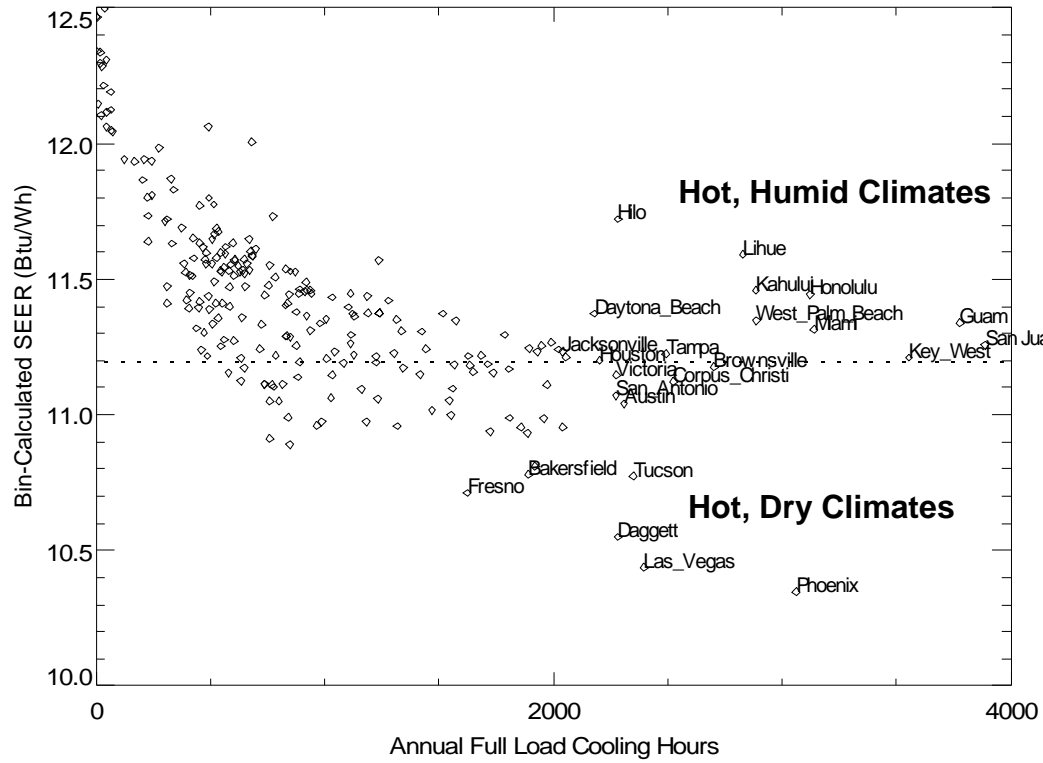


Figure 3. Trend of Bin-Calculated SEERs Versus Full Load Cooling Hours

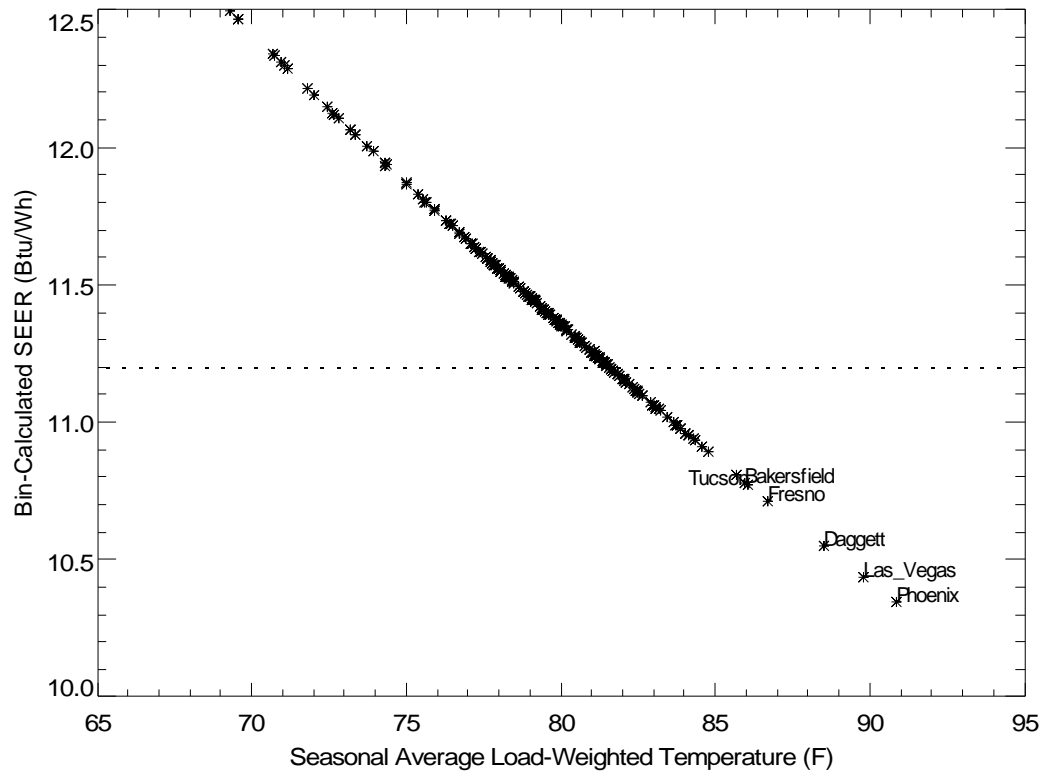


Figure 4. Trend of Bin-Calculated SEERs Versus Average Load-Weighted Seasonal Temperature

Figure 4 shows that the seasonal average load-weighted temperature (as defined by equation 2) is good predictor of seasonal efficiency for each climate. The seasonal average load-weighted temperature was 82.4°F for the DOE temperature bin data. The plot shows that the SEER of 11.12 Btu/Wh calculated with the DOE bin data closely corresponds to 82.4°F. The six hot dry hot dry climates with the lowest calculated SEER also have the warmest seasonal average temperature. The seasonal average load-weighted temperature in Phoenix exceeds 90°F. Each 1°F increase in the load-weighted temperature decreases the bin-calculated SEER by 0.09 Btu/Wh (or 0.8% per °F).

Table 2 lists the 34 TMY2 cities where the load-weighted temperature is within 0.5°F of the DOE bin data.

Figure 5 and Figure 6 return to the details of the bin calculations to provide insight into why some climates deviate substantially from the average. The bin-calculated SEER for Tampa, which is shown in Figure 5, is in close agreement with the nominal SEER. This occurs because the load-weighted temperature is 81.3°F. The temperature bin data shows that the outdoor temperature never exceeds 95°F in the TMY2 data file. In contrast, Figure 6 shows that the bin-calculated SEER for Fresno is

10.71 Btu/Wh, or 4.4% lower than the nominal SEER. The actual SEER is lower because the load-weighted temperature is 86.7°F. The higher load-weighted temperature occurs in part because there are nearly 400 hours over 95°F and 100 hours over 100°F in Fresno

Table 2. 34 Cities with Weather Data Near DOE Bin Data

Albuquerque-NM	Montgomery-AL
Amarillo-TX	Nashville-TN
Austin-TX	North_Platte-NE
Boise-ID	Norfolk-NE
Brownsville-TX	Pendleton-OR
Columbia-SC	Pierre-SD
Corpus_Christi-TX	Pocatello-ID
Elko-NV	Pueblo-CO
Fort_Smith-AR	Reno-NV
Grand_Junction-CO	Scottsbluff-NE
Jackson-MS	Shreveport-LA
Kansas_City-MO	Sioux_Falls-SD
Little_Rock-AR	San_Antonio-TX
Lubbock-TX	Tonopah-NV
Lufkin-TX	Tucumcari-NM
Memphis-TN	Victoria-TX
Meridian-MS	
Miles_City-MT	

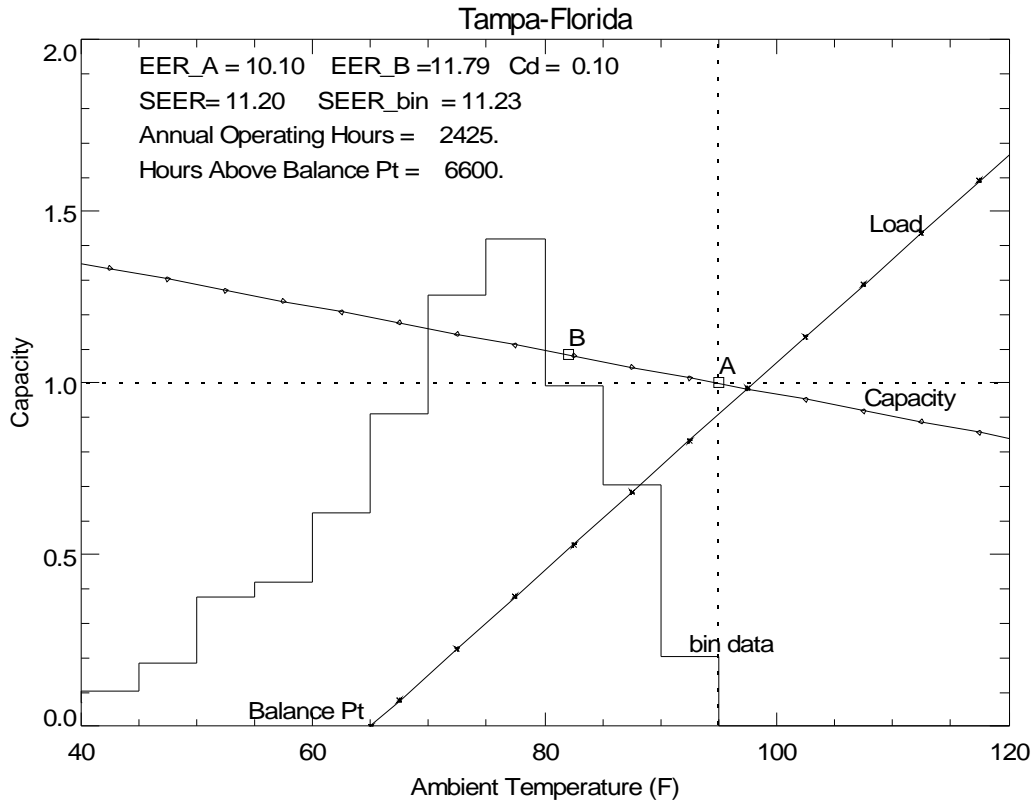


Figure 5. Bin-Calculations to Determine Regional SEER for Tampa, Florida

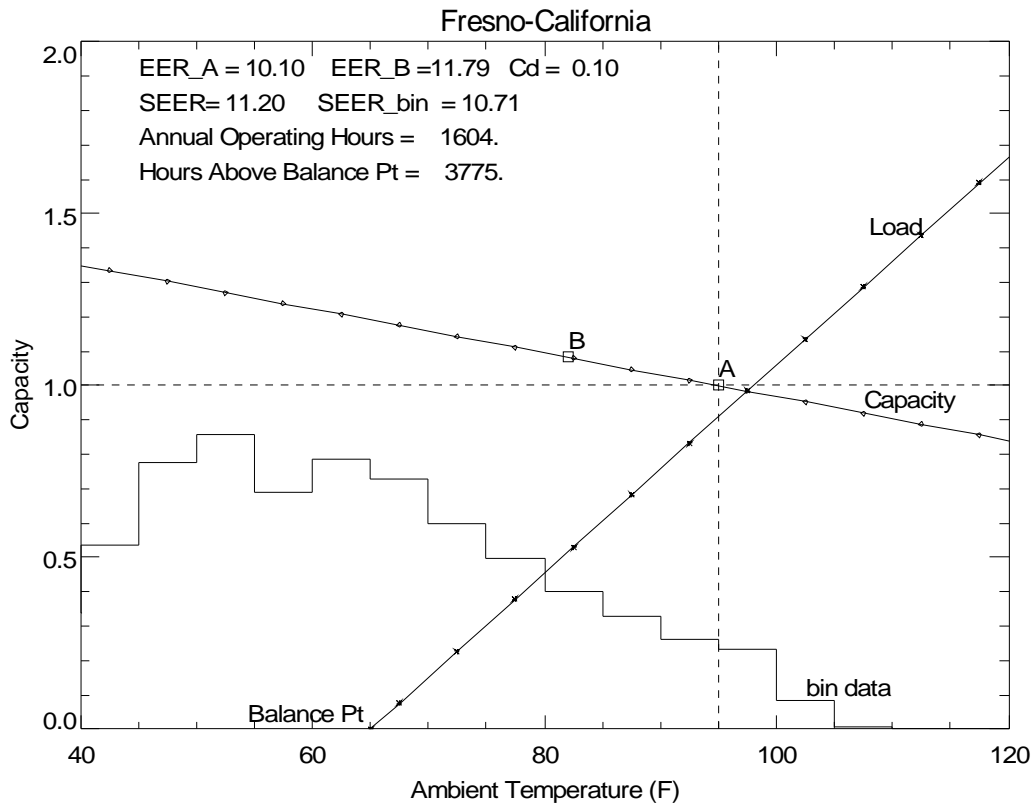


Figure 6. Bin-Calculations to Determine Regional SEER for Fresno, California

COMPARING BIN-CALCULATED SEER TO DETAILED SIMULATIONS

The bin-calculated SEERs appear to account for a good portion of the expected variation in the seasonal efficiency. To further test the validity of the bin-based SEER calculations, we compare them to seasonal efficiency predicted with a more detailed energy simulation model based on TRNSYS.

Building Simulation Details

We selected TRNSYS as the simulation model for this analysis. The model is similar to a TRNSYS-based simulation tool developed evaluate advanced cooling and dehumidification options (Henderson and Sand 2003). A major improvement to the simulation tool was that the building envelope is now modeled using TYPE56 in TRNSYS 16 (University of Wisconsin et al 2004) instead of the Type 19 transfer function method from TRNSYS 15. The new model with TYPE56 has been shown to compare favorably to the HERS reference house defined in EnergyGauge (Henderson 2005). This simulation model has several advantages compared to other hourly simulation models.

First, the air conditioner equipment model is the DXDOE model from the ASHRAE secondary toolkit (Brandemuehl et al 1993). A similar coil model is used in EnergyPlus (Energy Plus 2001). The DXDOE component model is based on a semi-empirical performance map that uses a bypass factor/apparatus dew point approach to accurately predict the mix of sensible and latent performance at different entering conditions (Henderson and Shirey 1992). DXDOE also is able to realistically predict how capacity and efficiency vary as the coil transitions from wet to dry conditions. The air conditioner component models in programs such as DOE-2 do not consider this impact and therefore can miss-predict coil performance in dry climates where the coil frequently operates at dry conditions.

For this comparison we developed a detailed model of the HERS reference home (RESNET 2005) as the base case. The cooling set point was 76°F and no explicit humidity control was provided. We also took the following steps to ensure that the simulation model and bin calculations could be compared. Both the TRNSYS simulation model and the bin-calculations used the following details for air conditioner performance.

- Used the same TMY2 weather data files (bin data was developed into 5°F bins from the hourly TMY2 data).
- Used the same DX coil performance map and nominal AC performance data (at Test A conditions with 450 cfm per ton: EER = 13.3 Btu/W w/o supply fan, gross capacity = 36 MBtu/h, SHR = 0.77).
- Used the same supply fan power (0.35 W/cfm), air flow (1200 cfm), and method of control (fan cycles with compressor)
- Uses very similar part load efficiency degradation parameters ($C_d = 0.15$ and $N_{max} = 3 \text{ hr}^{-1}$, $\tau = 45 \text{ sec}$, where τ is the time constant of the capacity at startup and N_{max} is maximum cycling rate of the thermostat)

Comparing SEER to Simulation Results

Annual hourly simulations were run for 19 different TMY2 locations. The resulting seasonal efficiency determined from each detailed simulation are shown in Figure 7 and Table 3, where they are compared to the bin-calculated SEER and the nominal SEER. The nominal SEER for the air conditioning unit is 11.7 Btu/Wh. The seasonal efficiencies predicted by the simulation model ranged from 10.3 to 11.9 Btu/Wh. The bin-calculated SEER did generally provide a better prediction of simulated seasonal performance than the nominal SEER value, as shown by the percentage differences given in Table 3. For the 19 locations, the average difference between the nominal SEER and the detailed simulation was 4%. The bin-calculated was slightly closer with a 3.8% average difference. However, the bin-calculated SEER was not an improvement compared to the nominal SEER at every site. Figure 8 compares the percentage differences for each location.

The bin-calculated SEER did provide a significantly better seasonal prediction in the hot climates of Phoenix, Las Vegas, Fresno and El Paso. In these locations the nominal SEER was 8.9% to 15% higher than the simulated seasonal efficiency. The percentage difference between the bin-calculated SEER and the seasonal efficiency was about half as large, or 5.3% to 7.4%. So the bin-calculated SEER eliminates about half of the error associated with using the nominal SEER to predict seasonal performance.

The comparison in Figure 7 show that there is still a systematic trend or bias between the bin-calculated SEER and the simulated seasonal

efficiency. This bias occurs because the bin-calculated SEER uses entering coil conditions of 80°F dry bulb and 67°F wet bulb. In the actual simulations the entering conditions were 76°F for each house, though the entering wet bulb varied for each climate. The difference in entering wet bulb or humidity conditions for each climate explains most of the systematic bias. In the hot, dry climates, the entering space humidity conditions are much lower, so the entering wet bulb is much lower than 67°F. The lower wet bulb causes the cooling efficiency to be much lower. To demonstrate the impact of entering conditions, we repeated the SEER bin calculations using 76°F dry bulb and 63.4°F wet bulb (approximately 50% RH) as the entering conditions. Figure 9 shows how the bin-calculated SEER with lower entering coil conditions compare to the simulated seasonal efficiency. This change shifts the bin-calculated SEERs downwards, so that bin-

calculated SEER is now lower than the simulated seasonal efficiency for many climates. The average difference between to bin-calculated SEER and the simulated seasonal efficiency decreases to 2.1% with these entering condition (compared to 3.8% average difference at 80°F dry bulb and 67°F wet bulb, as shown in Table 3). The bin-calculated SEER is much closer for the hot, dry climates.

Using an entering wet bulb of 60°F (or 40% RH) makes the bin-calculated SEER for the four hot, dry locations closely match the simulated efficiency. Figure 10 shows results from the TRNSYS simulations that demonstrate how space humidity levels can vary significantly from hot, dry to humid climates.

Table 3. Comparing Seasonal from Detailed Simulations and Bin-Analysis

	Seasonal Efficiency (Btu/Wh) determined by:		Difference Between Detailed Simulation and:	
	Detailed Simulation	Bin Calculations	Bin-Calc SEER	Nominal SEER
Buffalo	11.94	12.13	1.6%	-1.7%
Portland	11.75	12.03	2.4%	-0.1%
Madison	11.68	11.95	2.3%	0.5%
Chicago	11.63	11.93	2.6%	0.9%
Detroit	11.84	12.05	1.8%	-0.8%
Wilmington	11.70	11.93	2.0%	0.3%
New_York_City	11.79	12.01	1.9%	-0.4%
San_Francisco	10.75	12.34	14.8%	9.2%
Fresno	10.74	11.31	5.3%	9.3%
Pittsburgh	11.65	12.00	3.0%	0.8%
Memphis	11.38	11.69	2.7%	3.2%
Atlanta	11.66	11.91	2.1%	0.7%
Phoenix	10.21	10.97	7.4%	15.0%
Oklahoma_City	11.14	11.57	3.9%	5.4%
El_Paso	10.78	11.50	6.7%	8.9%
Houston	11.48	11.73	2.2%	2.3%
Miami	11.67	11.82	1.3%	0.6%
Tampa	11.54	11.75	1.8%	1.7%
Las_Vegas	10.32	11.06	7.2%	13.8%
Average	11.35	11.77	3.8%	4.0%

Note: Nominal SEER = 11.7 Btu/Wh

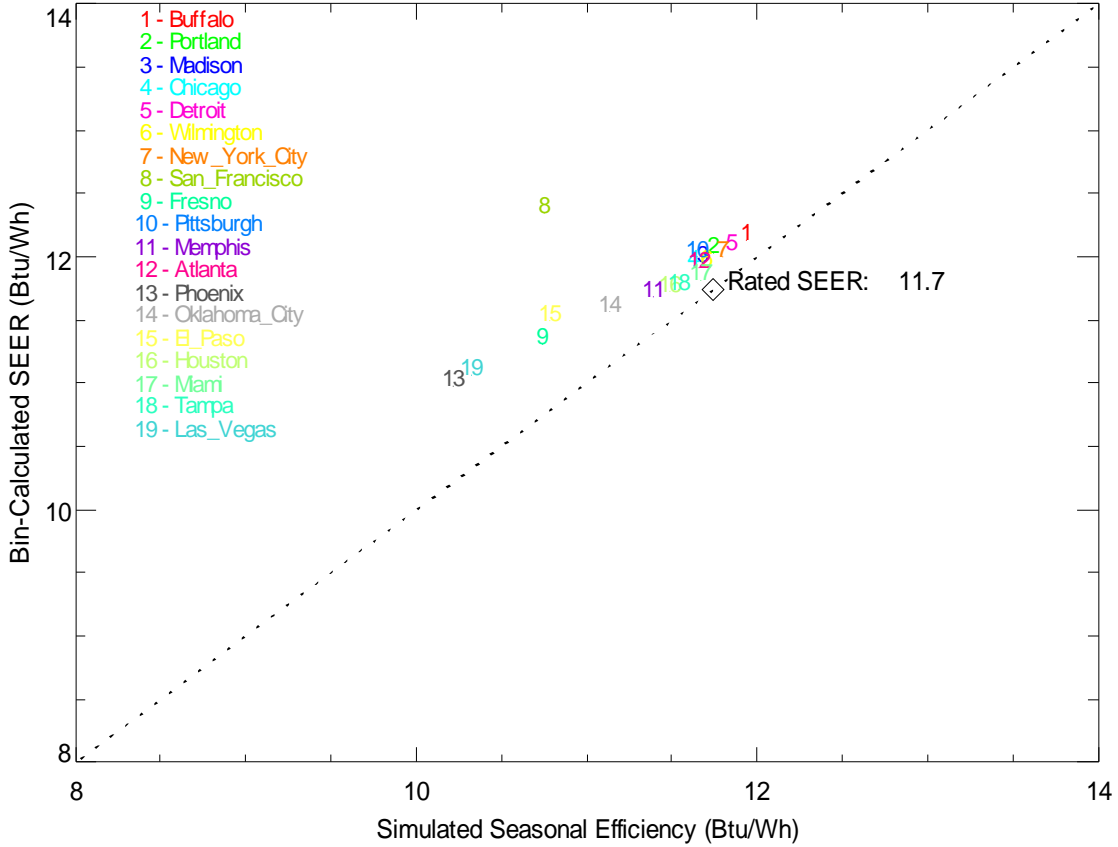


Figure 7. Comparing Bin-Calculated SEER to Simulated Seasonal Efficiency

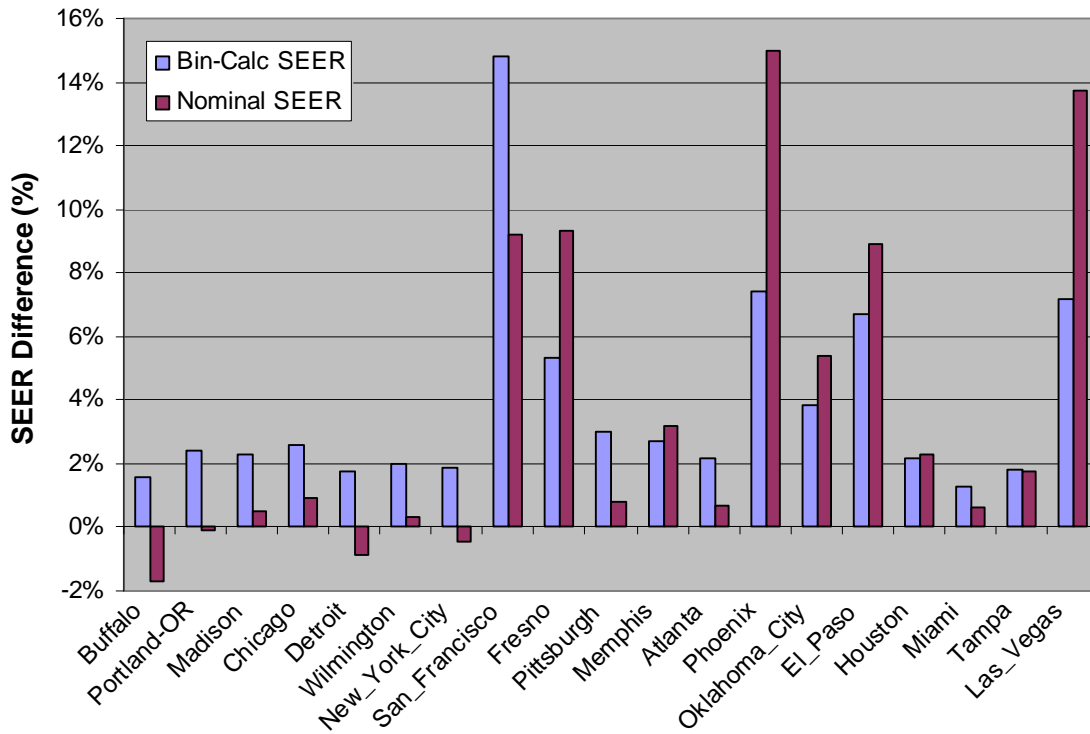


Figure 8. Comparing Nominal and Bin-Calculated SEER to the Simulated Efficiency

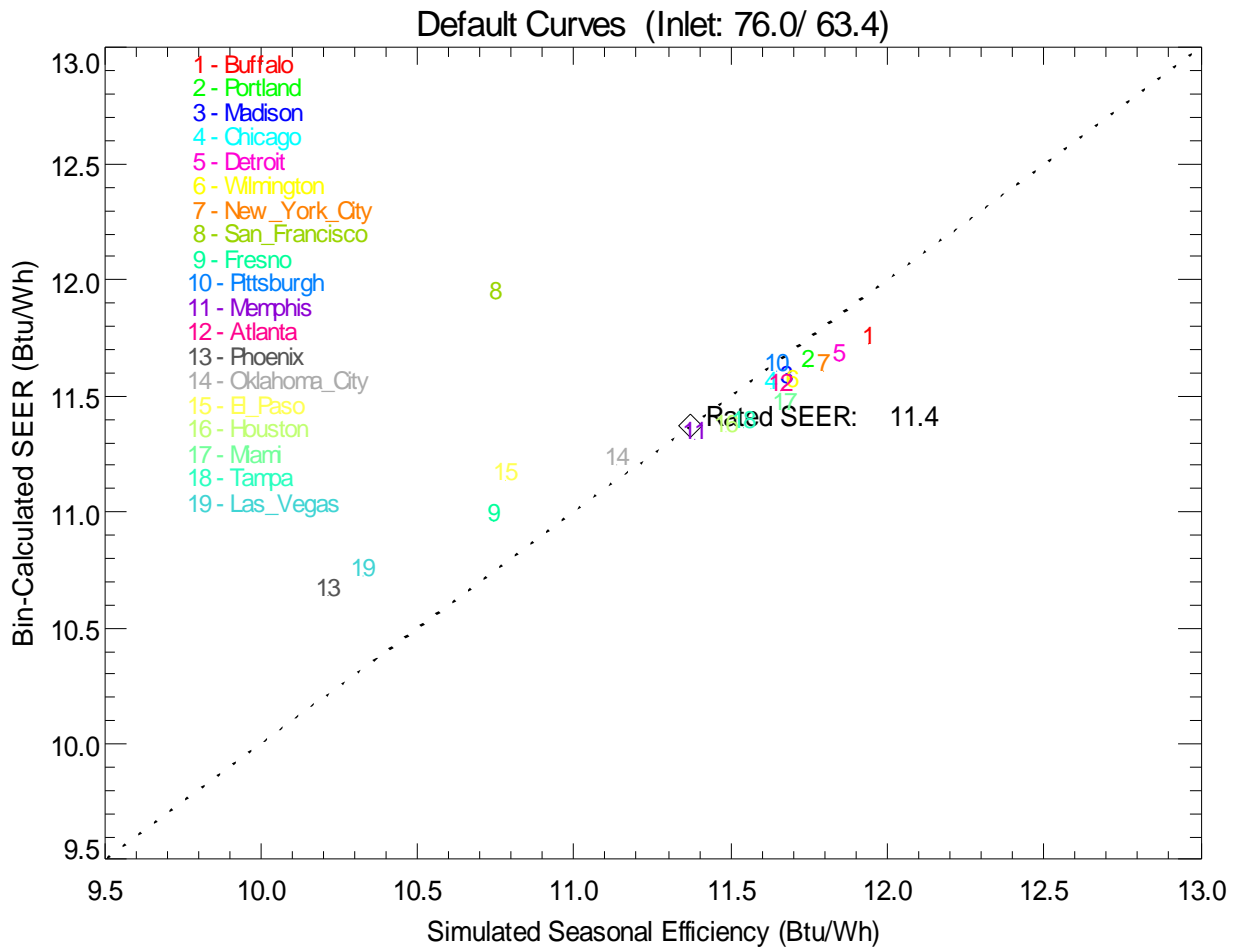


Figure 9. Comparing Bin-Calculated SEER to Simulated Seasonal Efficiency: 76°F DB & 63.4°F WB entering

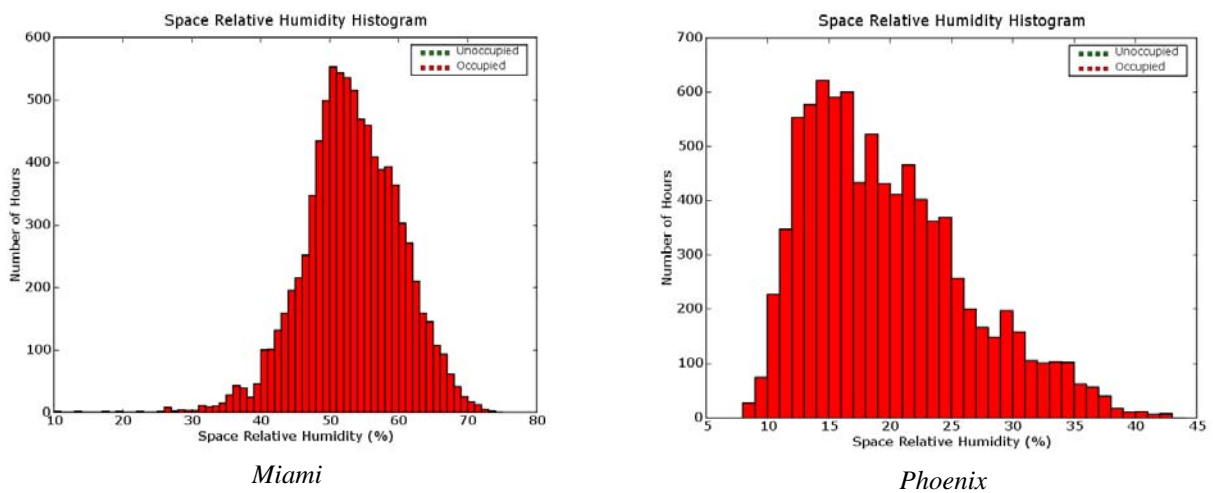


Figure 10. Annual Space Humidity Distributions Predicted by Simulation Model

SUMMARY IMPLICATIONS FRO SEER

The nominal SEER (as defined by equation 1) is calculated using an outdoor temperature 82°F, which that is meant to represent the average annual conditions for typical US climate. However, while the nominal SEER does reasonably represent seasonal efficiency in many US climates, it is an especially poor predictor in hot, dry climates.

The SEER procedure was originally based on temperature bin calculations. This bin-based approach is still used for multi-speed equipment, but was not retained for single speed systems. The bin-based SEER calculations inherently have the ability to consider regional climate variations. Temperature bin data for a specific climate of region could be applied in the calculations to determine a regional SEER value.

The analysis in this paper has demonstrated that a bin-calculated SEER can account for about half of the variation in seasonal efficiency we observe based on detailed hourly simulations. The next largest source of “error” in the SEER is the use of unrealistic entering conditions of 80°F dry bulb and 67°F wet bulb. This operating point is more representative of commercial than residential conditions. While the entering wet bulb varies for each climate, it possible that a more realistic entering condition – say 76°F and 50% RH – might improve the ability of a bin-calculated SEER to represent seasonal efficiency.

A bin-based SEER calculation has the advantage of using the same set of laboratory test data to calculate seasonal efficiency values for many different regions. This approach can potentially meet the regional needs of consumers without imposing additional testing burdens on equipment manufacturers.

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