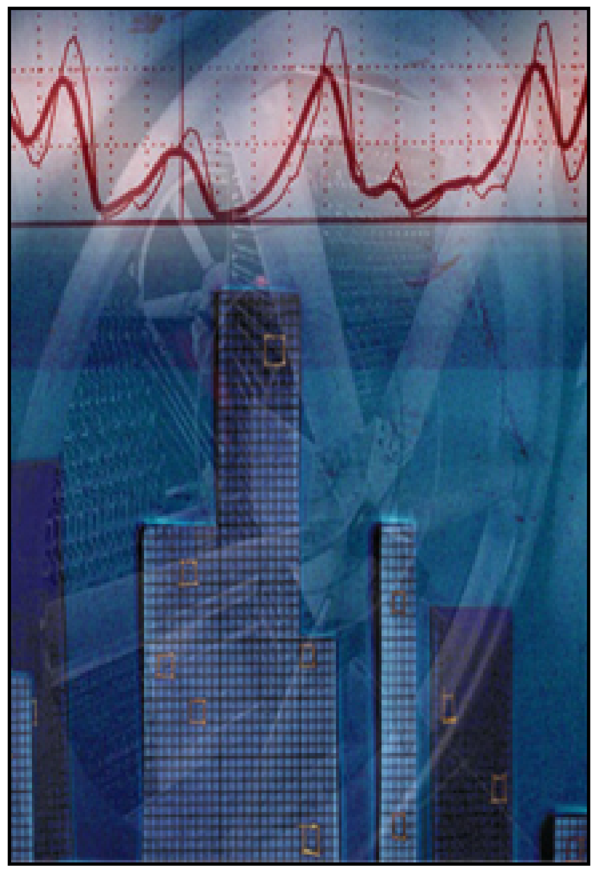
EER & SEER AS PREDICTORS OF RESIDENTIAL SEASONAL COOLING PERFORMANCE

UPDATED SUMMARY OF RESEARCH



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1.0 Introduction

The air conditioning industry in North America has long relied on the Energy Efficiency Ratio (EER) and the Seasonal Energy Efficiency Ratio (SEER) as indicators of cooling HVAC equipment efficiency and performance. EER is "a ratio calculated by dividing the cooling capacity in Btu/h by the power input in Watts at any given set of rating conditions, expressed in Btu/h/W" (ARI, 1984). Currently, all large (> 65,000 Btuh) direct expansion (DX) air conditioners are rated using EER, a rating standardized by the Air-Conditioning and Refrigeration Institute (ARI), which reports steady-state efficiency at 95°F outdoor and 80°F dry-bulb, 67°F wet-bulb indoor temperatures. Smaller residential-sized air-conditioners, i.e., < 65,000 Btu/hr, are rated using SEER, a rating developed by the U.S. Department of Energy (DOE) in 1977 (Kelly and Parken, 1978) and first adopted by DOE in 1979 (DOE 1979). SEER is "the total cooling of a central air conditioner in Btu's during its normal usage period for cooling … divided by the total electric energy input in watt-hours during the same period…" (ARI 1984). The SEER test procedure is very similar to that used for EER, i.e., a simple short-term steady-state laboratory test. By using a milder outdoor temperature (82°F rather than 95°F) considered to represent a national average cooling condition and by including cycling losses, the SEER rating is intended to better indicate average seasonal performance, or in other words, a season-long "average" EER. Details of the SEER testing and rating process are provided in Appendix A.

Since its inception over 20 years ago, SEER has become the codified standard by which the efficiency of small air-cooled electric HVAC cooling systems is compared. In California, Title 20 and Title 24 appliance and building energy standards have long mandated air conditioner efficiency levels using SEER. Consumers are also typically guided to make energy-wise purchases based on these ratings. For example, "consumers can compare the efficiency of central air conditioners and heat pumps (in the cooling cycle) using the SEER. The higher the SEER, the more efficient the system…" (California Energy Commission Web site).

Driven largely by suspicions that SEER may be an unreliable predictor of peak demand savings, in recent years the California utilities' state-wide efficiency programs have abandoned SEER in favor of EER as an indicator of both energy and demand benefit (for example, see the state-wide *Savings By Design* incentive program requirements at www.savingsbydesign.com/system.htm). Others have recently questioned the efficacy of SEER as an indicator of cooling efficiency (Kavanaugh, 2002). Accordingly, this study examines the efficacy of using SEER when making cooling system efficiency decisions and recommendations.

1.2 Organization of this Document

This document provides a summary of only the most important portions of a longer report by the same name. Consequently, this summary is intended to be brief and makes liberal use of bulleted descriptions. Key research questions are presented in bold font in each section, as are the most essential portions of the answer to the question. The contents are organized as follows:

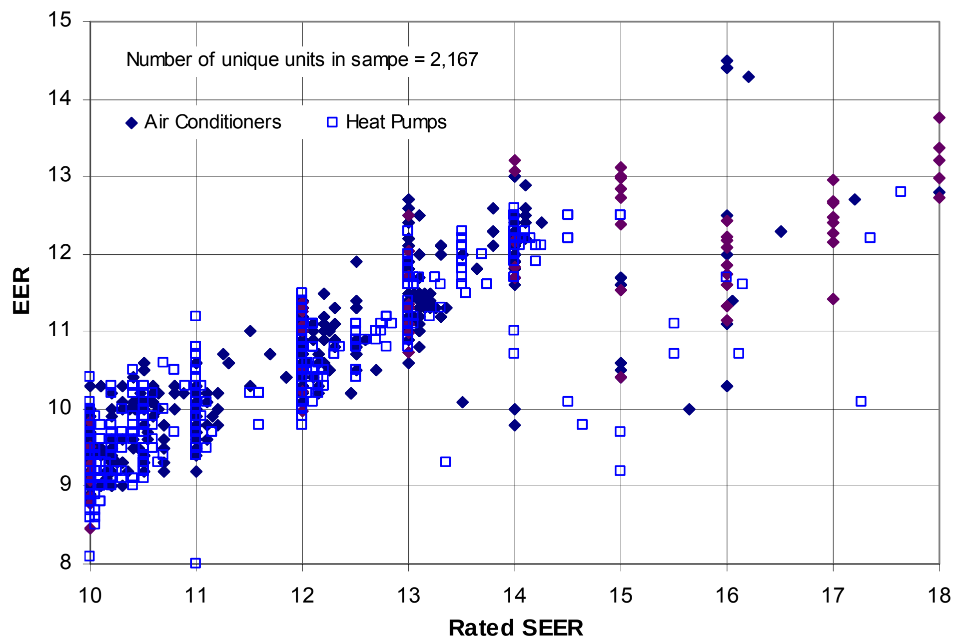
- An introduction and description of the questions that motivated and guided this study;
- A description of the key assumptions of the SEER rating process;
- A description of the analysis methodology used in the study;
- Findings regarding the validity of the key assumptions of the SEER rating procedure;

- Findings that address the questions that guided the research;
- A summary of findings and "next steps"

1.3 Objective of the Study

The justification for this study originated with the scatter observed in Figure 1 below. The data in Figure 1 are taken from the California Energy Commission (CEC) database of unitary HVAC equipment (approximately 13,000 HVAC systems). In Figure 1, the SEER rating (tested at 82°F) for residential split-system HVAC systems are plotted against the EER (tested at 95°F) rating for the same equipment. The data in Figure 1 indicate that HVAC systems with similar efficiency at 82°F (for example, SEER 12) show a large degree of variation in their efficiency at 95°F (EER 9.5 to 11.5+). Given the large amount of scatter in Figure 1, a reasonable question is: how could cooling systems with the same SEER, but with very different EER's (Figure 1), have the same season-long performance? The scatter in this data clearly indicates that many cooling systems that perform similarly at outdoor temperatures of 82°F (i.e., have the same SEER rating) may perform very differently at outdoor temperatures other than 82°F (i.e., not just at 95°F); hence, the reliability of SEER as an indicator of either seasonal energy efficiency or peak demand may be limited. Assessing the sign and magnitude of these limitations across typical California applications, both residential and non-residential, and across all California climates is the objective of this study.

Figure 1 Performance Characteristics of SEER-rated Cooling Systems
Rated SEER (at 82°F) versus Rated EER (at 95°F)



1.4 Questions that Guided the Research

This analysis seeks to answer the following specific questions regarding the efficacy of using SEER to make efficiency investment decisions and recommendations:

1) *How effective is SEER as a predictor of expected annual cooling energy use?*
2) *How effective is SEER in estimating cooling energy savings*?
   For example, based only on the difference in magnitude of SEER, upgrading from SEER 10 to SEER 13 represents a 30% improvement in SEER ((1-[13/10]), and suggests a 23% reduction in annual cooling energy use (1-[10/13]). All other things being equal, i.e., controlling for climate and user differences, will a 23% savings in annual cooling energy be realized?
3) *How effective is SEER in estimating the relative seasonal cooling efficiency of different cooling systems, i.e., rank ordering seasonal performance?*
   Like the EPA gas mileage label, "your mileage may vary", actual seasonal efficiency may vary due to user effects such as thermostat setpoint. Not withstanding this, can SEER be used to compare the *relative* cooling efficiency of air conditioners? For example, for a specific house and climate zone, will a SEER 14 system reliably use less annual cooling energy than a SEER 13 system?
4) *How effective is SEER as a predictor of expected cooling peak demand and demand savings*?
   This question has become all the more important since ARI decided in November of 2002 not to include a rated EER value for SEER-rated units in its directory of certified equipment.

2.0 Background: Key Assumptions in the SEER Rating Methodology

How can air-cooled cooling systems with the same SEER (same efficiency at 82°F), but with very different efficiencies at other temperatures (e.g., EER at 95°F, see Figure 1), actually have the same season-long cooling efficiency? Further, **how can an estimate of season-long cooling efficiency that is valid across varied climates and operating conditions, be determined using only one (or at most a few) steady-state test(s) conducted in a controlled laboratory setting?** Necessarily, the SEER rating process is based on several key assumptions.

2.1 How the SEER Rating Process Accommodates the "scatter" in Figure 1.

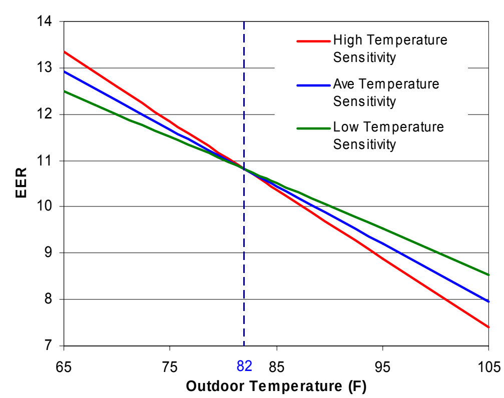
The following key assumptions are implicit in the SEER rating process.

1) Cooling energy use is entirely determined by the indoor-to-outdoor temperature difference.
2) The sensitivity of cooling system efficiency to outdoor temperature is linear.
3) A steady-state test conducted at the *mid-load* temperature (i.e., the outdoor temperature that separates annual cooling loads into two equal halves) will indicate the annual average energy efficiency of cooling systems (despite differing efficiency at other outdoor temperatures).

An example: imagine two cooling systems with equal SEER (i.e., equal efficiency measured at 82°F) but differing sensitivity to outdoor temperature (i.e., one system has higher EER than the other, as in Figure 1).

- The system with higher temperature sensitivity will be less efficient at hotter outdoor temperatures than the other system (e.g., in Figure 1, the system with lower EER).
- IF sensitivity to temperatures is even approximately linear, then the system with high sensitivity (lower EER in Figure 1) will also tend to be more efficient at lower temperatures than the other system (i.e., higher EER when measured at any temperature lower than 82°F, see Figure 2).
- While energy use measured at any temperature other than 82°F will differ between the two systems, over an entire cooling season, these differences in efficiency will balance out and the two systems will have the same season-long energy use, IF sensitivity to temperatures is perfectly linear and IF 82°F (the SEER outdoor test temperature) represents the *mid-load* temperature (i.e., the outdoor temperature above and below which occurs exactly half of the annual cooling coil load).

Figure 2
Cooling System Performance Assumptions Implicit in the SEER Rating Process Efficiency (EER) Sensitivity to Outdoor Temperature



In summary,

IF cooling efficiency sensitivity to outdoor temperatures is perfectly linear, AND

IF a cooling system's efficiency is measured at a mid-load temperature that is representative of varied climates and operating conditions, AND

IF cooling energy use is entirely determined by the indoor-to-outdoor temperature difference,

THEN

SEER should be able to provide a prediction of season-long cooling efficiency that is valid across varied climates and operating conditions. Further, cooling systems with identical SEER ratings (same efficiency at 82°F), but with different efficiencies at other temperatures (e.g., EER at 95°F) as illustrated in Figure 1, will have the same season-long cooling efficiency.

2.2 The Origin of 82°F in the SEER Rating Process

Probably the most widely known assumption implicit in the SEER rating procedure is the use of a national average standard seasonal cooling coil load profile with median of 82°F. The assumptions that were made in its selection are not as widely understood. They are as follows.

- The distribution of outdoor temperatures that coincide with cooling is as illustrated in Figure 3a (median value of approximately 76°F).
- The building thermal characteristics (e.g., overall shell U-value, solar gains, internal loads, thermostat cooling setpoint, etc.) yield a 65°F balance point for the building (i.e., no cooling required below 65°F as illustrated in Figure 3b).
- All cooling coil load is a linear function of outdoor temperature only (Figure 3b).
- The preceding three assumptions result in a seasonal average coil load with distribution as illustrated in Figure 3c with median of 82°F, i.e., a *mid-load* temperature. In other words, in Figure 3c, exactly half of the annual cooling coil load coincides with outdoor temperatures above 82°F, the other half coincides with temperatures below 82°F.

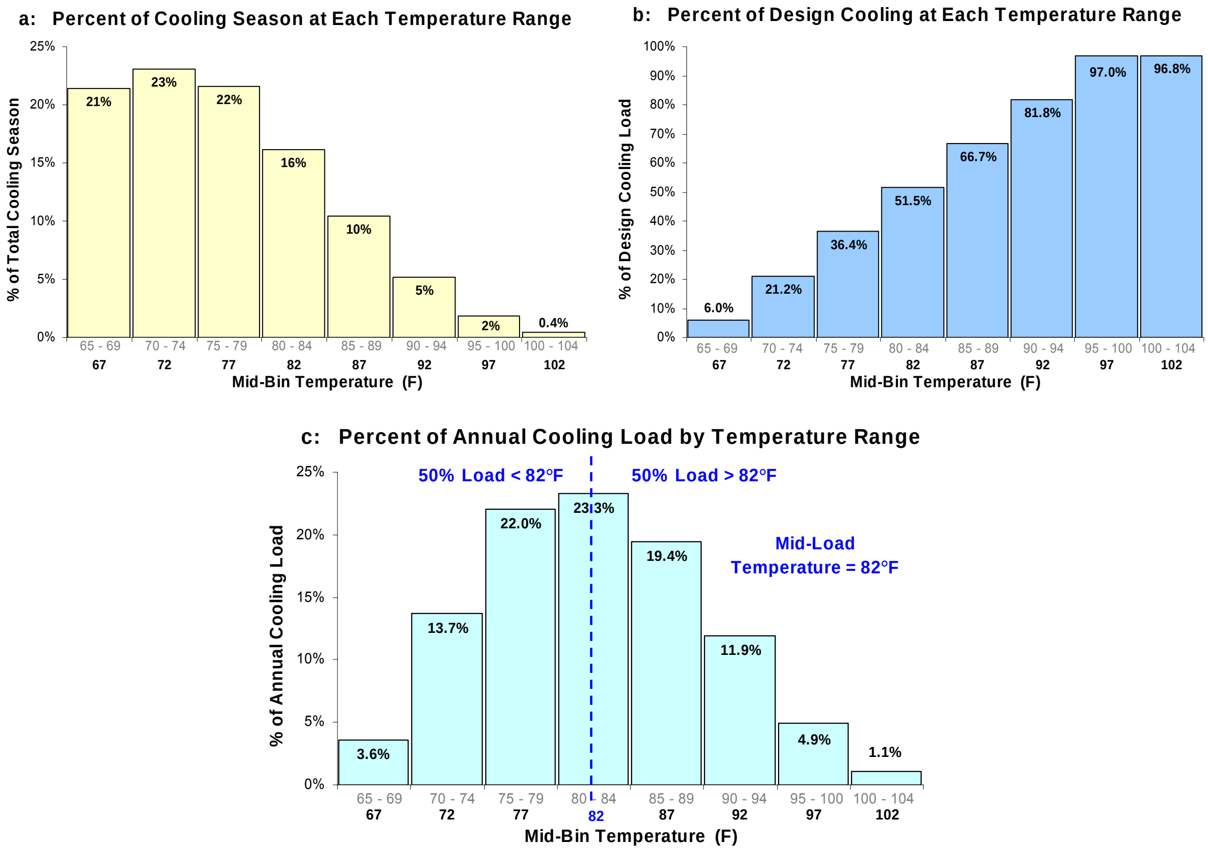
These assumptions led to the selection of 82°F as the outdoor temperature for the SEER rating.

2.3 Fan Energy in the SEER Rating Process

Fan energy is included in the total cooling system energy considered in the SEER rating process. Since indoor (evaporator) and outdoor (condenser) fan energy are included in the SEER rating, the assumption that total cooling energy is a linear function of outdoor temperature requires at least two further assumptions regarding the behavior of indoor and outdoor fans.

- Energy from both fans is assumed to be a relatively small portion of the total energy requirement.
- Both fans are assumed to cycle with the compressor, thus fan energy is proportional to compressor energy.

Figure 3: Key Assumptions Implicit in the SEER Rating Procedure
Derivation of the 82°F "Mid-Load" Temperature



Of course, the informed reader will recognize that none of the assumptions described above and which are implicit in the SEER rating process are universally valid. This research examines the validity and consequence of these assumptions for typical California residential buildings across all sixteen California climate zones and attempts to estimate both the sign and magnitude of any bias in SEER for common California applications.

3.0 Analysis Methodology: Understanding What Impacts SEER

3.1 Factors that Effect SEER Efficacy

An analysis methodology was selected to help understand the factors that affect SEER and its efficacy when used to make cooling equipment efficiency selection decisions. Broadly, these factors are:

- Climate characteristics
- Cooling load characteristics (due to building characteristics)
- Individual HVAC system characteristics

Climate characteristics

California climates vary from that assumed by the SEER rating methodology. i.e., the cooling season median temperature may not be 82°F.

- Initial analysis was conducted using five "indicator" climate zones: Oakland (CZ03), Long Beach (CZ06), San Diego (CZ07), Sacramento (CZ12), and Palm Springs (CZ15). These were selected to capture the typical range of California cooling climates and to include the area of population concentration.
- Final analysis was conducted using all climate zones except CZ01 (north coast) since no cooling is required (when used, this tended to unreasonably skew the results).

Cooling load characteristics (building load characteristics)

Several building thermal characteristics will help determine the *mid-load* temperature, including the following.

- Zone balance point — The balance point of a building is the outdoor temperature at which the losses through the building envelope are balanced by solar and internal gains. Below this outdoor temperature the building needs heating and above this temperature the building needs cooling. The balance point of the areas of a building served by SEER-rated HVAC systems may differ significantly from 65°F assumed by SEER due to building characteristics such as cooling thermostat setpoint, solar gain (i.e., zone glass area and zone orientation), internal load, zone shell overall U-value, and whether natural ventilation or economizer cycles are employed.
- Zone operating schedule — Does the zone served by the SEER-rated HVAC system operate overnight or only during the day and do building and system features such as natural ventilation or economizer cycles cause the HVAC equipment to operate only during the hours of warmest outdoor temperature?
- Linearity of the relationship between cooling coil load and outdoor temperature — Is the relationship between cooling coil load and outdoor temperature linear as assumed by the SEER rating methodology? Factors that cause the load not to be strictly linear include building envelope mass and internal mass, mass of the HVAC distribution system, long wave radiant losses, and sol-air effects (the effect of sunlight raising the outdoor surface temperatures of dark surfaces well above outdoor temperature).

These thermal characteristics will tend to vary by building type. To determine which building types should be included in the analysis, recent California new construction building surveys were examined to determine where the majority of the SEER-rated equipment was installed (*2000 Residential New Construction Market Share Tracking* (RMST) Database).

Variation in seasonal cooling load profiles will also be caused by variations in thermally significant building characteristics. Building prototypes included as many as twenty variable building features. These were used to describe and vary the thermal characteristics and operation of each building prototype. Building design and operations features were identified that were considered important in varying the cooling load "shape", i.e., the relationship between cooling load and outdoor temperature (see for example, Figure 3c). These include detailed descriptions of the building components (walls, windows, building orientation, shading devices, floor area, number of floors, etc.) and building operating conditions (occupancy levels, thermostat settings, equipment use, lighting, and schedules that describe how these vary over the day). Lists of building characteristics that impact the cooling load shape are provided in Table 1 for the single-family residential prototype. The building component and operational details are obtained from new construction building surveys conducted in California (*2000 Residential New Construction Market Share Tracking* (RMST) Database. Using these surveys, median, minimum, and maximum values of the components and operational features of the building prototypes were determined.

Table 1 Single-Family Residential Prototype Cooling Load-Related Characteristics

Total Floor Area	Conditioned floor area
Number of Stories	Typically a fraction that includes 1 & 2 stories
Aspect Ratio	Orientation of long axis varies
Occupancy	Includes number and schedule of use
Internal Gains	Net loads to the space
Glass Area (Fraction)	As a fraction of total wall area
Glass U-factor	NFRC U-factor
Glass SHGC	NFRC solar heat gain coefficient
Shading Level	Shading by overhang
Ceiling Type	Cathedral or attic
Roof Insulation	Roof overall U-value
Wall Construction Type	Construction and U-values varies
Floor Type	Crawlspace or Slab
Floor Insulation	U-value of floor or slab loss factor
Infiltration	Infiltration rate in air-changes/hour
Natural Ventilation	Varied by indoor temperature and ventilation rate
Cooling Thermostat	Consistent with natural ventilation
Cooling T-stat Setup	Consistent with occupancy schedules
Duct Loss (fraction)	Fraction of return and supply cfm lost to outside
Duct R-Value	Duct insulation value

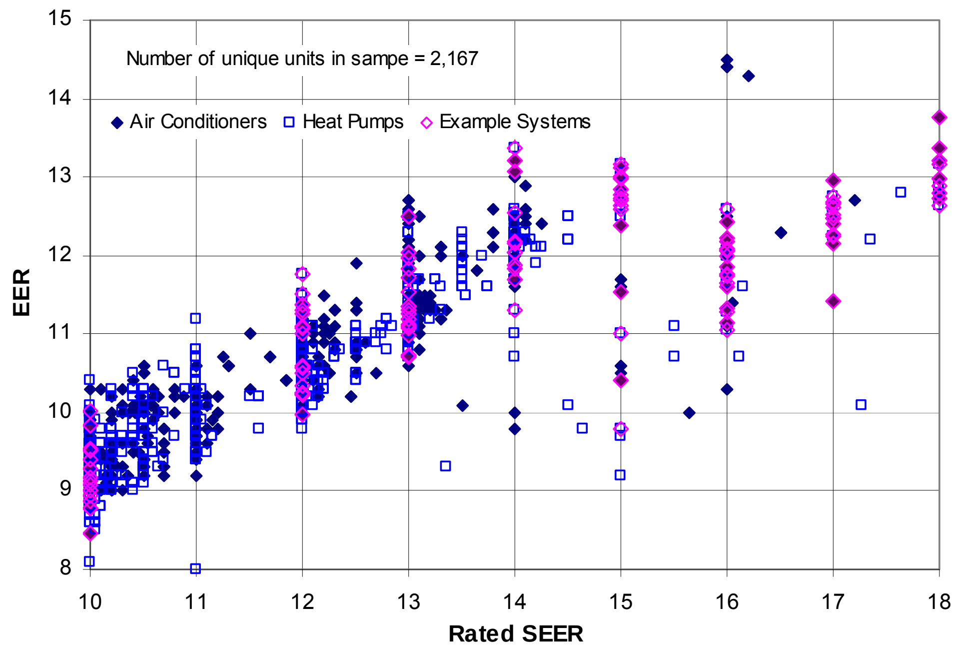
HVAC system characteristics

Individual differences amongst equivalent SEER-rated HVAC systems, as illustrated in Figure 1, can lead to variations in annual cooling energy and peak demand among identically SEER rated equipment. Approximately 119 HVAC systems were selected from a data base of over 570 to reflect the range of currently available systems. The selection process examined equipment sensitivity to the effects listed below. Actual systems were selected that closely represented high, median, or low sensitivity to each.

- Sensitivity to outdoor temperature
- Sensitivity to compressor cycling effects
- Sensitivity to coil entering conditions (indoor dry-bulb and wet-bulb temperature, the SEER rating methodology assumes a constant coil entering condition of 80°F dry-bulb and 67°F wet-bulb)

Figure 4 contains the same data as Figure 1 but also includes the 119 representative HVAC systems selected for this analysis. As can be seen in Figure 4, the selection process successfully reflects the range of systems originally illustrated in Figure 1.

Figure 4
Performance Characteristics of SEER-rated Cooling Systems Selected for this Analysis
Rated SEER (at 82°F) versus Rated EER (at 95°F)



3.2 Simulation Analysis Key Assumptions

DOE-2.2 was used to conduct the simulation analysis for this research. Several key assumptions underlying this analysis approach are:

- Substantial prior experience with DOE-2 has convinced the California energy efficiency industry that DOE-2 is fully capable of capturing the interaction of climatic and building thermodynamics, and replicating system performance when detailed manufacturers' data is used.

- For this research, all simulations were run using manufacturers' extended ratings data to fully capture individual system performance, i.e., each run used one or more "actual" cooling systems available in the market. No DOE-2 default performance characteristics were used.

- Since annual cooling energy use will vary widely depending on climate zone, building characteristics, and system characteristics, comparing rated SEER-predicted energy use against DOE-2 detailed simulation results must be normalized if results from different climates, building configurations, or systems are to be are to be compared. Toward this end:

    - This study determined to compare effects across various climates, buildings, and systems by comparing rated SEER with "DOE-2 simulated SEER" rather than comparing projected annual cooling energy use.

    - "DOE-2 Simulated SEER" is calculated using the results of detailed DOE-2 simulations, i.e., the ratio of simulated annual cooling coil load to the simulated cooling energy required to meet the load (including indoor fan energy).

    - For the purposes of this study, DOE-2 simulated SEER (using statistically valid climate and building characteristics and manufactures' detailed cooling performance data) provides a valid reference indicator of actual annual cooling energy efficiency.

- If agreement between rated SEER and DOE-2 simulated SEER were perfect, a graph plotting one against the other would show all points falling on a straight line having a slope of 1.0. Any scatter in such a graph, i.e., the vertical distance a point falls above or below the slope 1.0 line, provides a convenient indication of both the sign and magnitude of disagreement between rated and simulated SEER. Taking DOE-2-simulated SEER as the standard, the degree of scatter will indicate the amount of error in using rated SEER to anticipate annual cooling savings.

3.3 Simulation Analysis Process

Simulation analysis strategies were selected to estimate the sign and magnitude of bias in existing SEER ratings that compromise its efficacy when used to make cooling equipment efficiency selection decisions. This analysis attempts to partition the estimates of SEER bias into the following three effects:

- Climate effects — do differences between California climates and the national average climate assumed by the SEER rating process compromise the efficacy of SEER in predicting annual cooling energy use in California and if so what is the sign and magnitude of that effect?
- Cooling load (i.e., building) characteristics — how valid is the SEER-assumed 82°F *mid-load* temperature and cooling load distribution for typical California buildings in California climates? The mid-load temperature is a function of both the climate and building characteristics (e.g., via the balance point). What is the sign and magnitude of any effect building type and the typical range of variation in individual building characteristics may have on SEER efficacy?
- Performance variation among same-SEER HVAC systems — how much variation in annual cooling energy performance results from differences between systems with the same SEER rating as illustrated by the vertical scatter in Figure 1?

For convenience, these will be referred to subsequently as "climate effects", "building effects", and "system effects". The analysis process used to isolate the effect of each is described below.

<u>Determining the average climate effect</u> — To determine the average effect of California climate variation from the national average climate assumed in the development of the SEER rating, simulate <u>median</u> building prototypes and <u>median</u> system characteristics over the subset of indicator climate zones, i.e., Oakland (CZ03), Long Beach (CZ06), San Diego (CZ07), Sacramento (CZ12), and Palm Springs (CZ15). Compare simulated SEER (determined by detailed simulation) to rated SEER to identify the sensitivity of rated SEER to California climates.

<u>Determining the average effect of building characteristics on SEER</u> — To determine the average effect of building characteristics on SEER, modify building characteristics (approximately twenty for each prototype) in a sequential manner to determine the unique combination of characteristics that yield the highest and lowest simulated SEER values for each climate zone (i.e., differs by climate; use only the indicator climate zones). Compare simulated SEER to rated SEER to identify the sensitivity of rated SEER to the typical variation in California buildings. Use these results to estimate the expected uncertainty in SEER based on building characteristics.

<u>Determining the average effect of HVAC system characteristics on SEER</u> — To determine the average effect of variation in individual HVAC system characteristics on SEER, simulate the building prototypes that produce the median SEER values resulting from the previous step using the full set of example cooling systems having minimum, maximum, and median sensitivity to outdoor temperature and cycling effects. Use these results to estimate the expected uncertainty in actual SEER due to the typical variation in individual cooling system performance characteristics for systems with the same SEER rating (i.e., the vertical scatter in Figure 1).

4.0 Findings About Key Assumptions of the SEER Rating Procedure

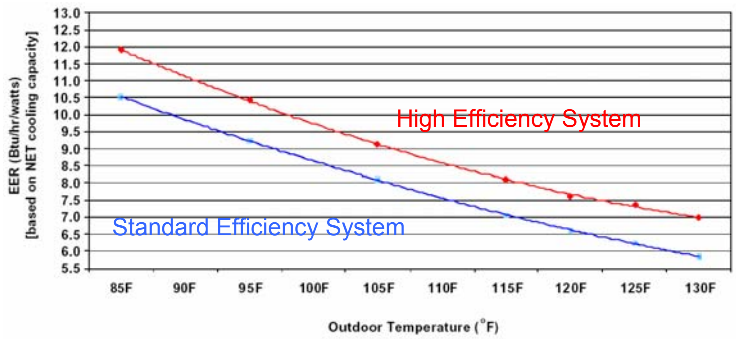
Several assumptions implicit in the SEER rating process, described in Section 2 above, are not realistic for California buildings and climates. This section examines the validity of these assumptions for typical California residential buildings across all California climate zones.

4.1 Cooling Efficiency is Linearly in Outdoor Temperature

How valid is the assumption that cooling efficiency sensitivity to outdoor temperature is linear? See Figure 5.

For many cooling systems, the sensitivity of cooling efficiency to outdoor temperature tends to be linear (Figure 2), however, this is not always the case (Figure 5).

Figure 5 System Efficiency (EER) as a function of outdoor temperature



Source: Performance Evaluation of Typical Five Ton Roof Top Air Conditioner Units Under High Ambient Temperatures, Southern California Edison, 2003

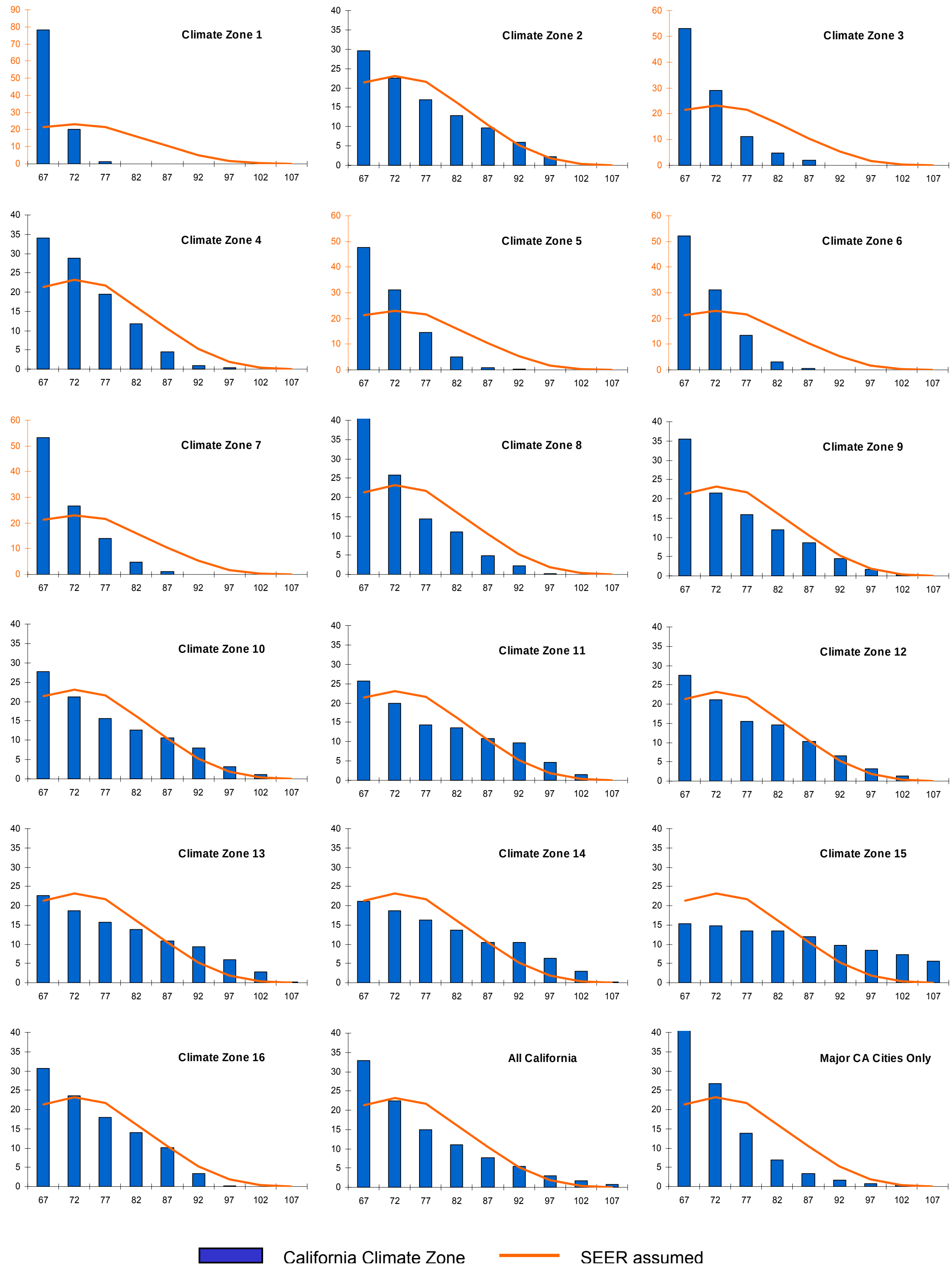
4.2 U.S. Average SEER Climate

How similar are California climates to that used in the SEER ratings process?

Figure 6 compares the outdoor air temperature distribution assumed by the SEER rating methodology (see Figure 3a) with the distribution of outdoor temperatures for each of the sixteen California climate zones. Figure 6 also includes a comparison to the California average distribution (i.e., average of all sixteen climate zones) and the average distribution from the major California urban centers, i.e., climate zones CZ 3 (Oakland), CZ 6 (Long Beach), CZ 7 (San Diego), and CZ12 (Sacramento). In Figure 6, the dark blue vertical bars represent the relative frequency distribution of outdoor temperatures in California climates. The orange curve represents the same relative frequency for outdoor temperatures assumed by the SEER rating procedure (i.e., same as Figure 3a). While most of the vertical axes in Figure 6 use a constant scale, those whose vertical scales differ are shown in color (i.e., orange).

The results in Figure 6 suggest that climate zones 10 and 12 are closest to the distribution of outdoor temperatures assumed in the development of SEER. **In general, most of the California climate zones appear to be cooler than that used to determine SEER**. Only climate zones 13, 14, and 15 (Palm Springs) appear to be warmer than the SEER national average.

Figure 6 Distribution of Cooling Season Outdoor Temperature California Climate Zones vs. SEER rating assumption



4.3 SEER 82°F mid-Load Temperature

How valid is the SEER 82°F *mid-load* temperature and associated distribution of annual cooling coil loads for typical single-family homes in California climates? See Figure 7.

The SEER rating procedure identified that 82°F represents the *mid-load* temperature for the assumed climate profile used in the SEER ratings process. Figure 7 compares the relative frequency distribution of cooling loads for a typical single family residence in California (as determined by DOE-2 simulation using the median single-family residential prototype) with the national average SEER-assumed distribution, for each of the sixteen California climate zones. Graph layout and color conventions in Figure 7 are the same as was explained for Figure 6. For each case in Figure 7, the mid-load temperature is indicated (contrast these temperatures with 82°F), as is the percentage of annual cooling hours above and below 82°F (the SEER rating procedure assumes that 50% of the cooling load falls above and below 82°F).

The results in Figure 7 suggest that climate zone 9 (Pasadena) is closest to the distribution of outdoor temperatures assumed in the development of SEER with cooling load distributions shifted toward the cooler range for about half of the climate zones and shifted toward the warmer range for the other half. Given the "symmetry" of the results in Figure 7, perhaps it is not surprising that the California average distribution turns out to be relatively similar to that assumed in the SEER ratings process (California average mid-load temperature = 77°F). Note that these results suggest that **for the median house, California urban residential applications would be better served with a SEER rating procedure that assumes 77°F, rather than 82°F.**

4.4 Linearity of Cooling Load with Outdoor Temperature

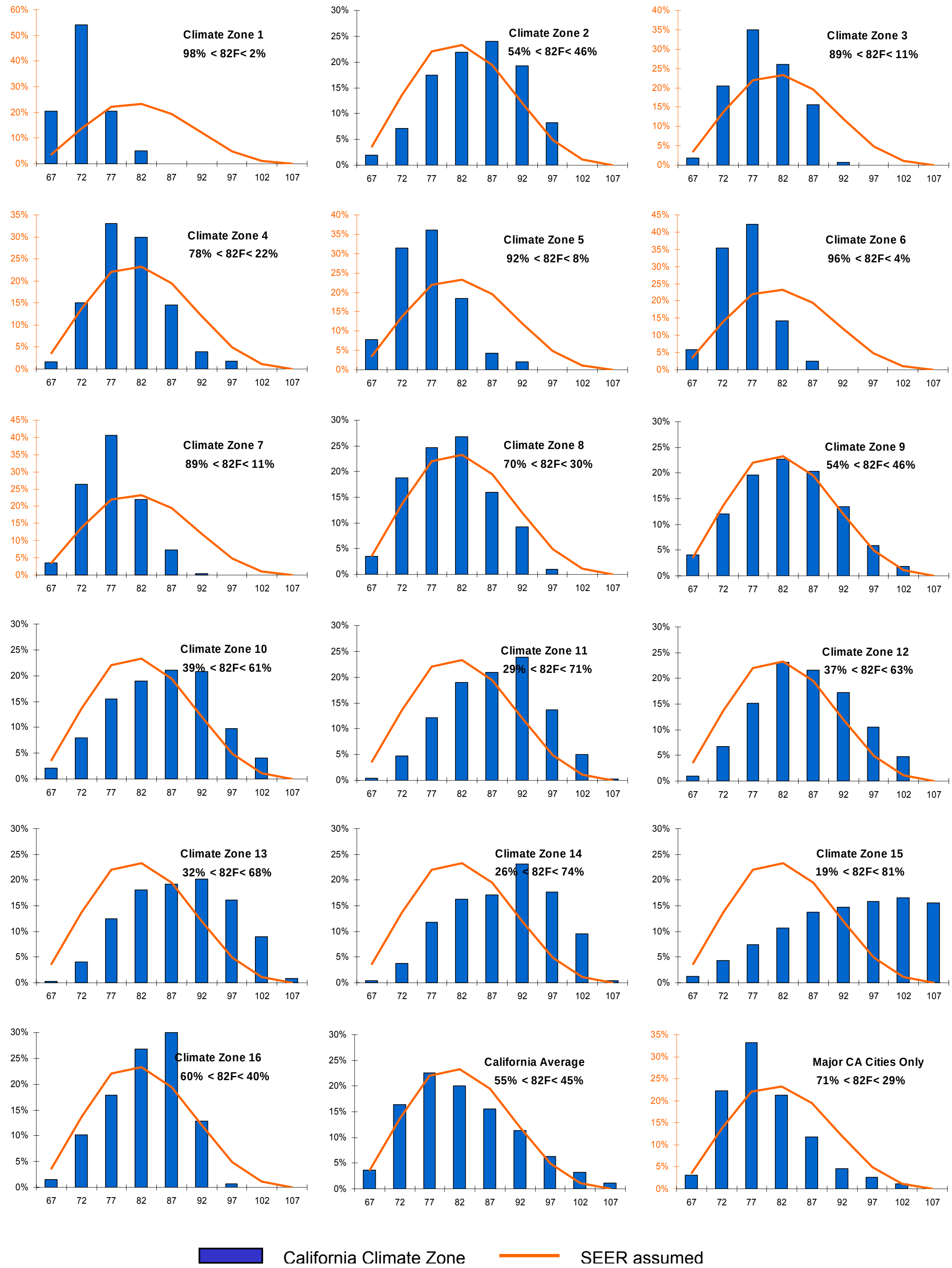
Is the linear relationship between cooling load and outdoor temperature assumed by SEER rating process valid for typical (median) California single-family houses? See Figure 8.

Figure 3b above illustrated the simple linear relationship between outdoor temperature and load implicit in the SEER rating procedure. Figure 8 illustrates the role various climate factors, as well as building design features, have on cooling coil load. The data in Figure 8 are a full year of simulated hourly cooling coil loads plotted against the outdoor temperature at which each hourly load occurred. They were generated using the DOE-2 model of the median single-family one-story house used in Figure 7. Climate zone 9 was selected for all cases illustrated in Figure 8 since it most closely matched the mid-load temperature assumptions implicit in SEER.

Figure 8a illustrates a simulation case that demonstrates a significantly linear relationship between hourly cooling coil load and outdoor temperature, as is assumed in the SEER methodology. The slope of the line in Figure 8a represents the overall U-value for the house (U_0). The point at which the line meets the X-axis (zero cooling coil load) represents the balance point of the house (in Figure 8a, in the absence of internal gains and solar gains, the cooling balance point is the same as the thermostat cooling setpoint, or 78°F).

Obtaining the straight line relationship between hourly cooling coil load and outdoor temperature illustrated in Figure 8a required numerous simplifications to the DOE-2 prototype and simulation procedure. Each of the cases included in Figure 8, other than the first one, i.e., Figure 8b through 8L, represent separate annual simulation results in which one important climate or house design

Figure 7 Distribution of Cooling Coil Load by California Climate Zones
median single family residence, DOE-2 cooling loads



variable, omitted from Figure 8a, was added to the model. Each new run adds a climate or house design variable to the previous runs, i.e., the effects are cumulative, such that the last case, Figure 8L, includes all effects omitted from Figure 8a. Figure 8L represents a much more realistic representation of the relationship between outdoor temperature and hourly cooling coil load than does Figure 8a. **Contrasting Figure 8a with 8L illustrates how differently cooling coil loads for a typical house behave than is assumed by the SEER rating procedure and suggests reasons to anticipate potentially large variability in the ability of SEER to accurately predict cooling energy use in California residential applications.**

Each simulation case in Figure 8 is briefly described below.

a) This is the simplest modeled case. It was devised to obtain a significantly linear relationship between in cooling coil load and outdoor temperature, similar to that which is implicit in the SEER rating procedure (compare Figure 3b). Numerous features of the more detailed (and realistic) model (case L) are omitted in this case. These include: cooling t-stat = 78F + no effects due to: internal loads, wind, radiant losses from ext surfaces, slab losses, infiltration, envelope mass, surface solar absorbtance, interior mass, window solar gain, or natural ventilation. In this first case, note that since there is no internal heat gains and no solar gains, the balance point is equal to the indoor thermostat setpoint (i.e., 78°F). The slope of the line is related to the building overall U_0.

b) Cooling thermostat was altered from 78°F in case “a” to 74°F. As expected, this shifts the balance point lower by 4°F, to 74°F.

c) Internal loads due to interior lights and appliances are added to case “b”. Since these internal heat gains become “trapped” in the house, the balance point is shifted lower yet to approximately 57°F.

d) Wind effects are “turned on”, i.e., wind speeds from the CZ09 weather file are used in the simulation. In the previous cases, wind speed was set to zero for all hours. The impact if this is small. It provides some cooling effects that cause a slight shift in the balance point (i.e., to approximately 58°F). It also “blurs” slightly (i.e., introduces additional variability into) the linear relationship between coil load and outdoor temperature.

e) Long wave radiant exchange at exterior surfaces is “turned on”, i.e., the exterior surface emissivity for all exterior walls and roof surfaces are reset from 0 to 0.9. The impact of this is similar to the effect due to wind, but more significant, i.e., it provides some cooling effects that cause a slight shift in the balance point (i.e., to approximately 64°F). It also further “blurs” slightly the linear relationship between coil load and outdoor temperature.

f) Slab edge losses are “turned on”. Similar to the previous two effects, this adds a further source of heat loss, slighting raising the balance point.

g) Infiltration, at a constant 0.35 air changes per hour, is added to case “e”. Due to the prior inclusion of internal loads, in case “g”, there are numerous cooling load hours when the outdoor temperature is cooler than the indoor temperature, hence, infiltration provides a cooling effect. Note that the general slope of the load-temperature relationship has increased (become steeper) due to a significant additional means of heat loss).

h) All exterior heat transfer surface constructions (i.e., walls and roofs) are converted from u-values (implies a steady-state $U \cdot A \cdot \Delta T$ calculation in the simulation) to use conduction transform functions (i.e., accounts for the time delay associated with the thermal mass of the roof and walls). All roof and wall construction are conventional wood frame. The u-values used in all previous cases were equivalent to the "delayed" constructions used in this and subsequent cases. The time delay of the heat gains through the envelope to the space further "blurs" the original straight line relationship between coil load and outdoor temperature.

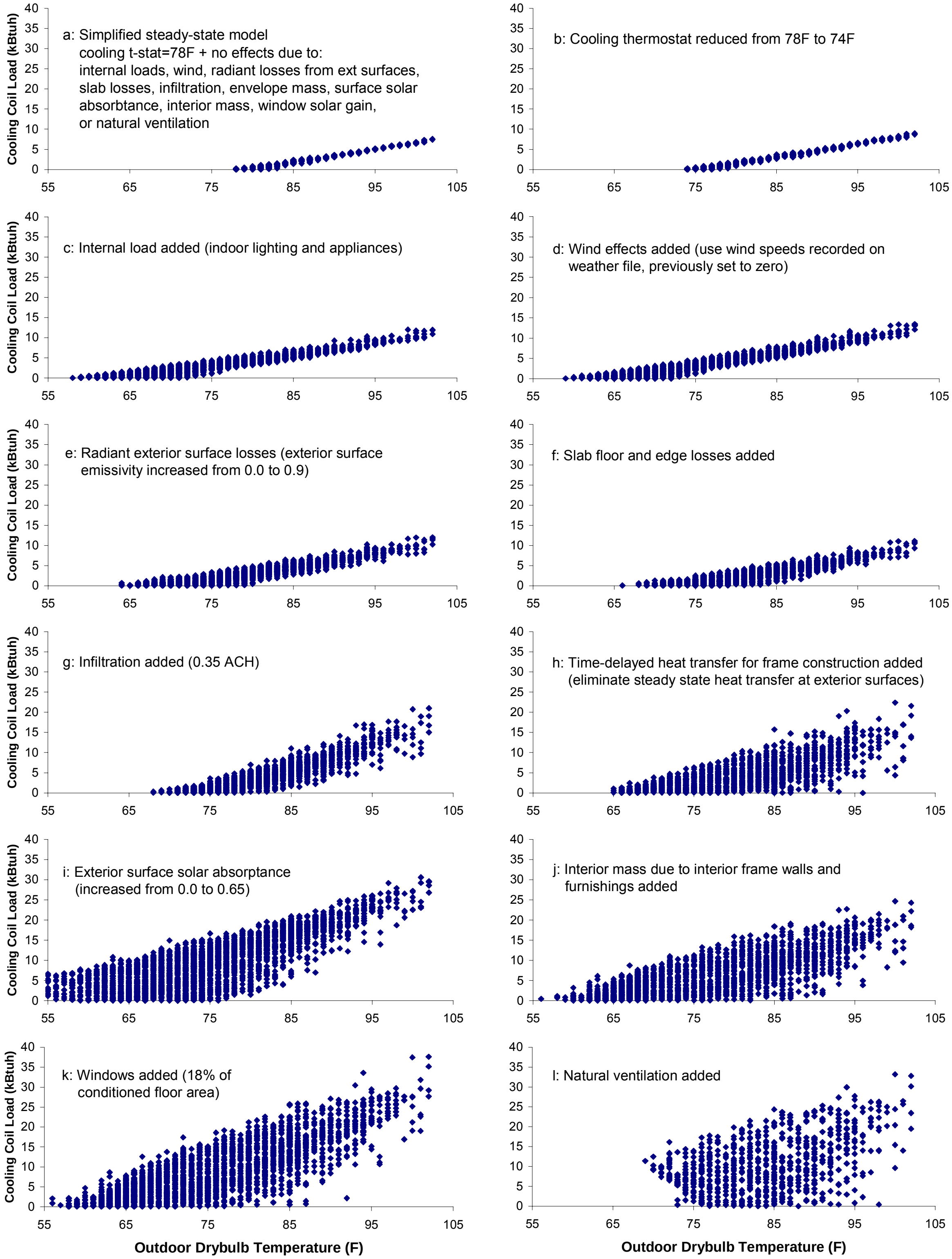
i) Solar absorptance is "turned on" at each exterior heat transfer surface, i.e., exterior surface solar absorptance is reset from 0 to 0.6 for roof and 0.7 for walls. This has the effect of adding additional heat gain to the space, hence the balance point is decreased. Since solar gain is only loosely correlated with outdoor temperature, this modification further blurs the relationship between coil load and outdoor temperature.

j) Interior mass is "turned on" by using custom weighting factors in DOE-2 to calculate the unique contribution of the house interior walls and other surrounding surfaces plus furnishings to the overall capacitance (i.e., mass) of the spaces. In the previous runs, the DOE-2 "floor weight" was set very low, thus providing virtually instantaneous response between surface heat gain and space cooling load.

k) Windows are added, predominantly on the north and south walls (18% of the conditioned floors area). This adds more heat gain, which both lowers the balance point (although more modestly due to the effect of internal mass) and further corrupts the original relationship between load and outdoor temperature.

l) Natural ventilation is enabled via the operable windows. This assumes a constant air change rate of 3 ACH whenever the indoor cooling load could be met using natural ventilation. If the entire cooling load could not be met using natural ventilation, the model assumed the windows were closed and the air conditioner was used to meet the cooling loads. The impact of natural ventilation is greatest on the coil loads that coincide with cooler outdoor temperatures, i.e., less than the 74°F thermostat temperature. The sloped boundary of the remaining cooling loads (i.e., starting at the X-axis near 74°F and toward the upper left) indicates that for hours with larger cooling loads, a greater temperature difference was necessary to provide the required cooling via natural ventilation to completely meet the load.

Figure 8 Cooling Coil Load as a Function of Outdoor Temperature median single family residence, DOE-2 cooling loads, CZ09



4.5 Can DOE-2 be Made to Match the SEER Rating Process?

Can a detailed simulation methodology such as is employed in DOE-2 reproduce the much more simplified assumptions implicit in the SEER methodology? See Table 2 and Figures 9 and 10.

A special DOE-2 simulation case was prepared in which much of the modeling sophistication of DOE-2 was simplified to match the SEER methodology. Key differences between the SEER methodology and DOE-2 and the changes needed to "force" DOE-2 agreement with the SEER assumptions are summarized in Table 2. In Table 2, items in blue font (with asterisks) indicate SEER assumptions that could not be replicated in DOE-2.

Table 2 Comparison of NIST & DOE-2 Calculation Methodologies

	Cooling System Performance Assumptions*	
Calculation Assumptions	SEER Rating Process	DOE-2 Program
Calculation Method	Steady-state from simplified bin analysis	Hour-by-hour simulation*.
Imposed Load Shape	Fixed	Example load profiles selected to closely match SEER assumptions. See Figure 10.
Cooling System Capacity	Fixed	Total cooling capacity as a function of outdoor temperature curve held constant
Cooling System Efficiency	Fixed value for at an outdoor temperature of 82ºF with entering air at 80° F dry- bulb and 67 F wet- bulb.	Allow variation with outdoor dry-bulb only*. Eliminate wet-bulb dependency by creating curve-fit at fixed 67ºF entering air wet-bulb.
Part-load performance	Assumes 50% cycling rate based on a fixed total cooling capacity	Varies with actual coil load and total capacity.*
Cooling System sensible-to-total ratio & Coil Load sensible-to-total ratio	Not addressed. Ratings and load based on total net capacity with no consideration of sensible and latent components	System sensible heat ratio set to 1.0. Effect of coil entering conditions on the cooling coil by-pass factor removed. Sensible capacity adjustment curve set to the total.
Cooling Coil Entering Conditions	Fixed at 80 F DB, 67 F WB	Fixed at 80 F DB, 67 F WB by setting capacity, efficiency, and by-pass performance curves to fixed ARI entering air conditions.

** Items in blue font (and with asterisk) indicate SEER assumptions DOE-2 simulations could not replicate.*

Mid-load temperatures and cooling load profiles for typical single-family California residences were found to vary widely as seen in Figure 7. Two cases having load profiles and mid-load temperatures similar to the SEER assumptions (Figure 9) were selected for further study since these will minimize any bias due to climate or building effects. In Figure 9, the two DOE-2 load profiles differ only by building orientation, i.e., north/south (mid-load temperature = 82.5 F) versus east/west (mid-load temperature = 84.5 F).

Figure 9 SEER Rating and DOE-2 Simulated Cooling Load Profiles

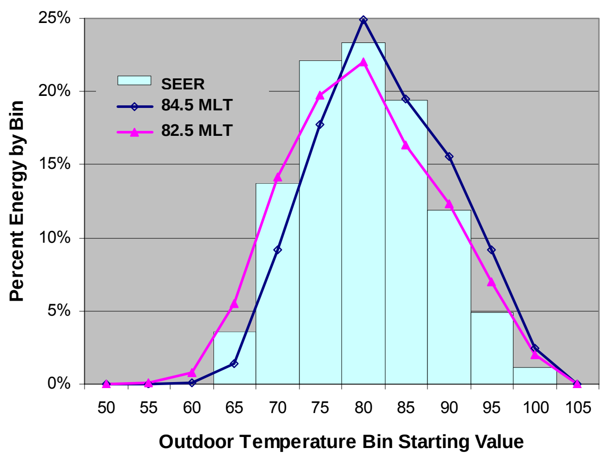
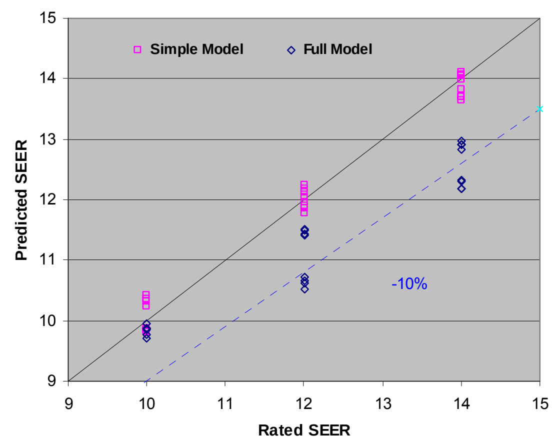


Figure 10 Effect of Simplified SEER Assumptions Rated SEER versus DOE-2 Predicted SEER



In Figure 10, the points noted as "Full Model" are DOE-2 simulation results that use cooling system equipment performance curves based on manufacturer's published data. Those points noted as the "Simple Model" are DOE-2 simulation results based on the performance curves adjusted to match the simplified assumptions used in the SEER ratings process, as noted in Table 2 above. In particular, performance curves in the "Simple Model" are forced to ignore differing cooling coil entering conditions, cooling capacity variation with temperature, both latent and sensible cooling performance, and the other of the seven issues outlined in Table 2. It can be seen in this figure that there is close agreement between rated SEER and DOE-2 simulated SEER when DOE-2's performance curves are limited to a simplified approach as is used in the SEER ratings process. When the simplifying assumptions are replaced with performance curves that replicate the manufacture's data ("Full Model") the rated SEER over-predicts simulation results.

Based on the results in Figure 10, it is clear that **for single-speed equipment, DOE-2 can closely reproduce the SEER rating methodology when modeling simplifications used in the SEER rating process are employed.** The SEER rating for two-speed equipment employs all of the same simplifying assumptions as noted for single speed equipment, plus an assumption regarding the amount of time spent at low versus high compressor speed. Reproducing, with DOE-2, the same assumed split in low versus high compressor speed would require a tedious process of matching specific load sequencing assumptions between the outdoor temperature, cooling load, and the equipment's response to the load. This was deemed to be unnecessary given that the results above for single-speed systems illustrates and confirms the role of the fundamental simplifying assumptions and the ability of DOE-2 to reproduce the results of the simplified characterization of the equipment behavior.

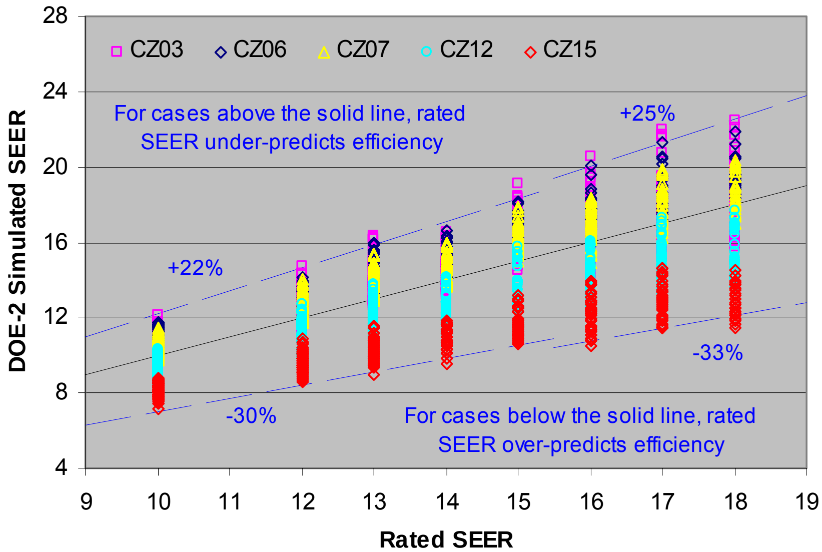
5.0 Findings that Address the Questions that Guided the Research

5.1 SEER as a Predictor of Residential Cooling Energy Use

Question 1: How effective is SEER as a predictor of expected annual cooling energy *use* in residential applications?

Figure 11 indicates that in residential California use, across the typical range of climate zones and across the typical range of house characteristics and HVAC system characteristics, **rated SEER predicts seasonal cooling efficiency only to within +22% to -30% for single-speed equipment and +25% to –33% for two-speed equipment**. The climate zones included in Figure 11 are five "indicator" climate zones. These represent the major population centers (Oakland — CZ03, Los Angeles — CZ06, San Diego — CZ07, and Sacramento — CZ12) plus climate zone 15 (Palm Springs). Cases that lie above the solid line (slope = 1.0) indicate that actual expected cooling efficiency (DOE-2-predicted SEER) exceeded the efficiency predicted by rated SEER, i.e., SEER under-predicted cooling efficiency. Cases that lie below the solid line indicate that SEER over-predicted cooling efficiency.

Figure 11: Rated SEER as a Predictor of Annual Cooling Efficiency
Single Family Residential Prototype, Five Representative California Climate Zones*
Min/Median/Max Building Characteristics, Min/Median/Max System Characteristics



** CZ03 (Oakland), CZ06 (Los Angeles), CZ07(San Diego), CZ12 (Sacramento) CZ15 (Palm Springs)*

What causes this variation?

This important question will be answered in term of three effects identified previously:

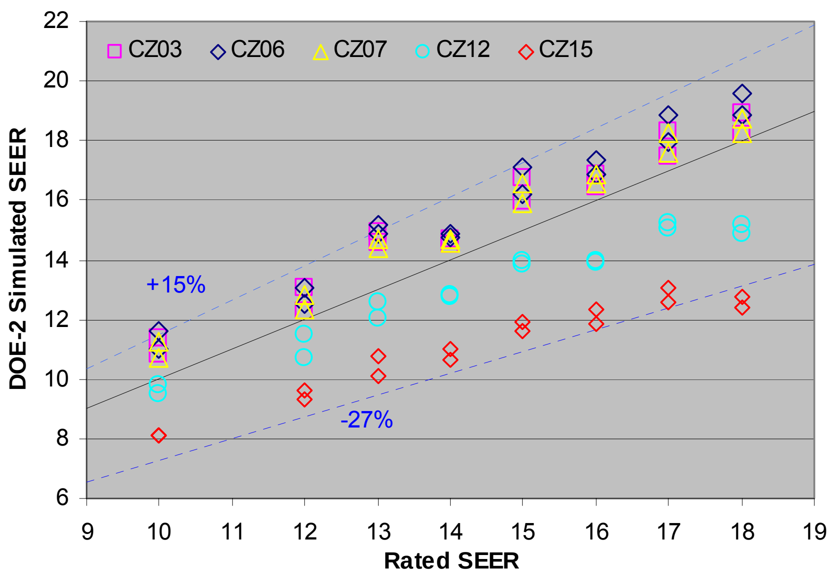
- Climate effects: simple correction factors were developed suitable for tabular application.
- Building effects: more complex corrections were investigated, but with less success than for climate
- System effects: more complex corrections were investigated, but with less success than for climate

5.2 Climate Effects in Residential SEER Bias

How much of the total variation in SEER-predicted residential energy use is due to climate zone effects, i.e., violations of the SEER-assumed standard climate?

In Figure 12, the results are limited to only median building characteristics (these differ by climate zone where required by Title 24) and median equipment characteristics (i.e., median cycling effects and sensitivity to climate) in order to estimate the average climate effect. By contrast, Figure 11 included min/median/max cases for both building characteristics and system characteristics. The variation in results in Figure 12 is +15% to –27%, reduced from the total variation (+22% to -30% for single-speed and +25% to –33% for two-speed units) in Figure 11. Therefore, **on average, one-half to almost two-third of the total inability of rated SEER to predict seasonal cooling efficiency in California residential applications appears to result from climate effects.** Note that this includes both the impacts due to outdoor temperature and indoor temperature (i.e., coil entering wet-bulb conditions). As in Figure 11, only the five indicator climate zones are included in Figure 12 (representing the major population centers plus hot arid Palm Springs.) In Figure 12, climate zone 3 and 6 represent one extreme of the range of results where SEER is a conservative predictor of seasonal cooling energy efficiency. The other extreme of the range of results, where SEER over-predicts seasonal cooling energy efficiency, is represented by climate zone 15. In several of the graphs that follow, climate zones 6 and 15 are used to indicate the likely range resulting from climate effects.

Figure 12 Effect of Climate on Simulation-Estimated SEER
Single Family Residential Prototype, Five Representative California Climates
Median Building Characteristics, Median System Characteristics



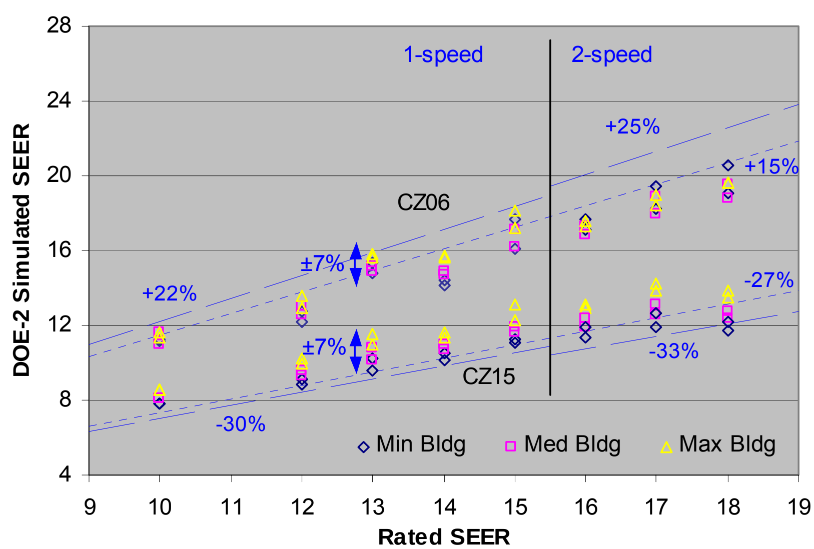
5.3 Building Effects in Residential SEER Bias

How much of the total variation in SEER-predicted residential energy use is due to variation in building characteristics that effect cooling coil load and its relationship with outdoor temperature? See Figure 13.

Figure 13 provides an estimate of building effects by including minimum, median, and maximum cases for building characteristics while holding equipment characteristics constant at median equipment cases only. Only results from climate zone CZ06 (Los Angeles, above the slope = 1.0 line) and CZ15 (Palm Springs, below the slope = 1.0 line) are shown. Fiducial marks from Figures 11 and 12 are also included for reference. The overall variation in Figure 13 (i.e., between climate zones) is less to that seen in Figure 11 since system effects are omitted, but is very similar to the range of total variation in Figure 12 since the two climate zones in Figure 13 tend to bound the range of climate effects. The variation in performance is ±7%. **The ±7% or more variation <u>within each climate zone</u> is due to building effects and accounts for a little over half of the variation not attributable to climate effects or about one-sixth to one-fourth of the total variation.** This is largely through the impact that building characteristics have on mid-load temperature (via the building balance point) and, for two-speed equipment, load profile variations. The effects appear to be of similar magnitude for both mild and hot arid climates. The building characteristics that were allowed to vary in Figure 13 are:

Total Floor Area	Number of Stories	Aspect Ratio	Occupancy Density
Internal Gains	Cathedral Roof %.	Floor Type	Window Area
Glass U-value	Glass SHGC	Wall Insulation	Roof Insulation
Crawlspace R-Value	Slab Perim. Insul.	Duct Leakage	Duct Insulation
Exterior Shading	Infiltration Rate	Natural Ventilation	Cool T-Stat Setpoint

Figure 13 Effect of Building Characteristics on Simulation-Estimated SEER
Single Family Residential Prototype, Climate Zones 6 (mild) and 15 (hot arid)
Min/Median/Max Building Characteristics, Median System Characteristics

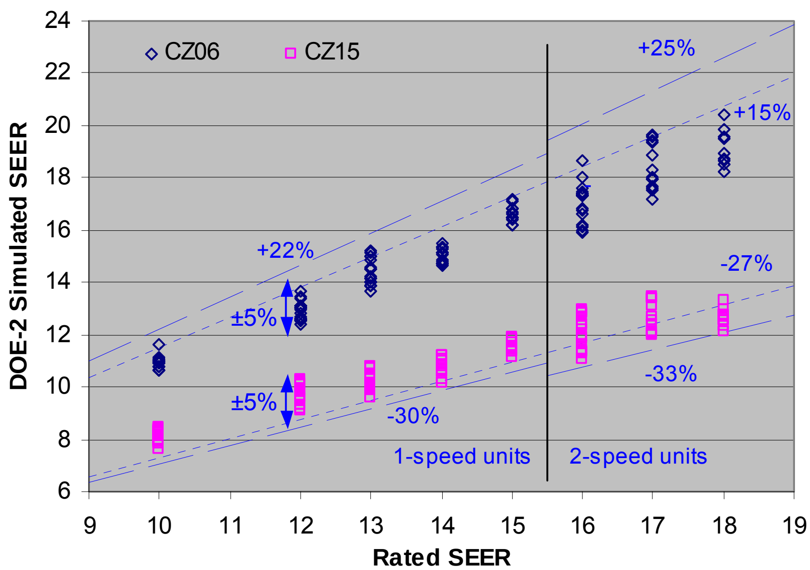


5.4 System Effects in Residential SEER Bias

How much of the total variation in SEER-predicted residential energy use is due to variation in individual HVAC system characteristics (i.e., the vertical scatter in Figure 1)? See Figure 14.

The results in Figure 14 estimate of system effects by including minimum, median, and maximum cases for system characteristics while holding building characteristics constant at median levels. Only results for climate zone CZ06 (Los Angeles) and CZ15 (Palm Springs) are shown since these tend to bound the total scatter due to climate effects. Fiducial marks from Figures 11 and 12 are also included for reference. The overall variation in Figure 14 (i.e., between climate zones) is less to that seen in Figure 11 since building effects are omitted but is very similar to the range of total variation in Figure 12 since the two climate zones in Figure 14 tend to bound the range of climate effects. **The ±5% variation <u>within each climate zone</u> is due to system effects (e.g., individual system differences sensitivity to outdoor temperature and to cycling degradation) and accounts for about one-third of the variation not attributable to climate effects or about one-fifth to one-fourth of the total variation.** System effects can be larger for two-speed units, but still represents around one-fifth to total variation. The effects appear to be of similar magnitude for both mild and hot arid climates, hence, there appears to be no significant interaction between the climate and system effects. The system characteristics that used to select single-speed equipment in Figure 14 were unit efficiency (EER) sensitivity to outdoor temperature and sensitivity to cycling effects. Other system characteristics that varied from unit-to-unit included capacity sensitivity to outdoor temperature, sensible heat ratio, and unit sensitivity to coil entering wet-bulb temperature.

Figure 14 Effect of HVAC System Characteristics on Simulation-Estimated SEER
Single Family Residential Prototype, Climate Zones 6 (mild) and 15 (hot arid)
Median Building and Expanded Equipment Prototypes



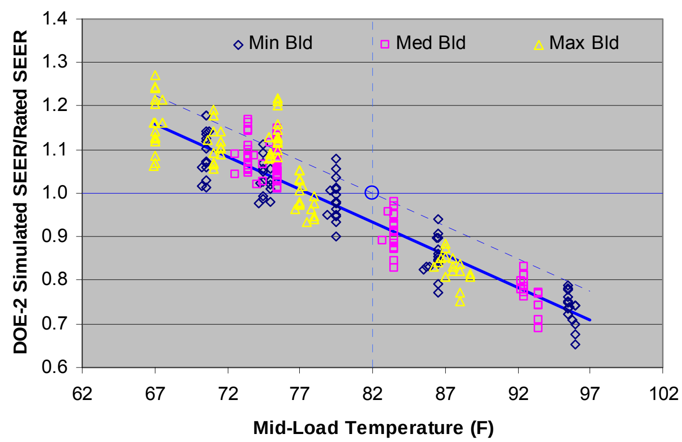
5.5 What mid-Load Temperature for California?

Can these simulation results recommend an improved mid-load rating temperature for California residential applications? See Figure 15.

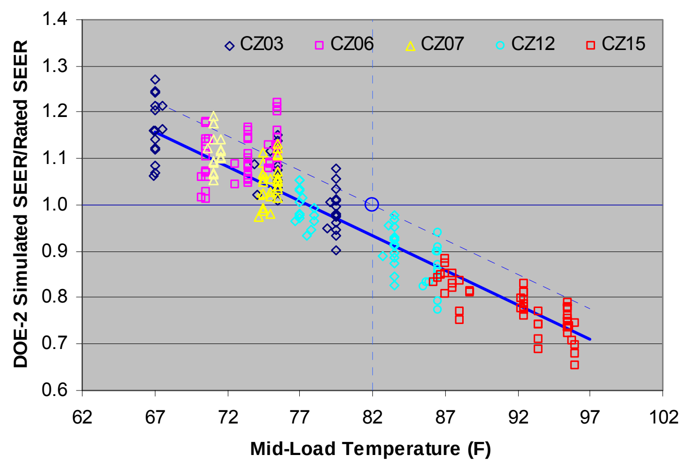
Figure 7 indicated that the mid-load temperatures for a median single-family house could vary widely between California climate zones and that the average mid-load temperature for the major California urban areas was approximately 76°F, rather than 82°F. Figure 15 provides an alternate view of the range in mid-load temperature for the typical range of single-family residences across representative California climates. In Figure 15, building (a) and climate (b) effects contribute to the wide variation in mid-load temperature (system characteristics are restricted to median systems only). Note that a best-fit line (bold solid blue) passes through the line where DOE-2 simulated SEER equals rated SEER at approximately 77°F rather than 82°F (i.e., as does the dashed line), which more nearly agrees with the results from Figure 7. **These results suggest that for California residential applications, 77°F would serve as a better SEER rating temperature, but that the required mid-load rating point varies considerably with both building characteristics and climate.**

Figure 15 Effect of Climate and Building Characteristics on Mid-Load Temperature
Single Family Prototype, Five Representative California Climates
Min/Median/Max Building Characteristics, Median System Characteristics

a: by Building Characteristics



b: by Climate Zone

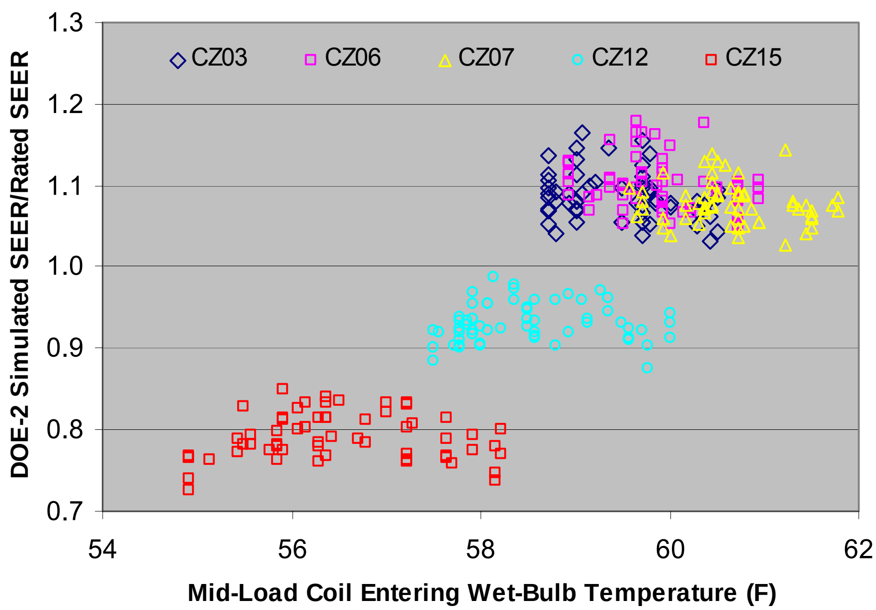


5.6 The Role of Indoor Coil Entering Conditions

What other effects tend to bias SEER-predicted energy use in California residential applications? See Figure 16.

Figure 16 presents the results shown in Figure 15, with the results are plotted against the mid-load wet-bulb temperature entering the cooling coil rather than the outdoor temperature. Caution should be used when interpreting Figure 16 as it implies a significant relationship between coil entering air wet-bulb temperature and SEER. While there is an impact, the effect on SEER shown in the figure is actually a result of outdoor temperature as shown in Figure 15. Statistically, there is a strong cross-correlation between higher outdoor temperature and lower coil entering air wet-bulb (hotter climates are dryer). The lack of climate zone dependency on coil entering wet-bulb temperature is illustrated in Figure 16 by the horizontal arrangement of points in a given climate zone and the overlap of points from climate zone to climate zone. Of greater importance is that typical coil entering wet-bulb conditions in California are less that 62°F, not the 67°F used in ratings tests. For most residential cooling systems, a 62°F coil entering wet-bulb is where dry coil conditions begin. System efficiency is 5% to 10% lower under dry coil conditions than at rated conditions (67°F coil entering wet-bulb). Once dry coil conditions occur, there is little further drop in cooling efficiency as the coil entering wet-bulb temperature continues to fall. **California's lower humidity leads to a 5% to 10% reduction in actual SEER, a statewide effect that has little climate zone dependency.**

Figure 16 Effect of Indoor Coil Entering Conditions on Simulation-Estimated SEER
Single Family Expanded Prototype, Five Representative California Climates
Median Building Characteristics, Min/Median/Max System Characteristics
Results shown by Climate Zone

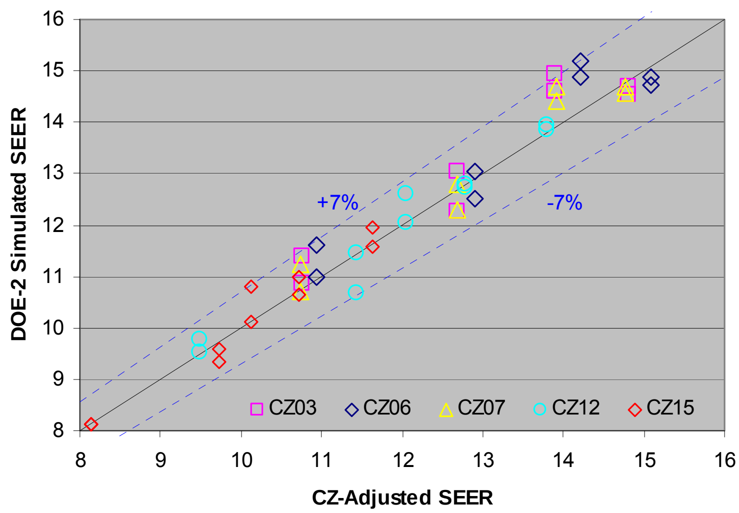


5.7 Climate Effects SEER Correction Factors

What corrections can be applied to these results (e.g., Figure 11) to allow SEER to more accurately predict energy use in California Climates? Figures 17a and 17b show the results of applying empirical climate zone multipliers (SEER-specific multipliers applied). Comparing to Figure 11, **using the SEER-specific climate zone multipliers reduces the variation in SEER-predicted annual energy use from +22% and –30% to ±7% for single-speed units and from +25% and –33% to ±9% for two-speed units.** It is important to note that these climate zone correction multipliers implicitly address both the impacts due to outdoor temperature and indoor temperature (i.e., coil entering wet-bulb conditions). Residential climate zone SEER multipliers (DOE-2 simulated SEER / rated SEER) for all California climate zones are provided in Table 3.

Figure 17 Climate Zone-Adjusted SEER as a Predictor of Annual Cooling Efficiency
Single Family Residential Prototype, Representative California Climates
Median Building Characteristics, Median System Characteristics

a: Single-Speed Units



b: Two-Speed Units

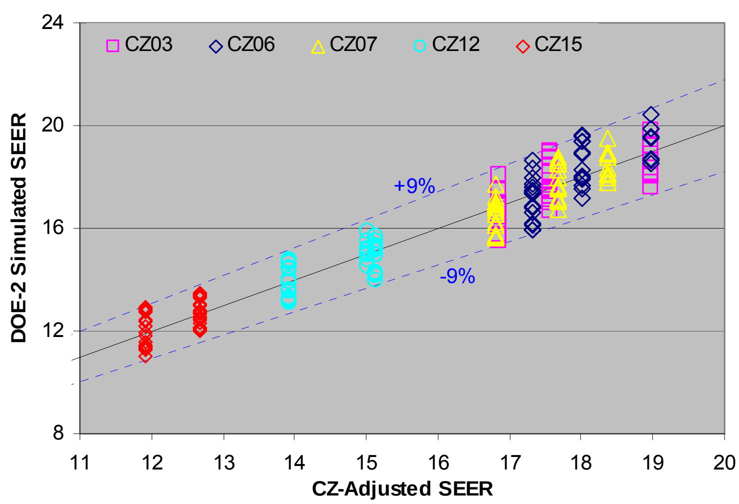


Table 3 Residential SEER Climate Zone Multipliers for All California Climate Zones
Single Family Residential Prototype, All California Climates
Median Building Characteristics, Median System Characteristics

	Single-Speed SEER Rating						Two-Speed SEER Rating				All Units
	10	12	13	14	15	All	16	17	18	All	
CZ01	1.16	1.16	1.15	1.13	1.20	1.16	1.10	1.10	1.11	1.10	1.14
CZ02	0.97	0.95	0.95	0.92	0.95	0.95	0.90	0.92	0.88	0.90	0.93
CZ03	1.08	1.06	1.07	1.04	1.08	1.07	1.05	1.04	1.03	1.04	1.06
CZ04	1.07	1.04	1.05	1.03	1.06	1.05	1.01	1.00	0.98	1.00	1.03
CZ05	1.07	1.07	1.07	1.04	1.08	1.07	1.08	1.06	1.05	1.06	1.06
CZ06	1.08	1.07	1.07	1.04	1.10	1.08	1.08	1.06	1.06	1.07	1.07
CZ07	1.07	1.06	1.06	1.04	1.07	1.06	1.05	1.04	1.03	1.04	1.05
CZ08	1.07	1.06	1.02	1.00	1.03	1.02	0.98	0.98	0.95	0.97	1.01
CZ09	0.99	0.97	0.97	0.95	0.97	0.97	0.91	0.94	0.89	0.91	0.95
CZ10	0.95	0.94	0.92	0.90	0.92	0.92	0.86	0.89	0.84	0.86	0.90
CZ11	0.92	0.90	0.89	0.86	0.89	0.89	0.83	0.85	0.80	0.83	0.87
CZ12	0.97	0.95	0.94	0.92	0.94	0.94	0.88	0.90	0.85	0.88	0.92
CZ13	0.93	0.91	0.89	0.88	0.88	0.89	0.83	0.85	0.80	0.83	0.87
CZ14	0.88	0.85	0.86	0.82	0.86	0.86	0.78	0.81	0.76	0.78	0.83
CZ15	0.83	0.81	0.79	0.78	0.79	0.80	0.74	0.75	0.71	0.74	0.78
CZ16	1.05	1.03	1.04	0.99	1.04	1.04	0.91	0.94	0.89	0.92	0.99

Note: Climate zone and SEER specific multipliers used in all presentation graphics and summary findings. Values noted as "All" are for the reader's interest only.

5.8 2001 and 2005 Title 24 SEER Correction Factors

How do the results from these empirical corrections for California climate zones compare with the temperature corrected SEER's recently and currently required to be used by Title 24 residential code compliance software (Alternate Calculation Methods – ACMs)? See Figures 18a through 18f.

Figures 18a through 18f compare the ability to predict anticipated actual SEER (i.e., DOE-2-simulated SEER) using the following four "methods" to provide values of "Adjusted SEER".

METHOD 1: rated SEER (no correction applied)

METHOD 2: climate zone adjusted SEER as required by 2001 Title 24 Residential ACM (based on a simple look up table by rated SEER and climate zone)

METHOD 3: SEER calculated by the 2005 Title 24 Residential ACM algorithm that takes both SEER and ERR as inputs (the analysis here uses rated EER rather than the ACM default ERR of 10.0 that is required to always be used for the compliance base case and required to be used for the proposed case if the unit rated EER is not specified)

METHOD 4: climate zone adjusted SEER (from this research)

Use the first two figures (Figures 18a and 18b) to compare the 2001 Title 24 SEER corrections. Use the third and fourth figures (Figures 18c and 18d) to compare the 2005 Title 24 corrections. Figures 18e and 18f compare the 2005 Title 24 corrections by SEER rating and are limited to systems that meet the new standard (vintage SEER 10 and SEER 12 systems eliminated).

All results in Figures 18a through 18f include results for California climates zones 2 through 15 and all HVAC systems. Climate zone 1 was omitted due to limited cooing requirements. 99% confidence limits (limits containing 99% of the cases) are shown for the corrected results.

The 2005 Title 24 corrected SEER data used in Figures 18c through 18f were calculated using manufacture's rated EER for each unit as input to the ACM algorithm, not the ACM default EER. The ACM EER for systems with SEER values 12 and above defaults to EER 10, which tends to be lower than manufacture's rated EER for higher efficiency systems.

The results presented in Figure 18 indicate the following:

- Rated SEER estimates of anticipated actual SEER (green squares in Figures 18 a-f) vary substantially (99% confidence limits: +15% to -25% for single-speed systems and +18% to -30% for two-speed systems). These results indicate a bias that tends to over-predict efficiency in California residential applications, i.e., anticipated seasonal cooling efficiency tends to be less than rated SEER. This means that rated SEER tends to underestimate actual cooling energy use in California. The tendency for rated SEER to underestimate actual cooling energy use appears to be somewhat greater for two-speed systems than for single-speed systems (compare the green square points in Figures 18a or 18c with Figures 18b or 18d).
- 2001 Title 24 corrected SEER (see magenta round points in Figures 18a and 18b) improves upon rated SEER (99% confidence limits: +24% to -5% for single-speed systems and +28% to -5% for two-speed systems), but these results indicate a bias that tends to under-predict efficiency for both single-speed and two-speed systems, i.e.,

anticipated seasonal cooling efficiency tends to be better than that provided by 2001 Title 24 corrected SEER. This means that the 2001 Title 24 SEER correction tends to overestimate actual cooling energy use and gives too little credit for improved efficiency cooling measures and cooling load reduction measures (e.g., high efficiency lights, solar control glass, window shading).

- 2005 Title 24 corrected SEER (see magenta round points in Figures 18c and 18d) improves somewhat further upon rated SEER than did the 2001 Title 24 correction (99% confidence limits: +24% to -7% for single-speed systems and +20% to -18% for two-speed systems). Ignoring vintage system (less than SEER 13), the confidence limits reduces slightly to +22% to -7% for single-speed systems (Figure 18e). In all cases, results indicate a bias that tends to under-predict efficiency, i.e., anticipated seasonal cooling efficiency tends to be greater than 2005 Title 24 corrected SEER. The average bias for single-speed equipment is approximately +15%, but only 1% for two-speed equipment. This means that the 2005 Title 24 SEER ACM method tends to overestimate actual cooling energy use and tends to give too little credit for high efficiency cooling systems and cooling load reduction measures (e.g., high efficiency lights, solar control glass, window shading.)

  The predictions of performance at differing SEER rated values for the 2005 Title 24 method can be seen in Figures 18e and 18f; the data in these plots is identical to that in Figures 18c and 18d except the data for the climate zone corrected SEER (blue triangle in Figures 18a-d) and SEER values below 13 (the minimum allowed under current code) have been removed.

- Climate zone corrected SEER (this research) substantially reduces variation in estimating anticipated actual SEER (99% confidence limits: ±8% for single-speed and ±10% for two-speed units). Note that this 99% confidence level variation is slightly more than similar results shown in Figure 17. The results in Figure 17 are only for median systems and five climate zones while Figure 18 reports results for all systems and all climate zones. While the corrections provided in this effort still include a level of uncertainty in expected seasonal cooling efficiency, they do not include a general bias. That is, there is no general trend toward either over-predicting or under-predicting cooling system seasonal energy efficiency.

Figure 18a 2001 Title 24 Temperature Corrected SEER, Single-Speed Systems Only
Single Family Residential Prototype, All California Climate Zones
Median Building Characteristics, and Min/Median/Max System Characteristics

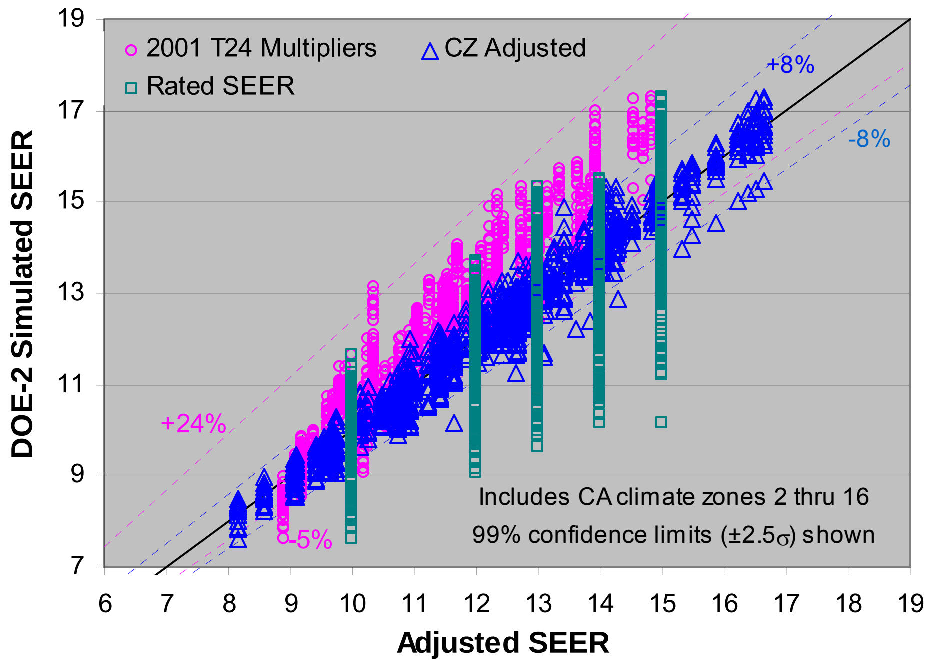


Figure 18b 2001 Title 24 Temperature Corrected SEER, Two-Speed Systems Only
Single Family Residential Prototype, All California Climate Zones
Median Building Characteristics, and Min/Median/Max System Characteristics

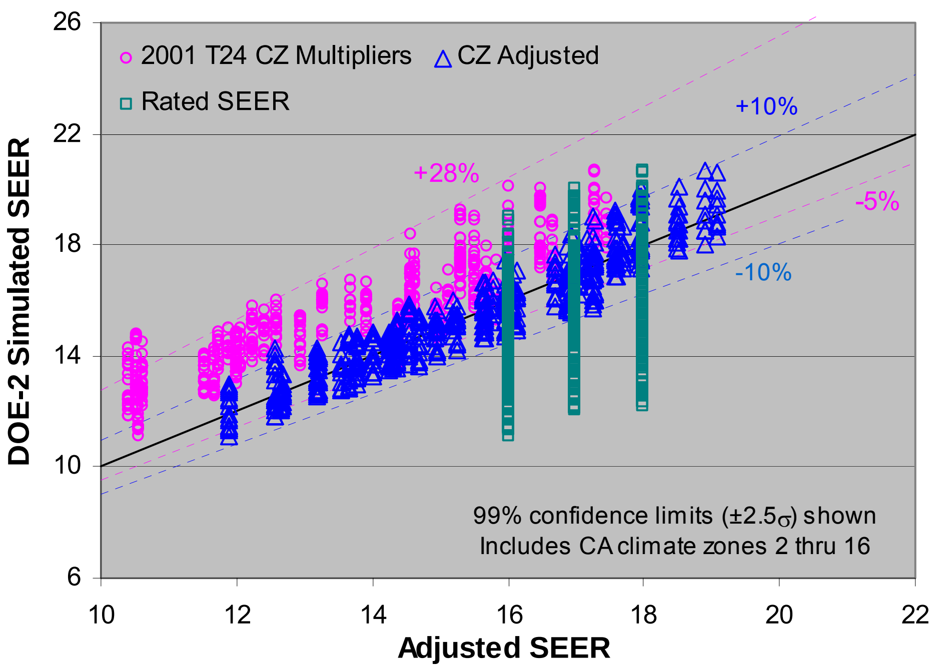


Figure 18c 2005 Title 24 Temperature Corrected SEER, Single-Speed Systems Only
Single Family Residential Prototype, All California Climate Zones
Median Building Characteristics, and Min/Median/Max System Characteristics

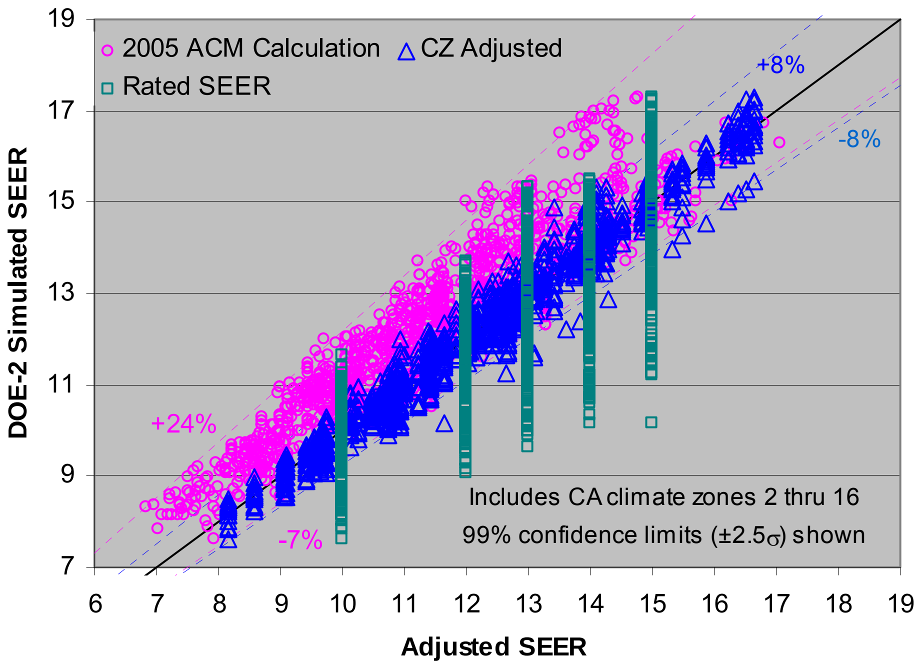


Figure 18d 2005 Title 24 Temperature Corrected SEER, Two-Speed Systems Only
Single Family Residential Prototype, All California Climate Zones
Median Building Characteristics, and Min/Median/Max System Characteristics

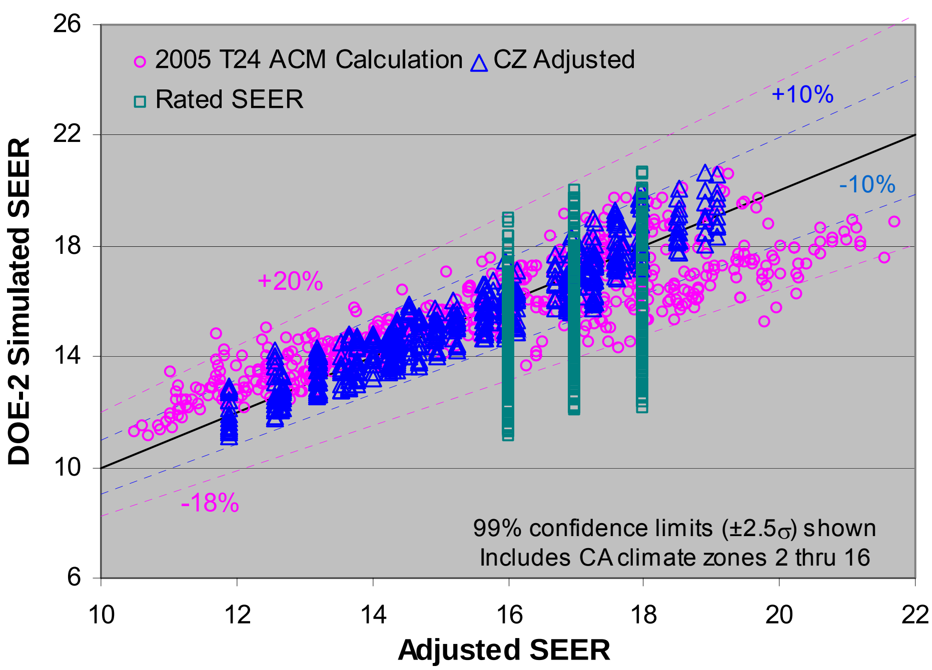


Figure 18e 2005 Title 24 Temperature Corrected SEER, Single-Speed Systems Only
Single Family Residential Prototype, All California Climate Zones
Median Building Characteristics, and Min/Median/Max System Characteristics

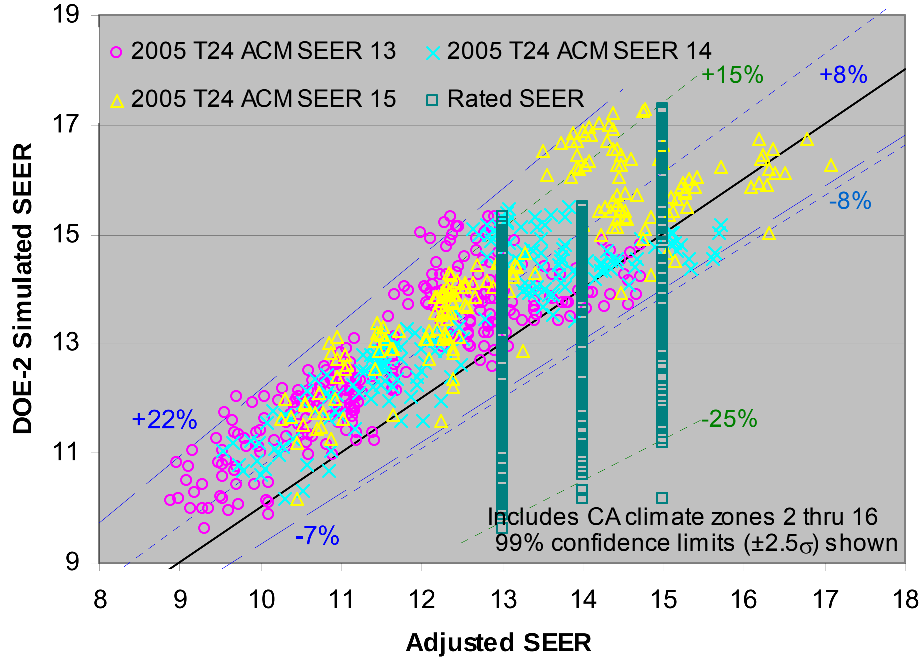
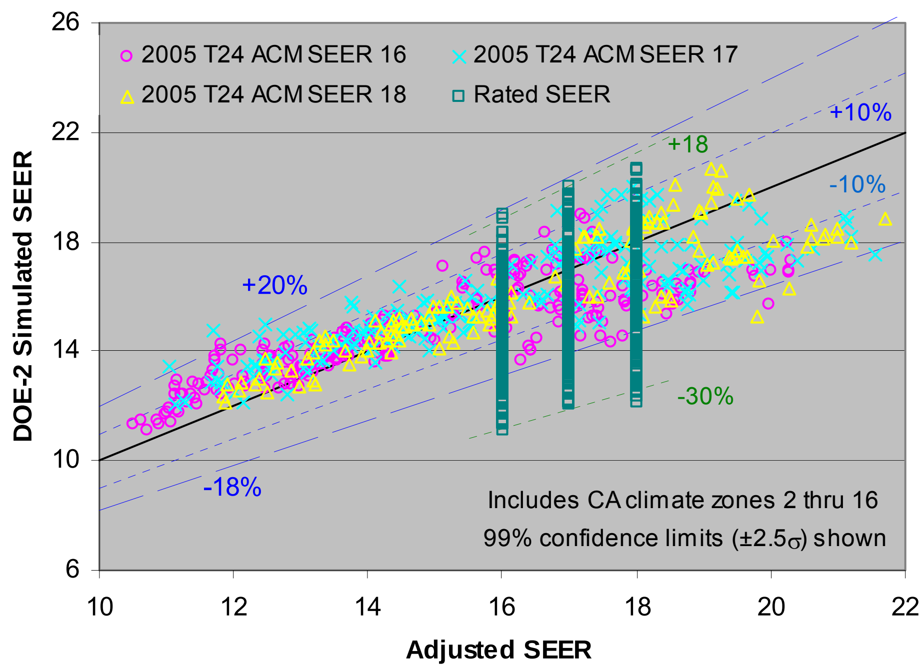


Figure 18f 2005 Title 24 Temperature Corrected SEER, Two-Speed Systems Only
Single Family Residential Prototype, All California Climate Zones
Median Building Characteristics, and Min/Median/Max System Characteristics



5.9 More Detailed SEER Correction Factors

Is there significant potential for more detailed correction procedures? See Figure 19.

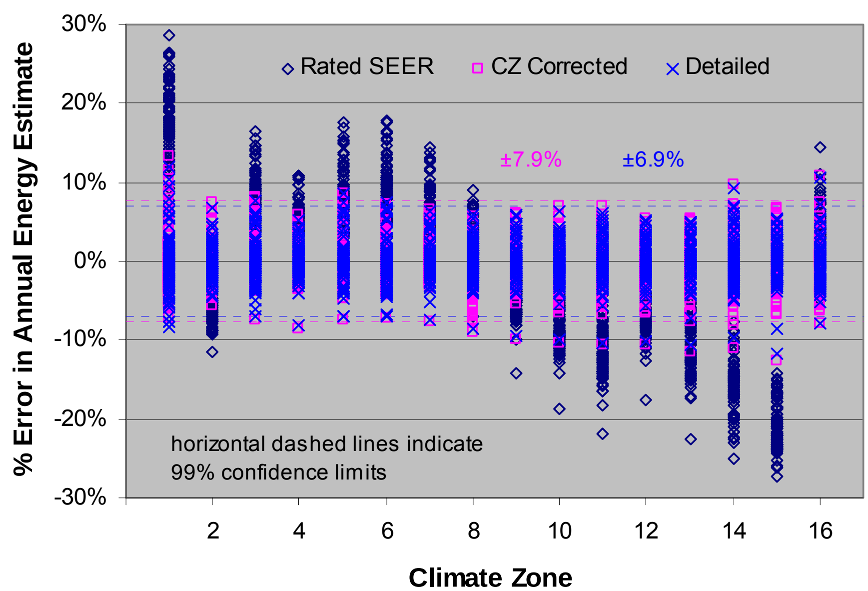
Figure 19 compares the relative error associated with the following:

- rated SEER (no correction applied),
- climate zone corrected SEER — simple empirical correction (from Table 3 above).
- detailed SEER correction model — applies only to single-speed equipment and includes terms based on C_D (degradation coefficient as determined in SEER cycling tests), mid-load temperature (determined from an empirical look-up table based on previous simulation cases), sensitivity of the system's efficiency to changing outdoor temperature, sensitivity of the system's efficiency to changing coil entering wet-bulb, and the system's sensible heat ratio. (For more details, see the full report).

The results presented below indicate the following:

- relative error associated with using rated SEER to estimate annual energy use (i.e., DOE-2 simulated SEER) can vary substantially — using only cases with median building characteristic, the 99% of the simulated cases lie between +20% and −25%.
- using SEER-specific and unit type (air conditioner or heat pump) climate zone corrected SEER multipliers (Table 3) to estimate annual energy use significantly reduces relative error — the 99% of the simulated cases lie between ±7.9%.
- **the detailed SEER correction model single-speed residential cooling energy use further reduces relative error only modestly, i.e., from ±7.9% to ±6.9%**

Figure 19 Relative Error Due to:
Rated SEER, Climate Zone Adjusted SEER & Detailed Adjusted SEER
Single Family Residential Prototype, All California Climate Zones
Median Building Characteristics, Min/Median/Max System Characteristics



5.10 SEER as a Predictor of Residential Cooling Energy Savings

QUESTION 2: How effective is SEER as a predictor of expected annual cooling energy *savings* in single-family residential applications?

Previous results indicate potentially large uncertainties in using rated SEER to anticipate annual cooling energy use in residential applications in California climates. Arguably, SEER is more frequently used to anticipate the *reduction* in annual cooling energy when upgrading from an HVAC system with a lower SEER rating to a system with a higher SEER rating, e.g., from a SEER 13 system to a SEER 14 or SEER 15.

Figures 20 and 21 show the results of upgrading from one SEER level to a higher SEER level. Six HVAC system upgrade cases are reported in Figure 20 for an upgrade from a vintage SEER 10 unit, e.g., SEER 10 to SEER 13, SEER 10 to SEER 14, etc. Figure 21 shows five upgrades from a SEER 13 unit. The upgrade cases are labeled along the X-axis, both in terms of the assumed SEER ratings and the total number of SEER "points" involved in the upgrade. Expected savings are shown in the left-most vertical bar (dark blue) for each upgrade case. This is the savings one should expect if rated SEER were a reliable indicator of cooling energy use.

Note that the calculation of SEER-predicted savings can be counter-intuitive for at least two reasons. First, to achieve a *reduction* in cooling energy consumption, the SEER value must *increase*. Second, the percentage *increase* in SEER (see Equation 1 below) does NOT indicate the anticipated percent *reduction* in cooling energy (i.e., savings) due to SEER upgrade (Equation 2 below).

Example calculation of the percentage improvement in SEER (Equation 1) and the percent reduction in annual cooling energy use due to an improvement in SEER

*If a home owner or builder is considering the purchase of a SEER 14 cooling system, rather than a minimally compliant system (SEER 10), **what is the percent improvement in SEER and what should be the resulting percentage reduction in cooling energy?***

Improvement in SEER:

$\left(SEER14 / SEER10\right) - 1 = 1.40 - 1 = 0.40$ … a **40% improvement in SEER** (1)

Anticipated reduction in annual energy use due to a SEER improvement:

$1 - \left(\dfrac{\frac{1}{SEER14}}{\frac{1}{SEER10}} \right) = 1 - \left(SEER10 / SEER14\right) = 1 - 0.714 = 0.286$ … a **29% reduction in energy use** (2)

Thus the 40% increase in SEER should yield a 29% reduction in annual cooling energy use.

Figures 20 and 21 also present the median savings achieved using the DOE-2 simulations (light blue bar). For each upgrade case, it is evident that on average actual cooling energy savings falls short of the expected savings. The shortfall illustrates inability of the standard SEER ratings process to account for California's climate features.

Figure 20: Percentage Savings Achieved by SEER Upgrade from a SEER 10 Unit (Upgrading from a Lower SEER System to a Higher SEER System) Single Family Residential Prototype, Min/Median/Max Buildings, Min/Median/Max Systems

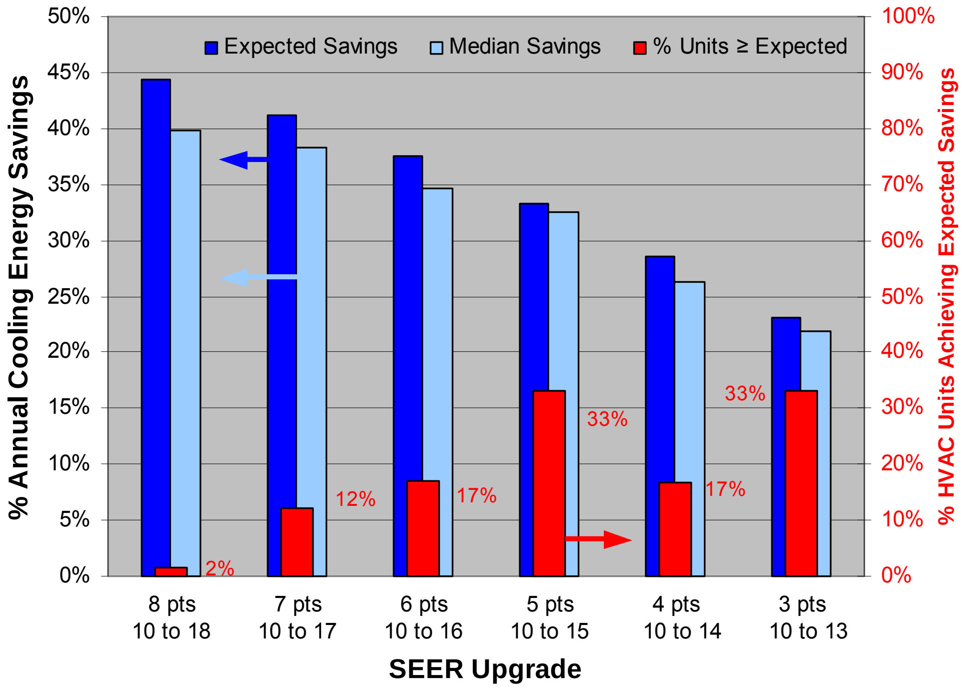
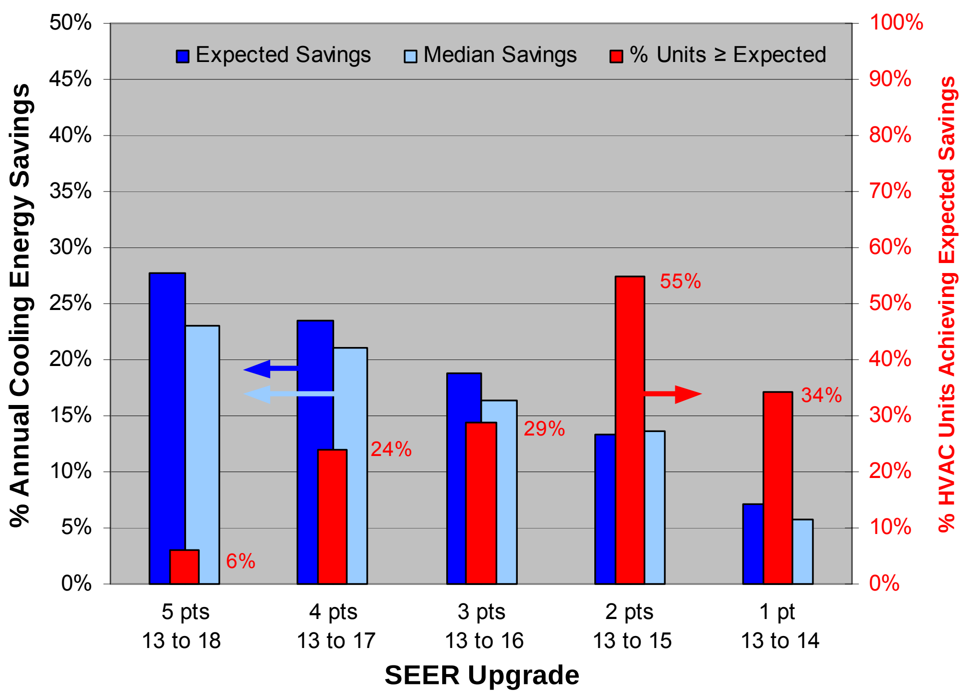


Figure 21: Percentage Savings Achieved by SEER Upgrade from a SEER 13 Unit (Upgrading from a Lower SEER System to a Higher SEER System) Single Family Residential Prototype, Min/Median/Max Buildings, Min/Median/Max Systems



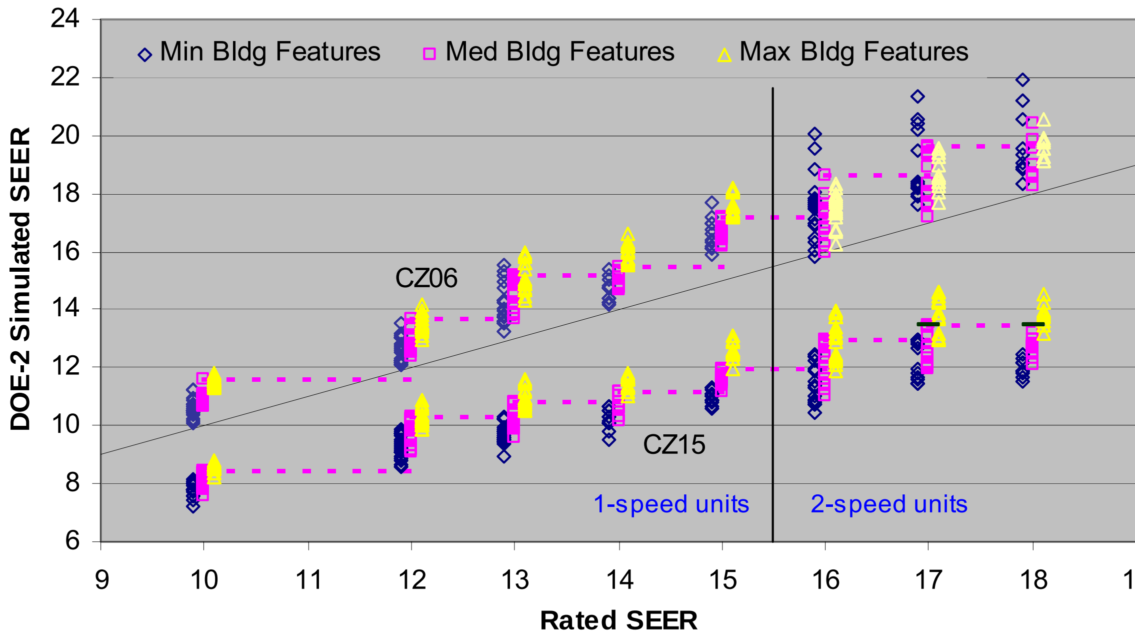
An additional result of interest in Figures 20 and 21 is indicated in red font and red vertical bars (read these bars against the RIGHT axis). These indicate the percentage of the simulated cases where the SEER-predicted ("expected") level of savings was achieved or exceeded. These results indicate that **in residential applications, upgrades beyond SEER 13 fail to achieve expected savings levels (as indicated by rated SEER) in 42% to 94% (i.e., one minus the red numbers reported in Figure 21) of the upgrade cases examined in this research.** For upgrades from SEER 10 systems to SEER 13 and beyond, 67% to 98% of the upgrade cases fail to achieve savings levels indicated by rated SEER). In general, the larger the SEER upgrade, (e.g., from SEER 13 to SEER 18) the lower the probability of achieving the expected savings.

5.11 SEER as a Predictor of Residential Relative Cooling Energy Savings

QUESTION 3: How effective is SEER in ranking the seasonal cooling efficiency of different SEER-rated HVAC systems? See Figure 22.

Like the EPA gas mileage label, "your mileage may vary", actual seasonal cooling efficiency (SEER) may vary due to user effects such as thermostat setpoint or differences between houses such as amount of glass, shading, and orientation. Not withstanding this, can SEER be used to compare the *relative* cooling performance of SEER-rated HVAC systems? For example, for a specific house and climate zone, will a SEER 14 unit reliably use less annual cooling energy than a SEER 13 unit? In Figure 22, the worst simulated SEER among the range of results for higher SEER systems should be better (i.e., greater) than the best simulated SEER among the range of results for the lower SEER system. In other words, there should be no "overlap" in the vertical range of simulated SEER results from a less efficient system to a more efficient system. Figure 22 indicates that **to assure savings, one most upgrade at least two SEER points**. Figure 22 also indicates there is a greater potential for concern for all systems in warmer climates and for two-speed systems in all climates (i.e., to assure savings, one may require a two-SEER point upgrade from the 13 SEER code minimum and two-to-four if considering an upgrade from a unit that exceeds the minimum).

Figure 22 Reliability of Rated SEER* in Ranking the Relative Savings of HVAC Systems
Single Family Residential Prototype, Climate Zones 6 (mild) and 15 (hot arid)
Min/Median/Max System Characteristics



* *rated SEER values in Figure 22 have been slightly juxtaposed along the X-axis to improve legibility. Actual rated SEER values are integer values.*

Looking more closely, the data in Figure 22 allows this question of reliability of SEER as an indicator of relative efficiency to be answered from two different perspectives:

Consumer perspective — the individual consumer is likely to be concerned about a cooling system upgrade to a specific house, i.e., to upgrade a system on an existing house or on a new home purchase. From the individual consumer's perspective, it is most appropriate to focus only on the results for the median houses, i.e., in Figure 22 examine the vertical ranges of the median building results (within a climate zone).

Regulatory perspective — the regulatory perspective must consider the reliability of SEER as an indicator of relative efficiency across a population of houses, whose characteristics will vary, i.e., in Figure 22 examine the vertical ranges across all building results (within a climate zone).

From the perspective of an individual consumer, i.e., for a specific house, Figure 22 indicates that one must upgrade at least two SEER points to be assured of savings (one may require a two-SEER point upgrade from the 13 SEER code minimum and two-to-four if considering an upgrade from a unit that exceeds the minimum). From the regulatory perspective, i.e., across all houses in a climate zone, the answer appears to be that even upgrading two SEER points will not necessarily assure savings. From both points of view, SEER is a more reliable predictor of relative efficiency in cooler climates than in warmer climates.

5.12 SEER as a Predictor of Residential Cooling Peak Demand

QUESTION 4: How effective is SEER as a predictor of expected cooling peak demand and demand savings in single-family residential applications? See Figures 23 through 26 on the following pages.

This question has always been of greatest interest to the utilities and state energy regulators and has become all the more important since ARI (Air-Conditioning and Refrigeration Institute) decided in November of 2002 to stop listing EER for SEER-rated units in its directory of certified equipment.

Analogous to the climate zone correction multipliers for SEER presented in Table 3, climate zone correction multipliers for rated EER were also developed and are presented in Table 4.

Table 4 Residential EER Climate Zone Multipliers for All California Climate Zones
Single Family Residential Prototype, All California Climates
Median Building Characteristics, Median System Characteristics

	Single-Speed SEER Rating						Two-Speed SEER Rating				All Units
	10	12	13	14	15	All	16	17	18	All	
CZ01	1.24	1.30	1.30	1.26	1.32	1.29	1.35	1.34	1.41	1.37	1.32
CZ02	1.08	1.04	1.03	1.02	1.01	1.04	1.03	1.02	1.00	1.02	1.03
CZ03	1.16	1.17	1.16	1.15	1.15	1.16	1.16	1.15	1.16	1.16	1.16
CZ04	1.10	1.10	1.08	1.06	1.05	1.08	1.07	1.06	1.06	1.06	1.07
CZ05	1.18	1.19	1.18	1.16	1.17	1.18	1.19	1.19	1.19	1.19	1.18
CZ06	1.18	1.20	1.20	1.18	1.19	1.19	1.20	1.22	1.22	1.21	1.20
CZ07	1.15	1.18	1.17	1.16	1.15	1.16	1.21	1.20	1.21	1.21	1.18
CZ08	1.15	1.18	1.08	1.07	1.07	1.09	1.09	1.09	1.08	1.08	1.10
CZ09	1.06	1.07	1.01	1.01	0.99	1.03	1.00	1.00	0.99	1.00	1.02
CZ10	1.05	1.01	0.99	0.98	0.96	1.00	0.99	0.99	0.98	0.99	0.99
CZ11	1.03	0.98	0.96	0.94	0.93	0.97	0.96	0.96	0.94	0.95	0.96
CZ12	1.04	1.01	0.99	0.98	0.96	1.00	0.98	0.98	0.96	0.98	0.99
CZ13	1.03	0.99	0.97	0.96	0.94	0.97	0.95	0.95	0.93	0.94	0.96
CZ14	1.02	0.97	0.95	0.93	0.92	0.96	0.95	0.94	0.92	0.94	0.95
CZ15	0.97	0.89	0.88	0.86	0.85	0.89	0.88	0.88	0.87	0.88	0.89
CZ16	1.10	1.09	1.06	1.04	1.05	1.07	1.06	1.06	1.03	1.05	1.06

Note: Climate zone and SEER specific multipliers used in all presentation graphics and summary findings. Values noted as "All" are for the reader's interest only.

Figure 23 and 25 on the following pages illustrate the ability of four methods to predict peak cooling demand in residential applications.

a) rated SEER, from manufacturer's test at 82°F and unit cycling test,

b) rated EER, from manufacturer's test at 95°F,

c) climate zone corrected SEER for single-speed unit data (using empirical tabular SEER multipliers developed in this research provided in Table 3), and

d) climate zone corrected SEER for two-speed unit data (using empirical tabular SEER multipliers developed in this research provided in Table 4).

Figures 24 and 26 illustrate climate zone corrected EER (using SEER-specific empirical tabular EER multipliers developed in this research as presented in Table 4) as a predictor of cooling system peak electric demand.

Figures 23 and 24 report EER at DOE-2 simulated HVAC peak. Figures 25 and 26 report DOE-2 simulated HVAC peak demand (in kW/ton). In all figures, the cases are labeled as enumerated above. For case (b), rated EER, the results are color coded first by climate zone, then by SEER. Where the cases are color coded by climate zone, results provided in the figure help distinguish the range in the results across all climates and within a specific climate zone.

Based on the results in Figures 23 and 25, the following can be concluded regarding the effectiveness SEER as a predictor of expected cooling peak demand and demand savings in single family residential applications:

e) **The variation in rated SEER agreed with the variation in peak EER only to within +14% and –30% of anticipated actual EER for single-speed equipment and –5% to –40% for two-speed equipment.** Interestingly, SEER appears no worse at predicting EER than SEER for single-speed equipment (compare with results in Figure 11). The two-speed systems operate with a disproportionately low EER. Two-speed systems exhibited demand performance similar to single-speed units that are at least 2 SEER points below that of the two-speed units.

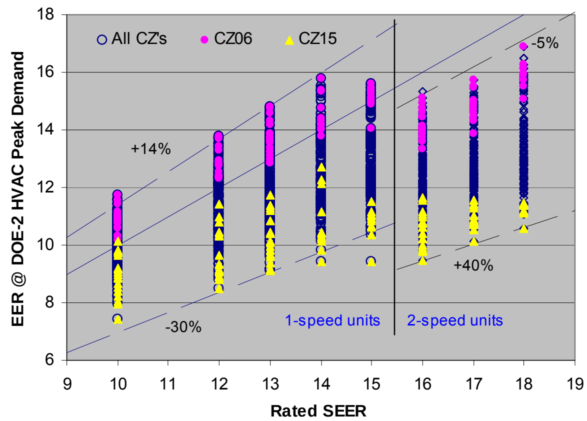
f) **Rated EER (from manufacturer's test at 95°F) was able to predict cooling system demand to within +23% and –17%.** Two "views' of these results are provided. Figure 23-b1, (color-coded by climate zone) indicates that rated EER <u>under</u>-predicts actual EER for the milder climate zones and <u>over</u>-predicts actual EER for the hotter climate zones. Figure 23-b2, (color-coded by rated SEER) indicates that the ability of rated EER to predict actual EER is similar for both single-speed and two speed systems.

g) Climate zone corrected <u>SEER</u> (i.e., from Table 3) was able to predict cooling system demand to within +12% and –17% for single-speed units. SEER climate zone multipliers do not provide a good estimate of HVAC system demand for 2-speed units as it tends of under predict demand impacts. This result is provided only as a matter of reference. The climate zone correction factors in Table 3 are <u>not</u> recommended for use with estimates of EER.

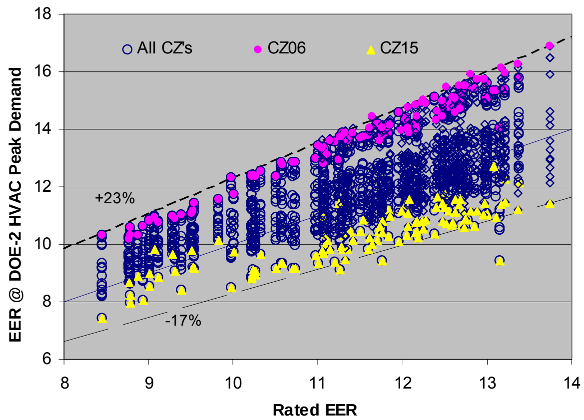
h) Climate zone corrected <u>EER</u> (i.e., from Table 4) was able to predict DOE-2 simulated EER to within ±8% as illustrated in Figures 24.

Figure 23: SEER and EER as Predictors of EER at HVAC Peak Demand
Single Family Residential Prototype, All California Climate Zones (except CZ01)
Median Building Characteristics, Min/Median/Max System Characteristics

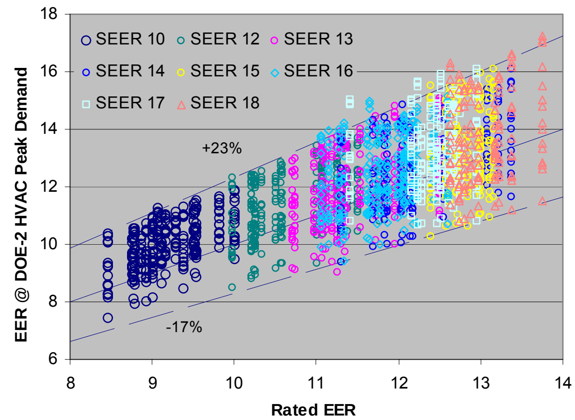
a: Rated SEER



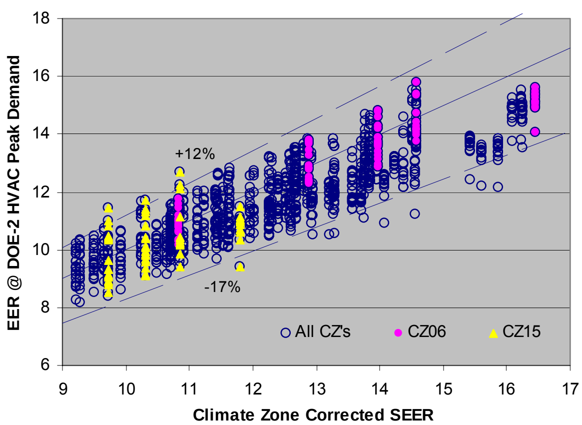
b1: Rated EER (by climate zone)



b2: Rated EER (by SEER)



c: Climate Zone Corrected SEER – 1 speed units



d: Climate Zone Corrected SEER – 2-speed units

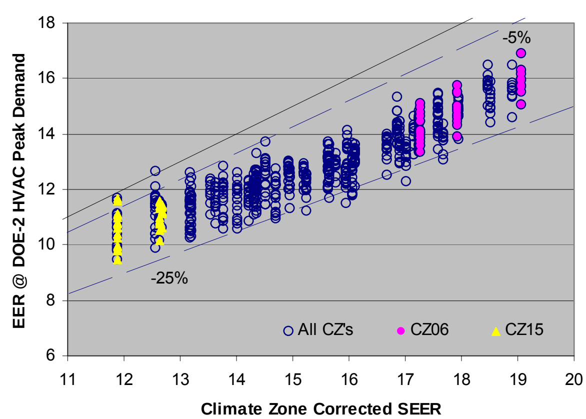


Figure 24: Climate Zone Corrected EER as Predictor of HVAC Peak Demand
Single Family Residential Prototype, All California Climate Zones (except CZ01)
Median Building Characteristics, Min/Median/Max System Characteristics

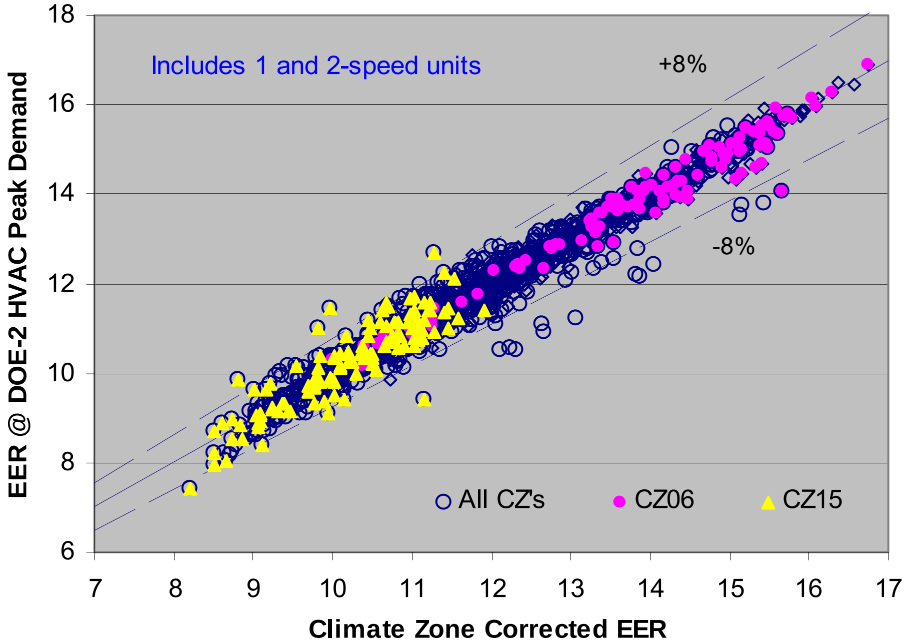
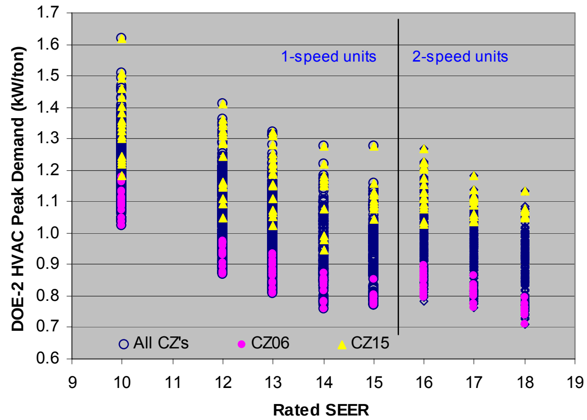
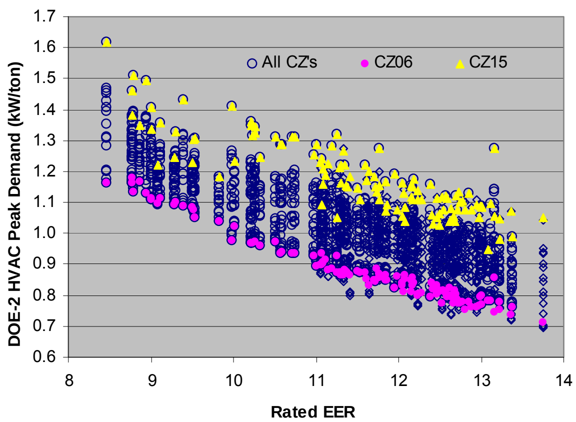


Figure 25: SEER and EER as Predictors of HVAC Peak Demand
Single Family Residential Prototype, All California Climate Zones (except CZ01)
Median Building Characteristics, Min/Median/Max System Characteristics

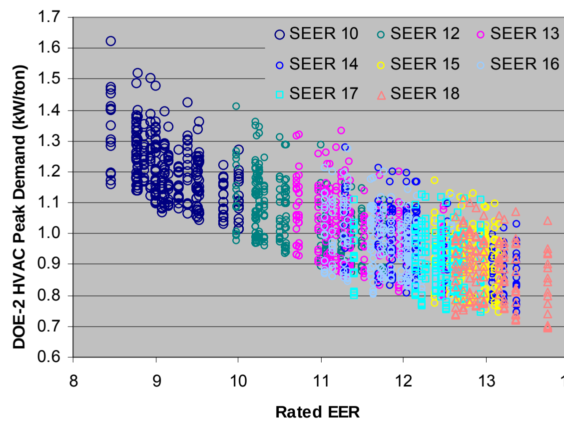
a: Rated SEER



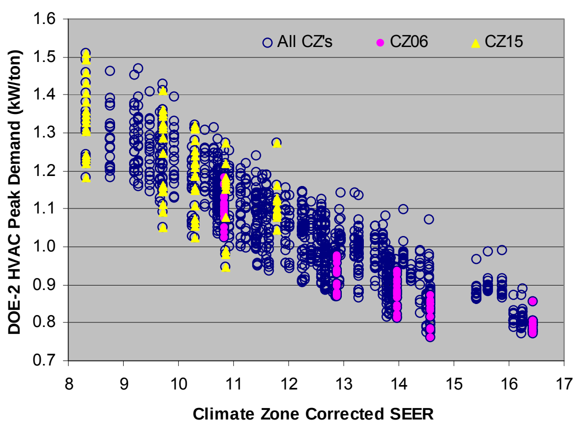
b1: Rated EER (by climate zone)



b2: Rated EER (by SEER)



c: Climate Zone Corrected SEER – 1-speed



d: Climate Zone Corrected SEER – 2-speed

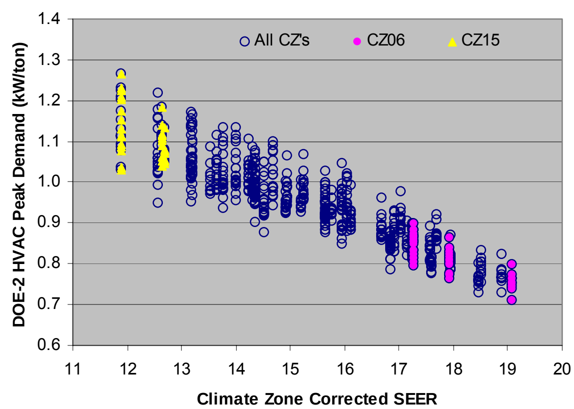
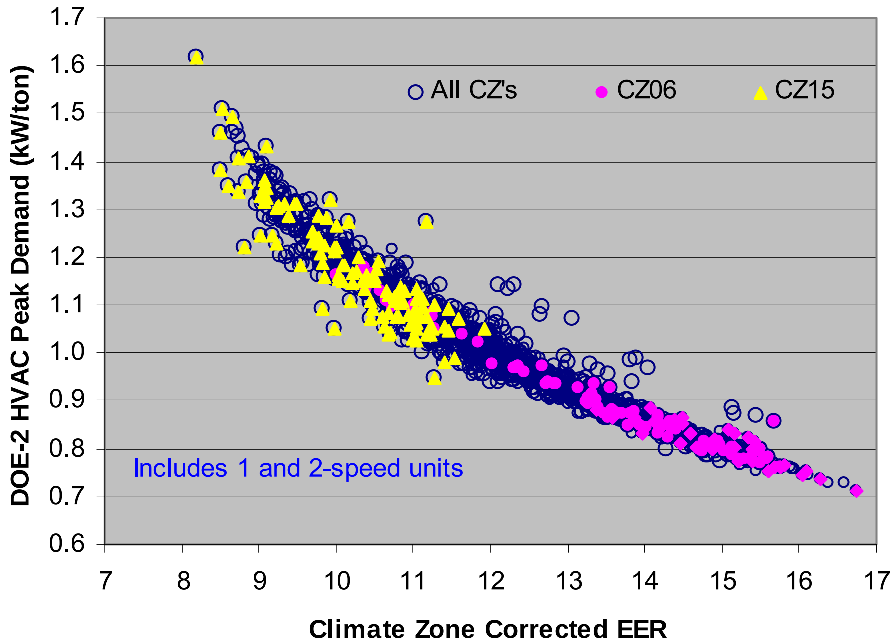


Figure 26: Climate Zone Corrected EER as Predictor of HVAC Peak Demand
Single Family Residential Prototype, All California Climate Zones (except CZ01)
Median Building Characteristics, Min/Median/Max System Characteristics



6.0 Summary of Findings

- Neither SEER nor EER is a sufficiently reliable indicator of cooling energy performance (consumption or demand) to meet the needs of California stakeholders. In residential applications, system efficiency upgrades will fall short of expected levels 45% to 98% of the time. Non-residential applications are more complex and require substantial additional research, but indications are that an even larger fraction will fall short of expected savings.

- Most of the basic assumptions implicit in the SEER rating process were found to be a poor match for typical California applications. As a results, the overall error or bias associated with using rated SEER to anticipate seasonal energy efficiency in California <u>residential applications</u> is from approximately +22% (in milder climates) to −30% (in warmer climates) for single speed equipment and from +25% to −33% for two-speed units. This overall bias was partitioned into the following effects.
  - Climate effects: The climate profile assumed in the SEER rating process is a poor match for most of the California climates. As a result, climate effects provide the largest source of bias in the reliability of rated SEER in California residential applications, approximately +15% to −27% or one-half to two-third of the total bias. Dryer conditions in the state will lead to a 5% to 10% reduction of seasonal cooling efficiency across all climate zones. Tabular correction factors were developed that were able to significantly reduce error in SEER to approximately ±7% for single-speed units and ±9% for two-speed units.
  - Building effects: The cooling load distribution and resulting mid-load temperature assumed in the SEER rating process (82°F) is poorly suited for California residential applications. As a result, building effects (i.e., typical variation found among California single-family residences) provide the second largest source of compromise in the reliability of rated SEER in California residential applications, approximately ±7%, or one-fourth to one-fifth of the total bias.
  - System effects: Differences between HVAC systems not accounted for in the SEER ratings process combined to provide the third largest source of compromise in the reliability of rated SEER, approximately ±5%, or $^1/_5$ to ¼ of the total bias. These differences include the effects of outdoor temperature and indoor coil conditions on capacity, impact of cooling efficiency on coil entering conditions, and the units' sensible cooling capacity.

- This study demonstrates that significant variation in annual cooling efficiency exists amongst equally rated cooling equipment (using only rated SEER as an indicator of cooling efficiency). To assure savings, one may require a two-SEER point upgrade from the 13 SEER code minimum and two-to-four points if considering an upgrade from a unit that exceeds the minimum. In November of 2002, ARI decided to no longer include EER in its equipment performance listings of SEER-rated equipment. <u>Having at least two ratings points, i.e., SEER and EER, is critical to the energy efficiency industry in California</u>.

7.0 Next Steps

This research has demonstrated that individual differences between identically rated HVAC systems, combined with simplifications implicit in the SEER ratings process, can significantly compromise the ability of a SEER rating to be a reliable predictor of cooling system performance in California. While the research summarized here has done much to characterize the scope of the problem with SEER ratings and demonstrate effective climate based SEER corrections, much more needs be done. The items below are suggested as important follow-on research.

- This work should be extended as follows.
  - Update systems rated as SEER 14 to include a representative sample range from the large number recently introduced units at this rating point;
  - Add HVAC equipment penetration rates and apply statistical methods to more accurately characterize the California statewide impacts of performance variability on expected savings and demand.
  - Performance testing of cooling systems to verify expanded ratings data.
- More study is needed to explore how the inherent performance variability of SEER-rated HVAC systems, as characterized by this research, can be applied to:
  - the future development of the California energy efficiency standards to better ensure resultant savings;
  - utility incentive programs to improve efficiency realization rates.
- Additional research is required to more effectively correct for:
  - building effects, e.g., varying mid-load temperatures;
  - system effects, e.g., especially off-rated coil entering conditions.

8.0 References/Bibliography

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Appendix A: EER and SEER Testing and Rating Process Details

The EER and SEER ratings require up to four laboratory tests. Two of the tests are required, one each for EER and SEER. The other two tests are optional and serve to determine C_D, a system's cycling degradation coefficient. If the two tests to determine C_D are not conducted, a default value for C_D is assigned (C_D = 0.25). Since the default value for C_D leads to lower SEER ratings given typical designs for today's cooling systems, all four tests are normally conducted. Table A.1 summarizes the tests and their conditions.

Table A.1 Summary of EER and SEER Test and Rating Requirements

			Mode of Operation	Outdoor Dry-Bulb Temperature	Outdoor Wet-Bulb Temperature	Indoor Dry-Bulb Temperature	Indoor Wet-Bulb Temperature
Test A	EER	required	steady state	95°F	75°F	80°F	67°F
Test B	SEER	required	steady state	82°F	65°F	80°F	67°F
Test C	C_D	optional[1]	steady state	82°F	65°F	80°F	57°F [2]
Test D	C_D	optional[1]	cyclic *(6 min. ON 24 min. OFF)*	82°F	65°F	80°F	57°F [2]

NOTES

1 If the two tests to determine C_D are not conducted, a default value for C_D is assigned (C_D = 0.25)

2 wet-bulb temperature should be sufficiently low that no condensate forms on the evaporator

EER is determined from equation A.1. SEER is determined from equation A.2.

$$EER = EER_A \qquad (A.1)$$

where:

$EER_A = \dfrac{cooling\ capacity\ (Btu/h)}{power\ input\ (W)}$ as determined by steady state test A (at 95°F)

$$SEER = EER_B * (1 - 0.5 * C_D) \qquad (A.1)$$

where:

$EER_B = \dfrac{cooling\ capacity\ (Btu/h)}{power\ input\ (W)}$ as determined by steady state test B (at 82°F)

$C_D = \dfrac{1 - \left(\dfrac{EER_D}{EER_C}\right)}{1 - \left(\dfrac{Cooling\ Capacity\ \ from\ Test\ D}{Cooling\ Capacity\ \ from\ Test\ C}\right)}$ as determined by steady state test C and cycling test D, else, if tests C and D are not conducted, C_D = 0.25

where:

$EER_C = \dfrac{cooling\ capacity\ (Btu/h)}{power\ input\ (W)}$ as determined by steady state test C (at 82°F)

$EER_D = \dfrac{cooling\ capacity\ (Btu/h)}{power\ input\ (W)}$ as determined by cyclic test D (at 82°F)