EER & SEER AS PREDICTORS OF SEASONAL COOLING PERFORMANCE

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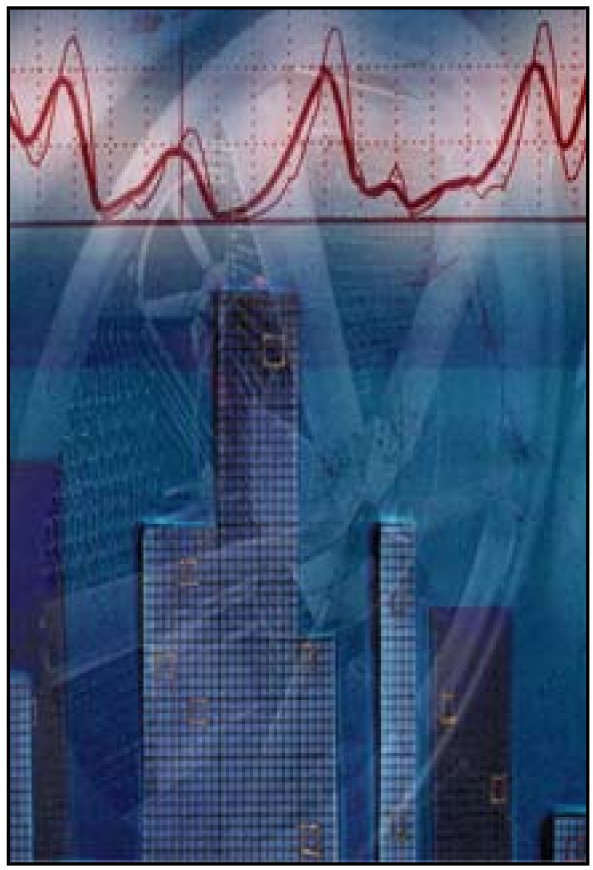

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This study was prepared by James J. Hirsch and Associates under contract to Southern California Edison Company as a portion of a project to investigate value of SEER and EER as seasonal energy performance indicators, as described herein. The work was conducted under the direction of Carlos Haiad, P.E. and Anthony Pierce, P.E., Southern California Edison Company. The principal investigators for this study were Marlin Addison, John Hill, Paul Reeves, and Steve Gates, James J. Hirsch and Associates. In support of this project, a new two-speed cooling system performance algorithm was designed and implemented in DOE-2.2 by Steve Gates.

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EXECUTIVE SUMMARY

This study evaluates the efficacy of using SEER (Seasonal Energy Efficiency Ratio) when making efficiency investment decisions and recommendations. All direct expansion cooling systems having a cooling capacity below 65,000 Btu/hr are required by federal regulations to be given an energy efficiency rating using SEER. Prescribed steady-state and cycling tests provide the information used to calculate a system's SEER (e.g., Air-Conditioning and Refrigeration Institute Standard 210/240). The SEER rating is, theoretically, the ratio of seasonal cooling electric consumption to the cooling load, thus providing an indicator of season-long cooling efficiency. Since its inception over 20 years ago, SEER has become the codified standard by which small electric HVAC cooling systems are compared. In California, the current Title 20 and Title 24 standards mandate air conditioner efficiency levels using SEER, electric utilities have until very recently designed their efficiency programs based on SEER, and consumers are typically guided to make energy-wise purchases based on these ratings.

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

- How effective is SEER as a predictor of expected cooling *energy use*?
- 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 12 represents a 20% improvement in SEER ([12/10]-1), and suggests a 17% reduction in annual cooling energy use (1-[10/12]). Will a 17% savings in annual cooling energy be realized?
- 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, "mileage may vary", actual annual energy use or savings may vary due to user effects such as thermostat setpoint and climate effects due to location. Not withstanding this, is SEER a reliable indicator of *relative* cooling efficiency of cooling system? As an example, for a specific house and climate zone, will a SEER 11 system reliably use less annual cooling energy than a SEER 10 system? Alternatively, will upgrading from a SEER 10 system to SEER 11 system reliably provide savings?
- 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 (Air-Conditioning and Refrigeration Institute) decided in November of 2002 to stop listing EER for SEER-rated systems in its directory of certified equipment.

The challenge in developing the SEER rating has always been to provide a useful estimate of season-long cooling efficiency using only one, or at most, a very few laboratory tests, i.e., the testing must be affordable and reliable (repeatable). Necessarily, several fundamental assumptions were made in the original development of the SEER rating. The most fundamental of which is an assumed seasonal coil load profile representative of a nation-wide average. The national average seasonal system coil load profile was developed using the following key assumptions:

1) The building overall shell U-value, solar gains, internal loads, and thermostat cooling setpoint yield a 65°F balance point for the building, i.e., cooling is required above outdoor air temperatures of 65°F; no cooling is required below 65°F;

2) The distribution of outdoor temperatures coincident with cooling is such that 76°F is the median outdoor temperature;

3) All cooling coil load is a linear function of outdoor temperature only.

4) The previous three assumptions results in a U.S. average seasonal average coil load distribution with a seasonal cooling *mid-load* temperature of 82°F. The mid-load temperature is the outdoor temperature above and below which exactly half of the seasonal cooling coil load occurs.

5) The sensitivity of capacity and efficiency to outdoor temperature for individual HVAC systems tends to be linear. This is significant because hour-by-hour operational performance for DX cooling systems will always vary with outdoor temperature (less efficient in warmer outdoor temperatures and more efficient in cooler temperatures). Even systems with equal SEER ratings will tend to differ in their sensitivity to outdoor temperature, i.e., some systems will be more sensitive to changes in outdoor temperature than others. If the sensitivity to outdoor condensing temperatures is linear, systems with equal SEER but differing efficiency at other temperatures (e.g., EER at 95°F) can still have equal annual cooling energy consumption. As an example, a system with high temperature sensitivity will be less efficient at hotter outdoor temperatures than a system with low temperature sensitivity. If sensitivity to temperatures is linear, then the system with high temperature sensitivity will also tend to be more efficient at cooler temperatures than the other system. Over an entire cooling season, this will tend to balance out, i.e., the two systems will have the same season-long energy use. Hence, if temperature sensitivities are linear, seasonal cooling system efficiency can successfully be predicted based on a steady-state test at the mid-load temperature (82°F).

6) The previous assumptions imply linearity of cooling energy use in outdoor temperature. This includes at least two important assumptions regarding indoor (evaporator) fans and outdoor (condenser) fans:

   - The energy from both fans is included in the overall SEER rating and is generally assumed to be a relatively small and relatively constant fraction of the total system energy requirements.
   - More importantly, both fans are assumed to cycle with the compressor; hence, fan energy is also a linear function of outdoor temperature.

This analysis examines the validity of these assumptions for typical California residential and non-residential buildings across all sixteen California climate zones. The overall motivation of this study is to assess whether SEER can accurately guide California consumers, designers, and builders in making efficiency investment decisions, and whether SEER can serve as an adequate regulatory basis for Title 20, Title 24, and state-wide efficiency programs.

This study uses the DOE-2 energy analysis program to better understand the factors that affect SEER and its efficacy when used to make efficiency investment decisions and recommendations. Specifically, DOE-2 thermal models were developed for building types likely to be served by SEER-rated air conditioners and heat pumps (<65,000 Btu/hr). For heat pumps, only the cooling energy was considered. These prototypes include: single-family residential, small office, small retail, and school classroom (including portable classroom) building types.

A broadly representative range of seasonal cooling coil load profiles was examined for each building type by varying key operational and design features of each prototype and by examining performance in each of the California climate zones. Operational and design features include envelope insulation levels, window area and properties, occupancy and equipment densities, and thermostat schedules and set points, among others. Title 24 requirements were used to determine median values for prototype characteristics, where applicable (i.e., some prototype characteristics varied by climate zone). Maximum and minimum values (and median values for prototype characteristics not governed by Title 24, e.g., building size) for the various features examined were obtained from the *2000 Residential New Construction Market Share Tracking* (RMST) Database and the *1999 California Non-Residential New Construction Characteristics* (CNRNCC) Database. DOE-2 prototypes included as many as twenty variable building features used to describe and vary the thermal characteristics and operation of each building prototype.

This analysis also examines a representative range of SEER-rated cooling systems that varied by SEER level, application (i.e., building type), and performance characteristics (e.g., sensitivity to outdoor operating temperatures and cycling effects). Residential simulations were executed using split-system single and two-speed air conditioners and heat pumps. The systems that were examined ranged from nominal SEER-10, SEER-12, and SEER-14 single-speed systems to nominal SEER-15 two-speed systems. Packaged cooling systems were used for office and retail simulations. Based on the availability of commercial package systems in the market at the time of this effort, these were limited to SEER-10 and SEER-12 systems.

Prior experience has shown that DOE-2 can reliably reproduce manufacturers' measured performance when manufactures extended ratings data are used to define system performance curves in DOE-2. In this analysis, all simulation runs were conducted using actual cooling systems currently available from major manufactures, i.e., all performance curves used in DOE-2 were based on manufactures extended ratings data for each system.

The cooling systems used in the analysis were selected from a database of over 570 systems based on their SEER rating and sensitivity to changing outdoor temperature and their cycling losses. Each system was selected to be representative of the range of performance characteristics typical of available systems, e.g., within each type of equipment (i.e., split or packaged air conditioner or heat pump) and SEER level. Systems were identified as having high, median, and low levels of sensitivity to operating temperatures (capacity and efficiency effects), and cycling losses. In all, over 90 cooling systems, representative of the range of currently available systems were used in the analysis.

Findings

The analysis revealed broadly different findings for residential and non-residential applications.

These differences were associated with differences in the building use and system operation, rather than the cooling systems themselves. These differences grossly violate the key SEER rating assumptions listed above. In consequence of these findings, study results are reported separately for residential and non-residential applications.

This work also attempted to develop adjustment factors to be applied to standard SEER ratings, using only readily available data, in order to improve the predictive power of SEER. The more complex adjustment models that were investigated did not offer significant improvements over a less complex method using empirical simulation-based corrections for climate zone; these are included below.

Findings: Residential Applications

Results from residential analysis include the following:

Rated SEER as a predictor of expected cooling energy use

SEER rating alone is a poor predictor of expected cooling energy use and consequently, cooling utility costs in residential applications.

> **Across all California climate zones, one should expect errors in estimated cooling energy and utility costs predictions of ±25%. In single-family residential applications, half to two-thirds of this error is associated with climate effects. The remaining error is approximately equally due to variations in building characteristics (i.e., operational and design features) and system effects (e.g., differences in sensitivity to outdoor temperature effects).**

Expressed in terms of the key SEER rating conditions assumptions, approximately half of the total error in SEER-predicted energy use in California residential applications result from the assumed distribution of cooling season outdoor temperatures. Assumptions regarding cooling coil entering air conditions appear to account for much of the remaining climate-related error. Fifteen to twenty percent of the total error is due to violations of the SEER rating assumptions regarding building balance point and the assumption of linearity between cooling load and outdoor temperature. The remaining error (approximately fifteen percent of the total) is due to system effects that result from violation of SEER rating assumptions regarding the operation of the cooling system. These include the assumption of linearity of temperature sensitivity of capacity and efficiency, the variability in sensible capacity from system-to-system, and the effect of these issues on cycling losses.

Errors associated with climate effects can be reduced by applying the climate zone multipliers in Table ES-1. These multipliers represent the ratio of DOE-2-simulated SEER and rated SEER for typical single family residences.

> **Using the climate zone SEER multipliers in Table ES-1 to estimate seasonal cooling energy reduces the error to ±6% for a typical single-family residence when compared to DOE-2 estimates.**

One should expect the possible error to expand to ±12% when considering the typical variation in home construction and cooling system operation.

Climate-based SEER multipliers provided in Table ES-1 provide different SEER estimates than current Title 24 Temperature Adjusted SEER values. Under the objectives of AB970, the Temperature Adjusted SEER values (i.e., SEER values adjusted by climate zone) currently included in 2001 Title-24 were developed to provide improved estimates of on-peak energy performance. No manufactures' performance data (i.e., actual temperature and cycling performance) were used. The findings of the present analysis indicate that this approach underestimates seasonal cooling efficiency (2001 Title 24 adjusted SEER is too low) in cooler climate zones, and over estimates cooling efficiency (2001 Title 24 adjusted SEER is too high) in warmer climates. Differences between the Title 24 Temperature Adjusted SEER values and those provided via Table ES-1 are typically within ten to fifteen percent.

Rated SEER as a predictor of energy savings

> **In residential applications, SEER consistently over predicts energy savings benefit associated with moving from a lower SEER to higher SEER system, from approximately 10% to 30% in most cases. System efficiency upgrades will fall short of expected levels 75% to 90% of the time (expected levels based on rated SEER).**

For single-speed systems, this over-prediction ranged from effectively 0% to 21%, where the lesser error tends to be associated with cooler climate zones and the larger error tends to be associated with warmer climate zones. In these same cases, only 15% to 30% of the upgrades met or exceeded expected levels of savings. For upgrades from single-speed systems to two-speed systems, where the upgrade covered three to five SEER points (e.g., SEER 12 to SEER 15, or SEER 10 to SEER 15), the over-prediction ranged from 12% to 35%. In these cases, only 8% to 10% of the upgrades met or exceeded expected savings. For upgrades from single-speed systems to two-speed systems, where the upgrade covered one SEER point (e.g., SEER 14 to SEER 15), the over-prediction was much higher, e.g., from 29% to 86%. In this case, only 20% of the upgrades met or exceeded expected savings.

SEER-related savings are also of interest in estimating the cooling energy-related savings associated with any building efficiency measure that reduces cooling load. These cases rely directly on the accuracy of SEER. Therefore, to estimate the uncertainty associated with this type of use for SEER, it is appropriate to rely on the estimates regarding the prediction of cooling energy, i.e., up to ±25% total variation across all climate zones and approximately half of that for variation in estimates with a particular climate zone where the tendency would be to over predict cooling related benefit in the milder climate zones and under predict benefit in the hotter climate zones.

Table ES-1 Residential SEER Climate Zone Multipliers

	Single-Speed SEER Rating			All Single-Speed	Two-Speed
	10	12	14		
CZ01	1.16	1.16	1.14	1.15	0.98
CZ02	0.97	0.95	0.92	0.95	0.83
CZ03	1.08	1.06	1.04	1.07	0.99
CZ04	1.07	1.04	1.03	1.05	0.93
CZ05	1.07	1.07	1.04	1.06	0.96
CZ06	1.08	1.07	1.05	1.07	1.02
CZ07	1.07	1.06	1.04	1.06	1.00
CZ08	1.07	1.06	1.04	1.02	0.95
CZ09	0.99	0.97	0.95	0.97	0.85
CZ10	0.95	0.94	0.90	0.93	0.81
CZ11	0.92	0.90	0.86	0.90	0.78
CZ12	0.97	0.95	0.92	0.95	0.87
CZ13	0.93	0.91	0.88	0.91	0.78
CZ14	0.88	0.85	0.82	0.85	0.75
CZ15	0.83	0.81	0.78	0.82	0.76
CZ16	1.05	1.03	0.99	1.03	0.84

Using rated SEER to rank order the relative efficiency of two cooling systems

If rated SEER can yield ±25% error in predicting seasonal cooling energy, can a home owner or home builder at least use SEER, like the EPA gas mileage label, i.e., to reliably select the more efficient system when applied to a specific house in a specific climate zone? As an example, although "your mileage may vary", for a specific application (i.e., for a specific house and climate zone), will a SEER 11 system reliably use less annual cooling energy than a SEER 10 system?

In residential applications, SEER cannot rank the relative efficiency of two cooling systems with any more precision than approximately two SEER rating "points". This analysis indicates that one should expect that differences in the way cooling systems respond to outdoor and indoor conditions, along with cycling rates, will mean that SEER is reliable only to within 0.6 ratings points (for a given house in a specific climate zone). That is, a nominal SEER 12 system could produce seasonal cooling energy values equivalent to a SEER as low as 11.4 or as high as 12.6. Because of this uncertainty, one could not be certain that purchasing the next higher SEER-rated system (e.g., SEER 11 instead of SEER 10, or SEER 12 instead of SEER 11, etc.) would actually realize seasonal energy savings.

Limitations on the data and scope of this analysis do not permit a reliable estimate of the probability of a higher SEER system using more cooling energy than a system with a lower

SEER rating.

> **In broad terms, for residential applications, <u>on average</u> one can expect a higher SEER-rated system to require less energy than a lower SEER-rated system, however, given the variability among the systems this work sampled, one must upgrade two SEER points to be assured of improved seasonal efficiency.**

Climate zone SEER multipliers provided in Table ES-1 should be used (not nominal SEER rating) to determine expected benefit associated with moving to a higher SEER-rated system in a specific climate zone. More work is needed (e.g., an estimate of the penetration of specific systems in the California market) to estimate the probability of failure if one assumes that a higher SEER system will use less energy than a lower SEER system.

Title 24 Temperature Adjusted SEER values currently in use differ from climate zone specific SEER obtained through the use of Table ES-1. Consequently, they provide estimates of the energy benefits associated with moving to a higher SEER-rated system that, at times, differ from the findings of this research. Differences vary from climate-zone to climate-zone and from one SEER level to another, but can be quickly determined through a comparison of the Title 24 Temperature Adjusted SEER values to those obtained from Table ES-1.

<u>**Rated SEER as a predictor of peak demand and demand savings**</u>

> **SEER is a poor predictor of cooling system electric demand in residential applications. For typical single-speed compressor systems, one has to move four SEER points (e.g., from SEER 10 to SEER 14) to be assured of cooling system demand reductions.**

Using climate zone SEER adjusters, either the Title-24 Adjusted SEER values or climate zone SEER adjustors provided in Table ES-1, does not yield substantially improved estimates of demand reduction.

The demand performance of typical SEER 15 two-speed compressor systems tends to be similar to the demand performance of typical SEER 12 single-speed systems. Therefore, while moving from a SEER 10 or SEER 11 single-speed system to a SEER 15 two-speed system will typically yield demand reductions, for most cases, moving from SEER 12 to SEER 15 systems will yield no demand benefit.

> **Moving from single-speed SEER 14 systems to two-speed SEER 15 systems will typically result in a demand penalty**.

Demand impacts can be predicted much more reliably using cooling systems' rated EER.

> **EER can distinguish relative (percent reduction) demand benefits associated with moving to a higher EER system to within ±10%.**

For a typical house, absolute demand improvement can be estimated to within 8% if Table ES-2 is used to produce climate-adjusted EER.

Table ES-2 Residential EER Climate Zone Multipliers*

	Single-Speed SEER Rating			All Single-Speed	Two-Speed
	10	12	14		
CZ01	1.26	1.30	1.29	1.29	1.28
CZ02	1.08	1.04	1.02	1.05	1.14
CZ03	1.17	1.17	1.15	1.17	1.21
CZ04	1.10	1.10	1.07	1.10	1.18
CZ05	1.18	1.19	1.16	1.18	1.23
CZ06	1.20	1.20	1.19	1.20	1.23
CZ07	1.17	1.18	1.17	1.17	1.25
CZ08	1.17	1.18	1.17	1.10	1.25
CZ09	1.10	1.07	1.07	1.07	1.11
CZ10	1.05	1.01	0.98	1.01	1.10
CZ11	1.03	0.98	0.94	0.99	1.07
CZ12	1.03	1.01	0.99	1.01	1.10
CZ13	1.01	0.99	0.95	0.99	1.06
CZ14	1.02	0.97	0.92	0.97	1.07
CZ15	0.94	0.89	0.85	0.90	1.02
CZ16	1.10	1.09	1.05	1.09	1.14

* *These multipliers are used to adjust EER ratings for a selected SEER-rated system (if the EER rating is available).*

Findings: Non-Residential Applications

The shortcomings of using SEER in non-residential applications were much more significant than in residential applications. The success of simple correction factors on SEER, e.g., by climate zone, could not be replicated in non-residential applications to the same level as for residential applications. The consistent difference between the utility of SEER in residential versus non-residential applications had nothing to do with the nature of residential versus commercial SEER-rated systems. Rather, the much greater limitation in using SEER in non-residential applications results from operational characteristics of non-residential buildings that grossly violate key assumptions implicit in the SEER rating method. Among the most problematic are the following (in approximate order of importance):

- Indoor fan power tends to play a much larger role in seasonal cooling energy use by virtue of non-residential ventilation requirements that cause fans to run continually during occupied hours. The SEER ratings process assumes that indoor fans cycle with the compressor. In addition, this produces significant variation in SEER estimates because of building operational schedules that can vary from 10 hours per day – five days a week to 24 hours per day – seven days per week.

- Non-residential buildings often have much larger solar and internal gains than do residences. Building "core" zones are relatively isolated from outdoor conditions. These characteristics tend to make non-residential cooling loads much less of a function of outdoor temperature and dramatically shift the assumed 65°F balance point temperature (and with it, the assume 82°F mid-load temperature).
- The introduction of ventilation air into the airstream can significantly impact the coil entering conditions assumed in SEER ratings (e.g., 80°F entering DB and 67°F entering WB). The relative impact of this affect can be highly variable from one application to another (due to varying occupancy loading).

Rated SEER as a predictor of expected cooling energy use or utility costs

Rated SEER significantly overstates cooling system seasonal efficiency in non-residential applications (i.e., will significantly under predict seasonal cooling energy use).

> **Across all California climate zones, one should expect non-residential cooling energy and utility costs that are as much as 2 ½ times as would be expected using rated SEER.**

In all cases examined, rated SEER under predicted cooling energy by at least 12%. As with residential systems, the variation in actual SEER is a result of climate conditions, building characteristics, and cooling system performance. Unlike residential systems, in non-residential applications, building characteristics dominate the variation in actual SEER. Statements concerning the affect of these issues on SEER are more complex than residential systems, but follow broadly similar trends. Specific findings for non-residential applications include the following:

1. Minimum actual SEER values are approximately 45% of the systems rated SEER. This holds across all climate zones. These values are associated with applications where indoor fan energy dominates and condensing unit energy is a small fraction of the total (e.g., typically "core" zones with minimal internal loads, especially when their schedules of use include overnight operation when outdoor temperatures are low).

2. Differences in actual SEER associated with differing cooling system performance are typically ±6% of the variation in SEER -- consistent with residential findings.

3. Climate effects are similar sign to those found in residential applications but differing significantly in magnitude, accounting for only approximately 15% of the variation in actual SEER. It differs from residential applications in that climate does not affect minimum actual SEER values, but instead limits maximum actual SEER values. For example, maximum actual SEER values for Climate Zone 6 are approximately 88% of a system's rated SEER. This drops to approximately 75% of rated SEER for systems operating in Climate Zone 15.

SEER Climate Zone multipliers for non-residential applications are provided in Table ES-3. As noted above, the expected variation in SEER in non-residential application can be quite large. Minimum actual SEER values equal to 45% of the rated SEER could occur. Other applications could generate actual SEER values 10% greater than that provided by the multipliers.

Using rated SEER to compare the relative efficiency of two air conditioners – non-residential applications

One should expect that differences in the way cooling systems respond to cooling loads, system operation, and differing entering air conditions is consistent with that observed with residential systems. Variation in actual SEER values associated with cooling system application (building and operating characteristics) precludes the development of a mid-load temperature (and associated ratings point) like that provided for residential systems. A comparison of the SEER-10 and SEER-12 systems applied to the same building in the same climate zone produced minimum energy saving percentages very similar to residential applications. As such, the overall finding that one must "step up" two or more SEER points to be assured of improved seasonal efficiency noted in residential applications is consistent with non-residential findings.

> **While energy benefits can't be guaranteed for particular systems without moving 2 SEER points, the data available suggest that statewide mandated programs will likely produce energy benefits when moving to higher SEER systems**.

Climate zone SEER multipliers provided in Table ES-3 should be used to adjust rated SEER in determining expected benefit associated with moving to a higher SEER-rated system in a specific climate zone.

Rated SEER as a predictor of peak demand and demand savings – non-residential application

The observation that SEER is a poor predictor of cooling system electric demand in residential applications holds true for non-residential application.

> **For packaged systems examined in this study, one has to move more than two SEER points to be assured of cooling system demand reductions in all climate zones.**

Cooler climate zones (CZ03, CZ05, CZ06) showed positive demand improvements for all systems examined. Hotter climate zones (CZ12 and CZ15) showed a chance of demand increase in moving from a SEER-10 system to a SEER 12 system. The climate zone SEER multipliers provided in Table ES-3, do not lead to improved estimates of demand reduction or indicates when demand increases will occur.

> **Like residential systems, EER is a better predictor of demand impacts than SEER. EER can distinguish relative (percent reduction) demand benefits associated with moving to a higher EER system to within ±10%.**

Climate zone EER adjustments as in Table ES-2 could not be developed for non-residential applications. The difficulty is due to the significant variability in coil load in relationship to outdoor temperature for differing non-residential building applications.

Table ES-3 Non-Residential SEER Climate Zone Multipliers

	Rated SEER	
	10	12
CZ01	0.66	0.65
CZ02	0.65	0.62
CZ03	0.68	0.65
CZ04	0.67	0.64
CZ05	0.72	0.70
CZ06	0.74	0.73
CZ07	0.73	0.72
CZ08	0.71	0.69
CZ09	0.69	0.66
CZ10	0.69	0.65
CZ11	0.62	0.58
CZ12	0.64	0.60
CZ13	0.62	0.58
CZ14	0.64	0.60
CZ15	0.63	0.59
CZ16	0.57	0.53

Findings: Summary

- 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 75% to 90% 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.

- Three of the basic assumptions implicit in the SEER rating process were found not to hold true for California applications. Use of these rating methodologies in the California market will require correction factors for each of those assumptions.
  - Climate effects: the assumed climate variation is a poor match for California CTZ's.
  - Building effects: the assumed load distribution is a poor match for California buildings.
  - System effects: the assumed equipment off-temperature and load performance is a poor match for real equipment on the market in California.

- For residential applications in California, climate effects account for the greatest inaccuracy of the SEER and EER ratings
  - Climate effects: tabular correction factors were developed that were effective in reducing error in both SEER and EER.

- In non-residential applications in California, climate effects account for the smallest inaccuracy of the SEER and EER ratings. Significant sources of error in using SEER or EER in non-residential applications require additional investigation to more fully understand. The major sources of error include the following:
  - Building effects: non-residential buildings tend to have much greater variation in internal load and solar load, greatly compromising the implicit relation SEER assumes between cooling load and outdoor temperature
  - System effects: in non-residential buildings, code requires indoor fans to run continuously to provide needed ventilation during occupancy periods; thus, indoor fan energy becomes a significant portion of the total HVAC system energy but the SEER rating assumes the fan cycles with the condensing unit compressor and fan.

- In November of 2002, ARI decided to no longer include EER in its equipment performance listings of SEER-rated equipment. Having at least two ratings points, i.e., SEER and EER, is critical to the energy efficiency industry in California.

Additional Research

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 an SEER rating to be an accurate 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 SEER climate based corrections, more needs be done. The items below are suggested as important follow-on research.

- Extend this work to include:
  - systems rated as SEER 13 (the minimum efficiency for the 2005 standards);
  - include additional high efficiency two-speed systems (SEER 15 and 18 ratings);
  - HVAC equipment penetration rates and apply statistical methods to more accurately characterize the California state-wide impacts of performance variability on expected savings and demand.

- 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.

- In <u>residential applications</u>, additional research is required to more effectively correct for:
  - building effects, e.g., varying mid-load temperatures;
  - system effects, e.g., including off-rated coil entering conditions.

- In <u>non-residential applications</u>, additional research is required to better understand and characterize:
  - building effects due to
    - increased internal loads,
    - core/perimeter HVAC zoning,
    - and occupancy ventilation;
  - system effects due to
    - indoor fan energy and operation,
    - and off-rated coil entering conditions.

1.0 INTRODUCTION

1.1 BACKGROUND

The air conditioning industry 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 direct expansion (DX) air conditioners are rated using EER (also know as the EER_A rating point), a rating standardized by ARI, which reports steady-state efficiency at 95°F outdoor and 80°F dry-bulb, 67°F wet-bulb indoor temperatures. Smaller (i.e., residential-sized, < 65,000 Btu/hr) air-conditioners are rated using SEER, a rating developed by the U.S. DOE. 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). It is intended to better indicate average seasonal performance, i.e., a season-long "average" EER.

The current California Title 20 and Title 24 standards mandate air conditioner efficiency levels using EER and SEER and consumers are 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]. Additionally, California electric utilities desire a reliable energy and peak demand savings predictor that is effective across the state. State-wide efficiency programs have recently abandoned SEER in favor of EER as an indicator of both energy and demand benefit (www.savingsbydesign.com/system.htm).

SEER ratings for single-speed cooling systems are based on a steady-state single-point rating system similar to EER rating. Systems are rated at 82°F outdoor and 80°F dry-bulb, 67°F wet-bulb indoor temperatures (EER_B ratings point). Additional cycling tests provide an estimate of the system's cycling losses which result largely from the time required after start-up to re-establish the operational pressure differences in the system. Results from the EER_B and cycling loss tests are used to calculate SEER. The equation is:

$$SEER = EER_B * (1 - 0.5 * C_D) \qquad (1.1)$$

where EER_B is as described above and C_D is the system's degradation coefficient determined from prescribed cycling tests. The 82°F outdoor temperature used in the EER_B rating point was selected as representative of a seasonal average outdoor temperature seen by the system. It also represents the mid-load temperature, i.e., half of the seasonal cooling coil load occurs above 82°F outdoor temperature, half below. The degradation coefficient multiplier, C_D, is adjusted for an assumed average 50% cycling over the course of the cooling season. The assumed load profile and mid-load temperature used to determine a SEER rating are shown in Figure 1.1.1.

Thus, the SEER ratings procedure replaces one steady-state rating point with another and accounts for load dynamics through a single loss calculation. The new rating point (EER_B) is based on an assumed system loading that may not be representative of actual conditions. Understandably, manufactures design their systems to maximize SEER ratings. However, there is no guarantee that SEER rating conditions reflect actual dynamic loading and temperature effects within the state of California. The question remains as to whether SEER can accurately guide the consumer or designer to make energy-wise equipment selections or the utility industry to design effective efficiency programs. Additionally, SEER may or may not serve as an adequate regulatory basis for Title 20 and Title 24.

The rating of two-speed systems differs somewhat from single-speed systems. Both rating procedures are based on the same assumed equipment loading and system entering air conditions. As such, neither may represent conditions found throughout the various California climate zones or reflect the range of common cooling system uses.

Figure 1.1.1
Cooling Coil Load Profile and Mid-Load Temperature
Assumed in the SEER Ratings Process

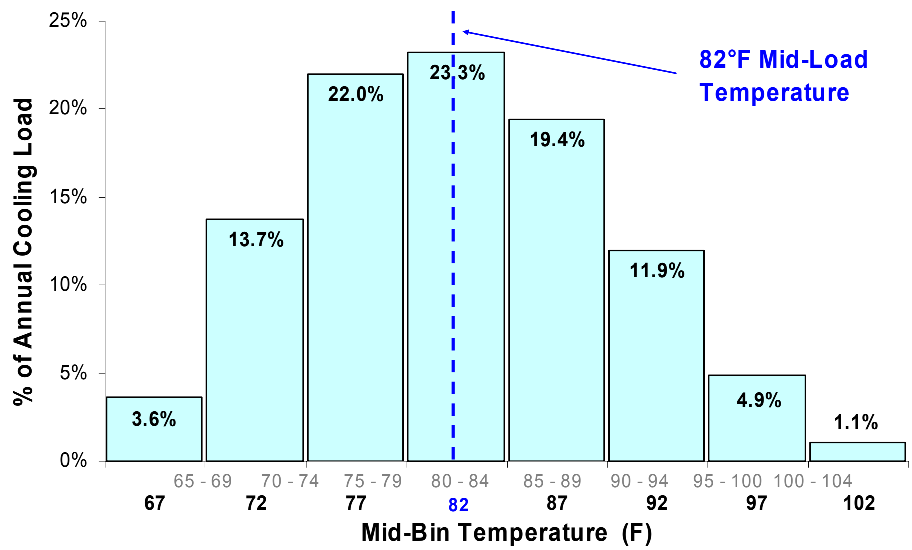
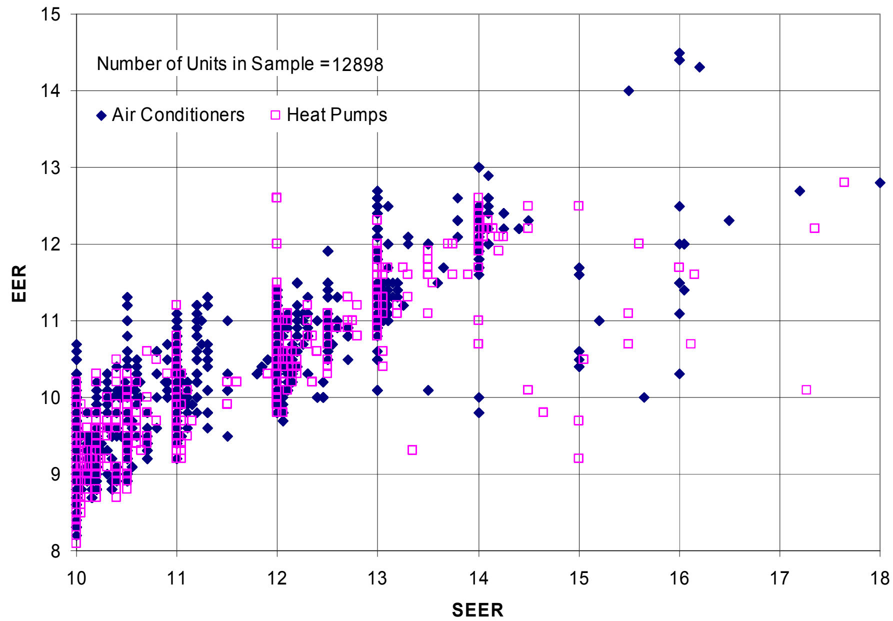


Figure 1.1.2 plots EER vs. SEER for approximately 13,000 SEER-rated cooling systems (< 65,000 Btu/hr) included in the CEC's listing of certified air conditioners. Note that for a given SEER level, there is a significant variation in EER (±15%), and for a given EER level, there is an even more significant variation in SEER (±25%). This variation results from the varied means manufactures use to obtain the highest possible SEER rating. It follows that these same systems will exhibit a great deal of variation in season-long performance under actual dynamic load and temperature effects.

Figure 1.1.2
Performance Characteristics of SEER-rated Cooling Systems
Rated SEER (at 82°F) versus Rated EER (at 95°F)



1.2 OBJECTIVES

This effort focuses on the general question — "All other issues being equal, which system should I choose for my application?" In this light, are there problems with the current SEER ratings system and are there reasonable solutions to the problem? Questions to be answered include the following:

- How effective is SEER as a predictor of expected cooling *energy use* or *utility costs*?
- How effective is SEER in ranking the seasonal cooling efficiency of different systems? Like the EPA gas mileage label, "your mileage may vary", actual SEER may vary due to various user effects such as thermostat setpoint. Not withstanding this, can SEER be used to compare the *relative* cooling efficiency of air conditioners and heat pumps? As an example, for a specific house and climate zone, will a SEER 11 system reliably use less annual cooling energy than a SEER 10 system?
- How effective is SEER in estimating cooling energy or utility *savings*? For example, based only on the difference in magnitude of SEER, upgrading from SEER 10 to SEER 12 suggests a 17% improvement in seasonal efficiency (1-[10/12]). All other things being equal (i.e., controlling for climate and user differences), will a 17% savings in annual cooling energy be realized?
- 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 (Air-Conditioning and Refrigeration Institute) decided in November of 2002 to stop listing EER for SEER-rated systems in its directory of certified equipment.

- Can a California-specific SEER adjustment procedure be developed that uses the existing published manufacture's performance data to calculate an "adjusted" SEER with improved value for decision makers?

The specific objectives of this study are to

1) quantify the reliability of SEER in predicting annual cooling *energy use*, *peak demand*, energy and demand *savings*, and *relative* efficiency (the ability to reliably rank order systems based on their efficiency).

2) derive and demonstrate improved methods to collect and predict more accurate energy use indicators.

In order to accomplish these tasks, this study will be separated into the following two tasks:

1) Phase 1: Part-Load Performance Evaluation. Using available detailed part-load and temperature performance data from air conditioner manufacturers, detailed DOE-2 energy simulations are conducted across a variety of building types and across five climate zones within the state. These simulations are used to calculate SEER values from simulated cooling load and energy results. This portion of the research would estimate the magnitude of the potential energy impact due to improved consumer information on SEER. This effort will also attempt to identify the efficacy of SEER as a regulatory index, from both energy and demand reduction standpoints.

2) Phase 2: Rating Development. If Phase 1 results show significant potential improvement in energy and demand estimates might be available from better characterization of weather, part-load, and other dynamic effects, derive and demonstrate a SEER adjustment to be used to improve the utility of the SEER rating. Ideally, the rating should be usable both in a regulatory context (Title 20 and Title 24) and as a consumer/builder-directed rating and would require no additional data or test procedures by manufactures beyond that which is currently being used or provided.

1.3 TECHNICAL APPROACH

This effort is based on detailed DOE-2 simulations. The use of the DOE-2 energy analysis program significantly expands the level of detail at which cooling system performance is evaluated in comparison to the DOE-mandated SEER calculation. Details of the differences in the calculation approaches and assumptions used in the SEER ratings process and DOE-2 calculations are given in Section 3.1 and Appendix A. Appendix A also includes the process whereby the DOE-2 program reproduces the SEER rating for a given cooling system. Some of the more salient issues addressed by the DOE-2 program, that are ignored by the standard ratings process include, but are not limited to, the following:

- Cooling system performance is evaluated under a full range of climate and load conditions rather than an assumed single load profile.
- The use of cooling system performance maps captures the dynamic impact of outdoor and entering air conditions on seasonal efficiency.

- Latent cooling loads are allowed to float in response to system runtime based on available sensible cooling capacity and sensible cooling load.
- Cycling losses are applied to dynamic hourly coil loads rather than via an assumed annual average condition.
- Peak system loads (both coil loads and electric input) are captured in addition to seasonal energy usage.

Building types were selected and characterized based on a statistical evaluation of statewide residential and non-residential, new construction surveys. Prototype DOE-2 building models were created and parametric runs were conducted to determine typical expected performance of SEER-rated split and packaged cooling systems. Simulations also examined their performance sensitivity to a variety of building characteristics and building operating conditions. The parametric variations of the prototypes were performed using one-at-a-time sensitivity analysis methods to search for the combination of building characteristics that leads to the maximum variation in predicted seasonal energy efficiency.

Manufacturers' expanded ratings charts were used in conjunction with rated EER, SEER and degradation coefficients to produce performance maps usable by the DOE-2 program. The performance maps account for changes in cooling system total and sensible capacities and energy input over a wide range of outdoor temperature and entering conditions to the coil. Cycling losses were determined from the DOE-mandated cyclical test in conjunction with a detailed thermostat model. Part-load curves captured these losses in DOE-2 simulations.

1.4 LIMITATIONS OF THE STUDY

Limitations of this study include the following:

1) This study assumes cooling system performance over a range of conditions based on data from manufacturer's expanded ratings charts. As such, all operating conditions inherent in the charts are assumed to apply to an actual system. These conditions include standard refrigerant line sets, proper system charge, and design airflows. While some system-level effects are included in simulations (air leakage in the duct system, ductwork transience, and duct thermal losses), all cooling systems are assumed to be installed properly.

2) The original SEER ratings concept is based on a simplified thermal/energy model of a cooling system. Use of the DOE-2 program greatly expands the complexity of the thermal model and more nearly replicates expected actual operating conditions. The DOE-2 simulation package is still a thermal model and can not reasonably capture all variability's in the operation of the cooling system. These unquantifiable operational effects are expected to increase the variation in seasonal performance of cooling systems. Because of this, study findings are expected to be conservative in their comparison to rated SEER values. Variability in SEER predicted by the DOE-2 program should be less than that found in actual applications.

3) The off-design and part-load performance of the various cooling systems have been

developed from manufacturers' expanded ratings charts. It is important to note that (other than the ARI point) performance data in these charts are not from direct system tests, rather, they are computer-generated, and are not warranted by the manufacturer. However, this data does serve as the best available information on the cooling systems included in this effort.

1.5 REPORT ORGANIZATION

The overall organization of the report is divided into five sections:

Section One provides this introduction.

Section Two provides details of the project implementation including a description of building prototypes and cooling system performance maps.

Section Three discusses simulation results and presents the basis for SEER adjustment factors.

Section Four presents the detailed SEER adjustment factors based on findings from Section Three.

Section Five compares the adjusted SEER models to results from expanded DOE-2 simulations that cover all climate zones and a full range of cooling systems.

Appendices contain detailed and/or background data such as details on building prototypes, system performance maps and approaches, and DOE-2 source code listings.

2.0 ANALYSIS METHODOLOGY

2.1 SEER RATING METHODOLOGY

The principal challenge in developing the SEER rating is to provide a reliable estimate of season-long cooling efficiency using very limited steady-state laboratory testing that is both repeatable and affordable. Necessarily, several fundamental assumptions were made in the original development of the SEER rating. The most significant of which is an assumed seasonal cooling coil load profile representative of a nation-wide average. The national average seasonal coil load profile was developed using the following key assumptions:

1) The building overall shell U-value, solar gains, internal loads, and thermostat cooling setpoint yield a 65°F balance point for the building, i.e., cooling is required at and above outdoor air temperatures of 65°F; no cooling is required below 65°F.

2) A national average cooling season temperature profile was determined, in part by weighting the penetration of residential cooling in selected cooling locations. The resulting distribution of outdoor cooling temperatures (i.e., outdoor temperatures coincident with cooling operations as per the first item above) has a median temperature of 82°F (see Figure 2.1.1a).

3) All cooling coil load is a linear function of outdoor temperature only (see Figure 2.1.1b). This assumption, combined with the previous assumption, allows 82°F to also be considered the seasonal cooling *mid-load* temperature, i.e., the outdoor temperature above and below which occurs exactly half of the seasonal cooling coil load (see Figure 2.1.1c). Consequently, 82°F is selected as the outdoor temperature for the SEER rating, i.e., for the EER_B rating point.

4) The sensitivity of capacity and efficiency to outdoor temperature for individual HVAC systems tend to be linear in temperature. This is necessary if systems with the same EER at 82°F (EER_B) and therefore the same SEER (assuming equal cycling losses) but with differing EER at other temperatures (e.g., EER_A at 95°F) are to have equal total annual cooling energy requirements. Hour-by-hour operational performance for DX systems will always vary with outdoor temperature, less efficient in warmer outdoor temperatures, and more efficient in milder temperatures. Even systems with equal SEER ratings will usually differ in their sensitivity to outdoor temperature with some systems being more sensitive than others. As an example, imagine two systems with equal SEER (i.e., same EER at 82°F and equal cycling losses) but with differing sensitivity to outdoor temperature. The system with higher temperature sensitivity will tend to be <u>less</u> efficient at hotter outdoor temperatures than the other system. If the sensitivity to outdoor temperatures is linear for both systems, then the system with high temperature sensitivity will also tend to be <u>more</u> efficient at milder temperatures than the other system (see Figure 2.1.2). If 82°F is the mid-load temperature for both systems, then the efficiency penalty that the higher sensitivity system experiences above 82°F outdoor temperature, relative to the other system, will be balanced by increased efficiency at outdoor temperatures below 82°F. While

energy use measured at any temperature other than 82°F will differ between the two systems, over the course of the entire cooling season, this will tend to balance out and the two systems will have the same season-long energy use.

5) An important caveat for the previous assumption involves at least two assumptions regarding indoor (evaporator) and outdoor (condenser) fans:
   - The energy from both fans is included in the overall SEER rating and is generally assumed to be a relatively small and relatively constant portion of the total system energy requirement.
   - More importantly, both fans are assumed to cycle with the compressor, hence, fan energy is also assumed to be a linear function of outdoor temperature.

This analysis will examine the validity and consequence of these assumptions for typical California residential and non-residential buildings across all sixteen California climate zones.

Several of the fundamental assumptions used in the SEER rating calculation methodology are illustrated below in Figure 2.1.1.

Figure 2.1.1

Key Climate and Load-Related Assumptions Implicit in the SEER Rating Procedure
Derivation of the 82°F "Mid-Load" Temperature

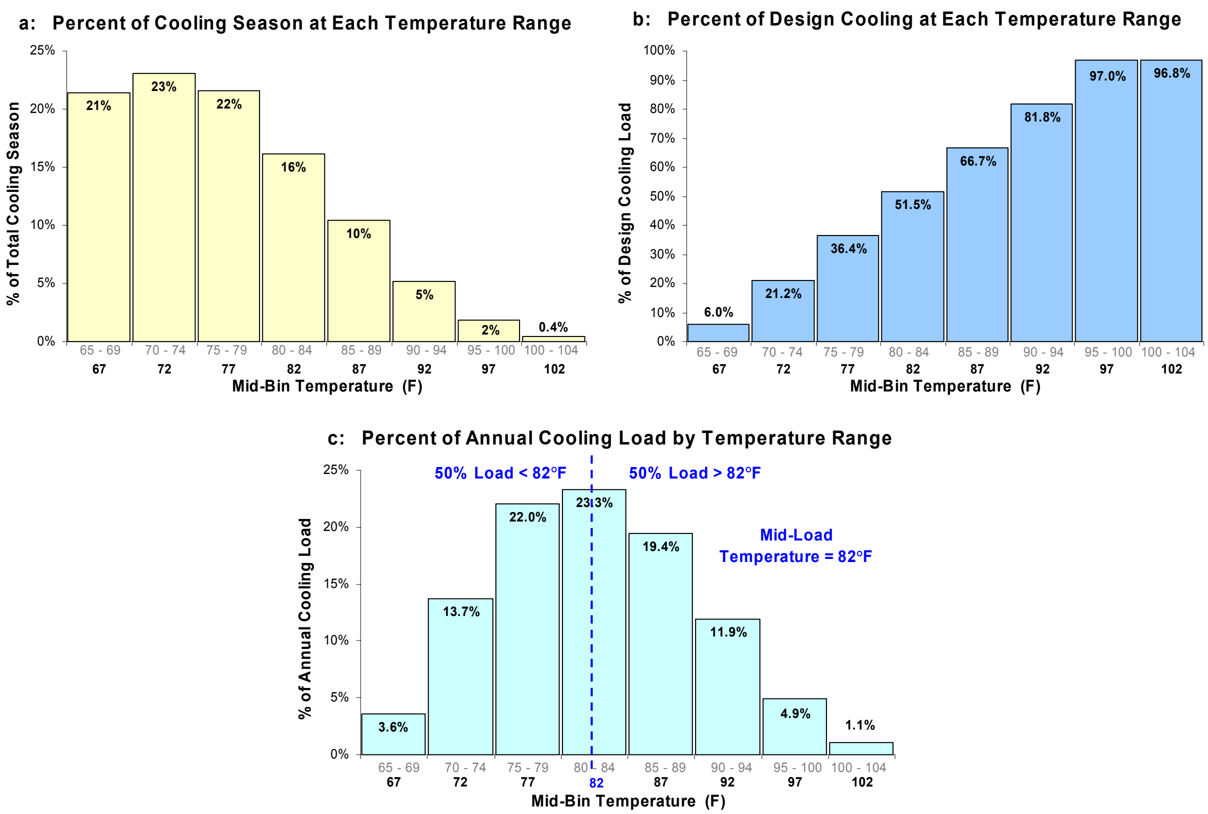
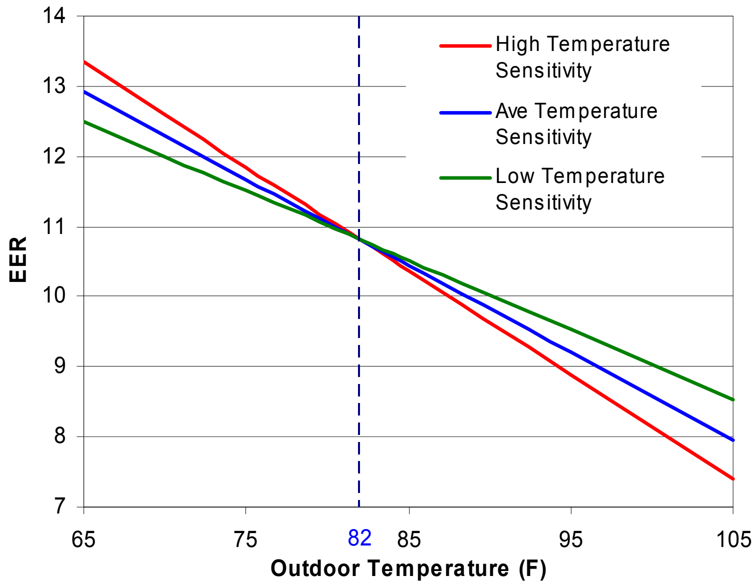


Figure 2.1.2
System Performance-Related Assumptions Implicit in the SEER Rating Procedure
Efficiency (EER) Sensitivity to Temperature



2.2 ENERGY ANALYSIS METHODOLOGY

2.2.1 Energy Simulation Package

Detailed computer simulations for this project were performed using the latest version of the DOE-2 building energy analysis program. DOE-2 calculates hour-by-hour building energy consumption over an entire year (8,760 hours) using hourly weather data for the location under consideration. The weather used for this analysis was the California Thermal Zone weather data, prepared by the California Energy Commission.

The version of DOE-2 used in this study, version 2.2, has been widely used and validated by public, private, and academic users. Much of the use of this version of DOE-2 is attributable to a number of widely used interfaces including eQUEST® and PowerDOE®. Version 2.2 is the latest enhanced version of DOE-2, which includes many new modeling features. It also improves and extends many prior capabilities, and corrects many previously existing bugs in the last version, more commonly known as DOE-2.1E. Driven by modeling requirements for this project, new capabilities were added to DOE-2 to allow the accurate modeling two-speed cooling systems. This new feature is an expansion of the staged-volume simulations additions recently added to DOE-2 and properly capture the high and low-speed operation of two-speed systems. The resulting version, including the new features used in this project, is available to the public as the currently posted freeware version 2.2.

2.2.2 Calculation Approach

The overall approach uses the DOE-2 program to calculate the seasonal energy performance of cooling system equipment when applied to typical building prototypes. The selected cooling systems are simulated within DOE-2 using detailed performance maps. These maps describe, in detail, the cooling systems' sensible and latent capacities, condenser unit energy, and fan energy under all operating conditions.

The operating conditions (i.e., operations schedules and coil loads) are calculated from building prototypes whose energy use characteristics are calculated from specific building features. 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). The building prototypes include residential and non-residential applications in which SEER-rated equipment is most commonly found. The building component and operational details are obtained from new construction building surveys executed in California. These surveys provide median, minimum, and maximum values of the components and operational features of the various building prototypes, which are used to determine the effects of building characteristics on SEER.

The buildings examined in this study were:

- Single-family Residential
- Small office
- Small Retail
- Conventional School Classrooms
- Portable School Classrooms

Details of the prototypes are provided in Section 2.4.

2.3 COOLING EQUIPMENT SELECTION PROCEDURE

2.3.1 Equipment Databases

Figure 1.1.2 plots EER vs. SEER for approximately 13,000 SEER-rated cooling systems (< 65,000 Btu/hr) included in the CEC's listing of certified air conditioners. This is actually only a fraction of available cooling systems on the market when one considers that the database only includes SEER-rated systems. SEER-rated systems are condensing unit and indoor coil (or fan coil) combinations that each manufacturer lists as its "most common" combination. There exist many more coil combinations that can be used with a given condensing unit. Some consistent and rational means was necessary to select among all of the available systems, to find a way to reasonably account for the range of equipment performance illustrated in Figure 1.1.

The selection mechanism began by expanding an equipment database put together by Hillier. This database sorted equipment by type (air conditioner or heat pump) and SEER rating. Only air-cooled systems are included in this effort. The databases were expanded and sorted to identify systems by the following metrics:

- System type - split, packaged, and wall-mounted
- SEER level – 10, 11, 12, 13, 14, >14 (SEER level is ±0.3 ratings points from levels

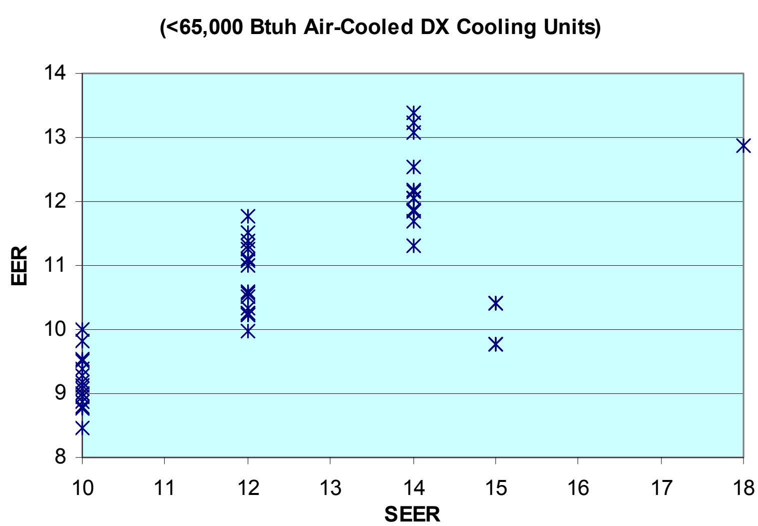
shown, e.g. SEER 12 systems can range from SEER 11.7 to 12.3. See note on the following page)

- Single and two-speed compressor operation
- Heat pump or air conditioner
- Degradation Coefficient (C_D in Equation 1.1) as obtained from the CEC's list of rated systems.
- EER sensitivity to changes in outdoor temperature, as determined from manufacturers' expanded ratings charts.

Since this effort is based on DOE-2 simulations, only equipment for which expanded ratings charts could be obtained was included in the database. The availability of expanded ratings charts tended to be manufacturer specific. Manufacturers included in the database include Carrier, Lennox, Marvair, Nordyne, and Trane. This analysis only examined air-cooled SEER-rated cooling systems (heat pumps and air conditioners).

The system selection process was developed to account for the variation in cooling system performance illustrated in Figure 1.1.2. Figure 2.3.1 shows the performance characteristics of SEER 10, 12, and 14 systems along with representative two-speed systems (nominally SEER 15) selected by this process. While the systems were not specifically selected by their EER, the selection process included systems that span the EER range given in Figure 1.1.2, as illustrated in Figure 2.3.1. Appendix B provides the details of the selection process.

Figure 2.3.1
Performance Characteristics of Selected
Split-System Cooling Systems



** Systems include both air conditioners and heat pumps*

This effort limits the systems examined to SEER 10, 12, and 14 single-speed systems, along with representative two-speed systems. This was done both to reduce the number of DOE-2 simulations and to provide adequate differentiation between cooling system efficiency.

A specific system selected for simulation is identified by the six metrics listed above. For example, a system simulated could be a SEER-12, single-speed, split-system air conditioner, with a median EER temperature sensitivity and high degradation coefficient. All single-speed equipment was chosen by their EER temperature sensitivity and degradation coefficient (see Appendix B for details). The number of two-speed systems available is limited, so the database includes the SEER-rated heat pumps and air conditioners for which expanded ratings charts were available. No SEER-14 packaged or two-speed systems were found, so only SEER 10 and SEER 12 packaged systems were examined. The lack of performance data limited the wall-mounted systems used in portable classrooms to one manufacturer (Marvair) and two systems (SEER-10 and SEER-12) heat pumps. In all, detailed performance maps were generated for over 90 cooling systems.

The DOE-2 simulation models are selective in which systems are used for a particular application. For example, residential simulations include only split systems, while commercial simulations only looked at packaged systems. The differentiation of system type by application matches field surveys of typical California new construction.

2.3.2 DOE-2 Performance Maps

DOE-2 performance curves were generated from manufacturers' expanded ratings charts and degradation coefficients from the CEC database for the systems selected for examination. Maps are based on rated cooling system values and off-rated and part-load adjustment curve fits. The information required by the DOE-2 program to fully simulate a cooling system includes design operating conditions and curve to adjust operating conditions from their design values. Design information includes the following:

- EIR – condenser unit energy input/ cooling system output at ARI rated conditions. Determined from expanded ratings charts and ARI rated conditions provided by manufacturer.†
- SHR – sensible heat ratio, or ratio of total to sensible cooling capacity at ARI rated conditions.
- Fan kW – fan energy in kW/cfm. Found or estimated from manufacturers' data
- Coil by-pass factor – ratio of actual temperature drop across the cooling coil to that if the air was fully saturated leaving the coil at ARI rated conditions. Calculated from manufacturers' total and sensible capacity at ARI rated conditions.
- Cfm – the air supply volume per Btu of cooling delivered by the system at ARI rated conditions. The DOE-2 program actually uses cfm directly, but program macros were used

† The databases of SEER-rated systems include cooling system with SEER ratings within ±0.3 ratings points of their nominal values. For example, the SEER-12 database includes systems with SEER ratings between 11.7 and 12.3. Where necessary, DOE-2 EIR values were adjusted to force all systems to their nominal SEER rating. This allows comparisons of systems with differing part-load and off-design characteristics in a consistent manner. The change in DOE-2 EIR is equivalent to replacing the existing compressor motor with one that is slightly more or less efficient (±5%). It does not change how a system responds to changes in coil entering or outdoor conditions, nor does it affect cycling losses.

to match the required air volume to the system capacity (which varied from simulation to simulation).

Curve fits include:

- Total Capacity_*f*(ODB,EWB) – a bi-quadratic curve fit that adjusts the design total gross capacity for non-design outdoor dry-bulbs (ODB) and cooling coil entering air wet-bulbs (EWB). Curve fit to manufacturers' data found in expanded ratings charts.
- Sensible Capacity_*f*(ODB,EWB) – same as Total Capacity_*f*(ODB,EWB), except it adjusts the gross sensible cooling capacity. Curve fit to manufacturers' data found in expanded ratings charts.
- EIR_*f*(ODB,EWB) – same as Total Capacity_*f*(ODB,EWB), except it adjusts the energy input to the condenser unit (EIR). Curve fit to manufacturers' data found in expanded ratings charts.
- Coil By-pass Factor_*f*(EDB,EWB) – a bi-quadratic equation that adjusts the design coil by-pass factor to account for differing cooling coil entering air dry-bulb (EDB) and wet-bulb (EWB) conditions. Curve fit to manufacturers' data found in expanded ratings charts.
- EIR_*f*(PLR) – a cubic curve fit that adjusts the condenser unit efficiency (EIR) to account for system cycling (PLR). Used when the system's fan runs continuously. Curve fit is obtained through a detailed thermostat model (Appendix C) applied to the degradation coefficient determine via the SEER ratings cycling test.
- Cycling Loss__*f*(PLR) – a cubic curve fit that adjusts the condenser unit efficiency (EIR) to account for system cycling (PLR). Used when the system's fan runs cycles with the condenser unit. Curve fit is obtained through a detailed thermostat model (Appendix C) applied to the degradation coefficient determine via the SEER ratings cycling test.

The performance curves were examined to determine if they would reproduce the systems' rated SEER. Two comparison methods were used. First, the single-point method was used as given by Equation 1.1. In this comparison, ODB was set to 82, EWB 67, EDB 80, and PLR 0.5. This matches the outdoor, coil entering, and cycling conditions assumed in the ratings procedure. The resulting ratio of total electric input (condenser unit and indoor fan) to net cooling capacity matched the SEER rating (no difference at the first decimal level). In the second method, the performance maps were exercised against the assumed cooling load profile assumed in the ratings process (Appendix A). Again, the ratio of seasonal total electric to seasonal net cooling matched the SEER rating.

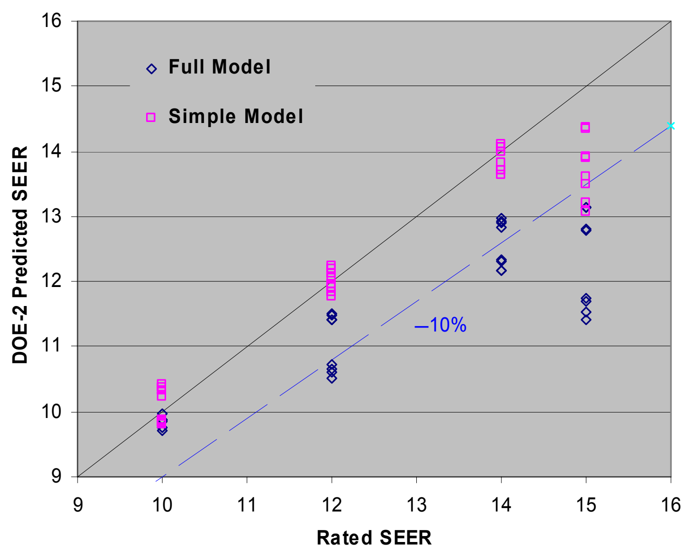
The question also arises as to whether or not the performance curves when used in the DOE-2 program will replicate SEER values. This is less straightforward as the SEER ratings process assumes a specific cooling load profile. The building loads simulation process would have to produce a load profile that matches that assumed in the ratings process. Some of the simulations run against climate zones 9 and 12 weather data did produce a load profile that was relatively close match to that used in SEER ratings.

Other problems include those associated with latent loads calculations in DOE-2. DOE-2 simulations maintain a fixed space temperature with floating (varying) space humidity. Consequently, simulation cooling coil entering conditions do not match conditions assumed in the ratings process (80 F dry-bulb and 67 F wet-bulb). This problem was resolved by altering performance maps so they were locked to 80 F dry-bulb and 67 F wet-bulb conditions. These and other issues relating to a comparison of the DOE-2 modeling process and assumptions used in the SEER ratings process are provided in Appendix A.

A comparison of simulated and rated SEER, once differences were resolved, are shown in Figure 2.3.2. Also included in Figure 2.3.2 are the results of the "full" DOE-2 simulations, i.e., do not include changes to performance maps needed to match the SEER ratings process assumptions.

The agreement between the SEER generated by the DOE-2 program and rated values for single speed (SEER 10, 12 and 14) systems is quite good. The scatter in the results is within ±5% of the rated SEER. This is on the order of the 10% variation Kelly and Parken reported in the development of the SEER ratings procedure when they applied the full bin method to real systems and compared results to the single point analysis. The scatter is associated with slight differences in the performance characteristics of the various systems. Some scatter in predicted SEER is to be expected as a result of differences in cooling equipment performance characteristics, load sequencing, and cycling losses.

Figure 2.3.2
Effect of Simplified HVAC System Assumptions of the SEER Rating Procedure
DOE-2 Predicted SEER vs. Rated SEER



* ***Full Model*** *represents a detailed DOE-2 model using full manufacture's performance data to characterize HVAC system sensitivity to outdoor temperature and cooling entering conditions;*
Simple Model *represents a DOE-2 simulation with performance curves altered to better match the simplified assumptions used in the SEER rating process (e.g., constant 80°F DB & 67°F WB entering conditions).*

2.3.3 System Sizing

Systems are sized in a manner consistent with the SEER ratings process. That is, systems are sized at 90% of the peak cooling coil load. This is equivalent to the assumption in the SEER ratings process that the system has 10% excess cooling capacity at ARI conditions (95 F outdoor temperature). The load profile used in the ratings process assumes that the peak outdoor temperature seen by the system is 105 F. This results in a capacity shortfall during peak cooling conditions. The sizing approach used in the ratings process is roughly equivalent to sizing a cooling system to the ASHRAE 1% design condition. Details on the how this sizing procedure was developed from the SEER ratings process are provided in Appendix B.

The sizing process requires a preliminary DOE-2 simulation to determine the peak coil load. Once the coil load is known and the peak load captured for future runs, the system is sized to 90% of this value. The DOE-2 program assumes that the capacity given is at ARI conditions (95 F outdoor temperature). Equipment performance maps are used in conjunction with 1% design temperatures representative of each climate zone to translate the peak cooling coil load into its ARI equivalent.

It is recognized that the sizing process results in non-standard cooling system capacities. While this is the case, the approach is equivalent to that used for SEER ratings. The SEER ratings process assumes that the load on the cooling system is always a fixed fraction of its ARI capacity. This will obviously not be the case in a real application. It would be impractical when doing DOE-2 simulations to scale the building up or down to match the capacity of the system. Rather, the nominal capacity of the system was altered to match the size of the cooling load so that the system was exercised under the same sizing operational sequence as is inherent in the SEER ratings process. Additional studies were performed at higher sizing ratios to determine the impact of this sizing approach on SEER by using a much higher sizing ratio that would be representative of an over-sized system.

2.4 BUILDING PROTOTYPES

Key variables in the ability of the SEER rating to accurately predict energy performance include the load shape of the coil loads and how these loads relate to outside ambient temperature. In other words, identical SEER-rated single-zone air conditioners on the different buildings in the same climate may perform very differently, depending on the building balance point and load shape of the cooling coil loads (especially the building's mid-load temperature). For example, the loads of a home that includes a large amount of south-facing glass, a large amount of cooking and entertainment equipment, a low thermostat setting, and limited or no use of natural ventilation could affect SEER differently than a home with less solar gain, a higher thermostat setting, and more frequently used natural ventilation. Similarly, in an office setting, an core zone with no connection via the building envelope to the exterior conditions will be dominated by interior lighting and equipment loads. East or west-facing perimeter zones with significant fenestration may be dominated by morning or afternoon solar gains. In each of these cases, the fundamental relationship between cooling load and outside temperature, and hence, the mid-load temperature, is likely to be very different.

DOE-2 models were developed to examine these issues. They included variable building design and operational characteristics expected to impact the building balance point and mid-load temperature. Each was characterized using the 2000 Residential New Construction Market Share Tracking (RMST) Database and the 1999 California Non-Residential New Construction Characteristics (CNRNCC) Database. These databases provided typical and extreme values of features that affect cooling loads in buildings. A description of the building types and the features that were expected to impact building balance point and mid-load temperature for each building type follows.

2.4.1 Single Family

To properly capture the loads seen by the residential HVAC system, DOE-2 models create realistic single-story and two-story models facing perpendicular directions, as shown below in Figure 2.4.1. The group of buildings has equal wall and window area facing each direction, but each individual building is dominated by east-west or north-south glazing. Typical characteristics for conditioned area, insulation levels, foundation type, etc. vary by climate zone, as defined in the RMST database. Details are provided in Appendix E. Twenty characteristics of single-family residences were varied in this study. These are listed in Table 2.4.1. Likely minimum (i.e., 10^{th} percentile of the sample), maximum (i.e., 90^{th} percentile), and median (i.e., 50^{th} percentile) values for each characteristic were identified for each climate zone. See Appendix E for details. Including changes in orientation, there are over 7,000 possible combinations of building features possible for examination in the DOE-2 simulations.

Figure 2.4.1
Single-Family Building Prototype

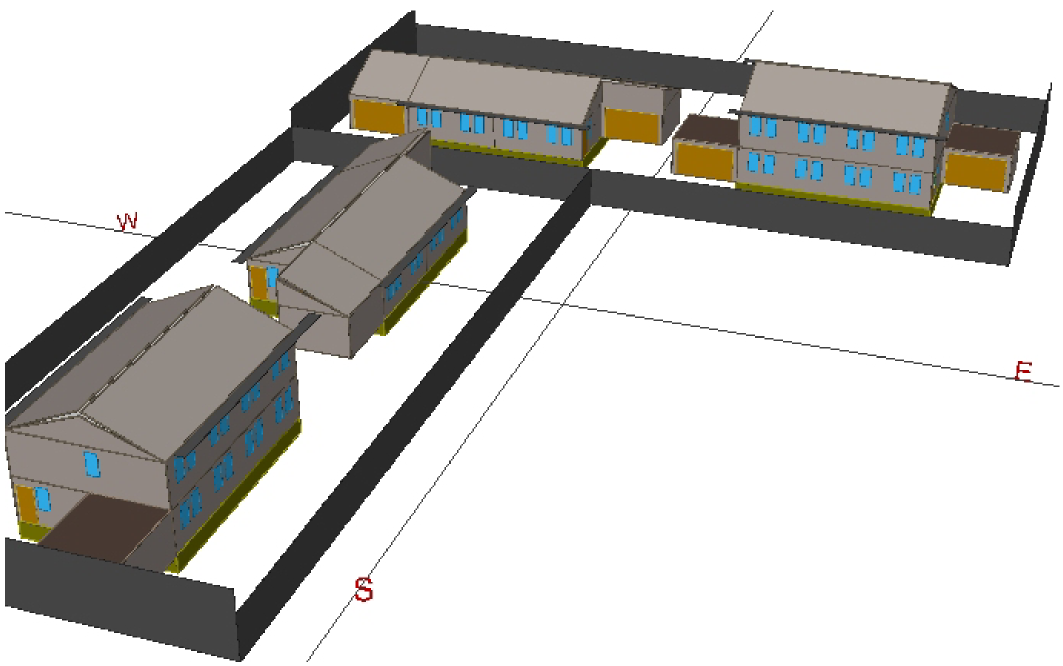


Table 2.4.1
Single-Family Building Characteristics Varied in DOE-2 Models

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

2.4.2 Small Office

The small office building DOE-2 prototype is based on a perimeter/core zoning, as shown in Figure 2.4.2. Each perimeter zone is assumed to face a cardinal direction – north, south, east, and west. Typical building characteristics, such as conditioned area, insulation levels, operational schedule, occupancy, lighting and equipment densities, were obtained from the 1999 California Non-Residential New Construction Characteristics (CNRNCC) Database. Details are provided in Appendix F. The building characteristics varied in this study are provided in Table 2.4.2. Minimum, maximum, and median values and details on how they were selected are provided in Appendix F.

Figure 2.4.2
Small Office Building Prototype

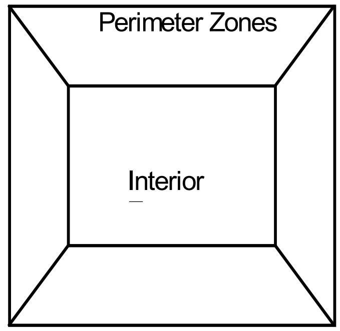


Table 2.4.2
Small Office Building Characteristics Included in DOE-2 Models

Total Floor Area	Conditioned floor area
Internal Shade Prob	Based on solar lighting levels
Perimeter Depth	Perimeter office depth
Occupancy	Given as floor area per person
Schedule	Total hours of occupancy per day
Roof Insulation	Built-up roof insulation
Exterior Wall Insulation	U-value of wall insulation
Wall Const Type	Heavy or light construction
Lighting Power Density	Watts/sq. ft.
Plug Power Density	Watts/sq. ft.
Glass U-factor	NFRC U-factor
Glass SHGC	NFRC solar heat gain coefficient
Glass Overhang	Shading by overhang
Economizer	Default is none
Glass Area (Fraction)	As a fraction of total wall area
Cooling Thermostat SP	Consistent with occupancy schedules
Aspect Ratio	Orientation of long axis varies

2.4.3 Retail

The retail DOE-2 prototype is based on a sales/storage zoning scheme, as shown in Figure 2.4.3. The wall dominated by glass is assumed to face varying cardinal directions (north, south, east, and west). Typical building characteristics, such as conditioned area, insulation levels, operational schedule, occupancy, lighting, and equipment densities, were obtained from the 1999 CNRNCC Database. The building characteristics varied in this study are listed in Table 2.4.3. Minimum, maximum, and median values and details on how they were selected are provided in Appendix F.

Figure 2.4.3
Retail Building Prototype

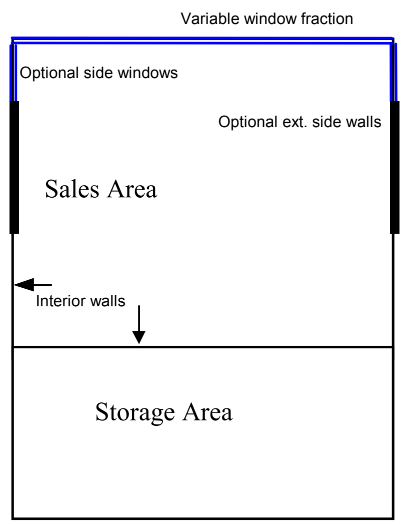


Table 2.4.3
Retail Building Characteristics Included in DOE-2 Models

Total Floor Area	Conditioned floor area
Internal Shade Prob	Based on solar lighting levels
Perimeter Depth	Perimeter office depth
Occupancy	Given as floor area per person
Schedule	Total hours of occupancy per day
Roof Insulation	Built-up roof insulation
Exterior Wall Insulation	U-value of wall insulation
Wall Const Type	Heavy or light construction
Lighting Power Density	Watts/sq. ft.
Plug Power Density	Watts/sq. ft.
Glass U-Factor	NFRC U-Factor
Glass SHGC	NFRC solar heat gain coefficient
Glass Overhang	Shading by overhang
Economizer	Default is none
Glass Area (Fraction)	As a fraction of total wall area
Cooling Thermostat SP	Consistent with occupancy schedules
Aspect Ratio	Orientation of long axis varies
Azimuth	Facing direction of main window wall

2.4.4 Conventional School Classrooms

The conventional school classrooms DOE-2 prototype is based on a single-story school with a series of classrooms on either side of a hallway, as shown in Figure 2.4.4. Each classroom has windows facing only one direction, and is adjacent to a common corridor. The entire set of six classrooms with glass facing North/South is duplicated and rotated 90 degrees, so that it has windows facing East/West. Typical building characteristics, such as classroom area, insulation levels, operational schedule, occupancy, lighting and equipment densities, were obtained from the 1999 CNRNCC Database. The building characteristics varied in this study are listed in Table 2.4.4. Minimum, maximum, and median values and details on how they were selected are provided in Appendix F.

Figure 2.4.4
Conventional School Classrooms Prototype

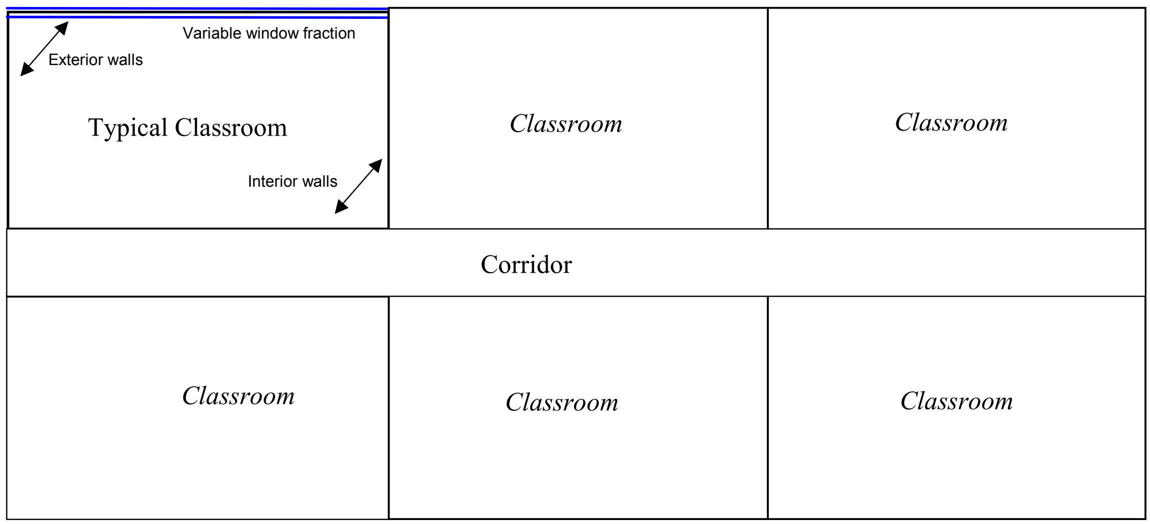


Table 2.4.4
Classroom Characteristics Included in DOE-2 Models

Total Floor Area	Typical Classroom area
Internal Shade Prob	Based on solar lighting levels
Occupancy	Given as floor area per person
Schedule	Hours per day, Year-round vs. Non-Year-round
Roof Insulation	Built-up roof insulation
Exterior Wall Insulation	U-value of wall insulation
Wall Const Type	Heavy or light construction
Lighting Power Density	Watts/sq. ft.
Plug Power Density	Watts/sq. ft.
Glass U-Factor	NFRC U-Factor
Glass SHGC	NFRC solar heat gain coefficient
Glass Overhang	Shading by overhang
Economizer	Default is none
Glass Area (Fraction)	As a fraction of total wall area
Cooling Thermostat SP	Consistent with occupancy schedules
Aspect Ratio	Orientation of long axis varies
Azimuth	Facing direction of main window wall

2.4.5 Portable Classrooms

The portable classroom DOE-2 prototype is based on a 23'x37' stand-alone classroom grouped together side-by-side and back-to-back, as shown in Figure 2.4.5. Each classroom has windows facing front and back. The entire set of six classrooms with glass facing North/South is duplicated and rotated 90 degrees, so that it has windows facing East/West. Typical building characteristics, such as classroom area, insulation levels, operational schedule, occupancy, lighting and equipment densities, were obtained from the 1999 CNRNCC Database. The building characteristics varied in this study are listed in Table 2.4.5. Minimum, maximum, and median values and details on how they were selected are provided in Appendix F.

Figure 2.4.5
Portable Classrooms Prototype

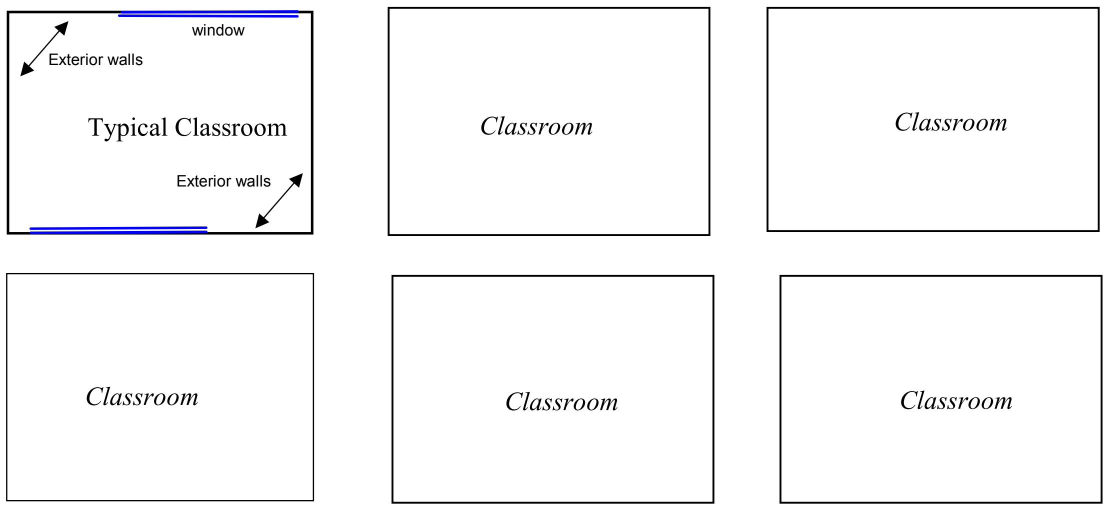


Table 2.4.5
Portable Classroom Characteristics Included in DOE-2 Models

Total Floor Area	Typical Classroom area
Internal Shade Prob	Based on solar lighting levels
Occupancy	Given as floor area per person
Schedule	Hours per day, Year-round vs. Non-Year-round
Roof Insulation	Built-up roof insulation
Exterior Wall Insulation	U-value of wall insulation
Lighting Power Density	Watts/sq. ft.
Plug Power Density	Watts/sq. ft.
Glass U-Factor	NFRC U-Factor
Glass SHGC	NFRC solar heat gain coefficient
Glass Overhang	Shading by overhang
Economizer	Default is none
Glass Area	Window size
Cooling Thermostat SP	Consistent with occupancy schedules
Aspect Ratio	Orientation of long axis varies
Azimuth	Facing direction of main window wall

3.0 ANALYSIS RESULTS

The possible combination of building prototype characteristics, cooling systems, and climate zones, provides a very large set of DOE-2 simulation results. A process was developed by which the impacts of each set of conditions were examined in a three step process:

1) Simulate median building prototypes and median system characteristics over the subset of climate zones chosen to represent the anticipated range of weather conditions. Compare simulated SEER (determined by detailed simulation) to rated SEER to identify the sensitivity of rated SEER to California climates.

2) Modify building characteristics in a sequential manner to determine the combination of characteristics that yield the highest and lowest simulated SEER values for each climate zone. Compare simulated SEER to rated SEER to identify the sensitivity of rated SEER to the typical variation in California buildings. Use these results to quantify the expected uncertainty in SEER based on the variation in building characteristics.

3) Simulate the building prototypes that produce the minimum, maximum, and median SEER values resulting from Step 2, using an expanded number of cooling systems, i.e., those that were selected to represent the expected range of performance (e.g., having minimum, maximum, and median sensitivity to outdoor temperature). Identify the sensitivity of rated SEER to the anticipated typical variation in cooling system performance characteristics, e.g., cooling system design features, fan power requirements, and system sizing criteria).

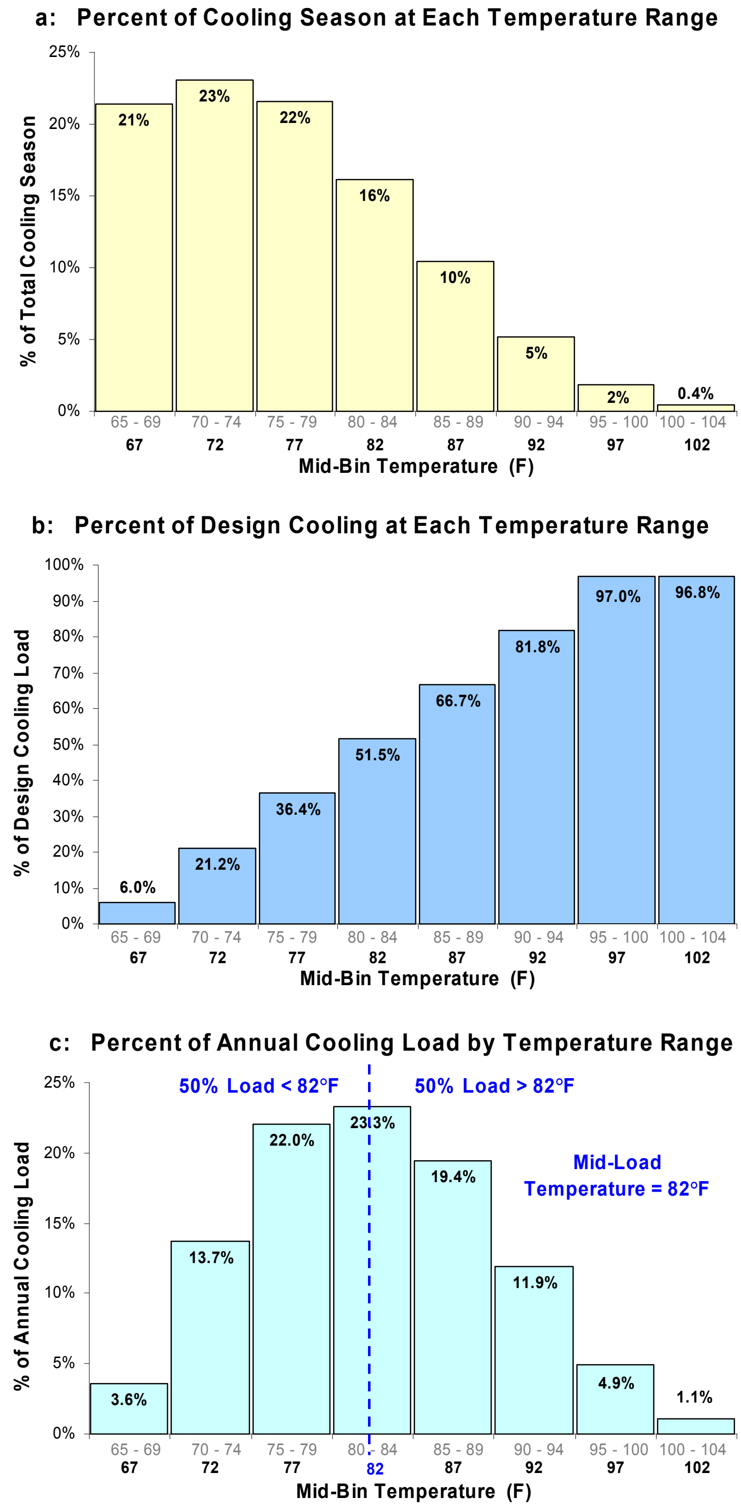
The process of sequential examination of the issues that affect SEER is expected to produce a set of SEER adjustments to be used to modify SEER to account for conditions not accounted for in the SEER ratings process. System demand information will be examined in parallel with SEER adjustments.

3.1 SEER RATING METHODOLOGY ASSUMPTIONS

Several assumptions implicit in the SEER rating process, described previously in Section 2.1, may not be realistic for California buildings and climates. Figure 2.1.1, which illustrates several of the key assumptions used in the SEER rating calculation methodology is repeated below for convenience as Figure 3.1.1. This section examines the validity of these assumptions for typical California residential and non-residential buildings across all sixteen California climate zones.

Figure 3.1.1*

Key Climate and Load-Related Assumptions Implicit in the SEER Rating Procedure
Derivation of the 82°F "Mid-load" Temperature



** same as Figure 2.1.1*

Figure 3.1.1a illustrates the assumed range and distribution of outdoor temperatures during the cooling season used as the basis for the SEER ratings methodology. The building balance point is assumed to be 65°F (the minimum temperature indicated in Figure 3.1.1). The SEER calculation procedure assumes no cooling is required below 65°F. Figure 3.1.1a also illustrates that the most extreme cooling temperature is assumed to be 104°F. This range of cooling season temperatures, from 65°F to 104°F, is divided into five degree bins with the midpoint temperature for each indicated. Note that the SEER rating procedure treats these temperatures as integers. For example, one of the five degree bins covers temperatures from 80°F up to and including 84°F (80°F ≤ bin < 85°F, not 80°F ≤ bin ≤ 85°F). This makes 82°F the midpoint temperature for that bin (i.e., not 82.5°F).

Figure 3.1.1b illustrates the assumed relationship between design cooling coil load and outdoor temperature, i.e., cooling load is a linear function of outdoor temperature, from 65°F (the building balance point) and 99°F, which represents the outdoor temperature for which the system's capacity was designed (more specifically, the system was assumed to be designed to have 10% excess capacity at 99°F). While this assumption of a simple and linear relationship between cooling coil load and only outdoor air and is consistent with the energy analysis methodologies in use at the time the SEER rating procedure was developed (i.e., "bin" methods), it ignores numerous other factors that contribute to cooling coil load, and which are included in detailed simulation tools such as DOE-2 (the simulation modeling tool used for this analysis).

Figure 3.1.1c illustrates the distribution of the seasonal (i.e., annual) cooling coil load assumed by the SEER rating procedure. Seasonal cooling coil loads in Figure 3.1.1c were calculated from the assumed distribution of outdoor temperatures in Figure 3.1.1a and the design cooling load represented in Figure 3.1.1b, i.e., number of cooling hours at each temperature bin (derived from Figure 3.1.1a) times the cooling coil load for each bin (from Figure 3.1.1b). The outdoor temperature that separates the total annual (seasonal) cooling coil load into two equal quantities is the "mid-load" temperature of 82°F. In other words, in the SEER rating procedure exactly half of the annual cooling coil load is assumed to occur at outdoor temperature below 82°F.

Figure 3.1.2 illustrates how well the assumed outdoor air temperature distribution from Figure 3.1.1a matches the distribution of long-term average outdoor temperatures for each of the sixteen California climate zones plus the overall California average and the average based on selected major urban centers, i.e., climate zones CZ 3 (Oakland), CZ 6 (Long Beach), CZ 7 (San Diego), and CZ12 (Sacramento). In Figure 3.1.2, the dark blue vertical bars represent the relative frequency distribution of outdoor temperatures in California climate zones. The orange curve represents the same relative frequency for outdoor temperatures assumed by the SEER rating procedure (i.e., in Figure 3.1.1a). While most of the vertical axes in Figure 3.1.2 use a constant scale, those that differ are shown in color (i.e., orange). These results suggest that climate zones 10 and 12 are closet to the distribution of outdoor temperatures assumed in the development of SEER.

Figure 3.1.3 illustrates how well the assumed annual distribution of cooling coil loads from Figure 3.1.1c matches distributions for each of the sixteen California climate zones and the overall California average. In Figure 3.1.3, the cooling coil distributions were prepared using the same assumptions as for Figure 3.1.1c, i.e., a simple linear relationship between cooling load

Figure 3.1.2
Distribution of Cooling Season Outdoor Temperature
California Climate Zones vs. SEER rating assumption

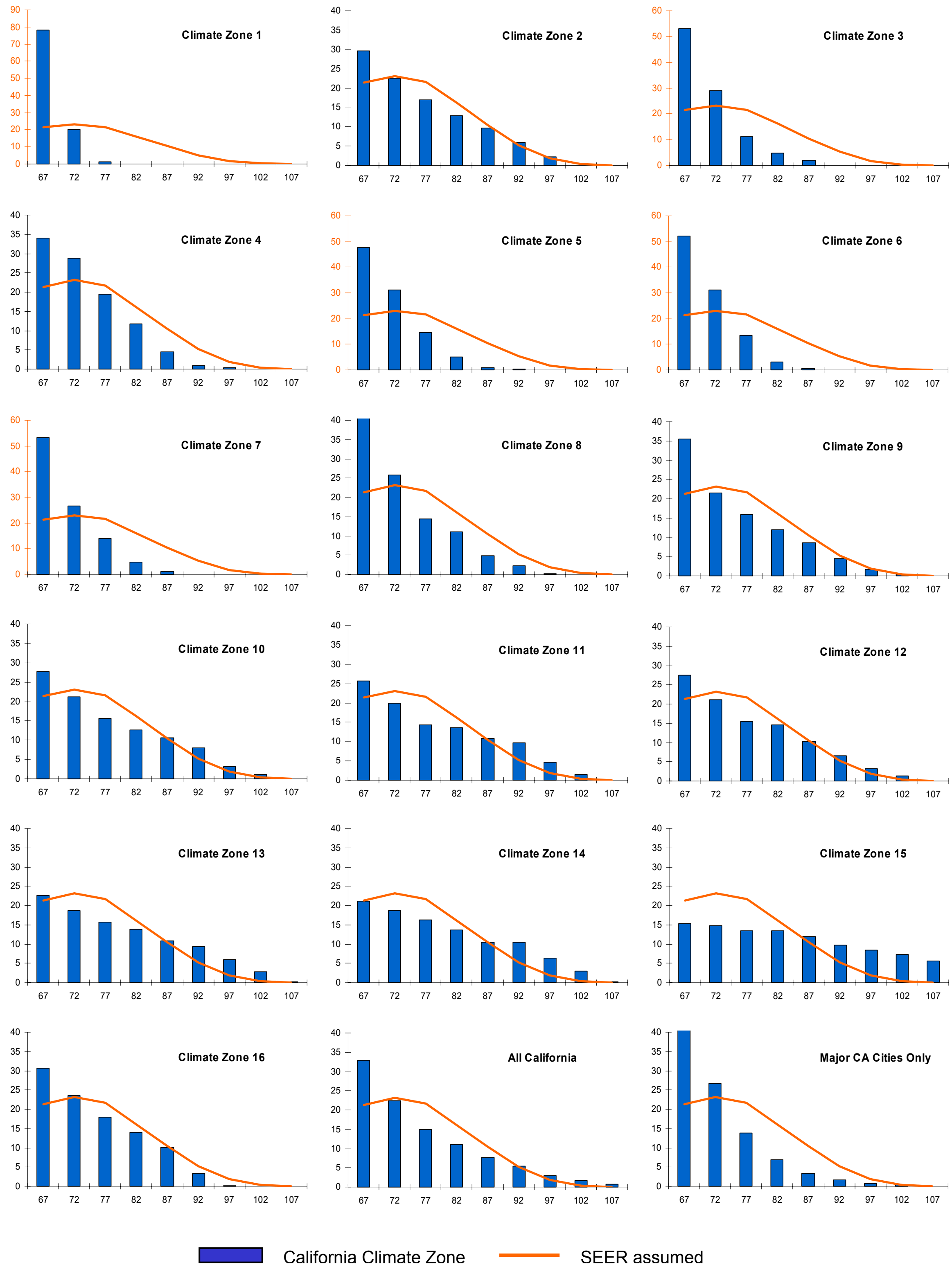
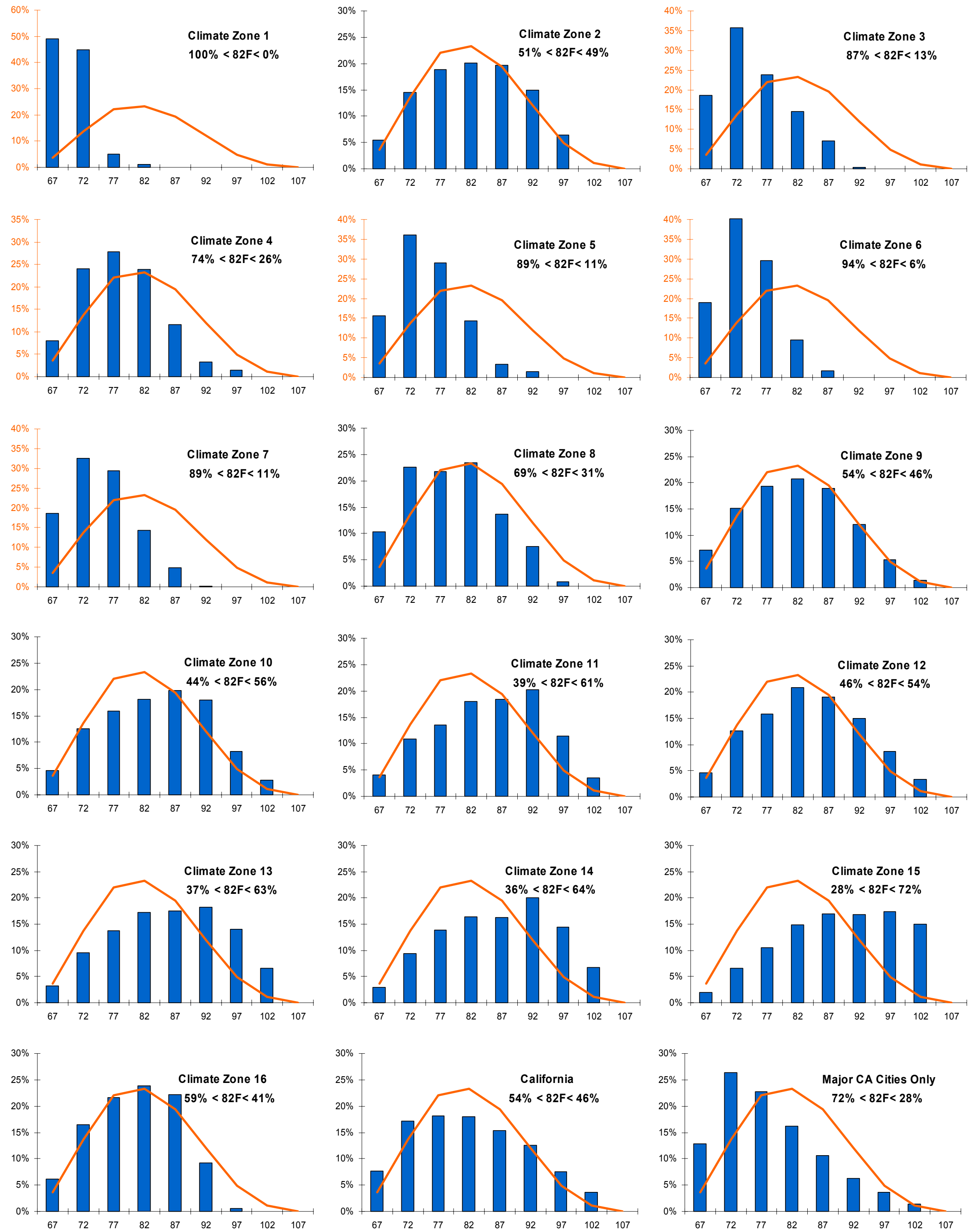


Figure 3.1.3
Distribution of Cooling Coil Load by California Climate Zones
(simple linear cooling load function assumed in the SEER ratings procedure)



and outside air ten California Climate Zone the (SEER assumed door temperature distributions in place of the distribution illustrated in Figure 3.1.1a, to calculate the coil load profile. Under these assumptions, climate zones 9 and 12 most closely match the distribution of coil loads assumed in the development of SEER. In Figure 3.1.3, each climate zone's distribution is also annotated to indicate what percentage of the annual coil load occurs above and below 82°F. Ideally, the distribution would divide perfectly at 50/50%, above and below 82°F.

Figure 3.1.4 also examines the distribution of annual cooling coil loads but uses coil load distributions generated using DOE-2 where the prototype is a statistically typical single-family one-story house. While many of the characteristics are taken to be median values from the 2000 RMST database, they also vary by climate zone as necessary to meet 2001 Title-24 requirements. Consistent with the RMST database, windows are not evenly distributed on all four orientations. Rather, the glass is primarily located at the "front" and "back" of the house. In Figure 3.1.4, the windows are assumed to face east and west. As in the previous figure, climate zones 9 and 12 appear to most closely match the distribution of cooling coil loads assumed during the development of the SEER rating procedure.

Figure 3.1.5 is the same as Figure 3.1.4 except that the house is rotated 90 degrees so that the windows face north and south. Again, climate zones 9 and 12 appear to most closely match the distribution of cooling coil loads assumed during the development of the SEER rating procedure.

Figure 3.1.2 through 3.1.5 illustrate how reasonable the SEER assumed national average distribution of outdoor temperatures (Figure 3.1.1a) and coil loads (Figure 3.1.1c) is when applied in California's climate zones. These illustrate that the departures from the temperature and load distribution assumptions implicit in the SEER rating procedure can be significant.

Figure 3.1.1b above illustrated the simple linear relationship between outdoor temperature and load implicit in the SEER rating procedure. Figure 3.1.6 illustrates the role various climate factors, as well as building design features, have on cooling coil load. The data in Figure 3.1.6 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 3.1.5 (i.e., a north-south orientation). Climate zone 9 was selected for all cases illustrated in Figure 3.1.6 since it most closely matched the mid-load temperature assumptions implicit in SEER.

Figure 3.1.6A illustrates a simulation case in which there is demonstrated a significantly linear relationship between hourly cooling coil load and outdoor temperature. The slope of the line in Figure 3.1.6A represents the overall U-value for the house. The point at which the line meets the X-axis (zero cooling coil load) represents the balance point of the house.

Figure 3.1.4
Distribution of Cooling Coil Load by California Climate Zones
(median single family residence, DOE-2 cooling loads, East-West Orientation)

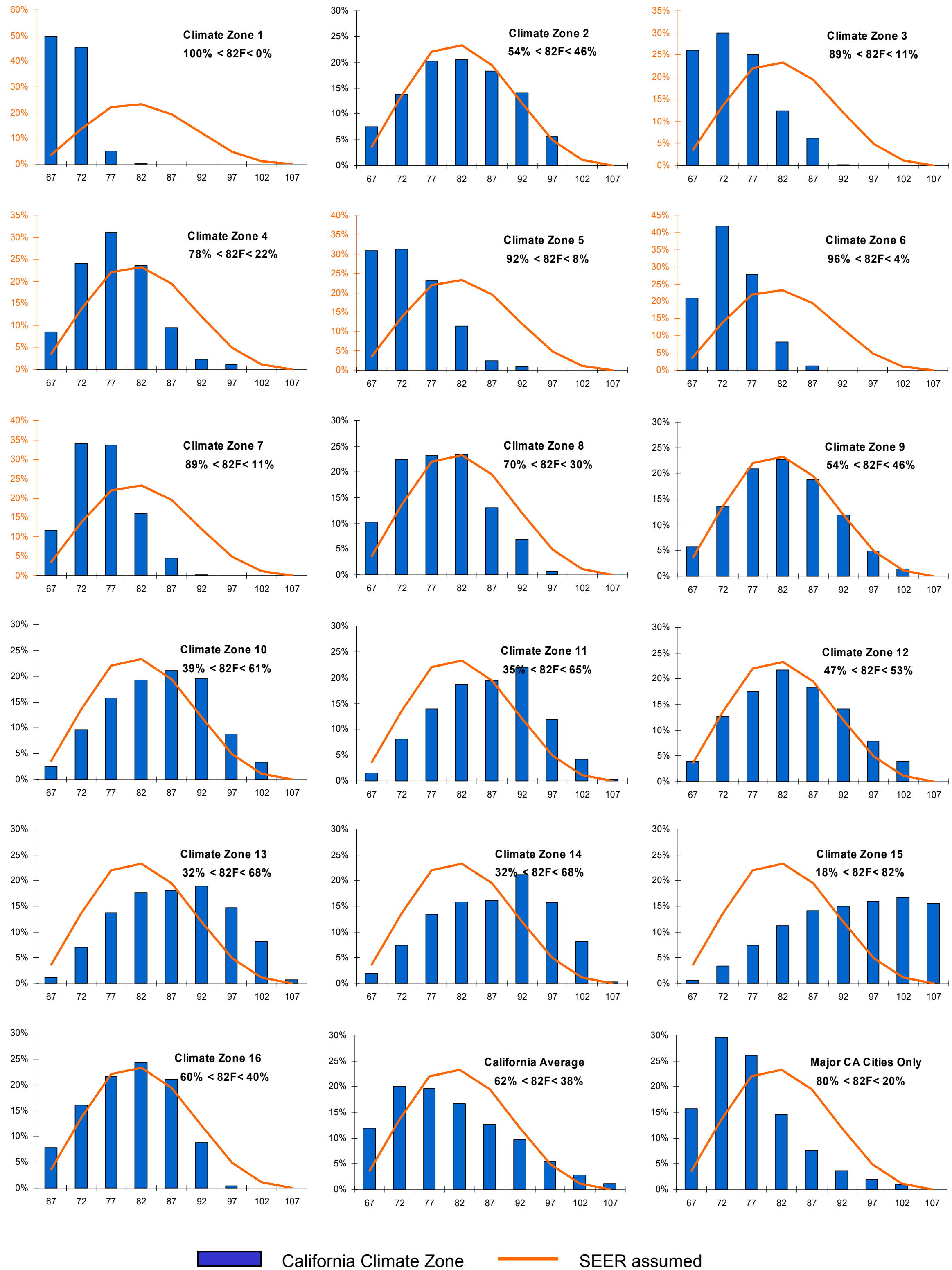


Figure 3.1.5
Distribution of Cooling Coil Load by California Climate Zones
(median single family residence, DOE-2 cooling loads, North-South Orientation)

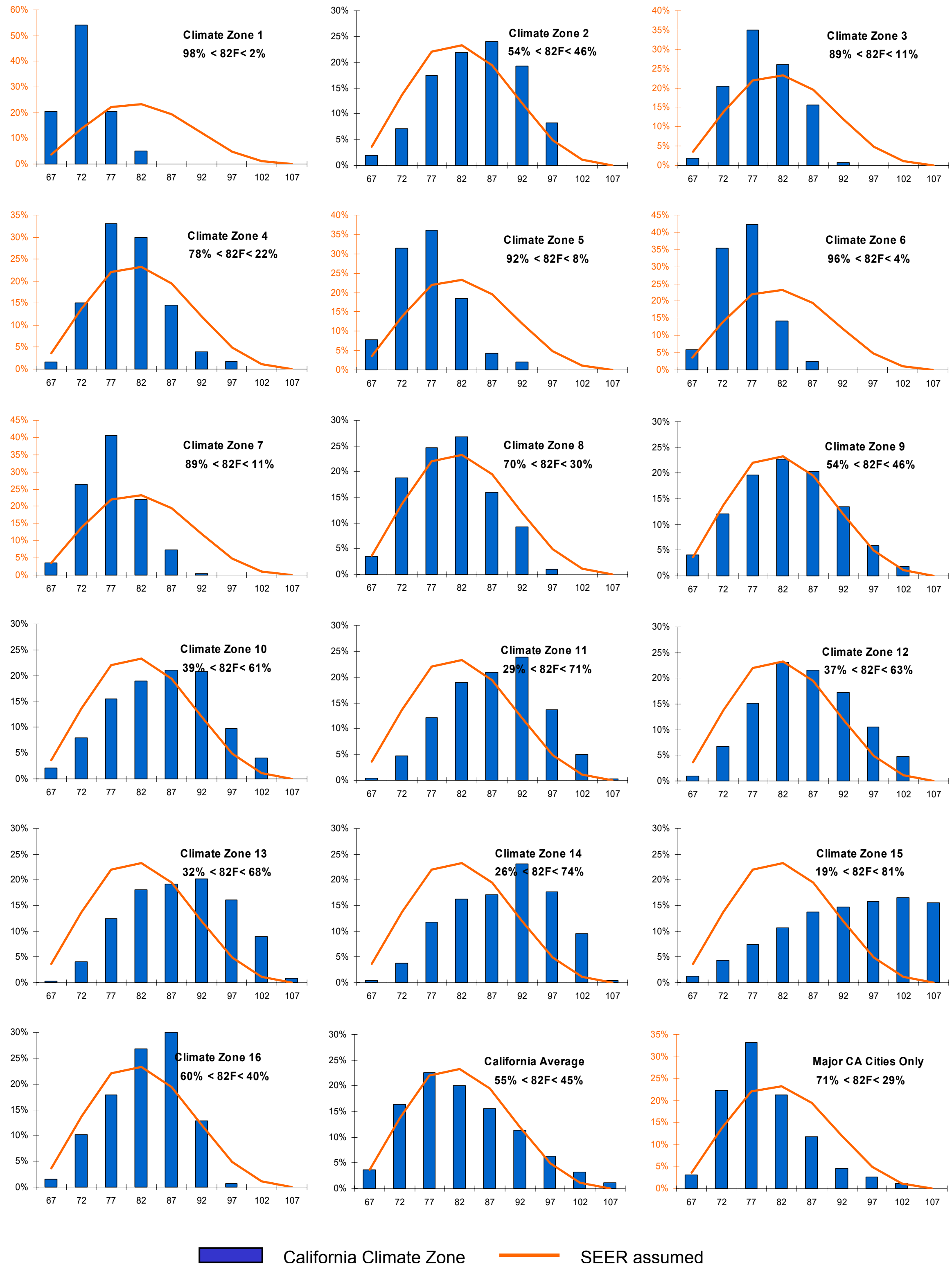
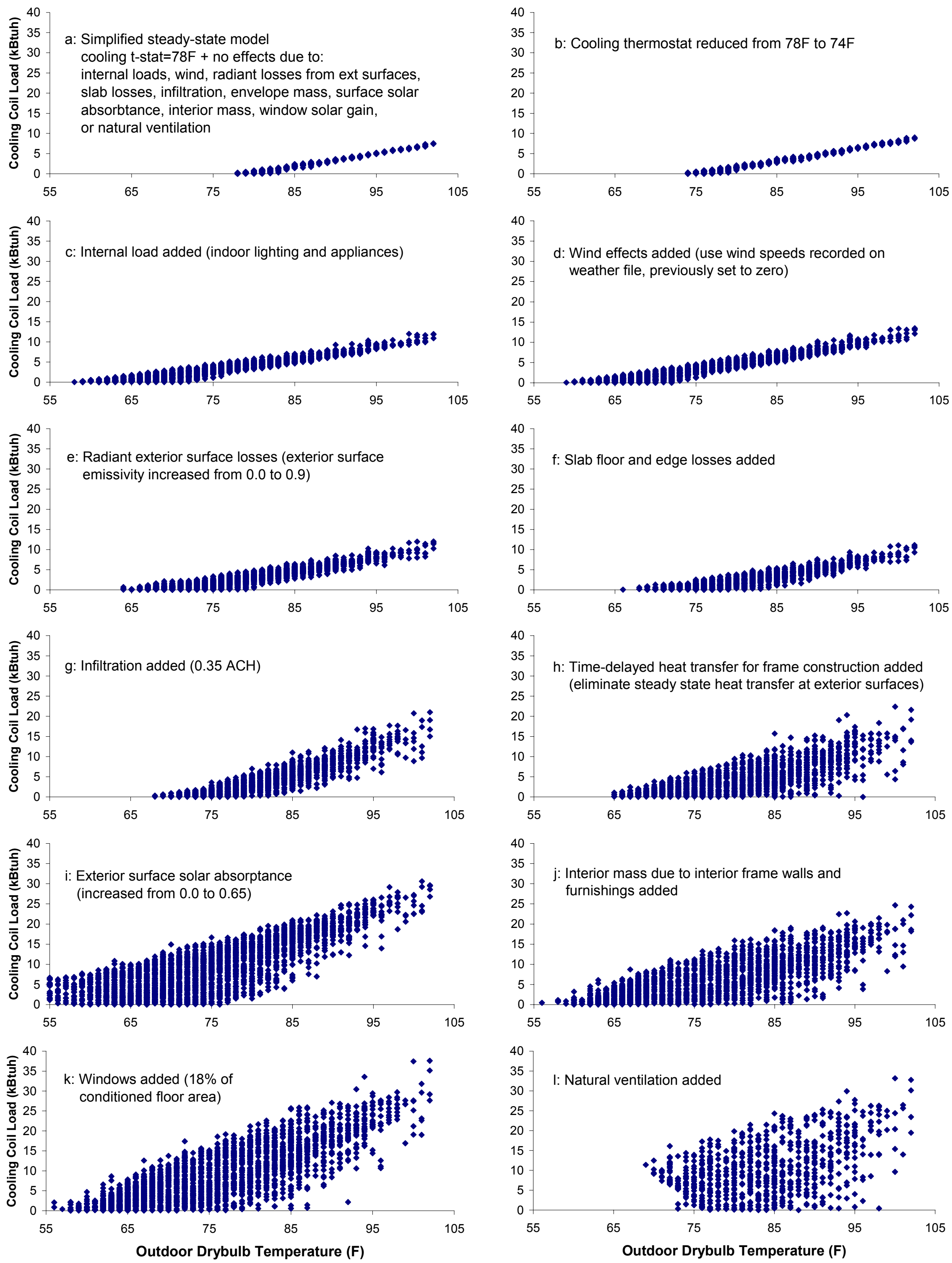


Figure 3.1.6
Cooling Coil Load as a Function of Outdoor Temperature
(median single family residence, DOE-2 cooling loads, North-South Orientation)



Obtaining the straight line relationship between hourly cooling coil load and outdoor temperature illustrated in Figure 3.1.6A required numerous simplifications to the DOE-2 prototype and simulation procedure. Each of the cases included in Figure 3.1.6, other than the first one, i.e., Figure 3.1.6B through 3.1.6L, represent separate annual simulation results in which one important climate or house design variable, omitted from Figure 3.1.6A was added back into 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 3.1.6L, includes all effects omitted from Figure 3.1.6A. Figure 3.1.6L represents a much more realistic representation of the relationship between outdoor temperature and hourly cooling coil load than does Figure 3.1.6A. Contrasting Figure 3.1.6A with 3.1.6L illustrates how differently cooling coil loads for typical house behave than is assumed by the assumptions implicit in 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 applications.

Each simulation case in Figure 3.1.6 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 3.1.1a). 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 should be 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 57°F). It also “blurs” slightly (i.e., introduces additional variability into) the linear relationship between coil load and outdoor temperature.

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

j) Interior mass was "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 to 1 lb/sqft, 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.

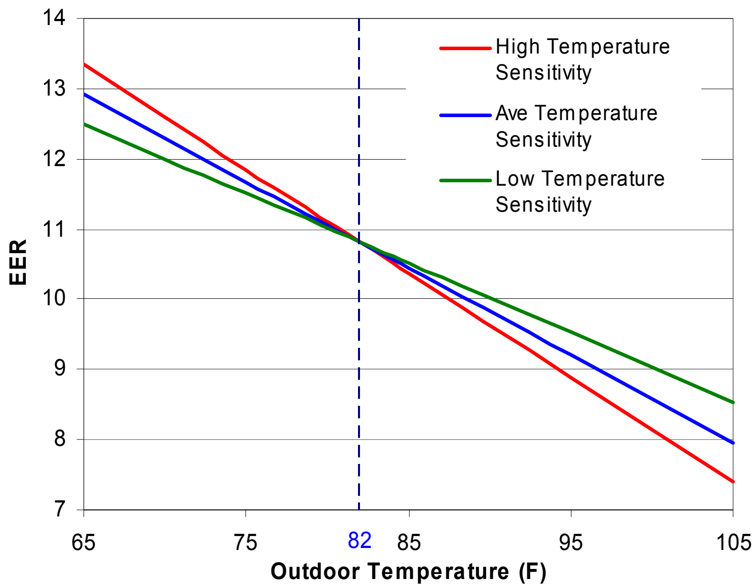
l) Natural ventilation is enabled via the operable windows. This assumes a constant air change rate of 3 ACH whenever the indoor cooling load could be met using natural ventilation. If the entire cooling load could not be met using natural ventilation, else the model assumed the windows were closed and the air conditioner was used to meet the cooling loads. The impact of natural ventilation is greatest on the coil loads that coincided 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 3.1.7 (same as Figure 2.1.2) illustrates another key assumption implicit in the SEER rating procedure, that the efficiency of the cooling process is linear with outdoor temperature. An important caveat for this involves at least two important assumptions regarding indoor (evaporator) and outdoor (condenser) fans:

- The energy from both fans is included in the overall SEER rating and is generally assumed to be a relatively small and relatively constant portion of the total system energy requirements.
- More importantly, both fan are assumed to cycle with the compressor, hence, fan energy is also assumed to be a linear function of outdoor temperature.

Figure 3.1.7

System Performance-Related Assumptions Implicit in the SEER Rating Procedure
Efficiency (EER) Sensitivity to Temperature



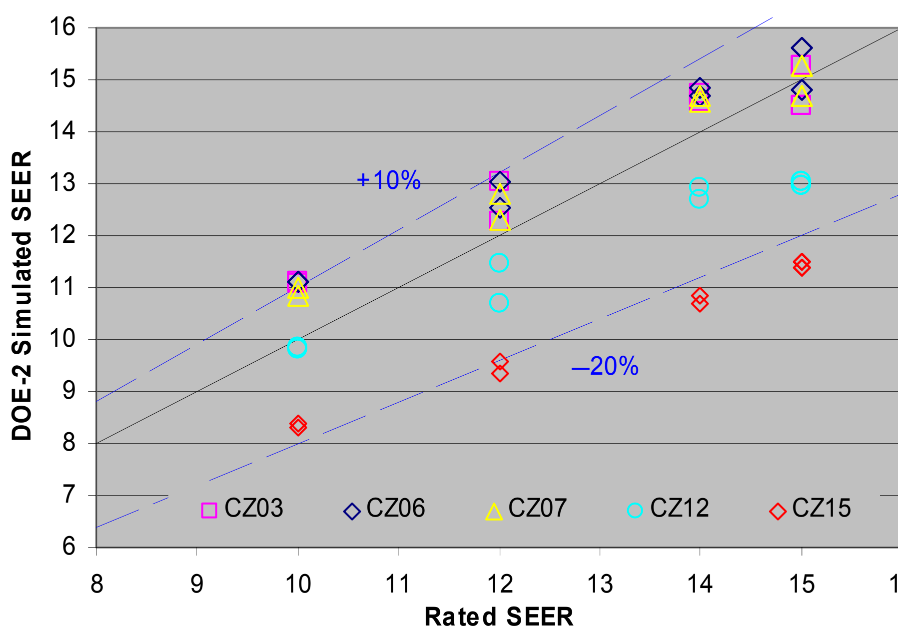
When the system fan is constant volume and cycles with the compressor, the typical case for residential applications, the fan energy is a relatively constant fraction of total system cooling energy. Actually, as compressor efficiency decreases with warmer temperatures, fan energy becomes a smaller fraction of the total, but the effect is small. Where system fans are constant volume and do not cycle with compressor operation (i.e., run continuously during occupied hours to provide ventilation), a common case in non-residential applications, fan energy use has no relationship with outdoor temperature. While condenser unit energy (i.e., compressor + condenser fan) still tends to be linear with outdoor temperature, the continuous indoor fan represents a constant that represents a potentially very large fraction of the total system energy (e.g., in milder climates).

3.2 SINGLE FAMILY RESIDENTIAL

3.2.1 Median Building Configuration, Median Cooling System Performance

Results of the detailed computer simulations for single-family building prototypes used in conjunction with median system operation are shown in Figure 3.2.1. The figure compares the rated SEER with that calculated via DOE-2 simulations. The DOE-2 simulated SEER is equal to the net cooling provided by the system divided by the total cooling system energy consumption. Net cooling is the reported gross cooling load less fan heat. The total cooling energy is that consumed by the condenser unit, the indoor fan, and (if required by the cooling system) crankcase heat. Crankcase heat for heat pumps is not typically included, as the heaters are required for proper operation of the system as a heating system. It is included for air conditioners and/or heat pumps if it is included as part of the standard, or rated, cooling system configuration. Results are presented for the five climate zones (CZ03, CZ06, CZ07, CZ12, and CZ15) examined in this phase of the study. Simulations of the single speed systems include both an air conditioner and a heat pump in each SEER range (10, 12, and 14). The 15-SEER systems are two-speed heat pumps and air conditioners from two manufacturer's (Carrier and Lennox).

Figure 3.2.1
Calculated vs. Rated SEER
Single Family Prototype, Representative California Climates
Median Building Characteristics, Median System Characteristics



Simulation results indicate that a system's performance is highly dependent on climate conditions. A cooling system used in the same house, but located in different climate zones, should be expected to have seasonal efficiencies between 7 to 10% higher and 18 to 23% lower than rated values. Cooler climates (CZ03, CZ06, and CZ07) produce conditions that lead to higher SEER values. Hot climates (CZ15) produce significantly lower SEER values. Humidity conditions also affect SEER as they lead to coil entering conditions that differ from those assumed in the SEER ratings process. Their relative effect is also strongly dependent on local weather conditions. California is a relatively dry state (low ambient dew point temperatures). This will lead to seasonal performance that is lower than reflected in the rated SEER. Thus, the climate dependency of SEER shown in Figure 3.2.1 is a combination of outdoor temperature and coil entering conditions that differ from those assumed in the DOE ratings process.

Additionally, the difference between the sensitivity of the cooling systems to outdoor temperature and its sensitivity to coil entering conditions produces additional variation in simulated SEER. However, cooling system impact on SEER for systems used in this set of simulations is typically small in comparison to climate effects.

Figure 3.2.1 suggests that climate zone-specific SEER adjustments could correct for much of the difference between rated and simulated SEER. Adjustment factors based on median single-family building prototypes are provided in Table 3.2.1. The adjustments are rated-SEER multipliers. For example, a SEER 12 system being used in a single-family home in Climate Zone 3 could be expected to operate at a seasonal efficiency ratio of 12.7. The same system place on a typical home in Climate Zone 15 could expect to perform at a seasonal efficiency ratio of 9.7. Different system load sequences affect different SEER-rated systems differently, and single-speed systems differently than two-speed systems. For this reason, climate zone adjustments are provided based on single or two-speed operation. Averaged multipliers are also provided for single-speed, two-speed and all systems. Given the lack of penetration of two-speed systems in the single-family market, the "All Single-Speed" multiplier should be used as a global adjustment factor for a given climate zone as opposed to that labeled as "All Systems".

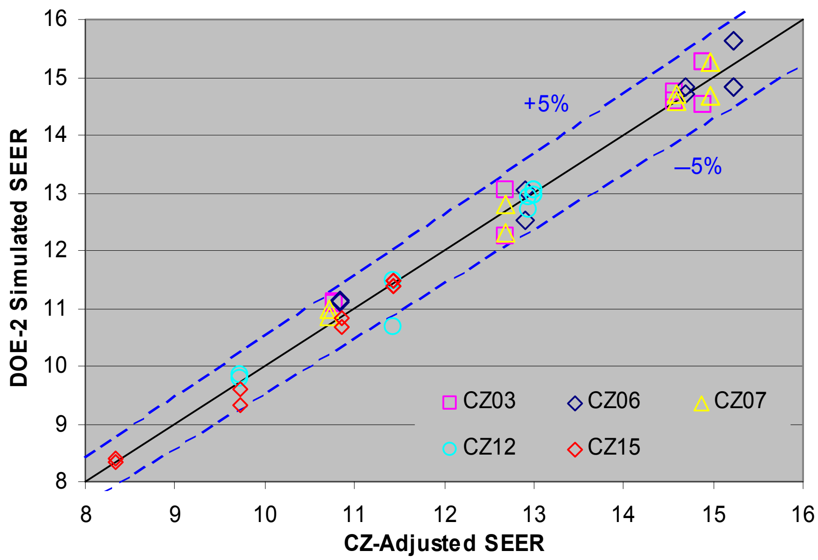
Table 3.2.1
SEER Climate Zone Multipliers
Single Family Prototype, Representative California Climates
Median Building Load, Median System Characteristics

	Single-Speed SEER Rating			All Single-Speed	Two-Speed	All Systems
	10	12	14			
CZ03	1.08	1.06	1.04	1.07	0.99	1.06
CZ06	1.08	1.07	1.05	1.07	1.02	1.07
CZ07	1.07	1.06	1.04	1.06	1.00	1.06
CZ12	0.97	0.95	0.92	0.95	0.87	0.94
CZ15	0.83	0.81	0.78	0.82	0.76	0.81

** Multipliers assume rated fan energy and system sizing consistent with the SEER ratings procedure. Both issues are likely to impact SEER rating and are addressed later.*

Figure 3.2.2 illustrates the impact of climate zone and system specific multipliers on SEER. The rated SEER is adjusted by multipliers provided in Table 3.2.1 and compared to calculated values. Differences between climate zone-adjusted SEER and calculated values are reduced to 6% from the +10% and -23% range that should be expected without the correction. Similar climate zone adjustments will be developed for the remaining climate zones later in this analysis process.

Figure 3.2.2
Calculated vs. Climate Zone-Adjusted SEER
Single Family Prototype, Representative California Climates
Median Building Characteristics, Median System Characteristics



3.2.2 Expanded Building Configuration, Median Cooling System Performance

The impact of building design on SEER was determined by varying the building features used to define the single-family prototype. These features, as described in Section 2.1.2, were varied through their minimum, median, and maximum values. Features that resulted in an increase in simulated SEER were noted, as were those that led to a decrease in simulated SEER. In this manner, a series of design features were found that produced minimum and maximum simulated SEER values for each particular climate zone. Table 3.2.2 provides a summary of features that produced an increase or decrease in simulated SEER resulting from an increase in their value.

As the table illustrates, features that increase SEER in one climate zone can cause a decrease in SEER in another. It is also important to note that the combination of features that leads to a higher SEER do not necessarily result in a reduction of annual cooling energy. Features that increase SEER can also lead to higher coil loads and higher seasonal energy consumption in spite of the increase in SEER.

The spread in SEER resulting from changes in building parameters is given in Figure 3.2.3. For clarity, results are given only for Climate Zone 6 (mild climate zone) and Climate Zone 15 (hottest climate zone) as these tend to bound the extremes of the total variation in results. The median values shown in Figure 3.2.3 are the same as those given in Figure 3.2.1. The "Max" and "Min" SEER values represent building configurations that maximize and minimize SEER for that particular climate zone. The scatter in simulated SEER about the median is similar for both climate zones and is representative of the other three climate zones examined in this phase of the analysis.

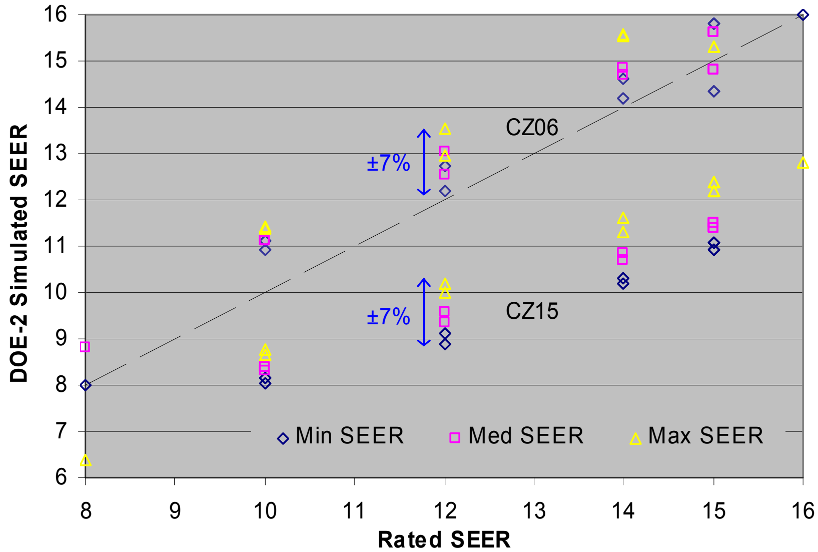
Table 3.2.2
Building Parameters Affecting SEER[1]
Affect on SEER Because of an Increase in Parameter Value

	CZ03	CZ06	CZ07	CZ12	CZ15
Total Floor Area	Lower	Lower	Lower	Lower	Lower
Number of Stories	None	None	None	None	None
Aspect Ratio	None	None	None	None	None
Occupancy[2]	Lower	Lower	Lower	Lower	Lower
Internal Gains	Higher	Higher	Higher	Higher	Higher
Cath Roof Frac	None	None	None	None	None
Floor Type	None	None	None	None	None
Glass Area	Higher	Lower	Lower	None	Higher
Glass U-value	Lower	Lower	Lower	Lower	Lower
Glass SC	Higher	Lower	None	Higher	Higher
Wall U-value	None	Higher	Higher	Higher	Higher
Roof Insul	None	None	None	None	None
Crawlspace Insul	None	None	None	None	None
Slab Insul	None	None	None	None	None
Duct Leakage	Higher	Higher	Higher	Higher	Higher
Duct Insul R-Value	Higher	Higher	Higher	Higher	Higher
Shading Level	Lower	Higher	None	Lower	Lower
Infiltration ACH	Higher	Higher	Higher	None	Lower
Natural Ventilation	Lower	None	Lower	Lower	Lower
Cool T'stat SP	Higher	Higher	Higher	Higher	None
Cool T-stat Setup	Lower	Lower	Lower	Lower	Lower

Notes:

1. *Changes in values that lead to an increase in simulated SEER do not necessarily result in lower total seasonal energy use.*
2. *Occupancy levels are given in terms of square foot per person. Thus, an increase in occupancy level results in fewer occupants in the space.*

Figure 3.2.3
Affect of Building Characteristics on Simulated SEER
Single Family Prototype, Representative California Climates
Min/Median/Max Building Characteristics, Median System Characteristics



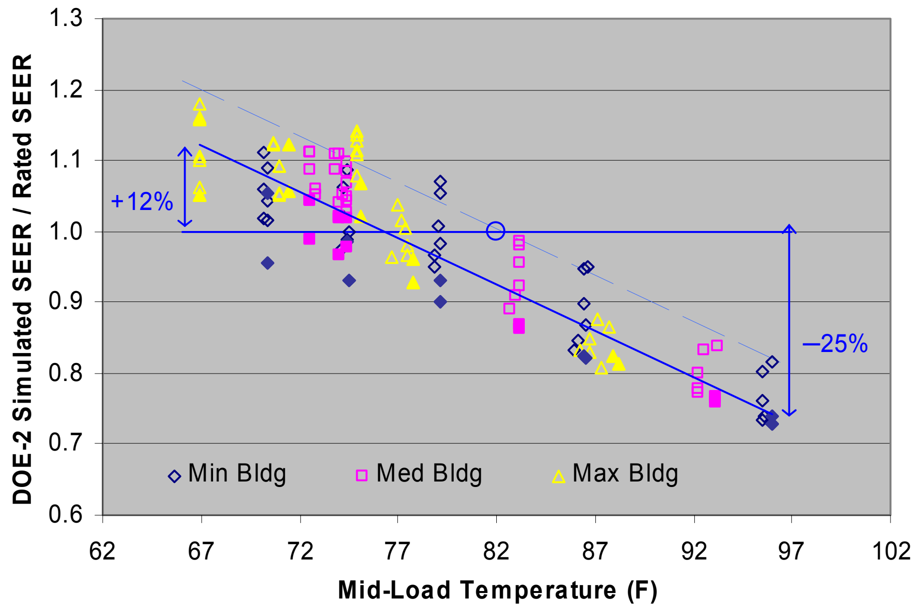
The impact of building features on SEER can also be illustrated via the mid-load temperature. The mid-load temperature is the outdoor temperature below and above which half of the seasonal cooling operation occurs (see Sections 2.1 and 3.1). For the SEER rating process, 82°F outdoor temperature is assumed to be the national average mid-load temperature. To mirror this approach, mid-load temperatures were captured for all DOE-2 simulations used to produce simulated SEER values. The relationship between simulated SEER and mid-load temperature is shown in Figure 3.2.4.

In Figure 3.2.4, the vertical axis is the ratio of simulated-to-rated SEER, which is equivalent to the SEER multipliers given in Table 3.2.1. Use of this ratio allows all systems in all climate zones to be presented in one figure. Simulation results are color-coded based on whether they are associated with building features that produce minimum, median, or maximum simulated SEER. Two-speed systems are shown as filled symbols to distinguish them from their single-speed counterparts. All three graphs in Figure 3.2.4, (a), (b), and (c), present the same data. They differ only in how the data are color-coded.

The benefit of plotting the data in this way is that mid-load temperature includes both climate effects (i.e., the outdoor temperature portion of climate effects) and the effect of building parameters on SEER. The climate conditions and building features that lead to lower mid-load temperatures tend to result in higher SEER values. This is because, on average, the compressor is operating at a lower outdoor temperature over the cooling season. SEER increases since condensing is accomplished more efficiently at lower outdoor temperatures. Conversely, climate or building features that lead to an increase in the mid-load temperature tend to cause a decrease in SEER since the condenser, on average, is operating during warmer outdoor temperatures.

Figure 3.2.4
DOE-2 Simulated SEER / Rated SEER vs. Mid-Load Temperature
Single Family Expanded Prototype, Representative California Climates
Min/Median/Max Building Characteristics, Median System Characteristics

a: by Building Min/Median/Max Characteristics



b: by Climate Zone

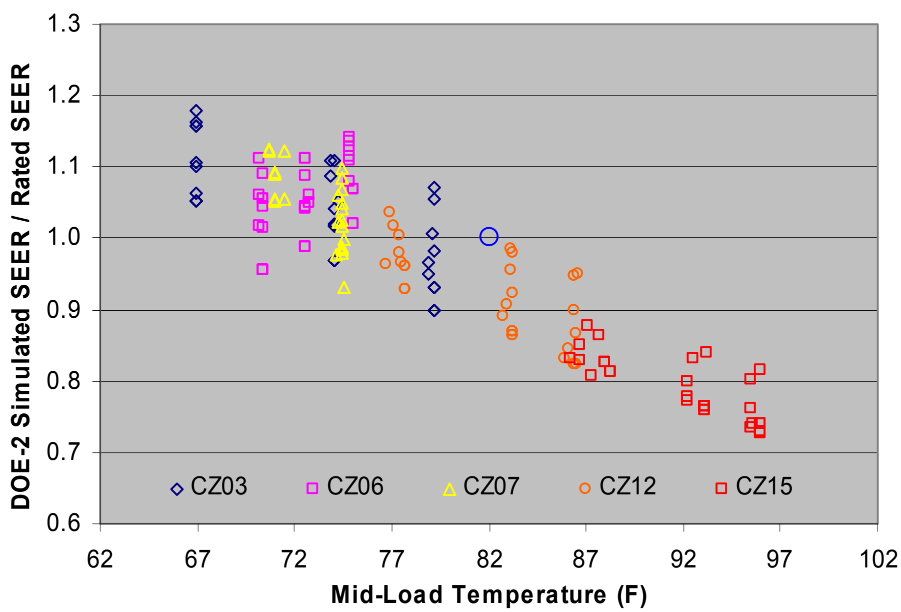
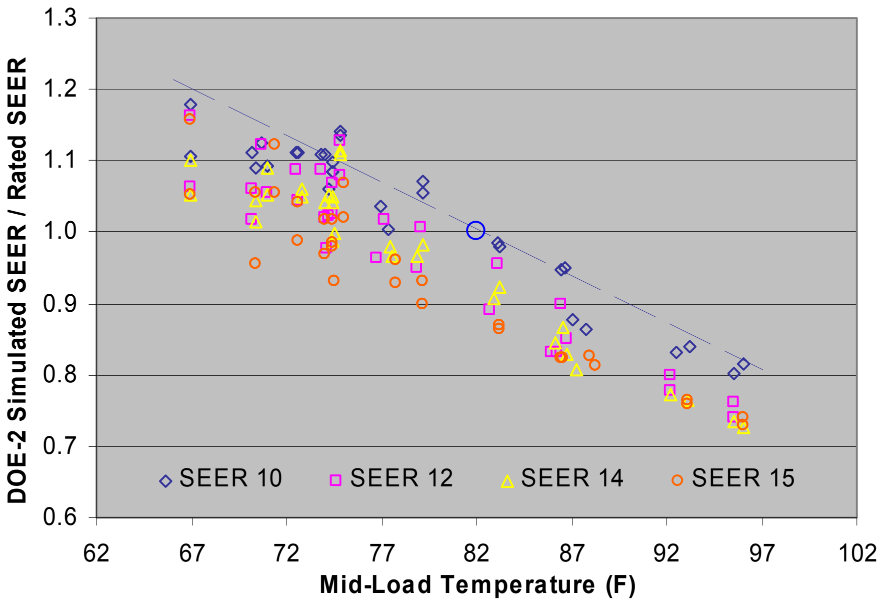


Figure 3.2.4 (continued)
DOE-2 Simulated SEER / Rated SEER vs. Mid-Load Temperature
Single Family Expanded Prototype, Representative California Climates
Min/Median/Max Building Characteristics, Median System Characteristics

c: by SEER Rating



In Figure 3.2.4, the scatter with respect to the x-axis (i.e., mid-load temperature) results from the influence of climate and building characteristics. Figure 3.2.4b distinguishes the data by climate zone. Figure 3.2.4a distinguishes the data by building characteristics (high, medium, and low SEER-producing characteristics). For a given mid-load temperature, the vertical scatter in Figure 2.3.4 is caused by differences in the sensitivity of various cooling systems to outdoor temperature and coil entering conditions. This is a result of design features of each system and the refrigerant used (R-410 is inherently more sensitive to outdoor temperature changes than R-22).

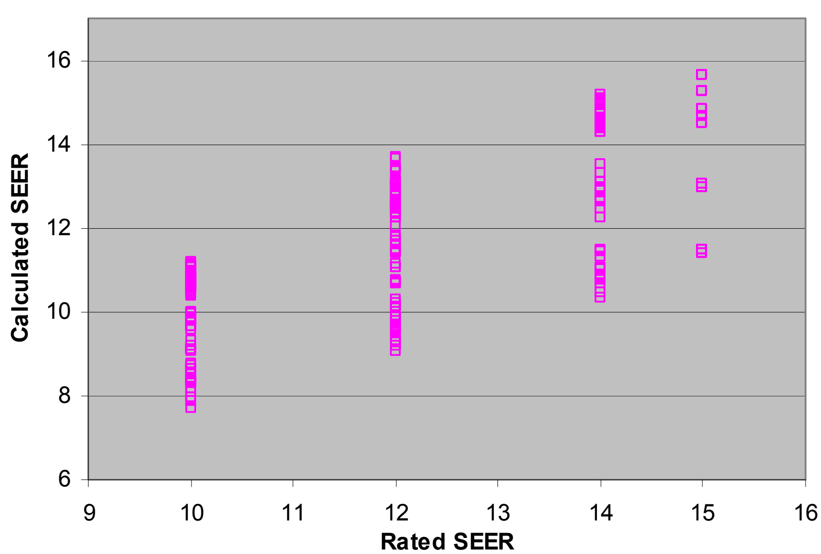
In Figure 3.2.4a, note that a best fit line (solid blue) does not pass through the line where DOE-2 simulated SEER divided by rated SEER equals 1.0 (i.e., simulated SEER = rated SEER) at 82°F (i.e., the dashed line). Rather, it passes through the simulated SEER = rated SEER horizontal line at approximately 76°F which seems to confirm results from Figure 3.2.5 above. The downward shift of the best fit line, relative to the 82°F mid-load temperature point (the open blue circle in Figure 3.2.4a) is due, at lest in part, to the influence of coil entering conditions, i.e., typical indoor wet-bulb temperatures lower than 67°F assume in the SEER rating process. This is corroborated in Figure 3.2.4c where the dashed line (same slope as the best fit line in Figure 3.2.4a, but forced through 82°F at simulated SEER = rated SEER) represents a good fit for the SEER 10 systems. As indicated in Figure 2.3.2, SEER 10 systems tend to be less sensitive to variation in cooling coil entering conditions than SEER 12 or 14 systems.

3.2.3 Expanded Cooling System Performance

Median cooling systems used in all prior analyses were selected because they were found to have mid-level performance characteristics of systems with like SEER. For example, the rated EER of the systems were near the middle of the range illustrated in Figure 2.3.1. The systems were not selected for their EER, but the selection criteria led to mid-range EERs. The actual selection criteria used to select the various systems were their EER sensitivity to outdoor temperature (EER Slope) and cycling loss coefficient (degradation coefficient C_D). The selection process is described in detail in Appendix B. The use of median values assures that a system selected at random will differ from the median system in an equal fashion. That is, a randomly selected system is as likely to have an EER temperature sensitivity that is higher than the median system than it is to have one lower. The same can be said of the likelihood of the system's C_D being higher or lower than the median system.

As a next phase in the analysis, the number of cooling systems was expanded beyond the median systems. DOE-2 performance maps were generated for additional systems to span the expected range of EER slope and C_D for a given SEER rating (from high to low temperature sensitivity in combination with high to low values of C_D). This selection process leads to the EER/SEER variation illustrated in Figure 2.3.1. The additional systems were then simulated using building features that produce minimum, median, and maximum simulated SEER values as described in Section 3.2.2. Simulation results for the median building prototype and five climate zones are shown in Figure 3.2.5. Results for expanded building configurations are shown in Figure 3.2.6 (for comparison to Figure 3.2.3) for Climate Zones 6 and 15.

Figure 3.2.5
Simulated SEER vs. Rated SEER
Median Building and Expanded Equipment Prototypes – All Climate Zones



The expansion of simulation cases to include different cooling systems leads to a significant increase in variation in simulated SEER. Figures 3.2.5 and 3.2.6 illustrate that rated SEER, without regard to location, building characteristics, or system details, is a poor predictor of annual residential energy use, even if seasonal loads are well known. One should expect that applying rated SEER to seasonal loads estimates could result in a 30% under prediction to a 20% over prediction of seasonal electrical energy consumption. The expansion in variation of simulated SEER is further illustrated by comparing Figures 3.2.3 to 3.2.6. What was a ±7% variation in simulated SEER over the range of building characteristics expands to a ±10% to 12% variation. This variation is on the order of the difference from one rated SEER value to another (10 to 11, or 11 to 12, etc.).

Figure 3.2.6
Simulated SEER vs. Rated SEER
Expanded Building and Equipment Prototypes – CZ06 & CZ15

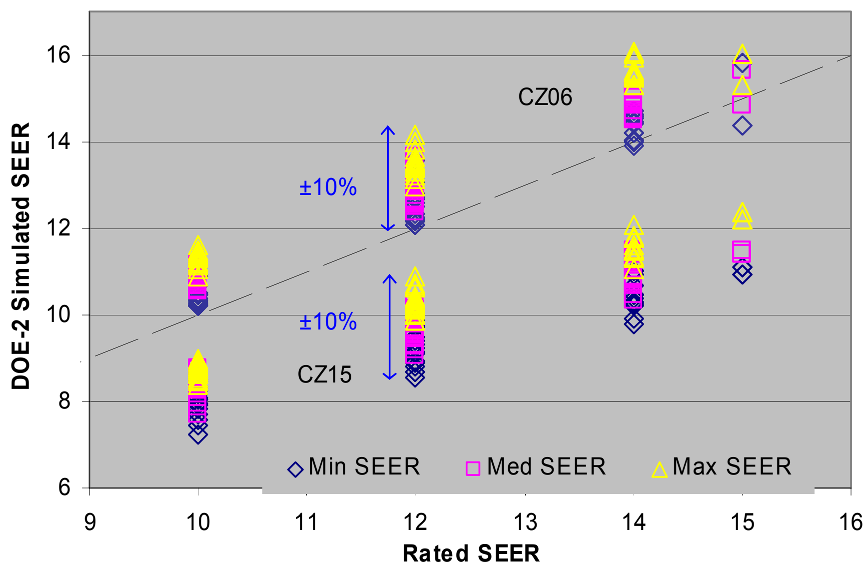
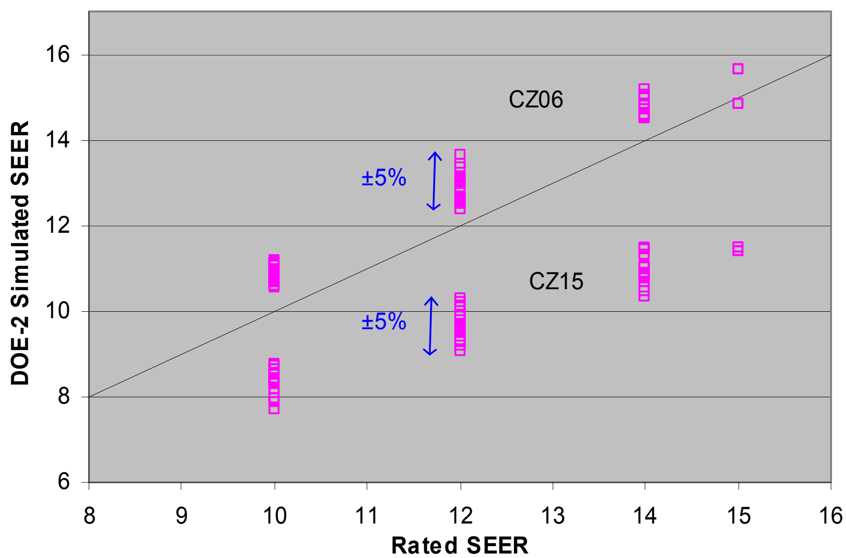


Figure 3.2.7 is a replication of Figure 3.2.5 with maximum and minimum SEER conditions associated with changes in the building removed. This allows a comparison of systems as if they were all applied to the same home operated under the same conditions. Figure 3.2.7 illustrates that the most widely held assumption related to SEER rating is incorrect. Those involved with the SEER rating process generally agree that SEER is not necessarily a good predictor of annual cooling energy consumption, even with reasonably accurate estimates of cooling loads. What is widely held is that SEER always reflects the relative efficiency of one system in comparison to another. That is, for a given application, a SEER 11 system is always more efficient than a SEER 10 system and less efficient than a SEER 12 system. Figure 3.2.7 indicates that this is not the case.

The expected scatter in simulated SEER resulting from differences in the performance characteristics of one system to another is approximately 5%. Thus, when selecting a SEER 10 rated system, one could only assume that it would operate at a seasonal efficiency between 9.4 and 10.6 (once climate and building operational effects are accounted for). A SEER 11 rated system applied in the same location to the same building could be expected to operate between a seasonal efficiency of 10.1 and 11.7. With only a standard SEER rating to differentiate the two, one could not be assured that the higher SEER-rated system would lead to lower annual cooling energy use as the expected SEER range overlaps between the two. Thus, SEER is neither an accurate measure of seasonal energy use nor a guaranteed ranking measure.

Figure 3.2.7
Simulated SEER vs. Rated SEER
Median Building and Expanded Equipment Prototypes



Previous results indicate potentially large uncertainties in using rated SEER to anticipate annual cooling energy use in residential applications in California climates. More frequently, SEER is 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 12 system to a SEER 15. Table 3.2.3 and Figures 3.2.8 and 3.2.9 illustrate the results of upgrading from one SEER level to a higher SEER level. Five HVAC system upgrade cases were considered, e.g., SEER 10 to SEER 12, SEER 10 to SEER 14, etc.

The calculation of rated SEER-predicted savings may seem counter-intuitive for at least two reasons. First, to achieve a *reduction* in cooling energy consumption, SEER value must *increase*. Second, the percentage increase in SEER (see Equation A) does NOT indicate the anticipated percent reduction in cooling energy (i.e., savings) due to SEER upgrade (Equation B).

$$\left(SEER14 / SEER10\right) - 1 = 1.40 - 1 = 0.40 \text{ (or a 40\% improvement in SEER)} \qquad \text{(A)}$$

$$1 - \left(\frac{1}{SEER14} \Big/ \frac{1}{SEER10} \right) = 1 - \left(SEER10 / SEER14\right) = 1 - 0.714 = 0.286 \text{ (or a 29\% reduction in energy use)} \qquad \text{(B)}$$

∴ a 20% improvement in SEER yields a 17% expected reduction in annual cooling energy use

Table 3.2.3 compares the maximum, median and minimum energy savings associated with moving to a higher SEER to that expected from the change in SEER rating. Values shown in the table are an average of savings from air conditioners and heat pumps. The upgrades assumed no fuel switching, i.e., no changing form air conditioners to heat pumps of visa versa. No consistent difference between savings for heat pump and air conditioners was evident. Savings in Table 3.2.3 are from simulation results based on the median building prototype. Subsequent figures illustrate the impact of expanding from median to maximum and minimum building prototypes.

Median annual energy savings associated with moving to a higher SEER-rated system are shown in Figure 3.2.8, by climate zone. While results varied by climate zone, no obvious pattern of relative savings associated with climate zone is apparent.

Figure 3.2.8
Percentage Savings Achieved by SEER Upgrade
(Upgrading from a Lower SEER System to a Higher SEER System)
Results by Climate Zone
Single Family Residential Prototype, All California Climate Zones
Median Buildings, Min/Median/Max Systems

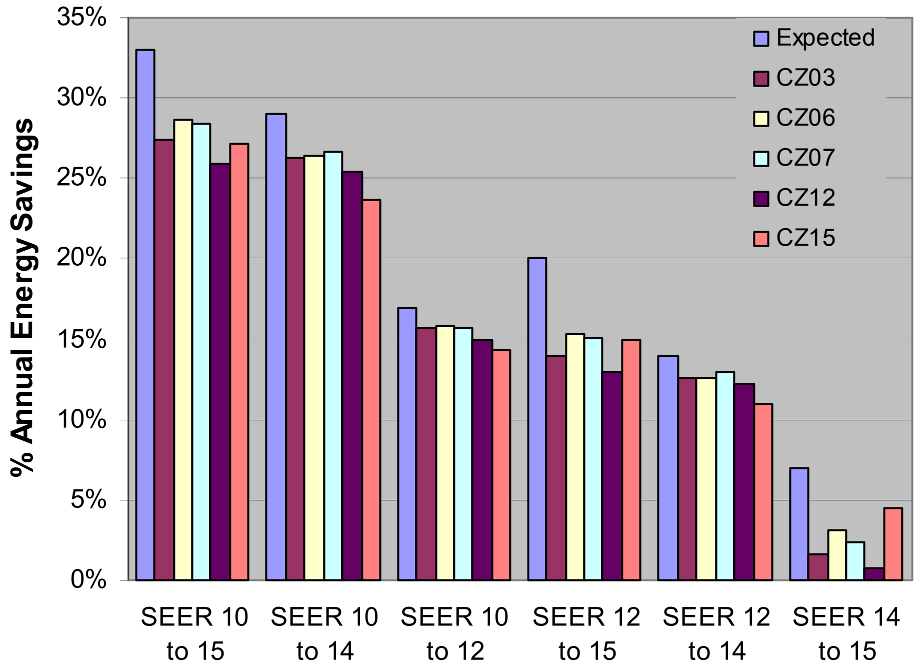


Table 3.2.3
Energy Benefits of Moving to a Higher SEER

	SEER Change	Percentage Decrease in Seasonal Cooling Energy			
		Expected	Maximum	Median	Minimum
CZ03	SEER 10 to 15	33%	30%	27%	25%
	SEER 10 to 14	29%	30%	26%	22%
	SEER 10 to 12	17%	23%	16%	10%
	SEER 12 to 15	20%	17%	14%	9%
	SEER 12 to 14	14%	18%	13%	6%
	SEER 14 to 15	7%	4%	2%	-1%
CZ06	SEER 10 to 15	33%	31%	29%	27%
	SEER 10 to 14	29%	30%	26%	23%
	SEER 10 to 12	17%	22%	16%	11%
	SEER 12 to 15	20%	18%	15%	11%
	SEER 12 to 14	14%	17%	13%	7%
	SEER 14 to 15	7%	5%	3%	1%
CZ07	SEER 10 to 15	33%	30%	28%	27%
	SEER 10 to 14	29%	30%	27%	24%
	SEER 10 to 12	17%	21%	16%	12%
	SEER 12 to 15	20%	17%	15%	11%
	SEER 12 to 14	14%	17%	13%	7%
	SEER 14 to 15	7%	4%	2%	0%
CZ12	SEER 10 to 15	33%	29%	26%	23%
	SEER 10 to 14	29%	31%	25%	19%
	SEER 10 to 12	17%	23%	15%	8%
	SEER 12 to 15	20%	16%	13%	8%
	SEER 12 to 14	14%	18%	12%	3%
	SEER 14 to 15	7%	5%	1%	-2%
CZ15	SEER 10 to 15	33%	31%	27%	24%
	SEER 10 to 14	29%	30%	24%	16%
	SEER 10 to 12	17%	23%	14%	7%
	SEER 12 to 15	20%	19%	15%	11%
	SEER 12 to 14	14%	17%	11%	2%
	SEER 14 to 15	7%	9%	5%	2%

Figure 3.2.9 illustrates the variation in results across all climate zones. Expected savings are shown in the left-most vertical bar (orange) for each upgrade case. This is the savings one would expect based on the SEER ratings, if SEER were a completely reliable indicator of cooling energy consumption. Figure 3.2.9 also presents minimum, median, and maximum savings achieved (light blue, yellow, and green bars, respectively — read these bars against the LEFT axis). Figure 3.2.9a presents results considering upgrades applied to median houses only. In Figure 3.2.9b the upgrade cases are expanded to include maximum and minimum houses

For each upgrade case, it is evident that median simulated cooling energy savings falls short of the expected savings. For most of the upgrade cases, the shortfall of the actual (simulated) savings is 10% to 30%. This variation results from differing levels of sensitivity by individual units to indoor and outdoor conditions. Much of this variation in individual systems was illustrated in Figure 1.1.2.

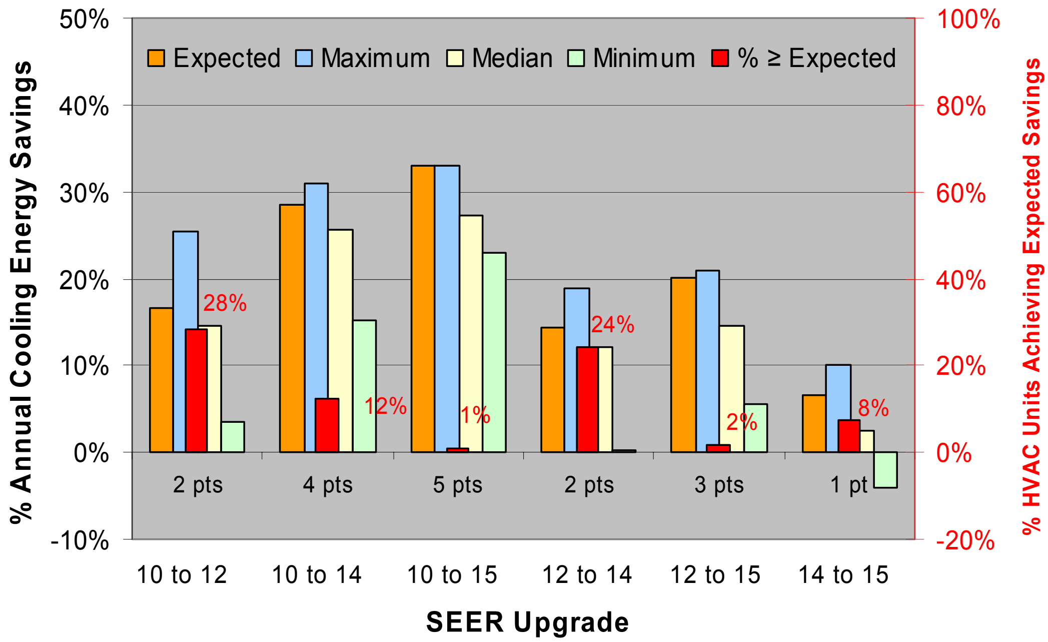
An additional result of particular interest in Figure 3.2.9 is indicated in red font and red vertical bars (read these bars against the RIGHT axis). These indicate the percentage of the simulated cases where the expected (i.e., SEER-predicted) level of savings was achieved or exceeded. Figure 3.2.9a indicates that in residential applications, 70% to 99% (i.e., one minus the red numbers reported in Figure 12) of the times consumers upgrade from a minimum efficiency HVAC system, their actual annual cooling energy savings will fall short of the level indicated by rated SEER. When the house characteristics are expanded to more fully reflect the range of houses found in California (Figure 3.2.9b) "failure rate for SEER-predicted savings improves slightly to 70% to 90%.

In general, the larger the SEER upgrade, e.g., from SEER 10 to SEER 15, the lower the probability of achieving the expected savings. Note that for each of the two point upgrades (e.g., SEER 10 to 12, etc.) the minimum savings was either very close to zero or was actually negative (meaning the for some upgrade cases, the two point upgrade actually resulted in increased energy use). This indicates that one point upgrades (e.g., from SEER 12 to 13) would not reliably yield savings.

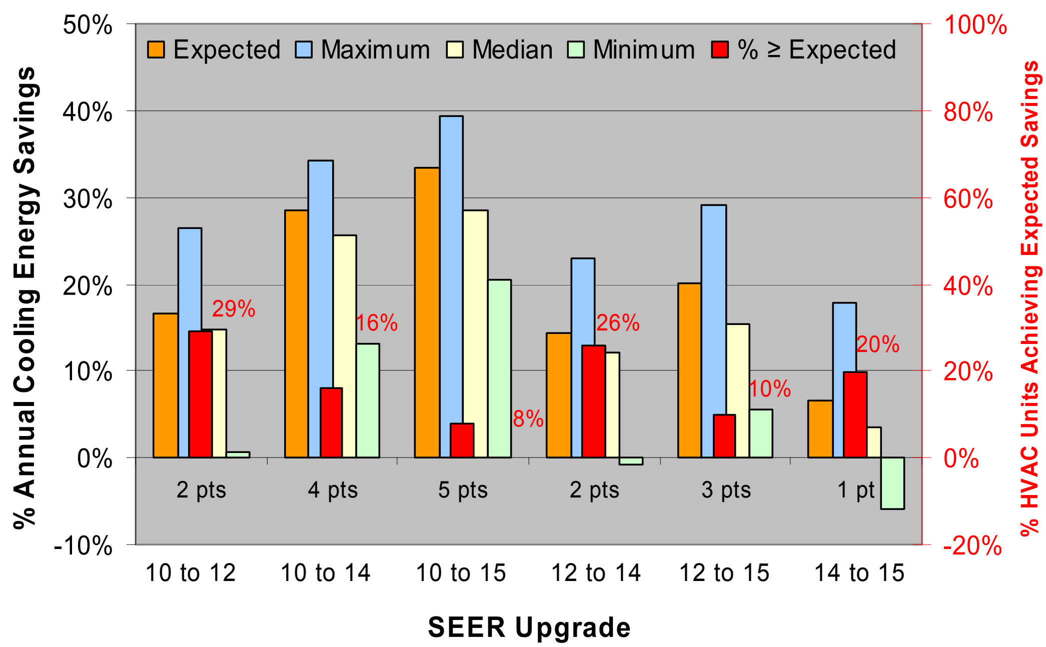
It is important to note the simulation results presented in Figure 3.2.9 do not reflect statistically valid penetration rates. For example, the median savings for upgrades in Figure 3.2.9b implicitly give equal weight the savings results from the minimum, maximum, and median building prototypes cases. Similarly, for these results to best reflect the potential for savings in the California market, the representative cooling systems used in the simulations should be weighted by penetration rate in the California market. As is, the cooling systems are representative of what actual products currently offered by major HVAC manufactures. It is best to consider the results in Figures 3.2.9a and 3.2.9b as bounding the actual savings, i.e., statistically weighted results would fall between the results presented in Figures 3.2.9a and 3.2.9b.

Figure 3.2.9
Percentage Savings Achieved by SEER Upgrade
Single Family Residential Prototype, All California Climate Zones
Min/Median/Max Systems

a: Results for Median Buildings Only



b: Results for Min/Median/Max Buildings



3.2.4 Cooling System Electric Demand

Peak cooling system electric demand was captured for each simulation. The relationship between system SEER and cooling demand is given in Figure 3.2.10 for Climate Zones 6 and 15 (coolest and hottest climates). Demand is presented as the operational EER and is equal to the nominal (ARI) cooling capacity of the system divided by the peak seasonal electric demand. (Cooling system peak electrical demand is found by multiplying the cooling system's nominal capacity by the operational EER.) Results for Climate Zone 6 are shown as filled symbols; those for Climate Zone 15 as open symbols. It should be noted that the results are based on a sizing approach that is roughly equal to the use of an ASHRAE 1% cooling design temperature. System over sizing is addressed later.

Figure 3.2.10
Operational EER vs. Rated SEER – CZ06 & CZ15
Single Family Residential Prototype, Climate Zones 6 (mild) and 15 (hot arid)
Min/Median/Max Building Characteristics, Min/Median/Max System Characteristics

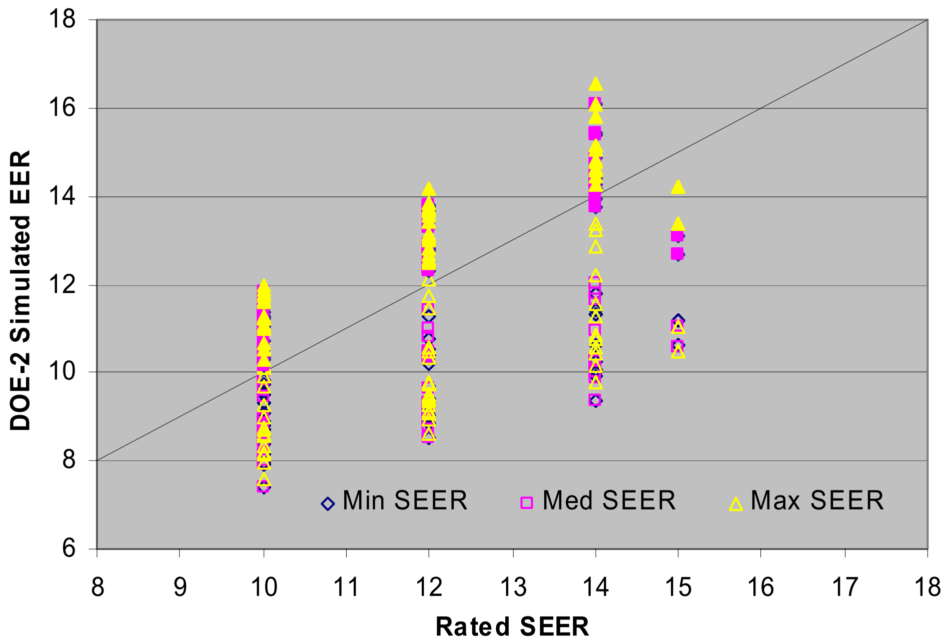
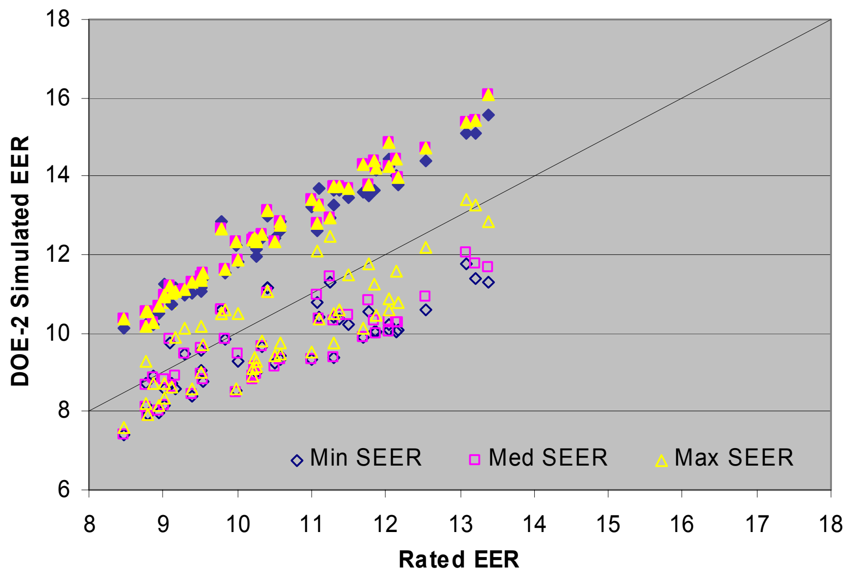


Figure 3.2.10 reinforces the common wisdom that SEER is a poor metric for predicting demand. Even when variations in weather and building characteristics are eliminated, simulations indicate that there are no guarantees that there will be any demand reduction when moving to a nest higher SEER level. Two-speed systems, as expected, impose cooling demands commiserate with their high-speed operation. This is typically similar to a SEER 12 system and is borne out by simulations.

Figure 3.2.11 shows the same results plotted against each system's rated EER, the standard metric for evaluating demand impacts. As with Figure 3.2.10, CZ06 results are shown as filled symbols and results for CZ15 are open symbols. While there is still a great deal of scatter, EER is a much better predictor of cooling system electric demand. Climate affects become obvious from the figure. Systems operating in cooler climates (CZ06) impose less electric demand than would be calculated using their rated EER. The same system used in the hotter climate zone (CZ15) have demands that frequently exceed that which would be calculated based on their rated EER. Figure 3.2.11 includes two-speed systems, which become indistinguishable from their single-speed counterparts. Climate zone multipliers that adjust the rated EER to the operation EER are provided in Table 3.2.4. The expected error in operational EER once adjusted for climate zone is ±0.8 for CZ03, CZ06, and CZ0; ±1.2 for CZ12; and ±1.5 for CZ15.

Figure 3.2.11
Operational EER vs. Rated EER – CZ06 & CZ15
Expanded Building and Expanded Equipment Prototypes



Scatter in the operational EER vs. the rated EER is more pronounced in the hotter climate zones (CZ 12 and CZ 15) than for the cooler (CZ03, CZ06, and CZ07). This appears to be caused by the outdoor conditions when the peak load occurs. In cooler climates, peak cooling loads occur at outdoor temperatures near the ARI 95ºF rating point. In hotter climates, the outdoor temperature is a good bit higher (115ºF to 120ºF for CZ15). Different systems have EERs that are more or less sensitive to changes in the outdoor temperature. Systems that have high temperature sensitivity have lower operational EERs in CZ15 (greater demand impact), those with lower sensitivity have higher operational EERs (less demand impact). This is illustrated in Figure 3.2.12, which shows the impact of system temperature sensitivity on operational EER for Climate Zone 15 simulations. The temperature sensitivity of the various systems can account for more than half of the scatter in the data shown in Figure 3.2.11. Figure 3.2.12 also implies that equipment-specific demand adjustments could be developed to better predict demand impacts from the rated EER‡. System temperature sensitivity can be determined from expanded ratings

‡ Equipment-based adjustments were found to improve demand estimates and are provided in Section 4.1.5

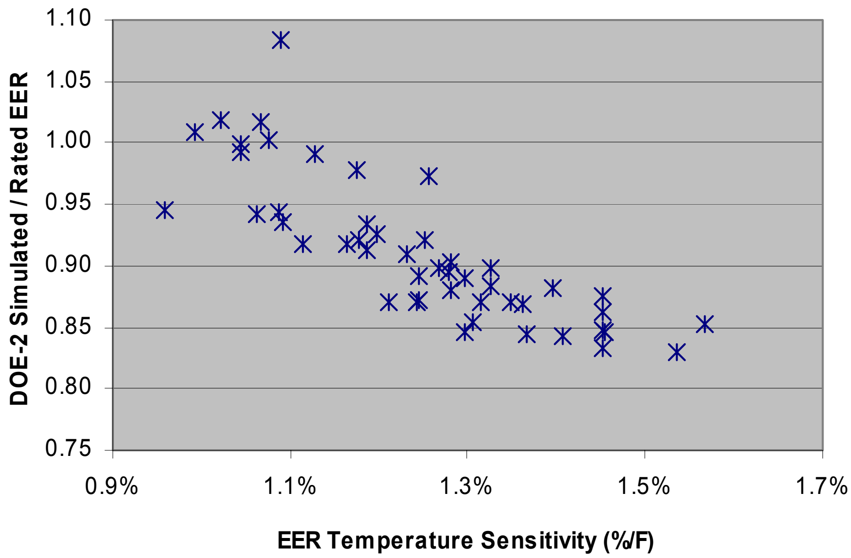
charts (preferred method) or EER_A and EER_B values determined during the SEER ratings process.

Table 3.2.4

Climate EER Multipliers

	CZ03	CZ06	CZ07	CZ12	CZ15
EER Multipliers	1.17	1.20	1.18	1.02	0.92

Figure 3.2.12
Impact of Cooling System Temperature Sensitivity on Cooling Demand
(CZ15 Only)



The overall demand benefits associated with moving to a higher SEER system are given in Table 3.2.5 for the median building prototype. Demand changes for building prototypes that produce maximum and minimum SEER values are essentially the same when comparing single speed systems (SEER 10, 12, and 14). They are somewhat dependent on building prototype when compared against two-speed systems. Demand improvement is greater for maximum SEER building prototype and less (or more negative) for the minimum SEER prototype. The “Expected” demand reduction in the table is based on the SEER change.

One of the more notable finding is the minimum potential demand benefit of systems located in hotter climates (CZ12 and CZ15). If one were to randomly exhange one SEER-rated system for another, higher SEER level system, one could not be assured that demand would not increase unless one went up four SEER ratings points (from a SEER 10 to at least a SEER 14). EER is a better indicator of potential demand reduction, but can not guarantee demand savings because of differing system sensitivity to outdoor temperature (Figure 3.2.12).

Table 3.2.5
Demand Reduction when Moving to a Higher SEER

	SEER Change	Percentage Decrease in Seasonal Cooling Energy			
		Expected	Minimum	Median	Maximum
CZ03	SEER 10 to 15	33%	10%	16%	21%
	SEER 10 to 14	29%	15%	24%	33%
	SEER 10 to 12	17%	4%	15%	25%
	SEER 12 to 15	20%	-5%	2%	7%
	SEER 12 to 14	14%	0%	11%	21%
	SEER 14 to 15	7%	-18%	-10%	-5%
CZ06	SEER 10 to 15	33%	9%	15%	20%
	SEER 10 to 14	29%	15%	25%	34%
	SEER 10 to 12	17%	5%	15%	25%
	SEER 12 to 15	20%	-7%	0%	4%
	SEER 12 to 14	14%	1%	12%	22%
	SEER 14 to 15	7%	-22%	-13%	-8%
CZ07	SEER 10 to 15	33%	13%	19%	23%
	SEER 10 to 14	29%	17%	25%	35%
	SEER 10 to 12	17%	5%	15%	25%
	SEER 12 to 15	20%	-2%	4%	8%
	SEER 12 to 14	14%	2%	12%	22%
	SEER 14 to 15	7%	-17%	-9%	-4%
CZ12	SEER 10 to 15	33%	13%	20%	27%
	SEER 10 to 14	29%	8%	21%	34%
	SEER 10 to 12	17%	*-5%*	12%	27%
	SEER 12 to 15	20%	0%	9%	17%
	SEER 12 to 14	14%	*-6%*	9%	25%
	SEER 14 to 15	7%	-11%	-1%	6%
CZ15	SEER 10 to 15	33%	11%	19%	29%
	SEER 10 to 14	29%	0%	17%	35%
	SEER 10 to 12	17%	*-11%*	10%	31%
	SEER 12 to 15	20%	-3%	11%	19%
	SEER 12 to 14	14%	*-15%*	8%	26%
	SEER 14 to 15	7%	-10%	3%	11%

3.2.5 Fan Energy

Simulation results presented to this point are based on rated fan energy. Fan energy requirements are specified in the ARI and DOE ratings process. Many rated air conditioners include the outdoor condensing unit and a cooling coil, but not the air handler or fan, as the rated combination. This configuration provides a rating for a cooling system added to a furnace that is not dependent on the furnace fan performance. Other air conditioners and all heat pumps are rated with an air handler and indoor fan (defined as a fan coil in the industry). The condensing unit/ coil combination is required to assume indoor fan energy of 365 W/1,000 cfm of supply air. Systems which include the indoor fan and air handler (fan coil systems) are rated at external static pressures between 0.15 and 0.25" w.g., depending on the system's cooling capacity. Care was taken in selecting cooling systems for simulation whose indoor fan energy under rated conditions was known. This was not always possible and, in cases where fan energy was not known, the system was assumed to have a fan energy requirement of 365 W/1,000 cfm, unless better information was available.

Several site studies have shown that the 365 W/1,000 cfm and external static pressures used in the ratings process are not realistic field values (Appendix D). External static pressures and fan energy values in residential systems are a good deal higher. A more realistic fan power value is 510 W/1,000 cfm and external static pressures are on the order of 0.55 in w.g. A fan power multiplier of 1.4 was applied to the rated fan energy for each system to account for these differences. The 1.4 multiplier is ratio of the standard 365 W/1,000 cfm to the field measure average of 510 W/1,000 cfm. A multiplier is used to account for the effects of the additional static pressure, while maintaining differences in fan power values from system to system (some systems are rated at more than 365 W/1,000 cfm, some less).

Additional simulations were made for the median building prototype with the extended range of cooling systems assuming the higher fan power. Simulation results are shown in Figure 3.2.13 as the percentage decrease in SEER caused by the higher fan energy. The reduction in SEER is compared to reduction in the standard ARI-rated EER caused by the higher fan energy. For the assumed 40% increase in fan power, the adjusted EER is calculated from the rated EER by:

$$EER_{adj} = (Cap_{ARI} - 0.4\ W_{fan} * 3.413)/(W_{ARI} + 0.4\ W_{fan}) \qquad (2)$$

where:

EER_{adj} is the fan-adjusted EER,

Cap_{ARI} is the total cooling capacity at ARI conditions,

W_{fan} is the fan power at ARI conditions, and

W_{ARI} is the total cooling electrical input (condenser unit + fan) at ARI conditions.

Fan power values can be difficult to obtain for residential split systems. Manufacturers rarely publish fan power data and normally do not monitor fans power separately in system ratings tests. If the system in question is rated as a cooling coil and compressor combination, then one can assume a fan power of 365 W/1,000 cfm. Heat pumps or air conditioners with fan coils are rated at specific external static pressures, so rated fan power seldom known. Sometimes it can be deduced from expanded ratings charts. Some manufactures provide gross cooling capacity and compressor power in their charts. If so, then fan power can be estimated from the ARI cooling capacity (which is net of fan power) and the ARI total system power (which includes fan power). At other times fan power can be estimated by comparing expanded ratings data for a system rated with a cooling coil to a system rated with a fan coil that uses the same cooling coil. If neither is available, then using 365 W/1,000 cfm should provide a reasonable estimate for most systems. The exception is fan coils that use variable-speed blowers. Variable speed blowers use more efficient fans and fan motors. A reasonable estimate of the fan power for these systems is 256 W/1,000 cfm (70% of standard systems).

Referring to Figure 3.2.11, the reduction in SEER caused by higher fan power requirement is nearly equal to the reduction in the systems EER. For example, if the higher fan power reduces the EER by 6%, one should assume a 6% reduction in SEER. Results do vary by climate zone. Condenser unit energy is a smaller fraction of the total (condenser unit + indoor fan) for cooler climates (CZ03, CZ06, & CZ07). Thus, the percentage impact on SEER is slightly higher than on EER. Conversely, compressor energy is a higher fraction of the total for warmer climate zones and fan power increases have less effect on SEER. Table 3.2.6 provides climate zone fan multipliers to be applied to the change in EER to yield the change in SEER, or

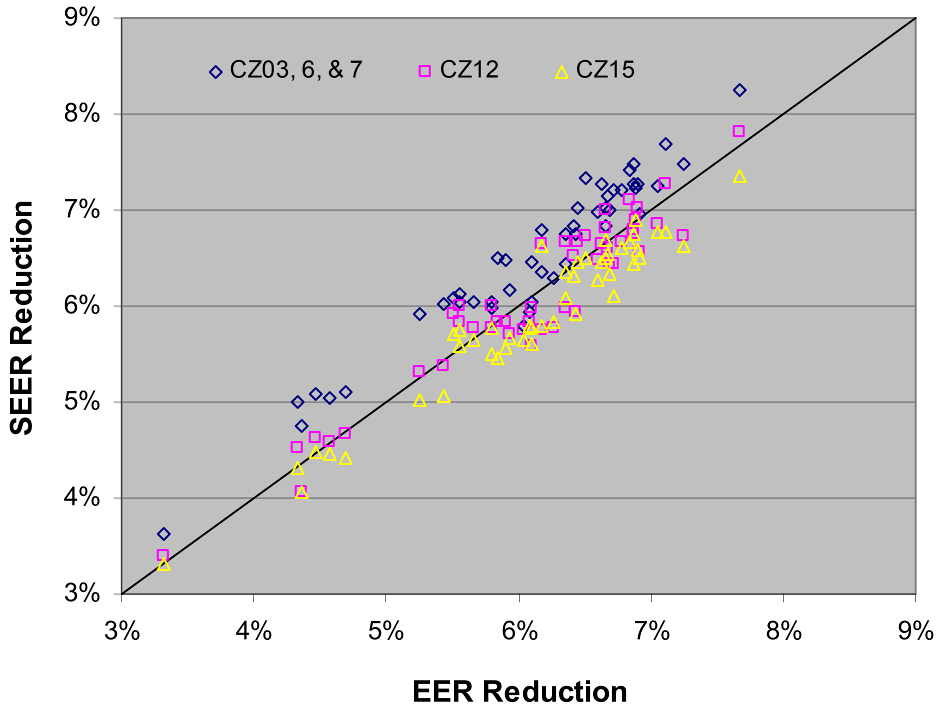
$$\%\ \text{SEER Reduction} = \text{SEER CZ Mult}_{fan} * \%\text{EER Reduction} \qquad (3)$$

where CZ Mult_{fan} are the climate zone fan multipliers as given in Table 3.2.6.

Table 3.2.6
Fan Power Climate Zone SEER Adjustments

	CZ03	CZ06	CZ07	CZ12	CZ15
SEER CZ Mult_{fan}	1.06	1.07	1.05	1.00	0.97

Figure 3.2.13
Impact of Higher Fan Energy on SEER
As Related to Change in EER



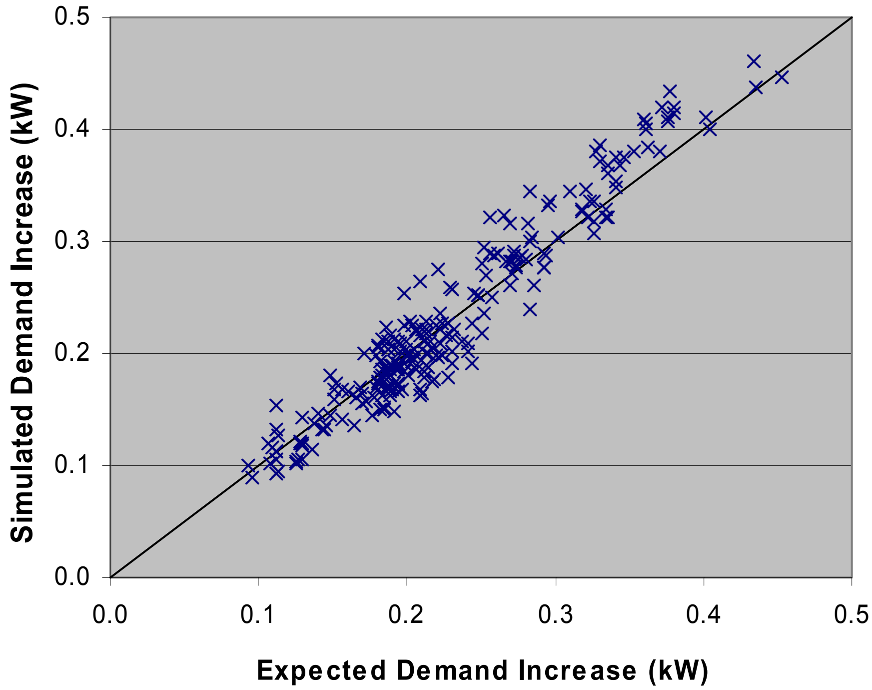
Note: Results for Climate Zones 03, 06, and 07 are nearly the same. Figure 3.2.11 shows the average effect for these three climate zones for clarity.

As one would expect, higher fan power increases the cooling system peak demand. Figure 3.2.14 compares the increase in demand from simulation results to the expected increase in demand. The expected increase in demand is given by:

$$\text{Expected Demand Increase} = \Delta\text{Fan kW} * (1 + \text{EIR}) \qquad (4)$$

Where ΔFan kW is the increase in fan power and EIR is the energy input ratio of the condenser unit. The EIR is defined as the cooling system condenser unit power divided by the gross cooling output in like systems (Btu/Btu or Watts/Watts). The (1 + EIR) multiplier accounts for the decrease in net cooling capacity caused by the larger fan. As the figure illustrates, the calculated demand impact caused by the larger fan closely matches the expected demand increase. Agreement is typically within ±10%. Since fan power is typically 10-15% of the total (fan + compressor), overall agreement is within 1% to 2% of the total system demand.

Figure 3.2.14
Impact of Higher Fan Energy on Cooling System Electric Demand



3.2.6 System Sizing

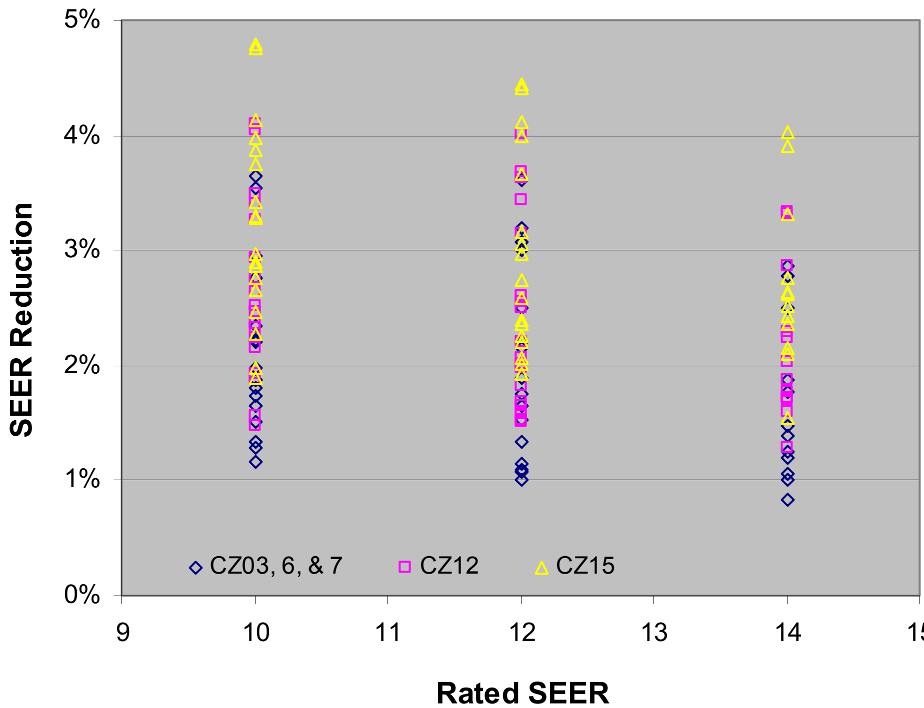
Simulation results presented to this point are based on an assumed sizing rule that matches the SEER ratings procedure. As described in Section 2.2, each system is sized at 90% of the annual peak cooling coil load. This is approximately equivalent to sizing the system to an ASHRAE 1% design condition for the assumed ratings cooling load profile.

Cooling systems are frequently oversized. A practice that is not uncommon would be to increase the design load to the nearest nominal capacity (say 32,000 Btu/hr to 36,000 Btu/hr, or 3 tons) and then install a system with the next larger capacity (a 3 ½ ton system instead of the 3 ton system). Thus a 32,000 Btu/hr cooling load would be met by a system with a cooling capacity of 42,000 Btu/hr. To capture this sizing approach, the original 90% sizing multiplier was replaced with a 125% sizing multiplier. Thus, systems were sized to 125% of the peak annual cooling coil load.

Simulations were run with the higher sizing multiplier for the median residential building prototype using the expanded database of cooling systems. Results showing the impact of over sizing on SEER are given in Figure 3.2.15. The figure shows the percentage reduction in SEER in comparison to the same system with the standard sizing applied to the same building prototype. While there is a good deal of scatter in the figure, the scale is very limited. Typical SEER impact is a 2 to 3% reduction, which is quite modest considering the system sizing was increased by nearly 40% (from 10% undersized to 25% oversized). Energy benefits associated with moving to a higher SEER are essentially unchanged from values provided in Table 3.2.3.

There is a modest climate zone relationship associated with over sizing. Hotter climates (CZ12 and CZ15) show slightly greater SEER reduction than the cooler climates (CZ03, CZ06, and CZ07). This appears to be caused by small differences in the total number of hours under-cooled between the hotter climates as compared to the cooler climates. The 90% original sizing rule tended to produce a slightly higher fraction of hours under-cooled for the hotter climates that for the cooler climates because of differing weather patterns.

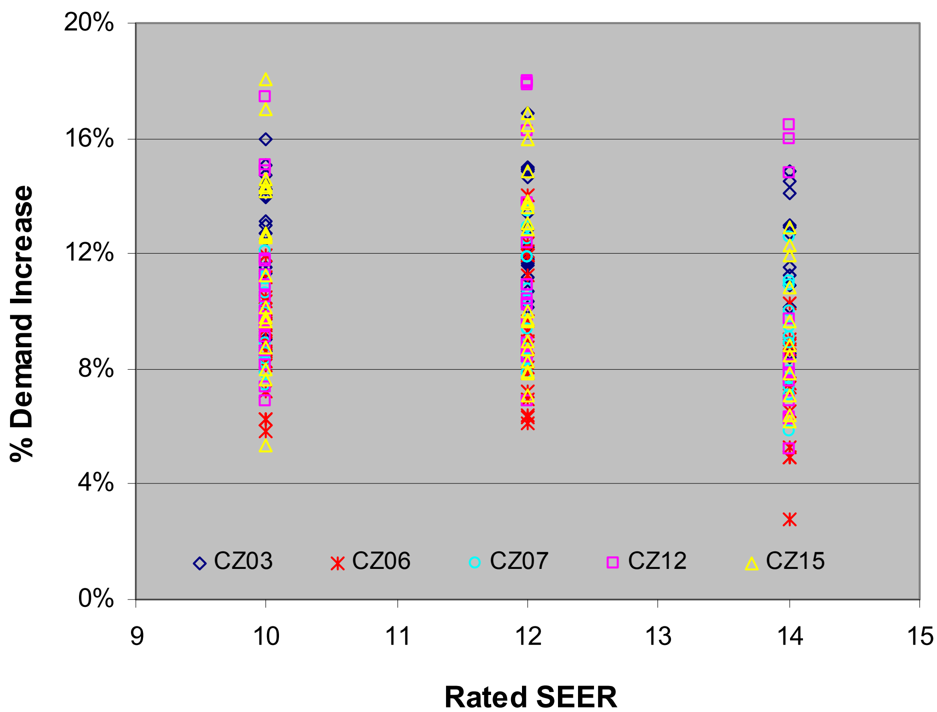
Figure 3.2.15
Impact of System Over Sizing on SEER



Simulations results predict that over sizing will have a significant impact on demand. With a change from a 90% sizing rule to the 125% sizing rule, one would expect an increase in peak demand as high as 16% to 18%. This increase includes the additional condenser unit energy from 90% to 100% of the coil load plus all of the increase in fan power. Minimum demand increase would be 4% to 5%, based on the increase in fan power with no change in condenser unit power. Simulation results, shown in Figure 3.2.15, produce results with a similar range of demand impact.

The fact that not all simulations showed demand changes at the expected maximum range has to do with the 90% sizing procedure used in the simulations. The standard sizing procedure used in all analyses begins with an initial DOE-2 simulation to determine the cooling peak coil load for the given building prototype. Cooling system performance maps are then used in conjunction with climate zone-specific design outdoor dry-bulb and mean coincident wet-bulb conditions to determine the required ARI cooling capacity to meet the coil load at peak conditions. The outdoor and indoor conditions that produce peak cooling coil loads differ slightly from design conditions. This leads to small differences among the various systems in the cooling capacity used as the 90% design value since each cooling system differs in its sensitivity to outdoor dry-bulb and entering air dry-bulb. If nominal design conditions are very close to those that occur when the seasonal cooling peak occurs, then the system will be sized very close to the desired 90% level. If design conditions are not close, then systems can vary as to how close they are to the actual 90% design condition, depending on how sensitive they are to the outdoor dry-bulb or indoor wet-bulb. These small differences between outdoor temperature and coil entering wet-bulb at design conditions and those DOE-2 calculates at peak coil conditions causes variations in the level of under sizing among the various cooling systems. While this affect has no significant impact on simulated SEER (a sizing increase of 40% produced only a 1% to 5% impact on SEER), it is enough to account for the scatter shown in Figure 3.2.16.

Figure 3.2.16
Impact of System Over Sizing on Demand



3.3 SMALL OFFICE

3.3.1 Cooling System Description

The analyses of office systems mirror those of residential systems, Section 3.3. A description of the office building prototypes is provided in Section 2.4.2, with details given in Appendix F. It is assumed that office systems are cooled by packaged systems rather than split systems. Since SEER-rated systems have cooling capacities less than 65,000 Btu/hr, these systems tend to be single compressor systems. While economizers are optional, all include ducted outside air for ventilation purposes. The range of packaged systems is somewhat limited in comparison to residential systems. They are almost exclusively SEER 10 or SEER12 systems. A few SEER 11 systems have been identified and one SEER 13 line, but these are unusual. As such, the cooling systems are limited to SEER 10 and 12 heat pumps and air conditioners.

The evaluation process begins by looking at packaged air conditioners and heat pumps with median values of degradation coefficient and efficiency sensitivity to temperature. These systems are used in conjunction with the building prototype to identify situations that lead to maximum and minimum SEER values as calculated from DOE-2 simulation results. Simulations are initially performed for five climate zones (CZ03, CZ06, CZ07, CZ12, and CZ15). Results of the simulations are used to determine the building design features, cooling system characteristics, and climate features that affect SEER. As with the residential systems, results are then used to generate climate and cooling system specific SEER modifiers appropriate for small office applications.

3.3.2 Use of SEER in Commercial Cooling Applications

The DOE definition of SEER is not well suited to commercial applications. The main problem has to do with indoor fan use. In a residential situation (for which SEER was developed), the indoor fan is typically used only to deliver cooling to the space. Accordingly, the fan is normally set to cycle with the compressor. Since the indoor fan and condenser unit turn on and off at the same time, the energy used with by the indoor fan can be added to that used by the condenser unit to define an overall cooling efficiency. This is not the case for commercial applications where the indoor fan serves two purposes – space conditioning and ventilation. Ventilation requirements in commercial settings (providing fresh air to occupants) means the indoor fan must operate continuously during occupied periods. The indoor fan does not cycle off with the compressor. This is not accounted for in the SEER rating.

The problem with this is threefold. First, SEER does not fully capture the seasonal energy use in that one could not divide a seasonal cooling load by SEER to determine the energy use of the cooling system. The SEER rating won't include all of the fan energy associated with continuous fan operation, or if the fan operation is added separately, SEER would double count fan energy during compressor operation. Therefore, SEER is not a good indicator of seasonal cooling energy use for a given cooling load.

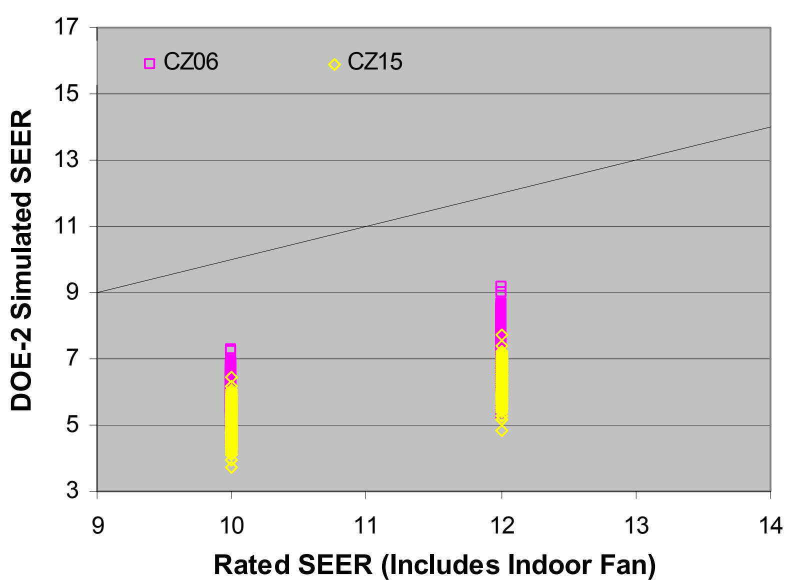
Secondly, SEER does not address the importance of the indoor fan in commercial applications as it does not distinguish between fan and condenser unit energy. Seasonal fan energy in a SEER rating is typically on the order of 10% to 15% of the total. In some commercial settings (mild climate with economizer operation), fan energy can exceed condenser unit energy over the cooling season.

In these cases, one could benefit more from selecting a cooling system based on fan efficiency rather than SEER as an equivalent or even higher SEER system could have a less efficient indoor fan.

Finally, for SEER to be most useful, it needs to be relatively independent of the cooling load. This turned out to be the case for residential applications where changes in building design and operation did not impact SEER by more than 5%. Therefore, while cooling loads varied by over 100%, SEER changed by no more than 5%. This is not the case in a commercial application where the indoor fan operates continuously, as illustrated in Figure 3.3.1. The SEER calculated from DOE-2 simulations is compared to the rated value. The simulated SEER includes indoor fan energy for each hour that coincided with the use of mechanical cooling that hour. Fan energy that occurred when there was no mechanical cooling for a given hour is not included in the SEER calculation. Results are shown for climate zones 6 and 15 in the figure (coolest and hottest zones where mechanical cooling is likely to be used).

Each symbol in Figure 3.3.1 represents a change in a building parameter, such as lighting power density, window area for perimeter offices, and use of economizer, among others. Simulations were run against median SEER 10 and 12 packaged heat pumps and air conditioners. As the figure illustrates, including fan energy in the SEER calculation produces a large variation in seasonal energy use. The variation is a result of changing cooling loads over the season, so SEER is no longer independent of cooling load. It is less a problem in hotter climates like CZ15 where condenser unit energy is much greater, but ±25% SEER variation still poses a problem.

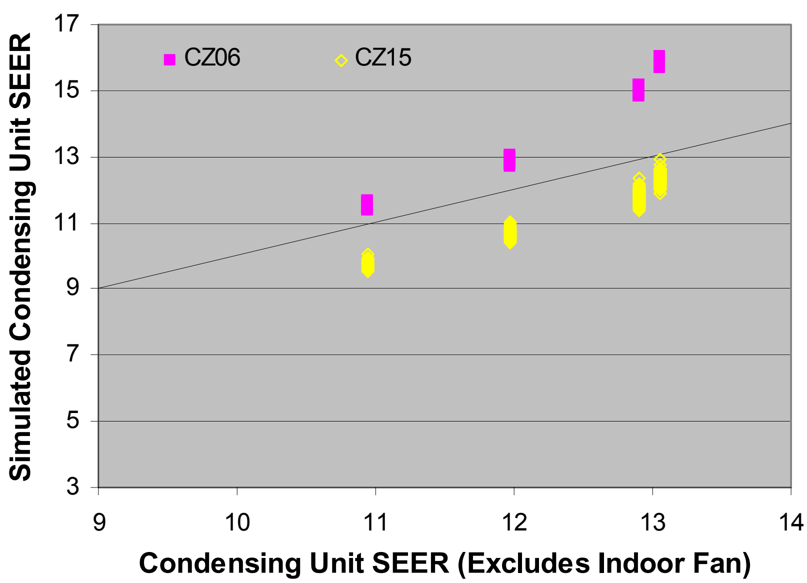
Figure 3.3.1
Simulated SEER vs. Rated SEER, Fan and Condenser Unit Energy Included



The way to resolve this issue is to separate fan and condenser unit energies. Seasonal fan energy can be estimated in a straightforward manner for commercial applications since the fan is operated on a schedule. This leaves condenser unit energy, which can still be addressed in the same fashion as SEER. In this case, seasonal cooling energy is that for the condenser unit only. The use of a condenser unit SEER is illustrated in Figure 3.3.2. The data presented in this figure is from the same DOE-2 simulations used to create Figure 3.3.1. The condenser unit SEER is the seasonal cooling load divided by the condenser unit energy. This is compared to a rated condenser unit SEER. The rated condenser unit SEER is the rated SEER of the system with the fan power removed.

As Figure 3.3.2 illustrates, condenser unit SEER is much less sensitive to the actual cooling load. The range of variation for a given cooling system and climate zone is similar to the ±5% observed in residential applications. The variation in cooling load is as much as ten-to-one for the simulations used to generate the figure. In fact, it is the large variation in cooling load that causes standard SEER to be such a poor indicator of seasonal cooling efficiency. The cooling load varies much more that fan energy, causing fan energy to be greater or lesser fractions of the total energy used for space cooling. This is not a problem when using a condenser unit SEER as the condenser unit operation directly tracks the cooling load. The results given in Figure 3.3.2 closely match residential finding, suggesting climate zone and SEER-specific multipliers for condenser unit SEER.

Figure 3.3.2
Calculated vs. Rated Condenser Unit SEER
Indoor Evaporator Fan Energy Not Included



From these observations, the overall approach used to evaluate cooling systems in office settings will include the following:

- Define and illustrate how one determines condenser unit SEER from rated SEER.
- Confirm that condenser unit SEER is an appropriate metric for determining cooling

energy from a known cooling load,

- Provide climate and equipment specific multipliers that would generate improved estimates of condenser unit SEER.
- Provide guidance on the relative importance of fan vs. condenser unit efficiencies to be used when selecting different systems of the same or differing SEER. This can only be an approximation as any approach is dependent on the actual seasonal cooling load.

3.3.3 Calculating Condenser Unit SEER from Rated SEER

The concept of calculating a condenser unit SEER from the rated SEER is very straightforward; just take out the fan energy. It is a bit more difficult in practice and, at a minimum, requires access to manufacturers' expanded ratings charts. This is less a problem for packaged systems as they are typically used in commercial applications where more detailed system engineering occurs.

The calculation of condenser unit SEER begins with recalling Equation (1.1), or:

$$SEER = EER_B * (1 - 0.5*C_D), \tag{3.1}$$

This equation is applicable to all single-speed, SEER-rated equipment, including the packaged systems addressed here. The only part of Equation 3.1 that is affected by the fan energy is EER_B, or the system's EER when operated at an 82 F outdoor temperature, or,

$$SEER_{cond} = SEER\ (EER_B/EER_{B,no\ fan}). \tag{3.2}$$

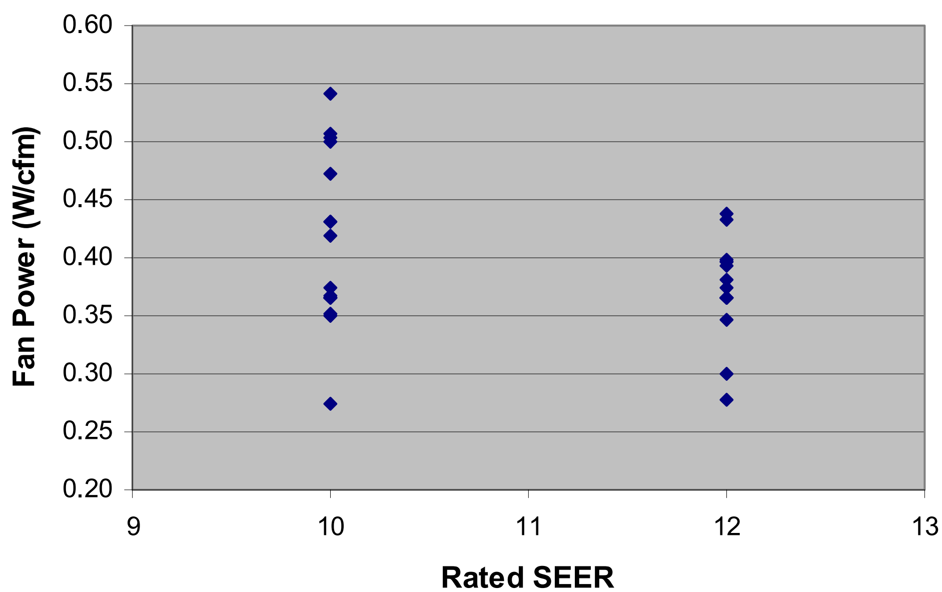
Thus, to calculate a condenser unit SEER, one needs to determine EER_B and remove the fan energy from EER_B. EER_B can be found from the expanded ratings charts. They will provide the net cooling capacity (gross less fan heat) and total system energy (condenser unit plus fan) over a range of outdoor temperatures. Use this information to either interpolate or extrapolate the information in the chart to determine the net cooling capacity and total electric input at an 82º F outdoor temperature. It is important to use chart data for the rated airflow and ARI conditions entering the cooling coil (80 F dry-bulb and 67 F wet-bulb). EER_B equals the values of net cooling capacity divided by the total system energy (system of Btu/Watts) at the 82º F outdoor temperature.

The "no fan" adjustment requires removing indoor fan effects from both the capacity and total system energy values. Like residential systems, fan power data can be difficult to obtain for SEER-rated packaged systems. Some manufacturers include an indoor fan power with their expanded ratings charts. If so, one should assume that this is the value used with the expanded ratings and is the appropriate value to use when adjusting EER_B. Other manufacturers include fan tables that include fan power data. If so, these tables should be used to determine an appropriate fan power estimate. The value used from the table is that necessary to meet the system's design flow rate (in cfm) for an external static pressure that equals, or exceeds that required in the ratings process. Minimum external static pressures used in the SEER ratings process are given in Table 3.3.1. Care should be used in understanding all that is included in the fan tables. Manufacturers can include filter pressure drop and wet coil pressure drop as external pressure drop. The SEER ratings process assumes the coil is wet and a filter is installed. Therefore, filter and wet coil pressure drops should be added to those given in Table 3.3.1 if they are not included in the fan tables. The manufacturer will provide appropriate filter and wet coil pressure drops in this case. Fan tables will also provide information for various fan speed settings (low, medium, or high). Assume the system was rated at the fan setting that meets flow and pressure requirements, but uses the least fan power. There are cases when no fan power data is given. If so, assume 365 Watts/1,000 cfm of rated air flow. It should be noted that fan power varies a great deal in packaged cooling systems (Figure 3.3.3) and the default value of 365 Watts/1,000 cfm should not be used if better estimates are available. Fortunately, fan power is typically only 10% to 15% of the total, so errors in their estimates don't strongly affect condenser unit SEER calculations.

Table 3.3.1
Minimum External Static Pressure for SEER-Rated Systems

Cooling Capacity (Btu/hr)	Min. External Static (in. w.g.)
Capacity < 28,000	0.10
29,000 < Capacity < 42,000	0.15
43,000 < Capacity < 65,000	0.20

Figure 3.3.3
Packaged System Fan Power Values
Systems Examined in This Study



Once net cooling capacity, total electric input, and fan power values are determined, the "no fan" EER_B is calculated as:

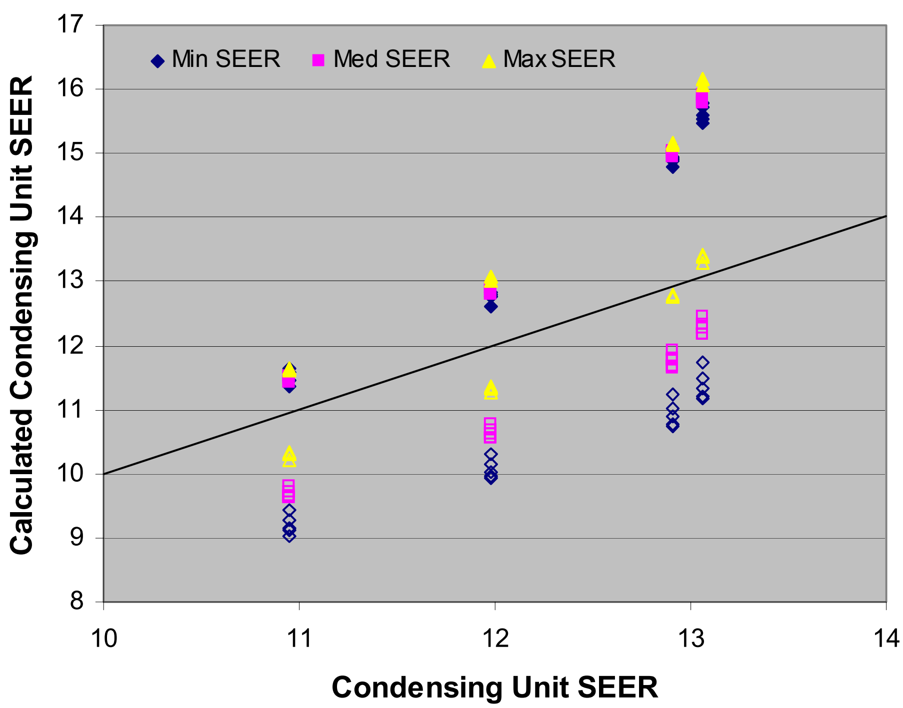
$$EER_{B,no\ fan} = (\text{Net Capacity} + \text{Fan Watts} * 3.413)/(\text{Total Electric} - \text{Fan Watts}) \qquad (3.3)$$

Where Net Capacity is in systems of Btu/hr and Total Electric and Fan Watts are in systems of Watts. The net capacity and total electric are those found for the 82º F outdoor temperature. Condenser unit SEER is then calculated using Equation 4.2.

3.3.4 Impact of Building Features on Simulated SEER, Median Cooling System Models

DOE-2 simulations were performed over the range of building characteristics as given in Section 2.4.2. These characteristics include: equipment, personnel, and lighting densities; core and perimeter cooling zones; multiple window-wall ratios and glass types; economizer operation; and operating schedules, among others. Each was varied over its minimum, median, and maximum values to determine its impact on condenser unit SEER. Building features that caused a significant increase or decrease in SEER were accumulated to produce a combination of features that lead to maximum and minimum values of calculated condenser unit SEER. These results are presented for climate zones 6 (coolest) and 15 (hottest) in Figure 3.3.4. Results for the other climate zones are qualitatively consistent and fall between these two. Results for CZ06 are shown as filled figures, those for CZ15 as open figures.

Figure 3.3.4
Minimum, Median, and Maximum Condenser Unit SEER
Median Cooling Systems - CZ06 and CZ15

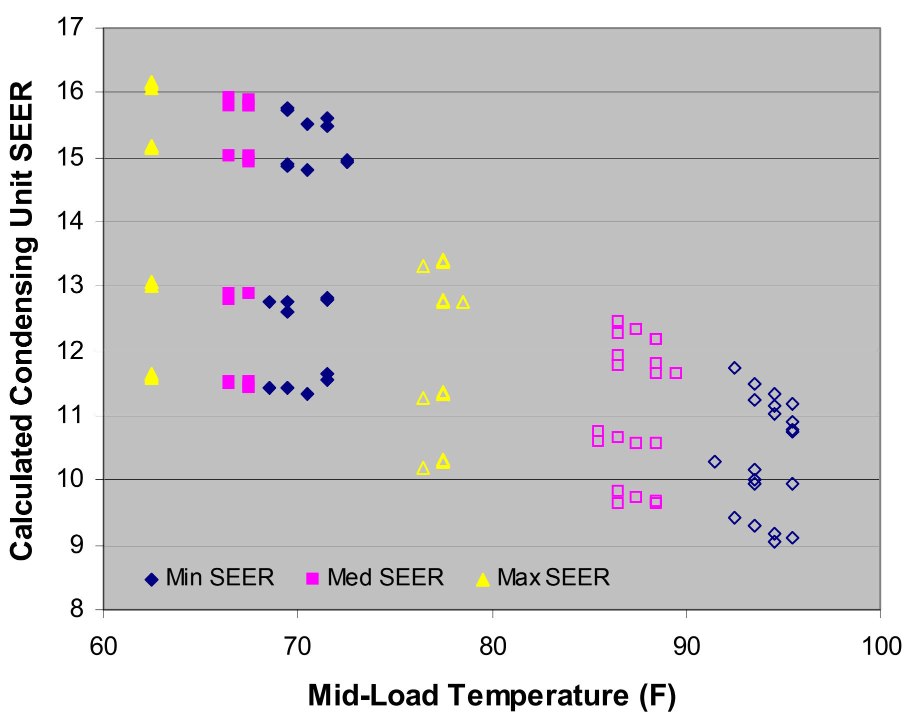


The findings illustrated in Figure 3.3.4 differ from those observed in a residential application (Figure 3.2.3). Of importance are the trend differences illustrated in Figures 3.2.3 and 3.3.4, rather than actual SEER values. Two key differences include the following:

1. The effect of building characteristics on SEER are much more climate zone dependent in an office setting than for a residence. That is, changes in the building operation and design have little effect on SEER in the cooler CZ06, but have a significant effect in CZ15. For residential systems, changes in building characteristics had about a ±5% impact for all climate zones.
2. The impact of various building design an operational features in an office setting can lead to a much greater impact on SEER; ±12% for CZ15.

These differences and the reason one should expect more uncertainty in SEER as applied to an office setting are illustrated in Figure 3.3.5. This figure compares the calculated condenser unit SEER to the mid-load temperature obtained from the simulation. As with residential systems, condenser unit SEER tracks the mid-load temperature quite well. The problem is that mid-load temperatures can vary much more in a commercial setting than a residential one. The variation in mid-load temperature in CZ15 for commercial systems is approximately 20º F, as compared to only 10º F in residential settings. The greater variation in mid-load temperature caused the increase in sensitivity of condenser unit SEER to changes in building operation.

Figure 3.3.5
Minimum, Median, and Maximum Condenser Unit SEER vs. Mid-Load Temperature
Median Cooling Systems - CZ06 and CZ15



Results presented in Figure 3.3.5 allow a number of observations to be made concerning the operation of cooling system in office settings. These include the following:

1. The data used to generate Figure 3.3.5 include simulation results from cooling systems serving the four perimeter zones and the core zone. The data tends to fall along four trend lines, each corresponding to a given cooling system with differing rated condenser unit SEER values. Thus, each group of points corresponds to a specific set of design features and one cooling system. For some simulations, the calculated condenser unit SEER differs so little from cooling zone to cooling zone (four perimeter and core zones) that it is difficult to determine that five simulations are included in the figure. Even when the points are distinguishable, there is almost no variation in SEER. From this one can conclude that building features that are related to skin loads (wall U-values, window area, window U-value, or window shading coefficient) have no significant impact on seasonal condenser unit efficiency. They can, and do, impact cooling loads; just not cooling system efficiency as illustrated by the condenser unit SEER.

2. Scheduling and space usage issues dominate condenser unit SEER changes by forcing changes in the mid-load temperature. For example, a high occupancy level with low lighting and equipment loads used in conjunction with a 10 hour per day operating schedule drives the mid-load temperature higher. The high occupancy load requires high ventilation rates that increase the load on the cooling coil in hot weather. The reduced lighting and equipment loads mean that less cooling is required when it is cool outside. Finally, the shorter operating schedule assures that the cooling load will occur during daylight hours when it is hotter. All of these features lead to increased compressor operation as the outdoor temperature increases (high mid-load temperature). Conversely, a low mid-load temperature occurs when occupancy levels are low, equipment and lighting levels are high, and the assumed operating schedule is extended. All lead to and increase in compressor operation when it is cool outside and a lower mid-load temperature. As with residential systems, there is no simple way to account for the interaction of these issues in a way that would produce improved estimates of the mid-load temperature or condenser unit SEER.

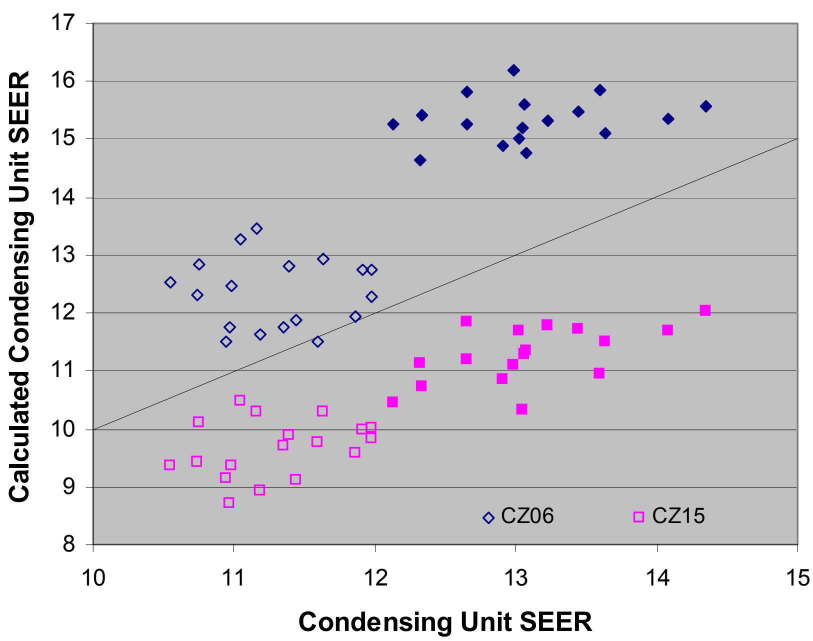
3. Variations in building operation have little effect on condenser unit SEER for cooler climates (CZ06). There are several reasons for this. First, the spread in mid-load temperature caused by these changes is relatively small. Second, mid-load temperatures tend not to significantly exceed 72º F. This is important because of the assumed operation of commercial cooling systems. All are assumed to have low ambient compressor controls installed. These controls cycle the outdoor fan as the outdoor temperature drops to limit the range of pressure differentials handled by the compressor. Simulations assume that this begins at a 70º F outdoor temperature. The effect of this control is that the condensing unit efficiency doesn't change significantly as the outdoor temperature drops below 70º F. Changes in the entering air conditions can impact efficiency, but these tend to be minor in comparison to changes in outdoor temperature. Similar effects are observed for the other cooler climate zones (CZ03 and CZ07) examined here.

The differences between minimum to maximum SEER also impact SEER benefit, which was not the case in residential applications. That is, the benefit of moving to a higher SEER compressor is consistent with differences in condenser unit SEER for building configurations that lead to maximum, median, and minimum condenser unit SEER. The building configuration that would lead to a 15% higher SEER also results in a 15% greater benefit when moving from a lower to a higher SEER rated compressor. Conversely, building configurations that produce a lower condenser unit SEER lead to a reduced benefit associated with moving from a lower SEER rated compressor to a higher one. Building features have very little impact on condenser unit SEER improvement when they have little impact on condenser unit SEER (cooler climates like CZ06, for example). Thus, in office applications, even condenser unit SEER is not as useful a predictor of cooling energy from known cooling loads as it is in a residential application. Condenser unit SEER can be dependent on the cooling system application for some climate zones. This obviously poses problems when viewing SEER as seasonal energy efficiency metric associated with a particular cooling system used in any similar application.

3.3.5 Impact of Cooling System Features on Simulated SEER, Median Building Models

Results in Section 3.3.4 were expanded to include the full range of cooling systems. Simulation results are shown in Figure 3.3.6. Data in the figure are for the entire building (energy weighted results of all five thermal zones – four perimeter and core) for median building characteristics. Results shown are for climate zones 6 and 15 (hottest and coldest of the five examined here). Systems with a nominal SEER-10 rating are shown as open symbols; those with a nominal 12 SEER as filled symbols. Cooling systems include both heat pumps and air conditioners. The figure compares each system rated condenser unit SEER (as calculated by Equation 3.2) to that calculated via DOE-2 simulations.

Figure 3.3.6
Calculated vs. Rated Condenser Unit SEER for All Packaged Systems
Median Building Features - CZ06 and CZ15



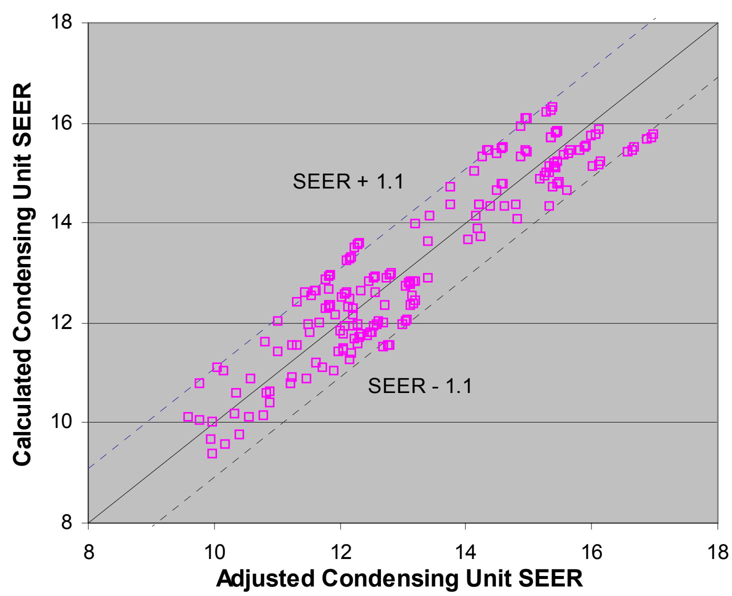
Calculated condenser unit SEER is related to rated condenser unit SEER much like calculated and rated SEER are related in residential applications. Both show similar climate trends (lower in hotter climates, higher in cooler climates), and both show strong relationships between calculated and rated values. They differ in that there is a good deal more variation in calculated condenser unit SEER for a given rated value in an office application (compare Figures 3.2.7 and 3.3.6).

Table 3.3.2
Condenser Unit SEER Climate Multipliers
Median Building Features – CZ03, CZ06, CZ07, CZ12 and CZ15

System SEER	CZ03	CZ06	CZ07	CZ12	CZ15
10	1.10	1.10	1.10	1.03	0.91
12	1.18	1.18	1.18	1.09	0.93

Simulation results do allow for the generation of climate zone and SEER-specific multiplier to account for gross differences in condenser unit SEER. These are presented in Table 3.3.2 for the five climate zones and two nominal SEER values examined in this effort. These are applied to the rated condenser unit SEER in Figure 3.3.7 and compared to calculated values. The multipliers eliminate the climate-related differences shown in Figure 3.3.6, but only can reproduce simulated SEER to within ±1.1 SEER ratings points. This scatter is a caused by differences in the cooling systems as all simulation results are for the same median building configuration. When the building configuration is allowed to vary to conditions that produce maximum and minimum SEER values, condenser unit SEER can only be predicted to within ±1.7 SEER ratings points (Figure 3.3.8).

Figure 3.3.7
Calculated vs. Rated Condenser Unit SEER for All Packaged Systems
Median Building Features - CZ06 and CZ15



Building features that lead to higher and lower values of condenser unit SEER for office applications are given in Table 3.3.3. As has been noted previously, building features that lead to higher values of condenser unit SEER do not necessarily result in reduced cooling energy, just improved compressor-operating efficiency. Higher lighting power densities and internal gains a examples of this. Both lead to increased condenser unit SEER and higher cooling energy. Higher lighting and internal gains increase condenser unit SEER because the compressor has increased hours of operation when it is cooler outside and condenser unit efficiency is higher. This produces a higher overall seasonal efficiency, or SEER, even though cooling loads are higher. Excluded from the table and consideration in condenser unit SEER is economizer operation. The inclusion of economizers skews SEER values lower to the point that they overwhelm the impact of all other building features. All results assume the median value for the economizer use, which is fixed ventilation flow based on design occupancy. There is no doubt that economizers have energy benefits, it is just that those benefits can't be properly cast in terms of SEER.

Some building parameters listed in Table 3.3.3 are not applicable to interior, or core, zones. These include window properties and areas and wall properties and areas. Roof parameters can affect interior zones.

Table 3.3.3

Building Parameters Affecting Condenser Unit SEER[1]

Affect on SEER Because of an Increase in Parameter Value

	CZ03	CZ06	CZ07	CZ12	CZ15
Use of Shades	Lower	Higher	Lower	Lower	Lower
Perimeter Depth	Higher	Higher	Higher	Higher	Higher
Occupancy[2]	Higher	Higher	None	Higher	Higher
Lighting Power Density	Higher	Higher	Higher	Higher	Higher
Internal Gains	Higher	Higher	Higher	Higher	Higher
Operating Hours	Higher	Higher	Higher	Higher	Higher
Glass Area	Lower	Lower	Lower	Lower	Lower
Glass U-value	Higher	Higher	Higher	Higher	Higher
Glass SC	Lower	Lower	Lower	Higher	Higher
Window Ovrhng Depth	Higher	Higher	Higher	Lower	Lower
Wall U-value	Higher	Higher	Higher	Higher	Higher
Roof Insul	Higher	None	Higher	Higher	Higher
Cool T'stat SP	Higher	Higher	Higher	None	Lower

Notes:

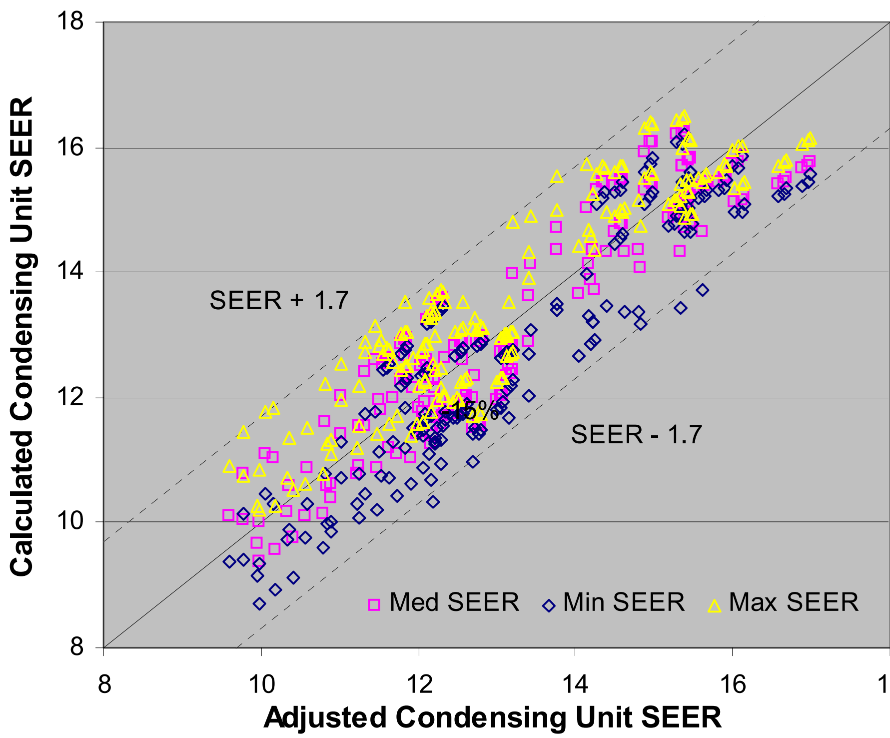
1. *Changes in values that lead to an increase in simulated SEER do not necessarily result in lower total seasonal energy use.*
2. *Occupancy levels are total number of occupants. Thus, an increase in occupancy level results in more*

occupants in the space.

One has to question the value of SEER as an energy predictive metric in office settings given the uncertainty in condenser unit SEER illustrated in Figures 3.3.7 and Figure 3.3.8. While climate corrections worked reasonably well in a residential setting (uncertainty on the order of +/5%), they are not as effective in an office setting where uncertainty is on the order of ±15% on the compressor alone. Added to this is the problem of combining seasonal fan energy use with condenser unit energy. This adds another level of uncertainty as the relative size of fan and condenser unit energy is related to the magnitude of the seasonal cooling load. Given these issues, it is fair to say that SEER, as a seasonal energy predictor, is not a workable concept in office settings. Part of the problem is associated with seasonal fan energy use. Part is the highly variable nature of the cooling loads in office settings and their impact on the seasonal performance of the cooling system. Either would be problematic; together they rule out the use of SEER as a reliable seasonal cooling system efficiency measure.

Figure 3.3.8

Calculated vs. Rated Condenser Unit SEER for All Packaged Systems
Minimum, Median and Maximum SEER Building Features - CZ06 and CZ15



3.3.6 SEER as a Cooling System Ranking Metric in Office Applications

The most strongly held position on SEER is that it provides a means of ranking cooling system in terms of their seasonal energy efficiency. That is, a higher SEER rated system will always use less cooling energy than a lower SEER rated system. While it is clear that SEER has problems in predicting seasonal cooling energy, will it rank cooling systems for use in an office application? For example, can we determine the relative importance of fan and condenser unit energy in a particular office setting that will allow a designer to choose one cooling system over another? In this case, the new rating may not provide an accurate estimate of seasonal energy use, but it may be accurate enough to choose one system over another. This is aided by the fact that there are fewer choices of packaged cooling systems typically used in office settings. The market is dominated by SEER 10 and SEER 12 systems. As such, the metric does not have to be as accurate as it would in a residential setting where there are much finer differences in equipment.

The use of SEER as a ranking tool in a commercial application needs to account for both annual condenser unit and fan operation. While the compressor runs only when cooling is needed, the fan runs during all occupied periods. It is important to include the seasonal fan operation in any measure of seasonal system energy efficiency as the indoor fan and air-handling system is included with the cooling system. Thus, once a cooling system is selected, included in the selection is the internal static pressure and fan/fan motor associated with that system. The energy consumed with the indoor fan occurs throughout the year, whether or not the system is providing cooling to the space. So any metric that is used to rank systems needs to include the impact the indoor fan might have on seasonal energy use along with the efficiency of the condenser unit.

In this light, a SEER rating was developed applicable to situations that require continuous fan operation. This SEER is given as:

$$SEER_f = [1/SEER_{cond} + (Hrs_{fan}/Hrs_{comp})*W_{fan}/Cool\ Cap]^{-1} \qquad (3.4)$$

Where:

$SEER_f$ is the SEER that includes continuous fan operation,

$SEER_{cond}$ is the condenser unit SEER as defined above,

Hrs_{fan} is the total hours of fan operation over the year,

Hrs_{comp} are the equivalent full-load hours of cooling operation (seasonal cooling energy divided by rated cooling capacity),

W_{fan} is the rated fan power in Watts, and

Cool Cap is the rated cooling capacity in Btu/hr.

Of the information necessary to calculate $SEER_f$, only the rated fan power and cooling capacity are known for a given system. They can be calculated or estimated from manufacturer's literature. Methods have been developed to estimate condenser unit SEER in Section 3.3.5, although with an uncertainty of ±15% of the estimate. The one remaining unknown is the ratio of hours of fan operation to the full-load cooling hours (runtime ratio). This unknown is the major obstacle in estimating SEER for commercial settings as it can vary tremendously by climate zone and application. The approach taken here is to determine reasonable estimates of this ratio for a typical office setting and see if it allows systems to be ranked as to their seasonal energy efficiency.

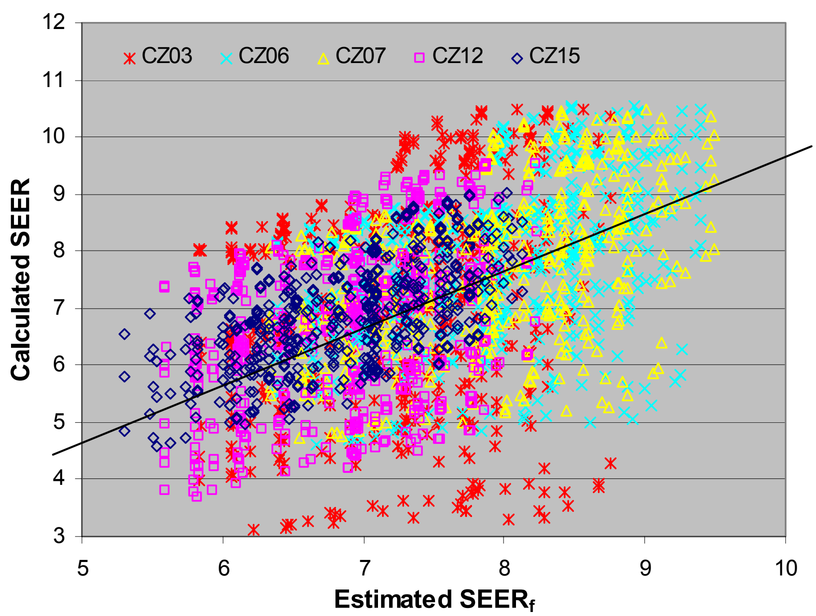
Ratios of fan and cooling operating hours are given in Table 3.3.4 based on the median office configuration. Values are presented for the five climate zones examined and by thermal zone. It was determined that the runtime ratio was dependent on the thermal zones served by the cooling system. Systems serving a core zone (no exterior walls or windows) tended to have lower runtime ratios that perimeter zones (those with walls and windows). The south-facing perimeter zone differed from north, east, and west-facing perimeter zones. The runtime ratios for north, east, and west-facing perimeter zones differed only slightly and did not need to be differentiated.

The runtime ratios provided in Table 3.3.4 were used in conjunction with condenser unit SEER multipliers provided in Table 3.3.2 to provide $SEER_f$ estimates. These are compared to SEER values obtained from DOE-2 simulations in Figure 3.3.9. DOE-2 results provided in the figure include those that produced maximum and minimum SEER values, along with median values. The range in simulated SEER in comparison to adjusted values provided by Equation 3.4 is quite large, reinforcing the assertion that SEER is a poor metric for predicting seasonal energy use in office applications.

Table 3.3.4
Fan-to-Cooling Runtime Ratios for Use with Equation 3.4
Median Building Features – CZ03, CZ06, CZ07, CZ12 and CZ15

Area Served	CZ03	CZ06	CZ07	CZ12	CZ15
Core	3.77	3.26	3.37	4.37	4.29
North, East, West	4.28	3.58	3.62	4.35	3.48
South	3.99	3.14	3.03	3.89	3.12
Average	4.10	3.41	3.48	4.28	3.50

Figure 3.3.9
Calculated (Simulated) vs. Estimate $SEER_f$ for All Packaged Systems
Minimum, Median and Maximum SEER Building Features



The results presented in Figure 3.3.9 would tend to indicate that the new $SEER_f$ has little or no value. It turns out that this is not the case. While not effective in predicting seasonal cooling efficiency, it is beneficial in ranking the cooling system efficiency from system to system. Differences in cooling systems with the ***same*** SEER rating can produce up to a 29% difference in annual cooling energy for a given application. Average differences in annual cooling energy are presented in Table 3.3.5 for median building configurations and building configurations that produce maximum and minimum SEER values.

$SEER_f$ provides a means of ranking systems independently of their SEER rating. It does so by comparing the relative benefits of a system with lower fan energy needs to one with a more efficient compressor. As such, it can compare systems of both the same and different SEER rating. Simulation results show that $SEER_f$ is not perfect, as it won't always select the most efficient system for a particular application. However, it will reduce the chances of selecting a bad system with the same SEER rating. This is significant since SEER provides no guidance.

Table 3.3.5

Differences in Annual Cooling System Energy Use for Same SEER Systems
Office Application Values Averaged Over All Zones

Rated SEER	CZ03	CZ06	CZ07	CZ12	CZ15
	Median Building				
10	13%	11%	11%	15%	17%
12	16%	13%	14%	13%	18%
	Maximum SEER Building				
10	10%	9%	8%	12%	14%
12	10%	10%	10%	9%	14%
	Minimum SEER Building				
10	18%	12%	14%	23%	24%
12	21%	15%	17%	21%	20%

General rules when using $SEER_f$ to rank systems are as follows:

1. $SEER_f$ is reliable to within 0.5 ratings points. That is, if two or more systems do not vary by more than 0.4 ratings points when ranked by $SEER_f$, one should assume that all would produce the same annual energy use. This is true no matter what the nominal rating (some nominal SEER-10 systems fared better than nominal SEER-12 in a few simulations, as was borne out in the $SEER_f$ ranking).

2. For the packaged systems examined in this study, selecting the system with the highest $SEER_f$ rating was always as least as good as the median system. Thus, the ranking process eliminated the worse 50% of systems under consideration at a minimum. In some cases it did much better. The difference in seasonal energy between the best and worse systems selected using $SEER_f$ would be, at most, half of that given in Table 3.3.5.

3. $SEER_f$ rated systems differently depending on the climate zone, application (core or perimeter use), and building configuration (median, maximum, and minimum SEER building models).

4. The multipliers used in the calculating $SEER_f$ (Tables 3.3.4 and 3.3.2) were developed from simulations based on the median building configurations. They were as effective in ranking systems that were simulated against building configurations that produced maximum and minimum SEER values as they were for the median case. As such, $SEER_f$ should be applicable for ranking systems used to cool buildings whose configurations fall within those examined in this study. See Appendix F for a full listing and range of building features examined.

The performance range given in Table 3.3.5 suggests that rated SEER may not properly rank systems in this application. A comparison of the energy benefit associated with moving from a SEER-10 to a SEER-12 system is given in Table 3.3.6. The tabular data are for the median building features; results for building features that produce minimum and maximum SEER values are similar.

Results provide in Table 3.3.6 illustrate that SEER is not as reliable ranking tool when used in an office application as it is for residential use. While moving to a higher SEER-rated system can produce energy saving that exceed expectations, it also may provide no significant energy benefit. This should not be surprising since most of the assumptions concerning system operation inherent in the SEER ratings process do not apply to commercial applications. Differences in fan energy requirements that are indistinguishable in SEER ratings but are a significant impact in commercial applications are a primary factor. Additional issues, such as variable coil entering conditions resulting from ventilation requirements and system loads that are less sensitive to outdoor temperature, also differ from SEER ratings assumptions.

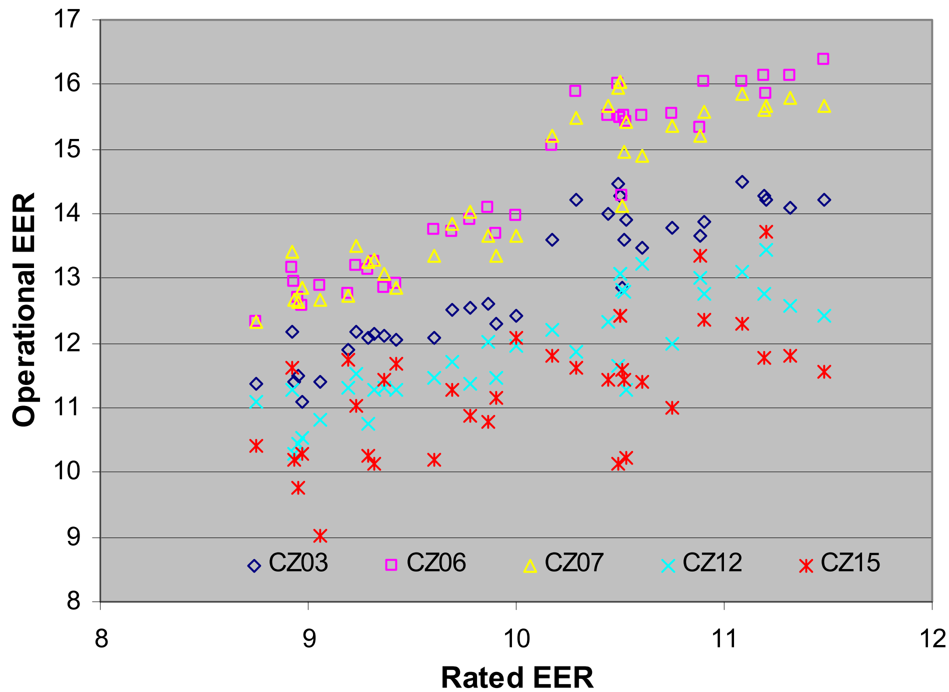
Table 3.3.6
Energy Benefits of Moving to a Higher SEER System (SEER 10 to 12)
Office Application Results for the Entire Building

	CZ03	CZ06	CZ07	CZ12	CZ15
	Air Conditioner				
Expected	17%				
Lowest	2%	5%	5%	7%	2%
Average	18%	18%	18%	13%	13%
Highest	32%	31%	31%	28%	29%
	Heat Pump				
Expected	17%				
Lowest	3%	5%	5%	2%	-4%
Average	15%	14%	13%	11%	7%
Highest	31%	29%	30%	31%	31%

3.3.7 Electric Demand

Peak electric demand calculated from DOE-2 simulations is almost as variable as SEER. One would expect some variation given that the DOE-2 models look at zones with different orientation. However, demand can be highly variable even when the only difference in the simulations is the cooling system, as illustrated in Figure 3.3.10. This figure shows the relationship between the operational EER (cooling system peak demand divided by the cooling system rated capacity) and rated EER for systems serving the west-facing perimeter zone. The only variables are climate zone and cooling system.

Figure 3.3.10
Operational (Simulated) vs. Rated EER – Commercial Systems
West-facing Perimeter Zone



Rated EER is a reasonably good metric for predicting system demand for cooler climates (CZ03, CZ06, and CZ07), but not for warmer climates (CZ12 and CZ15). Peak cooling conditions for a given system are dependent on both the outside air temperature and coil entering conditions. Each system varies as to how much its capacity and efficiency is dependent on each variable. This can lead to peak load conditions (day of year, time of day, solar load, internal gains, etc.) that differ from system to system. The peak cooling condition may occur on the hottest day for those systems that are very sensitive to outdoor temperature. They may occur during a period of high solar gains on a less hot day for other systems. These are not strong effects for the cooler climates, so operation EER tracks rated EER rather well. They do impact peak conditions for the warmer climates.

The range of demand benefit associated with replacing a SEER-10 rated system with a SEER-12 is given in Table 3.3.7. The "Expected" value is that associated with the change in rated SEER. As with residential systems, moving to a higher SEER system does not guarantee a demand reduction. Unlike residential systems, EER does not necessarily provide a guide to demand reduction. The variability of space loads and their interaction with ambient conditions (solar and temperature) can differ significantly from those assumed in the ARI ratings process. The only consistent finding was that packaged systems using R-410 refrigerant had poorer demand performance than their R-22 counterparts in hotter climates. R-410's temperature sensitivity leads to a higher SEER rating, all other factors equal (more efficient at the 82º F SEER rating point, but less efficient for outdoor temperatures greater than 95º F). This temperature sensitivity also means R-410 cooling systems tend to impose a higher electric demand in comparison to a similar R-22 based system. DOE-2 simulations showed this as the case.

Table 3.3.7
Demand Benefit of Moving to a Higher SEER System
Packaged Systems Used in Office Setting – Building Average

	CZ03	CZ06	CZ07	CZ12	CZ15
Expected			17%[1]		
Lowest	4%	4%	4%	-13%	-26%
Average	16%	18%	18%	10%	8%
Highest	25%	27%	25%	29%	29%

Note 1: Based on SEER increase

3.3.8 Increased Fan Energy and System Over Sizing

Simulation results up to this point are base on median values of fan energy and system sizing rules that match the SEER ratings process. Higher fan energy values and alternative sizing approaches were examined by adjusting both parameters independently and together in subsequent simulations. Their impacts on seasonal energy use are then compared to that associated with expected (median) fan and capacity parameters.

Median fan energy values assume a system external static pressure of 0.48" w.g.. This is the median total system static pressure determined from the CEC PIER Integrated Design of Small HVAC Systems. Since this is greater than the 0.10 to 0.20" w.g. used in the SEER ratings process (Table 3.3.1), median fan energy values used in this analysis are 22% greater than the nominal values used in the SEER ratings. This increase accounts for the system's internal static, increased filter static pressure, the higher external static pressure, and the effects of these changes on system volumetric flow. The high value of fan energy was assumed to be 45% greater than the nominal values used in the SEER ratings process. This includes a 0.78" w.g. increase in external static and filter static pressures.

Simulation results presented to this point are based on an assumed sizing rule that matches the SEER ratings procedure. As described in Section 2.2, each system is sized at 90% of the annual peak cooling coil load. This is approximately equivalent to sizing the system to an ASHRAE 1% design condition for the assumed ratings cooling load profile. Cooling systems are frequently oversized. A practice that is not uncommon would be to increase the design load to the nearest nominal capacity (say 32,000 Btu/hr to 36,000 Btu/hr, or 3 tons) and then install a system with the next larger capacity (a 3 ½ ton system instead of the 3 ton system). Thus a 32,000 Btu/hr cooling load would be met by a system with a cooling capacity of 42,000 Btu/hr. To capture this sizing approach, the original 90% sizing multiplier was replaced with a 125% sizing multiplier.

The impacts of increased fan energy and system over sizing are shown in Figures 3.3.11 and 3.3.12. Figure 3.3.11 compares the condenser unit SEER for median building parameters to those associated with increased fan static pressure, system over sizing, and increased fan static pressure plus system over sizing. Figure 3.3.12 compares median values of $SEER_f$. Both figures are for results obtained from simulation for Climate Zones 6 and 15 (hottest and coolest climate zones considered). Results for other climate zones are consistent with those given in the figures. Results are for the entire building and are energy-weighted results by thermal zone (perimeter offices plus core zone). Individual zonal results do not differ significantly.

Figure 3.3.11
Effect of Higher Fan Energy and System Sizing on Condenser Unit SEER
Office Building Average – CZ06 and CZ15

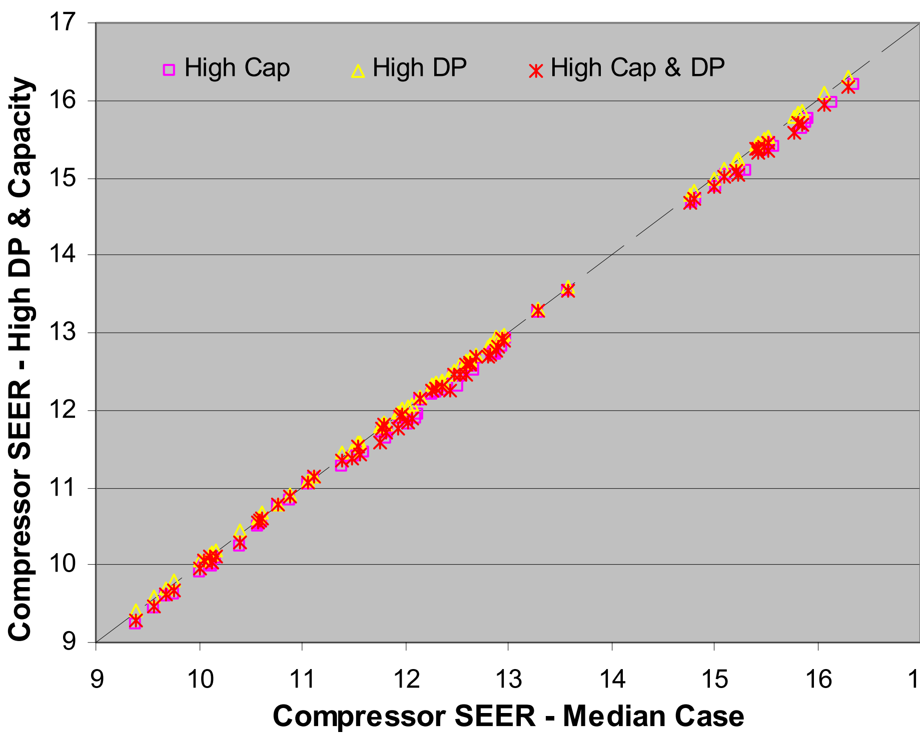
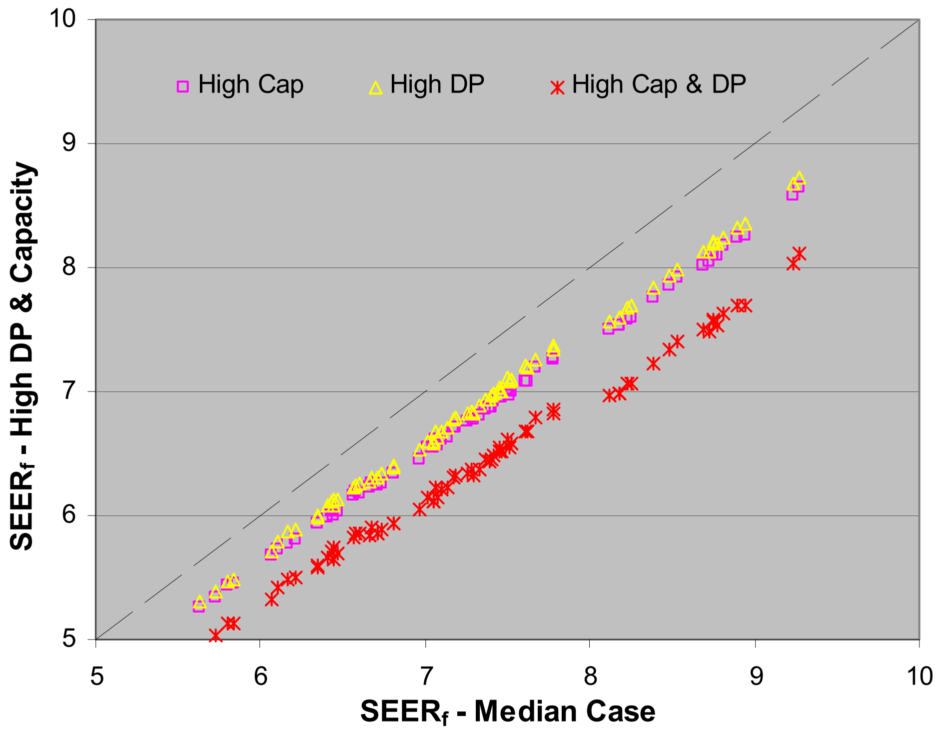


Figure 3.3.12
Effect of Higher Fan Energy and System Sizing on $SEER_f$
Office Building Average – CZ06 and CZ15



The main conclusion that can be drawn from an examination of the two figures is that losses in system efficiency are almost entirely a result of increased fan energy. This is based on the following observations:

1. Condenser unit SEER is essentially unaffected by increased system static pressure and weakly affected by system over sizing (less than 1%). Again, this does not mean that there is no increase in condenser unit seasonal energy use, just that the seasonal condenser unit efficiency is unaffected.

2. Fan static pressure and system over sizing do reduce overall system efficiency ($SEER_f$), as illustrated in Figure 3.3.12. This is because both lead to increased fan energy. The increase associated with fan static pressure is obvious. That associated with increased system capacity is because the larger system uses a larger fan. Because the fan operates even when the compressor does not, the higher fan energy causes a direct reduction in overall system SEER (fan + condenser system).

3. Within the range of increased static pressure and system over sizing, the effects are additive. Increased static pressure decreases $SEER_f$ by 4% - 5%. Increased system sizing reduces $SEER_f$ by 7%. Increased static pressure plus increased system sizing reduces $SEER_f$ by 11% - 12%.

4. The packaged systems examined in this study had cycling loss coefficients (C_D or

degradation coefficients) between 0.02 and 0.23. Based on these values and the DOE ratings assumptions, one would have expected up to an 11% reduction in condenser unit SEER for the level of over sizing examined in this study. In fact, while cycling losses followed trends in the loss coefficient (higher loss coefficient produced lower values of condenser unit SEER), the overall impact was never greater than 1%. This suggests that systems cycle much less in office applications and that the SEER ratings process overstates the benefit of system features that reduce cycling losses.

3.4 RETAIL SYSTEMS

The issues and simulation results of cooling systems used in retail applications are like those of small offices, Section 3.3. A description of the retail building prototypes is provided in Section 2.4.3, with details given in Appendix F. Like office applications, it is assumed that retail buildings are cooled by packaged systems and that their fans operate continuously during occupied periods. The issues and findings of cooling systems in a retail application are similar to those for small offices in that fan energy is a much larger fraction of seasonal energy use than in residential systems. Results presented in this section include intermediate finding used to illustrate the issues and findings presented in Section 3.3. The reader is referred to Section 3.2 for the details associated with the use of SEER-rated equipment applied to commercial applications.

3.4.1 Condenser Unit SEER and $SEER_f$

Like small office system, changes in building construction and operation have a significant affect on cooling system performance. Figure 3.4.1 illustrates how these factors impact condenser unit SEER (cooling system SEER exclusive of fan energy). Condenser unit SEER as determined by the DOE-2 simulations is compared to rated condenser unit SEER adjusted for climate zone. Climate zone adjustments for condenser unit SEER consistent with those presented in Table 3.3.2 for small office applications are given in Table 3.4.2 for retail applications. The results for retail operations closely match those for small offices (Figure 3.3.8).

Building features that lead to higher and lower values of condenser unit SEER for retail application are given in Table 3.4.1. As has been noted previously, building features that lead to higher values of condenser unit SEER do not necessarily result in reduced cooling energy, just improved compressor-operating efficiency (see related comments in Section 3.3.5).

Fan-to-compressor runtime ratios for retail cooling systems and median building features are given in Table 3.4.3. A comparison of Table 3.3.4 for office systems and Table 3.4.3 for retail systems indicates that, for median building features, fan energy is a slightly greater fraction of the total in retail applications than in offices. The resulting values of estimated $SEER_f$ are compared to values found from simulation in Figure 3.4.2. Results are similar to office applications as illustrated in Figure 3.3.8.

Figure 3.4.1
Calculated (Simulated) vs. Rated Condenser Unit SEER for All Packaged Systems
Minimum, Median and Maximum SEER Retail Building Features - CZ06 and CZ15

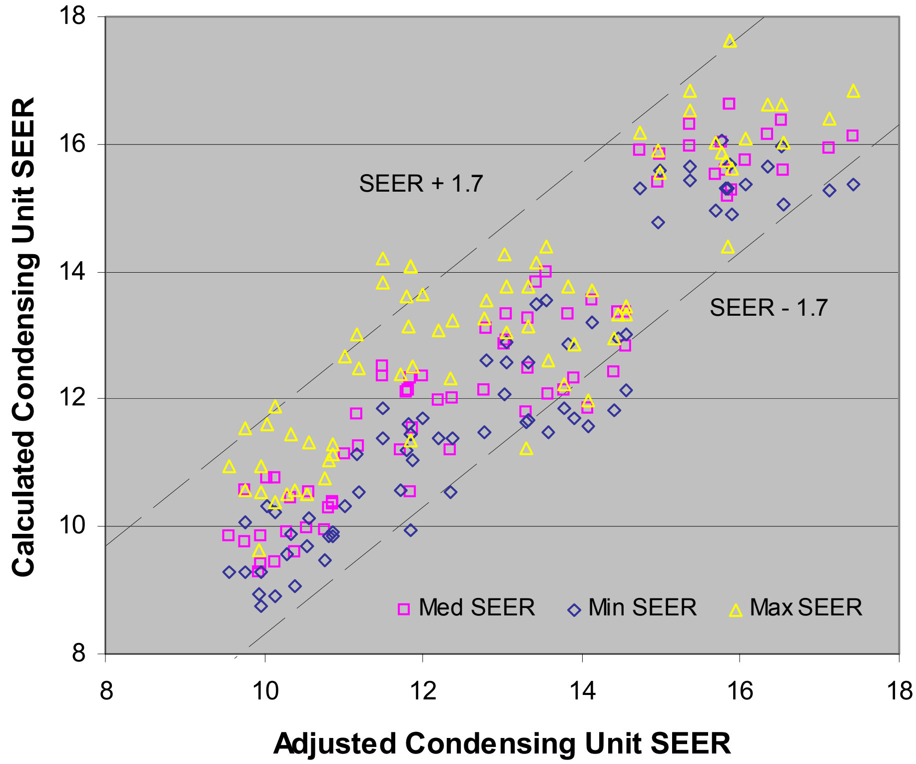


Table 3.4.1
Building Parameters Affecting Condenser Unit SEER[1]
Affect on SEER Because of an Increase in Parameter Value

	CZ03	CZ06	CZ07	CZ12	CZ15
Total Floor Area	Higher	Higher	Higher	Higher	Higher
Use of Shades	Lower	Lower	Lower	Lower	Higher
Sales Area Fraction	Higher	Higher	Higher	Higher	Higher
Occupancy[2]	Higher	Higher	None	Higher	Higher
Lighting Power Density	Higher	Higher	Higher	Higher	Higher
Internal Gains	Higher	Higher	Higher	Higher	Higher
Hours Open	Higher	Higher	Higher	Higher	Higher
Glass Area	Lower	Lower	Lower	Higher	Lower
Glass U-value	Higher	Higher	Higher	Higher	Higher
Glass SC	Higher	Lower	None	Higher	Lower
Window Ovrhng Depth	Lower	Lower	Lower	Lower	Lower
Wall U-value	Higher	Higher	Higher	Higher	Higher
Roof Insul	None	Lower	Lower	Higher	Higher
Cool T'stat SP	Higher	Higher	Higher	None	Lower

Notes:

1. *Changes in values that lead to an increase in simulated SEER do not necessarily result in lower total seasonal energy use.*
2. *Occupancy levels are total number of occupants. Thus, an increase in occupancy level results in more occupants in the space.*

Table 3.4.2
Condenser Unit SEER Climate Multipliers
Retail Median Building Features – CZ03, CZ06, CZ07, CZ12 and CZ15

System SEER	CZ03	CZ06	CZ07	CZ12	CZ15
10	1.14	1.14	1.13	1.02	0.89
12	1.21	1.21	1.20	1.08	0.90

Table 3.4.3
Fan-to-Cooling Runtime Ratios for Use with $SEER_f$
Retail Median Building Features – CZ03, CZ06, CZ07, CZ12 and CZ15

Area Served	CZ03	CZ06	CZ07	CZ12	CZ15
Sales	4.82	3.82	3.60	4.95	3.56
Storage	6.41	4.44	4.15	5.68	3.60
Building	5.06	3.93	3.70	5.09	3.57

Figure 3.4.2
Calculated (Simulated) vs. Estimate $SEER_f$ for All Packaged Systems
Retail Minimum, Median and Maximum SEER Building Features

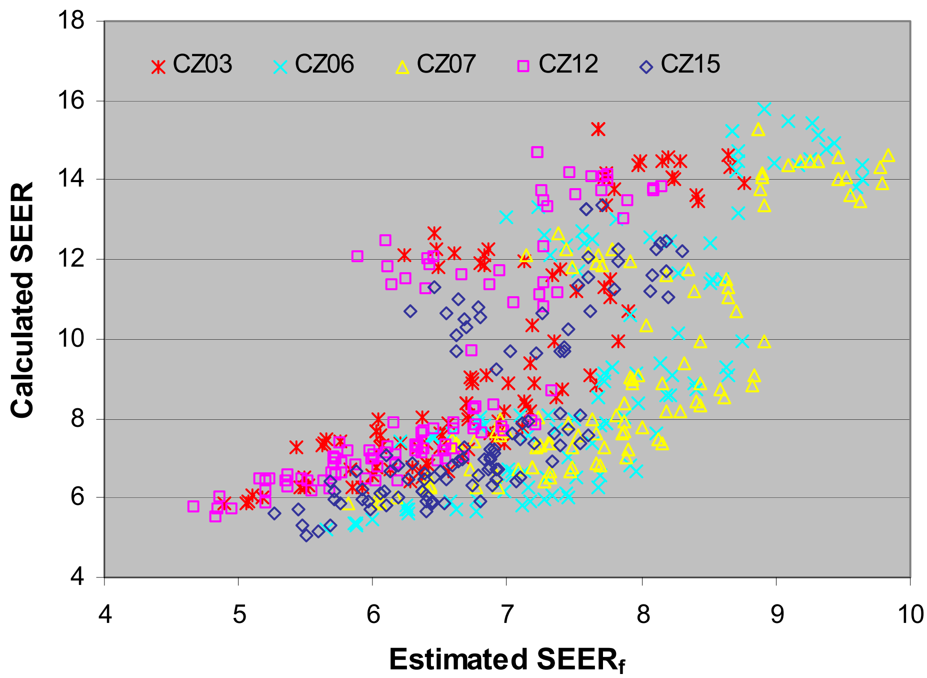


Figure 3.4.2 illustrates that, as with office systems (Figure 3.3.9), $SEER_f$ is not a very useful metric for estimating seasonal cooling energy from the cooling load. It is, however, useful in selecting from among various cooling systems for use in a retail application. Like the office systems, using $SEER_f$ to rank packaged cooling systems can reduce the chance of selecting a system with poor seasonal performance over selecting the systems by rated SEER alone (see Section 3.3.6 for a more complete discussion). The variation in actual energy use for same-SEER systems observed in the DOE-2 simulations is given in Table 3.4.4. Tabular values are for the entire building with building features that produce minimum, median, and maximum total SEER (fan plus condenser unit). Using $SEER_f$ to reject the worse systems typically reduced the variation by at least half of that in Table 3.4.4.

For example, assume one used $SEER_f$ to rank SEER-12 systems for use in a typical retail application in Climate Zone 3. The system selected with the best $SEER_f$ rating would fare no worse than 12% from the best performer of the systems considered. If one selected the system at random, one should expect that the system selected could use as much as 24% more cooling energy than the best for this application. The only way to guarantee that the system selected is the best available would be to simulate all systems (using performance curves based on each system's manufacturer's data) using a detailed energy simulation package like DOE-2.

Table 3.4.4
Differences in Annual Cooling System Energy Use for Same SEER Systems
Retail Application Values Averaged Over Results for the Entire Building

Rated SEER	CZ03	CZ06	CZ07	CZ12	CZ15
	Median Building				
10	13%	9%	10%	15%	17%
12	24%	20%	20%	19%	22%
	Maximum SEER Building				
10	17%	19%	14%	26%	25%
12	25%	25%	20%	23%	28%
	Minimum SEER Building				
10	24%	22%	20%	24%	20%
12	16%	18%	13%	17%	22%

Note: Maximum and minimum SEER values are based on SEER calculations that include fan energy.

The performance range given in Table 3.4.4 is similar to office systems as given in Table 3.3.5. A comparison of the energy benefit associated with moving from a SEER-10 to a SEER-12 system is given in Table 3.4.5. The tabular data are for the median building features; results for building features that produce minimum and maximum SEER values are similar. Results for retail applications are similar to those for office applications (Table 3.3.6). Conclusions for retail applications mirror those discussed for office systems above.

Table 3.4.5
Energy Benefits of Moving to a Higher SEER System (SEER 10 to 12)
Retail Application Results for the Entire Building

	CZ03	CZ06	CZ07	CZ12	CZ15
	Air Conditioner				
Expected	17%				
Lowest	2%	5%	2%	5%	0%
Average	16%	17%	18%	12%	10%
Highest	38%	35%	35%	30%	30%
	Heat Pump				
Expected	17%				
Lowest	-2%	6%	4%	1%	-9%
Average	11%	14%	16%	9%	9%
Highest	30%	30%	33%	32%	30%

3.4.2 Electric Demand

As with SEER, the demand results for retail applications mirror those of offices. The conclusions and observations related to peak cooling system demand in retail applications are the same as those noted in Section 3.3.6. Result provided for office systems in Figure 3.3.10 and Table 3.3.7 are repeated for retail applications as Figure 3.4.3 and Table 3.4.6.

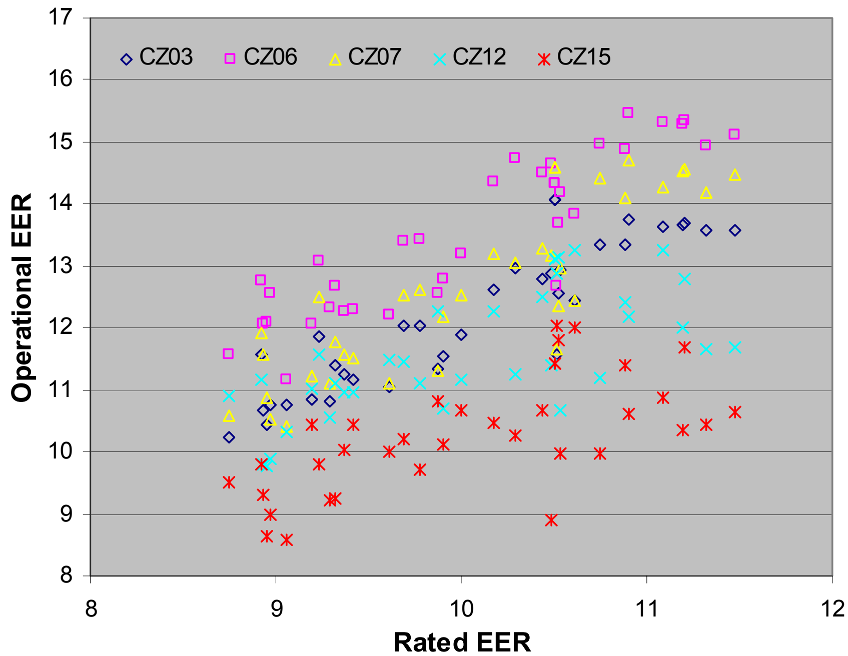
Table 3.4.6
Demand Benefit of Moving to a Higher SEER System
Packaged Systems Used in Retail Setting – Building Average

	CZ03	CZ06	CZ07	CZ12	CZ15
	Air Conditioner				
Expected	17%[1]				
Lowest	5%	2%	-1%	-3%	-18%
Average	19%	21%	22%	11%	4%
Highest	31%	32%	35%	24%	26%
	Heat Pump				
Expected	17%[1]				
Lowest	-4%	-6%	-8%	-15%	-9%
Average	22%	14%	24%	18%	17%
Highest	32%	33%	36%	32%	37%

Note 1: Based on SEER increase

Figure 3.4.3

Operational (Simulated) vs. Rated EER – Retail Application
Building Average



3.4.3 Increased Fan Energy and System Over Sizing

The impacts of higher external static pressure and system over sizing on condenser unit SEER and $SEER_f$ are illustrated in Figures 3.4.3 and 3.4.4. The results presented in the figures are for the entire building and are based on simulations for Climate Zones 6 and 15. They mirror the findings of office systems (Figures 3.3.11 and 3.3.12). The reader is referred to Section 3.3.7 for details on the changes in the cooling system parameters that produced the results shown in the figures and for a discussion of those results.

Figure 3.4.3
Effect of Higher Fan Energy and System Sizing on Condenser Unit SEER
Retail Building Average – CZ06 and CZ15

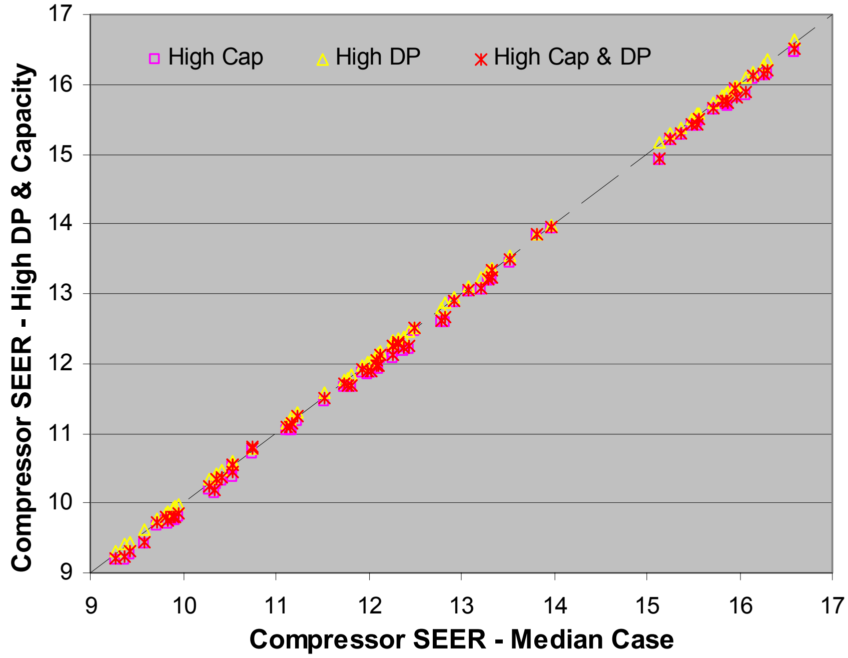
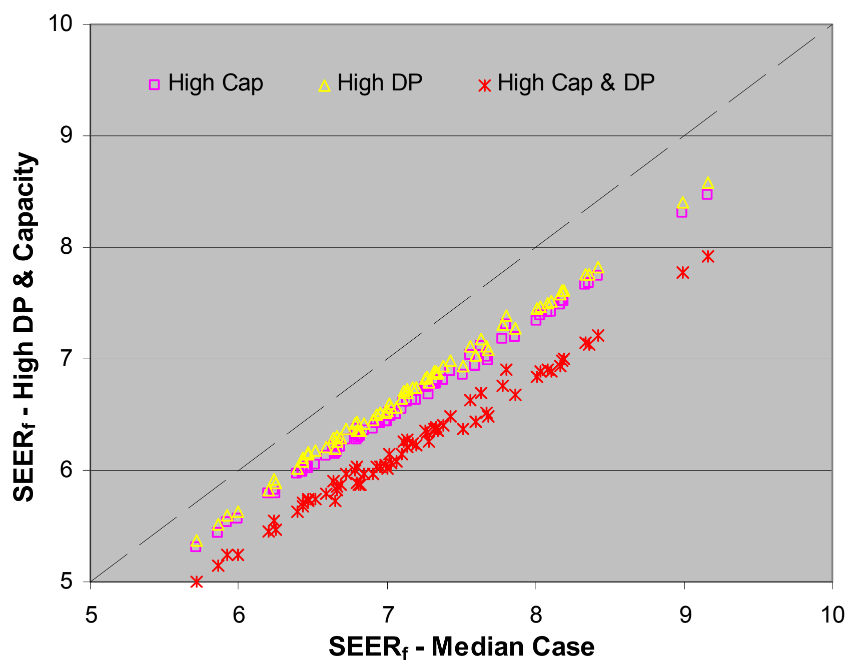


Figure 3.4.4
Effect of Higher Fan Energy and System Sizing on $SEER_f$
Retail Building Average – CZ06 and CZ15



Tables that provide condenser unit SEER multipliers and fan/compressor runtime ratios are given in Section 4.3 for all climate zones. Also included in this section are tables that give the variation in annual cooling energy (like Table 3.3.5) and demand benefits (like Table 3.3.7) for all climates zones.

3.5 SCHOOL CLASSROOM SYSTEMS

The issues and simulation results of cooling systems used in school classroom applications are like those of small offices, Section 3.3. A description of the school building prototype is provided in Section 2.4.4, with details given in Appendix F. Like office and retail applications, it is assumed that school classrooms are cooled by packaged systems and that their fans operate continuously during occupied periods. The issues and findings of cooling systems in a school application are similar to those for small other commercial applications in that fan energy is a much larger fraction of seasonal energy use than in residential systems. Results presented in this section include intermediate finding used to illustrate the issues and findings presented in Section 3.3. The reader is referred to Section 3.2 for the details associated with the use of SEER-rated equipment applied to commercial applications.

School classroom simulations differ from other commercial applications in their schedule of operation. School classroom systems can be operated for part of the year (no use during summer break) or for the full year (year-round classroom use). Operational schedules are typically treated as a building parameter when examining SEER. This is not the case for schools since the operational schedule can exclude the summer peak cooling season. Separate results presented in this section for non-summer and year-round operational schedules.

Note that this section deals with the application of packaged cooling systems to school classrooms. Other areas of the school, such as administrative offices, which are more likely to be operated year-round, are given usage characteristics like commercial offices. Results from Section 3.2 apply to these areas. Other school areas types, such as cafeterias, auditoriums, and gymnasiums, are cooled by larger systems whose cooling capacity would exclude them from SEER rating.

3.5.1 Condenser Unit SEER and $SEER_f$

Like the other commercial applications, changes in building construction and operation impact cooling system performance. This is illustrated in Figures 3.5.1.a and 3.5.1.b, for condenser unit SEER (cooling system SEER exclusive of fan energy). The two figures are for partial year (summer break) and full year (no summer break) operations. The figure includes condenser unit SEER values associated with minimum, median and maximum system SEER. Building features that lead to higher and lower values of system SEER for classroom application are given in Table 3.5.1. Median SEER is that associated with median values of building and operational features. As has been noted previously, building features that lead to higher values of SEER do not necessarily result in reduced cooling energy, just improved operating efficiency (see related comments in Section 3.3.5).

Condenser unit SEER as determined by the DOE-2 simulations is compared to rated condenser unit SEER adjusted for climate zone. Climate zone adjustments for condenser unit SEER are given in Table 3.5.2 for school classroom applications. Condenser unit SEER is slightly more predictable than for office or retail applications (compare to Figures 3.3.8 and 3.4.1). Most of the variation in condenser unit SEER is related to performance differences between the various cooling systems rather than changes in building features.

Fan-to-compressor runtime ratios for classroom cooling systems and median building features are given in Table 3.5.3. Fan operation is slightly greater for partial year operation than for full-year. This is not surprising, as one would expect greater compressor operation during the summer, leading to a lower fan-to-compressor runtime ratio. The resulting estimated $SEER_f$ are compared to values obtained from DOE-2 simulations in Figures 3.5.2.a and 3.5.2.b. Results are similar to office applications as illustrated in Figure 3.3.8.

Figure 3.5.1.a

Calculated (Simulated) vs. Rated Condenser Unit SEER for All Packaged Systems
Minimum, Median and Maximum SEER Building Features
No Summer Usage - CZ06 and CZ15

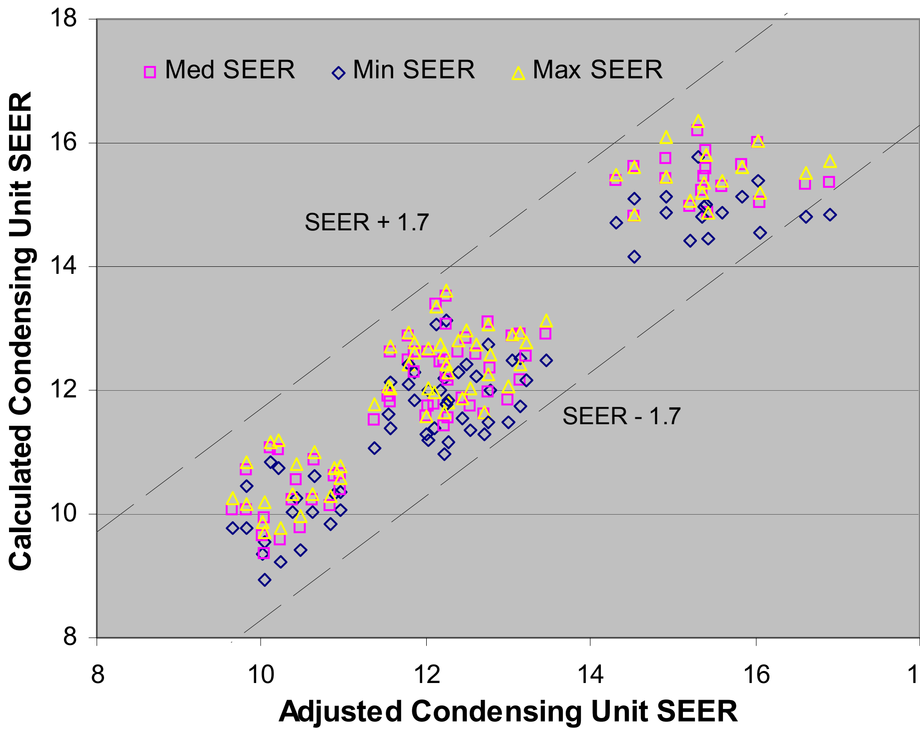


Figure 3.5.1.b
Calculated (Simulated) vs. Rated Condenser Unit SEER for All Packaged Systems
Minimum, Median and Maximum SEER Building Features
Year-Round Usage - CZ06 and CZ15

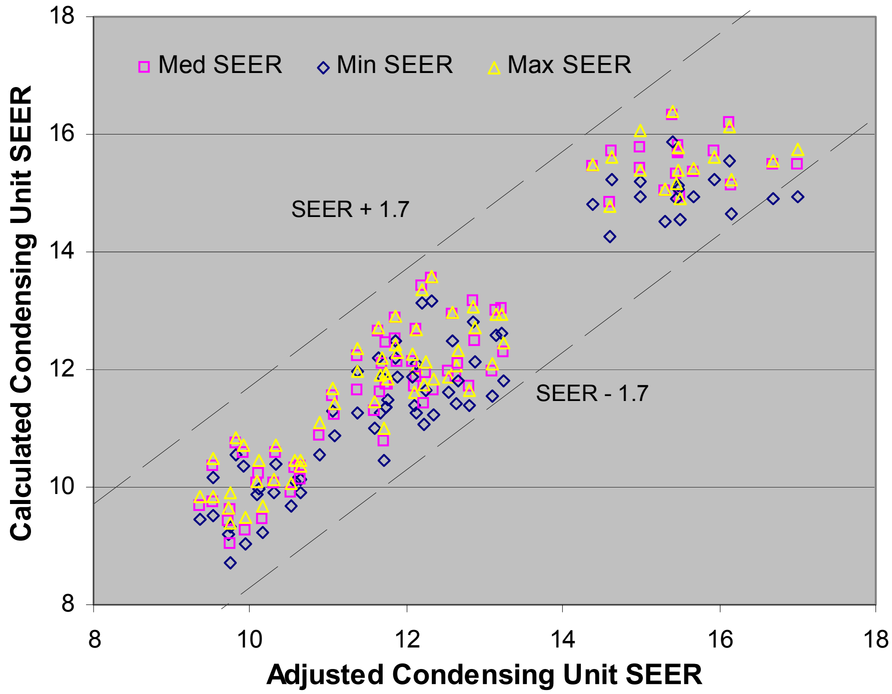


Table 3.5.1
School Classroom Building Parameters Affecting Overall SEER[1]
Affect on SEER Because of an Increase in Parameter Value

	CZ03	CZ06	CZ07	CZ12	CZ15
Classroom Floor Area	Lower	None	Lower	Lower	Lower
Use of Shades	Lower	None	None	Lower	Lower
Aspect Ratio[2]	Higher	Higher	Higher	Higher	Higher
Occupancy[3]	Higher	Higher	Higher	Higher	Higher
Light Power Density	Higher	Higher	Higher	Higher	Higher
Internal Gains	Higher	Higher	Higher	Higher	Higher
Hours Open	Lower	Lower	Lower	Lower	Lower
Glass Area	Higher	Higher	Higher	Higher	Higher
Glass U-value	Higher	Higher	Higher	Higher	Higher
Glass SC	Higher	Higher	Higher	Higher	Lower
Window Ovrhng Depth	Lower	Lower	Lower	Lower	Lower
Wall U-value	Higher	Higher	Higher	Higher	Higher
Roof Insul	Lower	Lower	Lower	Lower	Lower
Cool T'stat SP	Higher	Higher	Higher	Higher	Higher

Notes:

1. *Changes in values that lead to an increase in simulated SEER do not necessarily result in lower total seasonal energy use.*
2. *Aspect ratio determines the ratio of exterior wall and window wall to the total floor area. High aspect ratio classrooms have more glass wall than low aspect ratio classrooms.*
3. *Occupancy levels are total number of occupants. Thus, an increase in occupancy level results in more occupants in the space.*

Table 3.5.2
Condenser Unit SEER Climate Multipliers
Classrooms – CZ03, CZ06, CZ07, CZ12 and CZ15

	CZ03	CZ06	CZ07	CZ12	CZ15
System SEER	Partial Year Usage (with Summer Break)				
10	1.10	1.10	1.10	1.02	0.91
12	1.17	1.18	1.17	1.07	0.94
	Year-Round Usage (no Summer Break)				
10	1.10	1.10	1.10	1.00	0.89
12	1.18	1.19	1.17	1.04	0.90

Table 3.5.3
Fan-to-Cooling Runtime Ratios for Use with $SEER_f$
Classroom Median Building Features – CZ03, CZ06, CZ07, CZ12 and CZ15

	CZ03	CZ06	CZ07	CZ12	CZ15
Partial Year	4.65	4.27	3.86	4.15	3.83
Year-Round	4.27	3.62	3.89	3.82	3.62

Figures 3.5.2.a and 3.5.2.b illustrate that, as with other commercial systems (Figure 3.3.9), $SEER_f$ is not a very useful metric for estimating seasonal cooling energy from the cooling load. It is, however, useful in selecting from among various cooling systems for use in a classroom application. Like the office systems, using $SEER_f$ to rank packaged cooling systems can reduce the chance of selecting a system with poor seasonal performance over selecting the systems by rated SEER alone (see Section 3.3.6 for a more complete discussion). The variation in actual energy use for same-SEER systems observed in the DOE-2 simulations is given in Table 3.5.4. Tabular values are for the average of all classrooms (partial-year operation) with building features that produce minimum, median, and maximum total SEER (fan plus condenser unit). Full-year results are similar. Using $SEER_f$ to reject the worse systems typically reduced the variation by at least half of that in Table 3.5.4.

Figure 3.5.2.a
Calculated (Simulated) vs. Estimate $SEER_f$ for All Packaged Systems
Partial Year Operation, Min, Median and Max SEER Building Features

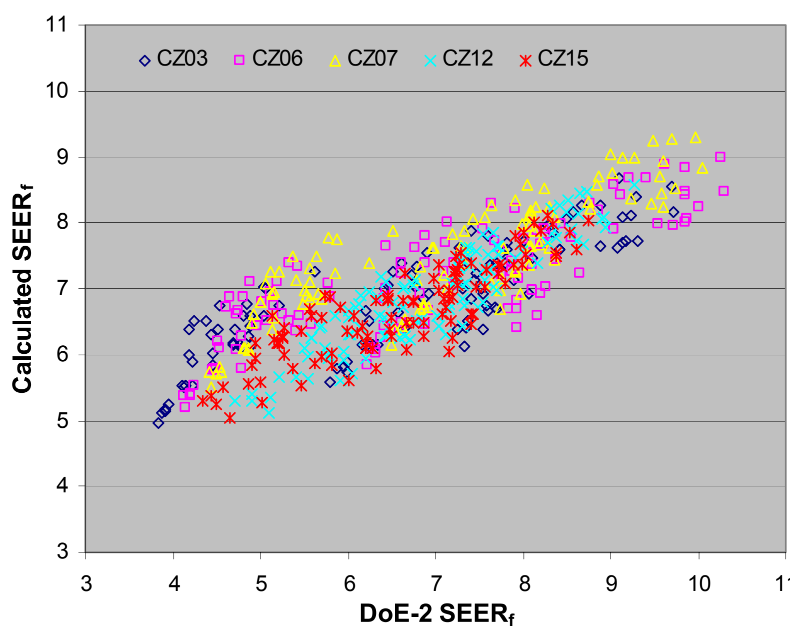
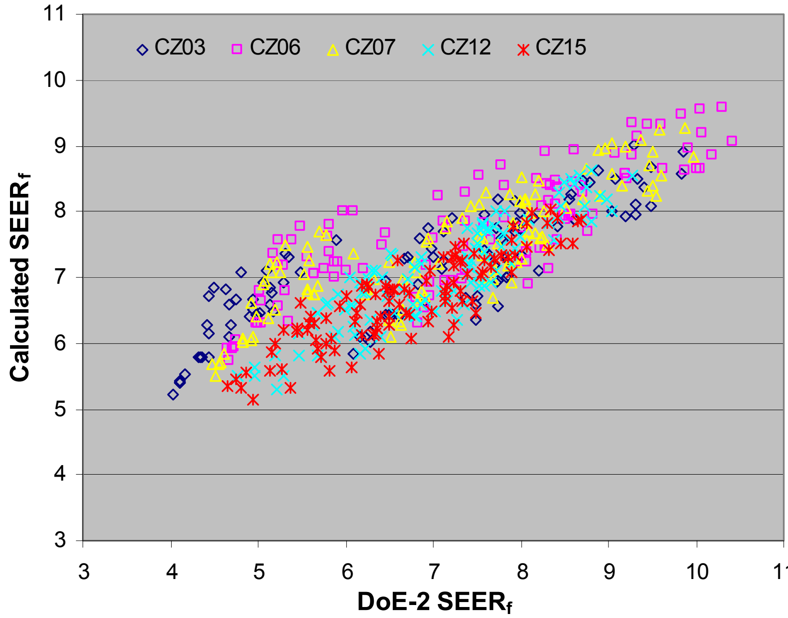


Figure 3.5.2.a
Calculated (Simulated) vs. Estimate $SEER_f$ for All Packaged Systems
Year-Round Operation, Min, Median and Max SEER Building Features



For example, assume one used $SEER_f$ to rank SEER-12 systems for use in a typical classroom application in Climate Zone 3. The system selected with the best $SEER_f$ rating would fare no worse than 12% from the best performer of the systems considered. If one selected the system at random, one should expect that the system selected could use as much as 24% more cooling energy than the best for this application. The only way to guarantee that the system selected is the best available would be to simulate all systems (using performance curves based on each system's manufacturer's data) using a detailed energy simulation package like DOE-2.

Table 3.5.4.a
Differences in Annual Cooling System Energy Use for Same SEER Systems
Classroom Application - Partial-Year Operation

Rated SEER	CZ03	CZ06	CZ07	CZ12	CZ15
	Median Building				
10	15%	14%	11%	22%	23%
12	22%	24%	18%	18%	20%
	Maximum SEER Building				
10	9%	9%	8%	11%	14%
12	15%	14%	13%	11%	14%
	Minimum SEER Building				
10	24%	26%	20%	28%	31%
12	20%	25%	13%	23%	32%

Note: Maximum and minimum SEER values are based on SEER calculations that include fan energy.

The performance range given in Tables 3.5.4.a and 3.5.4.b are similar to office systems as given in Table 3.3.5. Comparisons of the energy benefit associated with moving from a SEER-10 to a SEER-12 system are given in Table 3.5.5.a and 3.5.5.b. The tabular data are for the median building features; results for building features that produce minimum and maximum SEER values are similar. Results for classroom applications are similar to those for other commercial applications (Tables 3.3.6 and 3.4.5). The lowest improvement values are slightly less than other commercial applications because of the greater relative importance of fan energy in partial-year classroom applications. A SEER-10 system with a good fan outperforms a SEER-12 system with a poor fan. However, overall conclusions for classroom applications mirror those discussed for office systems in Section 3.3.5.

Table 3.5.4.b
Differences in Annual Cooling System Energy Use for Same SEER Systems
Classroom Application – Full-Year Operation

	CZ03	CZ06	CZ07	CZ12	CZ15
Rated SEER	Median Building				
10	13%	11%	14%	22%	22%
12	21%	21%	19%	19%	22%
	Maximum SEER Building				
10	10%	8%	8%	10%	14%
12	14%	13%	12%	10%	14%
	Minimum SEER Building				
10	23%	23%	28%	30%	28%
12	20%	22%	29%	28%	27%

Note: Maximum and minimum SEER values are based on SEER calculations that include fan energy.

Table 3.5.5.a
Energy Benefits of Moving to a Higher SEER System (SEER 10 to 12)
Partial-Year Classroom Application

	CZ03	CZ06	CZ07	CZ12	CZ15
	Air Conditioner				
Expected			17%		
Lowest	-6%	-7%	0%	-1%	-7%
Average	19%	18%	18%	15%	15%
Highest	37%	35%	33%	37%	34%
	Heat Pump				
Expected			17%		
Lowest	-3%	-5%	1%	-7%	-12%
Average	17%	17%	17%	11%	13%
Highest	36%	37%	32%	39%	37%

Table 3.5.5.b
Energy Benefits of Moving to a Higher SEER System (SEER 10 to 12)
Full-Year Classroom Application

	CZ03	CZ06	CZ07	CZ12	CZ15
			Air Conditioner		
Expected			17%		
Lowest	-4%	-4%	-3%	-2%	-10%
Average	19%	19%	18%	16%	14%
Highest	36%	34%	32%	38%	35%
			Heat Pump		
Expected			17%		
Lowest	-1%	-1%	-1%	-8%	-13%
Average	17%	18%	18%	12%	14%
Highest	35%	33%	35%	39%	36%

3.5.2 Electric Demand

As with SEER, the demand results for classroom applications mirror those of other commercial applications. The conclusions and observations related to peak cooling system demand in retail applications are the same as those noted in Section 3.3.6. Result provided for office systems in Figure 3.3.10 and Table 3.3.7 are repeated for classroom applications as Figures 3.5.3.a and 3.5.3.b and Tables 3.5.6.a and 3.5.6.b.

Table 3.5.6.a
Demand Benefit of Moving to a Higher SEER System
Packaged Systems Used in Classroom Setting – Partial Year

	CZ03	CZ06	CZ07	CZ12	CZ15
			Air Conditioner		
Expected			17%[1]		
Lowest	4%	6%	-1%	-6%	-13%
Average	20%	20%	19%	8%	8%
Highest	30%	34%	29%	22%	25%
			Heat Pump		
Expected			17%[1]		
Lowest	-5%	-2%	-8%	-8%	-6%
Average	19%	18%	18%	15%	13%
Highest	31%	34%	36%	36%	41%

Note 1: Based on SEER increase

Table 3.5.6.b
Demand Benefit of Moving to a Higher SEER System
Packaged Systems Used in Classroom Setting – Full Year

	CZ03	CZ06	CZ07	CZ12	CZ15
			Air Conditioner		
Expected			17%[1]		
Lowest	4%	4%	-2%	-5%	-17%
Average	19%	19%	21%	10%	8%
Highest	29%	35%	35%	22%	29%
			Heat Pump		
Expected			17%[1]		
Lowest	-3%	-2%	-11%	-7%	-6%
Average	20%	19%	19%	15%	14%
Highest	30%	32%	30%	35%	40%

Note 1: Based on SEER increase

Figure 3.5.3.a
Operational (Simulated) vs. Rated EER – Classroom Application
Partial Year

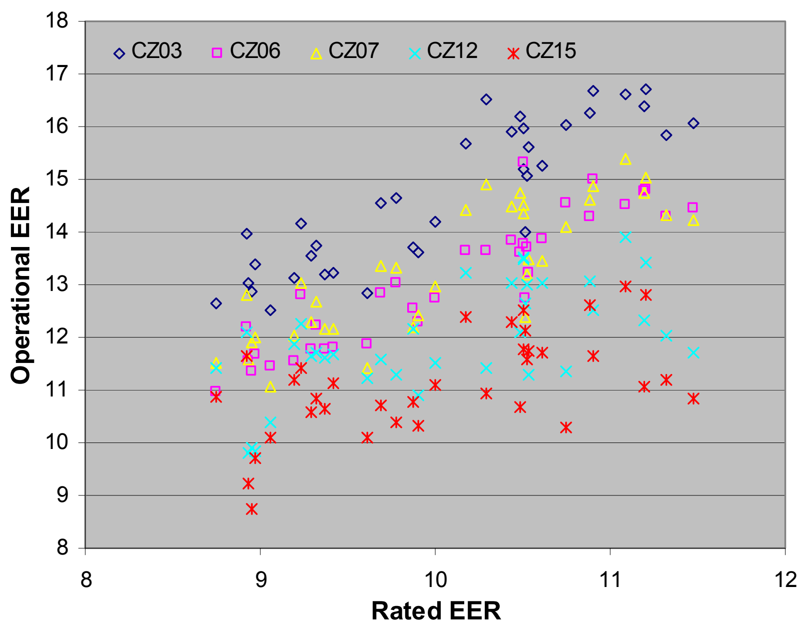
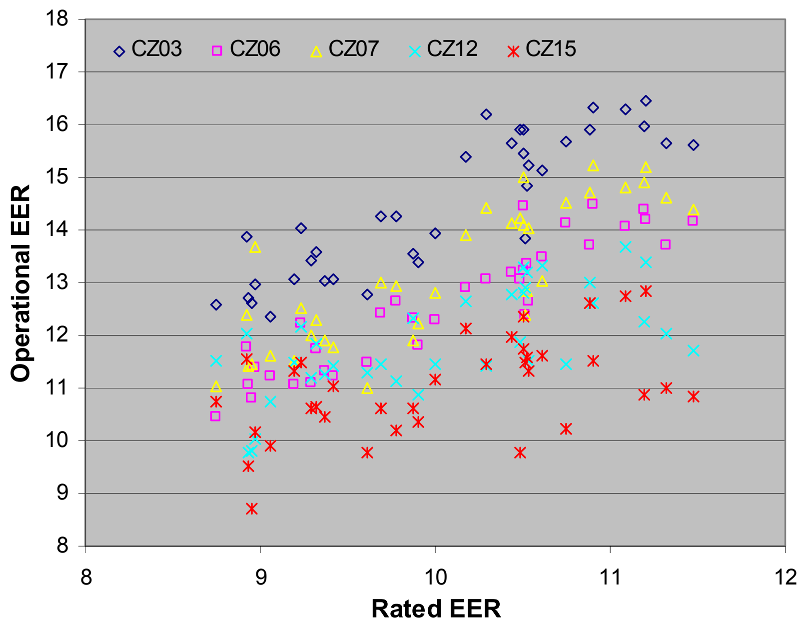


Figure 3.5.3.b
Operational (Simulated) vs. Rated EER – Classroom Application
Partial Year



3.5.3 Increased Fan Energy and System Over Sizing

The impacts of higher external static pressure and system over sizing on condenser unit SEER and $SEER_f$ are illustrated in Figures 3.5.3 and 3.5.4. The results presented in the figures are for the entire building and are based on simulations for Climate Zones 6 and 15. They mirror the findings of office systems (Figures 3.3.11 and 3.3.12). The reader is referred to Section 3.3.7 for details on the changes in the cooling system parameters that produced the results shown in the figures and for a discussion of those results.

Figure 3.5.3
Effect of Higher Fan Energy and System Sizing on Condenser Unit SEER
Retail Building Average – CZ06 and CZ15

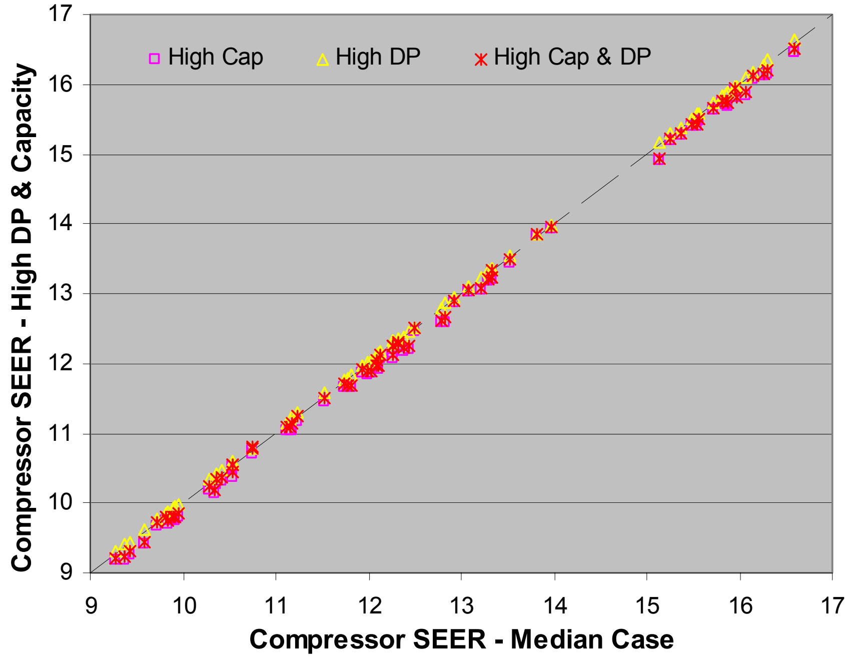
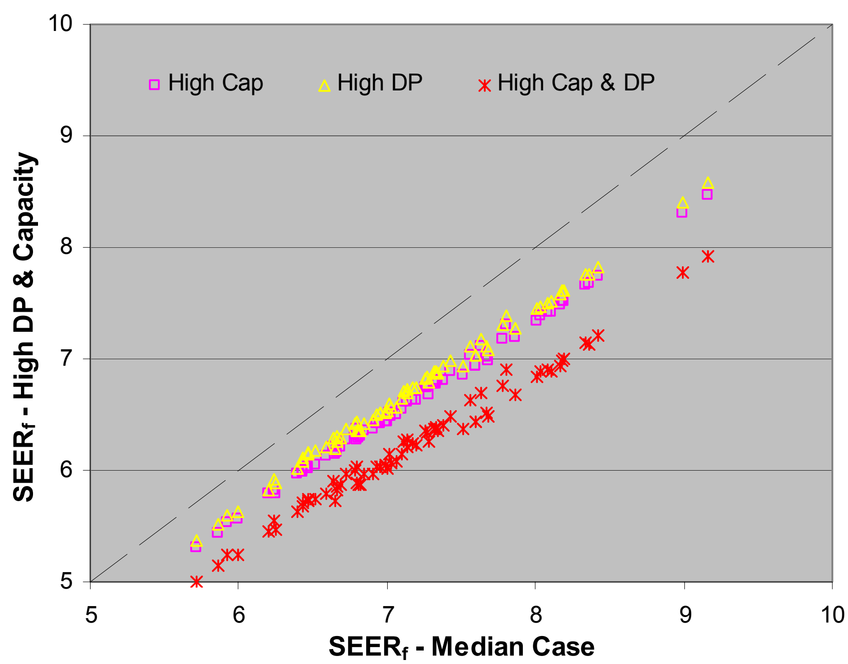


Figure 3.5.4
Effect of Higher Fan Energy and System Sizing on $SEER_f$
Retail Building Average – CZ06 and CZ15



Tables that provide condenser unit SEER multipliers and fan/compressor runtime ratios are given in Section 4.4 for all climate zones. Also included in this section are tables that give the variation in annual cooling energy (like Table 3.3.5) and demand benefits (like Table 3.3.7) for all climates zones.

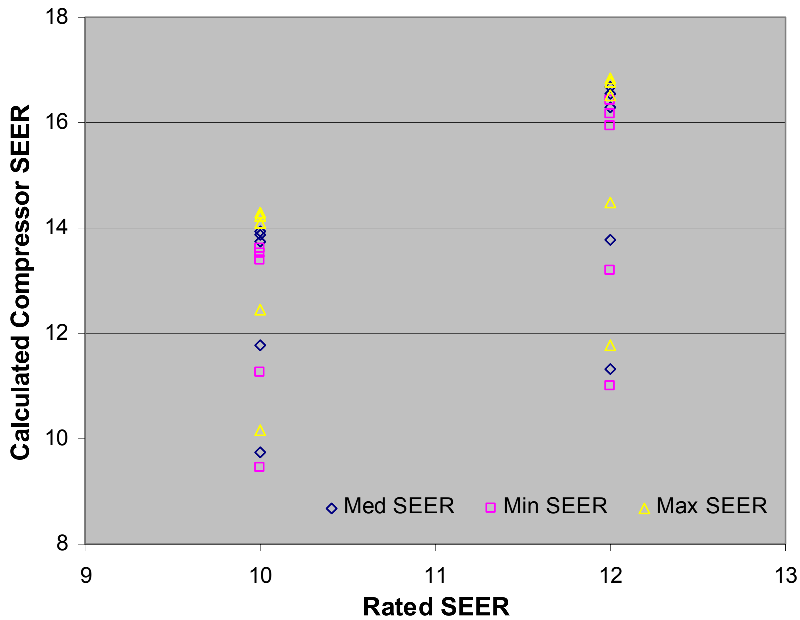
3.6 PORTABLE CLASSROOM SYSTEMS

Portable classroom applications are somewhat unique in comparison to other commercial applications. Almost all use wall-mounted heat pumps that are manufactured by either Bard or Marvair. Only Marvair publishes extended ratings data that can be translated into DOE-2 performance maps. The limited climate locations that use air conditioners in a portable classroom application do so because they are combined with gas-fired heating systems. These are Bard systems, as Marvair does not manufacture a system with gas heat. Thus, this effort is limited to looking at Marvair SEER 10 and SEER 12 heat pumps. Because of this, the information provided in this section is limited in comparison to other commercial applications, with SEER providing the only selection criteria.

3.6.1 Condenser Unit SEER and $SEER_f$

Like the other commercial applications, changes in building construction and operation impact cooling system performance. This is illustrated in Figures 3.6.1 for condenser unit SEER (cooling system SEER exclusive of fan energy) and 3.6.2 total SEER, (or $SEER_f$ with fan energy included). The two figures are for partial year (summer break) operation. Results for full year operation are slightly lower than those shown for partial year operation. The figures include values associated with minimum, median and maximum system SEER. Building features that lead to higher and lower values of system SEER for classroom application are given in Table 3.6.1. Median SEER is that associated with median values of building and operational features. As has been noted previously, building features that lead to higher values of SEER do not necessarily result in reduced cooling energy, just improved operating efficiency (see related comments in Section 3.3.5).

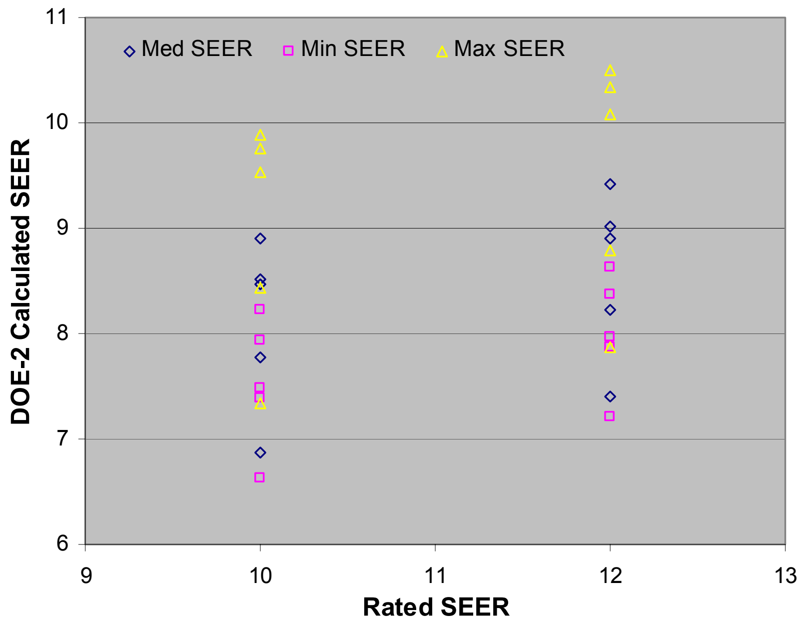
Figure 3.6.1
Calculated Condenser Unit SEER vs. Rated SEER for Portable Classroom Systems
Minimum, Median and Maximum SEER Building Features
No Summer Usage - CZ03, CZ06, CZ07, CZ12 and CZ15



Results for portable classrooms are similar to other applications where fans must run continuously. When fan energy is ignored, climate effects dominate system performance, as illustrated by Figure 3.6.1. Results for high, median, and low SEER building characteristics group by climate zone, where the lowest values are associated with the hottest climate zone (CZ15) and the highest values are for the cooler climate zones (CZ03, CZ06, and CZ07). In all cases, climate zone has a much greater impact on condenser unit SEER than variations in building parameters.

The opposite conclusion is found when fan energy is included in SEER, as shown in Figure 3.6.2. While climate does affect total SEER, building parameters are at least as important to seasonal efficiency.

Figure 3.6.2
Calculated (Simulated) Total SEER vs. Rated SEER for Portable Classroom Systems
Minimum, Median and Maximum SEER Building Features
No Summer Usage - CZ03, CZ06, CZ07, CZ12 and CZ15



The reduction in seasonal cooling energy associated with moving from the SEER 10 to SEER 12 system is provided in Table 3.6.2. Results are provided for building parameters that produce minimum, median, and maximum SEER levels, and for partial and full year operation. The nominal reduction based on the difference in rated SEER is 16.7%. The actual benefit is much lower, from 4% to 9%. The difference between nominal and actual energy reduction is almost entirely a result of continuous fan operation. Fan energy use for both systems was similar (the SEER 12 system was slightly higher than the SEER 10 system because of differences in design air flows) and represented 30% to 50% of seasonal cooling energy. In all cases, moving to a higher SEER level did result in positive annual cooling energy savings.

Table 3.6.1
Portable Classroom Building Parameters Affecting Overall SEER[1]
Affect on SEER Because of an Increase in Parameter Value

	CZ03	CZ06	CZ07	CZ12	CZ15
Classroom Floor Area	None	None	Lower	Lower	None
Use of Shades	Lower	Lower	Lower	Lower	Lower
Aspect Ratio[2]	Lower	Lower	Higher	Lower	Lower
Occupancy[3]	Higher	Higher	Higher	Higher	Higher
Light Power Density	Higher	Higher	Higher	None	Higher
Internal Gains	Higher	Higher	Higher	Higher	Higher
Hours Open	Higher	Higher	Lower	None	None
Glass Area	None	None	Higher	None	Higher
Glass U-value	None	Higher	Higher	Higher	Higher
Glass SC	Lower	Higher	Higher	None	Higher
Window Ovrhng Depth	Lower	Lower	Lower	None	Lower
Wall U-value	Lower	None	None	None	Higher
Roof Insul	Lower	Lower	Lower	Lower	Higher
Cool T'stat SP	Higher	Higher	Higher	Lower	Lower

Notes:

1. *Changes in values that lead to an increase in simulated SEER do not necessarily result in lower total seasonal energy use.*
2. *Aspect ratio determines the ratio of exterior wall and window wall to the total floor area. High aspect ratio classrooms have more glass wall than low aspect ratio classrooms.*
3. *Occupancy levels are total number of occupants. Thus, an increase in occupancy level results in more occupants in the space.*

Table 3.6.2
Cooling Energy Reduction from Moving to a Higher SEER System
Portable Classrooms – CZ03, CZ06, CZ07, CZ12 and CZ15

SEER Level	CZ03	CZ06	CZ07	CZ12	CZ15
	Partial Year Usage (with Summer Break)				
Minimum	5.2%	4.8%	4.7%	7.3%	8.1%
Median	4.8%	5.5%	5.4%	5.4%	7.2%
Maximum	5.6%	5.7%	5.8%	4.0%	6.8%
	Year-Round Usage (no Summer Break)				
Minimum	5.6%	5.5%	9.2%	9.0%	13.2%
Median	5.3%	5.8%	7.0%	8.2%	11.6%
Maximum	5.8%	5.6%	6.0%	4.2%	9.0%

3.6.2 Electric Demand

Median demand reductions associated with a move to the higher SEER system were between 1% and 5%. This is comparable to the relative difference in the rated EER of the two systems. The SEER 10 system has an EER of 9.7, while the SEER 12 system has a 10.0 EER. The expected demand reduction based on EER would be 3%. As with other applications, differences in EER provide a much better indicator of demand changes than differences in SEER. Partial vs. full-year operation had little impact on cooling system peaks or the relative demand benefit of moving to the more efficient system. Cooling system demand levels were much more sensitive to assumed building parameters (u-values, lighting density, occupancy levels, glass area, etc.) and climate zone.

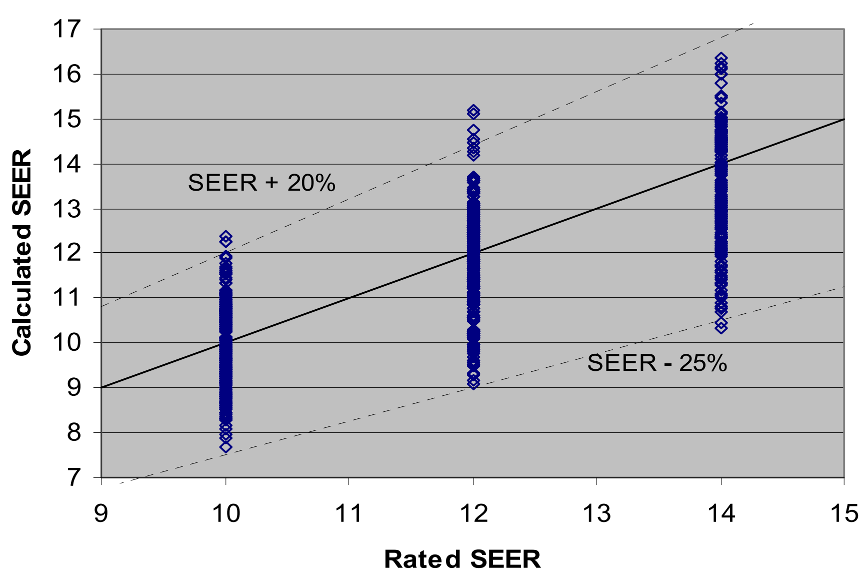
4.0 SEER IMPROVEMENT MODELS

4.1 SINGLE FAMILY

Section 3.1 illustrated that SEER is not well represented by a single ratings value, but is dependent on building characteristics, climate conditions, and cooling system performance differences not included in their SEER rating. While differing building characteristics can have a tremendous impact on annual energy use, they were found to have no more than a ±5% effect on SEER. The interaction of weather patterns, building characteristics, building use and operation, and mechanical system control that produce the changes in SEER are at a level of complexity that are beyond simple quantification. One should expect a ±5% uncertainty in SEER associated with variation in building operation and characteristics. Fortunately, this uncertainty in SEER is not a big factor when selecting between systems of differing SEER. That is, for a given house design, operational or design features that would tend to drive one cooling system to a significantly higher or lower SEER will tend to drive all systems in the same direction. Improving SEER estimates is reduced to accounting for climate conditions and cooling system performance differences.

The SEER multipliers given in Table 3.2.1 offer a means of providing climate and SEER-specific corrections to improve SEER estimates. The multipliers developed in Section 3 were expanded to include all climate zones through additional DOE-2 simulations. All 48 mechanical systems were simulated against the prototypical single family residential DOE-2 model for all California climate zones. SEER values calculated in this process are compared to their rated values in Figure 4.1.1 for single-speed systems. Simulations results were used to expand Table 3.2.1 to include all climate zones.

Figure 4.1.1
Calculated (Simulated) vs. Rated SEER – All Climate Zones



4.1.1 Improved SEER – Climate Zone Multipliers

Climate and SEER specific multipliers are presented in Table 4.1.1. This is an expansion of Table 3.2.1 to include all climate zones. Multipliers that are SEER-specific can be applied to systems not in the table through interpolation. Using the average climate zone multiplier ignores general differences among systems as their efficiency increases. SEER-specific multipliers include those differences in a climate specific manner.

The SEER multipliers reduce the error in SEER estimate from +20% to –25% to an average uncertainty of around ±0.66 SEER points. They do this by accounting for overall climate affects and the climate-specific sensitivities of each system. General climate effects result in a change in the mid-load temperature associated with each climate zone from the 82 F assumed in the ratings process. Climate zones with multipliers greater than 1.0 are associated with cooler climates, those less than 1.0 with hotter climates. The multipliers are based on results from DOE-2 simulations that also account for more realistic air conditions entering the cooling coil, as opposed to the standard 80 F dry-bulb, 67 F wet-bulb conditions used in the ratings process. So the multipliers actually include two climate effects – differing outdoor temperature and temperature and moisture conditions entering the cooling coil. Both are climate specific.

Differences in the SEER-specific multipliers from the average account for the fact that systems that are more efficient tend to operate differently than their lower efficiency counterparts. This difference, while not large, is consistent across all climate zones.

4.1.2 Improved SEER – Detailed Single-Speed Equipment Model

The climate and SEER-specific multipliers provide a tremendous improvement in SEER estimates. However, differences in equipment performance still lead to an estimate error around ±0.66 SEER points at a 95% confidence level. A nominal 12 SEER system could provide a corrected seasonal efficiency as low as 11.3 or as high as 12.7. This is obviously a potential problem for regulators who seek to use SEER as energy standard.

The uncertainty in the SEER estimate appears to be associated with subtle differences in equipment performance that are not addressed in the SEER ratings process. Many of these have been discussed in the previous section. The importance of among equipment differences varies from climate zone to climate zone. For example, differences in the systems' efficiency to changes in outdoor temperature are most important in the hotter climates zones. In cooler climates, the dominant factor is often related to how sensitive a system is to the humidity of the air entering the cooling coil. At other times, differences in cycling efficiency come into play.

Table 4.1.1
Climate Zone SEER Multipliers

	Single-Speed SEER Rating			All Single-Speed	Two-Speed
	10	12	14		
CZ01	1.16	1.16	1.14	1.15	0.98
CZ02	0.97	0.95	0.92	0.95	0.83
CZ03	1.08	1.06	1.04	1.07	0.99
CZ04	1.07	1.04	1.03	1.05	0.93
CZ05	1.07	1.07	1.04	1.06	0.96
CZ06	1.08	1.07	1.05	1.07	1.02
CZ07	1.07	1.06	1.04	1.06	1.00
CZ08	1.07	1.06	1.04	1.02	0.95
CZ09	0.99	0.97	0.95	0.97	0.85
CZ10	0.95	0.94	0.90	0.93	0.81
CZ11	0.92	0.90	0.86	0.90	0.78
CZ12	0.97	0.95	0.92	0.95	0.87
CZ13	0.93	0.91	0.88	0.91	0.78
CZ14	0.88	0.85	0.82	0.85	0.75
CZ15	0.83	0.81	0.78	0.82	0.76
CZ16	1.05	1.03	0.99	1.03	0.84

Detailed, equipment-based models for single-speed systems were developed to account for these factors as a means to reduce the uncertainty in the SEER estimate. Two-speed systems are not included as their operational characteristics and SEER ratings procedures differ significantly from their single-speed counterparts. The climate zone multipliers in Table 4.1.1 are appropriate for two-speed systems. The general form of the single-speed, detailed model is as follows:

$$SEER_{mult} = C_0 + C_1*C_D + C_2*DB_{mult} + C_3*S_{WB} + C_4*SHR \quad (4.1)$$

where:

$SEER_{mult}$ is the SEER multiplier used to adjust rated SEER (like those in Table 4.1.4),

C_D is the cooling system's degradation coefficient as determined in cycling tests,

DB_{mult} is a dry-bulb multiplier used to adjust for differing outdoor conditions and the system's sensitivity to changing outdoor temperature,

S_{WB} is the sensitivity of the system's efficiency to changing coil entering wet-bulb,

SHR is the system's sensible heat ratio, or ratio of sensible cooling capacity to total at ARI design conditions, and

C_0, C_1, C_2, C_3, and C_4 are equation constants.

The independent variable, DB_{mult}, is a combination of two terms, and is calculated as:

$$DB_{mult} = S_{DB} * (82 - MLT) \tag{4.2}$$

Where:

S_{DB} is the sensitivity of the system's efficiency to changing outdoor dry-bulb temperature and

MLT is the climate zone-specific mid-load temperature as given in Table 4.1.2.

The form of Equation 4.2 illustrates that DB_{mult}, is a measure of how much a given system is affected by outdoor conditions that differ from the assumed 82 F rated condition.

Determining the various independent variables requires access to manufacturer's ratings and expanded ratings charts. Expanded ratings charts provide sufficient data to estimate S_{DB} and S_{WB} and calculate SHR at ARI design conditions. The California Energy Commission maintains a database of rated systems that includes their degradation coefficients obtained during the SEER ratings process. Values of the degradation coefficient can be estimated for systems not in the database using the equation for SEER, expanded ratings charts, and the rated SEER, or:

$$C_D = 2*(1 - SEER/EER_{82}) \tag{4.3}$$

Where EER_{82} is the energy efficiency ratio of the system at 82 F outdoor temperature and 80 F dry-bulb, 67 F wet-bulb conditions entering the cooling coil. This can be obtained from manufacturer's expanded ratings charts.

The equation coefficients and climate zone-specific mid-load temperature are given in Table 4.1.2. A comparison of Figures 4.1.1 and 4.1.2 illustrate the improvement in SEER estimate obtained by using either the climate zone or detailed multipliers.

Adjusted SEER values are compared to those calculated by DOE-2 in Figure 4.1.2. Adjusted SEER values include those based on the multipliers in Table 4.1.1 (Climate Zone SEER Multipliers) and those using the detailed model as defined by Equation 4.1 (Detailed). The detailed model reduced the expected error in the adjusted SEER to within ±0.47 SEER ratings points. The ability to reproduce DOE-2 simulated SEER via climate multipliers or the detailed model is dependent on the climate zone. Both SEER multiplier methods reproduce calculated results better for hotter climates (CZ02, and CZ10 – CZ15). Thus, SEER is more predictable for climate zones with the higher cooling loads. Standard errors expected from the SEER adjustments are given in Tables 4.1.3a and 4.1.3b by climate zone. Table 4.1.3a provides values for the climate-zone multipliers, while Table 4.1.3b is for the detailed model.

Table 4.1.2
Detailed Model Coefficients

	C_0	C_1	C_2	C_3	C_4	MLT
CZ01	1.5333	0.1417	-0.4026	4.4762	-0.5559	69.5
CZ02	1.1877	0.1932	23.1097	4.0373	-0.1730	81.7
CZ03	1.2904	0.1163	0.1731	3.1657	-0.2576	74.0
CZ04	1.1478	0.1371	0.9667	2.0203	-0.0502	77.1
CZ05	1.3492	0.0753	-0.1078	3.2366	-0.3749	72.3
CZ06	1.3134	0.0858	-0.1105	2.5910	-0.3224	72.6
CZ07	1.1694	0.1203	0.0459	2.5229	-0.1293	74.5
CZ08	1.1904	0.1506	1.4139	3.1316	-0.1092	77.7
CZ09	1.1484	0.1303	12.4709	3.2199	-0.0599	81.2
CZ10	1.1566	0.1881	-5.5198	3.5647	-0.0942	84.2
CZ11	1.1278	0.2202	-2.7487	4.6503	-0.0973	86.2
CZ12	1.1514	0.1926	-10.4838	2.9696	-0.0683	83.2
CZ13	1.1213	0.2048	-2.9483	3.0168	-0.0473	86.9
CZ14	1.0686	0.1590	-1.4650	7.2651	-0.0967	87.2
CZ15	0.9913	0.1743	-1.5452	4.2966	0.0487	92.2
CZ16	1.4017	0.2347	4.1897	5.1020	-0.3436	80.2

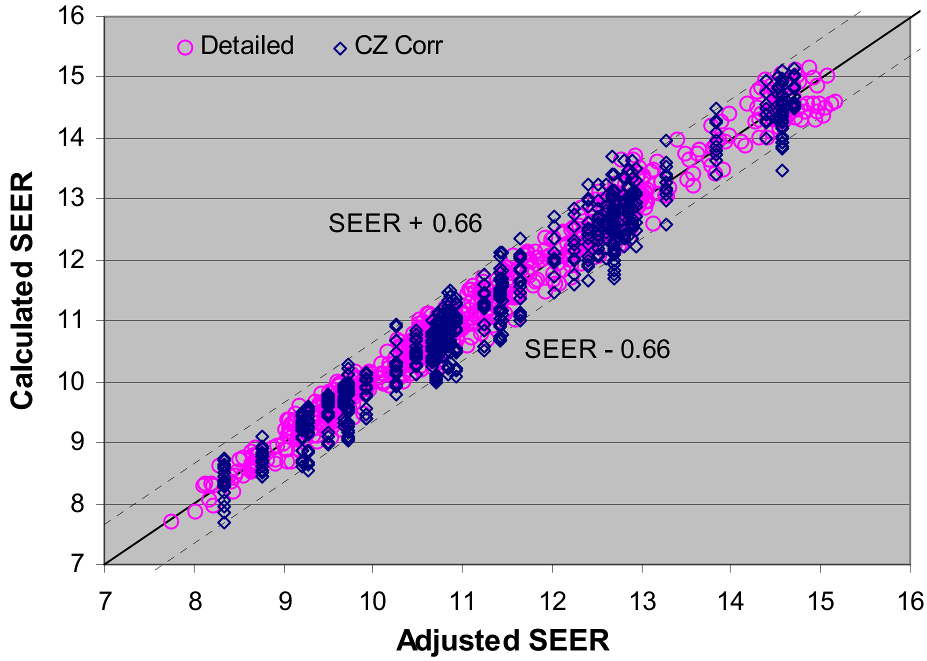
Table 4.1.3a
Standard Errors of Adjusted SEER Estimate – Climate Zone Multipliers

CZ01	CZ02	CZ03	CZ04	CZ05	CZ06	CZ07	CZ08
0.48	0.29	0.31	0.26	0.30	0.27	0.22	0.31
CZ09	CZ10	CZ11	CZ12	CZ13	CZ14	CZ15	CZ16
0.34	0.34	0.35	0.36	0.37	0.29	0.33	0.34

Table 4.1.3b
Standard Errors of Adjusted SEER Estimate – Detailed Multipliers

CZ01	CZ02	CZ03	CZ04	CZ05	CZ06	CZ07	CZ08
0.46	0.22	0.30	0.23	0.30	0.27	0.22	0.26
CZ09	CZ10	CZ11	CZ12	CZ13	CZ14	CZ15	CZ16
0.27	0.23	0.23	0.27	0.24	0.20	0.17	0.25

Figure 4.1.2
Adjusted SEER vs. Rated SEER – All Climate Zones
Single-Speed Systems



4.1.3 Benefit of Improved SEER

The benefits of adjusted SEER in predicting seasonal energy use are illustrated in Figure 4.1.3a. This figure compares the error in seasonal energy estimates based on rated and climate zone-adjusted SEER. Seasonal energy estimates are compared to rated SEER in Figure 4.1.3b for the detailed model. Both approaches have the ability to significantly improve estimates of seasonal energy use from known seasonal cooling loads. The figures also illustrate that neither can be done with absolute certainty because of performance differences between systems that can not be captured in a single ratings value.

Figure 4.1.3a
Error in Seasonal Energy Use – Rated SEER vs. CZ-Adjusted SEER
Single-Speed Systems

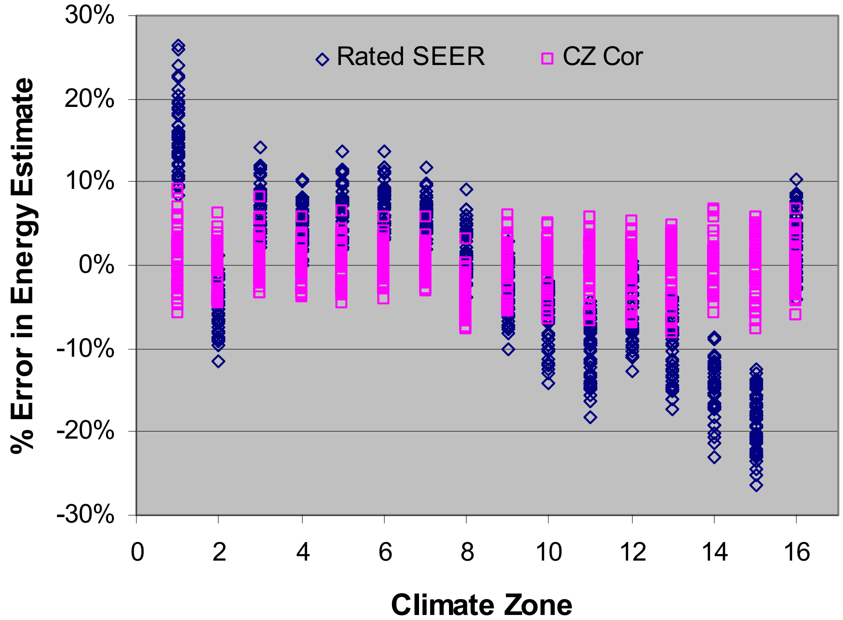
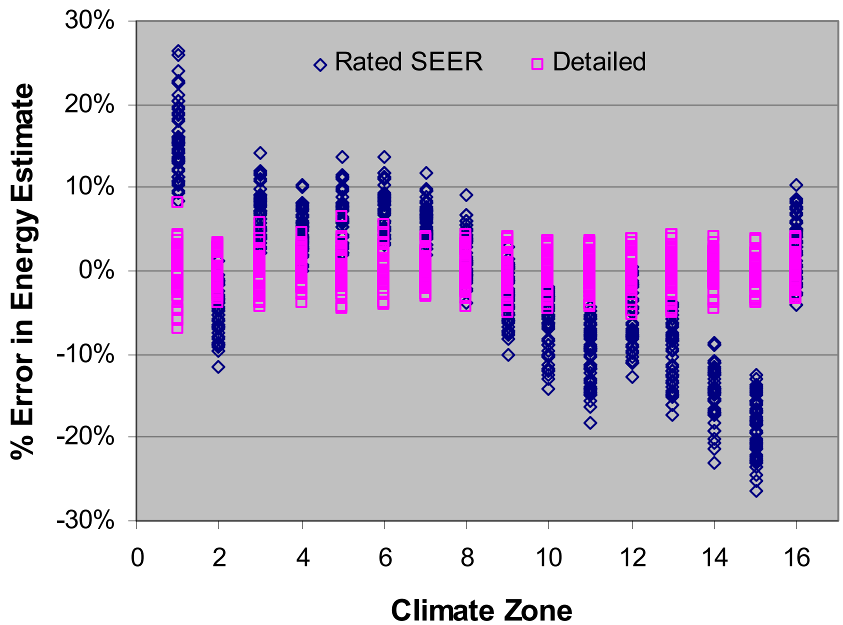


Figure 4.1.3b
Error in Seasonal Energy Use – Rated SEER vs. Detailed-Adjusted SEER
Single-Speed Systems



4.1.4 Fan Sizing and Equipment Over Sizing

Section 3.2.6 provided a mechanism for adjusting SEER for changes in fan operating conditions as compared to those used in the ratings process. Field studies of residential air conditioners and heat pumps have shown that systems operate at average external static pressures of 0.55” w.g. as compared to test standards. Test standards required external static pressures between 0.15” and 0.25” w.g., depending on system capacity. Because of these differences, average field observed fan power is typically 40% higher than rated conditions. The impact of higher fan power on SEER was related to the change in system EER caused by the higher fan power (Equation 3, Section 3.2.6), or:

$$\text{\% SEER Reduction} = \text{SEER CZ Mult}_{fan} * \text{\%EER Reduction.} \quad (4.4)$$

Equation 4.4, provides the means for determining the %EER reduction for a given cooling system. This is system-specific and will vary from system-to-system. The climate zone fan multipliers accounts for changes in the fraction of cooling energy used by the fan (constant from climate zone to climate zone) to that used by the compressor (varies with climate zone). Climate zone fan multipliers (CZ Mult_{fan}) have been expanded to include all climate zones as opposed the five in Section 3.2.t. The expanded list is given in Table 4.1.4.

Table 4.1.4
Fan Power Climate Zone SEER Adjustments, CZ Mult_{fan}

CZ01	CZ02	CZ03	CZ04	CZ05	CZ06	CZ07	CZ08
1.10	1.01	1.06	1.03	1.07	1.07	1.05	1.03
CZ09	CZ10	CZ11	CZ12	CZ13	CZ14	CZ15	CZ16
1.01	0.99	0.99	1.00	0.98	0.98	0.97	1.02

Section 3.2.7 illustrated that even gross equipment over sizing would have as relatively minor impact on SEER (typically 2-3% reduction). This finding was unchanged when all climate zones were examined. The relatively small change in SEER precludes the inclusion of a specific sizing rule or adjustment.

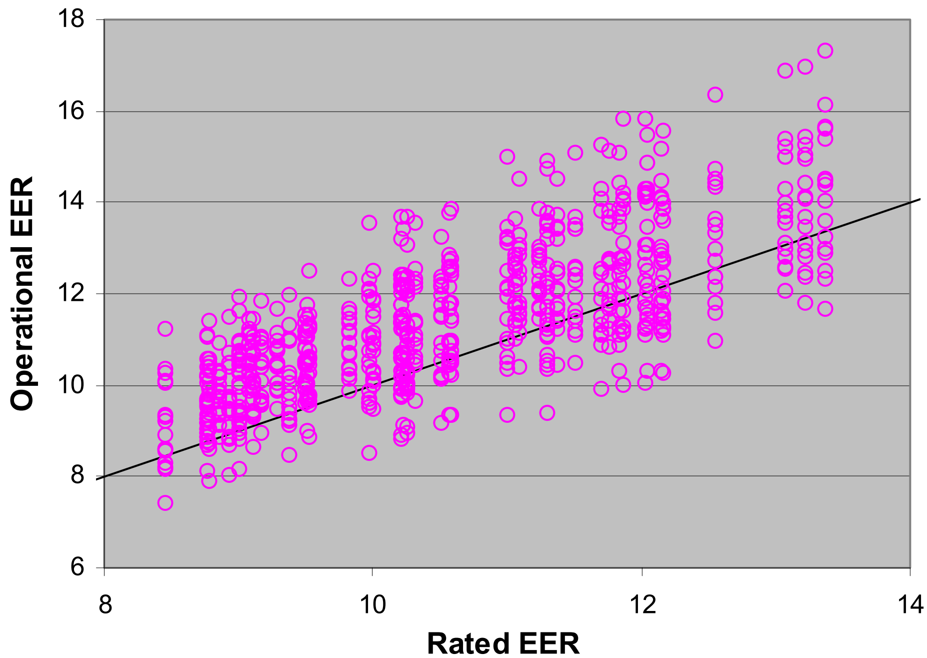
4.1.5 System Electric Demand

Section 3.2.5 showed that SEER is an inappropriate indicator of cooling system electrical demand – EER is a much better predictor even for two-speed equipment. It was also determined that demand impacts, for a given system, are climate zone specific. Simulations applied to all climate zones were used to determine appropriate climate zone multipliers applicable to cooling electric demand. These multipliers adjust a system’s EER to peak weather conditions specific to each climate zone.

Raw simulation results are shown in Figure 4.1.4 where cooling system peaks are given as an operational EER. The operational EER is equal to the cooling system’s design cooling capacity (ARI-rated conditions) divided by the peak electric demand determined for DOE-2 simulations.

A systems electric demand is found by dividing its rated cooling capacity by the operational EER. The figure illustrates both the relationships between rated EER and operational EER and the variation across all the simulations.

Figure 4.1.4
Operational (Simulated) vs. Rated EER – All Climate Zones



Climate zone multipliers that adjust rated EER to operational values are given in Table 4.1.5. The multipliers provide estimates of cooling system demand by equation 4.5. In equation 4.5 the

$$\text{Cool kW} = \text{Rated Cooling Capacity} / (\text{Rated EER} * \text{CZ EER}_{Mult}) \qquad (4.5)$$

climate zone EER multipliers (CZ EER_{Mult}) are given in Table 4.1.5. A comparison of the values in Table 4.1.1 and Table 4.1.5 shows consistent trends in the SEER and EER multipliers. The multiplier is lower in hotter climates than cooler and lower for higher SEER systems that lower SEER systems. This general trend, when applied to demand, illustrates a case of diminishing return for demand reduction when moving to higher efficiency systems.

Table 4.1.5
Climate Zone EER Multipliers

	Single-Speed SEER Rating			All Single-Speed	Two-Speed
	10	12	14		
CZ01	1.26	1.30	1.29	1.29	1.28
CZ02	1.08	1.04	1.02	1.05	1.14
CZ03	1.17	1.17	1.15	1.17	1.21
CZ04	1.10	1.10	1.07	1.10	1.18
CZ05	1.18	1.19	1.16	1.18	1.23
CZ06	1.20	1.20	1.19	1.20	1.23
CZ07	1.17	1.18	1.17	1.17	1.25
CZ08	1.17	1.18	1.17	1.10	1.25
CZ09	1.10	1.07	1.07	1.07	1.11
CZ10	1.05	1.01	0.98	1.01	1.10
CZ11	1.03	0.98	0.94	0.99	1.07
CZ12	1.03	1.01	0.99	1.01	1.10
CZ13	1.01	0.99	0.95	0.99	1.06
CZ14	1.02	0.97	0.92	0.97	1.07
CZ15	0.94	0.89	0.85	0.90	1.02
CZ16	1.10	1.09	1.05	1.09	1.14

The average climate zone multipliers leave a good deal of uncertainty in the operational EER. A somewhat better estimate of operational EER can be obtained using a detailed model that accounts for differences in equipment performance for single-speed equipment. An operational EER multiplier model was developed similar to the detailed SEER model. The general form of the single-speed, detailed model is as follows:

$$EER_{mult} = C_0 + C_1 * S_{DB} \tag{4.6}$$

where:

EER_{mult} is the EER multiplier used to adjust rated EER to operational EER and

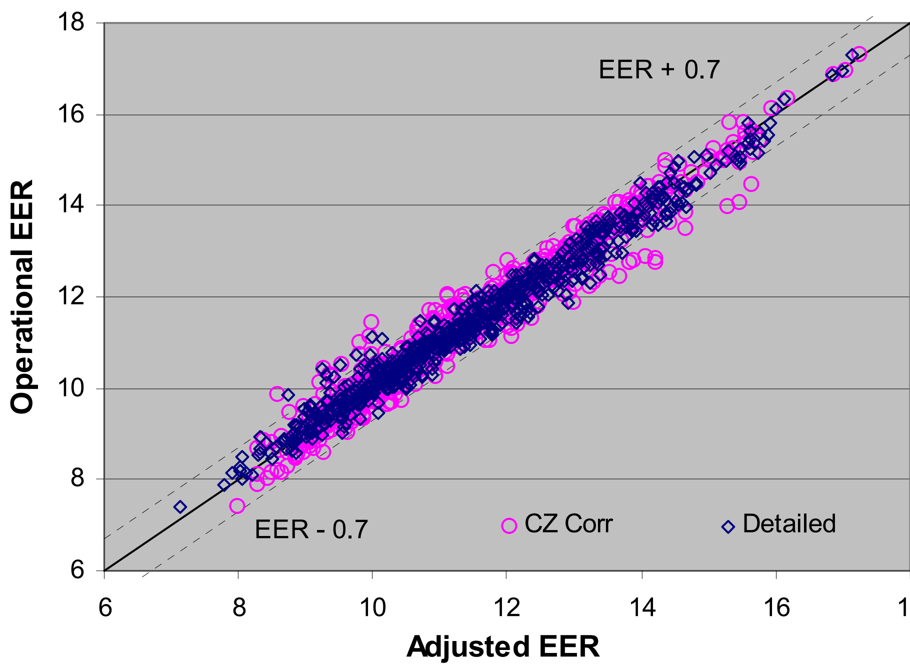
S_{DB} is the sensitivity of the system's efficiency to changing outdoor dry-bulb temperature. It is the same system independent variable used in Equation 4.2.

Climate zone-specific coefficients are given in Table 4.1.6. Coefficients C_1 are a measure of the difference between the outdoor temperature at the time of the cooling peak and the 95 F outdoor temperature used as the ARI condition. Cooler climates are less than the ARI point and have negative coefficients. Hotter climates are positive, indicating outdoor temperatures at peak load that are higher than 95 F. Differences in the average conditions entering the cooling coil from climate zone to climate zone are accounted for in the constant C_0. Results of the detailed model and the climate zone-corrected models are compared to the operational EER in Figure 4.1.5.

Table 4.1.6
Detailed EER Model Coefficients

	C_0	C_1		C_0	C_1
CZ01	1.0718	-17.176	CZ09	1.2534	14.170
CZ02	1.2203	13.424	CZ10	1.2471	18.273
CZ03	1.1157	-4.084	CZ11	1.2582	21.355
CZ04	1.1144	1.298	CZ12	1.1990	14.717
CZ05	1.1376	-3.433	CZ13	1.2583	21.413
CZ06	1.1236	-5.952	CZ14	1.2704	23.216
CZ07	1.0660	-8.308	CZ15	1.3211	32.874
CZ08	1.2059	8.127	CZ16	1.1635	6.228

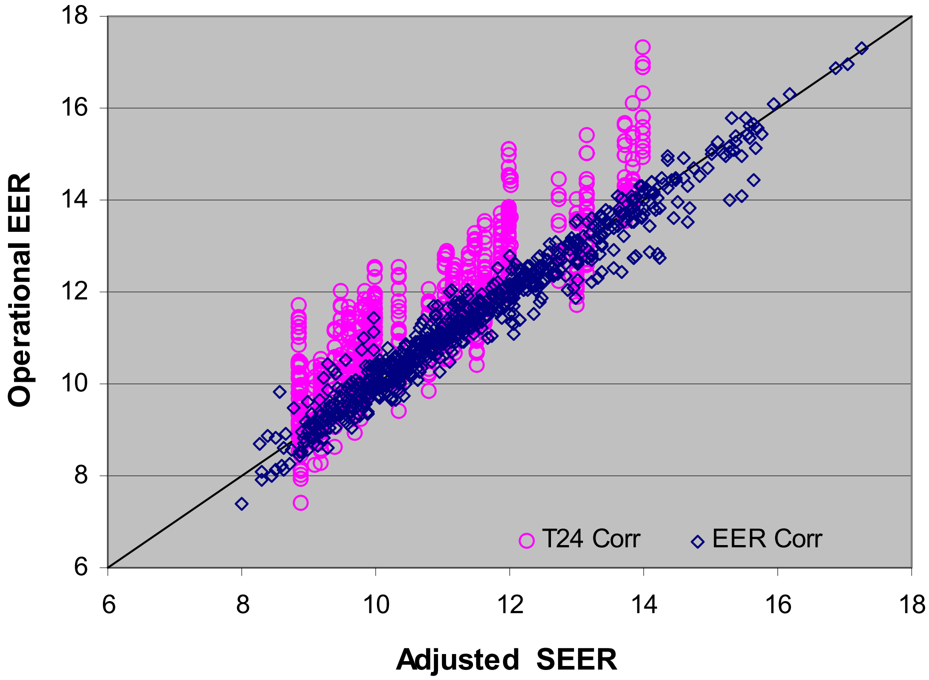
Figure 4.1.5
Comparison of Adjusted EER to Operational (Simulated) EER
Climate Zone and Detailed Models



Title-24 for residential applications now includes SEER multipliers whose purpose is to provide a SEER adjustment to better reflect cooling system electric demand impacts. The multipliers, as many proposed in this effort, are climate zone and rated SEER specific. Title-24 adjusted SEER values are compared to the operational EERs calculated in this effort in Figure 4.1.6. Also shown in the figure are predicted values of operational EER using the system's rated EER and the climate zone and SEER level multipliers given in Table 4.1.5.

Figure 4.1.6

Comparison of Adjusted EER to Operational (Simulated) EER
T-24 SEER Adjusted and Climate Zone EER Adjusted



A comparison of the two approaches as illustrated in Figure 4.1.6 leads to the following conclusions:

- The Title-24 adjustments provide a much better estimate of demand impacts than rated SEER. In fact, they are relatively good at identifying minimum demand benefits of SEER-rated systems. The problem with these multipliers is that their use can still result in a great deal of uncertainty in predicting demand benefits. This is caused by design differences among cooling systems (as illustrated in Figure 1.1). Because systems with the same SEER can have significantly different EER's, using SEER as a predictor of demand is always problematic. Because of this, the Title-24 multipliers frequently don't credit cooling systems with desirable demand characteristics in order not to over-predict the demand benefits of less desirable systems.

- Demand impacts can be predicted much more reliably when based on cooling systems' rated EER as opposed to its SEER, as illustrated by the EER corrected ("EER Corr" symbols in the figure) results shown in Figure 4.1.6. Applying climate and SEER specific multipliers to a cooling system's rated EER would allow regulators to better select systems that minimize their impact on the electric grid.

4.2 SMALL OFFICE SYSTEMS

Findings presented in Section 3.2 illustrated the problems associated with the traditional definition of SEER as an indicator of seasonal cooling system efficiency or as a ranking metric when applied to office settings. A modified SEER that includes continuous fan operation ($SEER_f$) was shown useful when selecting among competing cooling system alternatives. This form of SEER evaluates the relative merits of more or less efficient indoor fan systems against more or less efficient compressors. While $SEER_f$ does not always predict the best system for a given application, it can rule out the worst systems.

Table 4.2.1 provides the range in seasonal cooling system energy consumption obtained from DOE-2 simulations of systems serving small offices for all climate zones. Simulations differed only in the cooling system. $SEER_f$ was used to rank the cooling systems to provide a “best” selection. If this system was chosen, then its seasonal energy consumption, while not always the lowest, was within half the value given in Table 4.2.1 of the lowest. For example, if one were selecting a SEER-10 system for an office application in climate zone 12, one should expect a 15% difference in annual cooling and fan energy between the best and worst cooling systems. If one ranked the systems by $SEER_f$ and chose the one with the highest $SEER_f$ value, then the selected system’s annual energy consumption would be at least within 7.5% of the best system. The ranking of systems by $SEER_f$ varies by climate zone and application (core, south perimeter, etc.) depending on the relative contribution of the indoor fan versus the condenser unit to seasonal cooling system energy consumption.

$SEER_f$ is calculated using Equations 4.7 through 4.8. Climate zone and system-specific multipliers used with the equations are Tables 4.2.2 and 4.2.3.

$$SEER_f = [1/SEER_{cond} + (Hrs_{fan}/Hrs_{comp})*W_{fan}/\text{Cool Cap}]^{-1} \qquad (4.7)$$

Where:

$SEER_f$ is the SEER that includes continuous fan operation,

$SEER_{cond}$ is the condenser unit SEER as defined above,

Hrs_{fan}/Hrs_{comp} are given in Table 4.2.3 for all climate zones,

W_{fan} is the rated fan power in Watts, and

Cool Cap is the rated cooling capacity in Btu/hr.

$$SEER_{cond} = CZ_{mult} * SEER\ (EER_B/EER_{B,no\ fan}) \qquad (4.8)$$

where:

$EER_{B,no\ fan}$ = (Net Capacity + Fan Watts * 3.413)/(Total Electric – Fan Watts)

where all values are when the system is operating at an 82º F outdoor temperature and ARI coil entering conditions, and

EER_B is the system’s EER at 82º F outdoor temperature and ARI coil entering conditions.

Table 4.2.1
Difference in Seasonal Energy Use Among Range of Packaged Systems Examined
Office Application

	SEER-10	SEER-12		SEER-10	SEER-12
CZ01	12%	20%	CZ09	13%	10%
CZ02	14%	13%	CZ10	14%	10%
CZ03	13%	16%	CZ11	18%	13%
CZ04	12%	13%	CZ12	15%	13%
CZ05	12%	15%	CZ13	18%	13%
CZ06	11%	13%	CZ14	17%	13%
CZ07	11%	14%	CZ15	17%	18%
CZ08	10%	11%	CZ16	15%	15%

Table 4.2.2
Condenser Unit SEER Climate Zone Multipliers - CZ_{mult}
Office Application

	SEER-10	SEER-12		SEER-10	SEER-12
CZ01	1.11	1.20	CZ09	1.04	1.10
CZ02	1.05	1.11	CZ10	1.02	1.08
CZ03	1.10	1.18	CZ11	1.00	1.06
CZ04	1.07	1.15	CZ12	1.03	1.09
CZ05	1.10	1.19	CZ13	1.00	1.06
CZ06	1.10	1.18	CZ14	0.99	1.04
CZ07	1.10	1.18	CZ15	0.91	0.93
CZ08	1.07	1.14	CZ16	1.06	1.13

Table 4.2.3
Fan-to-Compressor Runtime Ratios - Hrs_{fan}/Hrs_{comp}
Office Application

	Zone Type Served				Zone Type Served		
	Core	South	N, E, or W		Core	South	N, E, or W
CZ01	4.14	4.01	4.83	CZ09	3.73	3.28	3.76
CZ02	4.26	3.95	4.33	CZ10	3.79	3.25	3.59
CZ03	3.77	3.99	4.28	CZ11	4.96	3.94	4.47
CZ04	4.07	3.73	4.15	CZ12	4.37	3.89	4.35
CZ05	3.43	3.63	3.84	CZ13	4.96	3.94	4.47
CZ06	3.26	3.14	3.58	CZ14	4.43	3.64	3.92
CZ07	3.37	3.03	3.62	CZ15	4.29	3.12	3.48
CZ08	3.58	3.19	3.57	CZ16	5.97	4.80	5.57

4.3 RETAIL SYSTEMS

The simulation results for packaged cooling systems used in a retail application mirror those of small offices. This section provides error bounds and $SEER_f$ multipliers appropriate to retail applications (Tables 4.3.1 through 4.3.3). The application of the constants and overall benefits of $SEER_f$ are essentially the same as for systems used in an office setting.

Table 4.3.1
Variation in Seasonal Energy Use Among Packaged Systems Examined
Retail Application

	SEER-10	SEER-12		SEER-10	SEER-12
CZ01	16%	36%	CZ09	13%	14%
CZ02	14%	17%	CZ10	13%	13%
CZ03	11%	28%	CZ11	18%	16%
CZ04	13%	22%	CZ12	17%	16%
CZ05	10%	22%	CZ13	15%	14%
CZ06	10%	22%	CZ14	23%	23%
CZ07	12%	25%	CZ15	17%	20%
CZ08	10%	18%	CZ16	19%	20%

Table 4.3.2
Condenser Unit SEER Climate Zone Multipliers - CZ_{mult}
Retail Application

	SEER-10	SEER-12		SEER-10	SEER-12
CZ01	1.18	1.25	CZ09	1.05	1.11
CZ02	1.05	1.10	CZ10	1.02	1.07
CZ03	1.14	1.21	CZ11	0.98	1.03
CZ04	1.10	1.17	CZ12	1.02	1.08
CZ05	1.14	1.22	CZ13	0.99	1.02
CZ06	1.14	1.21	CZ14	0.94	0.99
CZ07	1.13	1.20	CZ15	0.89	0.90
CZ08	1.09	1.16	CZ16	1.05	1.12

Table 4.3.3
Fan-to-Compressor Runtime Ratios - Hrs_{fan}/Hrs_{comp}
Retail Application

	Zone Type Served				Zone Type Served		
	Sales	Storage	All		Sales	Storage	All
CZ01	6.70	11.69	7.29	CZ09	4.06	4.52	4.15
CZ02	4.96	5.92	5.12	CZ10	3.89	4.27	3.95
CZ03	4.82	6.41	5.06	CZ11	4.79	5.44	4.91
CZ04	4.63	5.52	4.79	CZ12	4.95	5.68	5.09
CZ05	3.82	4.44	3.93	CZ13	4.19	4.42	4.24
CZ06	3.82	4.44	3.93	CZ14	4.40	4.73	4.46
CZ07	3.60	4.15	3.70	CZ15	3.56	3.60	3.57
CZ08	3.74	4.17	3.82	CZ16	6.63	7.86	6.86

4.4 SCHOOL SYSTEMS

The simulation results for packaged cooling systems used in school applications are similar to those of small offices and retail applications. This section provides error bounds and $SEER_f$ multipliers appropriate to school applications (Tables 4.4.1 through 4.4.3). The application of the constants and overall benefits of $SEER_f$ are similar to systems used in office and retail settings.

Table 4.4.1
Variation in Seasonal Energy Use Among Packaged Systems Examined
School Application

	SEER-10	SEER-12		SEER-10	SEER-12
CZ01	24%	42%	CZ09	23%	18%
CZ02	20%	17%	CZ10	17%	13%
CZ03	15%	23%	CZ11	22%	18%
CZ04	18%	17%	CZ12	22%	20%
CZ05	14%	26%	CZ13	15%	13%
CZ06	21%	19%	CZ14	21%	16%
CZ07	13%	19%	CZ15	25%	24%
CZ08	13%	16%	CZ16	16%	16%

Table 4.4.2
Condenser Unit SEER Climate Zone Multipliers - CZ_{mult}
School Application

	SEER-10	SEER-12		SEER-10	SEER-12
CZ01	1.10	1.19	CZ09	1.02	1.09
CZ02	1.01	1.08	CZ10	0.99	1.05
CZ03	1.13	1.13	CZ11	0.98	1.03
CZ04	1.08	1.15	CZ12	1.04	1.04
CZ05	1.08	1.16	CZ13	0.98	1.03
CZ06	1.12	1.13	CZ14	0.96	1.01
CZ07	1.13	1.13	CZ15	0.93	0.92
CZ08	1.06	1.13	CZ16	1.02	1.09

Table 4.4.3
Fan-to-Compressor Runtime Ratios - Hrs_{fan}/Hrs_{comp}
School Application

	School Operation				School Operation		
	Minimum	Median	Maximum		Minimum	Median	Maximum
CZ01	6.19	6.49	5.79	CZ09	4.20	4.31	3.91
CZ02	3.88	4.09	3.80	CZ10	3.80	3.72	3.61
CZ03	4.40	4.65	4.27	CZ11	3.69	3.91	3.93
CZ04	3.82	4.09	3.87	CZ12	3.72	4.15	3.82
CZ05	4.30	4.50	4.23	CZ13	3.49	3.57	3.35
CZ06	4.17	4.27	3.62	CZ14	3.69	3.73	3.33
CZ07	3.81	3.86	3.89	CZ15	3.63	3.83	3.64
CZ08	3.41	3.79	3.43	CZ16	4.03	4.30	3.53

Note: Minimum, Median, and Maximum School Operation are as follows:
Minimum – 7 mos./year, 7 hours/day, 5 days/week
Median – 7 mos./year, 11 hours/day, 5 days/week
Maximum – year-round, 11 hours/day, 5 days/week

5.0 CONCLUSIONS

5.1 Single-Family Simulation Conclusions

Results from residential DOE-2 simulations include the following:

- SEER rating alone is a poor predictor of expected cooling energy use. One should expect errors in estimates cooling energy between –20% and +30%. Much of the error is associated with climate effects. Climate affects can be minimized by using multipliers given in Table ES-1. An uncertainty in rated SEER value of ±0.6 SEER ratings points can not be eliminated. This uncertainty appears to be caused by small differences in how cooling systems respond to changes in outdoor and cooling coil entering conditions.

- SEER does not always rank systems as to their energy efficiency. One should expect that differences in the way cooling systems respond to outdoor and indoor conditions, along with cycling rates, will mean that SEER is reliable only to within 0.6 ratings points. That is, a nominal SEER 12 system is as likely to produce seasonal cooling energy values equivalent to a SEER of 11.4 or 12.6. Because of this uncertainty, one could not be certain that purchasing the next higher SEER-rated system (SEER 11 instead of SEER 10, or SEER 12 instead of SEER 11, etc.) would provide seasonal energy savings.

- Residential building characteristics (insulation levels, glass type or amount, internal gains, thermostat settings, use of natural ventilation, etc.) have a relatively minor effect (±5%) on SEER. All these building characteristics can and do have a significant effect on annual cooling energy, but not on SEER. Their impact on savings in annual cooling energy resulting from replacing one SEER rated system with a higher SEER rated system is even less.

- SEER is poor predictor of cooling system electric demand in residential applications. Demand impacts can be predicted much more reliably when based on cooling systems' rated EER. One has to move to a SEER-14 rated system from a SEER-10 system to be assured of cooling system demand reductions. EER, when adjusted for climate effects via multipliers given in Table ES-2, can distinguish demand benefits to within ±8% of the climate-adjusted EER.

- Current Title-24 Climate Zone multipliers are useful in identifying minimum demand benefits associated with choosing a cooling system with a higher SEER rating. They do not adjust SEER to reflect climate related changes in seasonal cooling system efficiency; Table ES-1 multipliers should be used for this. In addition, the Title-24 SEER-based multipliers can not distinguish between cooling systems with the same SEER, but different demand impacts. Demand benefits are best estimated by applying the climate zone multipliers given in Table ES-2 to the systems' rated EER. Applying the multipliers given in Table ES-2 to a cooling system's rated EER would allow regulators to better select systems that minimize their impact on the electric grid.

5.2 Small Office, Retail, and School Application Conclusions

Results from small office and retail DOE-2 simulations include the following:

- SEER can not be used to reliably predict seasonal cooling system efficiency in commercial applications. SEER was developed assuming indoor fan operation that cycles with the compressor. The additional fan energy associated with continuous fan operation in commercial applications renders a seasonal efficiency value meaningless.

- Ignoring fan issues, SEER is still problematic. The relationship between the outdoor temperature and cooling load produces unacceptably large variation in SEER. SEER is not independent of the cooling load in commercial applications as it is in residential applications.

- Neither SEER nor EER are useful in predicting demand or demand benefits. The interaction of the cooling system with changes in cooling coil entering conditions, space loads, and outdoor temperature are highly variable in commercial applications. The resulting shifts in what produces peak load conditions varies from system to system, leading to highly variable demand impacts.

- Simulation results showed significant differences in annual energy among systems of identical SEER rating. This difference often was close to that expected when moving from a SEER-10 system to a SEER-12 system. A modified SEER that accounts for continuous fan operation, $SEER_f$, was developed and found to be beneficial in ranking cooling systems. While it could not always select the most efficient cooling system, it could eliminate the selection of the poorest cooling systems. It does so by weighing the relative benefits of seasonal fan and condenser unit energy. Selecting the system with the highest $SEER_f$ rating typically eliminated the worse 50% of the systems examined.

6.0 REFERENCES

ARI, 1984. ARI Standard 210/240-84, unitary air-conditioning and air-source heat pump equipment. Air-Conditioning and Refrigeration Institute.

DOE 1979. Test procedures for central air conditioners including heat pumps. Federal Register Vol. 44, No. 249. pp 76700-76723. December 27, 1979.

Kavanaugh, Steve P. 2002. Limitations of SEER for Measuring Efficiency. *ASHRAE Journal*, July 2002.

Kelly, G. E. and W. H. Parken. 1978. Method of testing, rating and estimating the seasonal performance of central air-conditioners and heat pumps operating in the cooling mode. NBSIR 77-1271.

Lamb, G. and D. R. Tree. 1981. Seasonal performance of air-conditioners – an analysis of the DOE test procedures: The thermostat and measurement errors. Energy Conservation, US Department of Energy, Division of Industrial Energy Conservation, Report No. 2, DOE/CS/23337-2.

Parken, W.H., Didion, D.A., Wojciechowshi, P.H., and Chern, L. 1985. Field Performance of Three Residential Heat Pumps in the Cooling Mode. NBSIR 85-3107.

APPENDICES

The following information is provided here as supporting detail and reference:

APPENDIX A **Differences between the SEER Ratings Process and DOE-2 Calculations**

APPENDIX B **Cooling System Selection Procedure**

APPENDIX C **Generating Part-Load Curves for DOE-2**

APPENDIX D **Review of Residential Fan System Operation and Duct Losses**

APPENDIX E **Details of Single Family Building Prototype**

APPENDIX F **Details of Non-Residential Building Prototypes**

APPENDIX A: THE SEER RATINGS PROCESS AND DOE-2 CALCULATIONS

The process whereby NIST conditions are matched by changes in the DOE2 models is given in Table A.1.

Table A.1.
Comparison of NIST & DOE-2 Calculation Approaches

	Cooling System Performance Assumptions	
Calculation Assumptions	NIST	DOE-2 Program
Calculation Method	Single point from simplified bin analysis	Hour-by-hour simulation.
Imposed Load Shape	Fixed	Closely matching load profiles with mid-load temperatures of 82.5º F and 84.5º F. See Figure 1.
Cooling System Capacity	Fixed	Cooling total capacity adjustment curve (COOL-CAP-FT) changed to a fixed value of 1.0.
Cooling System Efficiency	Fixed value for at an outdoor temperature of 82º F and 67º F entering air wet- bulb. Original work using temperature dependency for actual systems produced SEER within 10% of single point value.	2nd order variation with outdoor dry-bulb only via COOL-EIR-FT. Wet-bulb dependency eliminated by creating curve-fit coefficients at a fixed 67º F 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 (COOL-CAP-FT = COOL-SH-FT)
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.

The load profiles generated in DOE-2 simulations are compared to that used by NIST in Figure A.1. They DOE-2 profiles are for the two possible building orientations – north/south and east/west. The east/west orientation produces a slightly higher mid-load temperature of 84.5º F as compared to the 82.5º F mid-load temperature for the north/south orientation. Both profiles are similar to the NIST profile, with the 82.5º F mid-load temperature profile providing the closer match. These profiles are representative of either a single story house with a single cooling system or a two story house with a single cooling system. Simulation results based on two story houses with a cooling system per floor were not used. The bottom floor load profile differed too much from NIST assumptions to be useful.

Figure A.1.
NIST and DOE-2 Generated Cooling Load Profiles

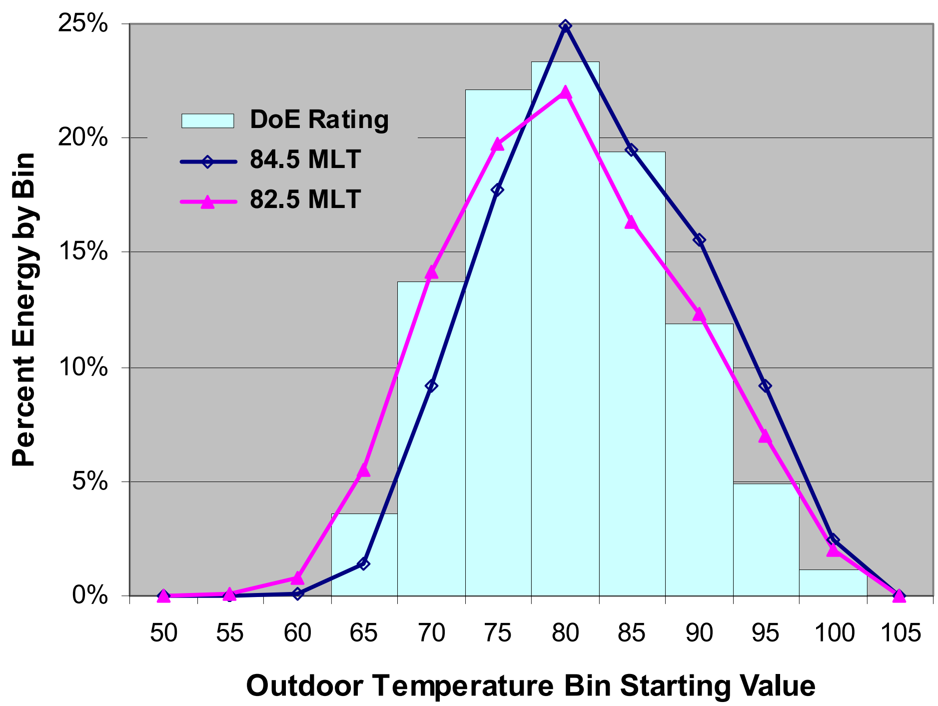


Figure A.2 provides a comparison of predicted SEER ratings using full DOE-2 performance curves versus those adjusted to match NIST assumptions. The points noted as "Full Model" use performance curves based on manufacturer's published data and expanded ratings tables. Those noted as the "Simple Model" have had their "Full Model" performance curves adjusted to match conditions noted in Table A.1. Performance curves in the "Simple Model" are no longer dependent on cooling coil entering air conditions and produce performance values that would occur at cooling coil entering conditions of 80º F dry-bulb and 67º F wet-bulb. The curves also force the sensible cooling capacity to equal the total since the NIST ratings procedure does not differentiate between the two.

The agreement between the SEER generated by the "Simple Model" and rated values for single speed (SEER 10, 12 and 14) systems is quite good. The scatter in the results is within ±5% of the rated SEER. This is within the variation Kelly and Parken reported in the development of the SEER ratings procedure when they applied the full bin method to real systems and compared results to the single point analysis. The scatter is associated with slight differences in the performance characteristics of the various systems (more so than differences in the load profiles). Some scatter in predicted SEER is to be expected as a result of even minor differences in cooling equipment performance characteristics, load sequencing, and cycling losses. On hindsight, it seems unrealistic that a single seasonal efficiency prediction should be expected given the detail to which the DOE2 program looks at the cooling system's response to building loads. A more reasonable view might be that DOE2-predicted SEER values are equivalent if within 5% of each other.

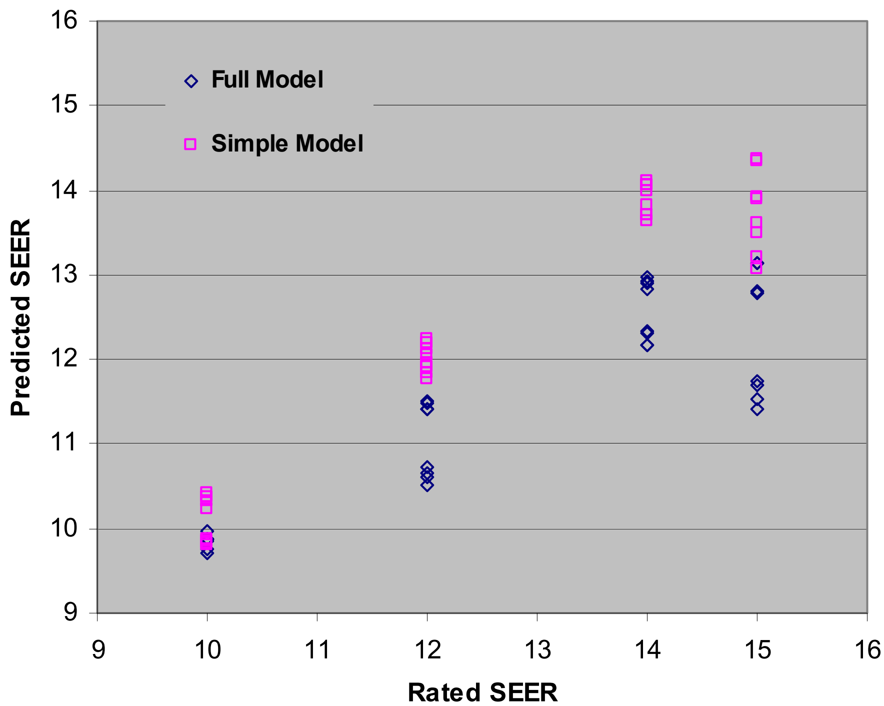
While SEER agreement using the "Simple Model" is good for single-speed systems, it is not so for two-speed systems. The "Simple Model" applied to two-speed systems did result in much better agreement than "Full Model" simulations. Differences improved from a range of 12% to 25% to a range of 4% to 13%. The rating of the two-speed systems are much more load shape dependent than the single speed systems. As such, greater differences between the rated and DOE2-predicted SEER values are to be expected. It is not clear at this point if there is an inherent problem in the NIST rating approach for two-speed systems or if the residential load models haven't adequately reproduced the necessary load sequencing to replicate the rated SEER.

Predicted SEER values for two-speed systems based on the "Simple Model" are more sensitive to changes in the mid-load temperature and system performance characteristics than single speed systems. Differences in mid-load temperature accounts for approximately 4% of the scatter in the points; differences between the performance characteristics of the two systems accounts for 6% of the scatter. Scatter for the single speed systems (about 5%) is almost entirely a result of differences in the different system performance characteristics.

A comparison of DOE2 predicted SEER between "Simple" and "Full" model simulations indicate that the lack of agreement between rated and DOE2-predicted SEER values for the "Full Model" are a result of more realistic cooling coil entering conditions rather than any problem with the DOE2 simulation process. The difference between predicted SEER of the full and simple models provides a measure of the impact of coil entering wet-bulb temperature on SEER (for at least climate zone 12.) The mid-load wet-bulb of the air entering the coil for simulations whose results are shown in Figure A.2 is 58º F ±1º F. The lower average entering air wet-bulb will lead to a loss of cooling efficiency in comparison to the 67º F rated conditions. A review of the EIR dependency on wet-bulb for the systems used in the simulations suggests efficiency reductions of 7%, 12% and 15% for the 10, 12, and 14 SEER systems respectively. The difference between the simple and full model predicted SEER values are 2%, 8%, and 9%, preserving the overall trend of increasing efficiency loss from lower to higher SEER-rated systems.

The magnitude of the efficiency loss is affected by factors that are also impacted by the lower entering air wet-bulb temperature. These include higher sensible fraction and lower total cooling capacity. The higher sensible fraction means that more of the condenser unit energy is used to control space temperature, rather than remove moisture. Since runtime is determined by the sensible capacity of the system, the higher the sensible fraction, the lower the system runtime for a given condenser unit energy input. The lower wet-bulb also causes a reduction in cooling capacity, which is why the EIR increases as the entering air wet-bulb decreases. But the reduced capacity means the system runs longer, leading to lower cycling losses. So, while the lower capacity increases the EIR, the increased runtime reduces the overall effect. Thus, both higher sensible fraction and reduced cycling losses work together to reduce the impact of the higher EIR on overall efficiency.

Figure A.2.
Comparison of DOE2—Predicted SEER, Full and Simple Models



From this it seems unlikely that the difference between the mid-load entering air wet-bulb and the NIST 67º F rating point will produce a SEER correction based on manufacturer's expanded ratings data alone. However, there may be some appropriate multipliers that can be applied to account for this effect, perhaps on a climate zone basis, or climate zone plus expanded rating data. A determination of possible correction factors will require a comparison of "Simple" and "Full" models in other climate zones.

APPENDIX B: COOLING SYSTEM SELECTION PROCEDURE

There are approximately 7,000 different cooling systems listed in the CEC air conditioner and heat pump database. The Hiller database contains details on nearly 1,000 systems. It would be an overwhelming effort to simulate even the systems in the Hiller database, let alone the full CEC database. As such, a rational means is required to select a subset of available systems for analysis. The approach taken was to use a number of metrics to identify specific cooling systems. Selected systems would be representative of other systems with the same or similar metrics. The metrics used include the following:

- Nominal SEER
- System arrangement – split system or packaged
- System type – air conditioner or heat pump
- Cycling performance – degradation coefficient (C_D) as determined in DOE SEER test procedures
- EER/SEER ratio – System's EER_{ARI}/SEER
- System's sensitivity of EER to outdoor temperature as indicated by the linear slope of its normalized EER curve, or $EER\_f(T_{osa})/EER_{ARI}$ = constant + $slope_{EER}$ * outside air temperature. $Slope_{EER}$ is the EER temperature sensitivity metric.
- System's sensitivity of capacity to outdoor temperature - linear slope of its normalized capacity curve, or $Cap\_f(T_{osa})/CAP_{ARI}$ = constant + $slope_{CAP}$ * outside air temperature. $Slope_{CAP}$ is the capacity temperature sensitivity metric.

The best way to show how these metrics can be used to select cooling systems is to begin with the definition of SEER for single speed system, or

$$SEER \equiv EER_{82F}(1-0.5*C_D).$$

Thus, systems that only differ by their C_D value will have different EER's at ARI conditions. This is illustrated in Figure B.1, which shows how C_D reflects performance differences among similar nominal 10 SEER systems.

Notice that differing values of C_D cause a vertical shift in the system's EER curve. Higher values of C_D shift the EER curve upward; lower values shift the curve downward. This is because the EER_{82F} (large markers in the figure) must increase as C_D increases to maintain the same SEER. The values of C_D shown in Figure B.1 represent the range of values appropriate for SEER 10 air conditioners. As such, one should expect to see a range of EER_{ARI} (small marker in the figure) from as low as 8.7 to as high as 9.9 just to account for the full range of C_D.

The sensitivity of a system to outside air temperature also impacts its efficiency at differing conditions. This is illustrated in Figure B.2, where all systems are assumed to have the same value of C_D, and thus EER_{82F}, but differing sensitivity to outdoor temperature. The range of EER slope provided in the figure is typical of SEER 10 air conditioners. In this case, different values of EER_{ARI} result from the system's temperature sensitivity even though all have the same C_D.

Figure B.1.
Effect of C_D on System Performance – SEER 10 Systems

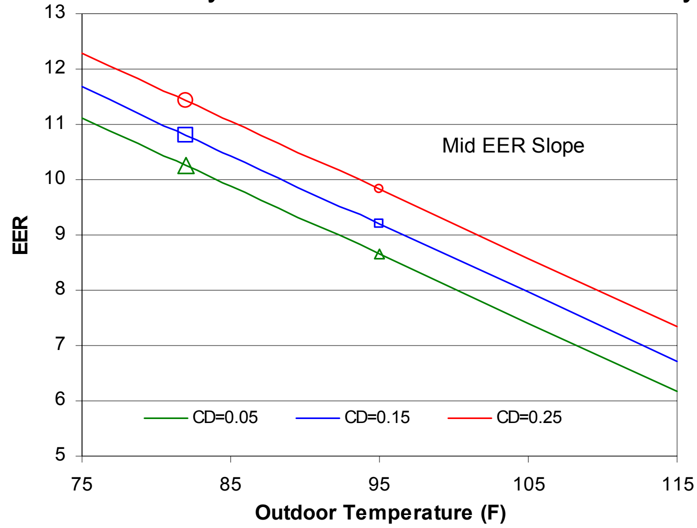
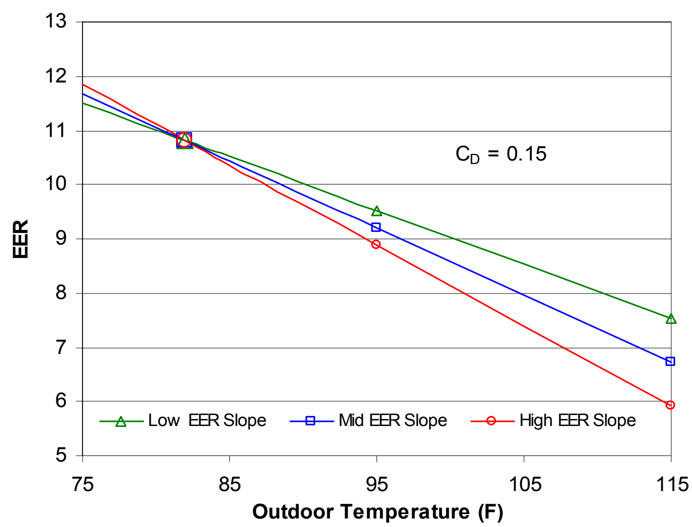
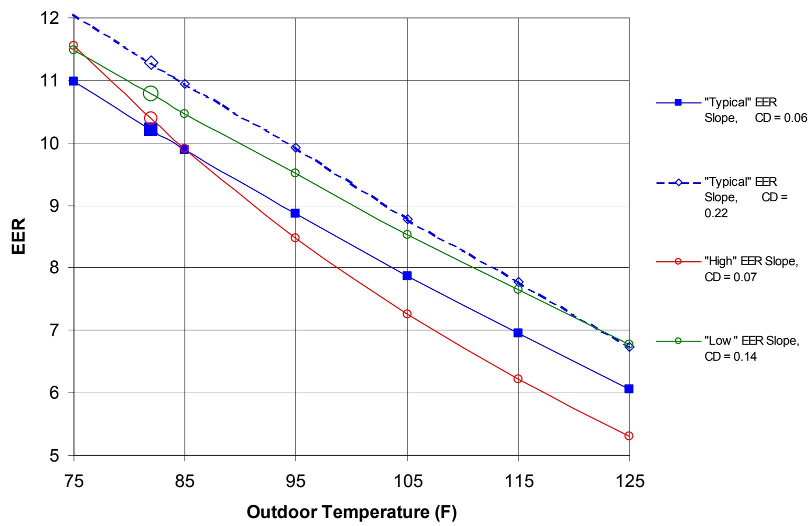


Figure B.2
Effect of $Slope_{EER}$ on System Performance – SEER 10 Systems



The significance of these particular metrics is that they define EER performance boundaries for a particular class of cooling systems. A cooling system class is defined by a system's nominal SEER rating, whether it is an air conditioner or a heat pump, and whether it is a split or packaged system. An example of the EER performance boundary for SEER 10 air conditioners is shown in Figure B.3. The EER curves are for actual systems from the Hiller database of single-speed, split system air conditioners with a nominal 10 SEER. They span the range of EERs expected for this type of cooling system. Different systems (higher efficiency systems, or heat pumps, or packaged systems for example) would have different EER boundaries.

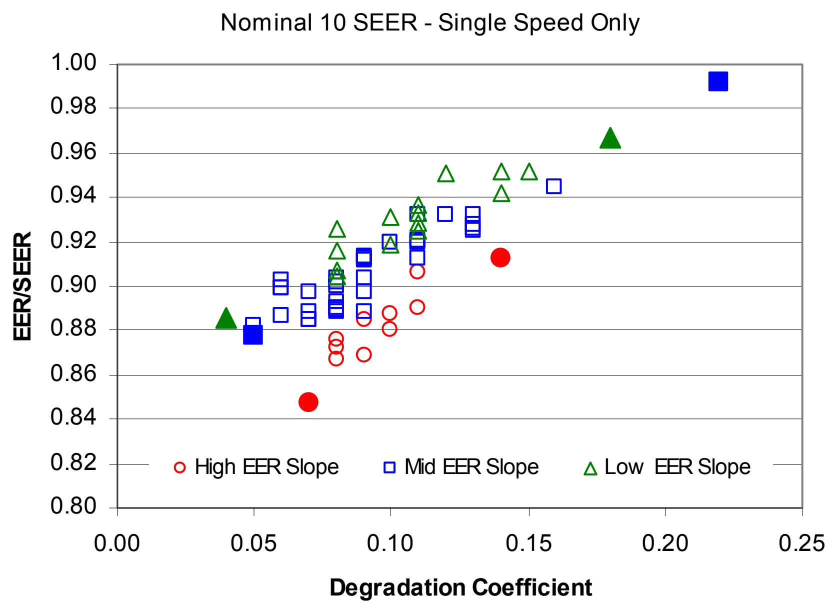
Figure B.3
Comparison of EER Data for SEER 10 Split-System Air Conditioners



The Hiller database provides additional information on the relationships between values of C_D and $Slope_{EER}$, Typically, systems with high values of $Slope_{EER}$ tend to have lower values of C_D. Systems with lower values of $Slope_{EER}$ tend to have higher values of C_D. Systems with mid-values of $Slope_{EER}$ can exhibit the full range of C_D values. The range of expected values of both C_D and $Slope_{EER}$ changes when going from low SEER systems to high SEER systems and differs between air conditioners and heat pumps, split and packaged systems. The Hiller database provides the expected range of conditions for each cooling system class as systems were selected by Hiller to represent performance extremes. In particular, for a particular cooling system class, it provides high and low values of C_D for high, low, and mid values of $Slope_{EER}$.

The selection process is illustrated in Figure B.4. (The actual selection would be based on a sorting and ranking process rather than graphics). The figure is a plot of the EER_{ARI}/SEER ratio for all SEER 10, single-speed, split system air conditioners in the database. System capacity ranges from 1.5 to 5.0 tons. The EER_{ARI}/SEER ratio is plotted against the system's C_D. Color-coding identifies systems with high, mid, and low values of $Slope_{EER}$. The figure shows the relationships between the various selection metrics and limits on their values. The selection process would pick systems shown as filled symbols in the figure. Three others, representing median values of C_D would also be selected. If necessary, additional systems would be selected that have the highest and lowest EER_{ARI}/SEER ratio. This approach spans the expected performance range of all SEER 10 split system air conditioners. Systems selected by this approach would have $8.5 < EER_{ARI} < 9.9$.

Figure B.4
Example of System Selection Procedure



It is worth noting that a system's rated cooling capacity is not part of the selection process. This is because no trend has been found that suggests that capacity should be considered. There are some occasions when, within a given product line, larger capacity systems have somewhat different selection metrics than smaller capacity systems. However, differences within a product line are small in comparison to other product lines from the same manufacture or different manufacturers' products. More often than not, there is no discernable difference for systems within a product line, or there is no discernable trend (e.g. a 3.5-ton system looks like a 2-ton system while a 6-ton system looks like a 1.5-ton system, etc.)

This selection approach will be used when performing final statistical analyses over the full range of available systems. The CEC air conditioner database contains C_D values for all listed systems. In addition, the database provides EER at 95 F and at 82 F, which can be used to estimate the $Slope_{EER}$ metric. The database will be used to provide statistical profiles for C_D, $Slope_{EER}$, and correlate limits on their values (e.g. appropriate range and distribution of values of C_D for each selected value of $Slope_{EER}$, etc.).

The definition of HVAC system characteristics for Phase 1 includes both the selection of the SEER-rated cooling system and a definition of air distribution system. The method of selecting the SEER-rated cooling systems was identified in "HVAC Selection Process – Interim Report", issued December 2002. Single-speed air-conditioners and heat pumps were selected based on their rated degradation coefficient and their EER sensitivity to ambient temperature. As indicated in the interim report, variations in these two metrics define the full range of EER values for systems with a given SEER.

Once selected, a system performance database was developed which includes all the nominal values and performance curves required to define the systems' operational characteristics for a DOE-2 simulation. The database holds curve fit coefficients that define off-design characteristics for the DOE-2 simulations. Nominal values and off-design curve-fit coefficients held in the system performance database are described in Table 1. The database currently holds performance data on twelve systems. They include SEER 10, 12, & 14 rated split system heat pumps and air conditioners, SEER 10 and 12 packaged heat pumps and air conditioners, and two two-speed air conditioners. The single speed systems selected had median values of EER sensitivity to ambient temperature and degradation coefficient. The database will be expanded to include systems with high and low EER sensitivity and high and low degradation coefficient. The implementation of phase two will see the addition of SEER 11 and SEER 13 systems to the database.

The only variable that defines the size of the cooling system is its rated cooling capacity. All other performance variables given in Table B.1 are defined in terms of the cooling capacity. While the cooling capacity of each system is included in the equipment database, it typically is not the capacity used in DOE-2 simulations. A sizing criterion replicates the overall methodology of the SEER ratings process. The SEER ratings assume a building load based on the cooling system capacity. The building load is defined as:

$$BL(T_j) = \frac{5j - 3}{95 - 65} * \frac{Q_{ss}(95\ F)}{1.1} \qquad (B.1)$$

where:

$BL(T_j)$ is the building load at outdoor temperature T_j,

j is the temperature bin number from 1 to 8,

$Q_{ss}(95\ F)$ is the system's cooling capacity at 95 F ambient temperature and

the constant 1.1 represents 10% excess capacity at the 95 F ratings condition.

The peak load on the cooling system in the SEER ratings process occurs at the maximum bin temperature, or when j = 8. Using equation 1, the system's cooling capacity can be related to the peak cooling load by setting j to 8, or:

$$BL_{max} = 1.23 * \frac{Q_{ss}(95\ F)}{1.1} \qquad (B.2)$$

Rearranging,

$$Q_{ss}(95\ F) = BL_{max} * \frac{1.1}{1.23} \qquad (B.3)$$

or the capacity of the cooling system equals ~90% of the peak coil load.

This is the sizing criterion used in all simulations. This requires two simulations for each building prototype examined. The first determines the peak cooling coil load to determine the required cooling capacity. The second determines the seasonal performance of the system base on the cooling capacity as determined by the first run. This sizing approach is possible since it has been determined that cooling capacity is not a factor in the selection of the various cooling systems (see above). Finally, sizing issues will be reviewed in when the sensitivity of SEER to over and under-sizing is addressed.

Table B.1.
DOE-2 Equipment Performance Data Base

Field #	Description	Systems	Curve Fit Dependent Variable	Curve Fit Independent Variables
1	Evaporator Config.	Splt/Pkg	n/a	n/a
2	System Type	AC/HP	n/a	n/a
3	Nominal SEER	None	n/a	n/a
4	EER Slope	H, M, L	n/a	n/a
5	Degradation Coeff.	H, M, L	n/a	n/a
6	Mfg. & Model #	n/a	n/a	n/a
7	Gross Cooling Cap	Btu/hr	n/a	n/a
8	Sen. Heat Ratio	none	n/a	n/a
9	EIR	none	n/a	n/a
10	Rated Air Flow	cfm/Btu/hr	n/a	n/a
11	Fan Energy	W/cfm	n/a	n/a
12	Coil By-Pass Factor	none	n/a	n/a
13	Crankcase Energy	W/Total W	n/a	n/a
13	Crankcase Off Temp	F	n/a	n/a
14-19	Curve Fit Coefficients	none	Total Capacity	EA WB, Amb DB
20-25	Curve Fit Coefficients	none	Sensible Capacity	EA WB, Amb DB
26-31	Curve Fit Coefficients	none	EIR	EA WB, Amb DB
32-37	Curve Fit Coefficients	none	Coil By-Pass	EA WB, EA DB
38-49*	Curve Fit Coefficients	none	EIR	Part-load Ratio
50	Number Cooling Stages	1, 2	n/a	n/a
51	Low-Speed Cap Ratio	none	n/a	n/a
52	Low-Speed cfm Ratio	none	n/a	n/a

* Up to three curves are defined for each system to account for ductwork transients described below.

Additional information defines the air distribution system. This includes ductwork parameters such as R-value, area, leakage rate, and transient response time, along with fan energy requirements. Values for the various residential building prototypes are provided in Table B.2. Notes on the data sources and/or assumptions used in the table follow. Information on non-residential prototypes is given in Table B.3.

Table B.2.
Distribution System Definition – Residential Prototypes

Variable	Range	Residential Prototype		
		1 Story SF	2 Story SF	Multi-Fam.
Cooling Sources	n/a	A/C & HP	A/C & HP	A/C & HP
System Type	n/a	Split	Split	Split
System Capacity (% Peak Coil Load)	Low	90%	90%	90%
	Median	*110%*	*110%*	*110%*
	High	*150%*	*150%*	*150%*
System Fan Energy (Watts)[1]	Rated	*From System*	*From System*	*From System*
	High	*1.4 Mult*	*1.4 Mult*	*1.4 Mult*
Fan Operation	n/a	Intermittent	Intermittent	Intermittent
Fan Location	A/C	Blow-Thru	Blow-Thru	Blow-Thru
	HP	Draw-Thru	Draw-Thru	Draw-Thru
Supply Duct Area in Attic[2]	n/a	27% FA	18% FA	18% FA
Return Duct Area in Attic[2]	n/a	5% FA	10% FA	10% FA
Duct work R-Value[2]	n/a	4.9	4.9	4.9
Ductwork Time Delay[3]	Temp CZ's	12 sec	12 sec	12 sec
	Mod CZ's	21 sec	21 sec	21 sec
	Hot CZ's	29 Sec	29 Sec	29 Sec
Supply Leakage to Outside[4]	A/C Low	*3%*	*3%*	*3%*
	A/C Median	7%	7%	7%
	A/C High	*14%*	*14%*	*14%*
Supply Leakage to Outside[4]	HP Low	*2%*	*2%*	*2%*
	HP Median	4%	4%	4%
	HP High	*9%*	*9%*	*9 %*
Return Leakage to Outside[4]	A/C Low	*1%*	*1%*	*1%*
	A/C Median	3%	3%	3%
	A/C High	*7%*	*7%*	*7%*
Return Leakage to Outside[4]	HP Low	*3%*	*3%*	*3%*
	HP Median	7%	7%	7%
	HP High	*14%*	*14%*	*14%*

Notes:

1. *Data from Florida Solar Energy Center and PG&E residential survey reports. See Appendix D.*
2. *From California Non-Residential ACM manual, Appendix F. Ductwork R-value includes exterior and interior film resistance with nominal R-4.2 duct insulation.*
3. *Ductwork time delays based on CFD analysis presented in "EER-SEER Cooling System Cyclic*

Performance" forwarded December 2002. Time delays are based on expected attic temperatures related to the three climate zone categories listed in the table. Temperate climate zones (Temp CZ's) are CZ-03 through CZ-08, plus CZ-16. Moderate climate zones (Mod CZ's) are CZ-02, CZ-09, CZ-10, CZ-12, and CZ-13. Hot climate zones (Hot CZ's) are CZ-11, CZ-14, and CZ-15. Time delays assume lightweight ductwork including fiberboard and spiral flex duct. Time delays in the table add to the cooling systems' response times as incorporated in their degradation coefficients. Their effects are accounted for in DOE-2 simulations via EIR_f(PLR) performance curves. This is why there are up to 12 fields used define the EIR_f(PLR) curves in Table 1as they represent coefficients for three possible curves. Each curve includes the effects of the three ductwork time delays. Simulations will pick the appropriate curve for the climate zone used.

4. *Data from Florida Solar Energy Center and PG&E residential survey reports. See Appendix D. The PG&E RNC report suggest a higher duct leakage rate for multi-family in comparison to single-family construction. The report suggests that the additional leakage may be associated with the use of wall cavities for ductwork. It is assumed that leakage from wall cavities (typically return chases) is predominantly from the conditioned space and that overall leakage to the outside is similar to single-family construction. Low leakage values assume a duct-sealing program has been implemented.*

Phase I of the project is divided into phase 1a and 1b. Phase 1a uses typical system characteristics over the full range of residential and non-residential building prototype variation. Phase 1b examines the full range of system characteristics for "typical" building prototypes. Only median values of the system characteristics given in Tables B.2 and B.3 are used in Phase 1a, with the exception of system sizing. Here, the low value of system sizing is used as it matches SEER ratings procedures. Note that duct transients apply to the specific climate zone against which the simulation models are executed. As such, there are no low, median, and high values of duct transients – only temperate, moderate, and hot climate zones. Values used in Phase 1a in the table are presented in a standard font – those added in Phase 1b are shown in italics.

Once the go-ahead is given to execute Phase 1a, results will be generated by running all building prototype models against the typical mechanical systems. This will allow a statistical selection of building prototype variables that reflects median building characteristics. Once approved, Phase 1b will simulate low and high system variables (shown in italics in the tables) against "typical" building prototypes.

Table B.3.
Distribution System Definition – Non-Residential Prototypes

		Non-Residential Prototype		
Variable	Range	Retail	Office	School.
Cooling Sources	n/a	A/C & HP	A/C & HP	A/C & HP
System Type	n/a	Split & Pkgd	Split & Pkgd	Split & Pkgd
Packaged Systems – System	Low	*0.5*	*0.5*	*0.5*
External Static (in wg)	Median	0.75	0.75	0.75
	High	*1.0*	*1.0*	*1.0*
Split Systems – System Fan	Rated	*From System*	*From System*	*From System*
Energy (Watts)[1]	High	*1.4 Mult*	*1.4 Mult*	*1.4 Mult*
Fan Operation	n/a	Continuous	Continuous	Continuous
Fan Location	A/C	Blow-Thru	Blow-Thru	Blow-Thru
	All other	Draw-Thru	Draw-Thru	Draw-Thru
Ductwork Location	n/a	Rtrn Plenum	Rtrn Plenum	Rtrn Plenum
Supply Duct Area[2]	n/a	13% FA	13% FA	13% FA
Supply Duct R-Value	n/a	2.8	2.8	2.8
Supply Duct Leakage[3]	n/a	2%	2%	2%
Ductwork Transients[4]	n/a	0	0	0

Notes:

1. *Split systems can not support full range of external static pressures assumed for packaged systems.*
2. *Assumes half the duct surface area of residential system. Assumption based on a doubling of the flow per diffuser in commercial applications in comparison to residential. The larger flow results in half the number of branch ducts and reduced branch duct area per cfm delivered because of the large branch duct diameter (a 6" diameter duct supplies half the flow of an 8" diameter duct, but has only 1/4 less perimeter). The number of trunk ducts is also reduced because of the higher air-volume per branch duct.*
3. *Assumes Class C duct seal with a 0.5" wg static pressure differential across the supply duct. Ductwork leakage is assumed to be from the supply to a return plenum rather than to the outside.*

There are no ductwork transients with continuous fan operation. Thermal delays that occur when the compressor starts are assumed to be recovered when the compressor turns off.

APPENDIX C: GENERATING PART-LOAD CURVES FOR DOE-2

I. Generating Thermostat-Based Part-Load Curves for Use in DOE-2 Simulations

The cyclic performance of the air conditioning system is calculated from the equivalent delay time (Z_D) method. This is a thermostat-based approached developed by Honeywell and presented by Rice, et al (C.11). The equivalent delay time is defined such that difference between an air conditioner's capacity at start up and its steady state capacity is equal to an on-time delay, or

$$q_{cyc} = (t_{on} - Z_D)\, Q_{ss}, \qquad (1)$$

where

q_{cyc} = cooling output at start-up.

Q_{ss} = steady-state cooling capacity

t_{on} = the runtime in a cooling cycle, and

Z_D = the equivalent delay time.

The equivalent delay time is a close approximation of the first order air-conditioning system response model given in Henderson and Rengarajan (C.4). They define the cooling output over a cooling cycle as

$$q_{cyc} = [t_{on} - \tau(1 - \exp(-t_{on}/\tau))]\, Q_{ss}, \qquad (2)$$

where

τ = time constant of the air-conditioning system, and all other terms are as previously defined.

A comparison of Equations 1 and 2 show that

$$Z_D = \tau[1 - \exp(-t_{on}/\tau)]. \qquad (3)$$

The difference between Z_D and the time constant used by Henderson and Rengarajan can be determined by substituting reasonable values for the time constant and runtime in Equation 3. For a standard DOE cyclical test as mandated by ARI Standard 210 (C.1), the system's runtime is 6 minutes, or 360 seconds. From Henderson, et al (6), the largest time constant expected from the DOE cyclical test is 76 seconds, as this corresponds to a degradation coefficient of 0.25. Systems with lower degradation coefficients will have lower time constants. Using these values with equation 3 gives $Z_D = 0.992\tau$. Henderson, et. al. (C.6) suggest that the six minute system run times used in the DOE cyclical test are less than typically observed in the field. In addition, the 76 second system time constant (corresponding to a $C_D = 0.25$) is the highest value used in any cooling system SEER rating. A more typical value is based on a $C_D = 0.1$ is 29 seconds. Both factors will reduce differences between the equivalent time delay (Z_D) and the system time constant (τ). Thus, for typical cycling rates over the range of expected values of air-conditioning system time constants, the two approaches can be viewed as equivalent. Subsequent derivations based on the equivalent time delay approach will use the system time constant (τ) in lieu of the equivalent time delay (Z_D).

Using Equation 1, the cooling load factor (CLF), as defined in ARI Standard 210 (C.1), can be written as:

$$CLF = (t_{on} - Z_D)/(t_{on} + t_{off}) \tag{4}$$

where:

t_{off} = the off-time in a cooling cycle, and all other terms are as previously defined.

Defining the fractional on-time (f_{on}) as the on-time divided by the total cycle time, and the total number of cycles in an hour as N, Equation 4 can be re-written as:

$$CLF = f_{on} - N\,\tau/3600, \tag{5}$$

where:

N = the cycling rate of the air conditioner defined as $1/(t_{on} + t_{off})$ in cycles/hour.

The cycling rate is calculated from the thermostat characteristic equation given by (4, 5, 10, and 11)

$$N = 4N_{max}\, f_{on}\,(1 - f_{on}) \tag{6}$$

where:

N_{max} = the thermostat maximum cycling rate in cycles/hour.

From Equations 5 and 6, the fractional on-time of the air conditioning system can be calculated from the cooling load factor, the thermostat maximum cycling rate, and the cooling system's time constant, or:

$$f_{on} = \frac{-(1-X)+\sqrt{(1-X)^2 + 4X\,CLF}}{2X} \tag{7}$$

where:

$X = 4\, N_{max}\, \tau/3600.$

The part-load factor can then be determined from the fractional on-time by assuming that the power consumption of the system is achieved immediately, or

$$PLF = \frac{CLF}{f_{on} + (1 - f_{on})P_{off}} \tag{8}$$

where:

PLF = the ratio of the part-load EER to the steady state EER, and

P_{off} = percentage of off-cycle power consumption to that at full load. P_{off} would include any controls power consumption or, more likely, crankcase heat as controls power consumption is typically negligible.

Henderson, et al (C.6) show that the EIR_*f*(PLR) relationship used by the DOE-2 is equivalent to

$$EIR\_f(PLR) = PLR/PLF. \quad (9)$$

The cooling load factor used in the development of a SEER rating, as defined by Kelly and Parken (C.7), is the same as the part-load factor as used in the DOE-2 program. Equating the two (CLF = PLR) allows a combination of Equations 9 and 10, giving 10a.

$$EIR\_f(PLR) = f_{on} + (1 - f_{on})\, P_{off}\,, \quad (10a)$$

In 10a, the fractional on-time of the system (f_{on}) is calculated via Equation 7. From Equation 7, f_{on} is a function of CLF, τ, and N_{max}. Thus, for a given PLR (PLR = CLF), the impact of cycling on a cooling system's EIR is a function of the system time constant (τ) and maximum thermostat cycling rate (N_{max}). DOE-2 used the EIR_*f*(PLR) curve to simulate the cycling losses of a compressor when the fan operates continuously. The program uses a cycling loss curve [C-LOSS_*f*(PLR)] when the fan cycles with the compressor. The two curves are related to each other as the EIR curve equals the PLR divided by the C-LOSS curve, or:

$$C\text{-}LOSS\_f(PLR) = PLR/[\, f_{on} + (1 - f_{on})\, P_{off}] \quad (10b)$$

II. Determining the Cooling System Time Constant from C_D

The definition of the degradation coefficient (C.7) is

$$C_D = (1 - PLF)/(1 - CLF) \quad (11)$$

This can be cast in terms of the system's time constant by substituting Equation 8 into Equation 11. For essentially all air conditioner and most heat pumps, P_{off} can be assumed to be zero. This is appropriate since crankcase heat is typically the only significant off-cycle power consumption, and is invariably listed as an "option" and not part of the "standard test system" when cyclical tests are performed. Finally, f_{on} for the ARI Standard 210 cycling test is 0.2. With these observations,

$$C_D = (1 - 5\ CLF)/(1 - CLF) \quad (12)$$

Using Equation 5 to relate CLF to the system time constant,

$$\tau = 288\ C_D/(1 - 0.2\ C_D), \quad (13)$$

where τ is the time constant of the cooling system in seconds. This equation is important in that time constant can be assumed to be a physical characteristic of the cooling system. Time constants corresponding to various values of CD are given in Table C.1.

Table C.1
Response Time for Various Values of C_D

C_D	τ (sec)
0.25	76
0.20	60
0.15	45
0.10	29
0.05	15

There is some concern that the ARI cyclical test may skew the determination of the degradation coefficient, and thus the estimate of its time constant. In particular are issues associated with the use of isolation dampers in conjunction with highly insulated duct sections before and after the cooling coil. The effect of these features is to isolate the cooling coil from its environment during the off-cycle.

The literature is unclear as to the magnitude of this effect. Nguen et al (C.9) suggested that the use of dampers could result in significant differences in the calculation of the degradation coefficient. Their comparison, however, was based on two different systems with the same EER_A rating (EER at 95 F outdoor temperature; 80 F dry-bulb and 67 F wet-bulb return air temperature). There is no indication as to how much of the difference in the degradation coefficient is a result of physical differences between the two systems (type of refrigerant control device, refrigerant charge, system response to changing ambient conditions, etc.) as opposed to the measurement process.

Lamb and Tree (C.8) examined the potential errors associated with the use of dampers in cyclical test measurements. Their analysis looked at the transient thermal effects associated with the mass of the cooling coil and surrounding ductwork (5 feet ahead and behind the coil). The magnitude of the largest error calculated was within 3% of the "ideal" measurement associated with a zero-mass coil. While they felt that use of dampers could affect the response time of the system for some types of flow control devices, dampers would have minimal impact on response times resulting from the mass of coil and test ductwork.

Goldschmidt, et al (C.3) looked at the field performance of a heat pump in the heating and cooling mode and an air conditioner with the goal of determining seasonal degradation coefficients. They found that the transient response of both systems was essentially constant over the full test range of ambient and indoor conditions. They also found that the time constant of the heat pump in the heating mode differed from that measured in the cooling mode. The difference suggested to the authors that the transient response was related to refrigerant dynamics as the mass of the indoor coil, by itself, could not explain the differences in the heating and cooling response times, nor the magnitude of the response time observed. Goldschmidt used transient temperature responses in the cooling mode to calculate degradation coefficients based on Standard 210 cycling rates. Their estimates of C_D are presented in Table C.2, along with those that would have been calculated by Equation 13. There is good agreement between the two calculation methods.

Table C.2

Comparison of Measured and Calculated Values of C_D

	Measured Time Constant τ (sec)	C_D	
		From Measurements	From Equation 13
Heat pump – cooling	19.2	.066	.066
Air conditioner	28.2	.095	.096

Parken, et al (C.10) took seasonal test data on three heat pumps in the cooling mode. The data provided measured values of the systems' part load factors (PLF) over a range of cooling load factors (CLF). The seasonal data allowed relationships to be developed between fractional on-times and system cycling rates. They also performed standard cyclical tests to determine the degradation coefficient of one of the systems (System 3). Their results provide the following observations:

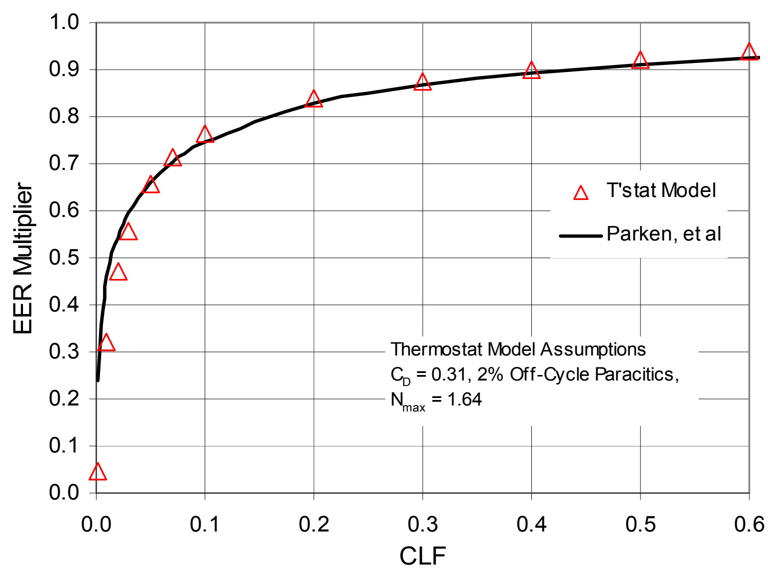
1. There was good agreement between the ideal thermostat model as provided in Equation 6 and observed cycling rates. The maximum cycling rate (N_{max}) for System 3 was calculated as 1.64 cycles per hour. Maximum cycling rates for the other two systems were 2.0 and 2.28 cycles per hour.
2. All three systems had a part-load factor that went to zero as the cooling load factor approached zero. This occurs when there are non-zero off-cycle power requirements – typically crankcase heat. Crankcase heaters would have been included in these systems as they were heat pumps located in a cold climate. It is unlikely that temperature controls to de-activate the crankcase in the cooling season would have been used at the time of the test (1980 cooling season).
3. The bench test of System 3 produced a degradation coefficient of 0.31 at the prescribed ARI maximum cycling rate of 3.125 cycles per hour. The measured degradation coefficient includes the off-cycle power consumption of the crankcase heater. The expected time constant of the system is less than that which would be predicted by Equation 13, as this equation assumes no off-cycle power consumption. Assuming 2% off-cycle parasitic losses, the time constant of System 3 as calculated via Equation 8 is 72.5 seconds.
4. They provided curve fits of measured PLF versus CLF for the three systems. Correcting for the delay in condensation formation on the cooling coil, PLF is related to CLF ($0.0 \leq CLF \leq 0.7$) for System 3 by

$$PLF_{System\ 3} = 1 - \exp(-3.0855\ CLF^{0.35}) \qquad (14)$$

Figure C.1 compares the measured performance of System 3 in the Parken et al test to that predicted by thermostat Equations 7 and 8. The thermostat equations use the measured degradation coefficient ($C_D = 0.31$), the measured maximum cycling rate ($N_{max} = 1.64$), and assumed off-cycle parasitic losses of 2% over a range of cooling load factors. As the figure shows, agreement is quite good.

The agreement between the Parken et al data and the equivalent time delay thermostat model suggest that the model is sufficiently robust to account for differences in thermostat maximum cycling rates and off-cycle parasitic losses. Given that the thermostat model can be translated into a DOE-2 EIR-f(PLR) curve, the agreement between the Parken et al data and the thermostat curve also suggests that current methods used by the DOE-2 program are sufficiently robust to account for cycling losses over a broad range of part-load operation. The data used by Parken to generate the curve fit shown in Figure 1 include points with fractional on times as low as 5%. The cooling load factor (part-load ratio in DOE-2 parlance) is always less than the fractional on-time. As such, part-load curve used by DOE-2 based on the thermostat model should account for cycling losses down to very low space loads.

Figure C.1
Comparison of Parken et al Data to Equiv. Time Delay T'stat Model



III. Appliance Cycling Losses

While the cooling system's time constant may be fixed, this is not the case for a system's cyclical losses. As illustrated by Equation 7, cyclical losses also depend on the load on the system and the thermostat maximum cycling rate. The ARI cyclical loss test procedure prescribes a maximum thermostat cycling rate by fixing the number of cycles per hour and the fractional on-time per cycle. The test forces two cycles per hour (two cycles of 6 minutes on and 24 off in one hour) with a 20% on-time fraction. Using these values (N=2 and f_{on} = 0.2) in Equation 6 gives a maximum cycling rate (N_{max}) of 3.125 cycles per hour. Thus, Equation 13, which relates degradation coefficients to system time constants, is valid for cycling rates as prescribed by the ARI test procedure. Once system time constants are known, however, the literature (C.3) suggests that they are unaffected by thermostat operation. Cycling losses will vary with changes in the thermostat cycling rate, but in response to a fixed cooling system time constant.

Actual maximum cycling rates depend on many factors, including the thermostat operation, minimum run-time controls, and the temperature response of the room in which the thermostat is located (C.5, C.3). In the literature maximum cycling rates from as low as 1.5 to as high as 3 (C.6) are reported. Henderson et al (C.6) recommends a value of 2.5 as typical. Lower maximum cycling rates result in reduced cycling losses for a given cooling system load factor. Seasonal energy consumption should decrease as a result. Part load factors for a 50% cooling load factor are compared in Table 3 for assumed maximum cycling rates of 3.125 cycles per hour (ARI Standard 210 test requirements) and 2.5 cycles per hour.

Table C.3.
Cooling System Time Constants for Various Values of CD

		PLF at CLF = 0.5	
C_D	τ (sec)	N_{max} = 3.125	N_{max} = 2.5
0.25	76	0.885	0.906
0.20	60	0.907	0.924
0.15	45	0.929	0.942
0.10	29	0.952	0.961
0.05	15	0.975	0.980

Note that PLF values in Table C.3 for N_{max} = 3.125 can differ from those used in SEER calculation as Table C.3 values are based upon the equivalent time delay thermostat model. Table C.3 suggests that the use of realistic thermostat-based part-load performance at more typical maximum cycling rates should lead lower seasonal energy consumption than that predicted by the SEER rating.

There are some potential problems with the use of the thermostat cycling model with the DOE-2 simulation program. The DOE-2 program forces a cooling cycle for every hour in its simulation in which a cooling load exists. Actual systems operating at very low loads may cycle the system only once in several hours, depending on the thermostat's response to the space load. For an assumed maximum thermostat cycling rate of 2.5 cycles per hour (the typical value as reported by Henderson et al), a system's cycling rate would drop to 1 cycle per hour at a part-load ratio around 8.5% (based on Equations 6 through 8). It would occur at a slightly higher value for cooling systems with lower time constants (low C_D values) and a lower value for systems with higher time constants (high C_D values). The associated overstatement of cycling losses increases as the part-load ratio decreases. For reasonably sized cooling systems, overstatement of cycling losses at low part-load conditions should not be a concern as they accumulate only when cooling loads are minimal. It could become a problem for grossly oversized cooling system where DOE-2 would tend to over-predict cycling losses.

IV. Cooling System Cycling Losses

The equivalent time delay method appears to reasonably predict the part-load performance of the cooling system at the coil. This is the approach taken by the Standard 210 test methods, treating the cooling system as an appliance. Test data taken by Goldschmit et al (C.3) and Parken et al (C.10) used to compare the thermostat model to actual performance were obtained via temperature and humidity measurement near the cooling coil. As such, both treat the cooling system as an appliance and ignore distribution transients and losses. Coil loads are equated to space loads, both in the calculation of the cooling system efficiency and in estimates of the cooling load factor.

This is not the case in DOE-2 simulations. Space loads are calculated directly and are used to determine a cooling load factor (part-load ratio in DOE-2 parlance). All cycling losses associated with the response of the cooling system to the space load under part-load conditions is accounted for by the cooling system's EIR-f(PLR) curve. This curve must account for transients associated with both the cooling system and the air distribution system (associated ductwork). While the program can account for steady-state duct losses, there is no separate part-load curve that can account for transients in the ductwork independently of the cooling system.

The significance of distribution system transients and losses can be illustrated by examining the formula used to calculate SEER ratings for single speed equipment (C.1), or:

$$SEER = EER_B\,(1 - 0.5\,C_D) \tag{15}$$

A particular SEER rating can be obtained by designing for a relatively high value of EER_B with a high degradation coefficient, C_D. Conversely, one could design a system with a low degradation coefficient, requiring a lower EER_B. Steady state distribution losses would affect both design approaches equally as they would reduce the effective EER_B equally. This is may not be the case with distribution system transients.

The actual transient response of the cooling system, including ductwork transients, would be the sum of the system and the ductwork time constants. If delay times are on the same order of magnitude as the cooling system time constants, then systems with low time constants (low C_D values) are affected to a greater proportion than those with high time constants (high C_D values). This is illustrated in Table C.4, which compares cooling system and cooling system degradation coefficients with assumed ductwork time constants of 14 and 47 seconds. The lower time constant is for a system with a fiberboard and flex-duct supply-air system, the higher is for a system using insulated metal ductwork. A system degradation coefficient is determined by adding the ductwork time constant to the cooling system time constant. Equation 13 is then used to give a system degradation coefficient based on the increased time constant.

A comparison of system and system degradation coefficients in Table C.4 illustrates the non-uniform impact of duct transience on overall system performance.

Table C.4
Effect of Duct Transients on SEER

Cooling System		Cooling System C_D	
C_D	τ (sec)	14 sec Delay	47 sec Delay
0.25	76	0.29	0.39
0.20	60	0.24	0.35
0.15	45	0.20	0.30
0.10	29	0.14	0.25
0.05	15	0.10	0.20

A simplified ductwork analysis was used to verify the overall approach and ductwork delay times used to generate the values in Table 4. A CFD analysis was used to determine the transient response of a "typical" run of supply ductwork. The ductwork consists of 27 feet of 8" diameter duct supplying 200 cfm. The diameter of the duct provides a typical ratio of cross-sectional area to perimeter for applications using SEER-rated cooling equipment (less than 65,000 Btu/hr rated capacity).

The length of the ductwork was estimated from typical ductwork sizes as provided in Means Mechanical Cost Data. Means suggests an average weight for ductwork for split-system cooling systems of 102 pounds/ton of installed capacity. It was assumed that duct was mostly comprised of 26-gauge sheet metal as the Means table is for commercial installations (residential systems will likely use 30-guage ducts). This results in a duct surface area of 113 square feet. The simulated ductwork would deliver ½ ton of cooling for the assumed 200 cfm volumetric flow. Thus, the 8" diameter duct would need to be 27 feet long to generate 56.5 square feet of surface area.

The model further assumed that the duct was located in 80 F surroundings and was wrapped with foil-faced R-2.1 insulation. Simulations with fiberboard ductwork replaced the insulated metal ductwork with flex-duct. The properties of the flex-duct differed from the insulating wrap only in that it included a 1% by volume internal metal spiral support. Finally, the temperature of the air delivered to the ductwork was varied over time to match the assumed time constant of the cooling system. The temperature of conditioned air entering the ductwork was calculated as:

$$T(t) = T_{ret} + \Delta T_{ss} * [1 - \exp(t/\tau)] \qquad (16)$$

where:

$T(t)$ = supply air temperature entering the duct at time = t,

T_{ret} = the return air temperature (80 F),

t = time,

ΔT_{ss} = stead-state temperature difference across the coil (20 F), and

τ = the cooling system time constant (values of 15, 45, and 76 seconds examined corresponding to C_D = 0.05, 0.15, and 0.25, respectively).

Results from the CFD analysis were used to determine an overall system (cooling system + ductwork) time constant. This was done by fitting the transient temperature response of air leaving the ductwork to Equation 16. The data fit provided a new value of τ that included both the cooling system and the ductwork. The difference between the system time constant and that of the cooling system was taken to be the ductwork time constant. Results of the CFD analysis are compared to a curve fit based on Equation 16 in Figure C.2 for one of the analyses. Simulations based on higher cooling system time constants provide a closer match between the curve fit and CFD results. Ductwork time constants are given in Table C.5 for systems using insulated metal and flex-duct distribution systems. Table C.4 was generated from the ductwork time constants presented in Table C.5. Figure C.2 also indicates that the response of a cooling system with its attached ductwork can be approximated by a system with a combined time constant. As such, the thermostat-based approach to creating DOE-2 part-load curves as embodied in Equations 2 through 9 remains valid.

Table C.5
Ductwork Time Constants

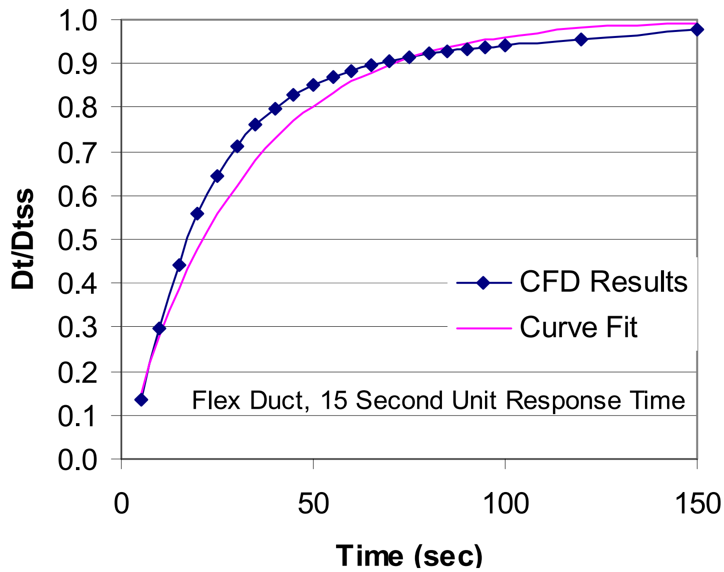
System Time Constant (sec)	Insulated Metal Ductwork	Fiber (Flex-duct) Ductwork
15 (C_D = 0.05)	16 sec	48 sec
45 (C_D = 0.15)	14 sec	47 sec
76 (C_D = 0.25)	14 sec	54 sec

It should be noted that "steady-state", as used in developing ductwork time constants, includes steady state ductwork heat gains. The steady-state temperature differential used in Figure C.2 is the difference between the return air temperature (assumed to be 80 F) and the average supply air temperature at the end of the ductwork. This is less than the assumed steady state temperature differential across the cooling coil.

There is concern about how effectively ARI cycling tests capture the cyclical response of split-system cooling systems whose indoor air handler and ductwork is located in an attic. It most likely does a poor job. An attic location will obviously increase the overall system transient response because of a warmer ductwork and air handler. A reasonable estimate based on an increased temperature differential would be to double ductwork time constants given above.

It is not clear how an attic location would affect refrigerant migration in the off-cycle. This is important, as refrigerant migration within the system appears to be the determining factor in the cooling system's transient response. Since attics tend to be warmer than the outdoors, systems that do not include a shut-off valve in the liquid line (bleed back TXV or orifice valve) should see a migration of refrigerant from the evaporator to the condenser. (This is the reverse of a non-attic application where the condenser coils are at a higher temperature than the evaporator.) Off-cycle migration of refrigerant to the condenser should reduce the response time of the system since a liquid seal at the expansion device would occur sooner. Conversely, attic locations typically require the compressor to pump refrigerant a longer distance and against gravity. This would seem to work against a quicker response time. No data have been found that looks at these issues and the effect of an attic location on response time remains unanswered.

Figure C.2
Comparisons of CFD Results and Time Constant Curve Fit



V. Summary

Results of our investigation into cooling system cycling issues include the following:

1. A thermostat model has been found that provides a means of determining cooling system time constants from published or estimated cooling system degradation coefficients.
2. Cooling system transient response, as embodied in their degradation coefficient, appears to be dominated by refrigerant migration issues in the off-cycle. This was noted by Goldschmidt et al and Lamb and Tree, and implied by Henderson et al. Analyses presented by Lamb and Tree showed that dampers used in the ARI cyclical test procedures should have no more than a 3% impact on test results, for a fixed system time constant. Reports to the contrary provide by Nguyen et al may not be reliable as the comparison of degradation coefficients measured with and without isolation dampers were apparently made on two different systems. While degradation coefficients obtained via ARI test procedures are probably made under more ideal settings than actual applications, our initial concerns that the use of isolation dampers may be "cooking the books" are probably overstated.
3. Time constants can be expanded to include ductwork transients through the addition of a ductwork time constant to that for the cooling system. CFD simulations of typical ductwork imply that a 14 second ductwork time constant would be appropriate for split-systems used in a residential application (fiberboard ductwork). A 47 second time constant should be used for commercial applications of split systems (insulated metal ductwork). Packaged systems may, or may not include significant distribution system transients, depending on whether or not the system includes connecting ductwork. Equations 4 through 9 can then be used to develop EIR-f(PLR) curves based on the total system time constant.
4. Overstatement of cycling losses at low part-load conditions by the DOE-2 program should not be a concern for reasonably sized systems. It could become a problem for grossly oversized cooling systems, in which case DOE-2 would tend to over-predict cycling losses.

Appendix C References

C.1. ARI, 1984. ARI Standard 210/240-84, unitary air-conditioning and air-source heat pump equipment. Air-conditioning and Refrigeration Institute.

C.2. DOE 1979. Test procedures for central air conditioners including heat pumps. Federal Register Vol. 44, No. 249. pp 76700-76723. December 27, 1979.

C.3. Goldschmidt, V., G. H. Hart, and R. C. Reiner, 1980. A note on the transient performance and degradation coefficient of a field tested heat pump – cooling and heating mode. ASHRAE Transactions 86(2): 368-375.

C.4. Henderson, H. and K. Rengarajan. 1996. A Model to Predict the Latent Capacity of Air Conditioners and Heat Pumps at Part Load Conditions with the Constant Fan Mode. ASHRAE Transactions. 102 (1) January.

C.5. Henderson, H.I. 1992. Simulating Combined Thermostat, Air Conditioner and Building Performance in a House. ASHRAE Transactions. 98(1) January.

C.6. Henderson, H., Y. J. Huang, and D Parker. 1999. Residential Equipment Part Load Curves for Une in DOE-2. LBLNL-42175.

C.7. Kelly, G. E. and W. H. Parken. 1978. Method of testing, rating and estimating the seasonal performance of central air-conditioners and heat pumps operating in the cooling mode. NBSIR 77-1271.

C.8. Lamb, G. and D. R. Tree. 1981. Seasonal performance of air-conditioners – an analysis of the DOE test procedures: The thermostat and measurement errors. Energy Conservation, US Department of Energy, Division of Industrial Energy Conservation, Report No. 2, DOE/CS/23337-2, Jan.

C.9. Nguyen, H. V., V. Goldschmidt, S. B. Thomas, and D. R. Tree. 1982. Trends of Residential Air-Conditioning Cyclic Test. ASHRAE Transactions Vol. 1, TO-82-8.

C.10. Parken, W.H., Didion, D.A., Wojciechowshi, P.H., and Chern, L. 1985. Field Performance of Three Residential Heat Pumps in the Cooling Mode. NBSIR 85-3107.

C.11. Rice, K., S. K. Fischer, and C. J. Emerson, The Oak Ridge Heat Pump Models: II. An annual performance factor/ loads model for residential air-source heat pumps. ORNL/CON-160.

APPENDIX D: REVIEW OF RESIDENTIAL FAN SYSTEM OPERATION AND DUCT LOSSES

D.1 Introduction

Two recent studies provide information on air handler and duct system leakage in new residential construction. Results from these studies are presented in the *Residential New Construction Study*[2] (RNCS) issued by Pacific Gas and Electric Company in September 2001 and *Field Testing and Computer Modeling to Characterize the Energy Impacts of Air Handler Leakage*[3] (FSEC) issued by the Florida Solar Energy Center in September 2002. The RNCS reports results of dust blaster tests from 72 newly constructed residences. The FSEC report is based on detailed examination of operating pressures, air handler leakages, and (for a subset of 20 homes) duct blaster tests for 69 cooling systems in Florida homes. Leakage rate estimates rely heavily on results from the FSEC report, as more system operational details are available. Summary information from the FSEC report compares favorably to that provided in the RNCS, allowing reasonable predictions of duct and air handler leakage rates for cooling system types built with typical California construction practices. Table D.1 compares the information available from the two databases.

Table D.1
RNCS and FSEC Duct Leakage Databases

	Database	
Data Description	RNCS	FSEC
Number of Systems	72	69
Duct Blaster Tests	72	20 Systems
Air Handler Leakage Tests	n/a	All Systems
Measured "in and out" Leakage	n/a	20 Systems
Operating Pressures	n/a	Four Points in Air Handler
Measured Air Flow Rates	n/a	All Systems
Rated Cooling Capacity	n/a	All Systems
Rated Heating Capacity	n/a	All Systems
System Model Numbers	n/a	All Systems
System Type (A/C, HP, Other)	n/a	All Systems
System Location	n/a	All Systems

There are differences in construction practices and system types observable from the two databases. The typical cooling system construction in California as provided by RNCS is overwhelmingly a split-system air conditioner with a central gas furnace (~ 99% of homes with cooling systems) with an air handler located in the attic (~79% of homes with cooling systems). Florida system are more likely to be heat pumps located in the garage or indoors (state-wide penetration estimates are not available). The FSEC database does include cooling systems with gas furnaces (13% of database) and systems located in the attic (33% of database), providing adequate information on systems typically found in California.

D.2 Results From FSEC Database

The FSEC database includes a wealth of information on operating pressures, system flows, air-handler and ductwork leakage rates, and leakage rates to the conditioned space and to outside. A summary of pertinent findings is included in Table D.2. The results presented in the table are value expected for air conditioners with gas furnaces. These were found to have slightly higher air handler leakage rates than heat pumps (~12 cfm at 25 Pa). As such, system leakage information in the table includes an adjustment to the observed leakage rates of heat pumps of 12 cfm at 25 Pa.

Table D.2
General Findings from FSEC Report and Database

FSEC Database		
Data Description	Value	Notes
Air Handler Leakage @ 25 Pa	33 cfm	Gas furnace systems only
AHU @ Leakage Operating Pressure	100 cfm	Gas furnace systems only
Air Handle total ΔP (in wg)	0.93	No difference between HP and A/C
Raw Total External ΔP (in wg)	0.61	May include filter
Raw Total Internal ΔP (in wg)	0.32	May not include filter
Adj. Total External ΔP (in wg)	0.51	0.12" wg filter allowance
Adj. Total Internal ΔP (in wg)	0.42	0.12" wg filter allowance
Rated Cooling Capacity	38 kBtu/hr	Based on cond./coil combination
Nominal Cooling Capacity	39.6 kBtu/hr	Based on cond. nominal capacity
System total Flow	1,204 cfm	All Systems – Measure total flow
cfm/ton (rated capacity)	380	All Systems
cfm/ton (nominal capacity)	365	All Systems
Duct Blaster Leakage @ 25 Pa	196 cfm	HP systems adjusted for AHU leakage
Percent Leakage at 25 Pa	15.8%	% leakage based on 20 system subset
Leakage at Operating Pressures	264 cfm	HP systems adjusted for AHU leakage
20 System Subset Total Flow	1,241 cfm	Measured total flow
Percent Leakage at Operating Press	21.5%	% leakage based on 20 system subset

In addition, the presentation of operating pressures includes "raw" data, and "filter adjusted" data. The "raw" data are actual field measurements of pressures on the return side of the air handler. The database includes information on the location of filters. Filters were located in return grilles for approximately 2/3 of the systems; filters were located in the air handler for the remaining systems. The data set suggest that, on average, the return ductwork pressure drop was 0.12” greater for systems with filters in the return grilles than for systems with filters in the system. The “filter adjusted” data in the table increases the system’s internal static pressure by 0.12” w.g. and reduces the return external pressure by 0.12” w.g. for those systems with filters in the return grille. These resulting “filter adjusted” values provide a better basis for comparisons to ARI-rated cooling systems, which include filters in the air handler and specify total external pressure drops.

The cooling capacities provided in the table include rated and nominal values. Rated values are those associated with the particular condensing unit and indoor coil combination. The nominal capacity is that associated with the condensing unit model number. The rated capacity was typically less than the nominal (e.g. nominal 6 ton system had a rated capacity or 55 kBtu/hr); however reverse conditions were noted. These values are important since estimates of percentage leakage rates in the NRCS report were based on noted nominal capacities and assumed flow rates for the given nominal capacity (i.e. 400 cfm/ton of nominal capacity).

Approximately 26% of the total leakage is via the return system (portion of distribution system including the air handler that is under negative pressure) for air conditioners with gas furnaces. The supply and return leakage rates are approximately equal for heat pump cooling systems. The difference in the two types of systems is largely a result of the air handler configuration. Air conditioners with furnaces are blow through systems (blower is located immediately after filter section and before furnace and cooling coil). Approximately 2/3 of the air handler is under positive pressure, while the remainder is under negative pressure. Heat pumps are draw-through systems (blower is located after filter and coil) and essentially the entire air handler is under negative pressure. Because of this, heat pump systems have a greater fraction of the distribution system under negative pressure (and thus return system leakages) than do air conditioners.

The FSEC duct blaster tests also included measurements of “inside” and “outside” leakage rates. This was accomplished by adjusting the pressure within the residence to –25 Pa while the same pressure drop was imposed on the supply and return ductwork. This, essentially, equalized the pressure on both sides of all ductwork located within the residence so that the remaining leakage was to “outside”. Results of these test for various air handler locations is provided in Table D.3.

Table D.3
Duct Leakage to Outdoor

Portion of Leakage to Outdoors		
Air Handler Location	Return	Supply
Attic	81.4%	56.5%
Garage	67.6%	51.7%
Indoors	28.0%	52.6%

D.3 Comparison of FSEC and NRCS Findings

The NRCS reports an average leakage rate of 218 cfm for their 72 tests on single-family detached residences. This compares favorable with the 198 cfm (±36 cfm at 95% confidence interval) found in the FSEC study. However, percentage leakage rates differ. NRCS reports leakage rates of 13.5% of the total flow, while the value determined from the FSEC data was 15.8% (±2% at the 95% confidence level). The method in which the percentage leakage rates were determined differed in the two studies. The NRCS estimated the total system air flow rate assuming a system flow of 400 cfm per ton of nominal capacity. The FSEC study indicates that a better estimate of system flow is 365 cfm/ton of nominal capacity (380 cfm per ton of actual capacity). Adjusting the NRCS leakage percentage to account for the lower volumetric flow gives an adjusted leakage rate of 14.8% (=13.5% * 400/365). This is within the 2% confidence level associated with the 15.8% leakage rate found in the FSEC study. Given this, duct leakage results from the two tests are essentially equivalent.

Table D.4
Duct Blaster Test Leakage Categories

Leakage Category	NCRS	FSEC
cfm ≤ 100	23.1%	20%
100 > cfm ≥ 300	55.9%	70%
300 > cfm ≥ 500	13.4%	10%
cfm ≥ 500	7.6%	0%

Leakage categories from the NRCS and FSEC reports are compared in Table D.4. The general trends in leakage categories are consistent between the two databases. The largest leakage category is between 100 and 300 cfm. There is insufficient data to determine whether or not differences in the leakage categories are statistically significant.

D.4 Application of Leakage Data to DOE-2 Simulations

Equation 1 can be used to estimate total duct leakage rates as a percentage of the total system supply volume. The equation adjusts measured leakage rates obtained by duct blaster tests to actual operating conditions within the system. Typical values for use in Equation D.1 are provided in Table D.5. The table provides data on typical, high, and low values for each of the equation variables. It also provides high and low values of the variable that, when used in combination, produce the expected high and low values of the total leakage percentage. That is, the low value of total leakage percentage is obtained by applying the combination values of low percentage leakage at 25 Pa and low total static pressure to Equation 1.

$$\%\ \text{Total Leakage} = \%\ \text{Leakage}_{25\ \text{Pa}} * 1.533 * \text{TSP} \qquad \text{(D.1)}$$

where:

$\%\ \text{Leakage}_{25\ \text{Pa}}$ = the leakage rated determined from duct blaster tests,

TSP = total static pressure across fan (in. w.g.)

1.533 = adjustment value from FSEC duct blaster data.

Table D.5
Values for Total Leakage Equations

Equation Variable	Range	Value
% Leakage $_{25\ Pa}$	Typical	15%
	Alone Low†	10%
	Alone High†	20%
TSP (in. w.g.)	Typical	0.93
	Alone Low†	0.67
	Alone High†	1.19
% Leakage $_{25\ Pa}$	Combination Low‡	12%
	Combination High‡	19%
TSP (in. w.g.)	Combination Low‡	0.75
	Combination High‡	1.15

† *High and low values are typical ±1.15*standard deviation to span 75% of maximum range.*

‡ *High and low values used in combination to produce expected "High" and "Low" values of % Total Leakage.*

The total leakage can be broken down into its various components – return or supply-side leakage and leakage to the outdoors. Return system gains from outdoor is given by Equation 2, or:

$$\% \text{ Return}_{out} = \% \text{ Total Leakage} * f_{return} * f_{ret,out} \tag{D.2}$$

where:

$\%\ Return_{out}$ = leakage gains to the return system from the ambient surroundings (unconditioned spaces) as a percentage of total flow,

f_{return} = fraction of total leakage that is on the return side of the distribution system, and

$f_{ret,out}$ = fraction of leakage on the return system that are gains from the ambient surroundings (unconditioned spaces).

Similarly, Equation D.3 provides an estimate of supply system losses to the surroundings, or:

$$\% \text{ Supply}_{out} = \% \text{ Total Leakage} * f_{supply} * f_{sup,out} \tag{D.3}$$

where:

$\%\ Supply_{out}$ = leakage from the supply system to the ambient surroundings (unconditioned spaces) as a percentage of total flow,

f_{return} = fraction of total leakage that is on the supply side of the distribution system, and

$f_{ret,out}$ = fraction of leakage from the supply system that is to the ambient surroundings (unconditioned spaces).

The leakage fractions depend on the type of cooling system (air conditioner or heat pump) and the location of the air handler. For air conditioners with gas furnaces, f_{return} = 0.26 and f_{supply} = 0.74. For heat pumps, f_{return} = f_{supply} = 0.5. Values for $f_{ret,out}$ and $f_{sup,out}$ are given in Table 3 for air handlers located in attics, garages, or inside the residence. The typical California cooling system is a split system air conditioner (99% of single-family residences with cooling systems) located in the attic (79% of residences). Thus, for a typical residence, the lost air leakage on the return and supply sides of air conditioner are given in D.4 and D.5.

$$\% \text{ Return}_{out} = 0.21 * \% \text{ Total Leakage} \quad \text{(D.4)}$$

$$\% \text{ Supply}_{out} = 0.42 * \% \text{ Total Leakage} \quad \text{(D.5)}$$

The total leakage percentage ranges from 14% to 33%, with a typical value of 21%, of the total system flow rate, as given by Equation 1 and Table 5.

D.5 Fan Power Data in DOE-2 Simulations

It is recognized that ARI test requirements yield unrealistically low fan power values. Studies[4] in California suggest that average fan energy is 510 Watts per 1,000 cfm of cooling system air flow. The ARI[1] default is 365 Watts per 1,000 cfm for rated condensing unit/cooling coil combinations (coil without an air handler). Tests of SEER-rated condensing unit/ air handler combinations require test to be made with external pressure drops ranging from 0.1” to 0.2” w.g., depending on the system’s capacity. Pressure measurements from the FSEC test data suggest a median external pressure drop of 0.54” w.g. that is independent of system capacity.

The frequency distributions of total, internal, and external pressure drops from the FSEC database are shown in Figures D.1 through D.3. The internal and external pressure drops are best estimates based on filter adjustments. As discussed previously, approximately two-thirds of the systems tested had filters installed in return grilles as opposed to in the air handler. The best estimate of the average filter pressure drop from the database is 0.12” w.g. Internal static pressure drop was increased and external pressure drop was decreased by 0.12” w.g. for those systems with filters in the return grilles. This was done to produce internal and external pressure drops that represent air handler and ductwork configurations consistent with ARI test conditions. Total pressure drop is unaffected by the filter adjustment.

Figure D.1
Total Static Pressure Drop Across Fan – FSEC Database

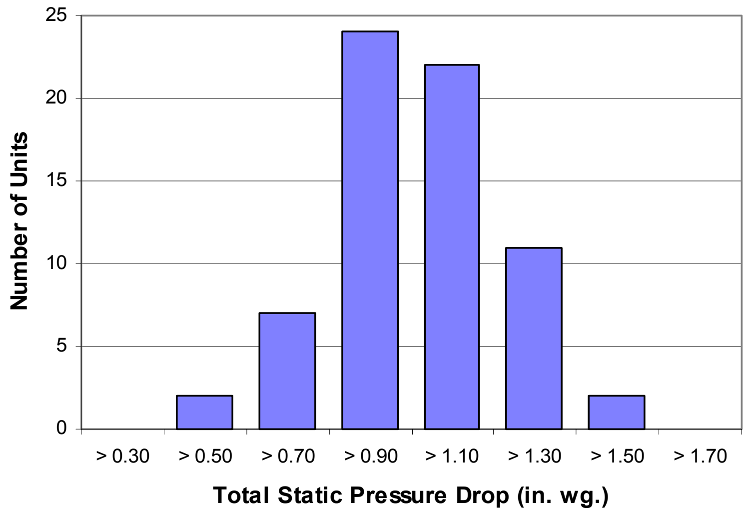


Figure D.2
External Static Pressure Drop Across Air Handler – FSEC Database

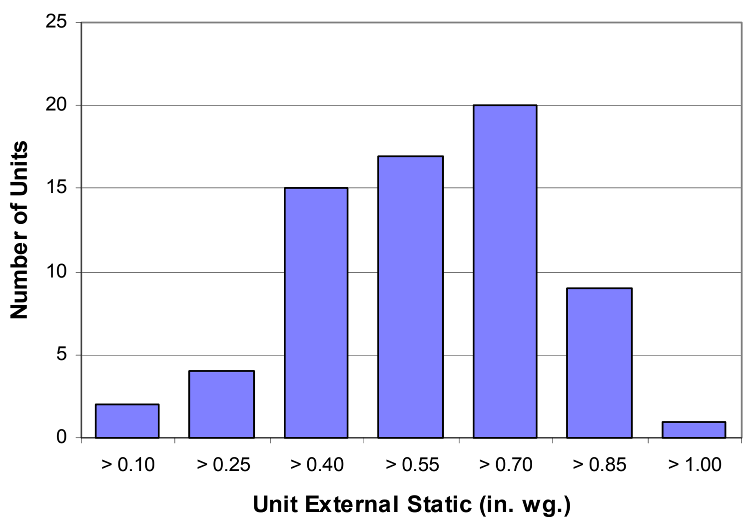
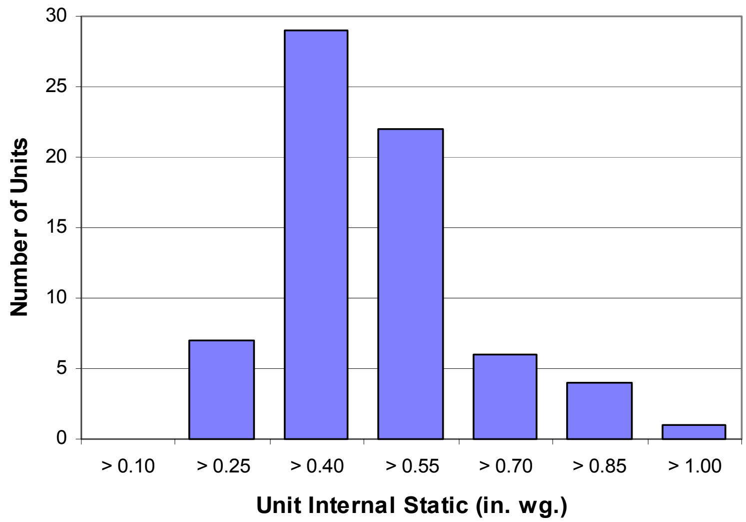


Figure D.3
Air Handler Internal Pressure Drop – FSEC Database



While the information on system pressure drop is informative, it does not provide a direct method for estimating fan power in residences. It is clear from the two reports that default assumptions used in ARI testing procedures are too low, but fan power measurements were not included in FSEC measurements. An approximate method for predicting fan power can be made by combining the average fan power of 510 Watts/1,000 cfm found in the study of California homes with the 0.93" w.g. average total static pressure noted in the FSEC study. An initial approach to estimate fan power could be to pro-rate it based on total static pressure. This would overstate changes in fan power as it ignores the effect of pressure differential on fan efficiency. A more realistic estimate of fan power would be:

$$\text{Fan Power} = 510 * (\text{TSP}/0.93)^{0.66} \qquad \text{(D.6)}$$

where:

Fan Power = Supply fan power in Watts/1,000 cfm of supply volume and

TSP = Total static pressure drop across the fan in inches w. g..

This equation predicts fan power of 365 Watts/1,000 cfm (ARI default) for a total static pressure of 0.56" w. g.. The 0.56" w. g. is the median value of internal static pressure from the FSEC database plus 0.15" w. g. external pressure, the average value specified in ARI testing of air handlers. Using low and high values of total static pressure as given in Table 5 in conjunction with Equation 6, one would expect that 75% of residential systems would have fan power values between 410 and 600 Watts per 1,000 cfm of supply air.

Appendix D References

1. *ARI, 1984. ARI Standard 210/240-84, unitary air-conditioning and air-source heat pump equipment. Air-conditioning and Refrigeration Institute.*
2. *Gobris, M., 2001, "Residential New Construction Study", Pacific Gas & Electric Report.*
3. *Lombardi, M., 2002, "Field Testing and Computer Modeling to Characterize the Energy Impacts of Air Handler Leakage," FSEC-CR-1357-02*
4. *Wilcox, B., Nittler, Proctor, & Modera, 2000. California Energy Commission Assembly Bill 970 Building Energy Efficiency Standards, Contractor Report, 2001 Update – AB 970 Draft Residential Building Standards. Energy Commission Publication No. P 400-00-023/V3.*

APPENDIX E: DETAILS OF SINGLE-FAMILY BUILDING PROTOTYPES

Details of the single-family building prototype DOE-2 models are as follows:

		Single Family Building Characteristics								
Climate Region	Wth File	Total Floor Area			Number of Stories			Aspect Ratio		
		Min	Median	Max	Min	Median	Max	Min	Median	Max
North Coast	CZ01	1400	1575	3427	1	2	2	1.0	1.2	1.5
North Coast	CZ02	1400	2335	3427	1	2	2	1.0	1.2	1.5
North Coast	CZ03	1400	2485	3427	1	2	2	1.0	1.2	1.5
North Coast	CZ04	1400	2586	3427	1	2	2	1.0	1.2	1.5
North Coast	CZ05	1400	2164	3427	1	2	2	1.0	1.2	1.5
South Coast	CZ06	1400	2858	3427	1	2	2	1.0	1.2	1.5
South Coast	CZ07	1400	2503	3427	1	2	2	1.0	1.2	1.5
South Coast	CZ08	1400	2718	3427	1	2	2	1.0	1.2	1.5
South Inland	CZ09	1400	2890	3427	1	2	2	1.0	1.2	1.5
South Inland	CZ10	1400	2343	3427	1	2	2	1.0	1.2	1.5
Central Valley	CZ11	1400	1953	3427	1	1	2	1.0	1.2	1.5
Central Valley	CZ12	1400	2216	3427	1	2	2	1.0	1.2	1.5
Central Valley	CZ13	1400	1952	3427	1	1	2	1.0	1.2	1.5
Desert	CZ14	1400	1958	3427	1	1	2	1.0	1.2	1.5
Desert	CZ15	1400	2155	3427	1	1	2	1.0	1.2	1.5
Mountain	CZ16	1400	2358	3427	1	2	2	1.0	1.2	1.5
	Min:	Itron data, 10th percentile			Itron data, 10th percentile					
Sources:	Median:	Itron data, average by CZ			Itron data, average by CZ			Itron data, derived from wall areas		
	Max:	Itron data, 90th percentile			Itron data, 90th percentile					

Climate Region	Wth File	Occupancy*			Roof Type			Floor Type		
		Min	Median	Max	Min	Median	Max	Min	Median	Max
North Coast	CZ01	2	3	5	Attic	Attic	25% Cath	Slab	Crawl	Crawl
North Coast	CZ02	2	3	5	Attic	Attic	25% Cath	Slab	Crawl	Crawl
North Coast	CZ03	2	3	5	Attic	Attic	25% Cath	Slab	Slab	Crawl
North Coast	CZ04	2	3	5	Attic	Attic	25% Cath	Slab	Slab	Crawl
North Coast	CZ05	2	3	5	Attic	Attic	25% Cath	Slab	Slab	Crawl
South Coast	CZ06	2	3	5	Attic	Attic	25% Cath	Slab	Slab	Crawl
South Coast	CZ07	2	3	5	Attic	Attic	25% Cath	Slab	Slab	Crawl
South Coast	CZ08	2	3	5	Attic	Attic	25% Cath	Slab	Slab	Crawl
South Inland	CZ09	2	3	5	Attic	Attic	25% Cath	Slab	Slab	Crawl
South Inland	CZ10	2	3	5	Attic	Attic	25% Cath	Slab	Slab	Crawl
Central Valley	CZ11	2	3	5	Attic	Attic	25% Cath	Slab	Slab	Crawl
Central Valley	CZ12	2	3	5	Attic	Attic	25% Cath	Slab	Slab	Crawl
Central Valley	CZ13	2	3	5	Attic	Attic	25% Cath	Slab	Slab	Crawl
Desert	CZ14	2	3	5	Attic	Attic	25% Cath	Slab	Slab	Crawl
Desert	CZ15	2	3	5	Attic	Attic	25% Cath	Slab	Slab	Crawl
Mountain	CZ16	2	3	5	Attic	Attic	25% Cath	Slab	Slab	Crawl
	Min:	Itron data, 10th percentile			Itron data (97% framed attic)			Itron data		
Sources:	Median:	Itron data, median for all CZ			Itron data (97% framed attic)			Itron data, median by CZ		
	Max:	Itron data, 90th percentile			SCE + DEER2001 data			SCE + DEER2001 data		

** see associated Occupancy level description*

Climate Region	Wth File	Single Family Building Characteristics								
		Glass Area (Fraction)			Glass U-value			Glass SC		
		Min	Median	Max	Min	Median	Max	Min	Median	Max
North Coast	CZ01	0.13	0.16	0.22	0.37	0.61	0.99	0.48	0.64	0.91
North Coast	CZ02	0.13	0.19	0.22	0.37	0.57	0.99	0.48	0.61	0.91
North Coast	CZ03	0.13	0.18	0.22	0.37	0.59	0.99	0.48	0.63	0.91
North Coast	CZ04	0.13	0.18	0.22	0.37	0.58	0.99	0.48	0.63	0.91
North Coast	CZ05	0.13	0.21	0.22	0.37	0.58	0.99	0.48	0.62	0.91
South Coast	CZ06	0.13	0.17	0.22	0.37	0.59	0.99	0.48	0.63	0.91
South Coast	CZ07	0.13	0.15	0.22	0.37	0.59	0.99	0.48	0.63	0.91
South Coast	CZ08	0.13	0.18	0.22	0.37	0.60	0.99	0.48	0.63	0.91
South Inland	CZ09	0.13	0.18	0.22	0.37	0.60	0.99	0.48	0.64	0.91
South Inland	CZ10	0.13	0.17	0.22	0.37	0.59	0.99	0.48	0.63	0.91
Central Valley	CZ11	0.13	0.17	0.22	0.37	0.57	0.99	0.48	0.61	0.91
Central Valley	CZ12	0.13	0.17	0.22	0.37	0.59	0.99	0.48	0.63	0.91
Central Valley	CZ13	0.13	0.15	0.22	0.37	0.69	0.99	0.48	0.70	0.91
Desert	CZ14	0.13	0.20	0.22	0.37	0.59	0.99	0.48	0.63	0.91
Desert	CZ15	0.13	0.18	0.22	0.37	0.57	0.99	0.48	0.61	0.91
Mountain	CZ16	0.13	0.16	0.22	0.37	0.60	0.99	0.48	0.64	0.91
	Min:	Itron data, 10th percentile			Itron data, minimum value			all values based on		
Sources:	Median:	Itron data, average by CZ			Itron data, average by CZ			corresponding glass U-val		
	Max:	Itron data, 90th percentile			Itron data, maximum value					

Climate Region	Wth File	Wall Cons Type			Roof Insulation			Crawlspace Insulation		
		Min	Median	Max	Min	Median	Max	Min	Median	Max
North Coast	CZ01	2x4,wd	2x6,st	2x6,ib	19	30	38	0	5	17
North Coast	CZ02	2x4,wd	2x6,st	2x6,ib	19	38	38	0	5	17
North Coast	CZ03	2x4,wd	2x6,st	2x6,ib	19	30	38	0	5	17
North Coast	CZ04	2x4,wd	2x6,st	2x6,ib	19	30	38	0	5	17
North Coast	CZ05	2x4,wd	2x4,st	2x6,ib	19	30	38	0	5	17
South Coast	CZ06	2x4,wd	2x4,st	2x6,ib	19	30	38	0	5	17
South Coast	CZ07	2x4,wd	2x4,st	2x6,ib	19	19	38	0	5	17
South Coast	CZ08	2x4,wd	2x4,st	2x6,ib	19	19	38	0	5	17
South Inland	CZ09	2x4,wd	2x4,st	2x6,ib	19	30	38	0	5	17
South Inland	CZ10	2x4,wd	2x4,st	2x6,ib	19	30	38	0	5	17
Central Valley	CZ11	2x4,wd	2x4,st	2x6,ib	19	38	38	0	5	17
Central Valley	CZ12	2x4,wd	2x4,st	2x6,ib	19	38	38	0	5	17
Central Valley	CZ13	2x4,wd	2x4,st	2x6,ib	19	38	38	0	5	17
Desert	CZ14	2x4,wd	2x4,st	2x6,ib	19	38	38	0	5	17
Desert	CZ15	2x4,wd	2x4,st	2x6,ib	19	38	38	0	5	17
Mountain	CZ16	2x4,wd	2x4,st	2x6,ib	19	38	38	0	5	17
	Min:	Itron data, minimum value			Itron data, minimum value			no insulation		
Sources:	Median:	Itron data, average by CZ			Itron data, average by CZ			R-5 crawlspace wall insulation		
	Max:	Itron data, maximum value			Itron data, maximum value			crwlspc ceiling insulation		

Min: 2x4 filled cav, wood siding
Med: filled cavity, stucco siding
Max: 2x6 filled cav, stucco w/ins board siding

		Single Family Building Characteristics								
Climate	Wth	Natural Ventilation			Cooling Thermostat SP			Cooling T-stat Setup		
Region	File	Min	Median	Max	Min	Median	Max	Min	Median	Max
North Coast	CZ01	none	5ach/72	10ach/75	74	76	78	80	82	85
North Coast	CZ02	none	5ach/72	10ach/75	74	76	78	80	82	85
North Coast	CZ03	none	5ach/72	10ach/75	74	76	78	80	82	85
North Coast	CZ04	none	5ach/72	10ach/75	74	76	78	80	82	85
North Coast	CZ05	none	5ach/72	10ach/75	74	76	78	80	82	85
South Coast	CZ06	none	5ach/72	10ach/75	74	76	78	80	82	85
South Coast	CZ07	none	5ach/72	10ach/75	74	76	78	80	82	85
South Coast	CZ08	none	5ach/72	10ach/75	74	76	78	80	82	85
South Inland	CZ09	none	5ach/72	10ach/75	74	76	78	80	82	85
South Inland	CZ10	none	5ach/72	10ach/75	74	76	78	80	82	85
Central Valley	CZ11	none	5ach/72	10ach/75	74	76	78	80	82	85
Central Valley	CZ12	none	5ach/72	10ach/75	74	76	78	80	82	85
Central Valley	CZ13	none	5ach/72	10ach/75	74	76	78	80	82	85
Desert	CZ14	none	5ach/72	10ach/75	74	76	78	80	82	85
Desert	CZ15	none	5ach/72	10ach/75	74	76	78	80	82	85
Mountain	CZ16	none	5ach/72	10ach/75	74	76	78	80	82	85
	Min:	no natural ventilation						constant t-stat schedule		
Sources:	Median:	5 ACH max, 72F max outdoor T						daytime t-stat setup to 80F		
	Max:	10 ACH max, 75F max outdoor T						daytime t-stat setup to 85F		

Occupancy Levels

Min: Two occupants, not home weekdays from 9a-5p,
- One Story: t-stat set up from 9a-5p weekdays
- Two Story: 1st floor, t-stat set up from 9a-5p weekdays
  2nd floor, t-stat set up from 9a-6p all days

Median: Three occupants, two not home weekdays from 9a-5p,
- One Story: no t-stat set up
- Two Story: 1st floor, no t-stat set up
  2nd floor, t-stat set up from 9a-6p all days

Max: Five occupants, two not home weekdays from 9a-5p,
- One Story: no t-stat set up
- Two Story: 2nd floor, no t-stat set up
  1st floor, no t-stat set up

Notes: One story house has a single A/C system
Two story house has dedicated A/C for the first and second floors

Climate Region	Wth File	Single Family Building Characteristics: Slab F2 Min	Slab F2 Median	Slab F2 Max	Duct Loss (fraction) Min	Duct Loss (fraction) Median	Duct Loss (fraction) Max	Duct R-Value Min	Duct R-Value Median	Duct R-Value Max
North Coast	CZ01	0.60	0.77	1.10	6%	10%	20%	0	4.2	8.4
North Coast	CZ02	0.60	0.77	1.10	6%	10%	20%	0	4.2	8.4
North Coast	CZ03	0.60	0.77	1.10	6%	10%	20%	0	4.2	8.4
North Coast	CZ04	0.60	0.77	1.10	6%	10%	20%	0	4.2	8.4
North Coast	CZ05	0.60	0.77	1.10	6%	10%	20%	0	4.2	8.4
South Coast	CZ06	0.60	0.77	1.10	6%	10%	20%	0	4.2	8.4
South Coast	CZ07	0.60	0.77	1.10	6%	10%	20%	0	4.2	8.4
South Coast	CZ08	0.60	0.77	1.10	6%	10%	20%	0	4.2	8.4
South Inland	CZ09	0.60	0.77	1.10	6%	10%	20%	0	4.2	8.4
South Inland	CZ10	0.60	0.77	1.10	6%	10%	20%	0	4.2	8.4
Central Valley	CZ11	0.60	0.77	1.10	6%	10%	20%	0	4.2	8.4
Central Valley	CZ12	0.60	0.77	1.10	6%	10%	20%	0	4.2	8.4
Central Valley	CZ13	0.60	0.77	1.10	6%	10%	20%	0	4.2	8.4
Desert	CZ14	0.60	0.77	1.10	6%	10%	20%	0	4.2	8.4
Desert	CZ15	0.60	0.77	1.10	6%	10%	20%	0	4.2	8.4
Mountain	CZ16	0.60	0.77	1.10	6%	10%	20%	0	4.2	8.4
	Min:	carpeted slab, R-5 insulation								
Sources:	Median:	carpeted slab, no insulation								
	Max:	uncarpeted slab, no insulation								

Climate Region	Wth File	Shading Level Min	Shading Level Median	Shading Level Max	Internal Gains Min	Internal Gains Median	Internal Gains Max	ACH Min	ACH Median	ACH Max
North Coast	CZ01	low	medium	high	50%	T-24 std	135%	0.20	0.35	0.50
North Coast	CZ02	low	medium	high	50%	T-24 std	135%	0.20	0.35	0.50
North Coast	CZ03	low	medium	high	50%	T-24 std	135%	0.20	0.35	0.50
North Coast	CZ04	low	medium	high	50%	T-24 std	135%	0.20	0.35	0.50
North Coast	CZ05	low	medium	high	50%	T-24 std	135%	0.20	0.35	0.50
South Coast	CZ06	low	medium	high	50%	T-24 std	135%	0.20	0.35	0.50
South Coast	CZ07	low	medium	high	50%	T-24 std	135%	0.20	0.35	0.50
South Coast	CZ08	low	medium	high	50%	T-24 std	135%	0.20	0.35	0.50
South Inland	CZ09	low	medium	high	50%	T-24 std	135%	0.20	0.35	0.50
South Inland	CZ10	low	medium	high	50%	T-24 std	135%	0.20	0.35	0.50
Central Valley	CZ11	low	medium	high	50%	T-24 std	135%	0.20	0.35	0.50
Central Valley	CZ12	low	medium	high	50%	T-24 std	135%	0.20	0.35	0.50
Central Valley	CZ13	low	medium	high	50%	T-24 std	135%	0.20	0.35	0.50
Desert	CZ14	low	medium	high	50%	T-24 std	135%	0.20	0.35	0.50
Desert	CZ15	low	medium	high	50%	T-24 std	135%	0.20	0.35	0.50
Mountain	CZ16	low	medium	high	50%	T-24 std	135%	0.20	0.35	0.50
	Min:	soffits only			50% of T-24 standard					
Sources:	Median:	soffits + site shading			T-24 Residential standard					
	Max:	architectural + site shading			135% of T-24 standard*					

* approx equivalent to the proposed IECC/HERS std

APPENDIX F: DETAILS OF NON-RESIDENTIAL BUILDING PROTOTYPES

F1. Overview

Since this analysis is focused on single-zone air conditioning systems (i.e., air-cooled SEER-rated systems less than 5.5 tons), for the analysis of multiple zone non-residential buildings, the selection of zone types and the characteristics of the zones are arguably more important to the analysis of SEER as an energy predictor than is the selection of building type. Key variables in the ability of the SEER rating to accurately predict energy performance include: 1) the load shape of the coil loads and 2) how these loads relate to outside ambient temperature, a relationship that is fundamental to the SEER rating system. In other words, the SEER rating of identical single-zone air conditioners on the same building (and therefore in the same climate) may perform very differently in predicting space cooling energy use, depending on which zone is served. For example, the loads of an interior zone with no connection via the building envelope to the exterior conditions will be dominated by interior lighting and equipment loads while east or west-facing zones with significant fenestration may be dominated by morning or afternoon solar gains. In each of these cases, the fundamental relationship between cooling load and outside temperature may be very different.

Accordingly, while this research will use those building types with the most SEER-rated air conditioners (based on installed tons), the configuration of these models is intended to capture the variation in the thermal loading characteristics and the relationship of those loads to outdoor temperatures typical in the selected non-residential buildings. The modeling approach for the selected prototypes will be simple, flexible, and effective in modeling the variety of thermal zone conditions to be considered.

F2. Selection of Building Types

Building types were selected based on the fraction of the installed tonnage for SEER-rated systems. Table F.1 on the following page presents results for three statistics important to the selection of building types for this analysis: building size, percentage of cooling provided by SEER-rated systems (i.e., systems less than 5.5 tons), and total installed tonnage of SEER-rated systems. These data are taken from the *1999 California Non-Residential New Construction Characteristics* (CNRNCC) Database.

Since many building characteristics vary by both building type and building size, Table F.1 reports building size and cooling service by both building type and building size quartile, i.e., percentile ranges, from the minimum size to the maximum size. The 0% quartile corresponds to the minimum value in the database, the 100% quartile corresponds to the maximum value, and the 50% quartile corresponds to the median value.

In Table F.1b, buildings types (by size range) with at least 50% of their cooling capacity provided by SEER-rated DX air conditioners are shown in yellow highlight. These include Fire and Police Stations (60% to 93% of cooling capacity provided by SEER-rated DX, depending on building size), general commercial and industrial work and storage buildings (roughly 50% to

100% of cooling capacity provided by SEER-rated DX), and schools (roughly 60% to 80% of cooling capacity provided by SEER-rated DX).

Table F.1c provides an arguably better selection criterion, installed tons, i.e., select those building types that comprise the majority of the installed tons of SEER-rated systems. Table F.1c indicates that Offices, Schools and Retail buildings (shown in green highlight) contain up to 71% (differs somewhat by size range) of all of the SEER-rated air conditioning systems installed in non-residential buildings in California. This same breakdown is also shown in Figure F.1.

Table F.1 – Non-Residential Buildings Selection Characteristics

a: Total Building Area

Total Building Area (1000's sqft)			C&I Storage	Community Center	Fire / Police / Jails	General C&I Work	Grocery Store	Gymnasium	Hotels / Motels	Libraries	Medical / Clinical	Office	Other	Religious / Assembly	Restaurant	Retail / Wholesale Store	School	Theater
Building Area Quantiles:	**Maximum**	100%	837	115	385	346	147	28	27	188	320	955	260	142	27	264	201	132
		90%	206	34	9	87	56	28	27	32	74	81	38	28	9	120	88	80
		80%	100	32	8	46	50	24	27	32	34	56	27	19	6.1	86	49	80
	3rd Quartile	75%	94	32	8	33	48	24	22	32	22	51	22	19	5.5	45	39	80
		70%	85	24	7.8	27	46	24	22	32	19	47	19	19	4.5	33	35	64
		60%	40	22	7.8	17	36	16	22	27	10	29	17	14	3.5	28	31	59
	Median	50%	40	15	7.6	11	35	15	10	16	9	16	16	10	3.3	22	19	46
		40%	20	13	7.0	10	32	15	10	16	8	13	13	7	3.0	17	12	33
		30%	15	8	6.8	7	32	14	10	7	7.0	9	9	5.4	2.1	14	7.2	15
	1st Quartile	25%	15	8	4.0	6	30	14	10.3	7	4.9	6	8	4.5	1.9	11	6.3	15
		20%	12	6.7	4.0	6	11	9.1	4.9	7	4.9	5.0	7.4	4.5	1.6	10	5.3	3
		10%	5	4.6	4.0	3.2	11	3.3	4.9	5.8	2.3	2.9	3.0	3.2	1.2	5.8	4.2	2.4
	Minimum	0%	5.2	3.3	2.5	0.1	2.7	2.0	4.9	5.8	2.0	0.1	0.6	2.6	0.7	0.3	1.8	2.4

b: Percent of Cooling Provided via SEER-Rated (< 5.5 ton) Systems

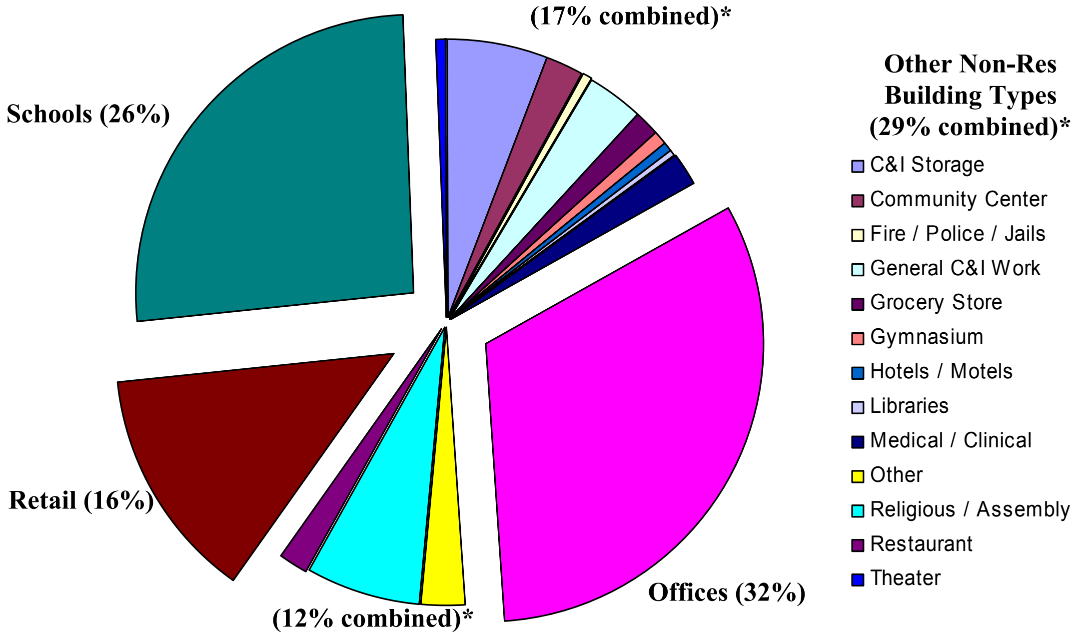
% of DX Cooling Provided by <= 5.5 ton units			C&I Storage	Community Center	Fire / Police / Jails	General C&I Work	Grocery Store	Gymnasium	Hotels / Motels	Libraries	Medical / Clinical	Office	Other	Religious / Assembly	Restaurant	Retail / Wholesale Store	School	Theater
Total Building Area Quantiles:		100%	47%	24%	**92%**	38%	12%	23%	**79%**	14%	32%	26%	30%	28%	23%	19%	**60%**	4%
		90%	**50%**	23%	**93%**	47%	13%	23%	**79%**	14%	44%	35%	30%	42%	20%	25%	**69%**	5%
		80%	**62%**	31%	**92%**	**64%**	13%	22%	**79%**	14%	**51%**	39%	20%	46%	18%	26%	**74%**	5%
		75%	**62%**	31%	**92%**	**70%**	15%	22%	0%	14%	**53%**	49%	21%	46%	16%	34%	**74%**	5%
		70%	**56%**	32%	**92%**	**77%**	18%	22%	0%	14%	**53%**	50%	20%	39%	14%	37%	**73%**	7%
		60%	49%	31%	**92%**	**93%**	19%	18%	0%	**54%**	50%	**51%**	22%	37%	11%	36%	**74%**	8%
	Median	50%	45%	44%	**89%**	**100%**	24%	19%	0%	**54%**	46%	**67%**	22%	44%	14%	46%	**73%**	13%
		40%	46%	45%	**89%**	**100%**	28%	19%	0%	**54%**	48%	**81%**	37%	**64%**	22%	39%	**82%**	15%
		30%	**100%**	49%	**89%**	**100%**	28%	30%	0%	**100%**	**51%**	**78%**	25%	**50%**	34%	**58%**	**78%**	30%
		25%	**100%**	**50%**	**83%**	**100%**	31%	49%	0%	**100%**	**72%**	**80%**	48%	36%	34%	**65%**	**77%**	30%
		20%	**100%**	**57%**	**83%**	**100%**	36%	48%	0%	**100%**	**72%**	**82%**	48%	36%	**72%**	**66%**	**70%**	30%
		10%	**100%**	20%	**76%**	**100%**	36%	**100%**	0%	0%	**54%**	**100%**	**59%**	**53%**	0%	**64%**	**77%**	0%
		0%	**100%**	**100%**	**60%**	0%	**100%**	**100%**	0%	0%	**100%**	**100%**	0%	23%	0%	0%	0%	0%

c: Total Installed Tons of SEER-Rated (< 5.5 ton) Systems

1000 Tons of <= 5.5 ton Rooftop DX Units			6%	2%	1%	3%	1%	1%	1%	0%	2%	**32%**	3%	7%	2%	**13%**	**26%**	1%	Ofc/Ret/Sch
Total Building Area Quantiles:		100%	6.9	2.3	0.8	4.0	1.5	1.0	0.8	0.4	2.2	37.3	3.2	7.8	1.8	15.8	30.8	0.7	71%
		90%	6.1	1.8	0.6	2.8	1.3	1.0	0.8	0.4	2.2	29.4	3.2	7.1	1.3	14.8	29.0	0.7	71%
		80%	6.0	1.8	0.6	1.8	1.2	1.0	0.8	0.4	2.2	23.0	1.2	6.3	1.0	11.9	19.9	0.7	69%
		75%	6.0	1.8	0.6	1.8	1.0	1.0	0.0	0.4	2.1	22.5	1.2	6.3	0.8	11.1	16.6	0.7	68%
		70%	2.9	1.6	0.6	1.6	0.9	1.0	0.0	0.4	2.1	18.1	1.1	3.4	0.7	10.3	13.3	0.4	71%
		60%	2.2	1.3	0.6	1.1	0.8	0.5	0.0	0.4	1.5	12.3	1.1	2.7	0.4	8.1	7.6	0.4	69%
	Median	50%	1.8	1.3	0.4	0.7	0.6	0.5	0.0	0.4	1.3	10.2	1.1	2.1	0.4	7.3	5.3	0.3	68%
		40%	1.3	1.0	0.4	0.7	0.4	0.5	0.0	0.4	1.0	7.2	1.0	1.4	0.4	4.3	3.7	0.2	63%
		30%	0.9	0.8	0.4	0.4	0.4	0.3	0.0	0.4	0.5	4.1	0.3	0.7	0.3	3.8	2.0	0.2	64%
		25%	0.8	0.6	0.2	0.3	0.4	0.3	0.0	0.4	0.4	2.7	0.3	0.4	0.2	3.2	1.5	0.2	61%
		20%	0.7	0.6	0.2	0.2	0.4	0.1	0.0	0.4	0.4	2.0	0.3	0.4	0.2	2.4	1.1	0.2	57%
		10%	0.3	0.1	0.2	0.1	0.4	0.0	0.0	0.0	0.1	0.7	0.2	0.2	0.0	0.6	0.6	0.0	54%

indicates > 50% of bldg conditioned area cooled via SEER-rated DX systems (yellow)
indicates building types with the most SEER-rated installed tonnage (green)

Figure F.1 Percent of Total Installed Tons of SEER-Rated A/C Systems in California Non-Residential Buildings



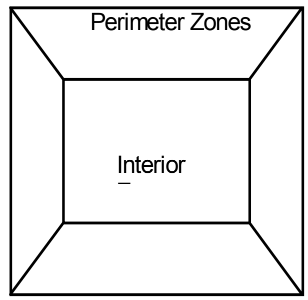
* for a breakdown of the percentages by building type, see the first row of Table 2c

F3. Configuration of the Prototypes

Each of the non-residential prototypes will be analyzed on a whole building as well as on a zone-by zone basis. The zone-by-zone analysis will quantify differences due to orientation exterior wall configuration, while the weighted sum of all zones will make up a typical building.

Office Prototype

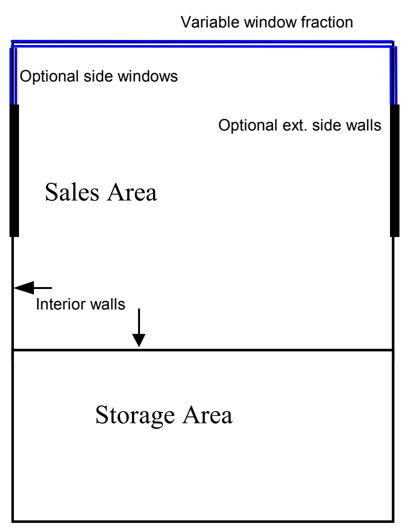
The office prototype is one story with typical 5-zone layout having one interior and five perimeter zones. The office will have a shallow perimeter zone depth (e.g., 15 ft) and large interior zone, configured to represent the 16,000 square foot median size. Each zone will be served by a separate PSZ HVAC system, defined in detail per the analysis requirements.



Retail Prototype

The small retail prototype is a simple two-zone model with a main sales area and a smaller storage area. The retail model is orientation specific, and a single simulation run will be defined with fours sets of sales/storage areas, with one set facing each cardinal direction.

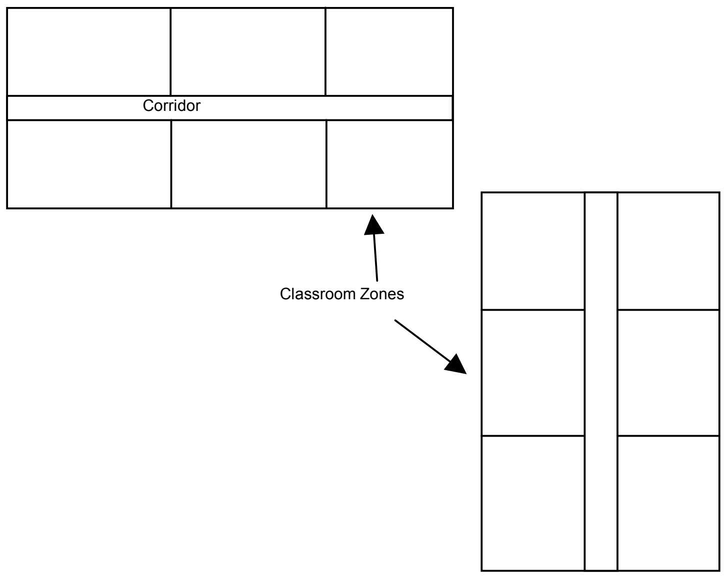
The retail model will have a deep perimeter zone depth and small interior zone (storage), configured to represent the 22,000 square foot median size. The side walls can be exterior walls, interior walls, or a fraction of each, depending on the sensitivity analysis being evaluated.



Each zone will be served by a separate PSZ HVAC system, defined in detail per the analysis requirements. Post-processing of the simulation results will allow for each zone to be analyzed separately, or for the results to be analyzed on any aggregated basis (e.g., all orientations, sales only, whole-building level).

School Building Prototype

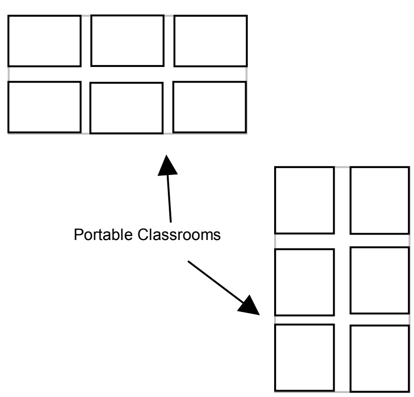
The school building prototype represents the classroom areas only of a single-story school complex. The perimeter depth for these zones is approximately 30 ft and windows will be located on the long axis only. Two sets of six classroom buildings will be modeled to provide for all combinations of classroom position/orientation combinations.



As with the other prototypes, each zone will be served by a separate PSZ HVAC system, defined in detail per the analysis requirements. Post-processing of the simulation results will allow for each zone to be analyzed separately, or for the results to be analyzed on a whole building basis.

Portable Classroom Prototype

The portable classroom prototype will be modeled as a stand-alone building of approximately 24’ x 40 feet. Survey information regarding the portable classrooms will define the exact configuration of the building. Two classroom orientations will be modeled in a single simulation to eliminate orientation sensitivity when reporting whole-building results.



The classroom will be served by a single PSZ HVAC system. HVAC installations specific to portable classrooms will be used to define the models whenever possible.

Typical Values and Sensitivity Analysis Values for Non-Residential Prototypes

F4. Office Building Model Input Values by Climate Zone (page 1 of 4)

Climate Region	Wth File	Office Building Characteristics: Total Floor Area			Number of Stories			Perim Depth (ft)		
		Min	Median	Max	Min	Median	Max	Min	Median	Max
North Coast	CZ01	2500	15000	70000	1.0	1.2	1.9	13	15	20
North Coast	CZ02	2500	15000	70000	1.0	1.2	1.9	13	15	20
North Coast	CZ03	2500	15000	70000	1.0	1.2	1.9	13	15	20
North Coast	CZ04	2500	15000	70000	1.0	1.2	1.9	13	15	20
North Coast	CZ05	2500	15000	70000	1.0	1.2	1.9	13	15	20
South Coast	CZ06	2500	15000	70000	1.0	1.2	1.9	13	15	20
South Coast	CZ07	2500	15000	70000	1.0	1.2	1.9	13	15	20
South Coast	CZ08	2500	15000	70000	1.0	1.2	1.9	13	15	20
South Inland	CZ09	2500	15000	70000	1.0	1.2	1.9	13	15	20
South Inland	CZ10	2500	15000	70000	1.0	1.2	1.9	13	15	20
Central Valley	CZ11	2500	15000	70000	1.0	1.2	1.9	13	15	20
Central Valley	CZ12	2500	15000	70000	1.0	1.2	1.9	13	15	20
Central Valley	CZ13	2500	15000	70000	1.0	1.2	1.9	13	15	20
Desert	CZ14	2500	15000	70000	1.0	1.2	1.9	13	15	20
Desert	CZ15	2500	15000	70000	1.0	1.2	1.9	13	15	20
Mountain	CZ16	2500	15000	70000	1.0	1.2	1.9	13	15	20
	Min:	CNRNCC, 10% percentile			CNRNCC, 10% percentile			assumes 15ft deep perim		
Sources:	Median:	CNRNCC, 50% percentile			CNRNCC, 50% percentile			zone for the min/median/max		
	Max:	CNRNCC, 90% percentile			CNRNCC, 90% percentile			floor area		

Climate Region	Wth File	Int. Shade (Probability of Use)			Hrs per day operating			Months per Year Operating		
		Min	Median	Max	Min	Median	Max	Min	Median	Max
North Coast	CZ01	0%	20%	75%	10	14	24	12	12	12
North Coast	CZ02	0%	20%	75%	10	14	24	12	12	12
North Coast	CZ03	0%	20%	75%	10	14	24	12	12	12
North Coast	CZ04	0%	20%	75%	10	14	24	12	12	12
North Coast	CZ05	0%	20%	75%	10	14	24	12	12	12
South Coast	CZ06	0%	20%	75%	10	14	24	12	12	12
South Coast	CZ07	0%	20%	75%	10	14	24	12	12	12
South Coast	CZ08	0%	20%	75%	10	14	24	12	12	12
South Inland	CZ09	0%	20%	75%	10	14	24	12	12	12
South Inland	CZ10	0%	20%	75%	10	14	24	12	12	12
Central Valley	CZ11	0%	20%	75%	10	14	24	12	12	12
Central Valley	CZ12	0%	20%	75%	10	14	24	12	12	12
Central Valley	CZ13	0%	20%	75%	10	14	24	12	12	12
Desert	CZ14	0%	20%	75%	10	14	24	12	12	12
Desert	CZ15	0%	20%	75%	10	14	24	12	12	12
Mountain	CZ16	0%	20%	75%	10	14	24	12	12	12
	Min:	CNRNCC very limited			CNRNCC, 10% percentile			CNRNCC, 10% percentile		
Sources:	Median:	therefore, estimate only			CNRNCC, 50% percentile			CNRNCC, 50% percentile		
	Max:				CNRNCC, 90% percentile			CNRNCC, 90% percentile		

Office Building Model Input Values by Climate Zone (page 2 of 4)

		Office Building Characteristics								
Climate	Wth	Roof Insulation			Exterior Wall Insulation			Wall Cons Type		
Region	File	Min	Median	Max	Min	Median	Max	33%	48%	19%
North Coast	CZ01	13	19	30	3	13	19	CMU	Wd-Frm	Stl-Frm
North Coast	CZ02	13	19	30	3	13	19	CMU	Wd-Frm	Stl-Frm
North Coast	CZ03	13	19	30	3	11	19	CMU	Wd-Frm	Stl-Frm
North Coast	CZ04	13	19	30	3	11	19	CMU	Wd-Frm	Stl-Frm
North Coast	CZ05	13	19	30	3	11	19	CMU	Wd-Frm	Stl-Frm
South Coast	CZ06	7	11	19	3	11	19	CMU	Wd-Frm	Stl-Frm
South Coast	CZ07	7	11	19	3	11	19	CMU	Wd-Frm	Stl-Frm
South Coast	CZ08	7	11	19	3	11	19	CMU	Wd-Frm	Stl-Frm
South Inland	CZ09	7	11	19	3	11	19	CMU	Wd-Frm	Stl-Frm
South Inland	CZ10	13	19	30	3	13	19	CMU	Wd-Frm	Stl-Frm
Central Valley	CZ11	13	19	30	3	13	19	CMU	Wd-Frm	Stl-Frm
Central Valley	CZ12	13	19	30	3	13	19	CMU	Wd-Frm	Stl-Frm
Central Valley	CZ13	13	19	30	3	13	19	CMU	Wd-Frm	Stl-Frm
Desert	CZ14	13	19	30	3	13	19	CMU	Wd-Frm	Stl-Frm
Desert	CZ15	13	19	30	3	13	19	CMU	Wd-Frm	Stl-Frm
Mountain	CZ16	13	19	30	3	13	19	CMU	Wd-Frm	Stl-Frm
	Min:	CNRNCC, 10% percentile			CNRNCC, 10% percentile			CNRNCC for median size		
Sources:	Median:	T24 levels assumed, by CZ			T24 levels assumed, by CZ			office bldgs served by		
	Max:	CNRNCC, 90% percentile			CNRNCC, 90% percentile			SEER-rated DX units		

Climate	Wth	Occupancy (Sqft/occ)			Lighting Power Density (W/sf)			Equip Power Density (W/sf)		
Region	File	Min	Median	Max	Min	Median*	Max	Min	Median	Max
North Coast	CZ01	300	200	100	0.9	1.25	1.78	0.75	1.34	2.5
North Coast	CZ02	300	200	100	0.9	1.25	1.78	0.75	1.34	2.5
North Coast	CZ03	300	200	100	0.9	1.25	1.78	0.75	1.34	2.5
North Coast	CZ04	300	200	100	0.9	1.25	1.78	0.75	1.34	2.5
North Coast	CZ05	300	200	100	0.9	1.25	1.78	0.75	1.34	2.5
South Coast	CZ06	300	200	100	0.9	1.25	1.78	0.75	1.34	2.5
South Coast	CZ07	300	200	100	0.9	1.25	1.78	0.75	1.34	2.5
South Coast	CZ08	300	200	100	0.9	1.25	1.78	0.75	1.34	2.5
South Inland	CZ09	300	200	100	0.9	1.25	1.78	0.75	1.34	2.5
South Inland	CZ10	300	200	100	0.9	1.25	1.78	0.75	1.34	2.5
Central Valley	CZ11	300	200	100	0.9	1.25	1.78	0.75	1.34	2.5
Central Valley	CZ12	300	200	100	0.9	1.25	1.78	0.75	1.34	2.5
Central Valley	CZ13	300	200	100	0.9	1.25	1.78	0.75	1.34	2.5
Desert	CZ14	300	200	100	0.9	1.25	1.78	0.75	1.34	2.5
Desert	CZ15	300	200	100	0.9	1.25	1.78	0.75	1.34	2.5
Mountain	CZ16	300	200	100	0.9	1.25	1.78	0.75	1.34	2.5
	Min:	CNRNCC unavailable			CNRNCC, 10% percentile			estimate		
Sources:	Median:	therefore, estimate only			CNRNCC, 50% percentile			T24 ACM		
	Max:	T24 ACM			CNRNCC, 90% percentile			estimate		

* Title24 requirement: 1.2W/sf

Office Building Model Input Values by Climate Zone (page 3 of 4)

Climate Region	Wth File	Office Building Characteristics: Glass U-Value Min	Glass U-Value Median	Glass U-Value Max	Glass SHGC Min	Glass SHGC Median	Glass SHGC Max	Ovhg Depth (ft) Min	Ovhg Depth (ft) Median	Ovhg Depth (ft) Max
North Coast	CZ01	1.23	0.49	0.49	0.43	0.43	0.49	0	1.5	4
North Coast	CZ02	1.23	0.49	0.49	0.31	0.36	0.47	0	1.5	4
North Coast	CZ03	1.23	0.81	0.49	0.41	0.55	0.61	0	1.5	4
North Coast	CZ04	1.23	0.81	0.49	0.41	0.55	0.61	0	1.5	4
North Coast	CZ05	1.23	0.81	0.49	0.41	0.55	0.61	0	1.5	4
South Coast	CZ06	1.23	0.81	0.49	0.34	0.61	0.61	0	1.5	4
South Coast	CZ07	1.23	0.81	0.49	0.34	0.61	0.61	0	1.5	4
South Coast	CZ08	1.23	0.81	0.49	0.34	0.61	0.61	0	1.5	4
South Inland	CZ09	1.23	0.81	0.49	0.34	0.61	0.61	0	1.5	4
South Inland	CZ10	1.23	0.49	0.49	0.31	0.36	0.47	0	1.5	4
Central Valley	CZ11	1.23	0.49	0.49	0.31	0.36	0.47	0	1.5	4
Central Valley	CZ12	1.23	0.49	0.49	0.31	0.36	0.47	0	1.5	4
Central Valley	CZ13	1.23	0.49	0.49	0.31	0.36	0.47	0	1.5	4
Desert	CZ14	1.23	0.49	0.49	0.31	0.36	0.46	0	1.5	4
Desert	CZ15	1.23	0.49	0.49	0.31	0.36	0.46	0	1.5	4
Mountain	CZ16	1.23	0.49	0.49	0.43	0.43	0.49	0	1.5	4
Sources:	Min:	CNRNCC, 10% percentile			Only Non-North shown			CNRNCC, 10% percentile		
	Median:	T24 levels assumed, by CZ			assumes T24 values, based			CNRNCC, 50% percentile		
	Max:	CNRNCC, 90% percentile			WWR			CNRNCC, 90% percentile		

Climate Region	Wth File	Economizer Min	Economizer Median	Economizer Max*	External Static Pres (inWG) Min	External Static Pres (inWG) Median	External Static Pres (inWG) Max	Supply Ducts Leakage	Supply Ducts R-Value	Supply Ducts Transients
North Coast	CZ01	none	none	yes	0.25	0.50	0.85	2%	2.8	0
North Coast	CZ02	none	none	yes	0.25	0.50	0.85	2%	2.8	0
North Coast	CZ03	none	none	yes	0.25	0.50	0.85	2%	2.8	0
North Coast	CZ04	none	none	yes	0.25	0.50	0.85	2%	2.8	0
North Coast	CZ05	none	none	yes	0.25	0.50	0.85	2%	2.8	0
South Coast	CZ06	none	none	yes	0.25	0.50	0.85	2%	2.8	0
South Coast	CZ07	none	none	yes	0.25	0.50	0.85	2%	2.8	0
South Coast	CZ08	none	none	yes	0.25	0.50	0.85	2%	2.8	0
South Inland	CZ09	none	none	yes	0.25	0.50	0.85	2%	2.8	0
South Inland	CZ10	none	none	yes	0.25	0.50	0.85	2%	2.8	0
Central Valley	CZ11	none	none	yes	0.25	0.50	0.85	2%	2.8	0
Central Valley	CZ12	none	none	yes	0.25	0.50	0.85	2%	2.8	0
Central Valley	CZ13	none	none	yes	0.25	0.50	0.85	2%	2.8	0
Desert	CZ14	none	none	yes	0.25	0.50	0.85	2%	2.8	0
Desert	CZ15	none	none	yes	0.25	0.50	0.85	2%	2.8	0
Mountain	CZ16	none	none	yes	0.25	0.50	0.85	2%	2.8	0
Sources:	Min:	CNRNCC, 10% percentile			Split sys can't support full rng			Leak: Class C duct, 0.5"wg		
	Median:	CNRNCC, 50% percentile			of ext statics of packaged sys			R-Value: T24 requirement		
	Max:	CNRNCC, 90% percentile			~ 410,510,600 W/1000cfm			Trans: assumes cont fan ops		

* 28% of CA SEER-rated package units have economizers

Office Building Model Input Values by Climate Zone (page 4 of 4)

		Office Building Characteristics								
Climate Region	Wth File	Whole Bldg WWR			WWR (North, South)			WWR (East, West)		
		Min	Median	Max	Min	Median	Max	Min	Median	Max
North Coast	CZ01	6%	11%	49%	0% 0%	20% 17%	52% 45%	0% 0%	19% 21%	51% 56%
North Coast	CZ02	6%	11%	49%	0% 0%	20% 17%	52% 45%	0% 0%	19% 21%	51% 56%
North Coast	CZ03	6%	11%	49%	0% 0%	20% 17%	52% 45%	0% 0%	19% 21%	51% 56%
North Coast	CZ04	6%	11%	49%	0% 0%	20% 17%	52% 45%	0% 0%	19% 21%	51% 56%
North Coast	CZ05	6%	11%	49%	0% 0%	20% 17%	52% 45%	0% 0%	19% 21%	51% 56%
South Coast	CZ06	6%	11%	49%	0% 0%	20% 17%	52% 45%	0% 0%	19% 21%	51% 56%
South Coast	CZ07	6%	11%	49%	0% 0%	20% 17%	52% 45%	0% 0%	19% 21%	51% 56%
South Coast	CZ08	6%	11%	49%	0% 0%	20% 17%	52% 45%	0% 0%	19% 21%	51% 56%
South Inland	CZ09	6%	11%	49%	0% 0%	20% 17%	52% 45%	0% 0%	19% 21%	51% 56%
South Inland	CZ10	6%	11%	49%	0% 0%	20% 17%	52% 45%	0% 0%	19% 21%	51% 56%
Central Valley	CZ11	6%	11%	49%	0% 0%	20% 17%	52% 45%	0% 0%	19% 21%	51% 56%
Central Valley	CZ12	6%	11%	49%	0% 0%	20% 17%	52% 45%	0% 0%	19% 21%	51% 56%
Central Valley	CZ13	6%	11%	49%	0% 0%	20% 17%	52% 45%	0% 0%	19% 21%	51% 56%
Desert	CZ14	6%	11%	49%	0% 0%	20% 17%	52% 45%	0% 0%	19% 21%	51% 56%
Desert	CZ15	6%	11%	49%	0% 0%	20% 17%	52% 45%	0% 0%	19% 21%	51% 56%
Mountain	CZ16	6%	11%	49%	0% 0%	20% 17%	52% 45%	0% 0%	19% 21%	51% 56%
	Min:	CNRNCC, 10% percentile			CNRNCC, 10% percentile			CNRNCC, 10% percentile		
Sources:	Median:	CNRNCC, average by CZ			CNRNCC, 50% percentile			CNRNCC, 50% percentile		
	Max:	CNRNCC, 90% percentile			CNRNCC, 90% percentile			CNRNCC, 90% percentile		

Climate Region	Wth File	Cooling Thermostat SP		
		Min	Median	Max
North Coast	CZ01	72	73	75
North Coast	CZ02	72	73	75
North Coast	CZ03	72	73	75
North Coast	CZ04	72	73	75
North Coast	CZ05	72	73	75
South Coast	CZ06	72	73	75
South Coast	CZ07	72	73	75
South Coast	CZ08	72	73	75
South Inland	CZ09	72	73	75
South Inland	CZ10	72	73	75
Central Valley	CZ11	72	73	75
Central Valley	CZ12	72	73	75
Central Valley	CZ13	72	73	75
Desert	CZ14	72	73	75
Desert	CZ15	72	73	75
Mountain	CZ16	72	73	75
	Min:	CNRNCC, 10% percentile		
Sources:	Median:	CNRNCC, 50% percentile		
	Max:	CNRNCC, 90% percentile		

F5. Retail Building Model Input Values by Climate Zone (page 1 of 2)

Climate Region	Wth File	Retail Building Characteristics								
		Glass U-Value			Glass SHGC			Ovhg Depth		
		Min	Median	Max	Min	Median	Max	Min	Median	Max
North Coast	CZ01	1.23	0.49	0.49	0.43	0.49	0.49	0	3	7
North Coast	CZ02	1.23	0.49	0.49	0.31	0.47	0.47	0	3	7
North Coast	CZ03	1.23	0.81	0.49	0.41	0.61	0.61	0	3	7
North Coast	CZ04	1.23	0.81	0.49	0.41	0.61	0.61	0	3	7
North Coast	CZ05	1.23	0.81	0.49	0.41	0.61	0.61	0	3	7
South Coast	CZ06	1.23	0.81	0.49	0.34	0.61	0.61	0	3	7
South Coast	CZ07	1.23	0.81	0.49	0.34	0.61	0.61	0	3	7
South Coast	CZ08	1.23	0.81	0.49	0.34	0.61	0.61	0	3	7
South Inland	CZ09	1.23	0.81	0.49	0.34	0.61	0.61	0	3	7
South Inland	CZ10	1.23	0.49	0.49	0.31	0.47	0.47	0	3	7
Central Valley	CZ11	1.23	0.49	0.49	0.31	0.47	0.47	0	3	7
Central Valley	CZ12	1.23	0.49	0.49	0.31	0.47	0.47	0	3	7
Central Valley	CZ13	1.23	0.49	0.49	0.31	0.47	0.47	0	3	7
Desert	CZ14	1.23	0.49	0.49	0.31	0.46	0.46	0	3	7
Desert	CZ15	1.23	0.49	0.49	0.31	0.46	0.46	0	3	7
Mountain	CZ16	1.23	0.49	0.49	0.43	0.49	0.49	0	3	7
	Min:	CNRNCC, 10% percentile			Only Non-North shown			CNRNCC, 10% percentile		
Sources:	Median:	T24 levels assumed, by CZ			assumes T24 values, based			CNRNCC, 50% percentile		
	Max:	CNRNCC, 90% percentile			WWR			CNRNCC, 90% percentile		

Climate Region	Wth File	Economizer			External Static Pres (inWG)			Supply Ducts		
		Min	Median	Max*	Min	Median	Max	Leakage	R-Value	Transients
North Coast	CZ01	none	none	yes	0.05	0.50	0.85	2%	2.8	0
North Coast	CZ02	none	none	yes	0.05	0.50	0.85	2%	2.8	0
North Coast	CZ03	none	none	yes	0.05	0.50	0.85	2%	2.8	0
North Coast	CZ04	none	none	yes	0.05	0.50	0.85	2%	2.8	0
North Coast	CZ05	none	none	yes	0.05	0.50	0.85	2%	2.8	0
South Coast	CZ06	none	none	yes	0.05	0.50	0.85	2%	2.8	0
South Coast	CZ07	none	none	yes	0.05	0.50	0.85	2%	2.8	0
South Coast	CZ08	none	none	yes	0.05	0.50	0.85	2%	2.8	0
South Inland	CZ09	none	none	yes	0.05	0.50	0.85	2%	2.8	0
South Inland	CZ10	none	none	yes	0.05	0.50	0.85	2%	2.8	0
Central Valley	CZ11	none	none	yes	0.05	0.50	0.85	2%	2.8	0
Central Valley	CZ12	none	none	yes	0.05	0.50	0.85	2%	2.8	0
Central Valley	CZ13	none	none	yes	0.05	0.50	0.85	2%	2.8	0
Desert	CZ14	none	none	yes	0.05	0.50	0.85	2%	2.8	0
Desert	CZ15	none	none	yes	0.05	0.50	0.85	2%	2.8	0
Mountain	CZ16	none	none	yes	0.05	0.50	0.85	2%	2.8	0
	Min:	CNRNCC, 10% percentile			Split sys can't support full rng			Leak: Class C duct, 0.5"wg		
Sources:	Median:	CNRNCC, 50% percentile			of ext statics of packaged sys			R-Value: T24 requirement		
	Max:	CNRNCC, 90% percentile			~ 410,510,600 W/1000cfm			Trans: assumes cont fan ops		

* 28% of CA SEER-rated package units have economizers

Retail Building Model Input Values by Climate Zone (page 2 of 2)

		Retail Building Characteristics								
Climate Region	Wth File	Whole Bldg WWR			WWR (North, South)			WWR (East, West)		
		Min	Median	Max	Min	Median	Max	Min	Median	Max
North Coast	CZ01	0%	6%	34%	0% 0%	2% 2%	30% 50%	0% 0%	2% 2%	55% 35%
North Coast	CZ02	0%	6%	34%	0% 0%	2% 2%	30% 50%	0% 0%	2% 2%	55% 35%
North Coast	CZ03	0%	6%	34%	0% 0%	2% 2%	30% 50%	0% 0%	2% 2%	55% 35%
North Coast	CZ04	0%	6%	34%	0% 0%	2% 2%	30% 50%	0% 0%	2% 2%	55% 35%
North Coast	CZ05	0%	6%	34%	0% 0%	2% 2%	30% 50%	0% 0%	2% 2%	55% 35%
South Coast	CZ06	0%	6%	34%	0% 0%	2% 2%	30% 50%	0% 0%	2% 2%	55% 35%
South Coast	CZ07	0%	6%	34%	0% 0%	2% 2%	30% 50%	0% 0%	2% 2%	55% 35%
South Coast	CZ08	0%	6%	34%	0% 0%	2% 2%	30% 50%	0% 0%	2% 2%	55% 35%
South Inland	CZ09	0%	6%	34%	0% 0%	2% 2%	30% 50%	0% 0%	2% 2%	55% 35%
South Inland	CZ10	0%	6%	34%	0% 0%	2% 2%	30% 50%	0% 0%	2% 2%	55% 35%
Central Valley	CZ11	0%	6%	34%	0% 0%	2% 2%	30% 50%	0% 0%	2% 2%	55% 35%
Central Valley	CZ12	0%	6%	34%	0% 0%	2% 2%	30% 50%	0% 0%	2% 2%	55% 35%
Central Valley	CZ13	0%	6%	34%	0% 0%	2% 2%	30% 50%	0% 0%	2% 2%	55% 35%
Desert	CZ14	0%	6%	34%	0% 0%	2% 2%	30% 50%	0% 0%	2% 2%	55% 35%
Desert	CZ15	0%	6%	34%	0% 0%	2% 2%	30% 50%	0% 0%	2% 2%	55% 35%
Mountain	CZ16	0%	6%	34%	0% 0%	2% 2%	30% 50%	0% 0%	2% 2%	55% 35%
	Min:	CNRNCC, 10% percentile			CNRNCC, 10% percentile			CNRNCC, 10% percentile		
Sources:	Median:	CNRNCC, average by CZ			CNRNCC, 50% percentile			CNRNCC, 50% percentile		
	Max:	CNRNCC, 90% percentile			CNRNCC, 90% percentile			CNRNCC, 90% percentile		

Climate Region	Wth File	Cooling Thermostat SP		
		Min	Median	Max
North Coast	CZ01	72	74	76
North Coast	CZ02	72	74	76
North Coast	CZ03	72	74	76
North Coast	CZ04	72	74	76
North Coast	CZ05	72	74	76
South Coast	CZ06	72	74	76
South Coast	CZ07	72	74	76
South Coast	CZ08	72	74	76
South Inland	CZ09	72	74	76
South Inland	CZ10	72	74	76
Central Valley	CZ11	72	74	76
Central Valley	CZ12	72	74	76
Central Valley	CZ13	72	74	76
Desert	CZ14	72	74	76
Desert	CZ15	72	74	76
Mountain	CZ16	72	74	76
	Min:	CNRNCC, 10% percentile		
Sources:	Median:	CNRNCC, 50% percentile		
	Max:	CNRNCC, 90% percentile		

F6. Conventional School Classroom Model Input Values by Climate Zone (page 1 of 4)

Climate Region	Wth File	School Characteristics (Conventional Classrooms)								
		Classroom Area			Aspect Ratio			% Perim Zone		
		Min	Median	Max	Min	Median	Max	Min	Median	Max
North Coast	CZ01	700	1167	1806	0.75	1.00	1.50	n/a	n/a	n/a
North Coast	CZ02	700	1167	1806	0.75	1.00	1.50	n/a	n/a	n/a
North Coast	CZ03	700	1167	1806	0.75	1.00	1.50	n/a	n/a	n/a
North Coast	CZ04	700	1167	1806	0.75	1.00	1.50	n/a	n/a	n/a
North Coast	CZ05	700	1167	1806	0.75	1.00	1.50	n/a	n/a	n/a
South Coast	CZ06	700	1167	1806	0.75	1.00	1.50	n/a	n/a	n/a
South Coast	CZ07	700	1167	1806	0.75	1.00	1.50	n/a	n/a	n/a
South Coast	CZ08	700	1167	1806	0.75	1.00	1.50	n/a	n/a	n/a
South Inland	CZ09	700	1167	1806	0.75	1.00	1.50	n/a	n/a	n/a
South Inland	CZ10	700	1167	1806	0.75	1.00	1.50	n/a	n/a	n/a
Central Valley	CZ11	700	1167	1806	0.75	1.00	1.50	n/a	n/a	n/a
Central Valley	CZ12	700	1167	1806	0.75	1.00	1.50	n/a	n/a	n/a
Central Valley	CZ13	700	1167	1806	0.75	1.00	1.50	n/a	n/a	n/a
Desert	CZ14	700	1167	1806	0.75	1.00	1.50	n/a	n/a	n/a
Desert	CZ15	700	1167	1806	0.75	1.00	1.50	n/a	n/a	n/a
Mountain	CZ16	700	1167	1806	0.75	1.00	1.50	n/a	n/a	n/a
	Min:	CNRNCC, 10% percentile								
Sources:	Median:	CNRNCC, 50% percentile								
	Max:	CNRNCC, 90% percentile								

Climate Region	Wth File	Int. Shade (Probability of Use)			Hrs per day operating			Months per Year Operating		
		Min	Median	Max	Min	Median	Max	Min	Median	Max
North Coast	CZ01	0%	50%	75%	7	10	10	9	9	12
North Coast	CZ02	0%	50%	75%	7	10	10	9	9	12
North Coast	CZ03	0%	50%	75%	7	10	10	9	9	12
North Coast	CZ04	0%	50%	75%	7	10	10	9	9	12
North Coast	CZ05	0%	50%	75%	7	10	10	9	9	12
South Coast	CZ06	0%	50%	75%	7	10	10	9	9	12
South Coast	CZ07	0%	50%	75%	7	10	10	9	9	12
South Coast	CZ08	0%	50%	75%	7	10	10	9	9	12
South Inland	CZ09	0%	50%	75%	7	10	10	9	9	12
South Inland	CZ10	0%	50%	75%	7	10	10	9	9	12
Central Valley	CZ11	0%	50%	75%	7	10	10	9	9	12
Central Valley	CZ12	0%	50%	75%	7	10	10	9	9	12
Central Valley	CZ13	0%	50%	75%	7	10	10	9	9	12
Desert	CZ14	0%	50%	75%	7	10	10	9	9	12
Desert	CZ15	0%	50%	75%	7	10	10	9	9	12
Mountain	CZ16	0%	50%	75%	7	10	10	9	9	12
	Min:	CNRNCC very limited			basic schedule = 8a - 3p			inc. standard holidays		
Sources:	Median:	therefore, estimate only			basic schedule = 7a - 5 p			inc. standard holidays		
	Max:				basic schedule = 7a - 5 p			Year-round, inc. std holidays		

Conventional School Classroom Model Input Values by Climate Zone (page 2 of 4)

		School Characteristics (Conventional Classrooms)								
Climate	Wth	Roof Insulation			Exterior Wall Insulation			Wall Cons Type		
Region	File	Min	Median	Max	Min	Median	Max	35%	63%	2%
North Coast	CZ01	13	19	30	3	13	19	CMU	Wd-Frm	Stl-Frm
North Coast	CZ02	13	19	30	3	13	19	CMU	Wd-Frm	Stl-Frm
North Coast	CZ03	13	19	30	3	11	19	CMU	Wd-Frm	Stl-Frm
North Coast	CZ04	13	19	30	3	11	19	CMU	Wd-Frm	Stl-Frm
North Coast	CZ05	13	19	30	3	11	19	CMU	Wd-Frm	Stl-Frm
South Coast	CZ06	7	11	19	3	11	19	CMU	Wd-Frm	Stl-Frm
South Coast	CZ07	7	11	19	3	11	19	CMU	Wd-Frm	Stl-Frm
South Coast	CZ08	7	11	19	3	11	19	CMU	Wd-Frm	Stl-Frm
South Inland	CZ09	7	11	19	3	11	19	CMU	Wd-Frm	Stl-Frm
South Inland	CZ10	13	19	30	3	13	19	CMU	Wd-Frm	Stl-Frm
Central Valley	CZ11	13	19	30	3	13	19	CMU	Wd-Frm	Stl-Frm
Central Valley	CZ12	13	19	30	3	13	19	CMU	Wd-Frm	Stl-Frm
Central Valley	CZ13	13	19	30	3	13	19	CMU	Wd-Frm	Stl-Frm
Desert	CZ14	13	19	30	3	13	19	CMU	Wd-Frm	Stl-Frm
Desert	CZ15	13	19	30	3	13	19	CMU	Wd-Frm	Stl-Frm
Mountain	CZ16	13	19	30	3	13	19	CMU	Wd-Frm	Stl-Frm
	Min:	CNRNCC, 20% percentile			CNRNCC, 10% percentile			CNRNCC for median size		
Sources:	Median:	T24 levels assumed, by CZ			T24 levels assumed, by CZ			office bldgs served by		
	Max:	CNRNCC, 90% percentile			CNRNCC, 90% percentile			SEER-rated DX units		

Climate	Wth	Occupancy (Sqft/occ)			Lighting Power Density (W/sf)			Equip Power Density (W/sf)		
Region	File	Min	Median	Max	Min	Median*	Max	Min	Median	Max
North Coast	CZ01	50	33	25	1	1.36	1.9	0.50	1.00	2.00
North Coast	CZ02	50	33	25	1	1.36	1.9	0.50	1.00	2.00
North Coast	CZ03	50	33	25	1	1.36	1.9	0.50	1.00	2.00
North Coast	CZ04	50	33	25	1	1.36	1.9	0.50	1.00	2.00
North Coast	CZ05	50	33	25	1	1.36	1.9	0.50	1.00	2.00
South Coast	CZ06	50	33	25	1	1.36	1.9	0.50	1.00	2.00
South Coast	CZ07	50	33	25	1	1.36	1.9	0.50	1.00	2.00
South Coast	CZ08	50	33	25	1	1.36	1.9	0.50	1.00	2.00
South Inland	CZ09	50	33	25	1	1.36	1.9	0.50	1.00	2.00
South Inland	CZ10	50	33	25	1	1.36	1.9	0.50	1.00	2.00
Central Valley	CZ11	50	33	25	1	1.36	1.9	0.50	1.00	2.00
Central Valley	CZ12	50	33	25	1	1.36	1.9	0.50	1.00	2.00
Central Valley	CZ13	50	33	25	1	1.36	1.9	0.50	1.00	2.00
Desert	CZ14	50	33	25	1	1.36	1.9	0.50	1.00	2.00
Desert	CZ15	50	33	25	1	1.36	1.9	0.50	1.00	2.00
Mountain	CZ16	50	33	25	1	1.36	1.9	0.50	1.00	2.00
	Min:	CNRNCC unavailable			CNRNCC, 10% percentile			estimate		
Sources:	Median:	therefore, estimate only			CNRNCC, 50% percentile			T24 ACM		
	Max:	T24 ACM			CNRNCC, 90% percentile			estimate		

* Title24 requirement: 1.4W/sf

Conventional School Classroom Model Input Values by Climate Zone (page 3 of 4)

		School Characteristics (Conventional Classrooms)								
Climate	Wth	Glass U-Value			Glass SHGC			Ovhg Depth (ft)		
Region	File	Min	Median	Max	Min	Median	Max	Min	Median	Max
North Coast	CZ01	1.23	0.49	0.49	0.43	0.49	0.49	0	1.5	4
North Coast	CZ02	1.23	0.49	0.49	0.36	0.47	0.47	0	1.5	4
North Coast	CZ03	1.23	0.81	0.49	0.41	0.61	0.61	0	1.5	4
North Coast	CZ04	1.23	0.81	0.49	0.41	0.61	0.61	0	1.5	4
North Coast	CZ05	1.23	0.81	0.49	0.41	0.61	0.61	0	1.5	4
South Coast	CZ06	1.23	0.81	0.49	0.39	0.61	0.61	0	1.5	4
South Coast	CZ07	1.23	0.81	0.49	0.39	0.61	0.61	0	1.5	4
South Coast	CZ08	1.23	0.81	0.49	0.39	0.61	0.61	0	1.5	4
South Inland	CZ09	1.23	0.81	0.49	0.39	0.61	0.61	0	1.5	4
South Inland	CZ10	1.23	0.49	0.49	0.36	0.47	0.47	0	1.5	4
Central Valley	CZ11	1.23	0.49	0.49	0.36	0.47	0.47	0	1.5	4
Central Valley	CZ12	1.23	0.49	0.49	0.36	0.47	0.47	0	1.5	4
Central Valley	CZ13	1.23	0.49	0.49	0.36	0.47	0.47	0	1.5	4
Desert	CZ14	1.23	0.49	0.49	0.36	0.46	0.46	0	1.5	4
Desert	CZ15	1.23	0.49	0.49	0.36	0.46	0.46	0	1.5	4
Mountain	CZ16	1.23	0.49	0.49	0.43	0.49	0.49	0	1.5	4
	Min:	CNRNCC, 10% percentile			Only Non-North shown			CNRNCC, 10% percentile		
Sources:	Median:	T24 levels assumed, by CZ			assumes T24 values, based			CNRNCC, 50% percentile		
	Max:	CNRNCC, 90% percentile			WWR			CNRNCC, 90% percentile		

Climate	Wth	Economizer			External Static Pres (inWG)			Supply Ducts		
Region	File	Min	Median	Max*	Min	Median	Max	Leakage	R-Value	Transients
North Coast	CZ01	none	none	yes	0.25	0.50	0.85	2%	2.8	0
North Coast	CZ02	none	none	yes	0.25	0.50	0.85	2%	2.8	0
North Coast	CZ03	none	none	yes	0.25	0.50	0.85	2%	2.8	0
North Coast	CZ04	none	none	yes	0.25	0.50	0.85	2%	2.8	0
North Coast	CZ05	none	none	yes	0.25	0.50	0.85	2%	2.8	0
South Coast	CZ06	none	none	yes	0.25	0.50	0.85	2%	2.8	0
South Coast	CZ07	none	none	yes	0.25	0.50	0.85	2%	2.8	0
South Coast	CZ08	none	none	yes	0.25	0.50	0.85	2%	2.8	0
South Inland	CZ09	none	none	yes	0.25	0.50	0.85	2%	2.8	0
South Inland	CZ10	none	none	yes	0.25	0.50	0.85	2%	2.8	0
Central Valley	CZ11	none	none	yes	0.25	0.50	0.85	2%	2.8	0
Central Valley	CZ12	none	none	yes	0.25	0.50	0.85	2%	2.8	0
Central Valley	CZ13	none	none	yes	0.25	0.50	0.85	2%	2.8	0
Desert	CZ14	none	none	yes	0.25	0.50	0.85	2%	2.8	0
Desert	CZ15	none	none	yes	0.25	0.50	0.85	2%	2.8	0
Mountain	CZ16	none	none	yes	0.25	0.50	0.85	2%	2.8	0
	Min:	CNRNCC, 10% percentile			Split sys can't support full rng			Leak: Class C duct, 0.5"wg		
Sources:	Median:	CNRNCC, 50% percentile			of ext statics of packaged sys			R-Value: T24 requirement		
	Max:	CNRNCC, 90% percentile			~ 410,510,600 W/1000cfm			Trans: assumes cont fan ops		

* 28% of CA SEER-rated package units have economizers

Conventional School Classroom Model Input Values by Climate Zone (page 4 of 4)

		School Characteristics (Conventional Classrooms)								
Climate	Wth	Whole Bldg WWR*			WWR (North, South)*			WWR (East, West)*		
Region	File	Min	Median	Max	Min	Median	Max	Min	Median	Max
North Coast	CZ01	4%	10%	25%	0%	10%	25%	0%	10%	25%
North Coast	CZ02	4%	10%	25%	0%	10%	25%	0%	10%	25%
North Coast	CZ03	4%	10%	25%	0%	10%	25%	0%	10%	25%
North Coast	CZ04	4%	10%	25%	0%	10%	25%	0%	10%	25%
North Coast	CZ05	4%	10%	25%	0%	10%	25%	0%	10%	25%
South Coast	CZ06	4%	10%	25%	0%	10%	25%	0%	10%	25%
South Coast	CZ07	4%	10%	25%	0%	10%	25%	0%	10%	25%
South Coast	CZ08	4%	10%	25%	0%	10%	25%	0%	10%	25%
South Inland	CZ09	4%	10%	25%	0%	10%	25%	0%	10%	25%
South Inland	CZ10	4%	10%	25%	0%	10%	25%	0%	10%	25%
Central Valley	CZ11	4%	10%	25%	0%	10%	25%	0%	10%	25%
Central Valley	CZ12	4%	10%	25%	0%	10%	25%	0%	10%	25%
Central Valley	CZ13	4%	10%	25%	0%	10%	25%	0%	10%	25%
Desert	CZ14	4%	10%	25%	0%	10%	25%	0%	10%	25%
Desert	CZ15	4%	10%	25%	0%	10%	25%	0%	10%	25%
Mountain	CZ16	4%	10%	25%	0%	10%	25%	0%	10%	25%
	Min:	CNRNCC, 10% percentile			CNRNCC, 10% percentile			CNRNCC, 10% percentile		
Sources:	Median:	CNRNCC, average by CZ			CNRNCC, 50% percentile			CNRNCC, 50% percentile		
	Max:	CNRNCC, 90% percentile			CNRNCC, 90% percentile			CNRNCC, 90% percentile		
		*not based on classrooms only			*not based on classrooms only			*not based on classrooms only		

Climate	Wth	Cooling Thermostat SP		
Region	File	Min	Median	Max
North Coast	CZ01	72	73	78
North Coast	CZ02	72	73	78
North Coast	CZ03	72	73	78
North Coast	CZ04	72	73	78
North Coast	CZ05	72	73	78
South Coast	CZ06	72	73	78
South Coast	CZ07	72	73	78
South Coast	CZ08	72	73	78
South Inland	CZ09	72	73	78
South Inland	CZ10	72	73	78
Central Valley	CZ11	72	73	78
Central Valley	CZ12	72	73	78
Central Valley	CZ13	72	73	78
Desert	CZ14	72	73	78
Desert	CZ15	72	73	78
Mountain	CZ16	72	73	78
	Min:	CNRNCC, 10% percentile		
Sources:	Median:	CNRNCC, 50% percentile		
	Max:	CNRNCC, 90% percentile		

F7. Portable Classroom Model Input Values by Climate Zone (page 1 of 3)

		Portable Classrooms School Characteristics								
Climate	Wth	Total Floor Area*			Aspect Ratio			% Perim Zone		
Region	File	Min	Median	Max	Min	Median	Max	Min	Median	Max
North Coast	CZ01	638	851	1277	0.50	0.62	1.00	n/a	n/a	n/a
North Coast	CZ02	638	851	1277	0.50	0.62	1.00	n/a	n/a	n/a
North Coast	CZ03	638	851	1277	0.50	0.62	1.00	n/a	n/a	n/a
North Coast	CZ04	638	851	1277	0.50	0.62	1.00	n/a	n/a	n/a
North Coast	CZ05	638	851	1277	0.50	0.62	1.00	n/a	n/a	n/a
South Coast	CZ06	638	851	1277	0.50	0.62	1.00	n/a	n/a	n/a
South Coast	CZ07	638	851	1277	0.50	0.62	1.00	n/a	n/a	n/a
South Coast	CZ08	638	851	1277	0.50	0.62	1.00	n/a	n/a	n/a
South Inland	CZ09	638	851	1277	0.50	0.62	1.00	n/a	n/a	n/a
South Inland	CZ10	638	851	1277	0.50	0.62	1.00	n/a	n/a	n/a
Central Valley	CZ11	638	851	1277	0.50	0.62	1.00	n/a	n/a	n/a
Central Valley	CZ12	638	851	1277	0.50	0.62	1.00	n/a	n/a	n/a
Central Valley	CZ13	638	851	1277	0.50	0.62	1.00	n/a	n/a	n/a
Desert	CZ14	638	851	1277	0.50	0.62	1.00	n/a	n/a	n/a
Desert	CZ15	638	851	1277	0.50	0.62	1.00	n/a	n/a	n/a
Mountain	CZ16	638	851	1277	0.50	0.62	1.00	n/a	n/a	n/a
	Min:									
Sources:	Median:	"median" based on a 23' x 37'								
	Max:									

Climate	Wth	Int. Shade (Probability of Use)			Hrs per day operating			Months per Year Operating		
Region	File	Min	Median	Max	Min	Median	Max	Min	Median	Max
North Coast	CZ01	0%	50%	75%	7	10	10	9	9	12
North Coast	CZ02	0%	50%	75%	7	10	10	9	9	12
North Coast	CZ03	0%	50%	75%	7	10	10	9	9	12
North Coast	CZ04	0%	50%	75%	7	10	10	9	9	12
North Coast	CZ05	0%	50%	75%	7	10	10	9	9	12
South Coast	CZ06	0%	50%	75%	7	10	10	9	9	12
South Coast	CZ07	0%	50%	75%	7	10	10	9	9	12
South Coast	CZ08	0%	50%	75%	7	10	10	9	9	12
South Inland	CZ09	0%	50%	75%	7	10	10	9	9	12
South Inland	CZ10	0%	50%	75%	7	10	10	9	9	12
Central Valley	CZ11	0%	50%	75%	7	10	10	9	9	12
Central Valley	CZ12	0%	50%	75%	7	10	10	9	9	12
Central Valley	CZ13	0%	50%	75%	7	10	10	9	9	12
Desert	CZ14	0%	50%	75%	7	10	10	9	9	12
Desert	CZ15	0%	50%	75%	7	10	10	9	9	12
Mountain	CZ16	0%	50%	75%	7	10	10	9	9	12
	Min:	CNRNCC very limited			basic schedule = 8a - 3p			inc. standard holidays		
Sources:	Median:	therefore, estimate only			basic schedule = 7a - 5 p			inc. standard holidays		
	Max:				basic schedule = 7a - 5 p			Year-round, inc. std holidays		

Portable Classroom Model Input Values by Climate Zone (page 2 of 3)

		Portable Classrooms School Characteristics								
Climate	Wth	Roof Insulation			Exterior Wall Insulation			Wall Cons Type		
Region	File	Min	Median	Max	Min	Median	Max	Min	Median	Max
North Coast	CZ01	13	19	30	3	13	19	Wd-Frm	Wd-Frm	Stl-Frm
North Coast	CZ02	13	19	30	3	13	19	Wd-Frm	Wd-Frm	Stl-Frm
North Coast	CZ03	13	19	30	3	11	19	Wd-Frm	Wd-Frm	Stl-Frm
North Coast	CZ04	13	19	30	3	11	19	Wd-Frm	Wd-Frm	Stl-Frm
North Coast	CZ05	13	19	30	3	11	19	Wd-Frm	Wd-Frm	Stl-Frm
South Coast	CZ06	7	11	19	3	11	19	Wd-Frm	Wd-Frm	Stl-Frm
South Coast	CZ07	7	11	19	3	11	19	Wd-Frm	Wd-Frm	Stl-Frm
South Coast	CZ08	7	11	19	3	11	19	Wd-Frm	Wd-Frm	Stl-Frm
South Inland	CZ09	7	11	19	3	11	19	Wd-Frm	Wd-Frm	Stl-Frm
South Inland	CZ10	13	19	30	3	13	19	Wd-Frm	Wd-Frm	Stl-Frm
Central Valley	CZ11	13	19	30	3	13	19	Wd-Frm	Wd-Frm	Stl-Frm
Central Valley	CZ12	13	19	30	3	13	19	Wd-Frm	Wd-Frm	Stl-Frm
Central Valley	CZ13	13	19	30	3	13	19	Wd-Frm	Wd-Frm	Stl-Frm
Desert	CZ14	13	19	30	3	13	19	Wd-Frm	Wd-Frm	Stl-Frm
Desert	CZ15	13	19	30	3	13	19	Wd-Frm	Wd-Frm	Stl-Frm
Mountain	CZ16	13	19	30	3	13	19	Wd-Frm	Wd-Frm	Stl-Frm
	Min:	CNRNCC, 20% percentile			CNRNCC, 10% percentile					
Sources:	Median:	T24 levels assumed, by CZ			T24 levels assumed, by CZ					
	Max:	CNRNCC, 90% percentile			CNRNCC, 90% percentile					

Climate	Wth	Occupancy (Sqft/occ)			Lighting Power Density (W/sf)			Equip Power Density (W/sf)		
Region	File	Min	Median	Max	Min	Median*	Max	Min	Median	Max
North Coast	CZ01	50	33	25	1	1.36	1.9	0.50	1.00	2.00
North Coast	CZ02	50	33	25	1	1.36	1.9	0.50	1.00	2.00
North Coast	CZ03	50	33	25	1	1.36	1.9	0.50	1.00	2.00
North Coast	CZ04	50	33	25	1	1.36	1.9	0.50	1.00	2.00
North Coast	CZ05	50	33	25	1	1.36	1.9	0.50	1.00	2.00
South Coast	CZ06	50	33	25	1	1.36	1.9	0.50	1.00	2.00
South Coast	CZ07	50	33	25	1	1.36	1.9	0.50	1.00	2.00
South Coast	CZ08	50	33	25	1	1.36	1.9	0.50	1.00	2.00
South Inland	CZ09	50	33	25	1	1.36	1.9	0.50	1.00	2.00
South Inland	CZ10	50	33	25	1	1.36	1.9	0.50	1.00	2.00
Central Valley	CZ11	50	33	25	1	1.36	1.9	0.50	1.00	2.00
Central Valley	CZ12	50	33	25	1	1.36	1.9	0.50	1.00	2.00
Central Valley	CZ13	50	33	25	1	1.36	1.9	0.50	1.00	2.00
Desert	CZ14	50	33	25	1	1.36	1.9	0.50	1.00	2.00
Desert	CZ15	50	33	25	1	1.36	1.9	0.50	1.00	2.00
Mountain	CZ16	50	33	25	1	1.36	1.9	0.50	1.00	2.00
	Min:	CNRNCC unavailable			CNRNCC, 10% percentile			estimate		
Sources:	Median:	therefore, estimate only			CNRNCC, 50% percentile			T24 ACM		
	Max:	T24 ACM			CNRNCC, 90% percentile			estimate		

* Title24 requirement: 1.4W/sf

Portable Classroom Model Input Values by Climate Zone (page 3 of 3)

		Portable Classrooms School Characteristics								
Climate	Wth	Glass U-Value			Glass SHGC			Ovhg Depth (ft)		
Region	File	Min	Median	Max	Min	Median	Max	Min	Median	Max
North Coast	CZ01	1.23	0.49	0.49	0.43	0.43	0.43	0	3.5	5.5
North Coast	CZ02	1.23	0.49	0.49	0.31	0.31	0.31	0	3.5	5.5
North Coast	CZ03	1.23	0.81	0.49	0.41	0.41	0.41	0	3.5	5.5
North Coast	CZ04	1.23	0.81	0.49	0.41	0.41	0.41	0	3.5	5.5
North Coast	CZ05	1.23	0.81	0.49	0.41	0.41	0.41	0	3.5	5.5
South Coast	CZ06	1.23	0.81	0.49	0.34	0.34	0.34	0	3.5	5.5
South Coast	CZ07	1.23	0.81	0.49	0.34	0.34	0.34	0	3.5	5.5
South Coast	CZ08	1.23	0.81	0.49	0.34	0.34	0.34	0	3.5	5.5
South Inland	CZ09	1.23	0.81	0.49	0.34	0.34	0.34	0	3.5	5.5
South Inland	CZ10	1.23	0.49	0.49	0.31	0.31	0.31	0	3.5	5.5
Central Valley	CZ11	1.23	0.49	0.49	0.31	0.31	0.31	0	3.5	5.5
Central Valley	CZ12	1.23	0.49	0.49	0.31	0.31	0.31	0	3.5	5.5
Central Valley	CZ13	1.23	0.49	0.49	0.31	0.31	0.31	0	3.5	5.5
Desert	CZ14	1.23	0.49	0.49	0.31	0.31	0.31	0	3.5	5.5
Desert	CZ15	1.23	0.49	0.49	0.31	0.31	0.31	0	3.5	5.5
Mountain	CZ16	1.23	0.49	0.49	0.43	0.43	0.43	0	3.5	5.5
	Min:	CNRNCC, 10% percentile			Only Non-North shown					
Sources:	Median:	T24 levels assumed, by CZ			assumes T24 values, based					
	Max:	CNRNCC, 90% percentile			WWR					

		Portable Classrooms School Characteristics					
Climate	Wth	Window Area			Cooling Thermostat SP		
Region	File	Min	Median	Max	Min	Median	Max
North Coast	CZ01	36	64	100	72	73	78
North Coast	CZ02	36	64	100	72	73	78
North Coast	CZ03	36	64	100	72	73	78
North Coast	CZ04	36	64	100	72	73	78
North Coast	CZ05	36	64	100	72	73	78
South Coast	CZ06	36	64	100	72	73	78
South Coast	CZ07	36	64	100	72	73	78
South Coast	CZ08	36	64	100	72	73	78
South Inland	CZ09	36	64	100	72	73	78
South Inland	CZ10	36	64	100	72	73	78
Central Valley	CZ11	36	64	100	72	73	78
Central Valley	CZ12	36	64	100	72	73	78
Central Valley	CZ13	36	64	100	72	73	78
Desert	CZ14	36	64	100	72	73	78
Desert	CZ15	36	64	100	72	73	78
Mountain	CZ16	36	64	100	72	73	78
	Min:	one 3 x 6' window front/back			CNRNCC, 10% percentile		
Sources:	Median:	one 4 x 8' window front/back			CNRNCC, 50% percentile		
	Max:	one 5 x 10' window front/back			CNRNCC, 90% percentile		