EER & SEER AS PREDICTORS OF COMMERCIAL SEASONAL COOLING PERFORMANCE

UPDATED REPORT OF COMMERCIAL RESEARCH

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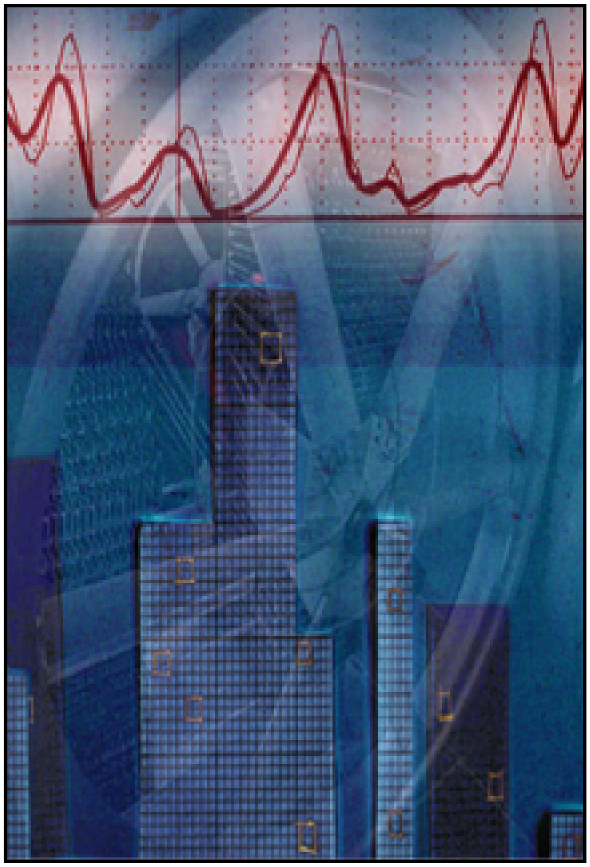

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This study was prepared by James J. Hirsch & Associates under contract to Southern California Edison Company as a portion of a project to investigate value of SEER and EER as seasonal energy performance indicators, as described herein. The work was conducted under the direction of Carlos Haiad of 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 a SEER energy efficiency rating. 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 in non-residential applications. Specific questions include:

- 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 13 represents a 23% reduction in annual cooling energy use (1-[10/13]). Will a 23% 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 set point 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 application and climate zone, will a SEER 13 system reliably use less annual cooling energy than a SEER 10 system? Alternatively, will upgrading from a SEER 10 system to SEER 13 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 set point 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 previous assumptions imply linearity of cooling energy use in outdoor temperature. This is valid only when the indoor fan cycles with the compressor. This is not the case for non-residential applications where ventilation requirements mandate continuous indoor fan operation.

This analysis examines the validity of these assumptions for typical California 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 statewide efficiency programs.

This study uses the DOE-2 energy analysis program to better understand the factors that affect SEER. 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 small office, small retail, and school 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 *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 examines a representative range of nominal SEER-10, 12, and 13 cooling systems that varied by SEER level, application (i.e., heat pump or air conditioner), and performance characteristics (e.g., sensitivity to outdoor operating temperatures and cycling effects). Forty-seven representative units were selected from a database of 240 SEER-rated packaged units.

The database includes systems from six major manufacturers: Carrier, Goodman, Lennox, Nordyne, Trane, and York.

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. Performance curves used in DOE-2 were based on manufactures extended ratings data for each system.

Findings

This work attempted to address the four questions listed above pertaining to the efficacy of SEER as a predictor of cooling energy use, cooling energy savings, ranking of units, and a predictor of cooling demand. Results from this effort produced the following findings:

Rated SEER as a predictor of expected cooling energy use

SEER rating is a poor predictor of expected cooling energy use, and thus cooling utility costs in commercial applications.

> **DOE-2 simulations produced seasonal energy efficiency as low as 20% that of rated SEER (calculated SEER of 2 compared to rated SEER of 10). Issues in commercial applications that preclude the use of SEER as a predictor of seasonal energy use include continuous indoor fan operation, scheduled cooling loads that are not dependent on outdoor conditions, and the introduction of ventilation air to the cooling coil.**

Continuous indoor fan operation (required to meet ventilation requirements) is a particular problem in that fan energy used to provide space cooling is expended even when the compressor is not running (fan runs continuously while compressor cycles). It also introduces a continuous cooling load to the space because of fan heat and ventilation air. Building features, such as operating schedules and differing internal loads, can produce situations where indoor fan energy exceeds that of the rest of the cooling system.

Even when indoor fan energy is excluded from consideration, variation in internal loads and the introduction of ventilation air produce seasonal cooling efficiencies that vary from cooling system to cooling system with the same SEER rating. Internal loads in commercial applications, such as heat released by lights, equipment, and personnel, produce cooling loads that are much less dependent on outdoor conditions. These loads are dependent on operating schedules and are frequently not active during cooler periods of the day (late night and early morning). Both accentuate the lack of one-to-one correspondence between cooling load and outdoor temperature assumed in the SEER ratings process.

> **Even when indoor fan energy is excluded, one should expect variation in the condensing unit seasonal energy efficiency of +11% to –10% for small office applications after results are adjusted for average climate variations. Results for small retail applications are +12% to -17% and +9% to –11% for classrooms.**

Commercial applications require the introduction of ventilation air whenever the cooling system is scheduled for operation (whether or not the compressor is operating). This affects seasonal energy efficiency is a couple of ways. First, cooling coil-entering conditions are much less likely to match those assumed in the SEER ratings process (80ºF dry bulb and 67ºF wet-bulb). Since units differ in their sensitivity to these conditions, there is an increase in the variation in seasonal cooling efficiency from unit-to-unit. Second, when the unit is providing cooling, ventilation air affects unit energy use because of its impact on unit sensible cooling capacity (affecting unit runtime) and on overall condensing unit efficiency (energy consumed over a given runtime). This differs from unit-to-unit, resulting in increased variation in seasonal performance among the various units. Neither of these issues are addressed explicitly in the SEER ratings process.

Rated SEER as a predictor of energy savings

Median values of energy savings associated with upgrading from a lower to a higher SEER cooling system are provided in Table ES.1.

> **<u>On average</u>, the energy benefits associated with a SEER upgrade is commensurate with the change in SEER level. For example, the expected energy savings of upgrading from a SEER-10 to a SEER-13 unit is 23%. Average savings obtained from DOE-2 simulations for all building types and most climate zones is near this value. Climate zone 15 is the exception where average energy savings can be as much as 58% less than that expected. Thus, from a regulatory standpoint, DOE-2 simulations in this effort suggest that SEER upgrades may provide expected energy savings.**

The problem with this finding is that the variation in seasonal performance among like-SEER units is typically equal to or greater than the expected savings from the 23% associated with an upgrade from a SEER-10 to a SEER 13 unit.

> **Differences in seasonal cooling energy efficiency among like SEER units can vary from 15% to 37% for small office applications, 18% to 69% in retail applications, and 16% to 75% in classroom applications. These differences are climate zone and SEER level dependent. SEER-12 units exhibit the least variation, SEER-13 units the most. There is less variation among like-SEER units in cooler climates and more in hotter climates.**

The variation in seasonal cooling efficiency affects upgrade savings in two ways. First, there is a good deal of uncertainty in average upgrade benefits. The average benefit calculated in this effort assumes that all 47 units examined in this effort are equally likely to be installed. This may not be the case.

Second, from a consumer's perspective, the variation in seasonal energy efficiency among like-SEER units means that one could not be assured of the expected energy benefit from a SEER upgrade, even when upgrading 3 SEER levels (from SEER 10 to SEER 13). The possibility exists that one could upgrade from one of the better performing units with a lower SEER rating to a poorly performing unit with a higher SEER rating. Conversely, an upgrade could provide significantly greater energy savings than expected. One way to help reduce uncertainty in energy savings from a SEER upgrade is to make sure that the indoor fan power of the higher

SEER unit is less than that of the lower SEER unit by the same margin as the SEER upgrade. That is, if one is upgrading from a SEER-10 to a SEER-13 unit, the fan power in Watts/cfm of the SEER-13 unit should be at least 23% less than that of the SEER 10 unit.

Table ES.1
Median Energy Benefits of Moving to a Higher SEER System
Median Building Features, All Systems, All Applications

		Percentage Decrease in Seasonal Cooling Energy				
	SEER Change	Expected	Small Office	Small Retail	Classroom Part-Year	Classroom Year-Round
CZ01	*SEER 10 to 13*	23%	23%	26%	15%	15%
	SEER 10 to 12	17%	14%	13%	8%	9%
	SEER 12 to 13	8%	10%	15%	7%	6%
CZ02	*SEER 10 to 13*	23%	22%	24%	20%	20%
	SEER 10 to 12	17%	13%	13%	10%	11%
	SEER 12 to 13	8%	11%	13%	10%	10%
CZ03	*SEER 10 to 13*	23%	22%	25%	18%	19%
	SEER 10 to 12	17%	13%	13%	11%	12%
	SEER 12 to 13	8%	11%	13%	7%	8%
CZ04	*SEER 10 to 13*	23%	22%	23%	19%	20%
	SEER 10 to 12	17%	13%	13%	12%	13%
	SEER 12 to 13	8%	11%	11%	8%	8%
CZ05	*SEER 10 to 13*	23%	23%	25%	20%	21%
	SEER 10 to 12	17%	14%	14%	13%	13%
	SEER 12 to 13	8%	11%	14%	9%	9%
CZ06	*SEER 10 to 13*	23%	23%	24%	21%	22%
	SEER 10 to 12	17%	13%	14%	14%	14%
	SEER 12 to 13	8%	11%	12%	9%	9%
CZ07	*SEER 10 to 13*	23%	23%	24%	21%	21%
	SEER 10 to 12	17%	14%	13%	14%	14%
	SEER 12 to 13	8%	11%	12%	8%	9%
CZ08	*SEER 10 to 13*	23%	23%	23%	21%	21%
	SEER 10 to 12	17%	14%	13%	12%	13%
	SEER 12 to 13	8%	11%	12%	9%	9%
CZ09	*SEER 10 to 13*	23%	22%	24%	4%	21%
	SEER 10 to 12	17%	13%	13%	-5%	12%
	SEER 12 to 13	8%	10%	13%	-8%	11%
CZ10	*SEER 10 to 13*	23%	22%	23%	21%	20%
	SEER 10 to 12	17%	13%	13%	11%	12%
	SEER 12 to 13	8%	10%	12%	11%	9%
CZ11	*SEER 10 to 13*	23%	21%	19%	20%	17%
	SEER 10 to 12	17%	13%	13%	12%	10%
	SEER 12 to 13	8%	10%	7%	9%	8%

Table ES.1 (Continued)

Percentage Decrease in Seasonal Cooling Energy

	SEER Change	Expected	Small Office	Small Retail	Classroom Part-Year	Classroom Year-Round
CZ12	*SEER 10 to 13*	23%	21%	19%	17%	19%
	SEER 10 to 12	17%	12%	11%	11%	11%
	SEER 12 to 13	8%	10%	9%	8%	9%
CZ13	*SEER 10 to 13*	23%	21%	19%	19%	19%
	SEER 10 to 12	17%	13%	12%	11%	12%
	SEER 12 to 13	8%	9%	7%	9%	8%
CZ14	*SEER 10 to 13*	23%	21%	18%	18%	19%
	SEER 10 to 12	17%	13%	15%	11%	11%
	SEER 12 to 13	8%	10%	3%	8%	9%
CZ15	*SEER 10 to 13*	23%	19%	18%	19%	19%
	SEER 10 to 12	17%	12%	11%	11%	12%
	SEER 12 to 13	8%	8%	8%	8%	8%
CZ16	*SEER 10 to 13*	23%	23%	28%	18%	19%
	SEER 10 to 12	17%	13%	14%	10%	11%
	SEER 12 to 13	8%	11%	16%	9%	9%

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

Given the 15% to 75% variation in seasonal cooling efficiency among like-SEER units observed in this study, can a builder at least use SEER to reliably select the more efficient system when applied to a specific building type in a specific climate zone? As an example, although, like the EPA gas mileage label, "your mileage may vary", for a specific application, will a SEER 13 system reliably use less annual cooling energy than a SEER 10 system?

> **SEER does rank the energy performance of packaged cooling systems on a class basis. That is, on average, SEER 13-units performed better than SEER-12 units, which perform better than SEER-10 units.**

However, simulations also showed a great deal of performance variation among like-SEER units. This variation was typically equal to or greater than the expected SEER-to-SEER difference. Thus, on an individual unit basis, SEER is not particularly effective in ranking units. The best SEER-10 unit was found to outperform over half of the SEER-12 units. This was also the case when comparing SEER-12 to SEER-13 units. There were building arrangements and climate conditions where the best SEER-10 unit outperformed at least one SEER 13 unit.

> **Thus the contention that "lower SEER units are always more efficient than higher SEER units" is not true for the packaged units in the non-residential applications examined in this effort.**

A seasonal energy efficiency metric (fan SEER, or SEER_f) was developed in this effort that includes the impact of continuous fan operation on cooling system efficiency. The new metric treats the energy consumption of the indoor fan and condensing unit separately. $SEER_f$ does not provide significantly improved estimates of cooling system seasonal efficiency. The range of building operating and design parameters examined generated too great a variation in condensing unit seasonal efficiency and condensing unit operation relative to that of the indoor fan. However, it did provide a better means of ranking cooling systems by their seasonal cooling efficiency. Selecting units based on $SEER_f$ reduces the variation in seasonal energy efficiency of like-SEER units by at least half by eliminating the worse performing units from consideration. Under some situations, it correctly suggested the selection of lower SEER units over their higher SEER counterparts.

Section 4 of this effort provides multipliers that adjust condensing unit seasonal cooling efficiency for climate effects and provide estimates of the relative energy use of the indoor fan to that of the condensing unit. $SEER_f$ is calculated from manufacturers' data and these multipliers.

Rated SEER as a predictor of peak demand and demand savings

SEER is a predictor of expected peak cooling demand only in that higher SEER systems tend to have higher values of EER. It is EER that provides the better predictor of peak cooling demand. Operational cooling system EER (peak cooling system capacity divided by simulated cooling system peak electric demand) was capture from DOE-2 simulations.

> **Once results were adjusted for system over sizing and climate affects, rated EER predicted values from simulation to within +12% to –17% for small office applications, +17% to –22% for retail applications, and ±12% for school classroom applications.**

The variation in demand among like-EER units appears to be caused by both the outdoor air temperature and coil entering air conditions at times of peak cooling energy use. Ventilation requirements affect cooling coil-entering conditions as outdoor air is introduced into the return air stream prior to entering the cooling coil. Since cooling systems differ in their sensitivity to both sets of conditions (outdoor air and cooling coil-entering), variation in peak demand from unit-to-unit is to be expected.

For the non-residential applications examined here, unit rated EER should be multiplied by the values in Table ES-2 when estimating demand impacts of packaged cooling systems. Caution should be used when doing this as this analysis indicates that cooling system peak electric demand is highly variable from unit-to-unit.

Table ES.2a

Operational EER Climate Zone Multipliers
Small Office Application, Median Building Parameters

	SEER-10	SEER-12	SEER-13		SEER-10	SEER-12	SEER-13
CZ01	1.18	1.21	1.24	CZ09	0.98	0.97	0.99
CZ02	0.98	0.98	1.00	CZ10	0.96	0.96	0.98
CZ03	1.05	1.06	1.09	CZ11	0.94	0.92	0.94
CZ04	1.03	1.03	1.06	CZ12	0.94	0.92	0.94
CZ05	1.03	1.04	1.05	CZ13	0.89	0.88	0.90
CZ06	1.04	1.06	1.08	CZ14	0.89	0.88	0.87
CZ07	1.07	1.09	1.10	CZ15	0.88	0.87	0.86
CZ08	0.96	0.96	0.98	CZ16	1.04	1.03	1.05

Table ES.2b

Operational EER Climate Zone Multipliers
Retail Application, Median Building Parameters

	SEER-10	SEER-12	SEER-13		SEER-10	SEER-12	SEER-13
CZ01	0.97	0.97	0.92	CZ09	0.88	0.86	0.86
CZ02	0.89	0.87	0.85	CZ10	0.94	0.91	0.90
CZ03	0.86	0.86	0.83	CZ11	0.88	0.85	0.84
CZ04	0.84	0.82	0.80	CZ12	0.90	0.89	0.90
CZ05	0.92	0.92	0.88	CZ13	0.82	0.80	0.80
CZ06	0.96	0.96	0.93	CZ14	0.81	0.80	0.77
CZ07	0.90	0.90	0.89	CZ15	0.83	0.79	0.79
CZ08	0.88	0.88	0.87	CZ16	0.84	0.83	0.81

Table ES.2c

Operational EER Climate Zone Multipliers
School Application, Partial Year Operation

	SEER-10	SEER-12	SEER-13		SEER-10	SEER-12	SEER-13
CZ01	1.14	1.14	1.15	CZ09	0.93	0.91	0.92
CZ02	0.92	0.90	0.92	CZ10	0.85	0.84	0.84
CZ03	1.09	1.10	1.13	CZ11	1.00	0.99	1.01
CZ04	0.89	0.89	0.90	CZ12	0.99	1.00	1.00
CZ05	0.89	0.90	0.90	CZ13	0.81	0.80	0.80
CZ06	0.92	0.91	0.93	CZ14	0.97	0.96	0.97
CZ07	0.98	0.98	0.98	CZ15	0.85	0.85	0.85
CZ08	0.84	0.84	0.84	CZ16	0.90	0.90	0.92

Table ES.2d
Operational EER Climate Zone Multipliers
School Application, Year-Round Operation

	SEER-10	SEER-12	SEER-13		SEER-10	SEER-12	SEER-13
CZ01	1.26	1.26	1.30	CZ09	0.89	0.89	0.89
CZ02	0.92	0.90	0.92	CZ10	0.89	0.88	0.89
CZ03	1.07	1.08	1.11	CZ11	0.94	0.91	0.93
CZ04	0.81	0.82	0.81	CZ12	0.93	0.94	0.95
CZ05	0.89	0.89	0.90	CZ13	0.84	0.83	0.84
CZ06	0.85	0.84	0.84	CZ14	0.88	0.86	0.86
CZ07	0.90	0.91	0.93	CZ15	0.87	0.84	0.83
CZ08	0.85	0.84	0.84	CZ16	0.92	0.91	0.92

Note: Multipliers do not include EER impacts caused by system over-sizing.

Findings Summary

- This study demonstrates that significant variation in annual cooling efficiency exists amongst equally rated cooling equipment (using only rated SEER as an indicator of cooling efficiency). Average savings associated with SEER upgrades found in this effort where close to that associated with changes in SEER levels. However, there is a great deal of uncertainty in these estimates because of the variability in cooling efficiency among the various units.
- Most of the basic assumptions implicit in the SEER rating process were found to be a poor match for non-residential applications. As a result, the variation in seasonal cooling energy efficiency among like-SEER units ranged from 15% to 37% for small office applications, 18% to 69% for retail applications, and 16% to 75% for classroom applications. The reasons for this include:
  - Fan cycling: Indoor fans must operate continuously to provide ventilation air in non-residential applications. The SEER ratings process assumes they cycle with the compressor. The additional energy use of the continuous fan operation along with differences in fan seasonal energy among the various cooling units precludes the use of rated SEER as an energy predictor and introduces a great deal of variation in seasonal cooling efficiency from unit-to-unit.
  - Building effects: Internal loads in non-residential applications have a greater impact on seasonal cooling requirements. The scheduling of these loads tends to match the scheduled operation of the cooling systems. As such, the assumed relationship between outdoor temperature and cooling load in the SEER ratings approach is less valid for non-residential applications.
  - Ventilation air: The SEER ratings process assumes fixed cooling coil entering conditions of 80ºF dry bulb and 67ºF wet-bulb. The introduction of ventilation air into the return air stream produces entering air conditions that not only do not match those assumed in the ratings process, but vary from application-to-application and among differing operating parameters within an application. Both cause a great deal of variation in cooling system seasonal efficiency from application-to-application and unit-to-unit within an application.
- Indoor fan efficiency is critical in determining seasonal cooling system efficiency in non-residential applications. Indoor fan energy can exceed that of the remainder of the cooling system in some climate zones and applications. <u>Standards on fan energy efficiency (Watts/cfm), along with SEER and EER ratings, should be established for SEER-rated units used non-residential applications.</u>

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 a SEER rating to be a reliable predictor of cooling system performance in California. While the research summarized here has done much to characterize the scope of the problem with SEER ratings and demonstrate effective climate based SEER corrections, much more needs be done. The items below are suggested as important follow-on research.

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

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:

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

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 is 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.

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

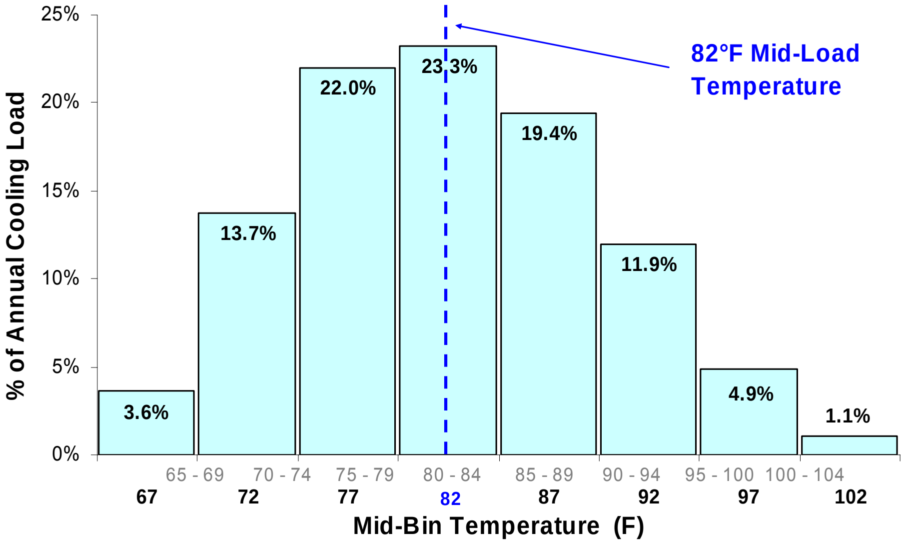
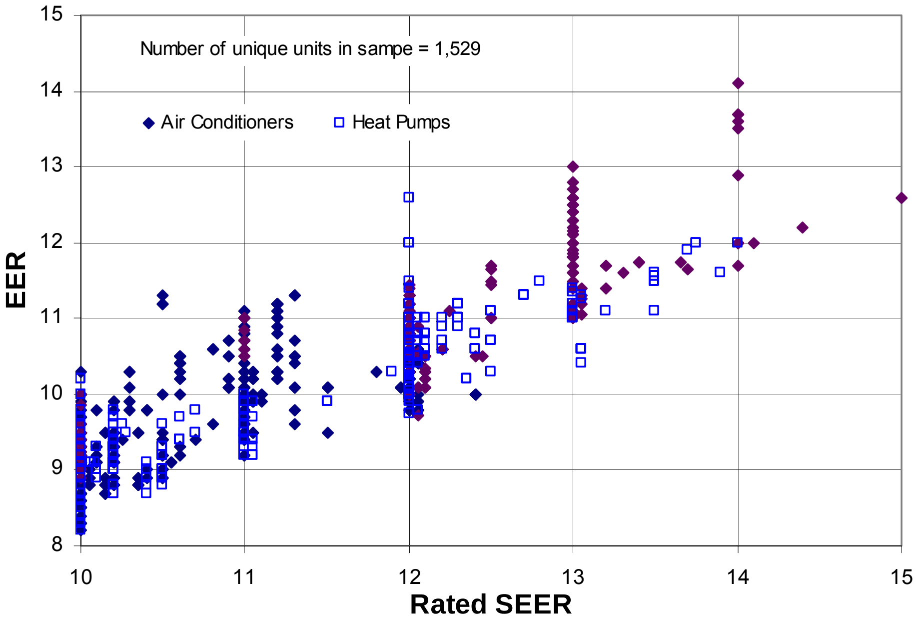


Figure 1.1.2 plots EER vs. SEER for approximately 2,200 unique, SEER-rated packaged cooling systems (< 65,000 Btu/hr) included in the CEC's listing of certified air conditioners. Note that for a given SEER level, there is a significant variation in EER (±15%), and for a given EER level, there is an even 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 Packaged 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 seasonal cooling system efficiency may vary due to various user effects such as thermostat set point. 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 application and climate zone, will a SEER 13 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 13 suggests a 23% improvement in seasonal efficiency (1-[10/13]). All other things being equal (i.e., controlling for climate and user differences), will a 23% savings in annual cooling energy be realized?
- 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, conduct DOE-2 energy simulations across a variety of building types and across five climate zones within the state. Simulation results are used to calculate SEER values from simulated cooling load and energy results. This portion of the research provides estimates of the magnitude of the potential energy impact due to improved consumer information on SEER and identifies 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 benefit, 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, rather than a single ratings point.

- 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 non-residential construction surveys. Prototype DOE-2 building models were created and parametric runs were conducted to determine typical expected performance of SEER-rated packaged cooling systems. Simulations also examined system 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. Performance maps are unique to each system examined in this study.

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 proper system charge and design airflows. While some system-level effects are included in simulations (air leakage in the duct system, and duct thermal losses), it is assumed that all cooling systems are 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 cannot 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 the seasonal cooling system energy efficiency 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 summarizes the findings provided in Sections 3 and 4.

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

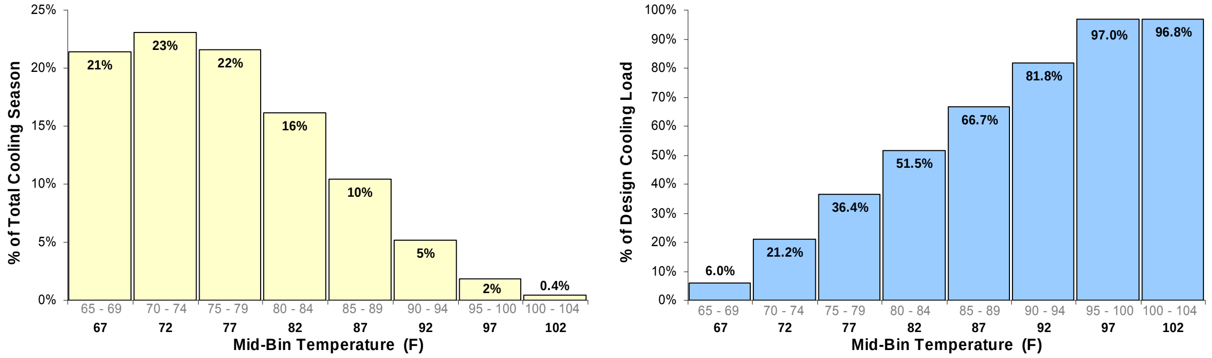
The principal challenge in developing the SEER rating is to provide a reliable estimate of season-long cooling efficiency using very limited steady-state laboratory testing that is both repeatable and affordable. Necessarily, several fundamental assumptions were made in the original development of the SEER rating. The most significant of which is an assumed seasonal cooling coil load profile representative of hotter areas with significant cooling loads. The 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 set point 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 single cooling season outdoor temperature profile, determined by weighting the penetration of residential cooling in selected cooling locations, is representative of cooling conditions for the U.S.. 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 approximately 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 cooling equipment 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 (see Figure 2.1.2). An important caveat for the previous assumption involves at least two assumptions regarding indoor (evaporator) and outdoor (condenser) fans:
    a) 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.
    b) 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 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


a: Percent of Cooling Season at Each Temperature Range

b: Percent of Design Cooling at Each Temperature Range

c: Percent of Annual Cooling Load by Temperature Range

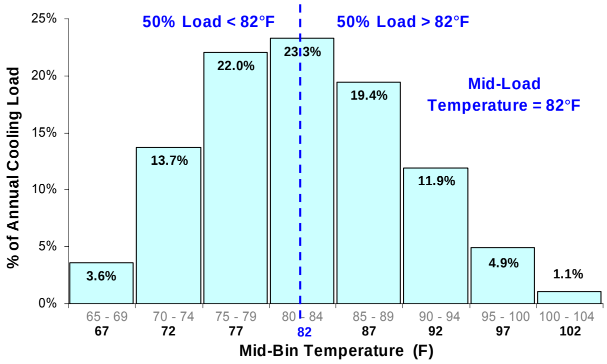
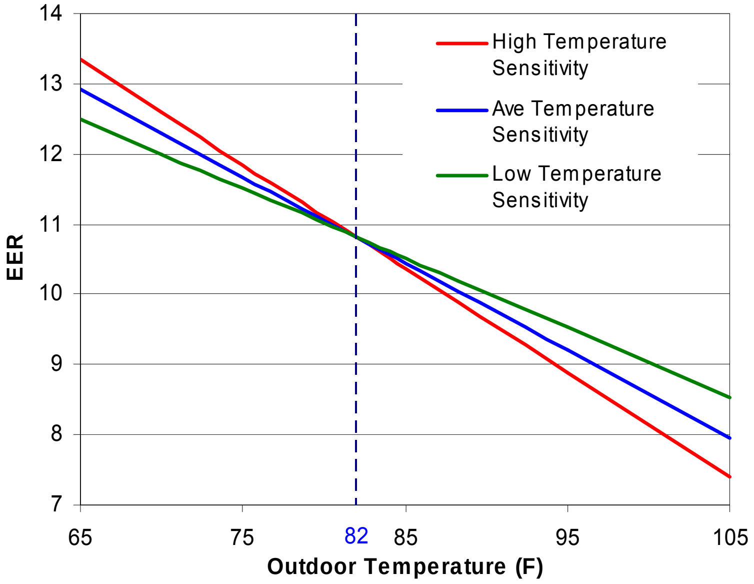


Figure 2.1.2

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, properly capturing 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, condensing 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 those commercial applications in which SEER-rated packaged equipment is most commonly found – small offices, small retail, and schools. 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.

2.3 COOLING EQUIPMENT SELECTION PROCEDURE

2.3.1 Equipment Databases

Figure 1.1.2 plots EER vs. SEER for approximately 2,200 unique SEER-rated packaged 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 1.1.2.

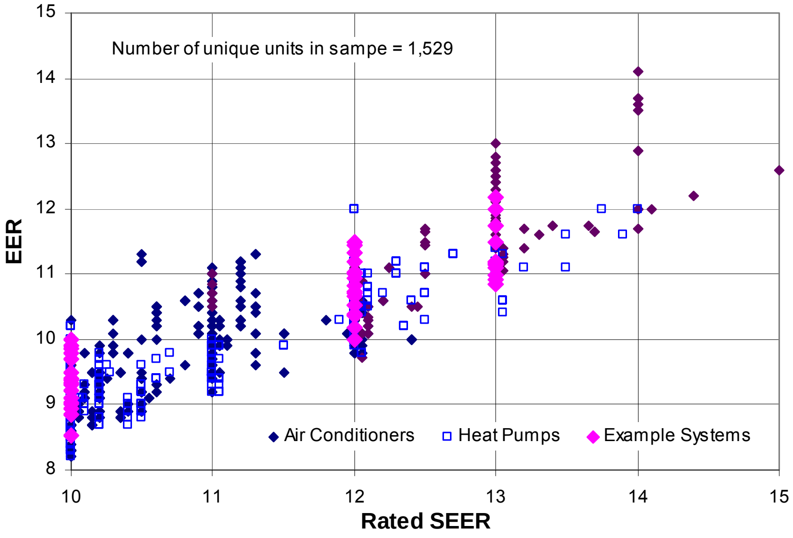
The selection mechanism began by developing an equipment database sorted equipment by type (air conditioner or heat pump) and SEER rating. Only air-cooled systems are included in this effort. The databases were expanded and sorted to identify systems by the following metrics:

- System type - heat pump and air conditioner
- SEER level – 10, 12, and 13, packaged single-speed (SEER level is ±0.3 ratings points from levels shown, e.g. SEER 13 systems can range from SEER 12.7 to 13.3. See note on the following page)
- Degradation Coefficient for single-speed equipment (C_D in Equation 1.1) as obtained from the CEC's list of rated systems or estimated from expanded ratings charts.
- 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 were included in the database. The availability of expanded ratings charts tended to be manufacturer specific. Manufacturers included in the database are Carrier, Goodman, Lennox, Nordyne, Trane, and York. 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, 11, and 13 packaged systems selected by this process. While the systems were not specifically selected by their EER, the selection process included systems that typically 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
Packaged Cooling Systems



** Systems include both air conditioners and heat pumps*

The SEER range of packaged systems is somewhat limited. While the market place is constantly changing, they are dominated by SEER 10 and SEER12 systems. SEER 13 units have become common because of residential minimal SEER requirements, but higher SEER single-speed units are limited, as are two-speed units. As of this writing, there is insufficient data on higher SEER and two-speed packaged units to allow the development of a usable equipment database. In addition, data was not found that would allow the development of detailed DOE-2 performance curves for two-speed units. Because of this, the cooling systems are limited to SEER 10, 12, and 13 heat pumps and air conditioners.

A specific system selected for simulation is identified by the four metrics listed above. A given packaged unit was chosen by its nominal SEER rating, heating source, EER temperature sensitivity, and degradation coefficient (see Appendix B for details). For example, a system simulated could be a SEER-12, packaged air conditioner, with a median EER temperature sensitivity and high degradation coefficient. In all, detailed performance maps were created for 47 packaged systems. The availability of manufacturers' expanded ratings charts (necessary to produce DOE-2 performance curves) and the lack of performance differentiation among the available units limited the number of units examined.

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 – condensing 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 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 condensing unit (EIR). Curve fit to manufacturers' data found in expanded ratings charts.
- Coil By-pass Factor_*f*(ODB,EWB) – a bi-quadratic equation that adjusts the design coil by-pass factor to account for differing outdoor air dry-bulb (ODB) and coil entering air wet-bulb

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[†] 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-13 database includes systems with SEER ratings between 12.7 and 13.3. 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.

(EWB) conditions. Curve fit to manufacturers' data found in expanded ratings charts.

- EIR_*f*(PLR) – a cubic curve fit that adjusts the condensing 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 condensing unit efficiency (EIR) to account for system cycling (PLR). Used when the system's fan cycles with the condensing 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 (condensing 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.

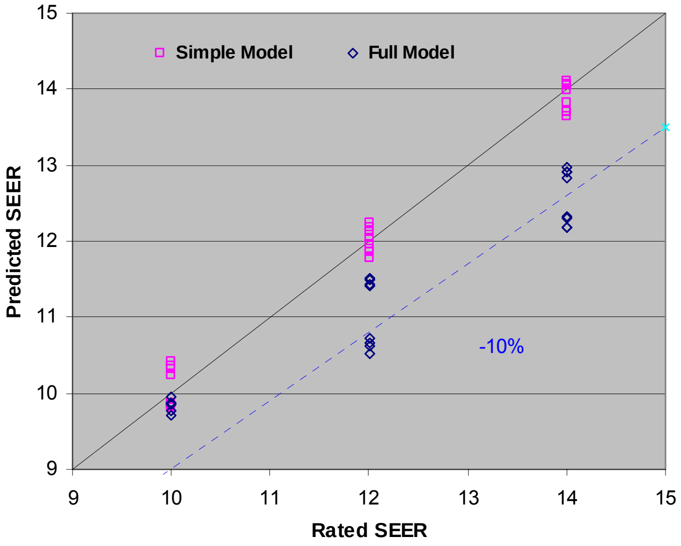
The question also arises as to whether or not the performance curves when used in the DOE-2 program will replicate SEER values. This is less straightforward as the SEER ratings process assumes a specific cooling load profile. The building loads simulation process would have to produce a load profile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

Other issues 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 cooling coil entering 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.

Figure 2.3.2 compares simulated and rated SEER using the altered performance maps and are shown as the "Simplified Model" point. The "Full Model" points in Figure 2.3.2 are based on unmodified equipment performance maps in DOE-2 simulations. These simulations do not include the simplifying changes to performance maps needed to match the SEER ratings process assumptions. While the information presented in Figure 2.3.2 are for split-system single and two-speed units, results for packaged systems are equivalent.

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 ±5% variation is caused by differences in cooling capacity with changing outdoor in indoor conditions, 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 differently in commercial applications than that assumed in the SEER ratings process. The SEER ratings process sizes systems to 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 (95ºF outdoor temperature). While this may be appropriate for residential applications, commercial systems are normally over-sized. For this analysis, cooling capacity was sized according to standard Title-24 sizing allowances.

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 131% 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.

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

The commercial analysis examines three building types in which SEER rated packaged equipment is likely to be found. These are small offices, retail, and conventional school classrooms. 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.

One of the assumptions in the SEER rating process is that the cooling coil load is a linear function of outdoor temperature. This assumption is much less likely to hold for commercial buildings than for residential buildings. In an office setting, a 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 include variable building design and operational characteristics expected to impact the building balance point and mid-load temperature. Each examined variable was characterized using 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.

2.4.1 Small Office

The small office building DOE-2 prototype is based on a perimeter/core zoning, as shown in Figure 2.4.1. 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 D. The building characteristics varied in this study are provided in Table 2.4.1. Minimum, maximum, and median values and details on how they were selected are provided in Appendix D.

Figure 2.4.1
Small Office Building Prototype

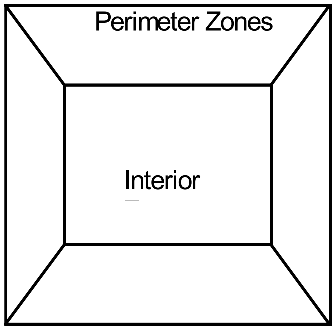


Table 2.4.1
Small Office Building Characteristics Allowed to Vary in DOE-2 Models

Component	Description
Floor Area	Total conditioned floor area
Internal Window Shading	User controlled, based on glare levels
Perimeter Depth	Perimeter office depth, affects ratio of core to perimeter zones
Occupancy Density	Total number of people in each zone
Operation Schedule	Building hours of operation (open/closed)
Roof Insulation	Built-up roof insulation level
Exterior Wall Insulation	Wall insulation level
Wall Construction Type	Heavy or light construction
Lighting Power Density	Total lighting Watts/ft^2 in each zone.
Plug Power Density	Total Plug/Equipment Watts/ft^2 in each zone.
Glass U-factor	Overall window heat-loss coefficient
Glass SHGC	Overall window solar heat gain coefficient
Window Overhang	Depth of window overhang
Economizer	Default is none
Glass Area (Fraction)	As a fraction of total exterior wall area
Thermostat set point	Cooling thermostat set point
Aspect Ratio	Ratio of front/back wall area to left/right wall area
Orientation	Direction that the front of the building faces

2.4.2 Retail

The retail DOE-2 prototype is based on a sales/storage zoning scheme, as shown in Figure 2.4.2. The entire building is rotated four times so that the front wall with the windows faces each of the 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 2.4.2. Minimum, maximum, and median values and details on how they were selected are provided in Appendix D.

Figure 2.4.2
Retail Building Prototype

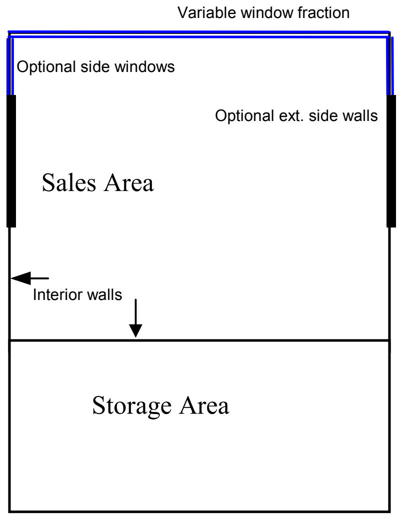


Table 2.4.2
Retail Building Characteristics Included in DOE-2 Models

Component	Description
Floor Area	Total conditioned floor area
Occupancy Density	Total number of people in each zone
Operation Schedule	Building hours of operation (open/closed)
Roof Insulation	Built-up roof insulation level
Exterior Wall Insulation	Wall insulation level
Wall Construction Type	Heavy or light construction
Lighting Power Density	Total lighting Watts/ft^2 in each zone.
Plug Power Density	Total Plug/Equipment Watts/ft^2 in each zone.
Glass U-factor	Overall window heat-loss coefficient
Glass SHGC	Overall window solar heat gain coefficient
Window Overhang	Depth of window overhang
Economizer	Default is none
Glass Area (Fraction)	As a fraction of front exterior wall area
Thermostat set point	cooling thermostat set point
Aspect Ratio	Ratio of front/back wall area to left/right wall area
Adiabatic Exterior Wall	Fraction of side walls that are connected to another building
Orientation	Direction that the front of the building faces

2.4.3 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 2.4.3. 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 2.4.3. Minimum, maximum, and median values and details on how they were selected are provided in Appendix D.

Figure 2.4.3
Conventional School Classrooms Prototype

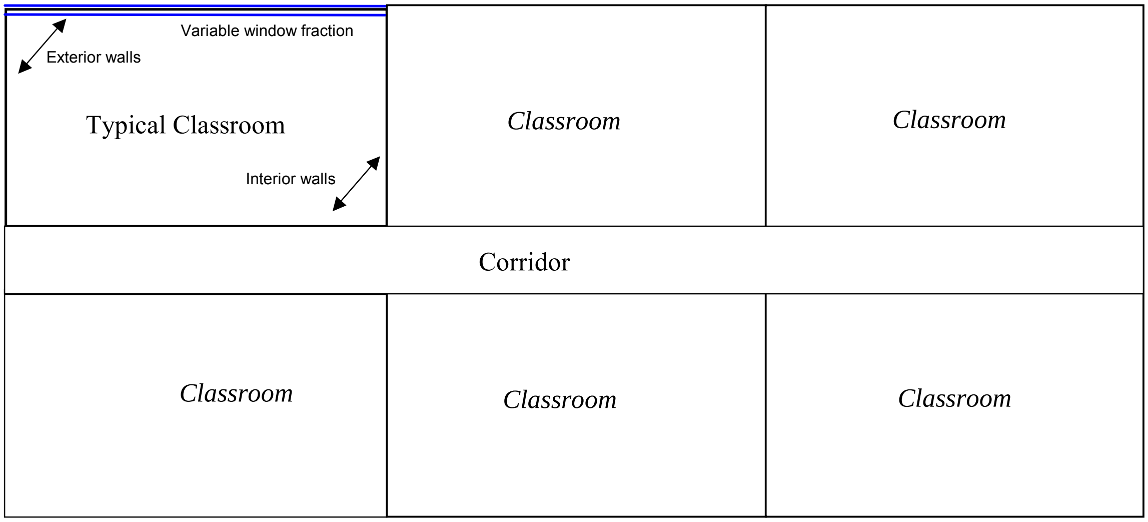


Table 2.4.3
Classroom Characteristics Included in DOE-2 Models

Component	Description
Floor Area	Total conditioned floor area
Internal Window Shading	User controlled, based on glare levels
Occupancy Density	Total number of people in each zone
Schedule	Hours per day, Year-round vs. Non-Year-round
Roof Insulation	Built-up roof insulation level
Exterior Wall Insulation	Wall insulation level
Wall Construction Type	Heavy or light construction
Lighting Power Density	Total lighting Watts/ft^2 in each zone.
Plug Power Density	Total Plug/Equipment Watts/ft^2 in each zone.
Glass U-factor	Overall window heat-loss coefficient
Glass SHGC	Overall window solar heat gain coefficient
Window Overhang	Depth of window overhang
Economizer	Default is none
Glass Area (Fraction)	As a fraction of front exterior wall area
Thermostat set point	cooling thermostat set point
Aspect Ratio	Ratio of front/back wall area to left/right wall area
Orientation	Direction that the front of the building faces

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 provides insight into how SEER is affected by the various building characteristics. This information is used to produce a set of SEER adjustments that account for conditions not addressed in the SEER ratings process. System demand information is 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. Section 3.1 of the accompanying report “EER and SEER as Predictors of Residential Seasonal Cooling Performance” examines the issues of outdoor temperature profile and cooling load as a function of outdoor temperature in depth.

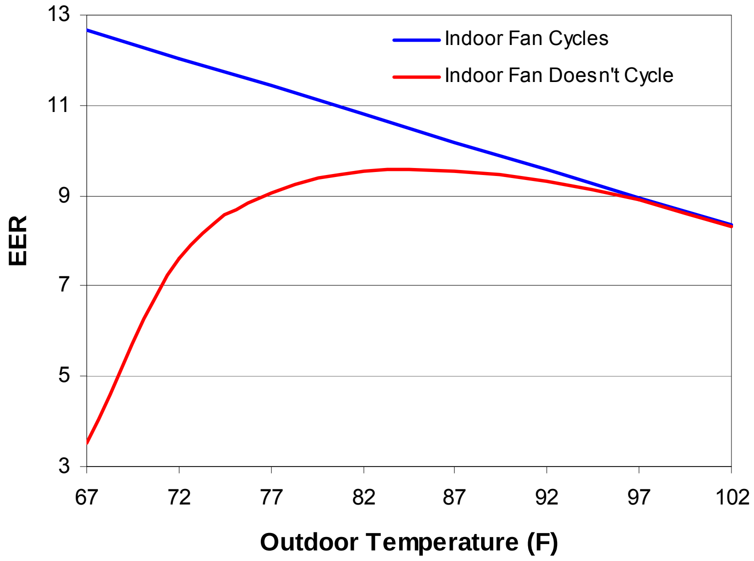
For commercial buildings, an additional and significant deviation from the SEER assumptions must be considered.

When the system fans are constant volume and cycle 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. The solid blue line in Figure 3.1.4 illustrates the relationship between EER and outdoor temperature under these conditions.

Where system fans are constant volume and do not cycle with compressor operation (i.e., run continuously during occupied hours to provide ventilation), indoor fan energy use is not related to outdoor temperature. This is the typical case for commercial applications. While condensing unit energy (i.e., compressor + condenser fan) still tends to be linear with outdoor temperature, the continuous indoor fan energy represents a constant that can be a potentially very large fraction of the total system energy. The red line in Figure 3.1.1 illustrates this. The EER represented by the red line assumes a condensing unit fractional run time that matches the cooling coil load assumed in the SEER ratings process. Indoor fan energy is assumed to be a constant value equal to 12% of the total electrical input at ARI rated conditions (95ºF outdoor temperature).

Figure 3.1.1

Impact of Fan Cycling on Unit Efficiency (EER) Sensitivity to Temperature
Unit Cycling Rate Based on SEER Rating Load Profile



When the fan doesn't cycle, the reduced system efficiency at lower outdoor temperature shown in Figure 3.1.1 is not because the compressor is less efficient. Compressor efficiency actually increases as illustrated by the blue line. Instead, the fixed indoor fan energy becomes a greater fraction of the total cooling energy as the unit cycles at lower outdoor temperatures. Under part-load when the indoor fan cycles with the compressor, the unit's EER is given by:

$$EER = Cap_{cool} * Runtime / (E_{IF} * Runtime + E_{CU} * Runtime). \qquad (3.1)$$

When the indoor fan doesn't cycle, the EER is equal to:

$$EER = Cap_{cool} * Runtime / (E_{IF} + E_{CU} * Runtime), \qquad (3.2)$$

where:

Cap_{cool} is the unit's cooling capacity,

E_{IF} is the indoor fan power,

E_{CU} is the condensing unit power, and

Runtime is the fraction of the hour the unit needed run to meet the cooling load.

A comparison of the two equations illustrates how indoor fan energy reduces EER when the unit cycles and the indoor fan continues to run. Because of this, indoor fan energy can be as, or more, important than overall system efficiency (as represented by SEER) in commercial applications.

3.2 ANALYSIS FINDINGS - SMALL OFFICE

3.2.1 Cooling System Description

A description of the office building prototypes is provided in Section 2.4.2, with details given in Appendix D. It is assumed that office systems are cooled by packaged systems. Since SEER-rated systems have cooling capacities less than 65,000 Btu/hr, the SEER 10, 12, and 13 units are single compressor systems. While economizers are optional, all include ducted outside air for ventilation purposes. The SEER range of packaged systems is somewhat limited. While the market place is constantly changing, they are dominated by SEER 10 and SEER12 systems. SEER 13 units have become common because of residential minimal SEER requirements, but higher SEER single-speed units are limited, as are two-speed unit. As of this writing, there is insufficient data on two-speed packaged units to allow the development of detailed DOE-2 performance curves. Because of this, the cooling systems are limited to SEER 10, 12, and 13 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. Results are then used to generate climate and cooling system specific SEER modifiers appropriate for small office applications.

3.2.2 Use of SEER in Commercial Cooling Applications

As illustrated in Figure 3.1.1, the definition of SEER is not well suited to commercial applications because of continuous indoor fan operation. 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 condensing unit turn on and off at the same time, the energy used by the indoor fan can be added to that used by the condensing 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.

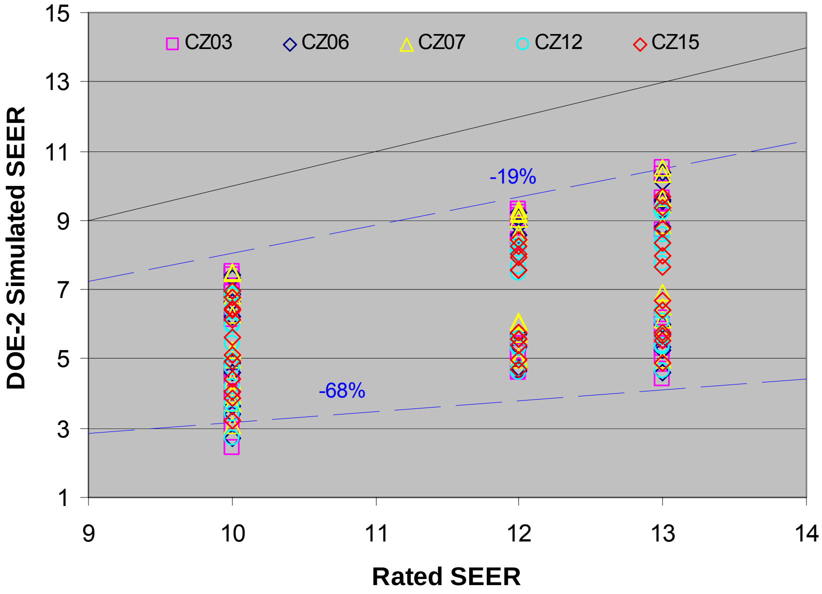
The problem with this is threefold.

1. 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 in commercial applications.

2. SEER does not address the importance of the indoor fan in commercial applications, as it does not distinguish between indoor fan and condensing unit energy. Seasonal fan energy in a SEER rating is typically on the order of 10% to 15% of the total. However, in some commercial settings (mild climate with economizer operation), fan energy can exceed condensing unit energy over the cooling season. In these cases, one could benefit more from selecting a cooling system with minimal indoor fan energy requirements rather than SEER since equivalent or even higher SEER systems could have greater indoor fan power.

3. Finally, for SEER to be most useful, it needs to be relatively independent of the cooling load. This turns out to be the case for residential applications where changes in building design and operation does not impact SEER by more than 5%. Therefore, while cooling loads may vary by over 100%, SEER would change by no more than 5%. This is not the case in a commercial application, as illustrated in Figure 3.2.1 where the seasonal cooling energy efficiency calculated from DOE-2 simulations is compared to rated SEER. The simulated SEER includes indoor fan energy for each hour that coincided with the use of mechanical cooling that hour.

Figure 3.2.1
Simulated SEER vs. Rated SEER
Supply Fan and Condensing unit Energy Included

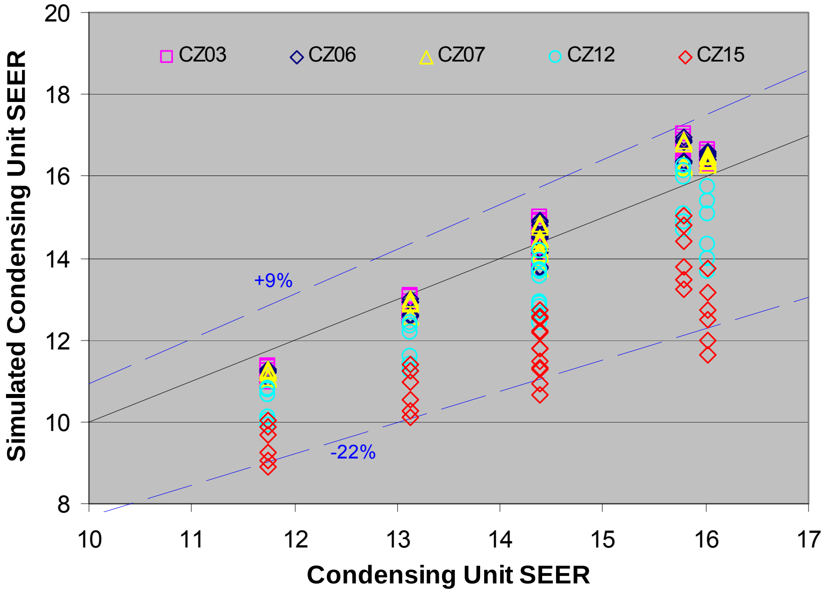


Each symbol in Figure 3.2.1 represents a different sets of building parameters, such as lighting power density, window area for perimeter offices, and hours of operation, among others. Simulations were run against "median" packaged heat pumps and air conditioners. Results are shown for climate zones 3, 6, 7, 12 and 15 in the figure (climate zone 6 is the coolest and 15 the hottest). As the figure illustrates, continuous fan operation results in SEER valuse that are significantly lower than rated values. For the conditions represented by these simulations, one should expect actual seasonal cooling efficiency to be between 19% and 68% lower than rated values. Within a given climate zone, one should expect a ±20% variation in annual cooling system efficiency for a given cooling system.

A possible way to resolve this issue is to separate fan and condensing 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 condensing unit energy (compressor plus outdoor fan), which can still be addressed in the same fashion as SEER. In this case, only the energy use of the condensing unit is used to calculate seasonal cooling efficiency. The condensing unit SEER is the seasonal cooling load (exclusive of indoor fan heat) divided by the condensing unit energy. Simulation results based on this SEER definition are presented in Figure 3.2.2. The data presented in this figure is from the same DOE-2 simulations used to create Figure 3.2.1. The simulated condensing unit SEER is compared to a rated condensing unit SEER, calculated by removing indoor fan energy from the conventional SEER definition.

As Figure 3.2.2 illustrates, removing the impact of the indoor fan energy lessens the impact of building parameters on seasonal cooling efficiency. Overall variation across all climate zones is reduced from ±25% (–19% to –68%) when supply fan energy is included to ±15% (+9% to -22%) when indoor fan energy is excluded.

Figure 3.2.2
Calculated vs. Rated Condensing Unit SEER
Indoor Supply Fan Energy Not Included



The variation in cooling load is as much as eight-to-one for the simulations used to generate Figures 3.2.1 and 3.2.2. 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 condensing unit SEER as the condensing unit operation directly tracks the cooling load. The results given in Figure 3.2.2 suggest that multipliers based on climate zone and rated SEER might improve the usefulness of condensing unit SEER as a predictor of seasonal energy use in office settings.

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

- Define and illustrate how one determines condensing unit SEER from rated SEER.
- Confirm that condensing 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 condensing unit SEER.
- Provide guidance on the relative importance of fan vs. condensing 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.
- Demonstrate the efficacy of the above approach in differentiating the seasonal cooling efficiency of units with the same SEER rating and amongst units with SEER ratings across the full the range of available units..

3.2.3 Calculating Condensing unit SEER from Rated SEER

The concept of calculating a condensing 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 condensing unit SEER begins with recalling Equation (1.1), or:

$$\mathrm{SEER} = \mathrm{EER_B} * (1 - 0.5*C_D), \qquad (3.3)$$

This equation is applicable to all single-speed, SEER-rated equipment, including the packaged systems addressed here. The only part of Equation 3.3 that is affected by the fan energy is $\mathrm{EER_B}$, or the system's EER when operated at an 82ºF outdoor temperature. A SEER based on the condensing unit energy only is determined by replacing the normal $\mathrm{EER_B}$ with the $\mathrm{EER_B}$ with the indoor fan energy removed, or,

$$\mathrm{SEER_{cond}} = \mathrm{SEER} * (\mathrm{EER_{B,no\ fan}} / \mathrm{EER_B}). \qquad (3.4)$$

Thus, to calculate a condensing unit SEER, one needs to determine and remove the fan energy from $\mathrm{EER_B}$. $\mathrm{EER_B}$ can be found from manufacturers' expanded ratings charts. They provide the net cooling capacity (gross less indoor fan heat) and total system energy (condensing unit plus indoor fan) over a range of outdoor temperatures. It is typically necessary to interpolate these values in the chart to determine the net cooling capacity and total electric input at an 82ºF outdoor temperature. It is important to use chart data for the rated airflow and ARI conditions entering the cooling coil (80ºF dry-bulb and 67ºF wet-bulb). $\mathrm{EER_B}$ equals the values of net cooling capacity divided by the total system energy (in units of Btu/Watts) at the 82° F outdoor temperature.

The "no fan" adjustment requires removing indoor fan effects from both the capacity and total system energy values. Fan power data is typically available for SEER-rated packaged systems, as fan tables are normally included with the expanded ratings charts. If they are, one should use the fan tables to determine the appropriate fan power value to use when adjusting EER_B. The fan power values obtained from manufacturers' fan tables are those 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 3.2.1. Care should be used in understanding all that is included in the fan tables. Manufacturers can list filter pressure drop and wet coil pressure drop as external pressure drop that need to be added to base values. Since SEER ratings process assumes the coil is wet and a filter is installed, filter and wet coil pressure drops should be added to those given in Table 3.2.1 if they are not included in the base values in the fan tables. 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 airflow. It should be noted that fan power varies a great deal in packaged cooling systems (Figure 3.2.3) and the default value of 365 Watts/1,000 cfm should never be used if better estimates are available.

Table 3.2.1

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

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

$$EER_{B,no\ fan} = (Net\_Capacity + Fan\_Watts * 3.413)/(Total\_Electric - Fan\_Watts) \quad (3.5)$$

Where Net Capacity is in units of Btu/hr and Total Electric and Fan Watts are in Watts. The net capacity and total electric are those found for the 82° F outdoor temperature. Condensing unit SEER is then calculated from Equation 3.4. Condensing unit SEER based on rated conditions ("Rated" Condensing Unit SEER in the figure) as calculated by Equations 3.4 and 3.5 are provided in Figure 3.2.3 for the packaged units examined in this study. Rated SEER values in Figure 3.2.3 are 10, 12, and 13. Values are offset slightly in the figure for clarity.

Figure 3.2.3
Packaged System "Rated" Condensing Unit SEER and Fan Power Values
Systems Examined in This Study

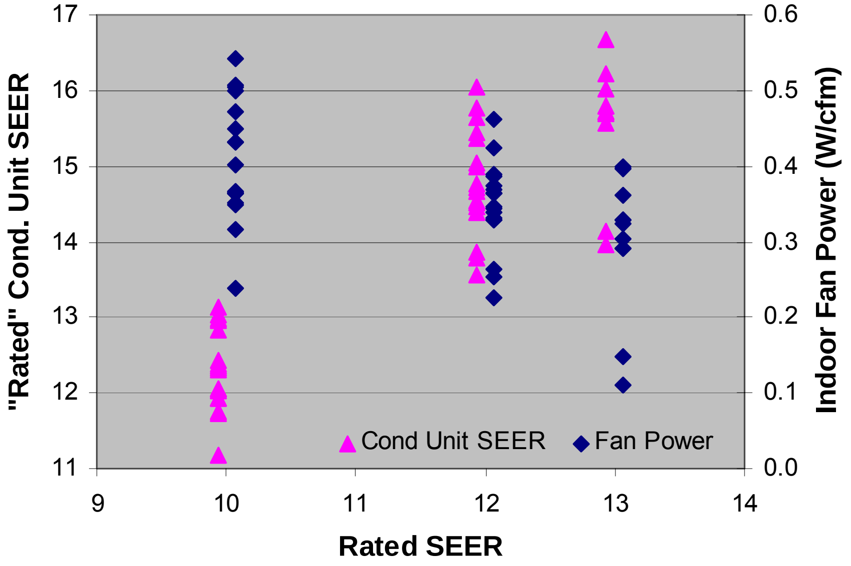


Figure 3.2.4 compares condensing unit SEER as calculated by Equation 3.4 to that obtained from DOE-2 simulations. Simulations that produce each point are for "median" packaged systems, median building parameters (window area, occupancy levels, etc.) and for each thermal zone (four perimeter plus core) and the total building. The results provided in the figure span those of the five climate zones examined (CZ03, CZ06, CZ07, CZ12, and CZ15). Results for the other climate zones are qualitatively similar to that provided in the figure.

The results illustrated in Figure 3.2.4 show the potential usefulness of separating indoor fan energy from standard SEER ratings in applications where the indoor fan does not cycle with the compressor. While climate differences have an obvious affect on condensing unit SEER, there is a consistent trend between condensing unit SEER obtained from rated data and that obtained from simulations. In addition, it appears that there is relatively little difference between simulated condensing unit SEER for the various thermal zones (four perimeter plus the core) and the value for the building as a whole. Based on this, results shown in Figure 3.2.4 were expanded to include all packaged units examined in this study and are shown in Figure 3.2.5. The results in Figure 3.2.5 are for the whole building with the filled data points corresponding to points in Figure 3.2.4. The relationship between condensing unit SEER obtained from rated data and that from DOE-2 simulations remains.

There is an obvious climate relationship between "Rated" condensing unit SEER and that calculated in simulations. Simulation results were used to generate SEER-specific climate zone multipliers. These are provided in Table 3.2.2 for the five climate zones and three nominal SEER values examined in this effort. The adjustments are condensing unit-SEER multipliers. For example, a SEER-12 system with a nominal condensing unit SEER of 13.5 being used in a typical small office application in climates zone 12 could be expected to operate with a condensing unit efficiency ratio of 12.8.

Figure 3.2.4

"Rated" and DOE-2 Simulated Condensing unit SEER
5 Zones plus Building, Median Cooling Systems - CZ06 and CZ15

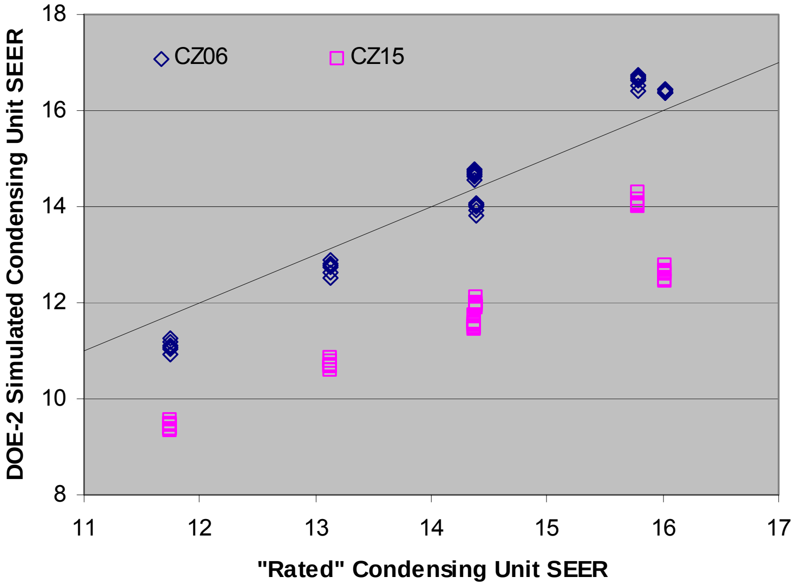


Figure 3.2.5

"Rated" and DOE-2 Simulated Condensing unit SEER
Total Building, All Cooling Systems - CZ06 and CZ15

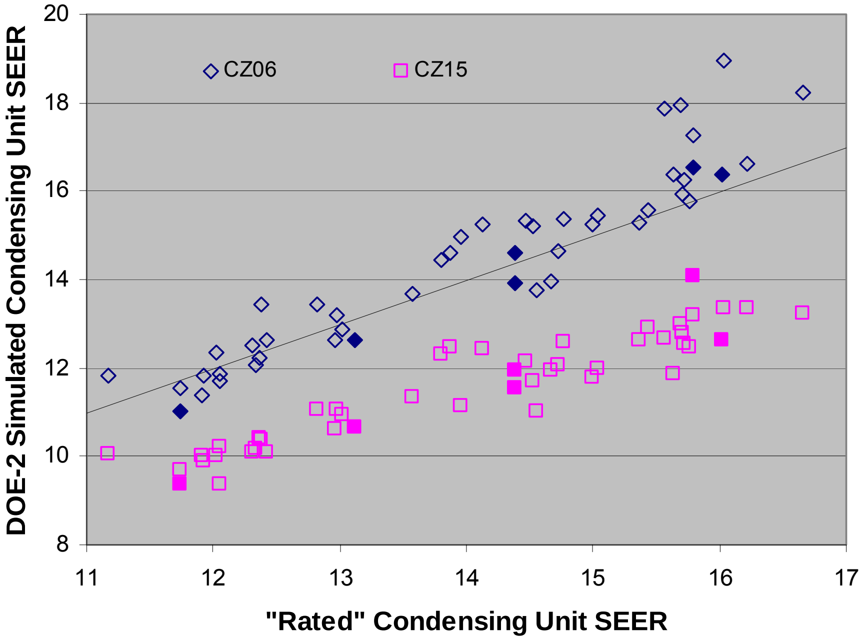
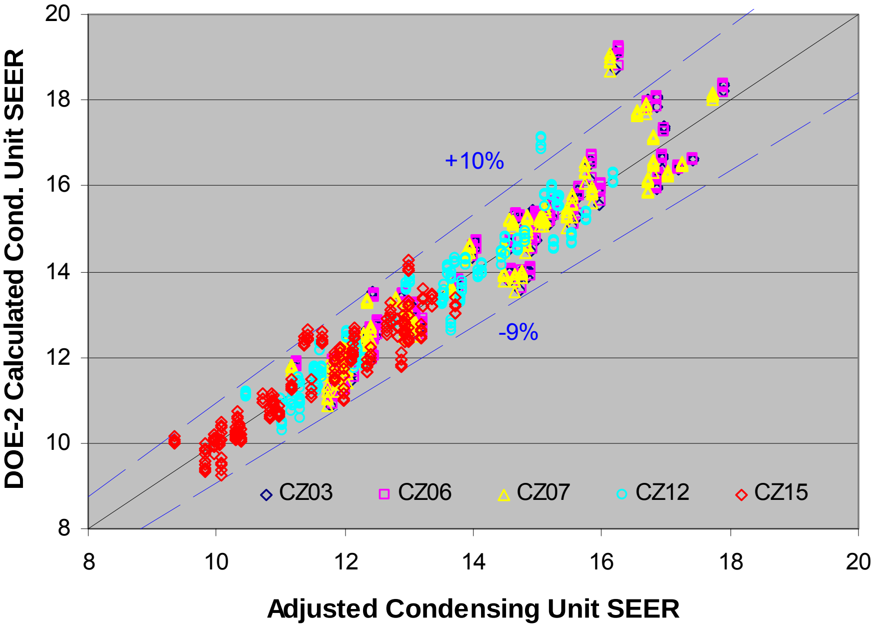


Table 3.2.2
Condensing Unit SEER Climate Multipliers
Median Building Features – CZ03, CZ06, CZ07, CZ12 and CZ15

Rated SEER	CZ03	CZ06	CZ07	CZ12	CZ15
10	1.00	1.01	1.00	0.94	0.84
12	1.01	1.01	1.01	0.94	0.82
13	1.07	1.07	1.06	0.97	0.82

The multipliers are both climate zone and SEER rating dependent. Higher SEER-rated units tend to be more sensitive to changes in outdoor temperature than their lower SEER counterparts. This can be a result of the refrigerant used (R-410 for more efficient systems instead of R-22), lower outdoor fan energy, or larger outdoor coils, among others. Because of this, higher SEER-rated units tend to be more efficient than their lower SEER counterparts in cooler climates, but less so in the hotter climates (climate zones 12 & 15).

Figure 3.2.6
Adjusted and Calculated Condensing Unit SEER
Five Thermal Zones, All Cooling Systems, CZ03, CZ06, CZ07, CZ12 and CZ15



The climate zone multipliers from Table 3.2.2 are applied to the rated condensing unit SEER and compared to simulated values in Figure 3.2.6. Data in the figure are for all packaged systems (47 units), the five thermal zones (four perimeter and core), and five climate zones. The multipliers reduce climate-related differences, reproducing simulated condensing unit SEER to within +10% to -9% at a 99% confidence level. This scatter is a caused by differences in the response of the various cooling systems to weather conditions as all simulation results are for the same median building configuration. The vertical grouping of like-colored points illustrates the relatively minor variation in system cooling performance from thermal zone to thermal zone for a given packaged unit.

3.2.4 Impact of Building Features on Simulated SEER

DOE-2 simulations were performed over the range of building characteristics as given in Section 2.4.1. 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 condensing 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 condensing unit SEER. Building features that lead to higher and lower values of condensing unit SEER for office applications are given in Table 3.2.3. It is important to note that building features that lead to higher values of condensing unit SEER do not necessarily result in reduced cooling energy, just improved compressor-operating efficiency. For example, higher lighting power densities and internal gains lead to both increased condensing unit SEER and higher cooling energy. Higher lighting and internal gains expand compressor runtime into periods when it is cooler outside and the condensing unit efficiency is higher. This produces a higher overall seasonal efficiency, or SEER, for the condensing unit even though cooling loads are higher.

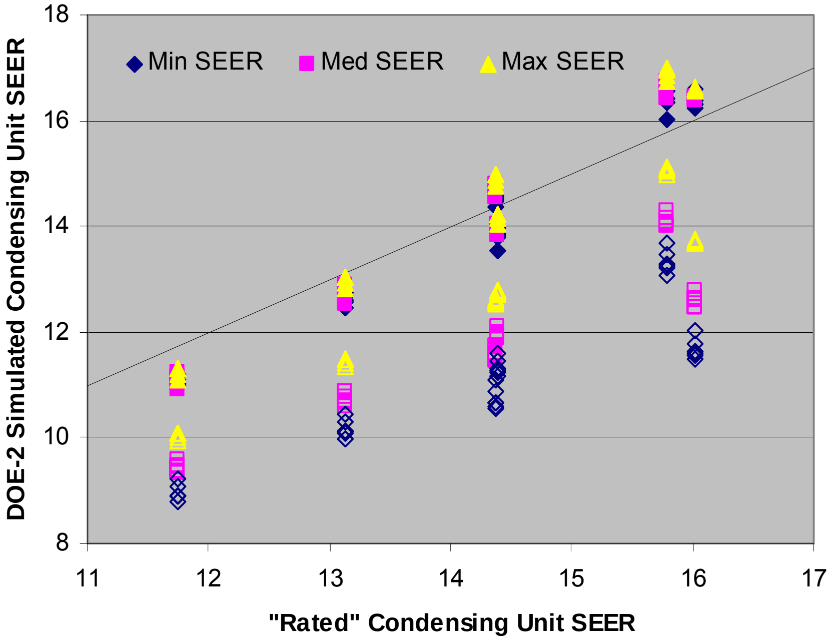
Excluded from the table and consideration in condensing unit SEER is economizer operation. The inclusion of economizers lowers SEER values to the point that they overwhelm the impact of all other building features. All results assume the median value for the economizer use, which is fixed ventilation 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. In addition, some building parameters listed in Table 3.2.3 are not applicable to interior, or core, zones. These include window properties and areas and wall properties and areas. Roof parameters can apply to all zones.

These results are presented for climate zones 6 (coolest) and 15 (hottest) in Figure 3.2.7 for "Median" packaged systems. Results for CZ06 are shown as filled figures, those for CZ15 as open figures. Results for the other climate zones are qualitatively consistent and fall between these two. The findings illustrated in Figure 3.2.7 suggest the following two key observations:

1. The effects of building characteristics on SEER can be climate dependent in an office setting. That is, changes in the building operation and design have little effect on calculated condensing unit SEER in the cooler climate zones (CZ06, CZ03 and CZ07), but have a significant effect in CZ15. For the cooler climates, building design features impact condensing unit SEER by only ±1%. This increases to ±8% for the hotter CZ15.
2. Climate has a stronger influence on seasonal cooling efficiency than the various building characteristics. Note that this observation is for cooling system efficiency, not cooling energy consumption. The various building features do have a significant impact on cooling loads, and thus cooling energy consumption.

Figure 3.2.7

Minimum, Median, and Maximum Condensing unit SEER
5 Thermal Zones, Median Cooling Systems - CZ06 and CZ15



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 Section 2.1). 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 3.2.8. The data in this figure is the same as that used to produce Figure 3.2.7. Figure 3.2.8 retains the convention of using filled points for CZ06 and open points for CZ15.

The figure illustrates both the impact of building features on mid-load temperature and mid-load temperature on condensing unit SEER. The variation in mid-load temperature for CZ15 caused by changes in building features is approximately 20º F, as compared to only 10º F for the cooler climate CZ06. The greater variation in mid-load temperature produces the increased variation in condensing unit SEER for warmer climates as compare to cooler climates, as illustrated in Figure 3.2.8.

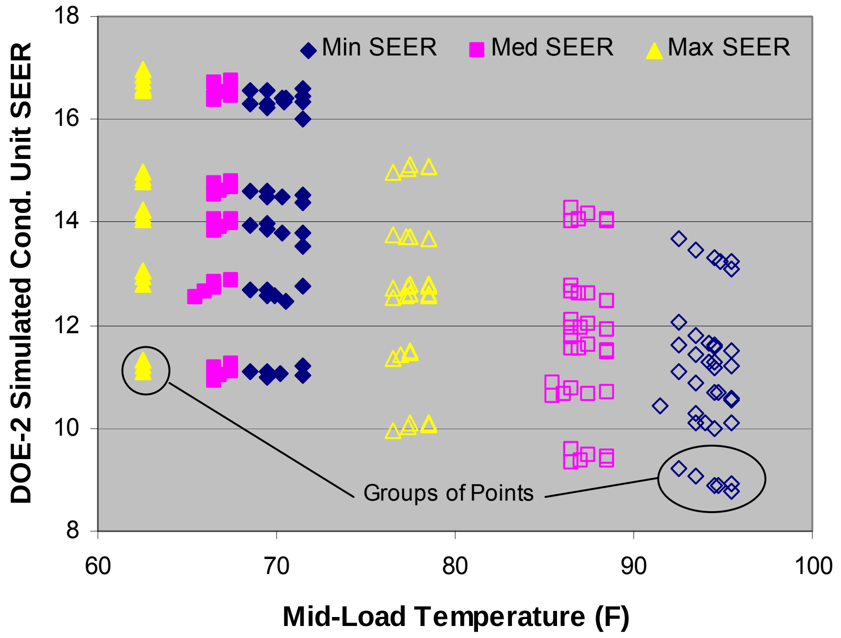
Table 3.2.3
Building Parameters Affecting Condensing Unit SEER[1]
Affect on SEER Because of an Increase in Parameter Value

	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 Overhang Depth	Higher	Higher	Higher	Lower	Lower
Wall U-value	Higher	Higher	Higher	Higher	Higher
Roof Insulation	Higher	None	Higher	Higher	Higher
Cooling Thermostat 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.*

Figure 3.2.8
Minimum, Median, and Maximum Condensing unit SEER vs. Mid-Load Temperature
5 Zones, Median Cooling Systems - CZ06 and CZ15



Results presented in Figure 3.2.8 allow a number of observations to be made concerning the efficiency of cooling system in office settings. These include the following:

1. The data used to generate Figure 3.2.8 include simulation results from cooling systems serving the four perimeter zones, the core zone, and the total building. The data tends to fall along six trend lines, each corresponding to a given cooling system. Groups of points correspond to a specific set of design features, five thermal zones, and one cooling system. For some simulations, the calculated condensing unit SEER differs so little from cooling zone to cooling zone (four perimeter and core zones) that it is difficult to distinguish the five simulations included in the figure. Even when the points are distinguishable, there is little variation in condensing unit SEER (vertical scatter). 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 condensing unit efficiency in these cases. They can, and do impact cooling loads; just not cooling system efficiency as illustrated by the condensing unit SEER.

2. Scheduling and space usage issues dominate condensing 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. Unfortunately, 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 condensing unit SEER.

3. Variations in building operation have little effect on condensing 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.

3.2.5 Impact of Cooling System Features on Simulated SEER, Minimum, Median, and Maximum SEER Building Models

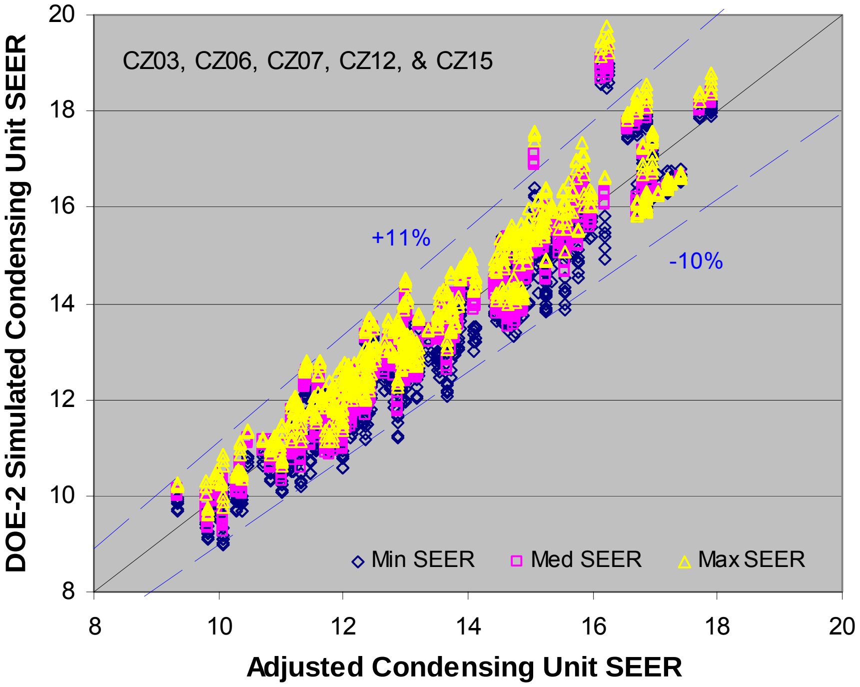
Results in Section 3.2.4 were expanded to include the full range of cooling systems. Simulation results are shown in Figure 3.2.9. Data in the figure are for the all zones and the entire building (energy weighted results of all five thermal zones – four perimeter and core). Results shown are for the five major climate zones (CZ03, CZ06, CZ07, CZ12, and CZ15). Cooling systems include both heat pumps and air conditioners. The figure compares each system's adjusted condensing unit SEER (using condensing unit SEER multiplier from Table 3.2.2) to that calculated via DOE-2 simulations.

When the building parameters are allowed to vary to produce maximum and minimum SEER values, multipliers provided in Table 3.2.2 allow condensing unit SEER to be estimated to within +11% to –10% of those calculated from DOE-2 simulations.

Figure 3.2.9

DOE-2 Simulated vs. Adjusted Condensing Unit SEER

All Packaged Systems, Minimum, Median and Maximum SEER Building Features



One has to question the value of SEER as an energy predictive metric in office settings given the uncertainty in condensing unit SEER illustrated in Figures 3.2.7 and Figure 3.2.8. Climate corrections leave an uncertainty is on the order of ±11% on the condensing unit alone. Added to this is the problem of combining seasonal fan energy use with condensing unit energy. This adds another level of uncertainty as the relative size of fan and condensing 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 rated SEER as a reliable predictor of seasonal cooling system efficiency.

3.2.6 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, the question remains as to whether or not it will rank cooling systems for use in an office application. Figure 3.2.1 suggests that it will not.

The use of SEER as a ranking tool in a commercial application needs to account for both annual condensing unit and fan operation. While the compressor runs only when cooling is needed, the fan runs during whenever the building is occupied. 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 condensing unit.

In this light, a SEER rating is suggested for situations that require continuous fan operation, or $\mathrm{SEER_f}$. This SEER is defined as the annual energy supplied by the cooling coil divided by the sum of the annual condensing unit energy and indoor fan energy. The indoor fan energy is that consumed any time the fan is on, not just when there is a cooling load. Using this, can one determine the relative importance of fan and condensing 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. SEER 10, SEER 12, and recently SEER 13 systems dominate the market. 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.

$\mathrm{SEER_f}$ can be calculated from cooling system and fan operational specifics as:

$$\mathrm{SEER_f} = [1/\mathrm{SEER_{cond}} + (\mathrm{Hrs_{fan}}/\mathrm{Hrs_{comp}})*\mathrm{W_{fan}}/\mathrm{Cool\ Cap}]^{-1} \tag{3.6}$$

Where:

$\mathrm{SEER_f}$ is the SEER that includes continuous fan operation,

$\mathrm{SEER_{cond}}$ is the condensing unit SEER as defined above,

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

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

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

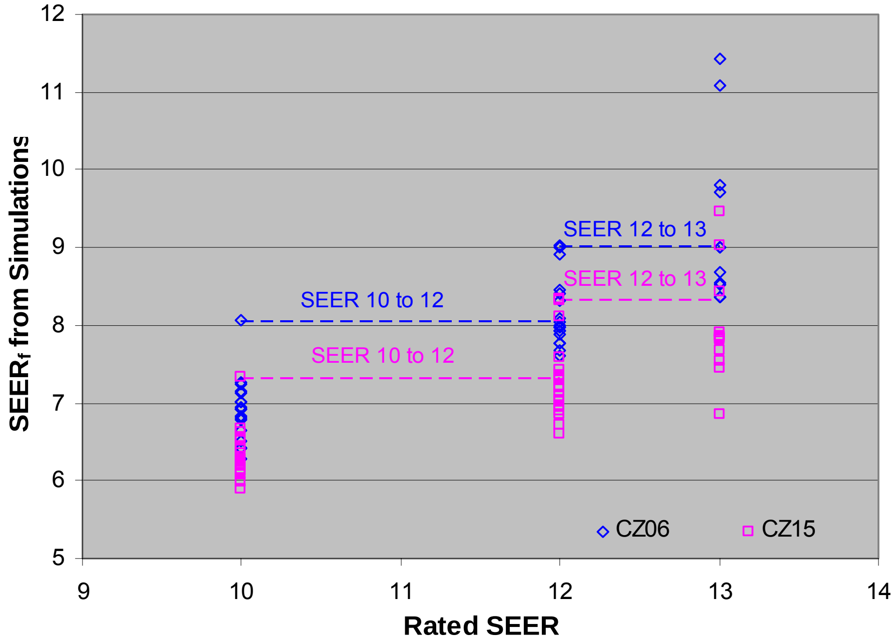
Cool Cap is the rated cooling capacity in Btu/hr.

Of the information necessary to calculate $SEER_f$ beyond the condensing unit SEER, only the rated fan power and cooling capacity are known for a given system. Both can be calculated or estimated from manufacturer's literature. Section 3.2.5 describes how one calculates the condensing unit SEER via Equations 3.4 and 3.5. The one remaining unknown is the ratio of hours of fan operation to the full-load cooling hours of operation (Hrs_{fan}/Hrs_{comp}). This ratio will be defined hear as the 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.

$SEER_f$ values calculated from DOE-2 simulations for all packaged systems examined are compared to each unit's rated SEER in Figure 3.2.10 for climate zone 6 (mildest climate zone) and 15 (warmest climate zone) and median building features. The DOE-2 calculated $SEER_f$ is the total cooling energy supplied to the building divided by the sum of the annual condensing unit energy plus and the annual indoor fan energy. Results are for the entire building (sum of all zones).

Figure 3.2.10

$SEER_f$ from DOE-2 Simulations vs. Rated SEER for All Packaged Systems Median Building Features – CZ06 & CZ15



Results from DOE-2 simulations demonstrate the ineffectiveness of rated SEER in selecting the most energy efficient system for an office application. The variation of seasonal energy use among same-SEER systems is significant, with values presented in Table 3.2.4. One should expect variation in seasonal performance among same-SEER units between 12% and 56%, depending on climate zone, building features, and operating schedules. This variation frequently exceeds the expected reduction in seasonal HVAC energy consumption associated with upgrading 3 SEER points (from a SEER-10 unit to a SEER-13).

This is illustrated in Figure 3.2.10, as referenced by the horizontal lines in the figure. These lines compare the best performing unit at one SEER level to those at the next. While higher SEER units can provide significant improvements in seasonal cooling efficiency, those improvements appear to be climate, unit, and application specific. As the figure illustrates, the best performing SEER-10 unit outperforms most SEER-12 and several SEER-13 units for a median office building located in climate zone 15. This particular SEER-10 unit had a very low indoor fan power in comparison to most SEER-12 units and many SEER-13 units. The overlap in indoor fan power values among different-SEER systems is illustrated in Figure 3.2.3.

Table 3.2.4
Differences in Annual Cooling System Energy Use for Same SEER Systems
Office Application Values Averaged Over All Zones

	CZ03	CZ06	CZ07	CZ12	CZ15
Rated SEER	Median Building				
10	22%	19%	18%	21%	16%
12	19%	15%	15%	20%	24%
13	37%	31%	31%	34%	26%
	Maximum SEER Building				
10	14%	14%	13%	15%	11%
12	13%	12%	12%	14%	18%
13	24%	23%	20%	22%	18%
	Minimum SEER Building				
10	30%	23%	25%	29%	22%
12	31%	25%	25%	33%	29%
13	68%	54%	52%	63%	36%

Runtime ratios used in the calculation of $SEER_f$ are given in Table 3.2.5 based on a median office configuration. Values are presented for the five climate zones examined and by thermal zone. DOE-2 simulations produced runtime ratios that were dependent on the thermal zones served by the cooling system. Systems serving a core zone (no exterior walls or windows) tended to have different runtime ratios than perimeter zones (those with walls and windows). The west-facing perimeter zone differed from north, east, and south-facing perimeter zones. The runtime ratios for north, east, and south-facing perimeter zones differed only slightly from each other and could be represented by one value.

Runtime ratios provided in Table 3.2.5 are based on median system operation of 85 hours per week. This is the number of hours per week the fan is on and the system is available for cooling for a week with no holidays. This includes 15 hours per day for weekdays, 10 hours per day for Saturday, and no operation on Sunday or holidays. This is in contrast to the minimum operating schedule of 70 hours per week and the maximum operating schedule of 144 hours per week. Based on median building systems other than the operating schedule, values in the table should be increased by 0.48% per hour additional hour of operation above 85 per week, or decrease by 0.48% per hour of operation less than 85 per week for perimeter zones. Thus, values in Table 3.2.5 should be increased by 28% for the maximum operating schedule of 144 hours per week and decreased by 8% for the minimum operating schedule of 70 hours per week. Runtime ratios for the core zone are essentially unaffected by operating schedules.

Table 3.2.5

Fan-to-Cooling Runtime Ratios for Use with Equation 3.6
Median Building Features – CZ03, CZ06, CZ07, CZ12 and CZ15

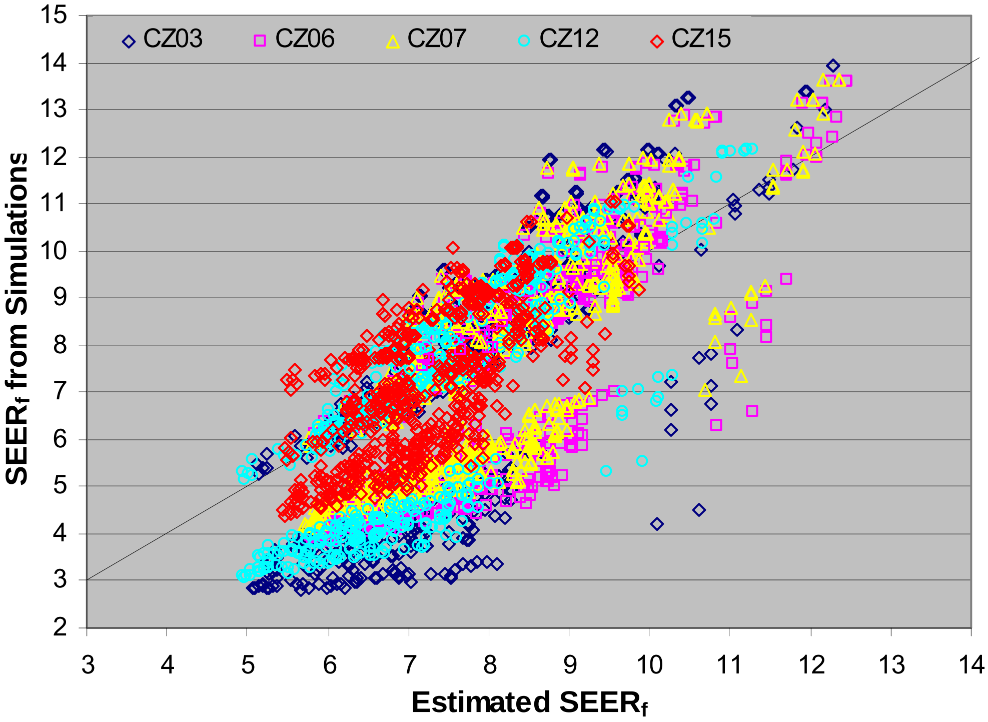
Area Served	CZ03	CZ06	CZ07	CZ12	CZ15
Core	5.73	4.58	4.65	5.77	4.40
North, East, South	4.28	3.39	3.52	4.23	3.28
West	3.84	3.10	3.28	3.94	2.99
Building	5.10	4.03	4.13	5.10	3.86

The runtime ratios provided in Table 3.2.5 were used in conjunction with condensing unit SEER multipliers provided in Table 3.2.2 to provide SEER_f estimates. Perimeter zone runtime ratios were adjusted upwards by 28% for minimum SEER simulations (since they are based on maximum system operating schedules) and downward by 8% for maximum SEER simulations (since they are based on minimum system operating schedules). These are compared to SEER values obtained from DOE-2 simulations in Figure 3.2.11. DOE-2 results provided in the figure include those that produced maximum and minimum SEER values, along with median values.

The scatter in results presented in Figure 3.2.11 would tend to suggest that the new SEER_f has little or no value. This may be true for estimating seasonal energy use, but not necessarily true for ranking units. Differences in cooling systems with the ***same*** SEER rating can produce up to a 68% difference in annual cooling energy for a given application, as shown in Table 3.2.4. 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 under these conditions.

Figure 3.2.11

DOE-2 Simulated vs. Estimate SEER$_f$ for All Packaged Systems
Minimum, Median and Maximum SEER Building Features



Figures 3.2.12a and 3.2.12b compare SEER$_f$ from DOE-2 simulations to estimated values when ranked by performance. The points in the figures are results for whole building with median building features. Data in Figure 3.2.12a are for simulation performed with climate zone 6 weather data, that for Figure 3.1.2b is for climate zone 15 weather data. The figures rank the packaged systems examined from best (rank of 1) to worse (rank of 47) based on SEER$_f$. The horizontal bars are the rankings using SEER$_f$ calculated from DOE-2 simulations, representing the ideal ranking of systems. The open diamond symbols are the system ranking using SEER$_f$ estimated from Equation 3.6 and data from Tables 3.2.2 and 3.2.2. The symbols are color-coded by their rated SEER – magenta points (both horizontal bars and open diamonds) are SEER-10 units, yellow are SEER-12 units, and cyan are SEER 13 units. Since the diamond values don't always fall on top of the horizontal line points, estimated values of SEER$_f$ doesn't provide perfect ranking. They do retain general ranking trends, even to the extent that some units of lower rated SEER are ranked higher than units of higher rated SEER.

Figure 3.2.12a

Ranking of Packaged Systems by SEER$_f$ – CZ06
Median Building Features, All Systems

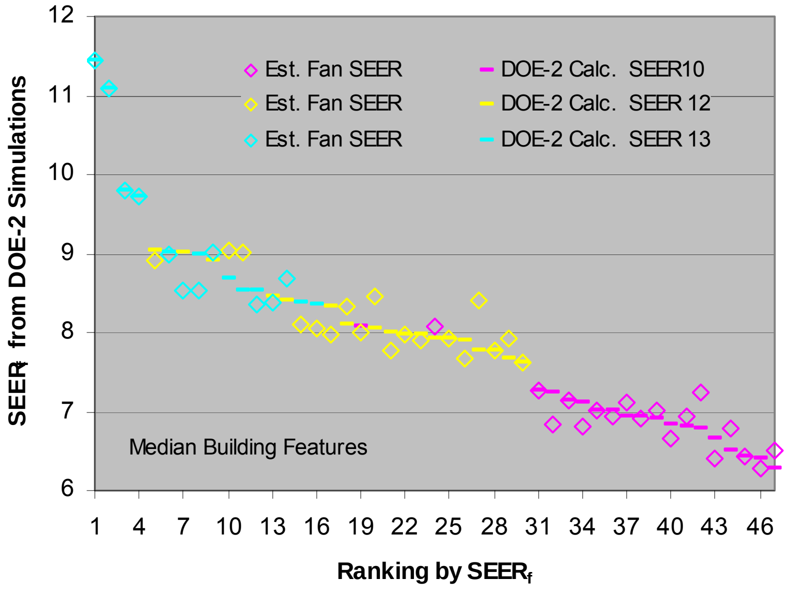
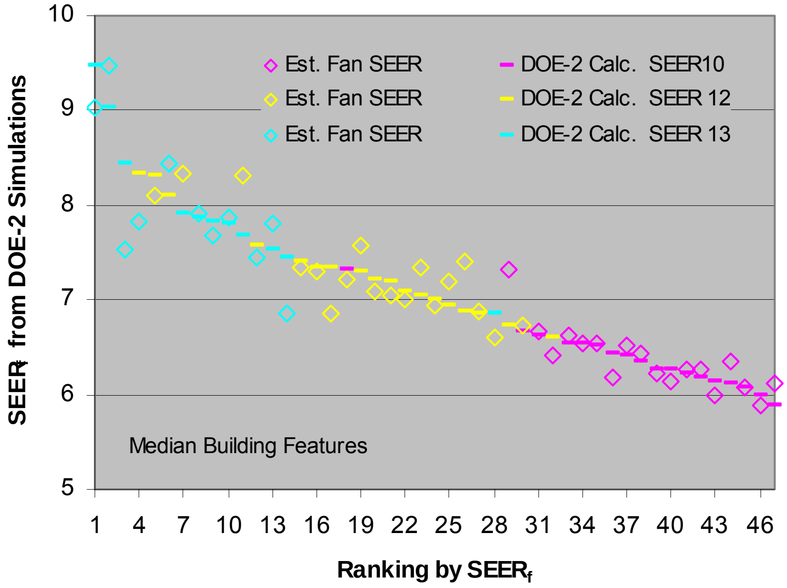


Figure 3.2.12b

Ranking of Packaged Systems by SEER$_f$ – CZ15
Median Building Features, All Systems



Figures 3.2.13a and b are counterparts to Figures 3.2.12a and b, except that they are for simulation results based on building features that produce maximum condensing unit SEER values. Similarly, Figures 3.2.14a and b are for simulation results based on building features that produce minimum condensing unit SEER values.

Figure 3.2.13a

Ranking of Packaged Systems by SEER$_f$ – CZ06
Maximum SEER Building Features, All Systems

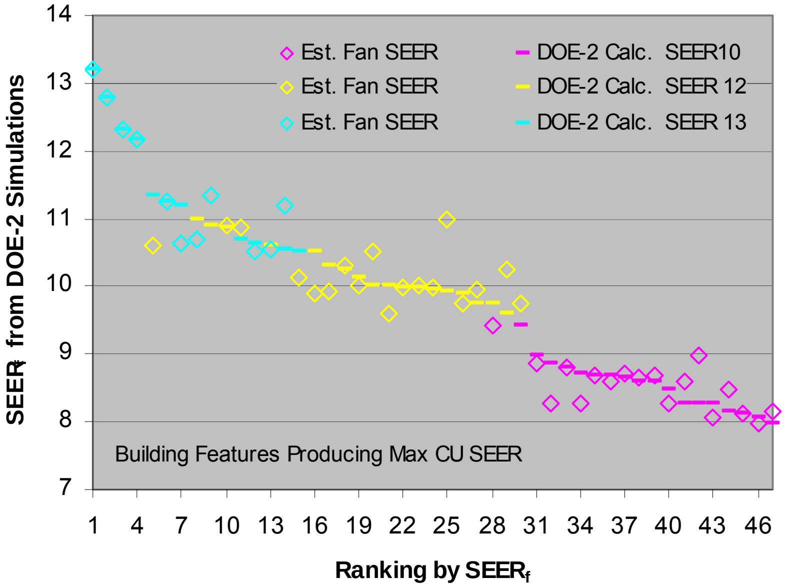


Figure 3.2.13b

Ranking of Packaged Systems by SEER$_f$ – CZ15
Maximum SEER Building Features, All Systems

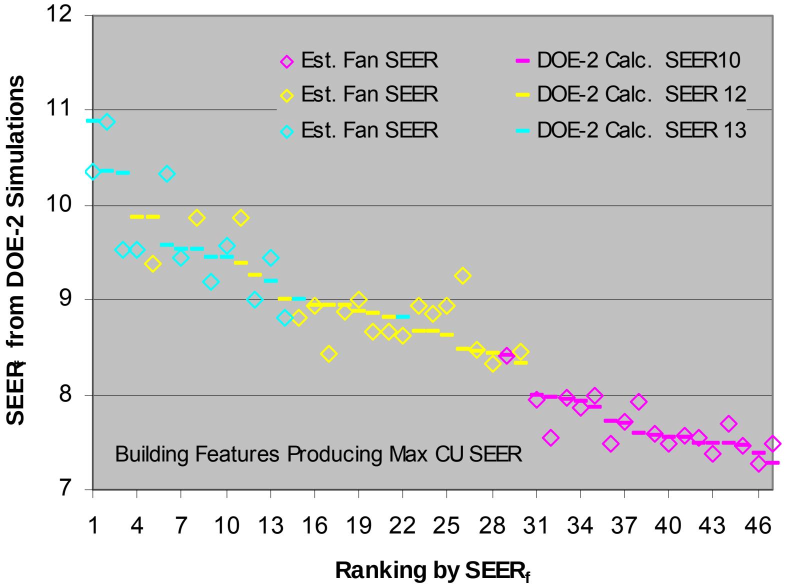


Figure 3.2.14a
Ranking of Packaged Systems by SEER$_f$ – CZ06
Minimum SEER Building Features, All Systems

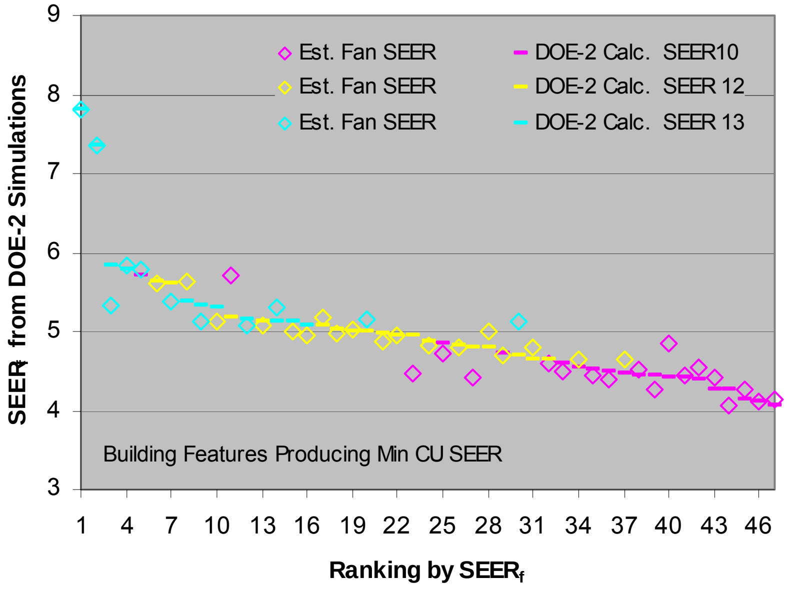
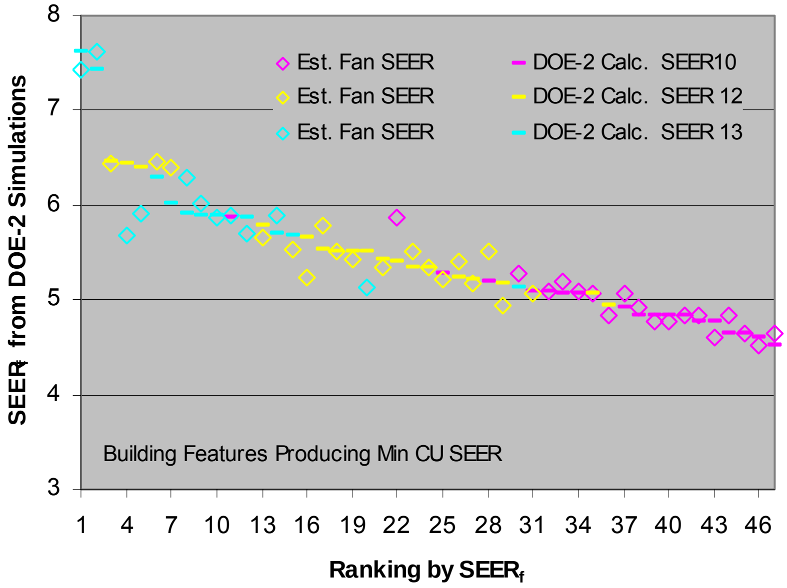


Figure 3.2.14b
Ranking of Packaged Systems by SEER$_f$ – CZ15
Minimum SEER Building Features, All Systems



It is worth noting that the data used to generate Figures 3.2.12.a and b through 3.2.14a and b are the same as that used to produce Figure 3.2.11. Thus, SEER$_f$, while not particularly effective in predicting seasonal energy use, does have benefit in ranking units as to their performance. Also, SEER$_f$ is nearly as effective in ranking systems for building features that produce minimum and maximum condensing unit SEER values as for median SEER values.

Finally, ranking errors from $SEER_f$ estimates obtained from Equation 3.6 and data from Tables 3.2.2 and 3.2.4 are mostly associated with uncertainties in estimates of condensing unit SEER (Figure 3.2.9). This is why the ability of estimated $SEER_f$ is poorest for building features that produce the maximum SEER and best for building features that produce the minimum SEER. Maximum SEER building features include the minimum building-operating schedule (70 hours per week). As such, the condensing unit energy use (with its ±11% uncertainty) plays a large role in estimating $SEER_f$. Conversely, minimum SEER building features include the maximum building-operating schedule (140 hours per week) where fan energy has a much larger impact on $SEER_f$. The greater fan energy associated with the minimum SEER case can be estimated with little error, improving the estimates of $SEER_f$.

General rules when using $SEER_f$ estimates 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-13 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 3.2.4.

3. $SEER_f$ ranked 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 3.2.2 and 3.2.5) 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.

The performance ranges given in Table 3.2.4 suggests that rated SEER may not properly rank packaged systems used in an office setting. A comparison of the energy benefit associated with moving from a lower to a higher SEER-rated system is given in Table 3.2.6. 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 3.2.6 suggest that while moving to a higher SEER-rated system can produce energy saving that exceed expectations, it also may provide no significant benefit or, ins some cased, result in an energy increase. 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 the assumptions used to develop SEER ratings.

Table 3.2.6
Energy Benefits of Moving to a Higher SEER System
Office Application Results for the Entire Building

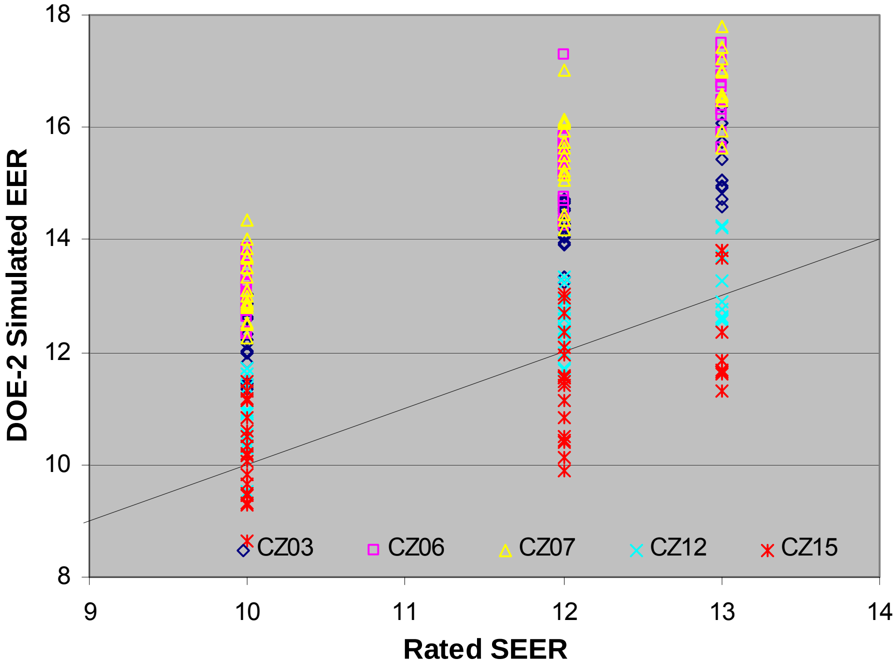
		Percentage Decrease in Seasonal Cooling Energy			
	SEER Change	Expected	Maximum	Median	Minimum
CZ03	*SEER 10 to 13*	23%	47%	22%	0%
	SEER 10 to 12	17%	31%	13%	*-10%*
	SEER 12 to 13	8%	36%	11%	*-10%*
CZ06	*SEER 10 to 13*	23%	45%	23%	3%
	SEER 10 to 12	17%	30%	13%	*-6%*
	SEER 12 to 13	8%	33%	11%	*-8%*
CZ07	*SEER 10 to 13*	23%	45%	23%	4%
	SEER 10 to 12	17%	30%	14%	*-6%*
	SEER 12 to 13	8%	33%	11%	*-8%*
CZ12	*SEER 10 to 13*	23%	44%	21%	*-3%*
	SEER 10 to 12	17%	31%	12%	*-10%*
	SEER 12 to 13	8%	33%	10%	*-14%*
CZ15	*SEER 10 to 13*	23%	38%	19%	*-7%*
	SEER 10 to 12	17%	29%	12%	*-11%*
	SEER 12 to 13	8%	30%	8%	*-22%*

Note: Seasonal cooling energy includes year-round indoor fan energy

3.2.7 Electric Demand

Peak electric demand calculated from DOE-2 simulations is compared to rated SEER in Figure 3.2.15. Results are for the west-facing perimeter zone (typically the zone with the highest peak load), but results for other zones are similar. The DOE-2 Calculated EER shown in the figure is the unit's cooling capacity divided by the peak cooling electric demand (condensing unit plus indoor fan). Common wisdom suggests that SEER is not a good predictor of cooling system demand. This is bourn out by simulation results obtained in this issue.

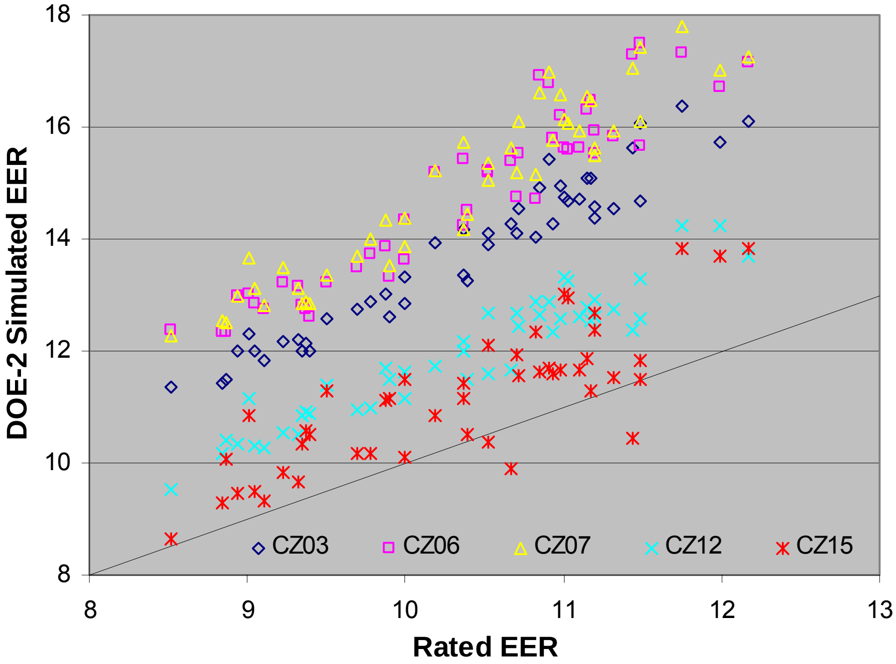
Figure 3.2.15
DOE-2 Simulated vs. Rated SEER – Packaged Systems
West-facing Perimeter Zone



The units' EER ratings are normally considered a much better predictor of demand. Results from this effort compare simulated EER to rated EER in Figure 3.2.16. The data in this figure are the same as those presented in Figure 3.2.15. There is an obvious trend between calculated and rated EER as illustrated by the figure. Climate also impacts demand, with higher EER values associated with cooler climate zones (climate zones 3, 6, and 7) and lower values with hotter (climate zones 12 and 15).

Rated EER is a more reliable metric for predicting cooling system demand for cooler climates (CZ03, CZ06, and CZ07) than for warmer climates (CZ12 and CZ15). More reliable means there is less difference in calculated EER for systems with similar EER ratings (less vertical scatter of points in Figure 3.2.16). Peak cooling electric demand for a given system is dependent numerous conditions, including both the outside air temperature and coil entering conditions. Each system varies as to how much its capacity and efficiency is dependent on each. 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. For other systems, outdoor wet-bulb temperature may have an overriding impact on peak loads because of outdoor air needed to meet ventilation requirements. These impacts are less extreme for cooler climates zones as peak outdoor conditions are similar to ARI ratings points. Differences in outdoor dry-bulb and wet-bulb temperatures from ARI conditions are greater for the hotter climate zones, producing greater unit-to-unit variation among packaged cooling systems with similar EER ratings.

Figure 3.2.16
Simulated vs. Rated EER – Packaged Systems
West-facing Perimeter Zone



System simulations assume a sizing ratio of 1.31, or cooling systems are over-sized by 31% (cooling load rounded up to the next rated capacity, plus unit upsizing to the next capacity). While this differs from assumptions used in the SEER ratings process, it is a more realistic sizing strategy for commercial systems and important in establishing the proper ratio of indoor fan and condensing unit energy use. The over-sizing approach impacts values of DOE-2 simulated EER provided in Figures 3.2.15 and 3.2.16 since the numerator in the EER calculation is the design capacity of the cooling system. Since the DOE-2 simulation was used to size units, the cooling system's design capacity is 31% greater than the peak cooling load calculated in annual simulations. In an actual design exercise, the capacity of the cooling system obtained from the design cooling load may be less than, or greater than (typically the case) that realized when the building is under use. As such, the amount of over-sizing is expected to vary. One way to account for this is to remove over-sizing from simulated demand values, allowing over-sizing estimates to be provided after the fact.

The results of eliminated over-sizing from simulation results are shown in Figure 3.2.17 (system design capacity used to calculated DOE-2 Simulated EER is 31% less than that used in Figures 3.2.15 and 3.2.16). Simulated EER values are quantitatively closer to rated values, with cooler climates slightly greater than rated values and hotter climates lower. This is what one would expect. Based on this, climate zone multipliers for EER were developed similar to those for condensing unit SEER. They are provided in Table 3.2.7. A comparison of rated EER adjusted for weather conditions to those obtained from simulations is shown in Figure 3.2.18. This figure includes the additional building zones, not just the west-facing zone. Rated EER, when adjusted for climate affects, can reproduce those from DOE-2 simulations to within +12% and –17% at a 99% confidence interval.

Figure 3.2.17
Simulated (without over-sizing) vs. Rated EER – Packaged Systems
West-facing Perimeter Zone

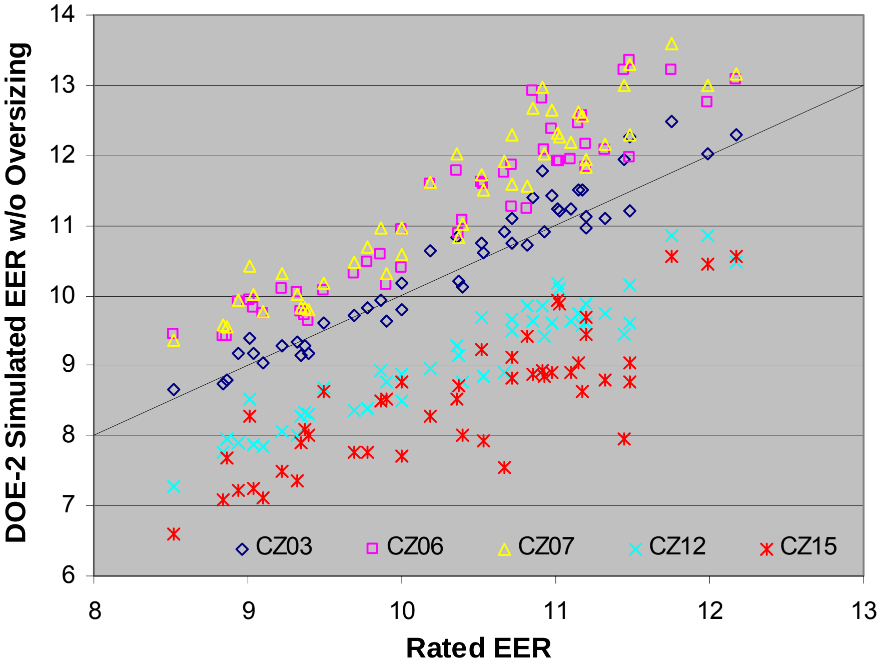


Figure 3.2.18
Simulated (without over-sizing) vs. Climate Zone Adjusted EER
Packaged Systems – Office Application

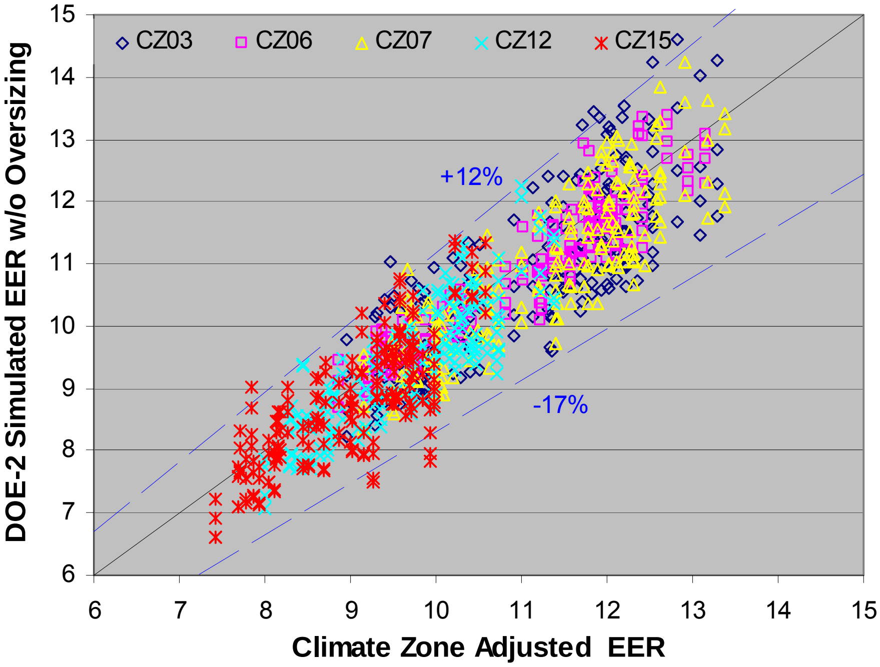


Table 3.2.7
Rated EER Climate Multipliers
Median Building Features – CZ03, CZ06, CZ07, CZ12 and CZ15

Rated SEER	CZ03	CZ06	CZ07	CZ12	CZ15
10	1.05	1.04	1.07	0.94	0.87
12	1.06	1.06	1.09	0.92	0.87
13	1.09	1.08	1.10	0.94	0.87

Note: Multipliers do not include EER impacts caused by system over-sizing

The range of demand benefits associated with upgrading to higher-SEER systems is given in Table 3.3.7. The "Expected" value is that associated with the change in rated SEER. As illustrated in Figure 3.2.15 and confirmed in Table 3.2.8, moving to a higher SEER system does not guarantee a demand reduction. One has to move 3 SEER ratings points to guarantee demand reductions for the systems examined in this study. Median demand reductions associated with moving to a higher SEER-rated unit are similar that associated with changes in SEER except for the hotter climate zones (CZ12 and CZ15).

Table 3.2.8
Demand Benefit of Moving to a Higher SEER System
Packaged Systems Used in Office Setting – Building Average

		Percentage Decrease in Peak Cooling Demand			
	SEER Change	Expected[1]	Maximum	Median	Minimum
CZ03	*SEER 10 to 13*	23%	35%	22%	10%
	SEER 10 to 12	17%	26%	15%	1%
	SEER 12 to 13	8%	24%	8%	*-6%*
CZ06	*SEER 10 to 13*	23%	34%	22%	11%
	SEER 10 to 12	17%	27%	16%	2%
	SEER 12 to 13	8%	23%	8%	*-7%*
CZ07	*SEER 10 to 13*	23%	33%	22%	8%
	SEER 10 to 12	17%	26%	16%	0%
	SEER 12 to 13	8%	23%	8%	*-7%*
CZ12	*SEER 10 to 13*	23%	36%	18%	7%
	SEER 10 to 12	17%	30%	13%	*-5%*
	SEER 12 to 13	8%	26%	5%	*-10%*
CZ15	*SEER 10 to 13*	23%	37%	16%	4%
	SEER 10 to 12	17%	31%	11%	*-9%*
	SEER 12 to 13	8%	27%	5%	*-11%*

Note 1: Based on SEER increase

EER, while a better indicator of system demand, does not necessarily provide a guide to demand reduction. The variability of space loads and their interaction with ambient conditions (solar and dry bulb and wet-bulb temperatures) can differ significantly from those assumed in the ARI ratings process. Simulations suggest one should expect a 39% (+12% to –17%) variability in cooling system demand among packaged systems with similar EER ratings. 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. R-410 systems are more efficient at the 82ºF SEER rating point, but less efficient for outdoor temperatures greater than 95ºF than their R-22 counterparts. 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. This was bourn out by DOE-2 simulations.

3.2.8 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.

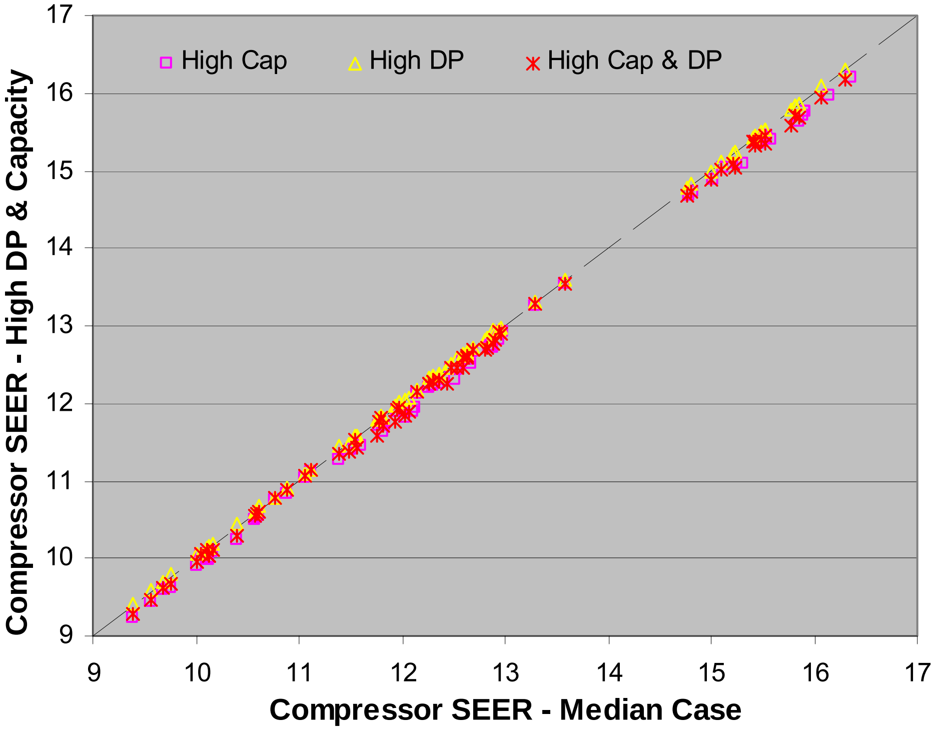
Median fan energy values assume a system external static pressure of 0.48" w.g.. This is the median total system static pressure determined from the CEC PIER Integrated Design of Small HVAC Systems. Since this is greater than the 0.10 to 0.20" w.g. used in the SEER ratings process (Table 3.2.1), median 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 31% over-sizing rule as described above. While this is felt to be an appropriate sizing approach for commercial applications, additional over-sizing was examined to establish the sensitivity of the analysis to sizing issues.

The impacts of increased fan energy and system over sizing are shown in Figures 3.2.19 and 3.2.20. Figure 3.2.19 compares the condensing 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 3.2.20 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 3.2.19

Effect of Higher Fan Energy and System Sizing on Condensing unit SEER
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. Condensing 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 condensing unit seasonal energy use, just that the seasonal condensing unit efficiency is unaffected.

2. Fan static pressure and system over sizing do reduce overall system efficiency ($SEER_f$), as illustrated in Figure 3.2.12. 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).

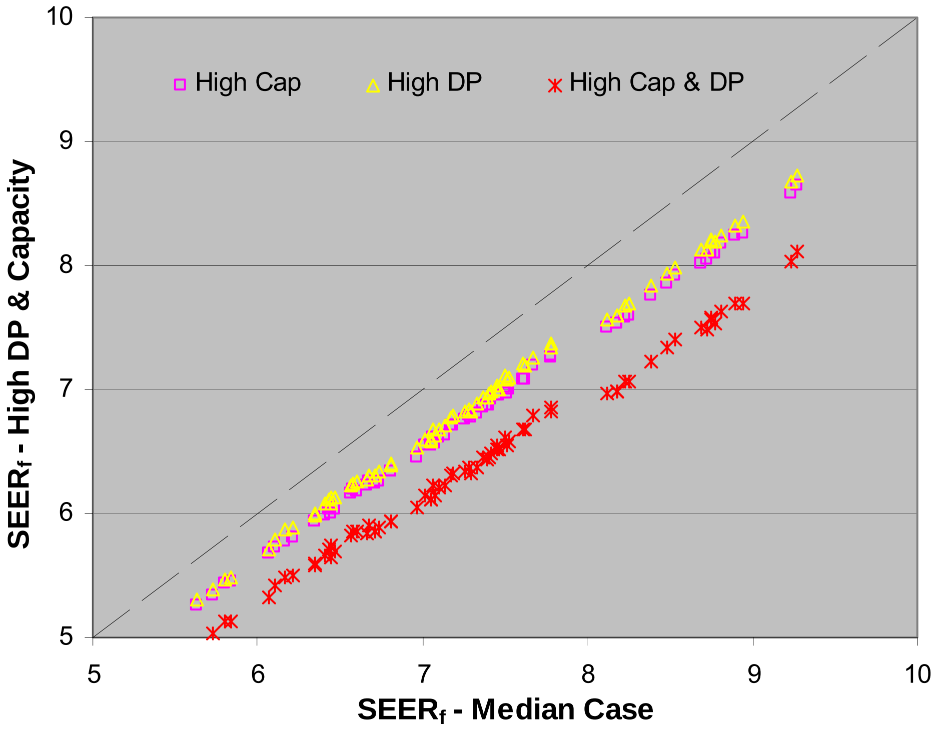
3. Within the range of increased static pressure and system over sizing, the effects are additive. Increased static pressure decreases $SEER_f$ by 4% - 5%. Increased system sizing reduces $SEER_f$ by 7%. Increased static pressure plus increased system sizing reduces $SEER_f$ by 11% - 12%.

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 condensing 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 condensing 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.

Figure 3.2.20

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



3.3 RETAIL SYSTEMS

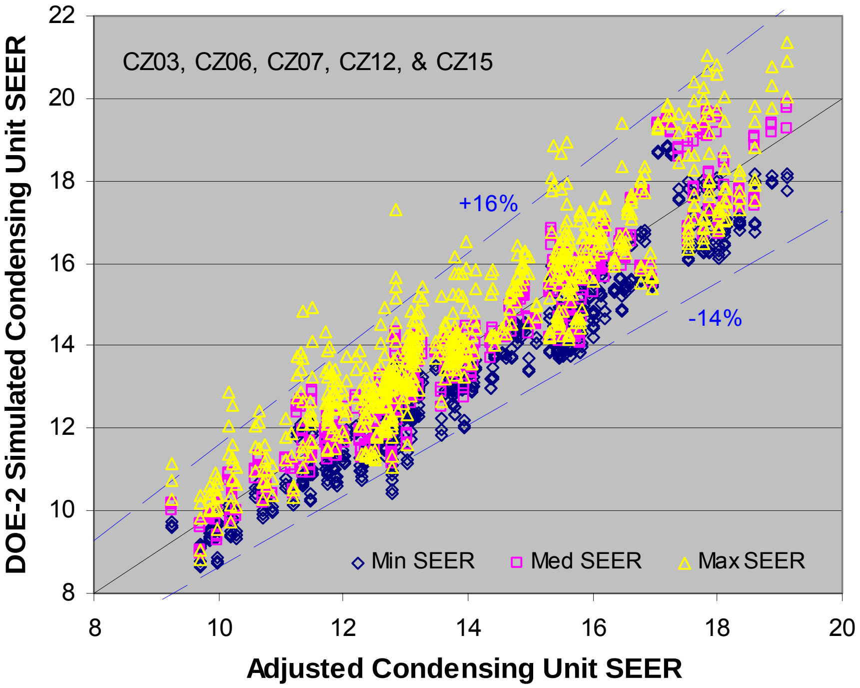
The issues and simulation results of cooling systems used in retail applications are like those of small offices, Section 3.2. A description of the retail building prototypes is provided in Section 2.4.2, with details given in Appendix D. Like office applications, it is assumed that retail buildings 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 significant fraction of seasonal energy use. Results presented in this section include intermediate finding used to illustrate the issues and findings presented in Section 3.2. The reader is referred to Section 3.2 for the details associated with the use of SEER-rated equipment applied to commercial applications.

3.3.1 Condensing Unit SEER and SEER$_f$

Like small office system, changes in building construction and operation have a significant affect on cooling system performance. Figure 3.3.1 illustrates how these factors impact condensing unit SEER (cooling system SEER exclusive of fan energy). Building features that lead to higher and lower values of condensing unit SEER for retail application are given in Table 3.3.1. As has been noted previously, building features that lead to higher values of condensing unit SEER do not necessarily result in reduced cooling energy, just improved compressor-operating efficiency (see related comments in Sections 3.2.4 and 3.2.5).

Figure 3.3.1

Calculated (Simulated) vs. Rated Condensing Unit SEER for All Packaged Systems
Minimum, Median and Maximum SEER Retail Building Features



Condensing unit SEER as determined by DOE-2 simulations is compared to rated condensing unit SEER adjusted for climate zone. Climate zone adjustments for condensing unit SEER consistent with those presented in Table 3.2.2 for small office applications are given in Table 3.3.2 for retail applications. The results for retail are similar to those for small offices (Figure 3.2.9), but with increased variation (+16% to –14% for retail applications as compared to +11%to –10% for offices). A likely cause for the difference is the additional ventilation air assumed in retail applications. Average ventilation rates for offices are ~9% of design air flow; those for retail applications is ~14%. Cooling system performance can vary significantly from unit-to-unit as coil entering conditions vary from standard ratings conditions of 80ºF dry bulb and 67ºF wet-bulb.

Fan-to-compressor runtime ratios for retail cooling systems and median building features are given in Table 3.3.3. Extending operating hours from the assumed 85 hours for the median case to 144 hours for the maximum operating schedule produced a 0.6% increase runtime ratio for each hour above the median value. Runtime ratio remains essentially constant as the operating hours decrease below the median value of 85 hours per week. The resulting values of estimated SEER_f are compared to values found from simulation in Figure 3.3.2.

Table 3.3.1

Building Parameters Affecting Condensing 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 3.3.2
Condensing Unit SEER Climate Multipliers
Retail Median Building Features – CZ03, CZ06, CZ07, CZ12 and CZ15

System SEER	CZ03	CZ06	CZ07	CZ12	CZ15
10	1.06	1.06	1.05	0.95	0.83
12	1.08	1.07	1.06	0.96	0.82
13	1.15	1.13	1.12	0.99	0.81

Table 3.3.3
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	3.54	2.88	2.90	4.52	3.36
Storage	4.81	3.47	3.38	5.22	3.41
Building	3.74	2.99	2.99	4.66	3.37

Figure 3.3.2
Calculated (Simulated) vs. Estimate $SEER_f$ for All Packaged Systems
Retail Minimum, Median and Maximum SEER Building Features

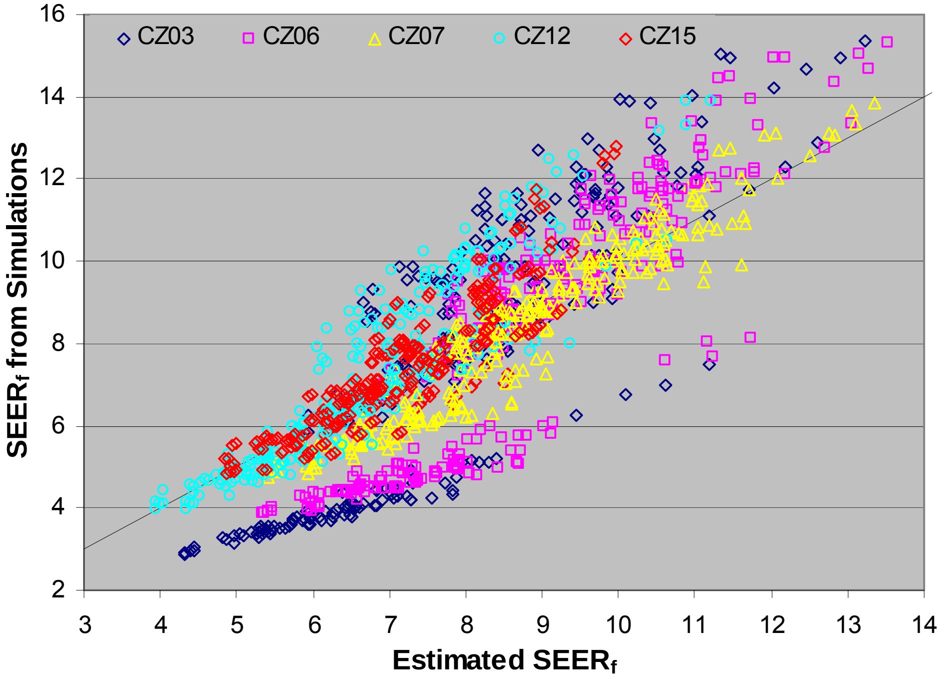


Figure 3.3.2 illustrates that, as with office systems (Figure 3.2.9), $SEER_f$ is not a very useful metric for estimating seasonal cooling energy from the cooling load. It is, however, useful in selecting from among various cooling systems for use in a retail application. Using $SEER_f$ to rank packaged cooling systems can reduce the chance of selecting a system with poor seasonal performance over selecting the systems by rated SEER alone (see Section 3.2.6 for a more complete discussion). System ranking based on estimates of $SEER_f$ using condensing unit multipliers given in Table 3.3.2 and runtime ratios in Table 3.3.3 are shown in Figures 3.3.3a through 3.3.5b. $SEER_f$ is less effective as a ranking tool for retail application than for small offices. This is because of higher variability in the condensing unit SEER for retail applications (+16% to –14%) than for offices (+11% to –10%).

Figure 3.3.3a

Ranking of Packaged Systems by $SEER_f$ – CZ06

Median Building Features, All Systems

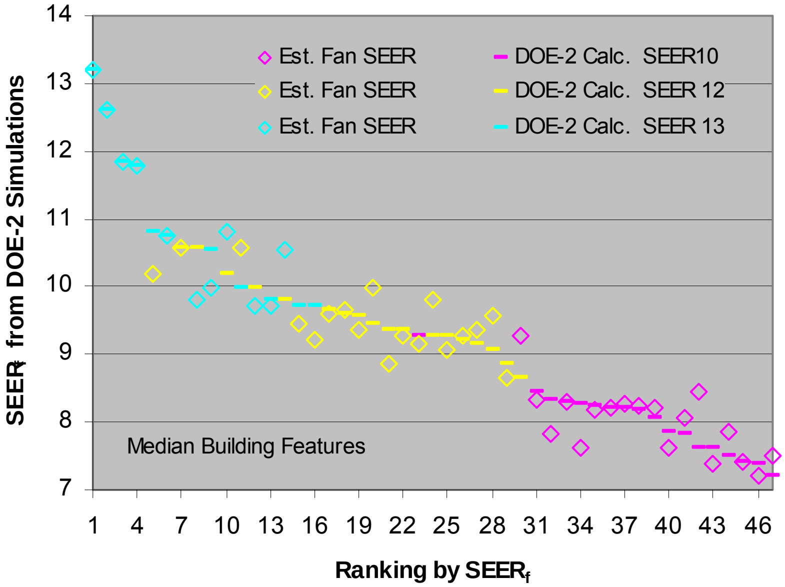
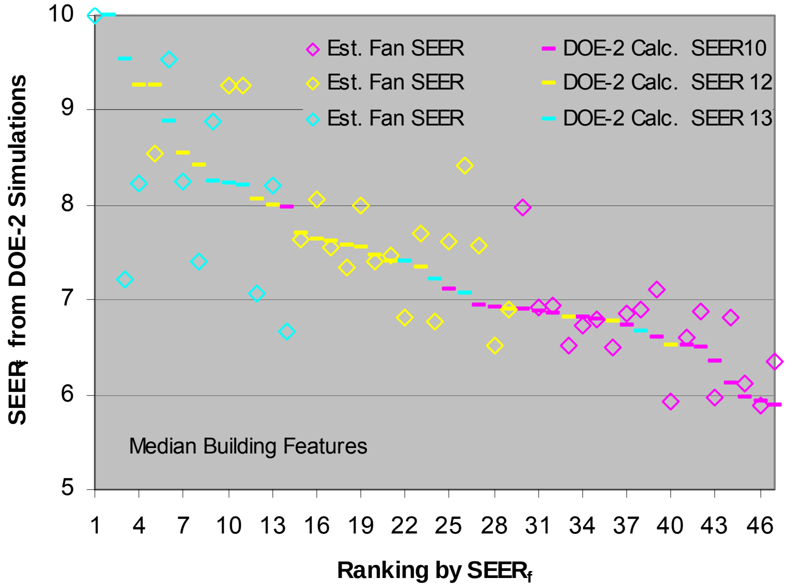


Figure 3.3.3b

Ranking of Packaged Systems by SEER$_f$ – CZ15
Median Building Features, All Systems



Figures 3.3.4a and b are counterparts to Figures 3.3.3a and b, except that they are for simulation results based on building features that produce maximum SEER values. Similarly, Figures 3.3.5a and b are for simulation results based on building features that produce minimum SEER values.

Figure 3.3.4a

Ranking of Packaged Systems by SEER$_f$ – CZ06
Maximum SEER Building Features, All Systems

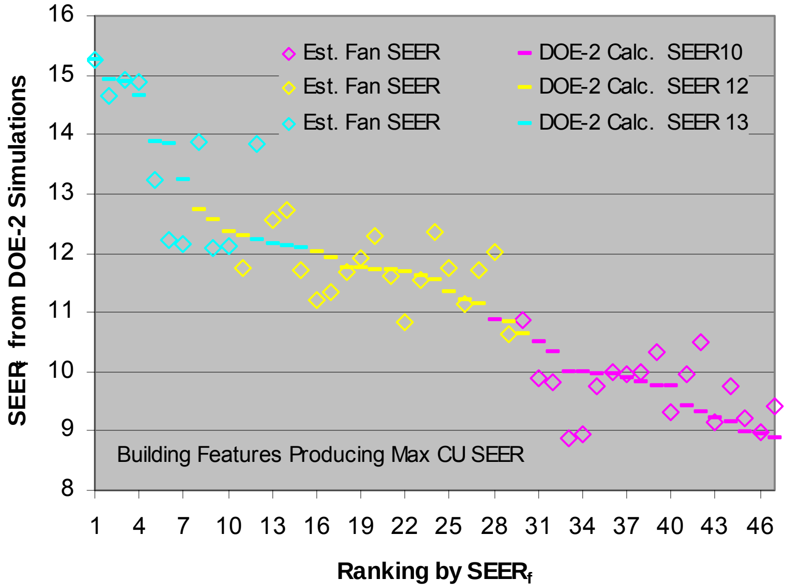


Figure 3.3.4b

Ranking of Packaged Systems by SEER$_f$ – CZ15
Maximum SEER Building Features, All Systems

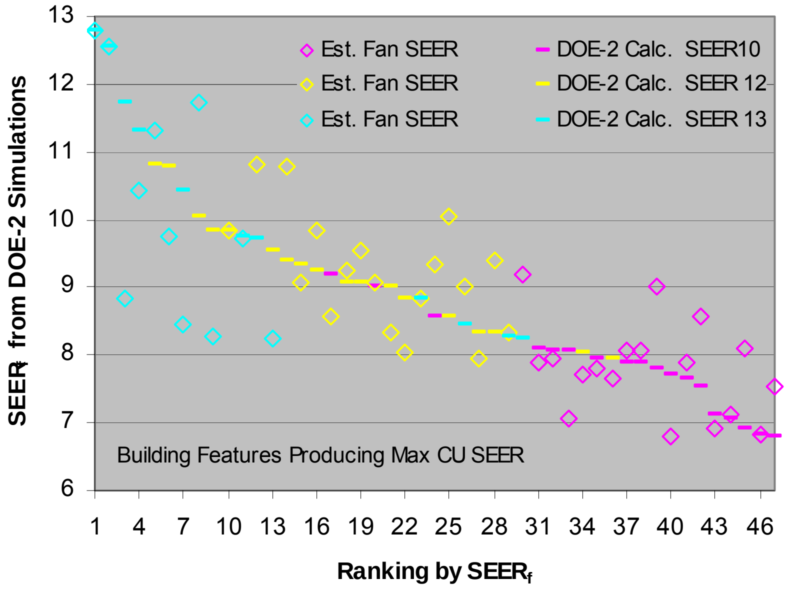


Figure 3.3.5a

Ranking of Packaged Systems by SEER$_f$ – CZ06
Minimum SEER Building Features, All Systems

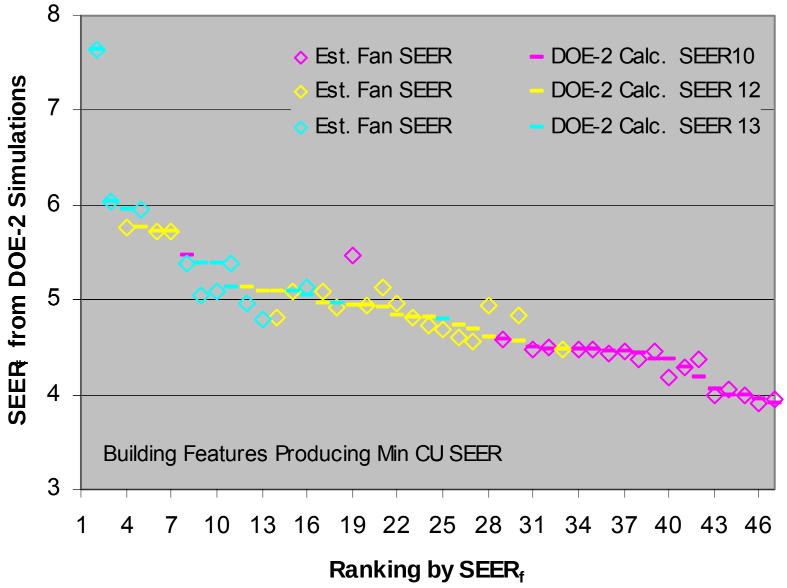
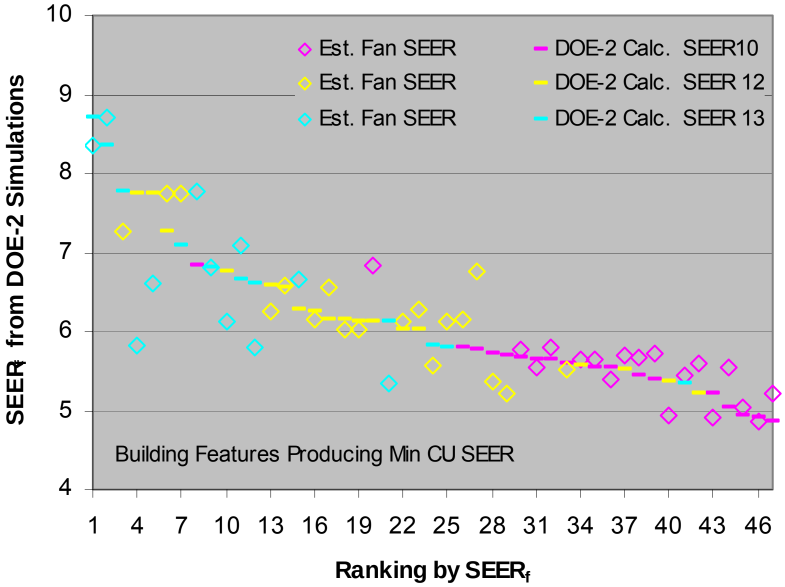


Figure 3.3.5b
Ranking of Packaged Systems by $SEER_f$ – CZ15
Minimum SEER Building Features, All Systems



The variation in actual energy use for same-SEER systems observed in the DOE-2 simulations is given in Table 3.3.4. Values in the table are for the entire building with building features that produce minimum, median, and maximum total SEER (fan plus condensing unit). Using $SEER_f$ to reject the worse systems typically reduces the variation by at least half of that in Table 3.3.4.

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 all the systems considered. If one selected the system at random, one should expect that the system selected could use as much as 25% more cooling energy than the best for this application. The only way to guarantee that the system selected is the best available would be develop detailed unit performance curves based on manufacturers' data and simulate all systems using a detailed energy simulation package like DOE-2.

It is worth noting that the data used to generate Figures 3.3.3.a and b through 3.3.5a and b are the same as that used to produce Figure 3.3.2. Thus, $SEER_f$, while not particularly effective in predicting seasonal energy use, does have benefit in ranking units as to their performance. Also, $SEER_f$ is nearly as effective in ranking systems for building features that produce minimum and maximum condensing unit SEER values as for median SEER values.

Table 3.3.4
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	27%	21%	20%	29%	27%
12	25%	19%	18%	31%	40%
13	45%	34%	33%	43%	45%
	Maximum SEER Building				
10	19%	19%	18%	28%	32%
12	15%	14%	16%	24%	33%
13	25%	25%	26%	36%	52%
	Minimum SEER Building				
10	35%	27%	29%	34%	29%
12	33%	27%	26%	37%	46%
13	74%	62%	55%	57%	50%

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

A comparison of the energy benefit associated with moving to a higher SEER system is given in Table 3.3.5. The tabular data are for 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 3.2.6).

Table 3.3.5

Energy Benefits of Moving to a Higher SEER System

Retail Application Results for the Entire Building, Median Building Parameters

		Percentage Decrease in Seasonal Cooling Energy			
	SEER Change	Expected	Maximum	Median	Minimum
CZ03	*SEER 10 to 13*	23%	49%	25%	-2%
	SEER 10 to 12	17%	35%	13%	-15%
	SEER 12 to 13	8%	39%	13%	-14%
CZ06	*SEER 10 to 13*	23%	46%	24%	4%
	SEER 10 to 12	17%	32%	14%	-7%
	SEER 12 to 13	8%	35%	12%	-9%
CZ07	*SEER 10 to 13*	23%	44%	24%	4%
	SEER 10 to 12	17%	31%	13%	-6%
	SEER 12 to 13	8%	33%	12%	-9%
CZ12	*SEER 10 to 13*	23%	47%	19%	-10%
	SEER 10 to 12	17%	36%	11%	-17%
	SEER 12 to 13	8%	36%	9%	-23%
CZ15	*SEER 10 to 13*	23%	43%	18%	-20%
	SEER 10 to 12	17%	36%	11%	-22%
	SEER 12 to 13	8%	37%	8%	-39%

Note: Seasonal cooling energy includes year-round indoor fan energy

3.3.2 Electric Demand

Climate zone multipliers for retail application are provided in Table 3.3.6. Demand reductions associated with moving to a higher SEER-rated unit are provided in Table 3.3.7. Finally, a comparison of DOE-2 simulated EER (reduced to eliminate the effects of assumed system over sizing) to climate-zone adjusted values (rated EER times multipliers in Table 3.2.6) is given in Figure 3.3.6.

Table 3.3.6

Rated EER Climate Multipliers, Retail Setting

Median Building Features – CZ03, CZ06, CZ07, CZ12 and CZ15

Rated SEER	CZ03	CZ06	CZ07	CZ12	CZ15
10	0.86	0.96	0.90	0.90	0.83
12	0.86	0.96	0.90	0.89	0.79
13	0.83	0.91	0.88	0.92	0.88

Note: Multipliers do not include EER impacts caused by system over-sizing

Table 3.3.7

Demand Benefit of Moving to a Higher SEER System

Packaged Systems Used in Retail Setting – Building Average

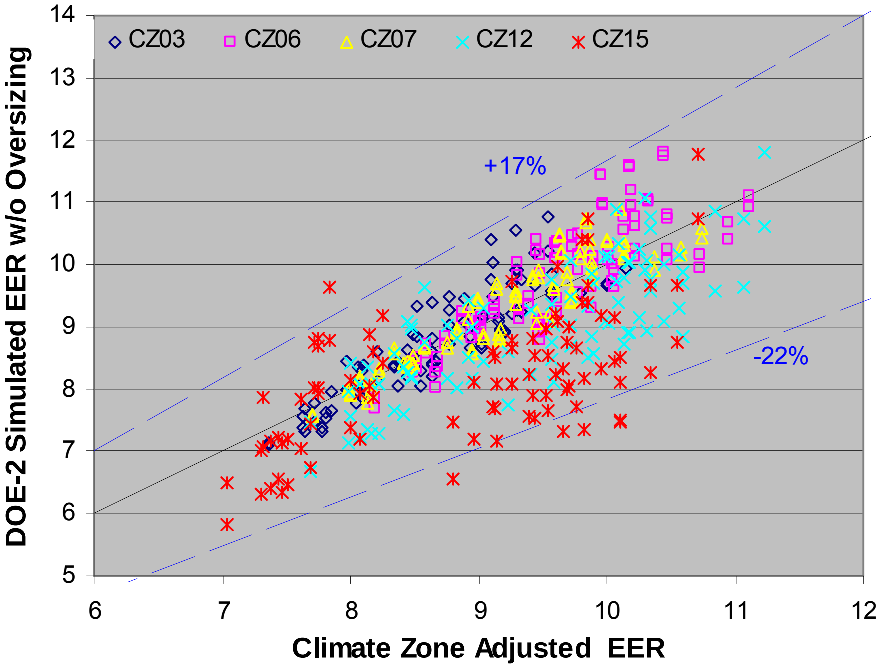
		Percentage Decrease in Peak Cooling Demand			
	SEER Change	Expected[1]	Maximum	Median	Minimum
CZ03	*SEER 10 to 13*	23%	32%	14%	-1%
	SEER 10 to 12	17%	33%	10%	-10%
	SEER 12 to 13	8%	19%	4%	-17%
CZ06	*SEER 10 to 13*	23%	33%	15%	0%
	SEER 10 to 12	17%	34%	12%	-13%
	SEER 12 to 13	8%	23%	3%	-16%
CZ07	*SEER 10 to 13*	23%	29%	17%	4%
	SEER 10 to 12	17%	30%	12%	-5%
	SEER 12 to 13	8%	17%	6%	-13%
CZ12	*SEER 10 to 13*	23%	37%	19%	1%
	SEER 10 to 12	17%	30%	11%	-13%
	SEER 12 to 13	8%	27%	9%	-9%
CZ15	*SEER 10 to 13*	23%	45%	14%	-18%
	SEER 10 to 12	17%	38%	10%	-30%
	SEER 12 to 13	8%	37%	4%	-27%

Note 1: Based on SEER increase

While the general conclusions and observations related to peak cooling system are similar to those noted in Section 3.2.6, the variation in demand from unit-to-unit is greater. This appears to be associated with assumed greater design outside air requirements for retail applications. This produces cooling coil entering conditions (dry bulb and wet-bulb) that are farther from standard ratings (80ºF dry bulb, 67ºF wet-bulb) than for office applications, causing greater differences in cooling efficiency from unit-to-unit. The result is a variation of +17% to –22% in peak demand for retail applications as compared to +12% to –17% for office applications. Because of this, one could not be guaranteed significant demand reductions when upgrading 3 SEER points (SEER-10 to SEE13). At least one SEER-10 unit had a demand value 18% lower that the worse performing SEER-13 unit.

Figure 3.3.6

DOE-2 Simulated vs. Rated EER – Retail Application
Building Average



3.3.3 Increased Fan Energy and System Over Sizing

The impacts of higher external static pressure and system over sizing on condensing unit SEER and $SEER_f$ do not differ significantly from that of office systems. The reader is referred to section 3.2.8 for system impacts associated with these issues.

3.4 SCHOOL CLASSROOM SYSTEMS

The issues and simulation results of cooling systems used in school classroom applications are like those of small offices as provided in Section 3.2. A description of the school building prototype is provided in Section 2.4.3, with details given in Appendis E. 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. 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 (closed 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 peak summer cooling season. Separate results presented in this section for non-summer and year-round operational schedules.

Note that this section deals with the assumed use of packaged cooling systems to cool school classrooms. Other areas of the school, such as administrative offices, which are more likely to be operated year-round, have 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 (>65,000 Btuh cooling capacity) that would not be SEER-rated.

3.4.1 Condensing 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 3.4.1.a and 3.4.1.b, for condensing unit SEER (cooling system SEER exclusive of fan energy). The two figures are for partial year (summer break) and year-round (no summer break) operations. The figures includes condensing unit SEER values associated with building features that lead to minimum, median and maximum system SEER. Building features that produce higher and lower values of system SEER for classroom applications are given in Table 3.4.1. 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 Sections 3.2.4 and 3.2.5).

Condensing unit SEER as determined by the DOE-2 simulations is compared to rated condensing unit SEER adjusted for climate zone. Climate zone adjustments for condensing unit SEER are given in Table 3.4.2 for school classroom applications for part and year-round operation. Climate zone multipliers are similar for the two operating schedules, with the greater differences occurring in the warmer climates (CZ12 and CZ15).

Condensing unit SEER is slightly more predictable than for office or retail applications (compare to Figures 3.4.1a and b to Figures 3.2.9 and 3.3.1). Most of the variation in condensing unit

SEER is related to performance differences between the various cooling systems rather than changes in building features.

Figure 3.4.1.a

DOE-2 Simulated vs. Adjusted Condensing Unit SEER for All Packaged Systems
Minimum, Median and Maximum SEER Building Features, No Partial-Year Operation

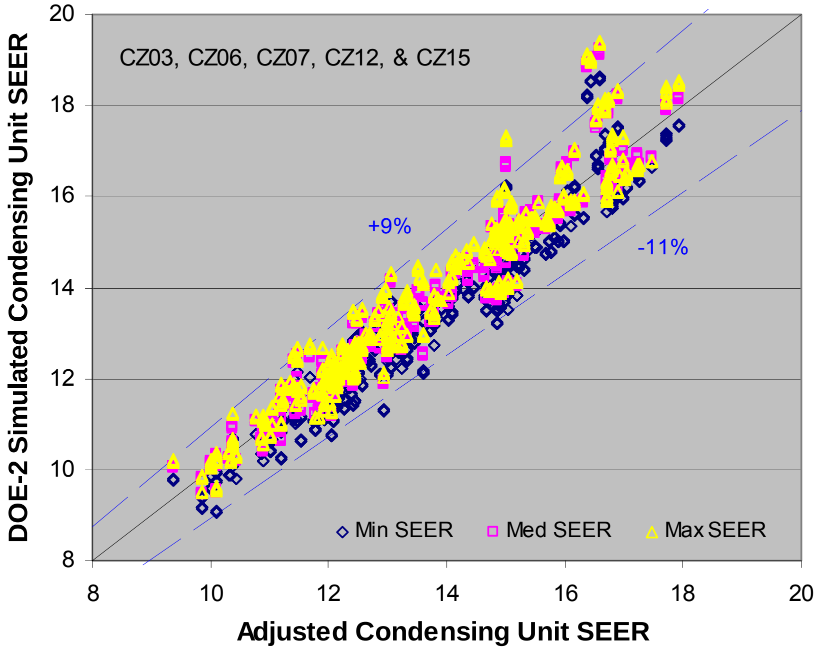
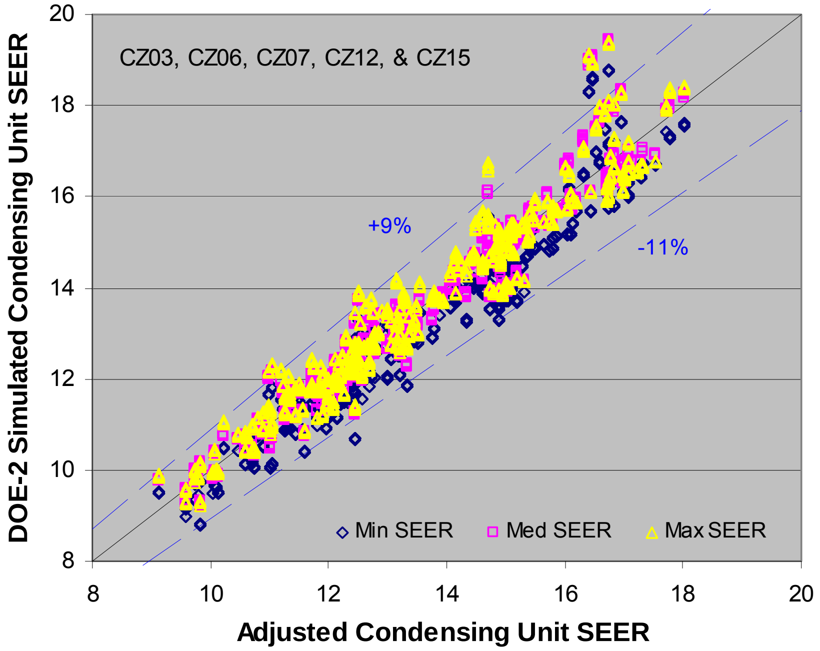


Figure 3.4.1.b

DOE-2 Simulated vs. Adjusted Condensing Unit SEER for All Packaged Systems
Minimum, Median and Maximum SEER Building Features, Year-Round Operation



Fan-to-condensing unit runtime ratios for classroom cooling systems are given in Table 3.4.3. Fan operation in comparison to condensing unit operation is slightly greater for partial year than for year-round operation. This is not surprising, as one would expect greater condensing unit operation during the summer, leading to lower fan-to-condensing unit runtime ratios. The resulting estimated $SEER_f$ are compared to values obtained from DOE-2 simulations in Figures 3.4.2.a and 3.4.2.b. Results are similar to office applications as illustrated in Figure 3.2.11.

Table 3.4.1
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 3.4.2
Condensing Unit SEER Climate Multipliers
Classrooms – CZ03, CZ06, CZ07, CZ12 and CZ15

System SEER	CZ03	CZ06	CZ07	CZ12	CZ15
	Partial Year Usage (with Summer Break)				
10	1.00	1.02	1.01	0.93	0.84
12	1.02	1.03	1.03	0.94	0.83
13	1.06	1.08	1.06	0.96	0.83
	Year-Round Usage (no Summer Break)				
10	1.01	1.03	1.01	0.91	0.82
12	1.02	1.04	1.03	0.92	0.80
13	1.07	1.08	1.06	0.93	0.79

Table 3.4.3
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	9.38	5.40	4.82	7.73	4.01
Year-Round	7.83	4.11	4.35	6.24	3.62

Figures 3.4.2.a and 3.4.2.b illustrate that $SEER_f$ is not a very useful metric for estimating seasonal cooling energy from the cooling load in classroom application. It is, however, useful in selecting more efficient units from a selection of same or differing SEER cooling systems. While not perfect, $SEER_f$ ranks the seasonal efficiency of cooling systems better than rated-SEER alone. It can reduce the chance of selecting a system with poor seasonal performance (see Section 3.2.6 for a more complete discussion). The variation in actual energy use for same-SEER systems obtained from DOE-2 simulations is given in Tables 3.4.4a and b. Values in Table 3.4.4a are for the average of all classrooms (partial-year operation) with building features that produce minimum, median, and maximum total SEER (fan plus condensing unit). Results for year-round school operation are similar as provided in Table 3.4.4b. Using $SEER_f$ to reject the worse systems typically reduced the variation by at least half of that shown in Tables 3.4.4a and b.

For example, assume one used $SEER_f$ to rank SEER-12 systems for use in a typical classroom application in Climate Zone 3 with partial-year usage. The system selected with the best $SEER_f$ rating would fare no worse than 13% 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 27% 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 use a detailed energy simulation package like DOE-2 to simulate all systems under consideration.

Figure 3.4.2.a
DOE-2 Simulated vs. Estimated SEER$_f$ for All Packaged Systems
Partial Year Operation, Min, Median and Max SEER Building Features

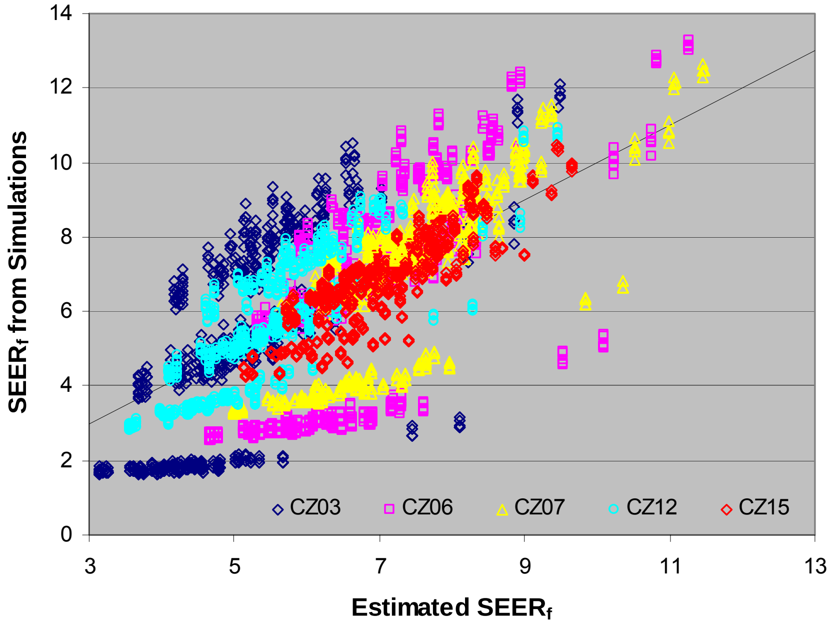
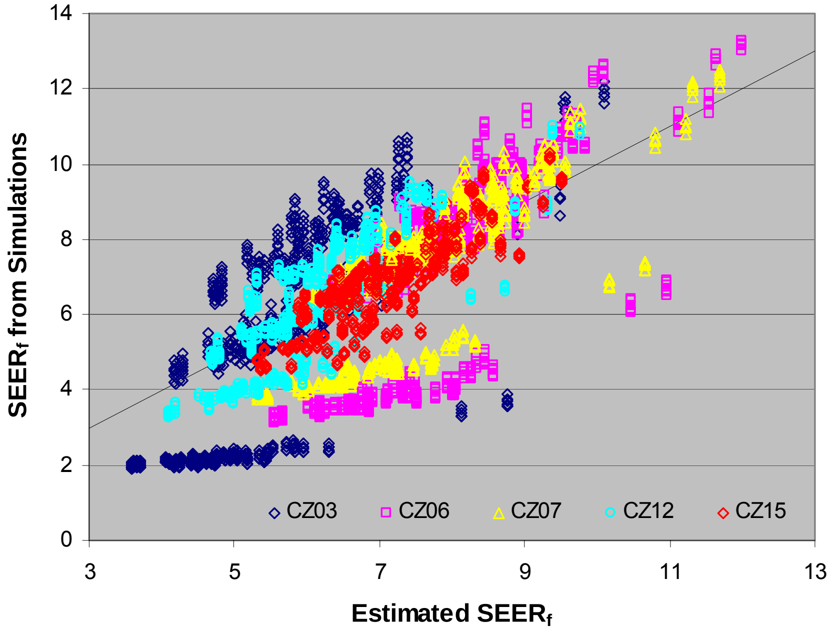


Figure 3.4.2.b
DOE-2 Simulated vs. Estimated SEER$_f$ for All Packaged Systems
Year-Round Operation, Min, Median and Max SEER Building Features



Figures 3.4.3a through 3.4.8b compare performance rankings of the various packaged systems based on DOE-2 simulation and estimates using fan SEER equations and values provided in Tables 3.4.2 and 3.4.3. The figures illustrate that SEER$_f$ is better able to rank systems for cooler climates (CZ06 vs. CZ15 in the figures) and building features that produce minimum SEER

values. Ranking errors are similar between schools on a partial-year schedule as compared to a year-round operating schedule.

Figure 3.4.3a

Ranking of Packaged Systems by $SEER_f$ – CZ06

Median Building Features, All Systems, Partial Year Operation

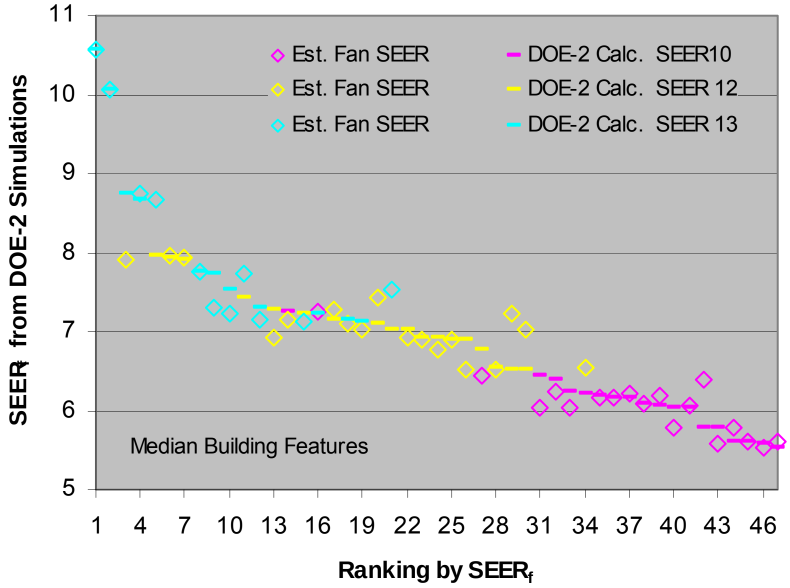


Figure 3.4.3b

Ranking of Packaged Systems by $SEER_f$ – CZ15

Median Building Features, All Systems, Partial Year Operation

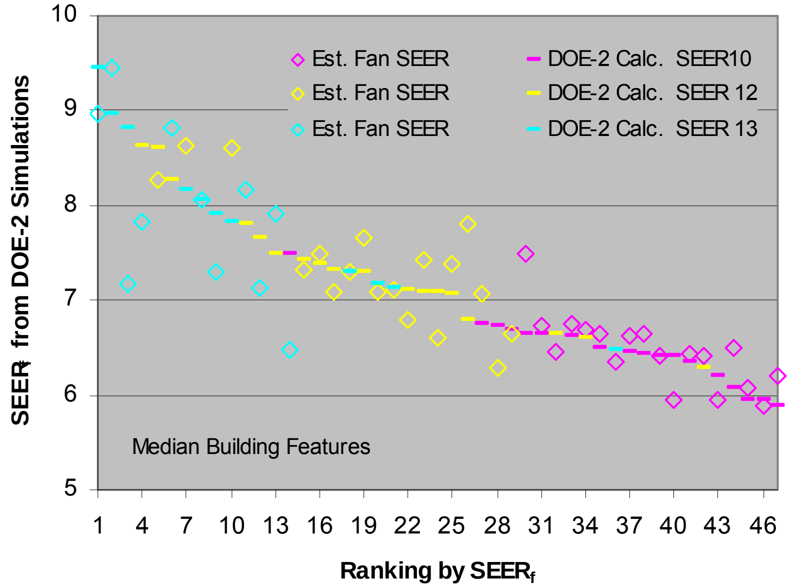


Figure 3.4.4a

Ranking of Packaged Systems by SEER$_f$ – CZ06
Maximum SEER Building Features, All Systems, Partial Year Operation

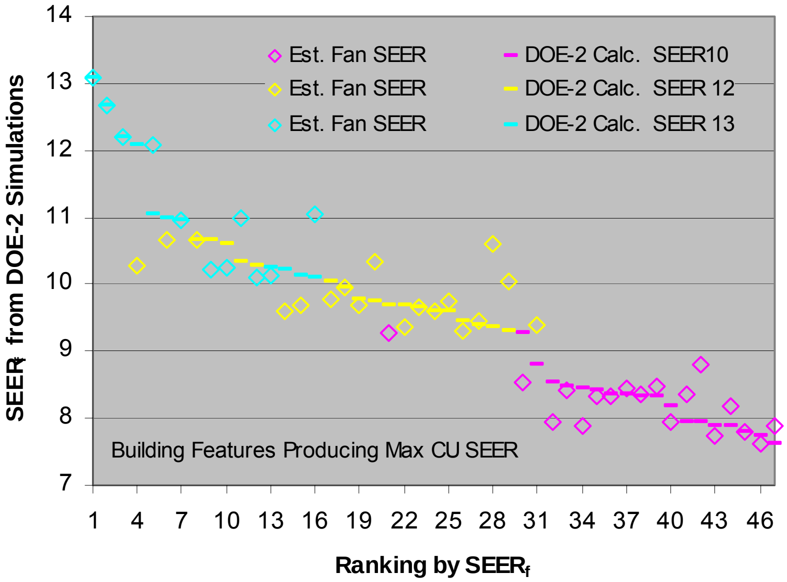


Figure 3.4.4b

Ranking of Packaged Systems by SEER$_f$ – CZ15
Maximum SEER Building Features, All Systems, Partial Year Operation

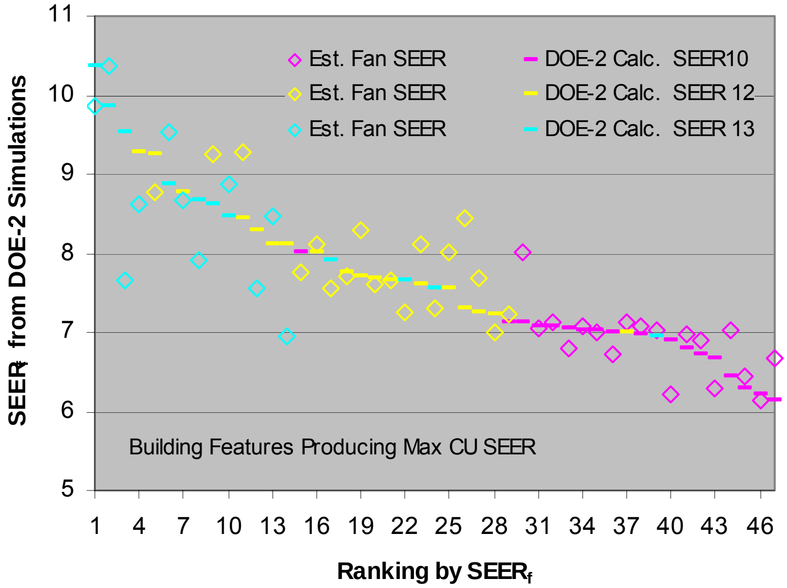


Figure 3.4.5a

Ranking of Packaged Systems by SEER$_f$ – CZ06

Minimum SEER Building Features, All Systems, Partial Year Operation

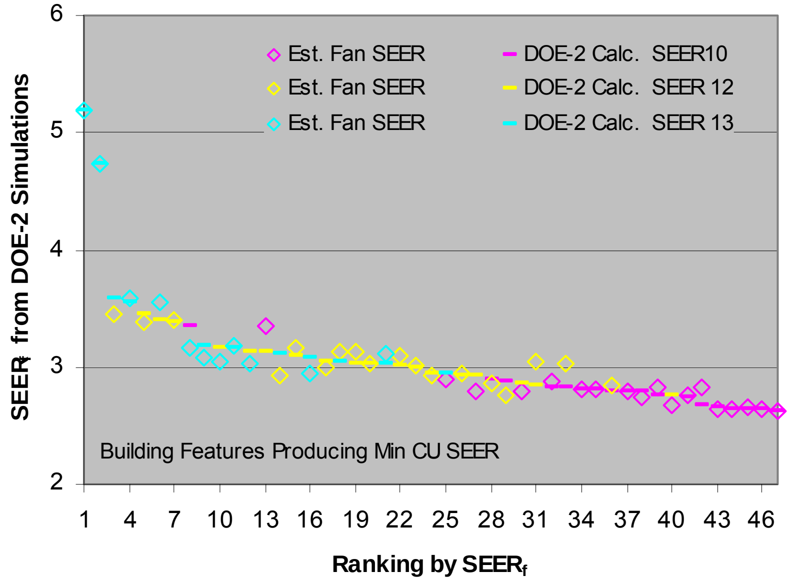


Figure 3.4.5b

Ranking of Packaged Systems by SEER$_f$ – CZ15

Minimum SEER Building Features, All Systems, Partial Year Operation

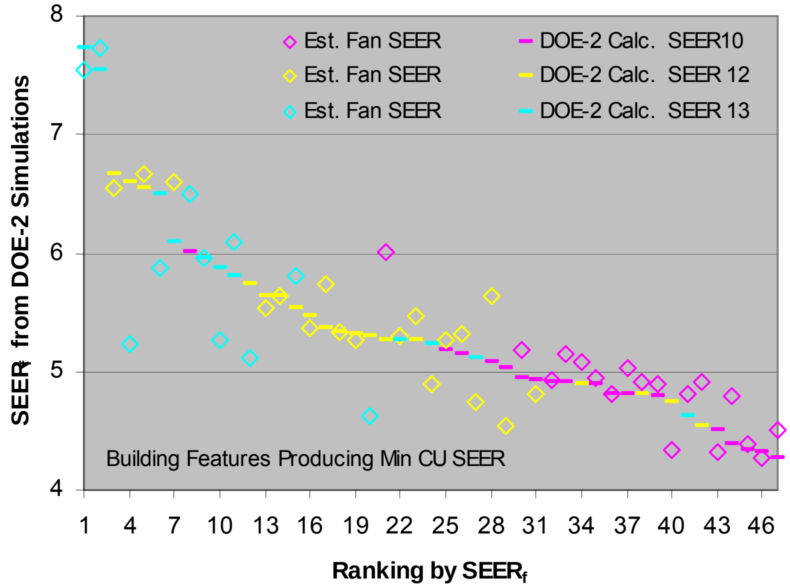


Figure 3.4.6a

Ranking of Packaged Systems by SEER$_f$ – CZ06

Median Building Features, All Systems, Year-Round Operation

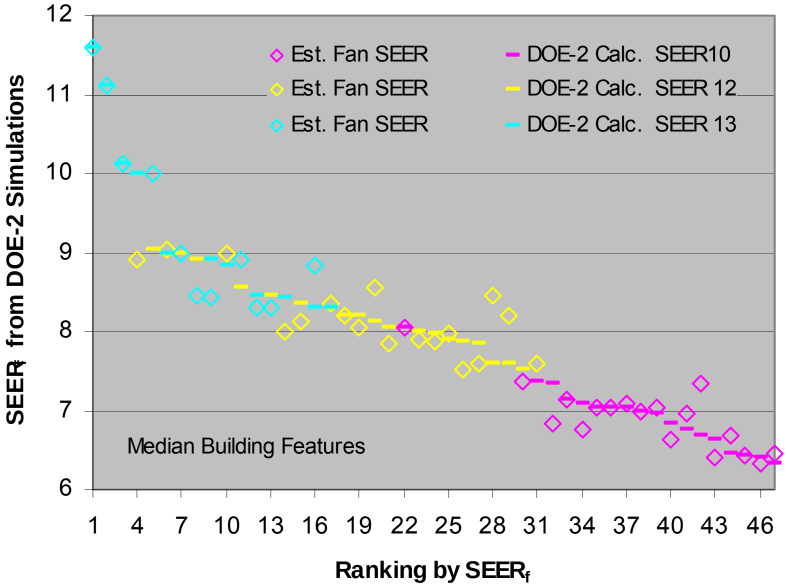


Figure 3.4.6b

Ranking of Packaged Systems by SEER$_f$ – CZ15

Median Building Features, All Systems, Year-Round Operation

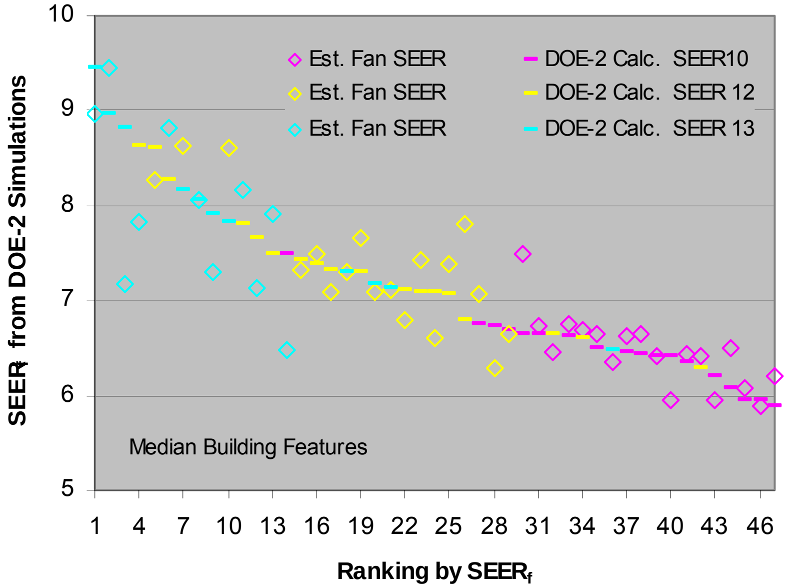


Figure 3.4.7a

Ranking of Packaged Systems by SEER$_f$ – CZ06

Maximum SEER Building Features, All Systems, Year-Round Operation

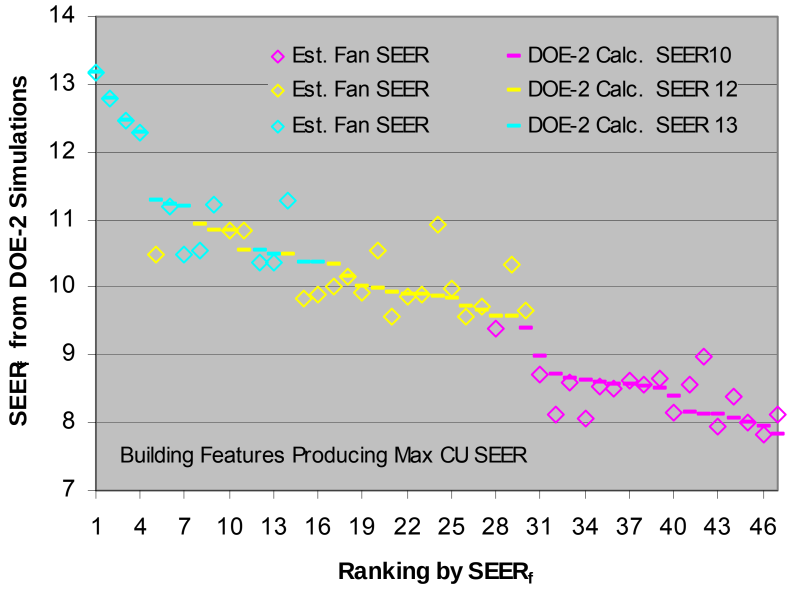


Figure 3.4.7b

Ranking of Packaged Systems by SEER$_f$ – CZ15

Maximum SEER Building Features, All Systems, Year-Round Operation

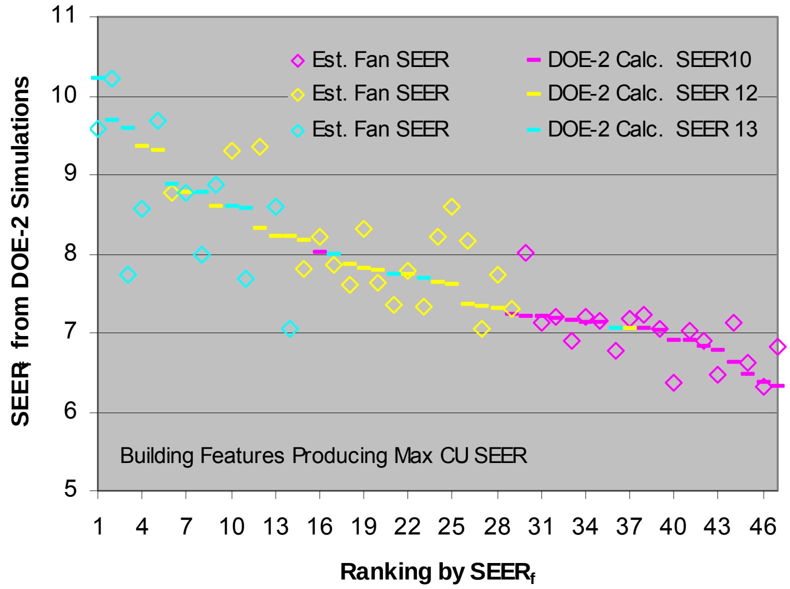


Figure 3.4.8a
Ranking of Packaged Systems by SEER$_f$ – CZ06
Minimum SEER Building Features, All Systems, Year-Round Operation

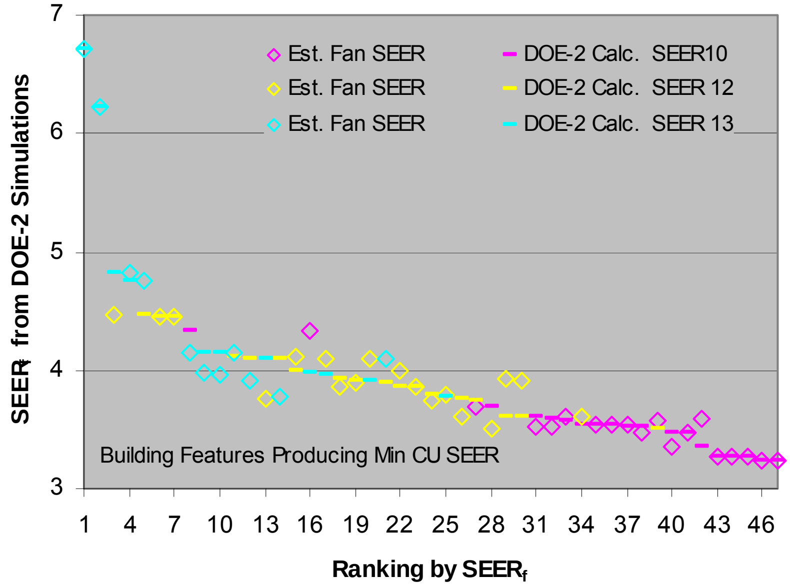
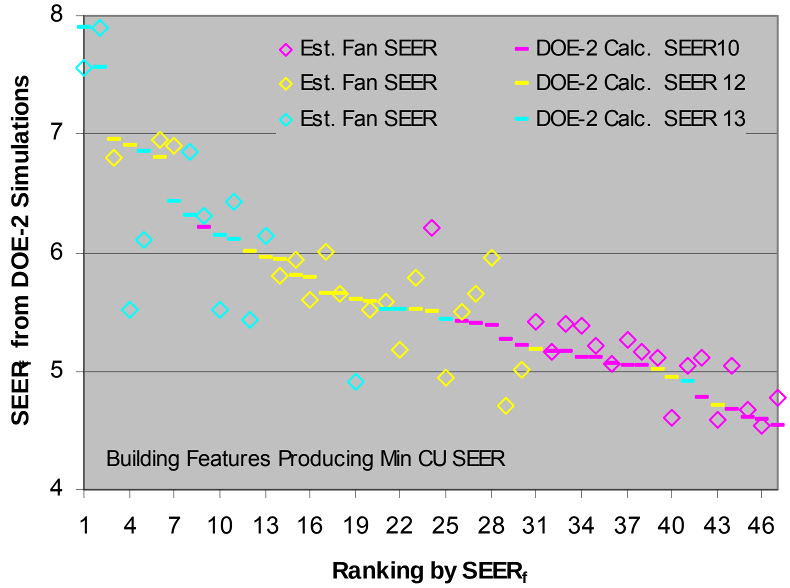


Figure 3.4.8b
Ranking of Packaged Systems by SEER$_f$ – CZ15
Minimum SEER Building Features, All Systems, Year-Round Operation



SEER$_f$ does a good job of ranking systems for cooler climates (CZ03, CZ06, and CZ07), even picking lower over higher rated SEER units when appropriate. It is less successful for hotter climates, particularly CZ15. School cooling systems have the highest fraction of outside air to the cooling coil (48%) of the applications examined here. Coil entering conditions that differ significantly from nominal ARI ratings values produce a good deal of variation in both condensing unit SEER and fan-to-condensing unit runtime ratio from unit-to-unit from the median values used in fan SEER calculations. This affect is greater in hotter climate zones, reducing the efficacy of $SEER_f$ as a seasonal cooling efficiency ranking tool.

Table 3.4.4.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	30%	23%	21%	32%	23%
12	27%	22%	20%	33%	33%
13	59%	44%	39%	55%	39%
	Maximum SEER Building				
10	23%	18%	19%	27%	21%
12	20%	14%	15%	26%	31%
13	37%	27%	28%	40%	37%
	Minimum SEER Building				
10	13%	19%	23%	34%	30%
12	17%	22%	24%	34%	43%
13	61%	66%	65%	71%	55%

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

Table 3.4.4.b

Differences in Annual Cooling System Energy Use for Same SEER Systems
Classroom Application –Year-Round Operation

Rated SEER	CZ03	CZ06	CZ07	CZ12	CZ15
	Median Building				
10	28%	21%	19%	29%	20%
12	25%	19%	18%	30%	34%
13	53%	37%	34%	47%	35%
	Maximum SEER Building				
10	22%	16%	17%	24%	19%
12	18%	13%	14%	24%	30%
13	35%	25%	26%	35%	33%
	Minimum SEER Building				
10	16%	23%	21%	33%	27%
12	21%	25%	23%	36%	44%
13	64%	68%	55%	62%	49%

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

The performance variation among like-SEER units given in Tables 3.4.4.a and 3.4.4.b are similar to office systems. Comparisons of the energy benefit associated with moving from lower SEER rated unit to a higher SEER rated packaged system are given in Table 3.4.5.a and 3.4.5.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 benefits associated with moving to a higher SEER unit are somewhat less than office applications. This is because of the greater relative importance of fan energy, especially in partial-year classroom applications. One SEER-10 system with relatively low fan energy outperformed a SEER-13 system with higher indoor fan energy. Overall conclusions for classroom applications mirror those discussed for office systems. A comparison of fan energy requirements for the various systems examined in this study is provided in Figure 3.2.4.

Table 3.4.5.a

Energy Benefits of Moving to a Higher SEER System
Median Building Parameters, Partial-Year Classroom Application

		Percentage Decrease in Seasonal Cooling Energy			
	SEER Change	Expected	Maximum	Median	Minimum
CZ03	*SEER 10 to 13*	23%	53%	18%	-9%
	SEER 10 to 12	17%	33%	11%	-20%
	SEER 12 to 13	8%	45%	7%	-17%
CZ06	*SEER 10 to 13*	23%	48%	21%	-2%
	SEER 10 to 12	17%	31%	14%	-11%
	SEER 12 to 13	8%	38%	9%	-12%
CZ07	*SEER 10 to 13*	23%	46%	21%	1%
	SEER 10 to 12	17%	30%	14%	-8%
	SEER 12 to 13	8%	36%	8%	-10%
CZ12	*SEER 10 to 13*	23%	50%	19%	-16%
	SEER 10 to 12	17%	36%	10%	-24%
	SEER 12 to 13	8%	42%	9%	-28%
CZ15	*SEER 10 to 13*	23%	40%	19%	-17%
	SEER 10 to 12	17%	33%	11%	-19%
	SEER 12 to 13	8%	35%	8%	-34%

Table 3.4.5.b
Energy Benefits of Moving to a Higher SEER System
Median Building Parameters, Year-Round Classroom Application

		Percentage Decrease in Seasonal Cooling Energy			
	SEER Change	Expected	Maximum	Median	Minimum
CZ03	*SEER 10 to 13*	23%	51%	19%	-6%
	SEER 10 to 12	17%	33%	12%	-17%
	SEER 12 to 13	8%	43%	8%	-15%
CZ06	*SEER 10 to 13*	23%	45%	22%	3%
	SEER 10 to 12	17%	30%	14%	-7%
	SEER 12 to 13	8%	35%	9%	-9%
CZ07	*SEER 10 to 13*	23%	44%	21%	3%
	SEER 10 to 12	17%	28%	14%	-6%
	SEER 12 to 13	8%	33%	9%	-8%
CZ12	*SEER 10 to 13*	23%	46%	19%	-12%
	SEER 10 to 12	17%	34%	11%	-20%
	SEER 12 to 13	8%	38%	9%	-24%
CZ15	*SEER 10 to 13*	23%	38%	19%	-15%
	SEER 10 to 12	17%	32%	12%	-19%
	SEER 12 to 13	8%	34%	8%	-33%

3.4.2 Electric Demand

Demand results for classroom applications mirror those of other commercial applications. The conclusions and observations related to peak cooling system demand in school applications are the same as those noted in Section 3.2.6. Result provided for office systems in Table 3.2.6, Figure 3.2.10, and Table 3.2.7 are repeated for classroom applications as Tables 3.4.6, Figures 3.4.3.a and 3.4.3.b and Tables 3.4.7.a and 3.4.7.b.

The ability of rated EER to predict system demand is better than expected for cooling systems serving schools. Climate zone adjusted rated EER predicts EER values obtained from DOE-2 simulations to within ± 12% for school applications at a 99% confidence interval. Confidence intervals are +12% to –17% for office applications and +17% to –22% for retail applications.

As noted previously, school systems have the greatest design outside air fraction than either office or retail applications. Differing sensitivities among the units to coil entering air conditions (dry bulb and wet-bulb temperatures) tends to produce additional variation in system efficiency from unit-to-unit. As such, one would expect the highest variation in DOE-2 simulated EER for school applications. The fact that this is not the case appears to be related to the fact that classrooms are not in full usage during times of the day when outdoor conditions are most severe. Both offices and retail building do operate at these times.

Table 3.4.6
EER Climate Multipliers, Classrooms
CZ03, CZ06, CZ07, CZ12 and CZ15

System SEER	CZ03	CZ06	CZ07	CZ12	CZ15
	Partial Year Usage (with Summer Break)				
10	1.09	0.92	0.98	0.99	0.85
12	1.10	0.91	0.98	1.00	0.85
13	1.13	0.93	0.98	1.00	0.85
	Year-Round Usage (no Summer Break)				
10	1.07	0.85	0.90	0.93	0.87
12	1.08	0.84	0.91	0.94	0.84
13	1.11	0.84	0.93	0.95	0.83

Note: Multipliers do not include EER impacts caused by system over-sizing

Figure 3.4.3.a
DOE-2 Simulated vs. Rated EER – Classroom Application
Partial Year Operation

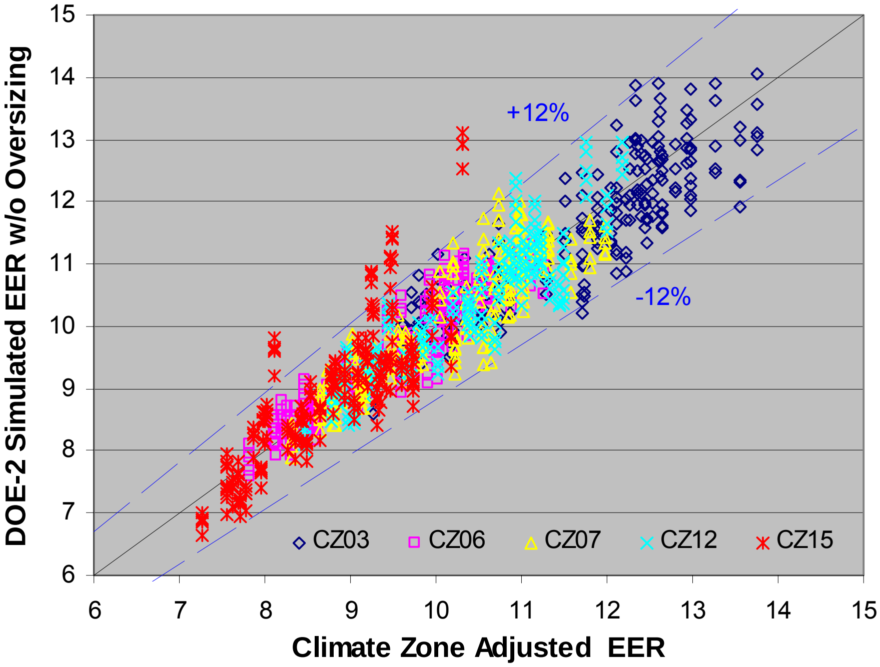


Figure 3.4.3.b
DOE-2 Simulated vs. Rated EER – Classroom Application
Year-Round Operation

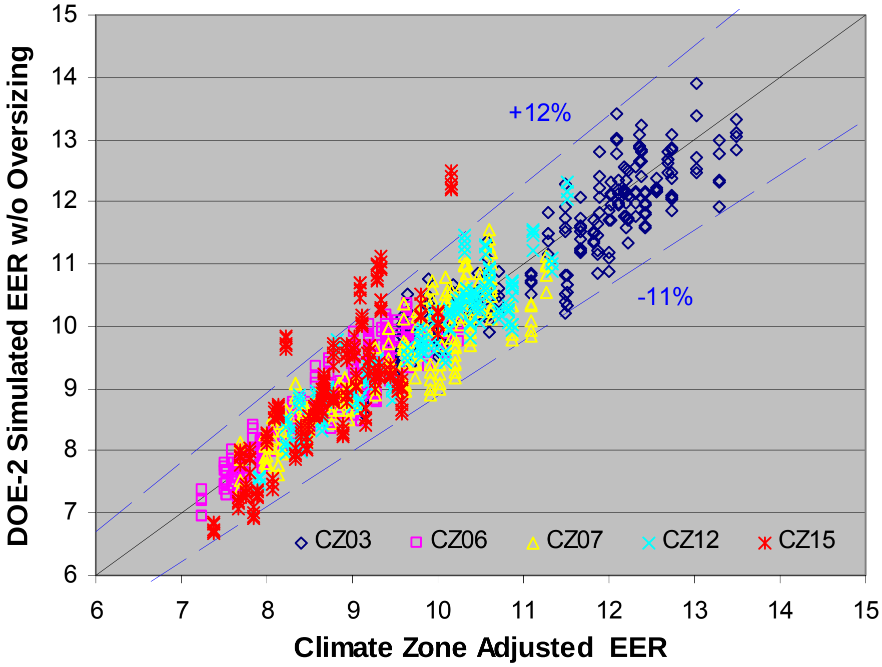


Table 3.4.7.a
Demand Benefit of Moving to a Higher SEER System
Packaged Systems Used in Classroom Setting – Partial Year Operation

		Percentage Decrease in Seasonal Cooling Energy			
	SEER Change	Expected[1]	Maximum	Median	Minimum
CZ03	*SEER 10 to 13*	23%	32%	22%	8%
	SEER 10 to 12	17%	31%	15%	-4%
	SEER 12 to 13	8%	20%	9%	-8%
CZ06	*SEER 10 to 13*	23%	28%	20%	7%
	SEER 10 to 12	17%	27%	15%	-1%
	SEER 12 to 13	8%	16%	6%	-9%
CZ07	*SEER 10 to 13*	23%	30%	20%	7%
	SEER 10 to 12	17%	28%	14%	-2%
	SEER 12 to 13	8%	18%	6%	-8%
CZ12	*SEER 10 to 13*	23%	35%	17%	5%
	SEER 10 to 12	17%	27%	12%	-7%
	SEER 12 to 13	8%	26%	6%	-5%
CZ15	*SEER 10 to 13*	23%	46%	17%	-9%
	SEER 10 to 12	17%	32%	11%	-19%
	SEER 12 to 13	8%	37%	7%	-16%

Note 1: Based on SEER increase

Table 3.4.7.b

Demand Benefit of Moving to a Higher SEER System
Packaged Systems Used in Classroom Setting –Year-Round Operation

		Percentage Decrease in Seasonal Cooling Energy			
	SEER Change	Expected[1]	Maximum	Median	Minimum
CZ03	*SEER 10 to 13*	23%	33%	22%	7%
	SEER 10 to 12	17%	30%	15%	-5%
	SEER 12 to 13	8%	20%	8%	-7%
CZ06	*SEER 10 to 13*	23%	29%	17%	5%
	SEER 10 to 12	17%	29%	13%	-3%
	SEER 12 to 13	8%	16%	6%	-11%
CZ07	*SEER 10 to 13*	23%	29%	18%	9%
	SEER 10 to 12	17%	31%	13%	2%
	SEER 12 to 13	8%	16%	6%	-13%
CZ12	*SEER 10 to 13*	23%	38%	19%	3%
	SEER 10 to 12	17%	29%	13%	-8%
	SEER 12 to 13	8%	26%	7%	-7%
CZ15	*SEER 10 to 13*	23%	45%	19%	-14%
	SEER 10 to 12	17%	35%	10%	-22%
	SEER 12 to 13	8%	35%	11%	-21%

Note 1: Based on SEER increase

3.4.3 Increased Fan Energy and System Over Sizing

The impacts of higher external static pressure and system over sizing on condensing unit SEER and SEER$_f$ do not differ significantly from that of office systems. The reader is referred to section 3.2.8 for system impacts associated with these issues.

4.0 SEER IMPROVEMENT MODELS

Section 3.2 illustrated that SEER is not well represented by a single ratings value in commercial applications, but is dependent on building characteristics, climate conditions, and cooling system performance differences not included in their SEER rating. Constant operation of the supply fan during occupied periods is a particular problem. Depending on the application, building features, and unit control, supply fan energy can exceed that of the condensing unit (compressor and outdoor fan). Another issue is ventilation requirements that can produce cooling coil entering conditions that are not represented by those assumed in the ratings procedure. Because of these issues, DOE-2 simulations predicted seasonal energy efficiencies that varied by as much as 74% among like-SEER units. These findings illustrated that rated SEER should never be used as an energy predictor in commercial applications

SEER was also found to be a poor metric when used to rank systems. Situations were found where upgrading systems by 3 SEER points (SEER10 to SEER 13) could not guarantee energy savings, depending on the application and climate characteristics. A new fan SEER ($SEER_f$) rating was developed to include the affect of continuous fan operation by specifically addressing indoor fan energy along with that of the condensing unit. $SEER_f$ was found to be a better metric for ranking the seasonal energy efficiency of different systems. Using $SEER_f$ to rank systems from best to worse, one could reduce the variation in seasonal efficiency between the best and worse units by half of that observed when based on using rated SEER. This metric was found to be successful in selecting some lower SEER units over higher SEER units in some applications and climate zones. While far from perfect, it provides significantly improve guidance over rated SEER.

This section provides the method and equation constants required to calculate $SEER_f$ for the small office, small retail and school applications examined in this study. $SEER_f$ accounts for differing indoor fan energy requirements among different packaged units by accounting for indoor fan and condensing unit energy inputs separately. $SEER_f$ is calculated as follows:

$$SEER_f = [1/CZ_{adj}*SEER_{cond} + (Hrs_{fan}/Hrs_{comp})*W_{fan}/\text{Cool Cap}]^{-1} \quad (4.1)$$

where:

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

CZ_{adj} is a climate zone-specific adjustment value,

$SEER_{cond}$ is the condensing unit SEER,

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),

(Hrs_{fan}/Hrs_{comp}) is noted as the runtime ratio of the unit,

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

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

The condensing unit SEER is the unit's rated SEER with the indoor fan removed from consideration, or:

$$SEER_{cond} = SEER * (EER_{B,\text{no fan}} / EER_B). \tag{4.2}$$

where:

EER_B is the ratings point used to determine SEER in the ARI test conditions of an outdoor temperature of 82ºF and cooling coil entering conditions of 80ºF dry bulb and 78ºF wet-bulb.

$EER_{B,\text{no fan}}$ is the value of EER_B with indoor fan energy removed, or

$$EER_{B,\text{no fan}} = (\text{Net\_Capacity} + \text{Fan\_Watts} * 3.413)/(\text{Total\_Electric} - \text{Fan\_Watts}) \tag{4.3}$$

Values of net cooling capacity, total system electric input, and nominal fan energy are typically available from manufacturers' expanded ratings charts for a give packaged cooling system. These values can be extrapolated or interpolated from manufacturers' expanded ratings charts by assuming an outdoor temperature of 82ºF and cooling coil entering conditions of 80ºF dry bulb and 67ºF wet-bulb. EER_B is the ratio of net cooling capacity to total system power at these conditions. Fan energy is obtained from fan charts provided with the literature for packaged systems. Details on determining supply fan energy are provided in Section 3.2.3. Because of the sensitivity of seasonal performance to supply fan energy requirement, units that do include this in manufacturers' engineering literature cannot be included in this evaluation. *Use of standard indoor fan power rules such as 365Watts/1,000 cfm should not be used.*

The ratio of fan hours of operation to that of the condensing unit (runtime ratio) is application specific, as are climate zone condensing unit SEER multipliers (CZ_{adj}). Typical values for both were obtained from DOE-2 simulations. The following sections gives condensing unit climate zone multipliers and run-time ratios for use with Equation 4.1. Also provided are expected variation in cooling system performance for like-SEER systems and the benefits associated with upgrading from a lower to a higher SSER unit for office, retail, and school applications.

Finally, cooling demand climate zone multipliers are given that can be applied to rated EER values for each unit. These provide climate zone adjusted EERs that better agree with those calculated in DOE-2 simulations. Multiplying a unit's rated EER by the demand climate zone multipliers provides a better estimate of the cooling demand required to meet the peak cooling load. Demand benefits associated with moving to higher SEER units are also provided.

4.1 SMALL OFFICE SYSTEMS

Table 4.1.1 provides the range in seasonal cooling system energy consumption obtained from DOE-2 simulations of units serving small offices for all climate zones. Simulations differed only in the cooling system. If $SEER_f$ was used to rank the cooling systems to provide a "best" selection, then its seasonal energy consumption, while not always the lowest, was within half the value given in Table 4.1.1 of the lowest. For example, if one were selecting a SEER-10 unit 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 units by $SEER_f$

and chose the one with the highest SEER$_f$ value, then the selected unit's annual energy consumption would be at least within 7.5% of the best unit. The ranking of units by SEER$_f$ varies by climate zone and application (core, south perimeter, etc.) depending on the relative contribution of the indoor fan versus the compressor to seasonal cooling system energy consumption.

Table 4.1.1

Difference in Seasonal Energy Use Among Same-SEER Packaged Units Examined
Small Office Application, Median Building Parameters

	SEER-10	SEER-12	SEER-13		SEER-10	SEER-12	SEER-13
CZ01	22%	20%	37%	CZ09	19%	18%	28%
CZ02	21%	18%	30%	CZ10	18%	17%	27%
CZ03	22%	19%	37%	CZ11	20%	21%	32%
CZ04	20%	17%	30%	CZ12	21%	20%	34%
CZ05	20%	16%	32%	CZ13	19%	20%	30%
CZ06	19%	15%	31%	CZ14	18%	19%	29%
CZ07	18%	15%	31%	CZ15	16%	24%	26%
CZ08	18%	14%	28%	CZ16	24%	19%	35%

Table 4.1.2

Condensing Unit SEER Climate Zone Multipliers – CZ$_{adj}$
Small Office Application, Median Building Parameters

	SEER-10	SEER-12	SEER-13		SEER-10	SEER-12	SEER-13
CZ01	0.98	1.03	1.08	CZ09	0.94	0.95	0.99
CZ02	0.94	0.96	1.00	CZ10	0.91	0.91	0.94
CZ03	0.98	1.02	1.07	CZ11	0.93	0.93	0.98
CZ04	0.96	0.99	1.03	CZ12	0.93	0.93	0.98
CZ05	0.99	1.02	1.07	CZ13	0.90	0.90	0.92
CZ06	0.99	1.02	1.07	CZ14	0.90	0.90	0.92
CZ07	0.98	1.01	1.06	CZ15	0.83	0.82	0.82
CZ08	0.97	0.98	1.03	CZ16	0.95	0.97	1.02

Table 4.1.3

Fan-to-Condensing Unit Runtime Ratios - Hrs_{fan}/Hrs_{comp}
Small Office Application, Median Building Parameters

	Building Thermal Zone					Building Thermal Zone			
	Core	West	S, N, or E	Bldg		Core	West	S, N, or E	Bldg
CZ01	5.93	4.08	3.69	5.09	CZ09	4.79	3.70	3.36	4.20
CZ02	5.42	3.76	3.43	4.64	CZ10	4.68	3.37	3.08	4.04
CZ03	5.73	4.48	4.07	5.10	CZ11	5.15	3.82	3.44	4.48
CZ04	5.13	3.72	3.38	4.40	CZ12	5.77	4.48	4.00	5.10
CZ05	4.91	3.46	3.14	4.19	CZ13	4.73	3.58	3.21	4.14
CZ06	4.58	3.53	3.25	4.03	CZ14	4.95	3.58	3.22	4.26
CZ07	4.65	3.72	3.37	4.13	CZ15	4.40	3.46	3.12	3.86
CZ08	4.37	3.29	2.98	3.80	CZ16	5.81	3.93	3.62	4.88

Table 4.1.4

Operational EER Climate Zone Multipliers
Small Office Application, Median Building Parameters

	SEER-10	SEER-12	SEER-13		SEER-10	SEER-12	SEER-13
CZ01	1.18	1.21	1.24	CZ09	0.98	0.97	0.99
CZ02	0.98	0.98	1.00	CZ10	0.96	0.96	0.98
CZ03	1.05	1.06	1.09	CZ11	0.94	0.92	0.94
CZ04	1.03	1.03	1.06	CZ12	0.94	0.92	0.94
CZ05	1.03	1.04	1.05	CZ13	0.89	0.88	0.90
CZ06	1.04	1.06	1.08	CZ14	0.89	0.88	0.87
CZ07	1.07	1.09	1.10	CZ15	0.88	0.87	0.86
CZ08	0.96	0.96	0.98	CZ16	1.04	1.03	1.05

Note: Multipliers do not include EER impacts caused by system over-sizing

Table 4.1.5
Energy Benefits of Moving to a Higher SEER System
Small Office Application, Median Building Parameters

		Percentage Decrease in Seasonal Cooling Energy			
	SEER Change	Expected	Maximum	Median	Minimum
CZ01	*SEER 10 to 13*	23%	49%	23%	-1%
	SEER 10 to 12	17%	32%	14%	-12%
	SEER 12 to 13	8%	39%	10%	-11%
CZ02	*SEER 10 to 13*	23%	46%	22%	0%
	SEER 10 to 12	17%	32%	13%	-9%
	SEER 12 to 13	8%	34%	11%	-11%
CZ03	*SEER 10 to 13*	23%	47%	22%	0%
	SEER 10 to 12	17%	31%	13%	-10%
	SEER 12 to 13	8%	36%	11%	-10%
CZ04	*SEER 10 to 13*	23%	45%	22%	2%
	SEER 10 to 12	17%	31%	13%	-9%
	SEER 12 to 13	8%	34%	11%	-10%
CZ05	*SEER 10 to 13*	23%	46%	23%	2%
	SEER 10 to 12	17%	31%	14%	-8%
	SEER 12 to 13	8%	35%	11%	-9%
CZ06	*SEER 10 to 13*	23%	45%	23%	3%
	SEER 10 to 12	17%	30%	13%	-6%
	SEER 12 to 13	8%	33%	11%	-8%
CZ07	*SEER 10 to 13*	23%	45%	23%	4%
	SEER 10 to 12	17%	30%	14%	-6%
	SEER 12 to 13	8%	33%	11%	-8%
CZ08	*SEER 10 to 13*	23%	43%	23%	4%
	SEER 10 to 12	17%	30%	14%	-5%
	SEER 12 to 13	8%	31%	11%	-8%

Table 4.1.5 (cont.)

		Percentage Decrease in Seasonal Cooling Energy			
	SEER Change	Expected	Maximum	Median	Minimum
CZ09	*SEER 10 to 13*	23%	43%	22%	1%
	SEER 10 to 12	17%	31%	13%	-7%
	SEER 12 to 13	8%	31%	10%	-11%
CZ10	*SEER 10 to 13*	23%	42%	22%	1%
	SEER 10 to 12	17%	31%	13%	-6%
	SEER 12 to 13	8%	30%	10%	-11%
CZ11	*SEER 10 to 13*	23%	44%	21%	-3%
	SEER 10 to 12	17%	32%	13%	-10%
	SEER 12 to 13	8%	33%	10%	-15%
CZ12	*SEER 10 to 13*	23%	44%	21%	-3%
	SEER 10 to 12	17%	31%	12%	-10%
	SEER 12 to 13	8%	33%	10%	-14%
CZ13	*SEER 10 to 13*	23%	42%	21%	-2%
	SEER 10 to 12	17%	31%	13%	-9%
	SEER 12 to 13	8%	31%	9%	-15%
CZ14	*SEER 10 to 13*	23%	43%	21%	-1%
	SEER 10 to 12	17%	31%	13%	-9%
	SEER 12 to 13	8%	32%	10%	-14%
CZ15	*SEER 10 to 13*	23%	38%	19%	-7%
	SEER 10 to 12	17%	29%	12%	-11%
	SEER 12 to 13	8%	30%	8%	-22%
CZ16	*SEER 10 to 13*	23%	49%	23%	-2%
	SEER 10 to 12	17%	34%	13%	-13%
	SEER 12 to 13	8%	38%	11%	-13%

Table 4.1.6

Demand Reduction From Moving to a Higher SEER System Small Office Application, Median Building Parameters

		Percentage Decrease in Seasonal Cooling Energy			
	SEER Change	Expected[1]	Maximum	Median	Minimum
CZ01	*SEER 10 to 13*	23%	35%	22%	10%
	SEER 10 to 12	17%	26%	15%	1%
	SEER 12 to 13	8%	24%	8%	-6%
CZ02	*SEER 10 to 13*	23%	36%	20%	6%
	SEER 10 to 12	17%	28%	15%	-4%
	SEER 12 to 13	8%	26%	6%	-10%
CZ03	*SEER 10 to 13*	23%	35%	22%	10%
	SEER 10 to 12	17%	26%	15%	1%
	SEER 12 to 13	8%	24%	8%	-6%
CZ04	*SEER 10 to 13*	23%	36%	21%	8%
	SEER 10 to 12	17%	28%	16%	-2%
	SEER 12 to 13	8%	26%	6%	-8%
CZ05	*SEER 10 to 13*	23%	35%	21%	6%
	SEER 10 to 12	17%	27%	16%	-2%
	SEER 12 to 13	8%	25%	6%	-10%
CZ06	*SEER 10 to 13*	23%	34%	22%	11%
	SEER 10 to 12	17%	27%	16%	2%
	SEER 12 to 13	8%	23%	8%	-7%
CZ07	*SEER 10 to 13*	23%	33%	22%	8%
	SEER 10 to 12	17%	26%	16%	0%
	SEER 12 to 13	8%	23%	8%	-7%
CZ08	*SEER 10 to 13*	23%	34%	21%	9%
	SEER 10 to 12	17%	27%	16%	0%
	SEER 12 to 13	8%	23%	7%	-7%

Table 4.1.6 (cont.)

	SEER Change	Expected[1]	Maximum	Median	Minimum
		Percentage Decrease in Seasonal Cooling Energy			
CZ09	*SEER 10 to 13*	23%	36%	18%	8%
	SEER 10 to 12	17%	30%	14%	-3%
	SEER 12 to 13	8%	26%	6%	-9%
CZ10	*SEER 10 to 13*	23%	35%	19%	9%
	SEER 10 to 12	17%	28%	14%	-3%
	SEER 12 to 13	8%	26%	5%	-8%
CZ11	*SEER 10 to 13*	23%	36%	18%	8%
	SEER 10 to 12	17%	29%	13%	-4%
	SEER 12 to 13	8%	26%	5%	-9%
CZ12	*SEER 10 to 13*	23%	36%	18%	7%
	SEER 10 to 12	17%	30%	13%	-5%
	SEER 12 to 13	8%	26%	5%	-10%
CZ13	*SEER 10 to 13*	23%	36%	18%	7%
	SEER 10 to 12	17%	31%	13%	-6%
	SEER 12 to 13	8%	26%	6%	-9%
CZ14	*SEER 10 to 13*	23%	34%	17%	5%
	SEER 10 to 12	17%	30%	13%	-6%
	SEER 12 to 13	8%	25%	4%	-12%
CZ15	*SEER 10 to 13*	23%	37%	16%	4%
	SEER 10 to 12	17%	31%	11%	-9%
	SEER 12 to 13	8%	27%	5%	-11%
CZ16	*SEER 10 to 13*	23%	35%	20%	6%
	SEER 10 to 12	17%	27%	16%	-2%
	SEER 12 to 13	8%	25%	5%	-10%

Note 1: Based on SEER increase

4.2 RETAIL SYSTEMS

Tabular data presented below is for retail applications and mirrors that for small offices presented in section 4.1.

Table 4.2.1

Difference in Seasonal Energy Use Among Same-SEER Packaged Units Examined
Retail Application, Median Building Parameters

	SEER-10	SEER-12	SEER-13		SEER-10	SEER-12	SEER-13
CZ01	32%	34%	60%	CZ09	23%	22%	36%
CZ02	31%	31%	49%	CZ10	25%	25%	38%
CZ03	27%	25%	45%	CZ11	35%	39%	56%
CZ04	23%	20%	36%	CZ12	29%	31%	43%
CZ05	24%	22%	41%	CZ13	26%	29%	38%
CZ06	21%	19%	34%	CZ14	42%	43%	76%
CZ07	20%	18%	33%	CZ15	27%	40%	45%
CZ08	20%	18%	31%	CZ16	41%	37%	69%

Table 4.2.2

Condensing Unit SEER Climate Zone Multipliers – CZ_{adj}
Retail Application, Median Building Parameters

	SEER-10	SEER-12	SEER-13		SEER-10	SEER-12	SEER-13
CZ01	1.09	1.10	1.20	CZ09	0.97	0.98	1.01
CZ02	0.98	0.99	1.02	CZ10	0.95	0.95	0.97
CZ03	1.06	1.07	1.14	CZ11	0.92	0.92	0.94
CZ04	1.02	1.03	1.07	CZ12	0.95	0.95	0.98
CZ05	1.06	1.07	1.14	CZ13	0.91	0.91	0.92
CZ06	1.06	1.07	1.13	CZ14	0.89	0.91	0.92
CZ07	1.05	1.06	1.11	CZ15	0.83	0.82	0.81
CZ08	1.02	1.02	1.06	CZ16	0.99	1.02	1.06

Table 4.2.3

Fan-to-Compressor Runtime Ratios - Hrs_{fan}/Hrs_{comp}
Retail Application, Median Building Features

	Zone Type Served				Zone Type Served		
	Sales	Storage	Building		Sales	Storage	Building
CZ01	4.21	4.62	7.55	CZ09	3.49	3.57	3.92
CZ02	4.15	4.30	4.99	CZ10	3.53	3.60	3.85
CZ03	3.54	3.74	4.81	CZ11	4.41	4.52	5.00
CZ04	3.60	3.73	4.29	CZ12	4.53	4.66	5.22
CZ05	3.06	3.22	4.01	CZ13	3.87	3.92	4.10
CZ06	2.88	2.99	3.47	CZ14	4.02	4.08	4.33
CZ07	2.90	2.99	3.38	CZ15	3.36	3.37	3.41
CZ08	3.03	3.10	3.41	CZ16	4.98	5.17	6.10

Table 4.2.4

Operational EER Climate Zone Multipliers
Retail Application, Median Building Parameters

	SEER-10	SEER-12	SEER-13		SEER-10	SEER-12	SEER-13
CZ01	0.97	0.97	0.92	CZ09	0.88	0.86	0.86
CZ02	0.89	0.87	0.85	CZ10	0.94	0.91	0.90
CZ03	0.86	0.86	0.83	CZ11	0.88	0.85	0.84
CZ04	0.84	0.82	0.80	CZ12	0.90	0.89	0.90
CZ05	0.92	0.92	0.88	CZ13	0.82	0.80	0.80
CZ06	0.96	0.96	0.93	CZ14	0.81	0.80	0.77
CZ07	0.90	0.90	0.89	CZ15	0.83	0.79	0.79
CZ08	0.88	0.88	0.87	CZ16	0.84	0.83	0.81

Note: Multipliers do not include EER impacts caused by system over-sizing

Table 4.2.5

Energy Benefits of Moving to a Higher SEER System
Retail Application, Median Building Parameters

		Percentage Decrease in Seasonal Cooling Energy			
	SEER Change	Expected	Maximum	Median	Minimum
CZ01	*SEER 10 to 13*	23%	53%	26%	-9%
	SEER 10 to 12	17%	37%	13%	-26%
	SEER 12 to 13	8%	46%	15%	-19%
CZ02	*SEER 10 to 13*	23%	50%	24%	-10%
	SEER 10 to 12	17%	38%	13%	-18%
	SEER 12 to 13	8%	39%	13%	-23%
CZ03	*SEER 10 to 13*	23%	49%	25%	-2%
	SEER 10 to 12	17%	35%	13%	-15%
	SEER 12 to 13	8%	39%	13%	-14%
CZ04	*SEER 10 to 13*	23%	45%	23%	2%
	SEER 10 to 12	17%	32%	13%	-9%
	SEER 12 to 13	8%	34%	11%	-10%
CZ05	*SEER 10 to 13*	23%	48%	25%	1%
	SEER 10 to 12	17%	34%	14%	-12%
	SEER 12 to 13	8%	38%	14%	-12%
CZ06	*SEER 10 to 13*	23%	46%	24%	4%
	SEER 10 to 12	17%	32%	14%	-7%
	SEER 12 to 13	8%	35%	12%	-9%
CZ07	*SEER 10 to 13*	23%	44%	24%	4%
	SEER 10 to 12	17%	31%	13%	-6%
	SEER 12 to 13	8%	33%	12%	-9%
CZ08	*SEER 10 to 13*	23%	43%	23%	5%
	SEER 10 to 12	17%	31%	13%	-6%
	SEER 12 to 13	8%	32%	12%	-9%

Table 4.2.5 (cont.)

		Percentage Decrease in Seasonal Cooling Energy			
	SEER Change	Expected	Maximum	Median	Minimum
CZ09	*SEER 10 to 13*	23%	44%	24%	-1%
	SEER 10 to 12	17%	33%	13%	-9%
	SEER 12 to 13	8%	33%	13%	-15%
CZ10	*SEER 10 to 13*	23%	45%	23%	-4%
	SEER 10 to 12	17%	34%	13%	-10%
	SEER 12 to 13	8%	33%	12%	-18%
CZ11	*SEER 10 to 13*	23%	50%	19%	-18%
	SEER 10 to 12	17%	40%	13%	-25%
	SEER 12 to 13	8%	41%	7%	-33%
CZ12	*SEER 10 to 13*	23%	47%	19%	-10%
	SEER 10 to 12	17%	36%	11%	-17%
	SEER 12 to 13	8%	36%	9%	-23%
CZ13	*SEER 10 to 13*	23%	44%	19%	-9%
	SEER 10 to 12	17%	35%	12%	-14%
	SEER 12 to 13	8%	33%	7%	-23%
CZ14	*SEER 10 to 13*	23%	55%	18%	-23%
	SEER 10 to 12	17%	42%	15%	-27%
	SEER 12 to 13	8%	48%	3%	-43%
CZ15	*SEER 10 to 13*	23%	43%	18%	-20%
	SEER 10 to 12	17%	36%	11%	-22%
	SEER 12 to 13	8%	37%	8%	-39%
CZ16	*SEER 10 to 13*	23%	56%	28%	-17%
	SEER 10 to 12	17%	41%	14%	-24%
	SEER 12 to 13	8%	46%	16%	-30%

Table 4.2.6

Demand Reduction From Moving to a Higher SEER System
Small Office Application, Median Building Parameters

		Percentage Decrease in Seasonal Cooling Energy			
	SEER Change	Expected[1]	Maximum	Median	Minimum
CZ01	*SEER 10 to 13*	23%	36%	14%	-4%
	SEER 10 to 12	17%	36%	12%	-19%
	SEER 12 to 13	8%	27%	2%	-20%
CZ02	*SEER 10 to 13*	23%	32%	13%	-5%
	SEER 10 to 12	17%	31%	9%	-17%
	SEER 12 to 13	8%	23%	4%	-13%
CZ03	*SEER 10 to 13*	23%	32%	14%	-1%
	SEER 10 to 12	17%	33%	10%	-10%
	SEER 12 to 13	8%	19%	4%	-17%
CZ04	*SEER 10 to 13*	23%	31%	14%	1%
	SEER 10 to 12	17%	29%	10%	-7%
	SEER 12 to 13	8%	18%	4%	-10%
CZ05	*SEER 10 to 13*	23%	31%	12%	-3%
	SEER 10 to 12	17%	33%	11%	-13%
	SEER 12 to 13	8%	20%	1%	-17%
CZ06	*SEER 10 to 13*	23%	33%	15%	0%
	SEER 10 to 12	17%	34%	12%	-13%
	SEER 12 to 13	8%	23%	3%	-16%
CZ07	*SEER 10 to 13*	23%	29%	17%	4%
	SEER 10 to 12	17%	30%	12%	-5%
	SEER 12 to 13	8%	17%	6%	-13%
CZ08	*SEER 10 to 13*	23%	32%	14%	3%
	SEER 10 to 12	17%	29%	10%	-6%
	SEER 12 to 13	8%	19%	4%	-9%

Table 4.2.6 (cont.)

		Percentage Decrease in Seasonal Cooling Energy			
	SEER Change	Expected[1]	Maximum	Median	Minimum
CZ09	*SEER 10 to 13*	23%	34%	14%	0%
	SEER 10 to 12	17%	30%	10%	-11%
	SEER 12 to 13	8%	23%	4%	-10%
CZ10	*SEER 10 to 13*	23%	30%	12%	0%
	SEER 10 to 12	17%	30%	10%	-12%
	SEER 12 to 13	8%	21%	2%	-12%
CZ11	*SEER 10 to 13*	23%	37%	19%	1%
	SEER 10 to 12	17%	30%	11%	-13%
	SEER 12 to 13	8%	27%	9%	-9%
CZ12	*SEER 10 to 13*	23%	37%	19%	1%
	SEER 10 to 12	17%	30%	11%	-13%
	SEER 12 to 13	8%	27%	9%	-9%
CZ13	*SEER 10 to 13*	23%	39%	18%	-3%
	SEER 10 to 12	17%	32%	12%	-14%
	SEER 12 to 13	8%	29%	6%	-12%
CZ14	*SEER 10 to 13*	23%	37%	15%	-14%
	SEER 10 to 12	17%	35%	12%	-22%
	SEER 12 to 13	8%	26%	3%	-23%
CZ15	*SEER 10 to 13*	23%	45%	14%	-18%
	SEER 10 to 12	17%	38%	10%	-30%
	SEER 12 to 13	8%	37%	4%	-27%
CZ16	*SEER 10 to 13*	23%	30%	15%	2%
	SEER 10 to 12	17%	29%	11%	-8%
	SEER 12 to 13	8%	19%	5%	-9%

Note 1: Based on SEER increase

4.3 SCHOOL SYSTEMS

Tabular data presented below is for retail applications and mirrors that for small offices presented in section 4.1 with the exception that data is presented for partial year (no summer school) and year-round (with summer school) operation.

Table 4.3.1a

Difference in Seasonal Energy Use Among Same-SEER Packaged Units Examined School Application, Partial Year Operation

	SEER-10	SEER-12	SEER-13		SEER-10	SEER-12	SEER-13
CZ01	34%	36%	94%	CZ09	24%	25%	42%
CZ02	34%	33%	58%	CZ10	25%	26%	40%
CZ03	30%	27%	59%	CZ11	37%	39%	62%
CZ04	26%	23%	45%	CZ12	32%	33%	55%
CZ05	27%	24%	52%	CZ13	28%	28%	44%
CZ06	23%	22%	44%	CZ14	34%	38%	58%
CZ07	21%	20%	39%	CZ15	23%	33%	39%
CZ08	21%	18%	37%	CZ16	46%	39%	75%

Table 4.3.1b

Difference in Seasonal Energy Use Among Same-SEER Packaged Units Examined School Application, Year-Round Operation

	SEER-10	SEER-12	SEER-13		SEER-10	SEER-12	SEER-13
CZ01	28%	31%	83%	CZ09	22%	23%	37%
CZ02	32%	30%	52%	CZ10	23%	25%	35%
CZ03	28%	25%	53%	CZ11	32%	36%	53%
CZ04	23%	21%	38%	CZ12	29%	30%	47%
CZ05	25%	22%	48%	CZ13	24%	27%	37%
CZ06	21%	19%	37%	CZ14	30%	36%	48%
CZ07	19%	18%	34%	CZ15	20%	34%	35%
CZ08	19%	16%	32%	CZ16	38%	32%	59%

Table 4.3.2a
Compressor SEER Climate Zone Multipliers – CZ_{adj}
School Application, Partial Year Operation

	SEER-10	SEER-12	SEER-13		SEER-10	SEER-12	SEER-13
CZ01	1.00	1.04	1.08	CZ09	0.94	0.95	0.99
CZ02	0.94	0.94	0.96	CZ10	0.90	0.90	0.92
CZ03	0.99	1.01	1.05	CZ11	0.93	0.93	0.95
CZ04	0.99	1.00	1.02	CZ12	0.93	0.93	0.95
CZ05	0.99	1.00	1.05	CZ13	0.91	0.91	0.92
CZ06	1.01	1.03	1.06	CZ14	0.89	0.90	0.92
CZ07	1.00	1.01	1.05	CZ15	0.84	0.83	0.82
CZ08	0.98	0.99	1.01	CZ16	0.96	0.97	1.01

Table 4.3.2b
Compressor SEER Climate Zone Multipliers – CZ_{adj}
School Application, Year-Round Operation

	SEER-10	SEER-12	SEER-13		SEER-10	SEER-12	SEER-13
CZ01	1.00	1.04	1.08	CZ09	0.94	0.94	0.96
CZ02	0.93	0.93	0.95	CZ10	0.88	0.88	0.88
CZ03	1.00	1.02	1.05	CZ11	0.91	0.91	0.92
CZ04	0.99	1.00	1.02	CZ12	0.91	0.91	0.92
CZ05	1.00	1.01	1.05	CZ13	0.89	0.88	0.89
CZ06	1.03	1.03	1.07	CZ14	0.86	0.85	0.86
CZ07	1.01	1.02	1.05	CZ15	0.81	0.80	0.79
CZ08	0.98	0.99	1.01	CZ16	0.95	0.94	0.97

Table 4.3.3

Fan-to-Compressor Runtime Ratios - $\text{Hrs}_{fan}/\text{Hrs}_{comp}$

School Application

	School Operation			School Operation	
	Partial Year	Year-Round		Partial Year	Year-Round
CZ01	26.52	20.22	CZ09	5.53	4.76
CZ02	7.80	6.64	CZ10	4.73	4.26
CZ03	9.38	7.83	CZ11	7.33	6.20
CZ04	6.54	5.32	CZ12	7.73	6.24
CZ05	6.47	5.65	CZ13	5.40	4.55
CZ06	5.40	4.11	CZ14	6.51	5.17
CZ07	4.82	4.35	CZ15	4.01	3.62
CZ08	4.57	3.97	CZ16	11.86	8.09

Table 4.3.4a

Operational EER Climate Zone Multipliers

School Application, Partial Year Operation

	SEER-10	SEER-12	SEER-13		SEER-10	SEER-12	SEER-13
CZ01	1.14	1.14	1.15	CZ09	0.93	0.91	0.92
CZ02	0.92	0.90	0.92	CZ10	0.85	0.84	0.84
CZ03	1.09	1.10	1.13	CZ11	1.00	0.99	1.01
CZ04	0.89	0.89	0.90	CZ12	0.99	1.00	1.00
CZ05	0.89	0.90	0.90	CZ13	0.81	0.80	0.80
CZ06	0.92	0.91	0.93	CZ14	0.97	0.96	0.97
CZ07	0.98	0.98	0.98	CZ15	0.85	0.85	0.85
CZ08	0.84	0.84	0.84	CZ16	0.90	0.90	0.92

Note: Multipliers do not include EER impacts caused by system over-sizing

Table 4.3.4b
Operational EER Climate Zone Multipliers
School Application, Year-Round Operation

	SEER-10	SEER-12	SEER-13		SEER-10	SEER-12	SEER-13
CZ01	1.26	1.26	1.30	CZ09	0.89	0.89	0.89
CZ02	0.92	0.90	0.92	CZ10	0.89	0.88	0.89
CZ03	1.07	1.08	1.11	CZ11	0.94	0.91	0.93
CZ04	0.81	0.82	0.81	CZ12	0.93	0.94	0.95
CZ05	0.89	0.89	0.90	CZ13	0.84	0.83	0.84
CZ06	0.85	0.84	0.84	CZ14	0.88	0.86	0.86
CZ07	0.90	0.91	0.93	CZ15	0.87	0.84	0.83
CZ08	0.85	0.84	0.84	CZ16	0.92	0.91	0.92

Note: Multipliers do not include EER impacts caused by system over-sizing.

Table 4.3.5a

Energy Benefits of Moving to a Higher SEER System
School Application, Partial Year Operation

		Percentage Decrease in Seasonal Cooling Energy			
	SEER Change	Expected	Maximum	Median	Minimum
CZ01	*SEER 10 to 13*	23%	60%	15%	-23%
	SEER 10 to 12	17%	32%	8%	-37%
	SEER 12 to 13	8%	57%	7%	-23%
CZ02	*SEER 10 to 13*	23%	52%	20%	-15%
	SEER 10 to 12	17%	37%	10%	-23%
	SEER 12 to 13	8%	43%	10%	-25%
CZ03	*SEER 10 to 13*	23%	53%	18%	-9%
	SEER 10 to 12	17%	33%	11%	-20%
	SEER 12 to 13	8%	45%	7%	-17%
CZ04	*SEER 10 to 13*	23%	48%	19%	-3%
	SEER 10 to 12	17%	32%	12%	-14%
	SEER 12 to 13	8%	39%	8%	-14%
CZ05	*SEER 10 to 13*	23%	51%	20%	-6%
	SEER 10 to 12	17%	33%	13%	-14%
	SEER 12 to 13	8%	41%	9%	-15%
CZ06	*SEER 10 to 13*	23%	48%	21%	-2%
	SEER 10 to 12	17%	31%	14%	-11%
	SEER 12 to 13	8%	38%	9%	-12%
CZ07	*SEER 10 to 13*	23%	46%	21%	1%
	SEER 10 to 12	17%	30%	14%	-8%
	SEER 12 to 13	8%	36%	8%	-10%
CZ08	*SEER 10 to 13*	23%	45%	21%	1%
	SEER 10 to 12	17%	30%	12%	-8%
	SEER 12 to 13	8%	34%	9%	-10%

Table 4.3.5a (cont.)

Percentage Decrease in Seasonal Cooling Energy

	SEER Change	Expected	Maximum	Median	Minimum
CZ09	*SEER 10 to 13*	23%	45%	21%	-5%
	SEER 10 to 12	17%	32%	11%	-14%
	SEER 12 to 13	8%	36%	11%	-16%
CZ10	*SEER 10 to 13*	23%	45%	20%	-7%
	SEER 10 to 12	17%	34%	12%	-14%
	SEER 12 to 13	8%	35%	9%	-21%
CZ11	*SEER 10 to 13*	23%	51%	17%	-22%
	SEER 10 to 12	17%	39%	11%	-29%
	SEER 12 to 13	8%	44%	8%	-36%
CZ12	*SEER 10 to 13*	23%	50%	19%	-16%
	SEER 10 to 12	17%	36%	10%	-24%
	SEER 12 to 13	8%	42%	9%	-28%
CZ13	*SEER 10 to 13*	23%	46%	19%	-11%
	SEER 10 to 12	17%	34%	11%	-16%
	SEER 12 to 13	8%	36%	9%	-24%
CZ14	*SEER 10 to 13*	23%	50%	18%	-21%
	SEER 10 to 12	17%	39%	11%	-27%
	SEER 12 to 13	8%	43%	8%	-35%
CZ15	*SEER 10 to 13*	23%	40%	19%	-17%
	SEER 10 to 12	17%	33%	11%	-19%
	SEER 12 to 13	8%	35%	8%	-34%
CZ16	*SEER 10 to 13*	23%	59%	18%	-21%
	SEER 10 to 12	17%	42%	10%	-31%
	SEER 12 to 13	8%	50%	9%	-31%

Table 4.3.5b
Energy Benefits of Moving to a Higher SEER System
School Application, Year-Round Operation

		Percentage Decrease in Seasonal Cooling Energy			
	SEER Change	Expected	Maximum	Median	Minimum
CZ01	*SEER 10 to 13*	23%	57%	15%	-21%
	SEER 10 to 12	17%	30%	9%	-33%
	SEER 12 to 13	8%	54%	6%	-21%
CZ02	*SEER 10 to 13*	23%	50%	20%	-12%
	SEER 10 to 12	17%	36%	11%	-20%
	SEER 12 to 13	8%	41%	10%	-23%
CZ03	*SEER 10 to 13*	23%	51%	19%	-6%
	SEER 10 to 12	17%	33%	12%	-17%
	SEER 12 to 13	8%	43%	8%	-15%
CZ04	*SEER 10 to 13*	23%	45%	20%	1%
	SEER 10 to 12	17%	31%	13%	-10%
	SEER 12 to 13	8%	36%	8%	-11%
CZ05	*SEER 10 to 13*	23%	49%	21%	-3%
	SEER 10 to 12	17%	32%	13%	-12%
	SEER 12 to 13	8%	39%	9%	-13%
CZ06	*SEER 10 to 13*	23%	45%	22%	3%
	SEER 10 to 12	17%	30%	14%	-7%
	SEER 12 to 13	8%	35%	9%	-9%
CZ07	*SEER 10 to 13*	23%	44%	21%	3%
	SEER 10 to 12	17%	28%	14%	-6%
	SEER 12 to 13	8%	33%	9%	-8%
CZ08	*SEER 10 to 13*	23%	42%	21%	4%
	SEER 10 to 12	17%	29%	13%	-5%
	SEER 12 to 13	8%	31%	9%	-8%

Table 4.3.5b (cont.)

Percentage Decrease in Seasonal Cooling Energy

	SEER Change	Expected	Maximum	Median	Minimum
CZ09	*SEER 10 to 13*	23%	43%	21%	-2%
	SEER 10 to 12	17%	31%	12%	-11%
	SEER 12 to 13	8%	33%	11%	-14%
CZ10	*SEER 10 to 13*	23%	42%	20%	-5%
	SEER 10 to 12	17%	32%	12%	-12%
	SEER 12 to 13	8%	33%	9%	-20%
CZ11	*SEER 10 to 13*	23%	48%	17%	-17%
	SEER 10 to 12	17%	37%	10%	-25%
	SEER 12 to 13	8%	40%	8%	-31%
CZ12	*SEER 10 to 13*	23%	46%	19%	-12%
	SEER 10 to 12	17%	34%	11%	-20%
	SEER 12 to 13	8%	38%	9%	-24%
CZ13	*SEER 10 to 13*	23%	42%	19%	-8%
	SEER 10 to 12	17%	33%	12%	-14%
	SEER 12 to 13	8%	34%	8%	-22%
CZ14	*SEER 10 to 13*	23%	46%	19%	-17%
	SEER 10 to 12	17%	37%	11%	-23%
	SEER 12 to 13	8%	39%	9%	-32%
CZ15	*SEER 10 to 13*	23%	38%	19%	-15%
	SEER 10 to 12	17%	32%	12%	-19%
	SEER 12 to 13	8%	34%	8%	-33%
CZ16	*SEER 10 to 13*	23%	54%	19%	-14%
	SEER 10 to 12	17%	39%	11%	-23%
	SEER 12 to 13	8%	44%	9%	-25%

Table 4.3.6a

Demand Reduction From Moving to a Higher SEER System
School Application, Partial Year Operation

		Percentage Decrease in Seasonal Cooling Energy			
	SEER Change	Expected[1]	Maximum	Median	Minimum
CZ01	*SEER 10 to 13*	23%	38%	17%	-2%
	SEER 10 to 12	17%	36%	14%	-22%
	SEER 12 to 13	8%	30%	3%	-16%
CZ02	*SEER 10 to 13*	23%	33%	16%	4%
	SEER 10 to 12	17%	28%	12%	-9%
	SEER 12 to 13	8%	24%	4%	-7%
CZ03	*SEER 10 to 13*	23%	32%	22%	8%
	SEER 10 to 12	17%	31%	15%	-4%
	SEER 12 to 13	8%	20%	9%	-8%
CZ04	*SEER 10 to 13*	23%	34%	20%	7%
	SEER 10 to 12	17%	30%	13%	-4%
	SEER 12 to 13	8%	20%	8%	-8%
CZ05	*SEER 10 to 13*	23%	30%	18%	8%
	SEER 10 to 12	17%	30%	13%	0%
	SEER 12 to 13	8%	16%	6%	-10%
CZ06	*SEER 10 to 13*	23%	28%	20%	7%
	SEER 10 to 12	17%	27%	15%	-1%
	SEER 12 to 13	8%	16%	6%	-9%
CZ07	*SEER 10 to 13*	23%	30%	20%	7%
	SEER 10 to 12	17%	28%	14%	-2%
	SEER 12 to 13	8%	18%	6%	-8%
CZ08	*SEER 10 to 13*	23%	30%	18%	7%
	SEER 10 to 12	17%	26%	12%	-1%
	SEER 12 to 13	8%	18%	6%	-6%

Table 4.3.6a (cont.)

Percentage Decrease in Seasonal Cooling Energy

	SEER Change	Expected[1]	Maximum	Median	Minimum
CZ09	*SEER 10 to 13*	23%	34%	16%	2%
	SEER 10 to 12	17%	28%	11%	-8%
	SEER 12 to 13	8%	23%	6%	-7%
CZ10	*SEER 10 to 13*	23%	37%	16%	-1%
	SEER 10 to 12	17%	31%	13%	-11%
	SEER 12 to 13	8%	26%	3%	-11%
CZ11	*SEER 10 to 13*	23%	41%	18%	-1%
	SEER 10 to 12	17%	33%	13%	-11%
	SEER 12 to 13	8%	29%	6%	-12%
CZ12	*SEER 10 to 13*	23%	35%	17%	5%
	SEER 10 to 12	17%	27%	12%	-7%
	SEER 12 to 13	8%	26%	6%	-5%
CZ13	*SEER 10 to 13*	23%	37%	19%	1%
	SEER 10 to 12	17%	29%	12%	-10%
	SEER 12 to 13	8%	27%	8%	-9%
CZ14	*SEER 10 to 13*	23%	40%	19%	-2%
	SEER 10 to 12	17%	32%	13%	-14%
	SEER 12 to 13	8%	31%	7%	-13%
CZ15	*SEER 10 to 13*	23%	46%	17%	-9%
	SEER 10 to 12	17%	32%	11%	-19%
	SEER 12 to 13	8%	37%	7%	-16%
CZ16	*SEER 10 to 13*	23%	35%	19%	3%
	SEER 10 to 12	17%	34%	13%	-5%
	SEER 12 to 13	8%	21%	6%	-16%

Note 1: Based on SEER increase

Table 4.3.6b

Demand Reduction From Moving to a Higher SEER System
School Application, Year-Round Operation

		Percentage Decrease in Seasonal Cooling Energy			
	SEER Change	Expected[1]	Maximum	Median	Minimum
CZ01	*SEER 10 to 13*	23%	35%	19%	2%
	SEER 10 to 12	17%	32%	16%	-11%
	SEER 12 to 13	8%	26%	4%	-16%
CZ02	*SEER 10 to 13*	23%	33%	16%	4%
	SEER 10 to 12	17%	28%	12%	-9%
	SEER 12 to 13	8%	23%	4%	-6%
CZ03	*SEER 10 to 13*	23%	33%	22%	7%
	SEER 10 to 12	17%	30%	15%	-5%
	SEER 12 to 13	8%	20%	8%	-7%
CZ04	*SEER 10 to 13*	23%	31%	17%	6%
	SEER 10 to 12	17%	28%	11%	-1%
	SEER 12 to 13	8%	18%	7%	-9%
CZ05	*SEER 10 to 13*	23%	30%	18%	8%
	SEER 10 to 12	17%	30%	13%	-1%
	SEER 12 to 13	8%	16%	6%	-10%
CZ06	*SEER 10 to 13*	23%	29%	17%	5%
	SEER 10 to 12	17%	29%	13%	-3%
	SEER 12 to 13	8%	16%	6%	-11%
CZ07	*SEER 10 to 13*	23%	29%	18%	9%
	SEER 10 to 12	17%	31%	13%	2%
	SEER 12 to 13	8%	16%	6%	-13%
CZ08	*SEER 10 to 13*	23%	30%	18%	7%
	SEER 10 to 12	17%	26%	12%	-1%
	SEER 12 to 13	8%	17%	6%	-7%

Table 4.3.6b (cont.)

Percentage Decrease in Seasonal Cooling Energy

	SEER Change	Expected[1]	Maximum	Median	Minimum
CZ09	*SEER 10 to 13*	23%	35%	17%	2%
	SEER 10 to 12	17%	29%	11%	-7%
	SEER 12 to 13	8%	23%	7%	-10%
CZ10	*SEER 10 to 13*	23%	38%	17%	1%
	SEER 10 to 12	17%	31%	14%	-9%
	SEER 12 to 13	8%	26%	4%	-10%
CZ11	*SEER 10 to 13*	23%	39%	19%	-3%
	SEER 10 to 12	17%	33%	12%	-13%
	SEER 12 to 13	8%	28%	8%	-14%
CZ12	*SEER 10 to 13*	23%	38%	19%	3%
	SEER 10 to 12	17%	29%	13%	-8%
	SEER 12 to 13	8%	26%	7%	-7%
CZ13	*SEER 10 to 13*	23%	38%	20%	2%
	SEER 10 to 12	17%	29%	13%	-10%
	SEER 12 to 13	8%	27%	8%	-8%
CZ14	*SEER 10 to 13*	23%	40%	20%	-7%
	SEER 10 to 12	17%	33%	13%	-18%
	SEER 12 to 13	8%	30%	8%	-16%
CZ15	*SEER 10 to 13*	23%	45%	19%	-14%
	SEER 10 to 12	17%	35%	10%	-22%
	SEER 12 to 13	8%	35%	11%	-21%
CZ16	*SEER 10 to 13*	23%	34%	18%	5%
	SEER 10 to 12	17%	29%	14%	-9%
	SEER 12 to 13	8%	21%	5%	-4%

Note 1: Based on SEER increase

5.0 CONCLUSIONS

This effort set out to answer the following questions:

1. How effective is SEER as a predictor of expected cooling *energy use* or *utility costs*?
2. 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 because of various user effects such as thermostat set point. 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?
3. 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 13 suggests a 23% improvement in seasonal efficiency (1-[10/13]). All other things being equal (i.e., controlling for climate and user differences), will a 23% savings in annual cooling energy be realized?
4. How effective is SEER as a predictor of expected cooling *peak demand* and demand savings? This question has become all the more important since ARI (Air-Conditioning and Refrigeration Institute) decided in November of 2002 to stop listing EER for SEER-rated systems in its directory of certified equipment.
5. 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?

5.1 EFFORT FINDINGS

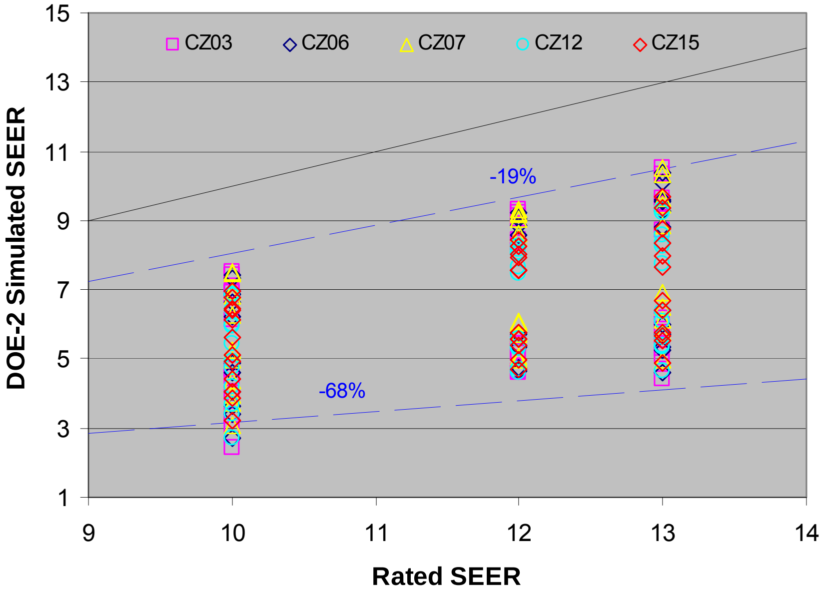
Results from DOE-2 simulations of 47 different SEER-rated packaged systems applied to building models of small offices, small retail, and classroom led to the following responses to the above objectives.

5.1.1 How Effective Is SEER as a Predictor of Expected Energy Use?

SEER rating is a poor predictor of expected cooling energy use, and thus cooling utility costs in commercial applications as illustrated in Figure 5.1.1 for small office applications. Results for other applications are similar. DOE-2 simulations produced seasonal energy efficiency as low as 20% that of rated SEER (calculated SEER of 2 compared to rated SEER of 10). Issues in commercial applications that preclude the use of SEER as a predictor of seasonal energy use include continuous indoor fan operation, scheduled cooling loads that are not dependent on outdoor conditions, and the introduction of ventilation air to the cooling coil.

Continuous indoor fan operation (required to meet ventilation requirements) is a particular problem in that fan energy is expended even when the compressor is not operating. It also introduces a continuous cooling load to the space because of fan energy and ventilation air. Building features, such as operating schedules and differing internal loads, can produce situations where indoor fan energy exceeds that of the rest of the cooling system.

Figure 5.1.1
DOE-2 Simulated SEER vs. Rated SEER
Small Office Application – Median Building Characteristics
Continuous Indoor Fan Operation During Occupied Periods



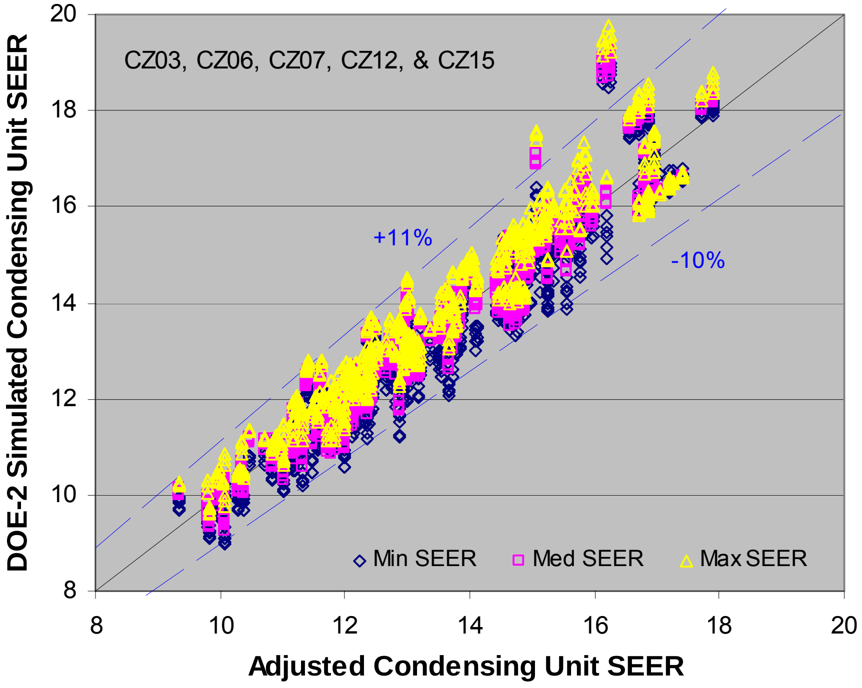
Internal loads in commercial applications, such as heat released by lights, equipment, and personnel, produce cooling loads that are much less dependent on outdoor conditions. These loads are dependent on operating schedules and are frequently not active during cooler periods of the day (late night and early morning). Both accentuate the lack of one-to-one correspondence between cooling load and outdoor temperature assumed in the SEER ratings process.

Commercial applications require the introduction of ventilation air whenever the cooling system is scheduled for operation (whether or not the compressor is operating). This affects seasonal energy efficiency is a couple of ways. First, cooling coil-entering conditions are much less likely to match those assumed in the SEER ratings process (80ºF dry bulb and 67ºF wet-bulb). Since units differ in their sensitivity to these conditions, variation in cooling efficiency from unit-to-unit is to be expected. Second, when the unit is providing cooling (condensing unit is operating), ventilation air is a load on the cooling coil, but not on the space. Thus, for the same space load, ventilation air can affect unit energy use because of its impact on unit sensible cooling capacity (affecting unit runtime) and on overall condensing unit efficiency (energy consumed over a given runtime). This differs from unit-to-unit, resulting in increased variation in seasonal performance among the various units. Neither of these issues are addressed explicitly in the SEER ratings process.

Even when indoor fan energy is excluded from consideration, variation in internal loads and the introduction of ventilation air produce seasonal cooling efficiencies that vary from cooling system to cooling system. This is illustrated in Figure 5.1.2 for a small office application. The figure compares the condensing unit SEER of the units examined in this study. Condensing unit SEER is that obtained when the indoor fan energy is excluded from conventional SEER calculations. The "Adjusted" condensing unit SEER is that obtained from manufacturers' data and adjusted for average California climate differences. Results shown in Figure 5.1.2 are qualitatively similar to those that would be obtained if the indoor fan were allowed to cycle with the compressor. Findings from this effort produced variations in condensing unit seasonal energy efficiency of +11% to –10% for small office applications, even when results are adjusted for average climate variations and indoor fan differences are removed. Results for other applications are +12% to -17% for small retail, and +9% to –11% for classrooms.

Figure 5.1.2

Adjusted and DOE-2 Simulated Condensing Unit SEER – Small Office Application
Five Thermal Zones, All Cooling Systems, CZ03, CZ06, CZ07, CZ12 and CZ15
Building Features that Lead to Minimum, Median and Maximum SEER Values



5.1.2 How Effective Is SEER at Ranking the Seasonal Efficiency of Different Systems?

SEER does rank the energy performance of packaged cooling systems on a class basis. That is, on average, SEER 13-units performed better than SEER-12 units, which perform better than SEER-10 units, as illustrated in Figure 5.1.1 for small office applications. However, simulations also showed a great deal of performance variation among like-SEER units. This variation was typically equal to or greater than the expected SEER-to-SEER difference. Thus, on an individual unit basis, SEER is not particularly effective in ranking units. The best SEER-10 unit was found to outperform over half of the SEER-12 units. This was also the case when comparing SEER-12 to SEER-13 units. There were building arrangements and climate conditions where the best SEER-10 unit outperformed at least one SEER 13 unit. Thus the contention that “lower SEER units are always more efficient than higher SEER units” is not true for the packaged units in the commercial applications examined in this effort.

5.1.3 How Effective Is SEER in Estimating Cooling Energy Savings?

The average, the energy benefits associated with a SEER upgrade is comparable to that which one would expect based on the change in SEER level, as provided in Table 5.1.1. For example, the expected energy savings of upgrading from a SEER-10 to a SEER-13 unit is 23%. Average savings obtained from DOE-2 simulations for all building types and most climate zones is near this value. Climate zone 15 is the exception where average energy savings can be as much as 58% less than that expected. Thus, from a regulatory standpoint, DOE-2 simulations in this effort suggest that SEER upgrades are likely to provide expected energy savings.

The problem with this finding is that the variation in seasonal performance among like-SEER units is typically equal to or greater than the expected savings from the 23% associated with an upgrade from a SEER-10 to a SEER 13 unit. This variation impacts upgrade savings conclusions in two ways. First, there is a good deal of uncertainty in the average upgrade benefits provided in Table 5.1.5. The average benefit assumes that all 47 units examined in this effort are equally likely to be installed. This may not be the case.

Second, from a consumer's perspective, the variation in seasonal energy efficiency among like-SEER units means that one could not be assured of the expected energy benefit from a SEER upgrade, even when upgrading 3 SEER levels (from SEER 10 to SEER 13). The possibility exists that one could upgrade from one of the better performing units with a lower SEER rating to a poorly performing unit with a higher SEER rating. Conversely, an upgrade could provide significantly greater energy savings than expected. One way to help reduce uncertainty in energy savings from a SEER upgrade is to make sure that the indoor fan power of the higher SEER unit is less than that of the lower SEER unit by the same margin as the SEER upgrade. That is, if one is upgrading from a SEER-10 to a SEER-13 unit, the fan power in Watts/cfm (see figure 3.2.3 above for fan powers used in this effort) of the SEER-13 unit should be at least 23% less than that of the SEER 10 unit.

Table 5.1.1

Median Energy Benefits of Moving to a Higher SEER System Median Building Features, All Systems, All Applications

		Percentage Decrease in Seasonal Cooling Energy				
	SEER Change	Expected	Small Office	Small Retail	Classroom Part-Year	Classroom Year-Round
CZ01	*SEER 10 to 13*	23%	23%	26%	15%	15%
	SEER 10 to 12	17%	14%	13%	8%	9%
	SEER 12 to 13	8%	10%	15%	7%	6%
CZ02	*SEER 10 to 13*	23%	22%	24%	20%	20%
	SEER 10 to 12	17%	13%	13%	10%	11%
	SEER 12 to 13	8%	11%	13%	10%	10%
CZ03	*SEER 10 to 13*	23%	22%	25%	18%	19%
	SEER 10 to 12	17%	13%	13%	11%	12%
	SEER 12 to 13	8%	11%	13%	7%	8%
CZ04	*SEER 10 to 13*	23%	22%	23%	19%	20%
	SEER 10 to 12	17%	13%	13%	12%	13%
	SEER 12 to 13	8%	11%	11%	8%	8%
CZ05	*SEER 10 to 13*	23%	23%	25%	20%	21%
	SEER 10 to 12	17%	14%	14%	13%	13%
	SEER 12 to 13	8%	11%	14%	9%	9%
CZ06	*SEER 10 to 13*	23%	23%	24%	21%	22%
	SEER 10 to 12	17%	13%	14%	14%	14%
	SEER 12 to 13	8%	11%	12%	9%	9%
CZ07	*SEER 10 to 13*	23%	23%	24%	21%	21%
	SEER 10 to 12	17%	14%	13%	14%	14%
	SEER 12 to 13	8%	11%	12%	8%	9%
CZ08	*SEER 10 to 13*	23%	23%	23%	21%	21%
	SEER 10 to 12	17%	14%	13%	12%	13%
	SEER 12 to 13	8%	11%	12%	9%	9%
CZ09	*SEER 10 to 13*	23%	22%	24%	4%	21%
	SEER 10 to 12	17%	13%	13%	-5%	12%
	SEER 12 to 13	8%	10%	13%	-8%	11%
CZ10	*SEER 10 to 13*	23%	22%	23%	21%	20%
	SEER 10 to 12	17%	13%	13%	11%	12%
	SEER 12 to 13	8%	10%	12%	11%	9%
CZ11	*SEER 10 to 13*	23%	21%	19%	20%	17%
	SEER 10 to 12	17%	13%	13%	12%	10%
	SEER 12 to 13	8%	10%	7%	9%	8%
CZ12	*SEER 10 to 13*	23%	21%	19%	17%	19%
	SEER 10 to 12	17%	12%	11%	11%	11%
	SEER 12 to 13	8%	10%	9%	8%	9%

Table 5.1.1 (Continued)

		Percentage Decrease in Seasonal Cooling Energy				
	SEER Change	Expected	Small Office	Small Retail	Classroom Part-Year	Classroom Year-Round
CZ13	*SEER 10 to 13*	23%	21%	19%	19%	19%
	SEER 10 to 12	17%	13%	12%	11%	12%
	SEER 12 to 13	8%	9%	7%	9%	8%
CZ14	*SEER 10 to 13*	23%	21%	18%	18%	19%
	SEER 10 to 12	17%	13%	15%	11%	11%
	SEER 12 to 13	8%	10%	3%	8%	9%
CZ15	*SEER 10 to 13*	23%	19%	18%	19%	19%
	SEER 10 to 12	17%	12%	11%	11%	12%
	SEER 12 to 13	8%	8%	8%	8%	8%
CZ16	*SEER 10 to 13*	23%	23%	28%	18%	19%
	SEER 10 to 12	17%	13%	14%	10%	11%
	SEER 12 to 13	8%	11%	16%	9%	9%

5.1.4 How Effective Is SEER as a Predictor of Expected Cooling Peak Demand and Demand Savings?

SEER is a predictor of expected peak cooling demand only in that higher SEER systems tend to have higher values of EER. It is EER that provides the better predictor of peak cooling demand. Operational cooling system EER (peak cooling system capacity divided by simulated cooling system peak electric demand) was capture from DOE-2 simulations. Once results were adjusted for system over sizing and climate affects, rated EER predicted values from simulation to within +12% to –17% for small office applications, +17% to –22% for retail applications, and ±12% for school classroom applications. Typical results are provided in Figure 5.1.3 for small offices. The variation in demand appears to be caused by both outdoor air temperature and coil entering air conditions at times of peak cooling energy use. Ventilation requirements affect cooling coil-entering conditions as outdoor air is introduced into the return air stream prior to entering the cooling coil. Since cooling systems differ in their sensitivity to both sets of conditions (outdoor air and cooling coil-entering), variation in peak demand from unit-to-unit is to be expected.

SEER upgrades, on average, produce demand reductions, as provided in Table 5.1.2. Average demand reductions from SEER upgrades in a small office application were 14% to 21% less than that associated with changes in SEER values. They were 35% to 42% less for retail applications and 15% to 24% less for school classroom applications. These are average demand reductions, but significant variation in peak cooling system demand should be expected among same-SEER units. Demand reductions can vary significantly (both higher and lower) when comparing particular units in a SEER upgrade.

Figure 5.1.3

Simulated (adjusted for over-sizing) vs. Climate Zone Adjusted EER
Small Office Application, Median Building Characteristics, All Systems
CZ03, CZ06, CZ07, CZ12, and CZ15

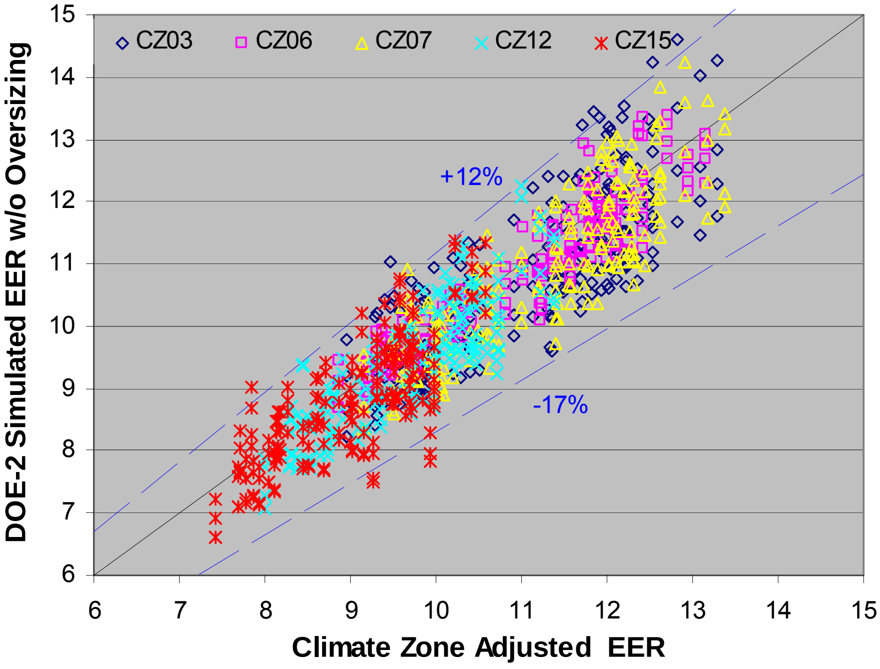


Table 5.1.2

Median Demand Reduction from Moving to a Higher SEER System
Median Building Features, All Systems, All Applications

			Percentage Decrease in Peak Cooling Demand			
	SEER Change	Expected[1]	Small Office	Small Retail	Classroom Part-Year	Classroom Year-Round
CZ01	*SEER 10 to 13*	23%	22%	12%	17%	19%
	SEER 10 to 12	17%	15%	11%	14%	16%
	SEER 12 to 13	8%	8%	1%	3%	4%
CZ02	*SEER 10 to 13*	23%	20%	15%	16%	16%
	SEER 10 to 12	17%	15%	12%	12%	12%
	SEER 12 to 13	8%	6%	3%	4%	4%
CZ03	*SEER 10 to 13*	23%	22%	17%	22%	22%
	SEER 10 to 12	17%	15%	12%	15%	15%
	SEER 12 to 13	8%	8%	6%	9%	8%
CZ04	*SEER 10 to 13*	23%	21%	14%	20%	17%
	SEER 10 to 12	17%	16%	10%	13%	11%
	SEER 12 to 13	8%	6%	4%	8%	7%

Table 5.1.2 (Continued)

		Percentage Decrease in Seasonal Cooling Energy				
	SEER Change	Expected[1]	Small Office	Small Retail	Classroom Part-Year	Classroom Year-Round
CZ05	*SEER 10 to 13*	23%	21%	12%	18%	8%
	SEER 10 to 12	17%	16%	11%	13%	-1%
	SEER 12 to 13	8%	6%	1%	6%	-10%
CZ06	*SEER 10 to 13*	23%	22%	15%	20%	5%
	SEER 10 to 12	17%	16%	12%	15%	-3%
	SEER 12 to 13	8%	8%	3%	6%	-11%
CZ07	*SEER 10 to 13*	23%	22%	17%	20%	9%
	SEER 10 to 12	17%	16%	12%	14%	2%
	SEER 12 to 13	8%	8%	6%	6%	-13%
CZ08	*SEER 10 to 13*	23%	21%	14%	18%	7%
	SEER 10 to 12	17%	16%	10%	12%	-1%
	SEER 12 to 13	8%	7%	4%	6%	-7%
CZ09	*SEER 10 to 13*	23%	18%	14%	16%	17%
	SEER 10 to 12	17%	14%	10%	11%	11%
	SEER 12 to 13	8%	6%	4%	6%	7%
CZ10	*SEER 10 to 13*	23%	19%	12%	16%	17%
	SEER 10 to 12	17%	14%	10%	13%	14%
	SEER 12 to 13	8%	5%	2%	3%	4%
CZ11	*SEER 10 to 13*	23%	18%	19%	18%	19%
	SEER 10 to 12	17%	13%	11%	13%	12%
	SEER 12 to 13	8%	5%	9%	6%	8%
CZ12	*SEER 10 to 13*	23%	18%	19%	17%	19%
	SEER 10 to 12	17%	13%	11%	12%	13%
	SEER 12 to 13	8%	5%	9%	6%	7%
CZ13	*SEER 10 to 13*	23%	18%	18%	19%	20%
	SEER 10 to 12	17%	13%	12%	12%	13%
	SEER 12 to 13	8%	6%	6%	8%	8%
CZ14	*SEER 10 to 13*	23%	17%	15%	19%	20%
	SEER 10 to 12	17%	13%	12%	13%	13%
	SEER 12 to 13	8%	4%	3%	7%	8%
CZ15	*SEER 10 to 13*	23%	16%	14%	17%	19%
	SEER 10 to 12	17%	11%	10%	11%	10%
	SEER 12 to 13	8%	5%	4%	7%	11%
CZ16	*SEER 10 to 13*	23%	20%	15%	19%	18%
	SEER 10 to 12	17%	16%	11%	13%	14%
	SEER 12 to 13	8%	5%	5%	6%	5%

Note 1: Based on SEER increase

5.1.5 Can a California-Specific "Adjusted" SEER Procedure Be Developed with Improved Value?

A seasonal energy efficiency metric ($SEER_f$) was developed in this effort that includes the impact of continuous fan operation on cooling system efficiency. The new metric treats the energy consumption of the indoor fan and condensing unit separately. $SEER_f$ does not provide significantly improved estimates of cooling system seasonal efficiency. The range of building operating and design parameters examined generated too great a variation in condensing unit seasonal efficiency and condensing unit operation relative to that of the indoor fan. However, it did provide a better means of ranking cooling systems by their seasonal cooling efficiency. Selecting units based on $SEER_f$ reduces the variation in seasonal energy efficiency of like-SEER units by at least half by eliminating the worse performing units from consideration. Under some situations, it correctly suggested the selection of lower SEER units over their higher SEER counterparts.

Unit rankings based on $SEER_f$ are compared to results from DOE-2 simulations in Figures 5.1.4a and 5.1.4b for a small office application with median building characteristics. Results are for the whole building (sum of zonal values weighted by cooling energy). Findings for other applications are similar. The figures compare the ranking of units from best (rank of 1) to worse (rank of 47) based on either DOE-2 simulation results (horizontal bar) or $SEER_f$ estimates (open diamonds). Symbols are color-coded by rated SEER with SEER-10 units colored magenta, SEER-12 units colored yellow, and SEER-13 units colored cyan. Results are presented for climate zones CZ06 (cooler climate zone) and CZ15 (warmest climate zone in the state).

Application specific multipliers were developed to adjust condensing unit seasonal efficiency for each California climate zone and to provide estimates of the relative energy consumption of the indoor fan versus the condensing unit. $SEER_f$ is calculated from these multipliers and manufacturers' data of the various units. This calculation requires access to manufacturers' expanded ratings tables and indoor fan tables, both of which are normally provided in engineering documents for packaged equipment.

Figure 5.1.4a
Ranking of Packaged Systems by SEER$_f$ – CZ06
Small Office Application, Median Building Features, All Systems

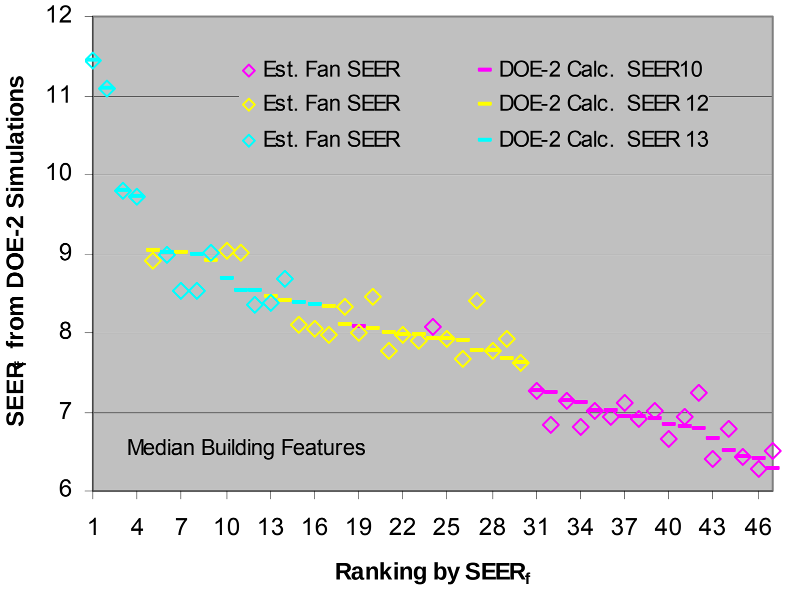
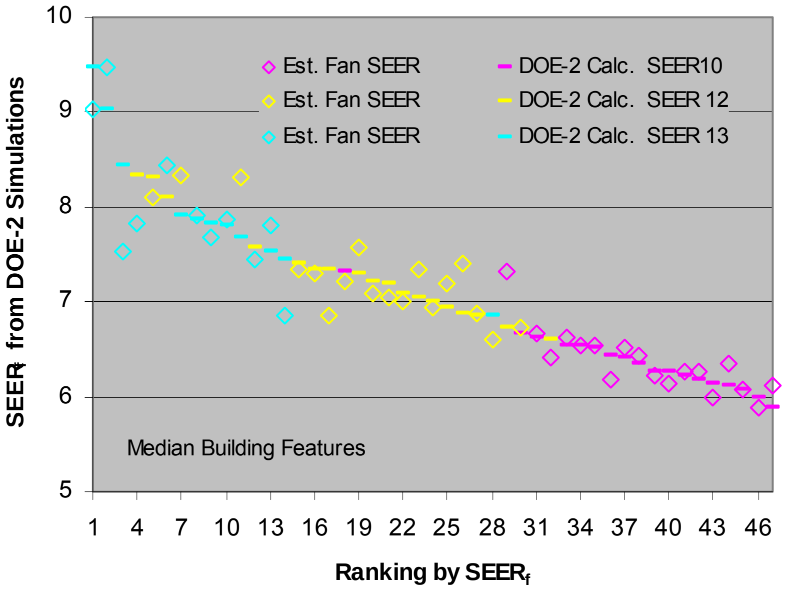


Figure 5.1.4b
Ranking of Packaged Systems by SEER$_f$ – CZ15
Small Office Application, Median Building Features, All Systems



6.0 REFERENCES

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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 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

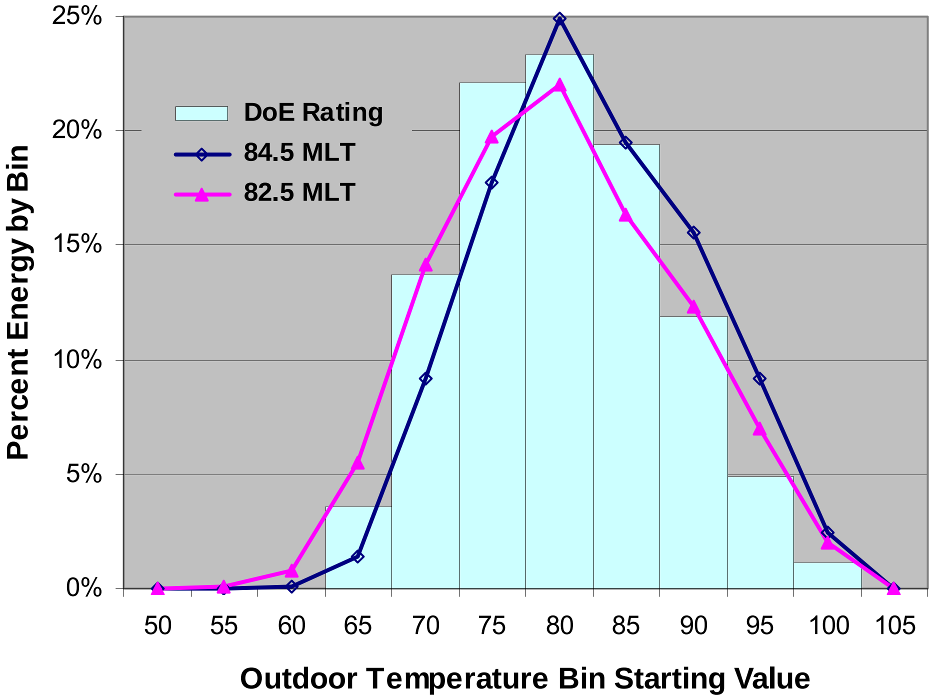


Figure A.2 provides a comparison of predicted SEER ratings using full DOE-2 performance curves versus those adjusted to match NIST assumptions. The points noted as “Full Model” use performance curves based on manufacturer’s published data and expanded ratings tables. Those noted as the “Simple Model” 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 condensing 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 condensing 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 67° 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

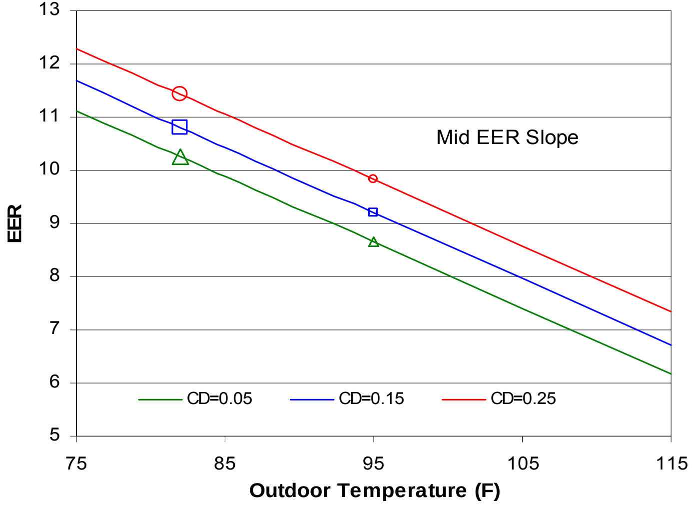
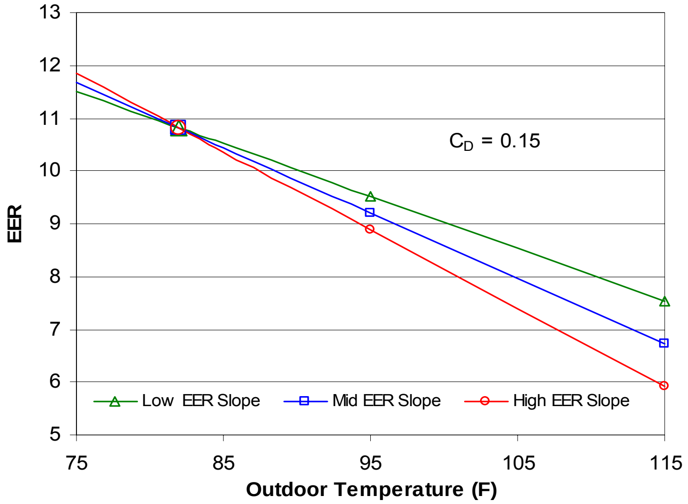


Figure B.2

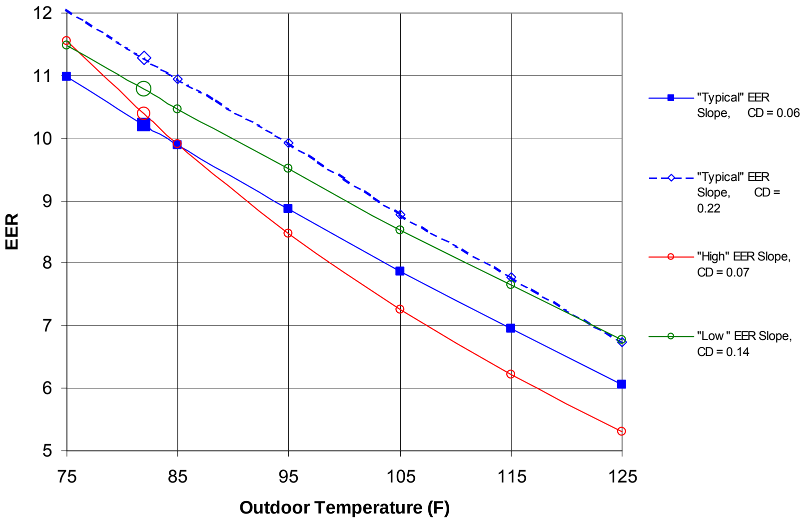
Effect of $Slope_{EER}$ on System Performance – SEER 10 Systems



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

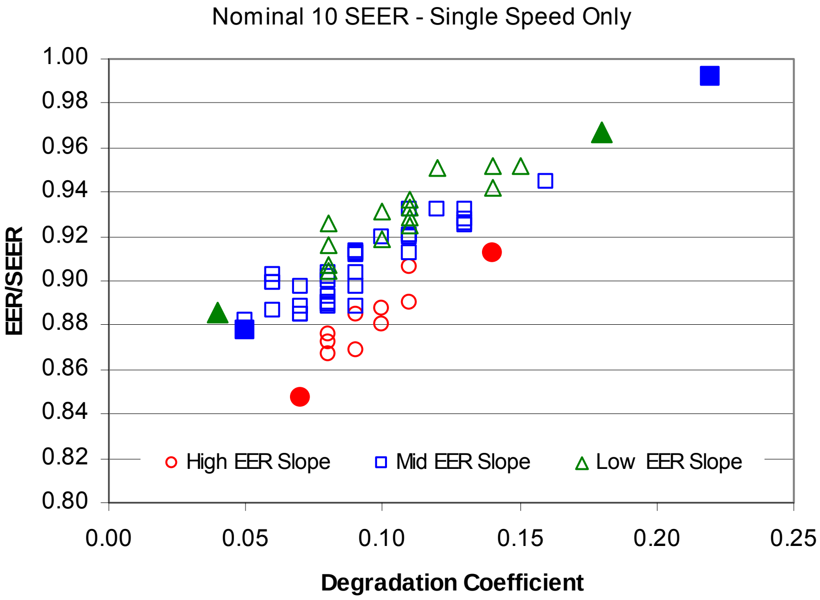


The Hiller database provides additional information on the relationships between values of C_D and $Slope_{EER}$, Typically, systems with high values of $Slope_{EER}$ tend to have lower values of C_D. Systems with lower values of $Slope_{EER}$ tend to have higher values of C_D. Systems with mid-values 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

		Residential Prototype		
Variable	Range	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 External Static (in wg)	Low	*0.5*	*0.5*	*0.5*
	Median	0.75	0.75	0.75
	High	*1.0*	*1.0*	*1.0*
Split Systems – 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	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

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

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

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

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

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

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:

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

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:

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

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:

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

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

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

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

$$\text{EIR\_}f(\text{PLR}) = \text{PLR}/\text{PLF}. \tag{9}$$

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.

$$\text{EIR\_}f(\text{PLR}) = f_{on} + (1 - f_{on})\, P_{off}\, , \tag{10a}$$

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:

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

II. Determining the Cooling System Time Constant from C_D

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

$$C_D = (1 - \text{PLF})/(1 - \text{CLF}) \tag{11}$$

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,

$$C_D = (1 - 5\ \text{CLF})/(1 - \text{CLF}) \tag{12}$$

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

$$\tau = 288\, C_D/(1 - 0.2\, C_D), \tag{13}$$

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 ($0.0 \le \text{CLF} \le 0.7$) for System 3 by

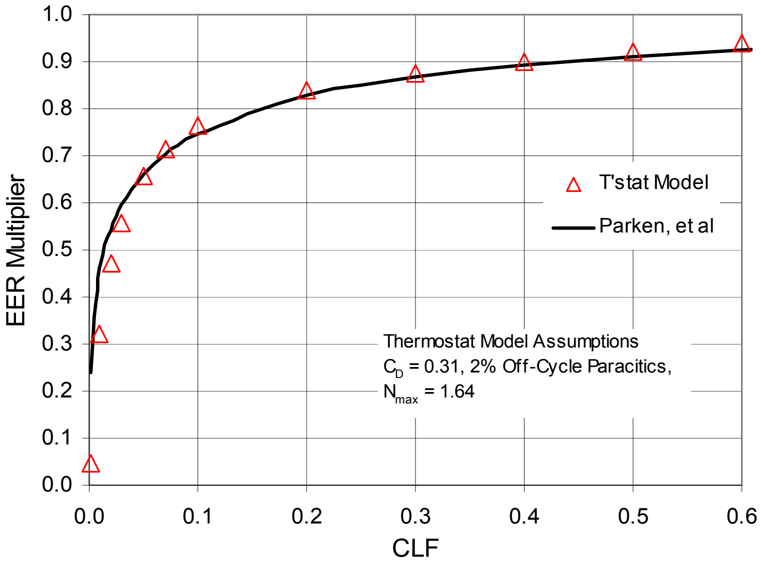
$$PLF_{\text{System 3}} = 1 - \exp(-3.0855\ CLF^{0.35}) \tag{14}$$

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:

$$\text{SEER} = \text{EER}_B\,(1 - 0.5\,C_D) \tag{15}$$

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:

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

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

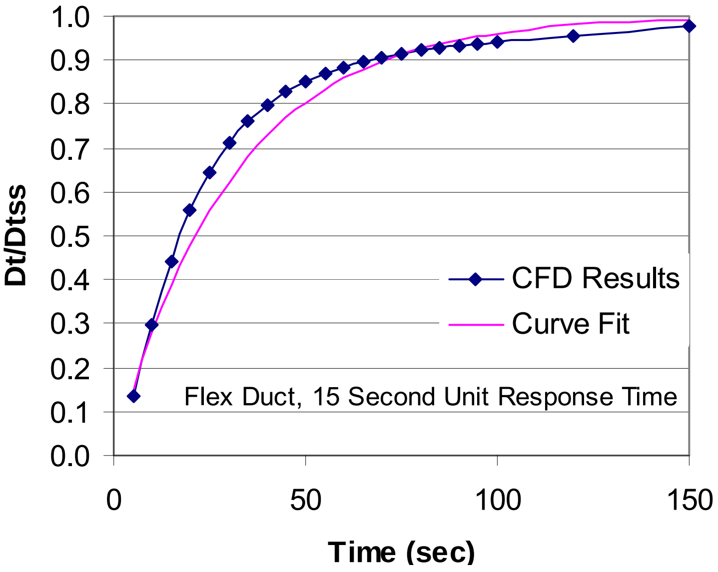
It should be noted that “steady-state”, as used in developing ductwork time constants, includes steady state ductwork heat gains. The steady-state temperature differential used in Figure C.2 is the difference between the return air temperature (assumed to be 80 F) and the average supply air temperature 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

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APPENDIX D: Details of Non-Residential Building Prototypes

Since this analysis is focused on single-zone air conditioning systems (i.e., air-cooled SEER-rated units 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.

Selection of Building Types

Building types were selected based on the fraction of the installed tonnage for SEER-rated units. Table 2 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 units (i.e., units less than 5.5 tons), and total installed tonnage of SEER-rated units. 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 2 reports building size and cooling service by both building type and building size quantile, i.e., percentile ranges, from the minimum size to the maximum size. The 0% quantile corresponds to the minimum value in the database, the 100% quantile corresponds to the maximum value, and the 50% quantile corresponds to the median value.

In Table 2b, 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 of cooling capacity provided by SEER-rated DX).

Table 2-c 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 units. Table 2-c 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 units installed in non-residential buildings in California. This same breakdown is also shown in Figure 1.

Table D2 – 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) Units

% of DX Cooling Provided by <= 5.5 ton units																	
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%

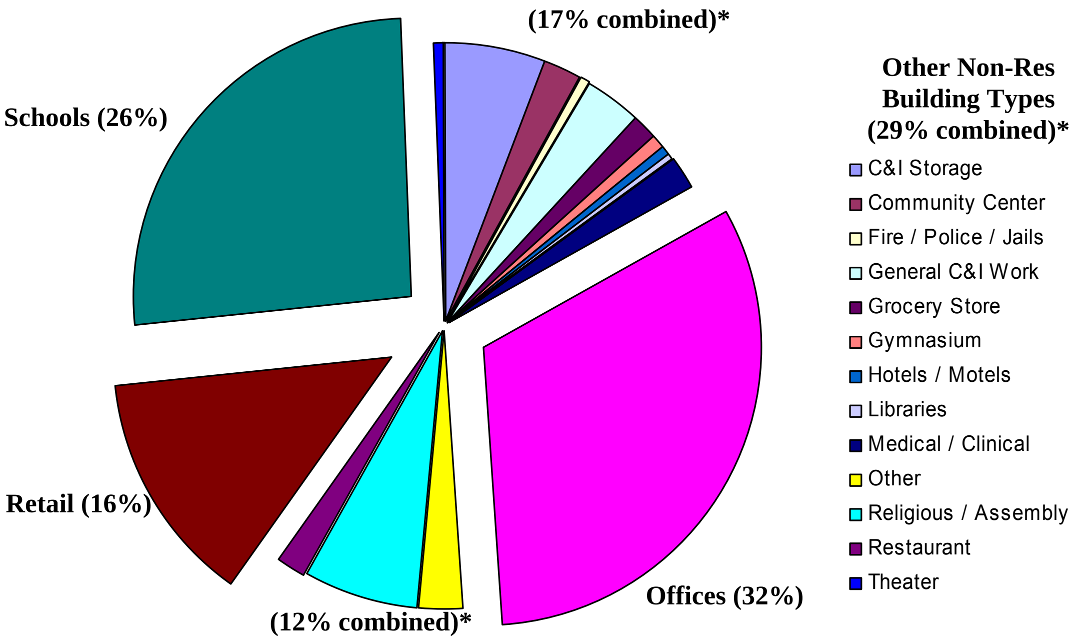
c: Total Installed Tons of SEER-Rated (< 5.5 ton) Units

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 units*

🟩 *indicates building types with the most SEER-rated installed tonnage*

Figure D1 –Percent of Total Installed Tons of SEER-Rated A/C Units in California Non-Residential Buildings

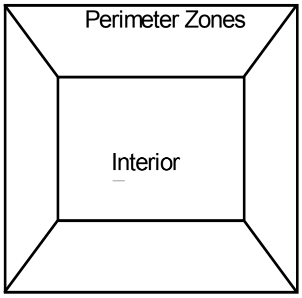


* for a breakdown of the percentages by building type, see the first row of Table 2c

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

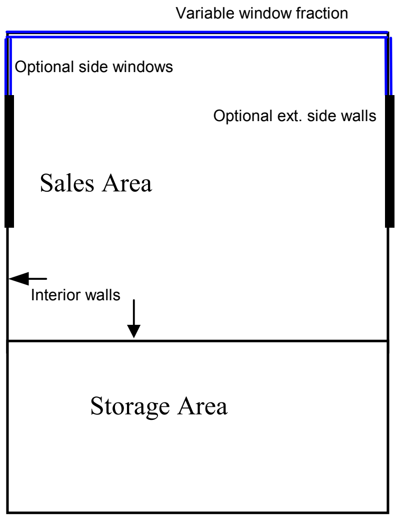
The office prototype is one story with typical 5-zone layout having one interior and five perimeter zones. The office will have a shallow perimeter zone depth (e.g., 15 ft) and large interior zone, configured to represent the 16,000 square foot median size. Each zone will be served by a separate PSZ 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.

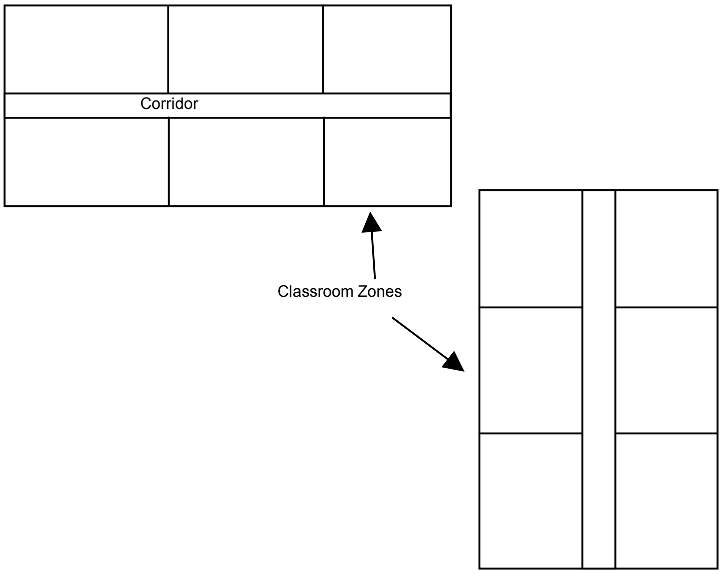
The retail model will have a deep perimeter zone depth and small interior zone (storage), configured to represent the 22,000 square foot median size. The sidewalls can be exterior walls, interior walls, or a fraction of each, depending on the sensitivity analysis being evaluated.



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.

Typical Values and Sensitivity Analysis Values for Non-Residential Prototypes

Office Building Model Input Values by Climate Zone (page 1 of 4)

		Office Building Characteristics								
Climate Region	Wth File	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 Region	Wth File	Roof Insulation			Exterior Wall Insulation			Wall Cons Type		
		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 Region	Wth File	Occupancy (Sqft/occ)			Lighting Power Density (W/sf)			Equip Power Density (W/sf)		
		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)

		Office Building 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	0.49	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
	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

Office Building Model Input Values by Climate Zone (page 4 of 4)

		Office Building Characteristics								
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	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	Wth	Cooling Thermostat SP		
Region	File	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		

Retail Building Model Input Values by Climate Zone (page 3 of 4)

		Retail Building Characteristics								
Climate Region	Wth File	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 4 of 4)

		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		

Conventional School Classroom Model Input Values by Climate Zone (page 1 of 4)

		School Characteristics (Conventional Classrooms)								
Climate Region	Wth File	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 Region	Wth File	Glass U-Value			Glass SHGC			Ovhg Depth (ft)		
		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 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	0.25	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 Region	Wth File	Whole Bldg WWR*			WWR (North, South)*			WWR (East, West)*		
		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 Region	Wth File	Cooling Thermostat SP		
		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		