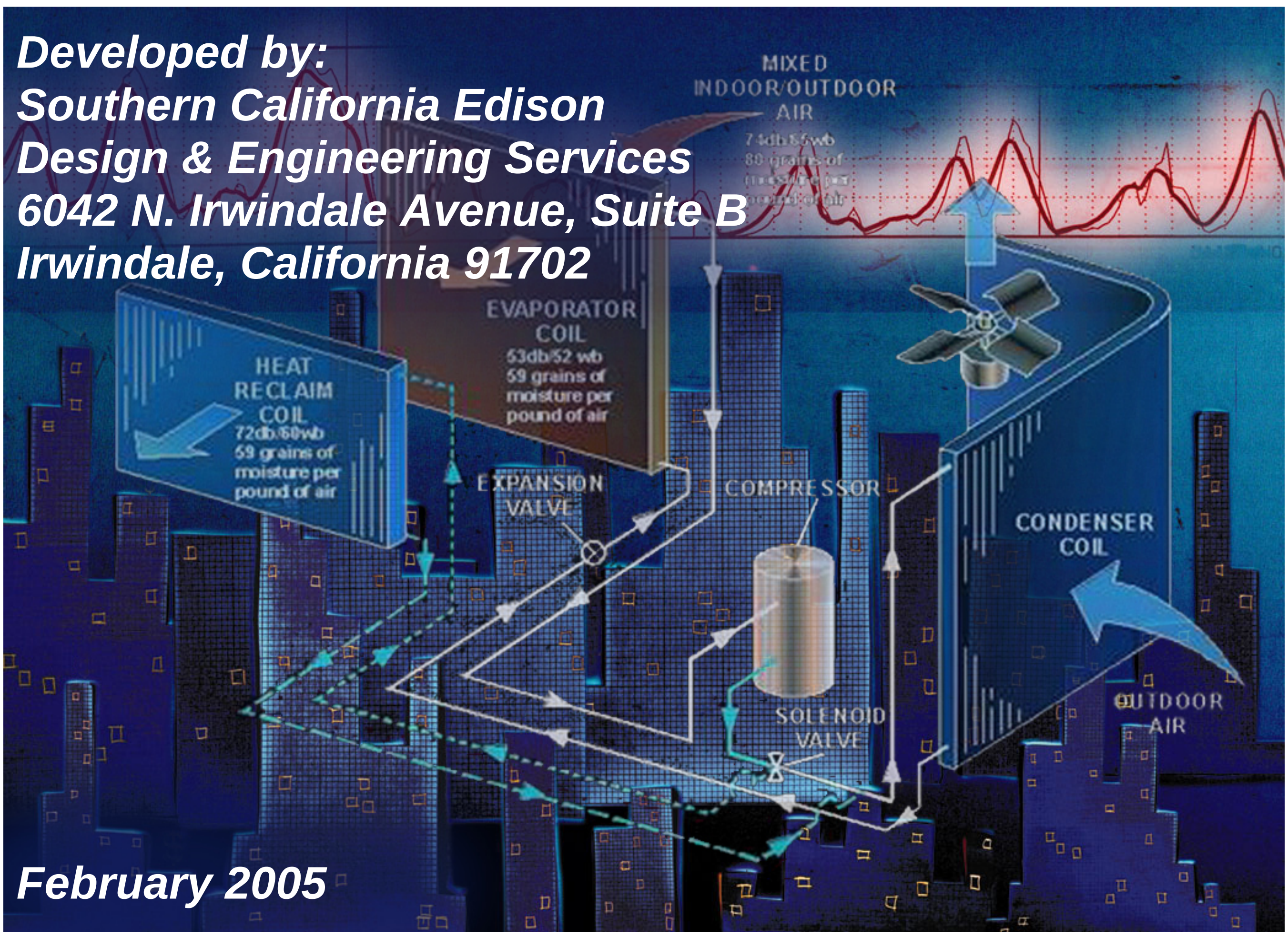
DEER RESIDENTIAL SEER-RATED UNITS PERFORMANCE MAPS

PHASE 2 REPORT: Performance Maps and Methodology Development

PRELIMINARY RESULTS



Developed by:
Southern California Edison
Design & Engineering Services
6042 N. Irwindale Avenue, Suite B
Irwindale, California 91702

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Phase 2 Report: Performance Maps and Methodology Development

Preliminary Results

1.0 RESULTS OF WORK

This report provides details of the development of performance maps to characterize residential direct expansion cooling units for use in the Database for Energy Efficient Resources (DEER) analysis. The attached spreadsheet contains the performance maps of the selected units for use in the DEER analysis. Just double click on the spreadsheet icon to open it.

A summary description of the spreadsheet is as follows:

Tab	Name	Description
1	*Unit Performance*	Brief description of unit selection process.
2	*Results All Units*	Contains a dynamic chart comparing the annual cooling energy consumption and demand of the air conditioners and heat pumps evaluated in this effort. Results are given for all units evaluated with dynamic selections for unit type (air conditioner or heat pump), climate zone, residence vintage, and plot type (energy consumption, cooling system demand, or cooling and heating consumption for heat pumps).
3	*Results All CZ's*	Contains dynamic charts comparing the annual energy consumption and demand of a given unit over all climate zones. Dynamic selection are provided for unit type, SEER level, and residence vintage.
4	*Incremental Savings*	Brief description of how the incremental savings, such as going from SEER 10 to SEER 13, are calculated.
5	*AC Savings*	Contains a dynamic chart illustrating range of savings associated with moving to a higher SEER-rated air conditioner. The median savings for a particular climate and vintage is presented along with the savings determined from the selected "median units".
6	*HP Savings*	Contains a dynamic chart illustrating range of savings associated with moving to a higher SEER-rated heat pump. The median savings for a particular climate and vintage is presented along with the savings determined from the selected "median units".
7	*Calibration Tables*	Tables of calibration factors required to produced Utility Energy

		Consumption (UEC) and Residential Appliance Saturation Study (RASS) weighting of raw DEER simulation results.
8	*AC-HP Unit Data*	Table of performance map coefficients for the 99 air conditioners and heat pumps simulated in this analysis.

2.0 Unit Selection Procedure

The units selected for this study were taken from available split-system residential air conditioners and heat pumps with seasonal energy efficiency ratio (SEER) ratings required by the DEER evaluation process. They included nominal SEER 10, 13, 14 and 15 single-speed units and SEER 16, 17, and 18 two-speed units. In addition to the SEER rating, some units were selected to meet California utilities Tier minimum energy efficiency ratio (EER[1]) values for air conditioners and heat pumps and heating seasonal performance factor (HSPF) values for heat pumps. Minimum EER and HSPF values were used only for equipment with SEER ratings greater than 13 as SEER 10 and SEER 13 equipment represent existing and near term minimally compliant efficiencies without regard to EER values.

The number of units within a given SEER level can be quite large (especially SEER 10 equipment). The California utilities database of Tier-level equipment includes over 16,000 split system air conditioners and heat pumps. Rational methods were needed to select a subset of units whose performance would likely span that of those available. The general approach was to use methods that would span the range of EER values for a given SEER. SEER is generally accepted as a measure of cooling system energy consumption while EER is generally accepted as a measure of a cooling system peak electric demand. Thus, selecting units with a full EER range within a given SEER level should provide a full range of cooling load factors (cooling energy consumption divided by peak cooling demand) from available equipment.

The first requirement in selecting units for consideration is that expanded ratings data on the unit are available from the manufacturer. An example of an expanded rating chart is provided in Appendix A. This data is necessary to produce DOE-2 performance maps for proper simulation of seasonal cooling (and heating in the case of heat pumps) operation. This limited the number of manufacturers to Carrier, Lennox, Nordyne, and Trane. These manufacturers sell their equipment under at least 10 different brand names and represent over half of the units sold nationally (see Appendix A for reference). Brand names represented by the units selected in this effort include Bryant and Carrier (manufactured by Carrier); Lennox; Frigidare, Gibson, Kelvinator, Maytag, Philco, Tappan, and Westinghouse (manufactured by Nordyne); and Trane and American Standard (manufactured by Trane). This is not an exhaustive list of all name brands represented by these manufacturers, but covers those listed as units approved for Tier rebates by the California utilities.

[1] Unless otherwise indicated, EER refers to the EER_A ARI test value. This is the energy efficiency ratio obtained with an outdoor temperature of 95º F and cooling coil entering conditions of 80º F dry bulb and 80º F wet-bulb temperatures.

The selection procedure for single-speed units is somewhat complex with details provided in Appendix A. In brief, the selection procedure looks at two metrics within a given SEER level,

1. how the energy efficiency of the various units responds to changes in the outdoor temperature and
2. system cycling losses.

The first (temperature sensitivity) accounts for possible changes in cooling system efficiency when units are moved from climate zone to climate zone. The second (cycling losses) generates a range of electric demand values within a given climate zone.

Using this approach, single-speed units were sorted by their temperature sensitivity in to Low, Mid, and High ranges and by their cycling losses in to Low, Mid, and High values within each temperature sensitivity level (See Appendix A for a concise definition of Low, Mid, and High and how they are used in the unit selection process). With a sufficient number of units available for consideration, this approach leads to a selection of nine units (all possible combinations of temperature sensitivity and cycling losses). The number of SEER 14 and 15 units are limited, reducing the temperature sensitivity levels to only Mid and High. This results in a set of six units to represent SEER 14 and 15 units (two temperature sensitivity levels combined with three cycling loss levels).

The single-speed unit selection process is illustrated in Figures 1 and 2, which compare the rated EER of the SEER 13 air conditioners (Figure 1) and heat pumps (Figure 2) examined. Each data point represents one of the nine units simulated. The unit descriptors are made up of three sets of characters. The first two (SA or SH) indicate that the unit is a split-system air conditioner or heat pump, respectively. The next two are the units' nominal SEER rating. The final two letters in the unit description shown in the figure are the units' temperature sensitivity and cycling loss levels, respectively. Thus, the left-most unit on Figure 1 (SA-13-LL) is a SEER-13, split-system air conditioner with low temperature sensitivity and low cycling losses. The selection procedure provided units with EER ratings from 10.7 to 12.5 with an average EER of 11.5. Average, minimum, and maximum EER ratings are given in Tables 1 for all SEER levels of the air conditioners examined. Also given is the total number of units examined from which the subset was selected. Table 2 provides similar information for the heat pumps and includes average HSPF values.

While the overall goal of providing a range of EER's for a given SEER level was unchanged, the selection process differed for two-speed air conditioners and heat pumps. There are a number of reasons for this. First, the SEER ratings process differs from single to two-speed units. Temperature sensitivity and cycling losses, while important, are less so than for single-speed units. The speed control of the unit (as set by the cooling capacity where it moves from low to high speed operation) figures more prominently in unit performance. This is manufacturer dependent and tends to be consistent within a given product line. Second, for the SEER levels of two-speed units examined in this effort, there are significantly fewer units to examine. A total of 205[2] SEER 16, 17 and 18, two-speed air conditioners and heat pumps with usable

[2] There are more than 205 units listed in the California utilities Tier database. This effort did not include some units

manufacturers' data were identified. This compares to over 16,000 single speed units listed in the California utilities Tier database. Because of this, it was possible to select representative units from every product line within a given SEER level. There was a single product line[3] of two-speed air conditioners and of two-speed heat pumps from each of the four manufacturers (Carrier, Lennox, Nordyne, and Trane) for which expanded rating charts were available.

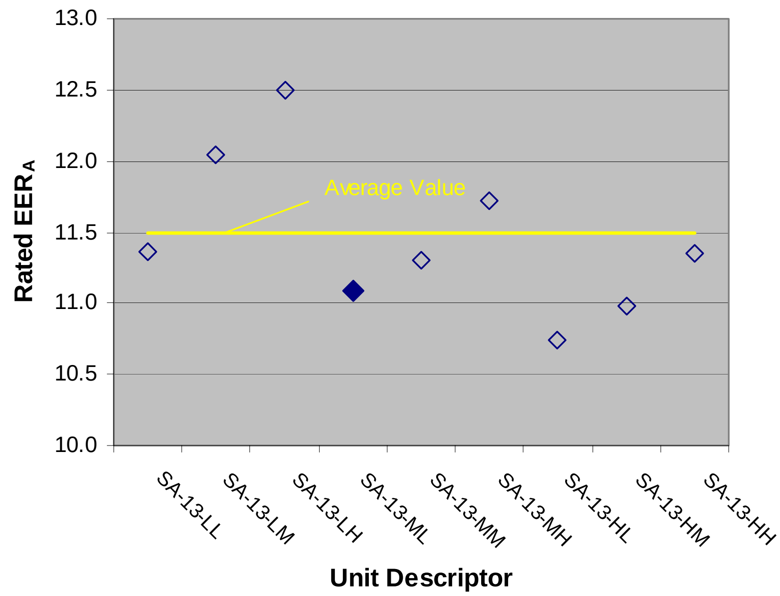

Figure 1 – Range of EER's for Selected SEER 13 Air Conditioners

Table 1 – Selected Single-Speed Air Conditioner Performance Summary

	SEER 10	SEE13	SEER 14	SEER 15
Database Average EER	9.1	11.3	12.2	12.8
Subset Average EER	9.1	11. 5	12.4	12.9
Minimum EER	8.5	10.7	11.7	12.4
Maximum EER	9.8	12.5	13.2	13.1
Units in database	65	63	20	14

Representative units were selected from each product line by selecting units with low, median, and high EER ratings for each SEER level. Units with low and high EER values were just that, the condensing unit and evaporator configuration that resulted in the lowest and highest EER

with fractional SEER ratings outside of the nominal rating +/- 0.25 SEER rating points, those units for which expanded ratings charts were not available, and multiple nameplates from the same manufacture. See Appendix A for an example of an expanded ratings chart.

[3] The Trane 2TTZ and 2TWZ product lines are the current configurations of the older TTZ and TWZ products listed in the California utilities Tier database.

values for a given product line and SEER level. There was a low limit placed on the acceptable EER. This was an EER of 11 for SEER 16 unit, EER of 11.4 for SEER 17 units, and an EER of 12 for SEER 18 units. Minimum EER levels were based on those observed in the California utilities Tier database.

The unit selected as a median unit had a rated EER near the median value of all units in the product line and SEER level. There were numerous instances where the lack of available units prevented a selection of three units within a product line. In some cases, there was only one unique unit available from a given manufacturer. In others, there was insufficient variation in rated EER from unit-to-unit to select a median performer. In this case, the selection of representative units was limited to those with high and low EER values.

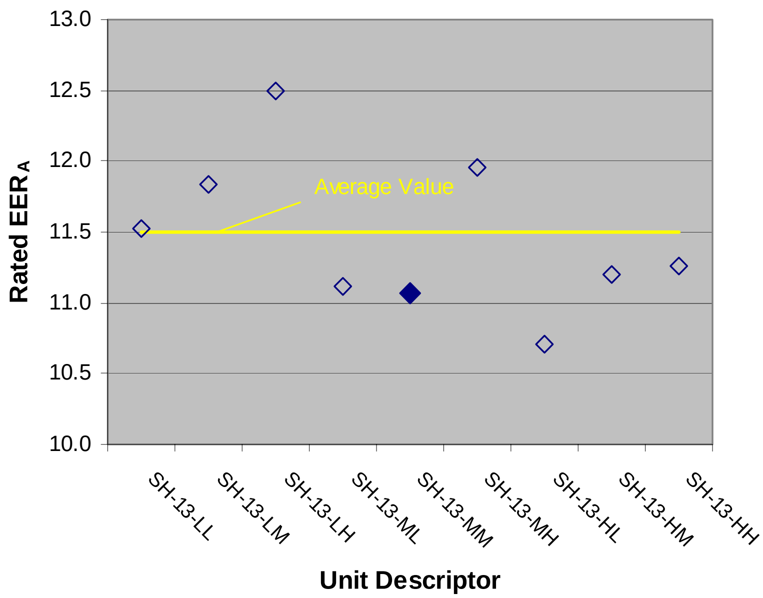

Figure 2 – Range of EER's for Selected SEER 13 Heat Pumps

Table 2 – Selected Single-speed Heat Pump Performance Summary

	SEER 10	SEE13	SEER 14	SEER 15
Database Average EER	9.2	11.3	12.2	12.8
Subset Average EER	9.3	11. 5	12.2	12.8
Minimum EER	8.8	10.7	11.3	12.6
Maximum EER	10.0	12.5	13.4	13.2
Average HSPF	7.1	8.2	8.4	8.7
Units in database	49	57	17	13

The number of units available for consideration, manufacturer and product line, and number of units selected is provided in Table 3. The number of units selected for analysis and the minimum, maximum, and median EER values are provided in Table 4.

The revised selection process for two-speed equipment led to a change in the unit naming convention. The unit descriptor still uses six characters, with the first four remaining the same as in single-speed equipment. The last two characters now refer to the unit's manufacturer and the EER level. Unit manufacturer indicators are C, L, N, and T, referring to Carrier, Lennox, Nordyne, and Trane respectively. The final character refers to the EER level and can be H, M, and L, representing high, median, and low EER values. Thus a SA-16-LM refers to a split system air conditioner (SA), with a nominal SEER rating of 16 (16), manufactured by Lennox (L), with a median EER value (M).

Table 3 - Number and Description of Two-Speed Units Considered for Analysis

Air Conditioner Manufacturer and Product Line

Nonimal SEER	Carrier 38TDB	Lennox HSXA19	Nordyne FS4BF	Trane 2TTZ	Total
16	39	32	2	4	77
17	28	7	0	20	55
18	0	6	0	12	18

Heat Pump Manufacturer and Product Line

Nonimal SEER	Carrier 38YDB	Lennox HPXA19	Nordyne n/a	Trane 2TWZ	Total
16	3	18	0	12	33
17	1	3	0	2	6
18	0	15	0	1	16

Table 4 - Selected Two-Speed Unit Summary

	Air Conditioner Manufacturer and Product Line												
	Carrier			Lennox			Nordyne			Trane			
Nonimal	EER			EER			EER			EER			
SEER	L	M	H	L	M	H	L	M	H	L	M	H	Total
16	11.7	11.9	12.2	11.6	12.1	12.2	-	12.4	-	11.1	-	11.3	9
17	12.4	12.5	12.7	12.3	12.5	12.7	-	-	-	11.4	12.2	13	9
18	-	-	-	13	-	13.2	-	-	-	12.7	13.5	13.8	5
	Heat Pump Manufacturer and Product Line												
	Carrier			Lennox			Nordyne			Trane			
Nonimal	EER			EER			EER			EER			
SEER	L	M	H	L	M	H	L	M	H	L	M	H	Total
16	12	-	12.1	11.8	12.1	12.6	-	-	-	11.1	11.3	11.6	8
17	-	12.6	-	-	12.8	-	-	-	-	12.2	-	12.5	4
18	-	-	-	12.8	12.9	13.2	-	-	-	-	12.6	-	4

3.0 SIMULATION RESULTS AND UNIT SELECTION

3.1 SIMULATION RESULTS

Simulation results are presented in the linked worksheet (see Section 1.0 for link or to open the worksheet). DEER results are based on 576 DOE-2 simulations that include 99 air conditioner and heat pumps, 16 climate zones, and four residential building prototype vintages. Additional post processing produces a fifth vintage that is a penetration-weighted combination of the four vintages simulated for a result set of 720 cases[4]. Additionally, up to three data sets are of interest from each case. These are the annual cooling energy consumption, the three-day heat wave peak cooling demand, and (in the case of heat pumps), annual cooling and heating energy consumption. Energy consumption and demand values include that of the outdoor unit and the indoor fan (supply air fan). The full results dataset is too extensive to reproduce here. The reader is encouraged to review the dynamic graphics provided in the worksheet.

Typical graphics from the worksheet are presented here to aid in the understanding of the data provided by the graphics. Examples and explanations are reported by section titles that correspond to the worksheet tab containing the graphics. Four tabs (*Unit Performance, Incremental Savings, Calibration Tables, and AC-HP Unit Data*) provide summary and descriptive information, are self-explanatory, and are not included here. Graphic examples are as follows:

3.1.1 Results - All Units

A typical chart from this tab is shown in Figure 3. This chart compares simulation results for all SEER levels for either air conditioners or heat pumps. Figure 3 illustrates results for air conditioners as referenced in the charts sub-title. Unit type refers to the various air conditioners or heat pumps simulated. Each symbol format (color and shape) is related to a particular SEER level and unit configuration (one or two speed) as indicated in the chart legend. For example, the nine red diamonds along the top of the chart provide the annual cooling energy use for the nine SEER-10 air conditioners examined in the study. Thus, this graphic compares the annual energy use of all air conditioning units (both single and two-speed) examined in this effort for a particular climate zone (climate zone 6 in this example) and residential construction vintage (the weighted average in this example). Climate zone and vintage used to generate the graphic are also included in the sub-title.

The air conditioner unit descriptions for each unit number are provided in Table 4, heat pumps in Table 5. The unit naming convention is described in Section 2. Note that the naming convention differs between single and two-speed units. Units that were selected as most representative of median performance across all vintages and climate zones are encircled with a black outline in Figure 3. Details of the median unit selection process are provided in Section 3.2.

[4] Simulations were also performed using thermostat profiles derived from the Residential Appliance Saturation Study (RASS). These results are included in the worksheet but were not used in this analysis.

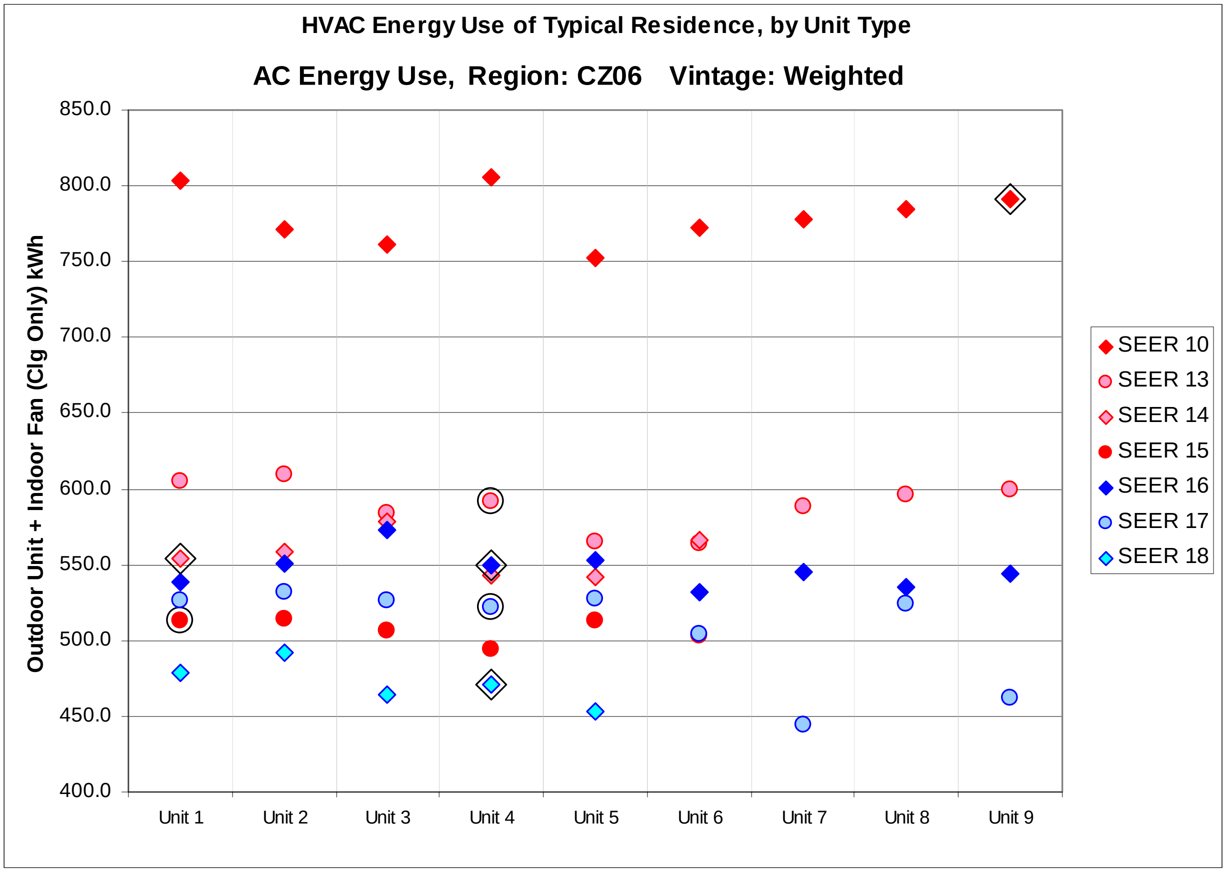

Figure 3 – *Results – All Units* Sample Graphic

Table 4 – Definition of AC Unit Type Used in *Results - All Units* Graphic

Unit Number	Unit SEER						
	10	13	14	15	16	17	18
1	SA-10-LL	SA-13-LL	SA-14-ML	SA-15-ML	SA-16-CL	SA-17-CL	SA-18-LL
2	SA-10-LM	SA-13-LM	SA-14-MM	SA-15-MM	SA-16-CM	SA-17-CM	SA-18-LH
3	SA-10-LH	SA-13-LH	SA-14-MH	SA-15-MH	SA-16-CH	SA-17-CH	SA-18-TL
4	SA-10-ML	SA-13-ML	SA-14-HL	SA-15-HL	SA-16-NM	SA-17-LL	SA-18-TM
5	SA-10-MM	SA-13-MM	SA-14-HM	SA-15-HM	SA-16-LL	SA-17-LM	SA-18-TH
6	SA-10-MH	SA-13-MH	SA-14-HH	SA-15-HH	SA-16-LM	SA-17-LH	
7	SA-10-HL	SA-13-HL			SA-16-LH	SA-17-TL	
8	SA-10-HM	SA-13-HM			SA-16-TL	SA-17-TM	
9	SA-10-HH	SA-13-HH			SA-16-TH	SA-17-TH	

Table 5 – Definition of HP Unit Type Used in *Results - All Units* Graphic

Unit Number	Unit SEER						
	10	13	14	15	16	17	18
1	SH-10-LL	SH-13-LL	SH-14-ML	SH-15-ML	SH-16-CL	SH-17-CL	SH-18-LL
2	SH-10-LM	SH-13-LM	SH-14-MM	SH-15-MM	SH-16-CM	SH-17-CM	SH-18-LM
3	SH-10-LH	SH-13-LH	SH-14-MH	SH-15-MH	SH-16-CH	SH-17-CH	SH-18-LH
4	SH-10-ML	SH-13-ML	SH-14-HL	SH-15-HL	SH-16-NM	SH-17-LL	SH-18-TM
5	SH-10-MM	SH-13-MM	SH-14-HM	SH-15-HM	SH-16-LL	SH-17-LM	
6	SH-10-MH	SH-13-MH	SH-14-HH	SH-15-HH	SH-16-LM	SH-17-LH	
7	SH-10-HL	SH-13-HL			SH-16-LH	SH-17-TL	
8	SH-10-HM	SH-13-HM			SH-16-TL	SH-17-TM	
9	SH-10-HH	SH-13-HH			SH-16-TH	SH-17-TH	

There are four pull-down menus at the top of the graphic. The first (left-most) allows results to be toggled between air conditioners and heat pumps. The second toggles through the 16 climate zones (note that there are no cooling results for Climate Zone 1 as there is no cooling load). The third menu toggles among the four vintages and the vintage-weighted results. The four vintages represent residential housing features in four time periods: pre-1978, 1978 through 1992, 1993 through1998, and post-1998. The Weighted vintage is the penetration-weighted average of the four time periods. The final toggle (right-most) selects the results that are plotted. They are annual cooling energy consumption, 3-day heat wave cooling demand, and (for heat pumps only) annual cooling and heating energy consumption. Energy consumption values include that for both the indoor fan and the outdoor unit. The three-day heat wave demand value is the average cooling system electric demand (outdoor unit plus indoor fan) over three consecutive hot days between the hours of 2:00 and 5:00 pm. This averaging method provides a good prediction of residential cooling system demand impacts on electric utility system demand peaks.

3.1.2 Results - All CZs

Typical charts from this tab are shown in Figures 4 and 5. These charts compare simulation results for all units with a given SEER level over all climate zones for either air conditioners or heat pumps. Figure 4 is the upper-most graphic in this worksheet tab and provides three-day heat wave demand information. Annual energy consumption is provided in the lower graphic as illustrated in Figure 5. Because demand and energy consumption vary greatly from climate zone to climate zone, both figures plot normalized results. The normalizing factor is the demand or energy consumption of the cooling system that is most representative of median values across all climate zones and all vintages (the circled units shown in the *Results – All Units* tab). Normalized values are used to illustrate variations from one unit to the next. Non-normalized results are provided in the *Results – All CZs* worksheet tab just to the right of the graphics illustrated in Figures 4 and 5. Each symbol on the graph represents one of the units simulated in this effort. Their unit descriptions are provided in the legend.

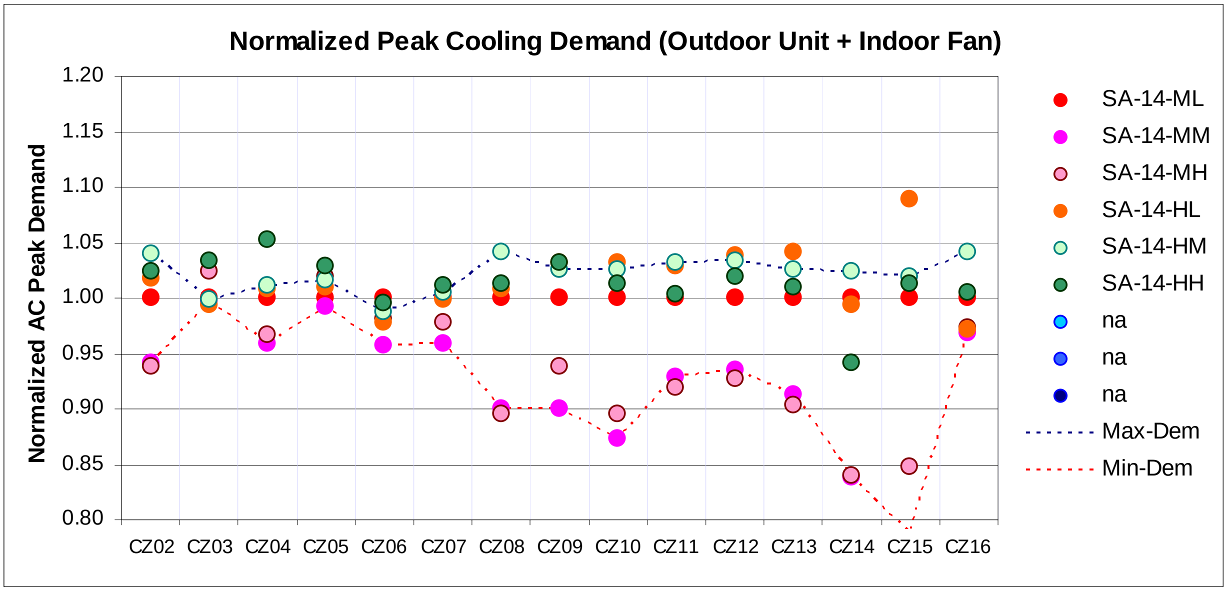

Figure 4 – *Results – All CZs* Sample Demand Graphic

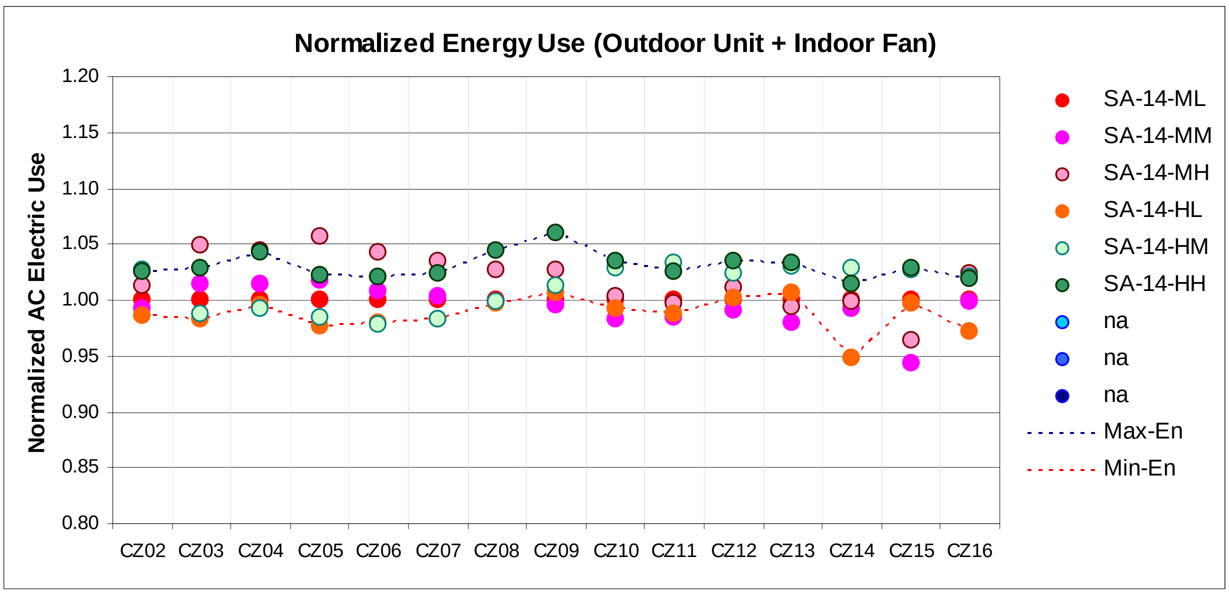

Figure 5 – *Results – All CZs* Sample Electric Use Graphic

Also included in the graphics are the units with maximum and minimum demand and energy performance. These are the units whose demand and energy use are the highest (Max-Dem and Max-En respectively) and lowest (Min-Dem and Min-En) across all climate zones and vintages. It is obvious from Figures 4 and 5 that there is no one best or worse performing unit for all climate zones. The units show as maximum and minimum demand and energy units are those that would impact a state-wide utility grid the most or the least. Best and worst performers for a particular location in the state (as represented by its climate zone) can be determined from the figures in this tag of the worksheet.

Three pull-down menus allow the user to cycle through all of the results generated in this effort. The first (left-most) cycles between unit types, either air conditioner or heat pump. The second (middle) menu allows the selection of SEER level. Available SEER levels are 10, 13, 14, and 15 single-speed units and 16, 17 and 18 two-speed units. The third (right-most) allows a selection of housing stock vintage. The results shown in Figures 4 and 5 are for SEER 14 air conditioners with vintage weighted results.

3.1.3 AC Savings

A sample chart from this tab is shown in Figure 6. The chart shows the cooling (outdoor unit plus indoor fan) energy savings when moving from a base SEER level to any higher SEER level. Base SEER levels are SEER-10 (the current minimum allowable SEER level) and SEER 13 (the future minimum allowable SEER level). The results shown in Figure 6 illustrate energy savings associated with moving from a SEER 13 air conditioner to a SEER 15 air conditioner. Energy savings are normalized to the nominal capacity of the cooling system to resolve scaling issues from climate zone to climate zone.

The deep red diamond symbols are the median savings associated with the SEER improvement. They are calculated by comparing the median energy use of the base SEER units to the median energy use of the improved SEER units. Savings are divided by the nominal capacity of the cooling systems (which does not change from SEER level to SEER level, but does from climate zone to climate zone) to provide the values shown in the figure. The light red symbols are the savings that are generated by the units selected as “typical” across all climate zones and all vintages (the ones shown with outlines in Figure 3).

Grey symbols illustrate possible minimum and maximum energy savings associated with a SEER upgrade. Minimum savings are determined by subtracting the cooling energy use of the worse performing higher SEER (the higher SEER unit with the highest energy use) unit to the best performing base SEER unit (the base SEER unit with the lowest energy use). Maximum energy savings are found by comparing the best performing higher SEER air conditioner to the worse performing base SEER air conditioner. These values illustrate possible[5] worse and best outcomes that could result from SEER upgrades.

Finally, the blue symbols represent the energy savings that would have been generated if one had used the 2001 CEC Alternative Calculation Method (ACM) to determine the benefit of moving to a higher SEER unit. Savings are based on climate zone adjusted SEERs given in Table 3.6c of the 2001 California Residential ACM manual. These calculations are provided as a general check of simulation results. Current ACM multipliers tend to correspond to minimum savings values found in this effort.

5 Actual worst and best performance ranges can not be determined as the manufacturers’ data required for this evaluation are not available for every residential air conditioner. Even if they were, the effort required to examine all possible combinations of equipment on the market would be overwhelming.

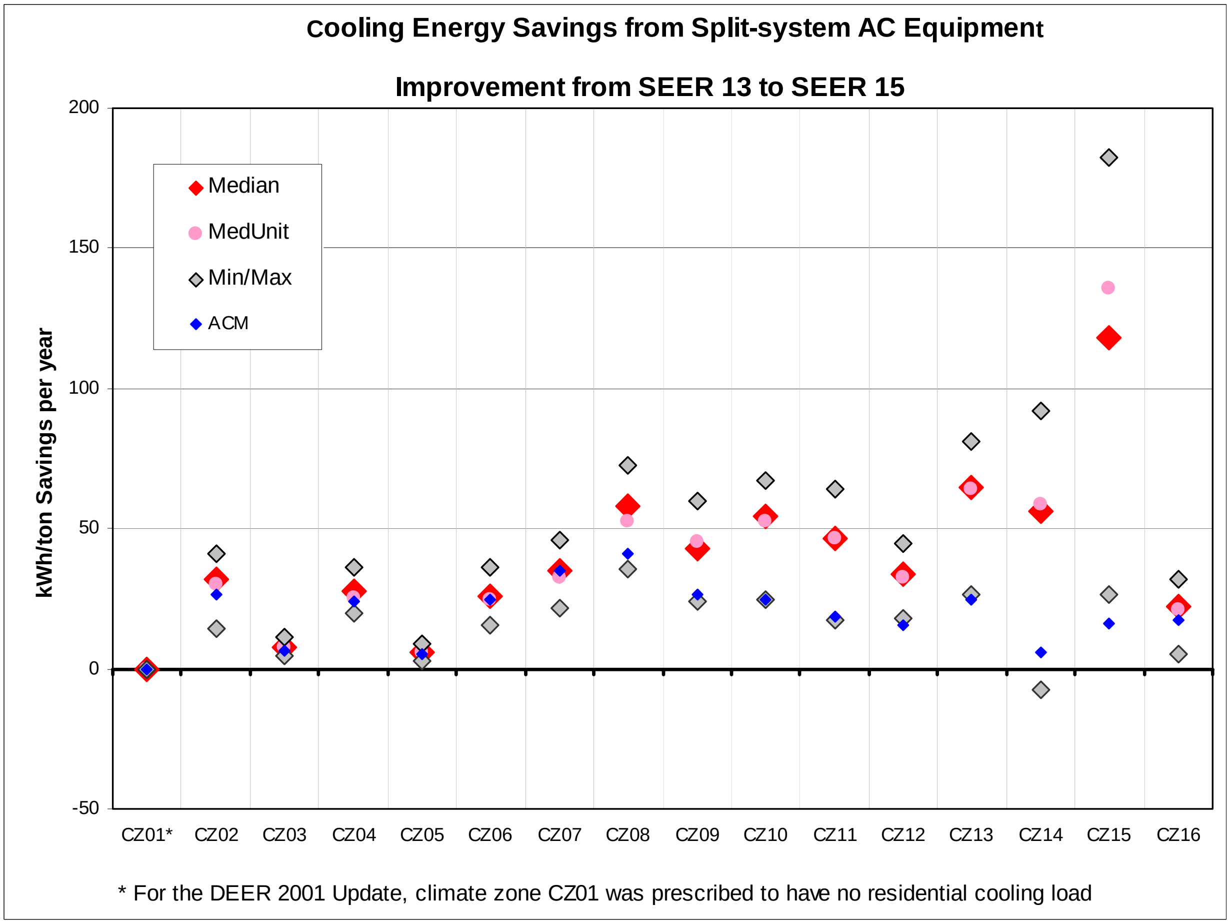

Figure 6 –*AC Savings* Sample Graphic

The full set of results can be reviewed by cycling through the three pull-down menus in this tab. The first (left-most) cycles through the 11 base-to-higher SSER upgrades. Six are associated with upgrades from SEER 10 air conditioners, five with upgrades from SEER 13 air conditioners. The second (middle) menu allows results to be viewed by housing vintage. Results in the Figure 6 are for the weighted average vintage. The last menu (right-most) allows the user to switch between DEER 2001 (UEC) and RASS-weighted results. Official DEER analyses and system selections from this effort are based on UEC calibration factors. RASS calibrations are from simulations based on thermostat set points and occupant behavior as provided in the Residential Appliance Saturation Study. The RASS results are for the user's information only and were not used in the unit selection process.

3.1.4 HP Savings

Graphic data provided in the *HP Savings* tab mirrors that of the AC Savings tab with the following two exceptions:

1. Annual energy use comparisons include both cooling and heating energy use as both are provided by the same unit.

2. No ACM results are shown as this calculation applies only to cooling results.

All other information and pull-down menus are the same as described in the AC Savings section above and are not repeated here.

3.2 UNIT SELECTIONS

Simulation results were used to select one unit in each SEER level that best represents average (mean) HVAC electricity consumption across all climate zones and all DEER vintage levels. For air conditioning units, this was the total cooling energy (outdoor condensing unit plus indoor fan). For heat pumps, this was the total of heating and cooling energy (outdoor unit plus indoor fan), including any supplemental heat. Heating energy was included with the heap pump selection since heating energy use can not be selected independently of cooling as one can with an air conditioner. Heating energy use is not included with air conditioner selection as the DEER analysis would assume the same heating source and efficiency for all HVAC system choices. The resulting heating energy (exclusive of indoor fan energy) would be the same for all systems, providing no information pertinent to the selection of one unit over another. This is not the case with heat pumps where the heating system performance varies from system to system.

There was some discussion concerning the inclusion of indoor fan energy for heating in the selection of air conditioning system. This is not appropriate for several reasons. First, and foremost, indoor fan energy is not provided by manufacturers, nor measured separately in the ARI tests. Thus fan energy values used are best estimates based on SEER level. This is not a problem when the indoor and outdoor units cycle together since any errors in fan energy estimates are accounted for by offsetting energy use by the outdoor unit (the sum of the two is provided in the manufacturer's expanded ratings charts). This occurs for air conditioners in the cooling mode and heat pumps in both the heating and cooling mode. This does not occur for non-heat pump heating systems. While indoor fan energy estimates are reasonable values that reflect technology differences from one SEER level to another, they are not accurate enough to distinguish performance differences within a given SEER ratings level. A second problem is that air conditioning/furnace systems frequently use different indoor air volumes in heating and cooling modes. Reduced air flow during heating is common. This requires indoor fan system details that, like cooling indoor fan energy data, are not available for residential systems.

The units selected were the ones with the minimum RMS (root mean squared) difference between the average energy consumption among all like-SEER units and the actual energy consumption of the selected units. RMS differences weigh the selection process most heavily by those climate zones and vintages with the highest annual cooling or cooling and heating energy use and least by climate zones and vintages with low annual energy use. It also provides higher weighting where the variation in annual energy use is high from unit to unit in comparison to cases (different climate zone and/or vintage) where the variation is low. High variation in annual energy consumption from unit to unit for a given climate zone and vintage is on the order of +/-6% of the median value. Low variation is on the order of +/- 2%.

Results of this process are provided in Table 6. The selected single-speed units are defined by their unit descriptor, the last two letters of which relate to their temperature sensitivity (low, mid, and high) and their cycling loss coefficient (low, mid, and high). Table 6 also includes the manufacturer of the selected units. The last two letters associated with the two-speed units (SEER 16, 17 and 18) are the unit manufacturer and EER level respectively.

The maximum variation value represents the greatest difference between the selected unit and the average energy use for any climate zone or any construction vintage. The RMS variation is the percentage difference between the energy use of the selected unit and the average of all like-SEER units over all climate zones and construction vintages. Both the maximum and RMS variations increase for heat pumps in comparison to air conditioners as the units' performance includes both heating and cooling energy use. This is caused by two factors. First are HSPF (heating system performance factor) and COP (coefficient of performance) differences among heat pumps with the same SEER rating. Second are differences in how the heat pump heating capacity changes with outdoor temperature, which differs from unit-to-unit. This can lead to differences in auxiliary heating energy among heat pumps with the same SEER rating. When heating energy is ignored, the RMS variation in energy use of heat pumps is similar to that of air conditioners with the same SEER rating

Table 6 - Selected "Typical" Units Based on Energy Use

Unit Type	Unit Descriptor	Unit Type	Unit Mfgr	Maximum Variation	RMS Variation
AC SEER 10	SA-10-HH	1-Speed	Trane	2.9%	0.9%
AC SEER 13	SA-13-ML	1-Speed	Lennox	2.7%	2.1%
AC SEER 14	SA-14-ML	1-Speed	Lennox	1.9%	1.0%
AC SEER 15	SA-15-ML	1-Speed	Trane	1.9%	0.9%
AC SEER 16	SA-16-LL	2-Speed	Lennox	4.3%	1.3%
AC SEER 17	SA-17-LL	2-Speed	Lennox	5.9%	1.9%
AC SEER 18	SA-18-TM	2-Speed	Trane	4.6%	2.3%
HP SEER 10	SH-10-MM	1-Speed	Nordyne	2.5%	1.6%
HP SEER 13	SH-13-MM	1-Speed	Trane	3.8%	2.3%
HP SEER 14	SH-14-HM	1-Speed	Carrier	4.6%	3.5%
HP SEER 15	SH-15-ML	1-Speed	Lennox	4.8%	2.8%
HP SEER 16	SH-16-LM	2-Speed	Lennox	5.3%	3.9%
HP SEER 17	SH-17-TH	2-Speed	Trane	14.6%	12.1%
HP SEER 18	SH-18-LM	2-Speed	Lennox	3.9%	2.6%

3.3 COOLING DEMAND IMPACTS OF SELECTED UNITS

Cooling electric demand impacts are calculated using a 3-day heat wave analysis. The peak electric demand of each unit is found by averaging the hourly cooling electric load (outdoor unit plus indoor fan) from 2:00 pm until 5:00 pm over the three consecutive hottest days for each climate zone. Experience has shown that this method produces results that are most representative of residential cooling system demand impacts that coincide with electric utility peak loads. This approach is more robust in identifying demand differences from one unit to the next for a couple of reasons. First, it better reflects overall climate differences among the diverse climate zones than single point estimates. Second, it is less susceptible to differences in building characteristics, some of which shift the time at which peak cooling loads occur. These shifts can produce demand peaks that are no less coincident with utility system peaks.

The unit selection process describe in Section 3.2 was applied to predicted cooling system demand (outdoor unit plus indoor fan) to determine the units whose demand most closely reflects median values. Results of the selection process are provided in Table 7. Except for 2 units (marked with an * in the unit descriptor in Table 7), units selected based on median energy consumption (Table 6) are the same ones as those selected for median demand performance. For the SEER-15 air conditioner (Unit SA-15-MM), differences in demand values between the unit selected based on energy use and that based on demand are less than 2% except for Climate Zone 14, where the difference is 7%. The other unit where a different unit is selected to best represent demand impacts is the two-speed SEER-16 heat pump (SA-16-CH). The reader is referred to the *All CZs* tab of the worksheet to review these differences.

Table 7 – Median Performing Units Based on Cooling Demand

Unit	Unit	Unit	Unit
Type	Descriptor	Type	Mfgr
AC SEER 10	SA-10-HH	1-Speed	Trane
AC SEER 13	SA-13-ML	1-Speed	Lennox
AC SEER 14	SA-14-ML	1-Speed	Lennox
AC SEER 15	SA-15-MM*	1-Speed	Lennox
AC SEER 16	SA-16-LL	2-Speed	Lennox
AC SEER 17	SA-17-LL	2-Speed	Lennox
AC SEER 18	SA-18-TM	2-Speed	Trane
HP SEER 10	SH-10-MM	1-Speed	Nordyne
HP SEER 13	SH-13-MM	1-Speed	Trane
HP SEER 14	SH-14-HM	1-Speed	Carrier
HP SEER 15	SH-15-ML	1-Speed	Lennox
HP SEER 16	SH-16-CH*	2-Speed	Carrier
HP SEER 17	SH-17-TH	2-Speed	Trane
HP SEER 18	SH-18-LM	2-Speed	Lennox

APPENDIX A: SYSTEM SELECTION PROCEDURE – SINGLE SPEED UNITS

There are over 23,000 units listed in the California Utilities database of Tier approved SEER-rated, slit-system air conditioners and heat pumps. Even accounting for multiple listings of units based on brand name for the same manufacturer, the number of units possible for examination is overwhelming. Because of this, a method was developed to select a range of representative units based on a number the cooling performance metrics.

The selection procedure used here was developed using a database of SEER-rated units produced by Hiller [A.2] in 2001 when updating the CALRES energy simulation program. Dr. Hiller added outdoor temperature dependency to the simulation of these units. In doing so, he recognized that only units for which the manufacturer offered expanded ratings charts (ERC) could be included in the analyses. Expanded ratings charts provide information on the total and sensible capacity and energy input of a cooling system over a range of outdoor temperatures, coil entering air conditions, and supply air volumes. A typical chart is provided in Figure A.1 for a Carrier model 38TRA, 1-1/2 ton air conditioner. This particular manufacturer uses capacity and unit power multipliers to provide data on this unit with other indoor sections (either cooling coils alone or cooling coils with particular air handlers).

EVAPORATOR AIR		CONDENSER ENTERING AIR TEMPERATURES °F														
		85			95			105			115			125		
		Capacity MBtuh†		Total System	Capacity MBtuh†		Total System	Capacity MBtuh†		Total System	Capacity MBtuh†		Total System	Capacity MBtuh†		Total System
CFM	EWB	Total	Sens‡	KW**	Total	Sens‡	KW**	Total	Sens‡	KW**	Total	Sens‡	KW**	Total	Sens‡	KW**
38TRA018-32 Outdoor Section With CK5BA018 Indoor Section																
525	72	19.5	9.60	1.40	18.8	9.33	1.58	18.0	9.05	1.77	17.2	8.75	1.98	16.3	8.44	2.21
	67	17.8	12.1	1.38	17.1	11.9	1.55	16.4	11.6	1.74	15.6	11.2	1.95	14.8	10.9	2.17
	62	16.2	14.6	1.37	15.6	14.3	1.54	14.9	14.0	1.72	14.3	13.6	1.93	13.5	13.2	2.16
	57	15.6	15.6	1.36	15.1	15.1	1.54	14.5	14.5	1.73	14.0	14.0	1.93	13.4	13.4	2.16
600	72	19.8	10.0	1.44	19.1	9.74	1.61	18.3	9.45	1.80	17.4	9.16	2.01	16.5	8.84	2.25
	67	18.1	12.8	1.41	17.4	12.6	1.58	16.7	12.3	1.77	15.9	11.9	1.98	15.0	11.6	2.21
	62	16.6	15.5	1.40	15.9	15.2	1.57	15.2	14.8	1.76	14.6	14.4	1.97	13.8	13.8	2.20
	57	16.1	16.1	1.39	15.6	15.6	1.56	15.0	15.0	1.75	14.5	14.5	1.96	13.8	13.8	2.19
675	72	20.0	10.4	1.46	19.2	10.1	1.63	18.4	9.81	1.82	17.6	9.51	2.03	16.7	9.19	2.26
	67	18.3	13.5	1.44	17.6	13.2	1.61	16.9	12.9	1.80	16.1	12.6	2.01	15.2	12.3	2.24
	62	16.8	16.4	1.43	16.2	16.0	1.60	15.5	15.5	1.79	14.9	14.9	2.00	14.2	14.2	2.23
	57	16.6	16.6	1.43	16.0	16.0	1.59	15.5	15.5	1.78	14.8	14.8	1.99	14.2	14.2	2.22

Multipliers for Determining the Performance With Other Indoor Sections

Indoor Section	Size	Cooling Capacity	Cooling Power	Indoor Section	Size	Cooling Capacity	Cooling Power
CC5A/CD5AA	018	1.00	1.00	FK4CNF	001	1.03	0.91
	024	1.02	1.00	40FKA/FK4CNF	002	1.03	0.91
CC5A/CD5AW	024	1.02	1.00	COILS + 58MVP060-14 VARIABLE-SPEED FURNACE			
CE3AA	024	1.01	1.00	CC5A/CD5AW	024	1.01	0.93
CK3BA	024	1.02	1.00	CK5BW	024	1.01	0.93
CK5BA	018	1.00	1.00	COILS + 58MVP080-14 VARIABLE-SPEED FURNACE			
	024	1.02	1.00	CC5A/CD5AW	024	1.01	0.92
CK5BW	024	1.02	1.00	CK5BW	024	1.01	0.92
F(A,B)4AN(F,C)	018	0.98	0.98	COILS + 58U(H,X)V060-12 VARIABLE-SPEED FURNACE			
	024	1.01	0.99	CC5A/CD5AA	018	0.98	0.90
FC4BNF	024	1.01	0.99		024	1.01	0.90
FF1(B,C,D)NA	018	0.98	0.96	CK3BA	024	1.01	0.90
	024	1.01	1.00	CK5BA	018	0.98	0.90
FG3AAA	024	1.00	1.00		024	1.01	0.90

Figure A.1 Typical Manufacturer's Expanded Ratings Chart

The necessity of ERC's limited the number of manufacturers that could be considered to Carrier, Lennox, Nordyne, and Trane. These manufacturers sell their equipment under at least 10 different brand names and, according to Hiller [A.2], represent over half of the units sold nationally. Brand names represented by the units selected in this effort include Bryant and Carrier (manufactured by Carrier); Lennox; Frigidare, Gibson, Kelvinator, Maytag, Philco, Tappan, and Westinghouse (manufactured by Nordyne); and Trane and American Standard (manufactured by Trane). This is not an exhaustive list of all name brands represented by these manufacturers, but covers those listed as units approved for Tier rebates by the California utilities. Major manufacturers not included included because of a lack of ERC's include Goodman, Rheem/Ruud, and York[6].

The units evaluated included single-speed, split system heat pumps and air conditioners with nominal SEER ratings of 10, 13, 14 and 15. The nominal SEER rating allows for units with SEER values +/- 0.2 SEER point from nominal ratings. Thus, the SEER 13 databases could include units with rated SEER values between 12.8 and 13.2. In addition to SEER level, SEER 14 and 15 units examined met minimum cooling EER values and HSPF values for heat pumps set by Tier requirements. Minimum Tier levels are provided in the main report. Tier minimums were not set for SEER 10 or 13 units as they represent current and near-future base level SEER ratings.

Manufacturers' ERC's are provided in formats that differ from manufacturer-to-manufacturer and, in some cases, from model number to model number among a given manufacturer. Hiller placed the differing data sets into a common format that was also used in this analysis. An example is provided in Figure A.2. Included in the data are the unit's model number (condensing unit plus indoor unit), cycling loss coefficient (C_D), and the total power requirement, total cooling capacity and energy efficiency ratio (EER) at various outdoor temperatures. Normalized data are normalized to conditions at an outdoor temperature of 95º F, the nominal ARI ratings point. The cycling loss coefficient was obtained from the California Energy Commissions database of SEER-rated equipment or extrapolated from expanded ratings data. The cycling loss coefficient was not part of the original Hiller database and was added in this effort. The remaining data is taken directly from manufacturer's literature.

38TRA018-31 + CC5A/CD5A/CD5BA018						
CRP	C_D	0.11	SEER	12.20		
COOLING			OD TEMP (F)			
600 CFM 67 WB	75	85	95	105	115	125
TOT CAP (KBTUH)		18.70	18.00	17.20	16.40	15.50
TOTAL KW INCL.FANS		1.52	1.71	1.93	2.10	2.41
EER INCL. FANS		12.30	10.53	8.91	7.81	6.43
Normalized EER		1.169	1.000	0.847	0.742	0.611
Normalized Capacity		1.039	1.000	0.956	0.911	0.861

[6] York (including York, Coleman, and Luxaire brand names) does provide ERC's for their units. Higher SEER (SEER 13 or greater) units manufactured by York were examined in this effort, but the ERC's were frequently found to be inconsistent with rated values of SEER and EER_A. While some inconsistencies between rated data and ERC's were found for all manufacturers, the number of instances where there was data problems with York units was much higher. Because of this, this manufacturer was not included with the other four.

Figure A.2 Manufacturer's Expanded Ratings Data in Consistent Format

The cycling loss coefficient (C_D) is an important feature of each unit, providing a measurement of how each cooling system is affected by cycling. It is sufficiently important that it is specifically measured in a cycling loss test specified in the Department of Energy SEER ratings process[A.1]. This measurement is obtained for each manufacturer's condensing unit model number used in conjunction with its "most popular" evaporator arrangement. Its value ranges from a low of 0.02 to 0.25. It is used to determine a unit's SEER rating as follows:

$$SEER = EER_B\ (1 - 0.5\ C_D) \qquad \text{A.1}$$

Where:

SEER is the seasonal efficiency ratio,

EER_B is the units energy efficiency ratio at the "B" ratings point corresponding to an 82º F outdoor temperature and entering air conditions of 80º F dry bulb, 67º F wet-bulb, and

C_D is the degradation coefficient measured in cycling loss tests.

Equation A.1 provides a means to calculate C_D when the unit under consideration is uses an evaporator arrangement that differs from the "most popular" or rated values are not available. SEER ratings are available for all units considered in this effort. The value for EER_B can be determined via an extrapolation or interpolation of the information provided by ERC's. EER values illustrated in Figure A.2 were used to perform this function. In fact, this process was used as a data check for all units examined. ERC data that could not extrapolate a C_D value between 0.02 and 0.25 based on the units rated SEER was discarded (this was how inconsistencies in the York data were found).

The data screening process still resulted in a database of nearly 300 split-system, residential units. As such, a rational means was 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 type – air conditioner or heat pump,
- Cycling performance – degradation coefficient (C_D) as determined in DOE SEER test procedures, and
- System's sensitivity of EER to outdoor temperature.

These metrics were used to select a number of same-SEER units with differing performance characteristics which would likely produce a broad range of demand impacts within a given climate zone, or would perform differently when moved from climate zone to climate zone. Examples of how these metrics identify potential peak cooling demand impacts are illustrated in Figures A.3 and A.4.

Figure A.3 illustrates how three different units with the same SEER rating and sensitivity to outdoor temperature, but different cycling losses (values of C_D) could produce three different peak demand values. Here it is assumed that the units' EERs at 95º F (or EER_A value) are a measure of their peak demand. High EER values result in low demand impacts while low EER values produce high demand impacts. Because the units have differing values of C_D, each must have different EERs at 82º F (or EER_B value) based on the definition of SEER in Equation A.1. Since all three of our units respond to changes in outdoor temperature in the same way (slopes of the lines are equal), each unit ends up with different EER_A values and different efficiencies at peak cooling conditions. From the figure it is easy to see that, for units with the same SEER rating, those with higher cycling losses would have the lowest electric demand impacts because of their overall higher EER at all outdoor temperatures. Conversely, units with low cycling losses (low C_D) produce low EER values, resulting in higher peak demands.

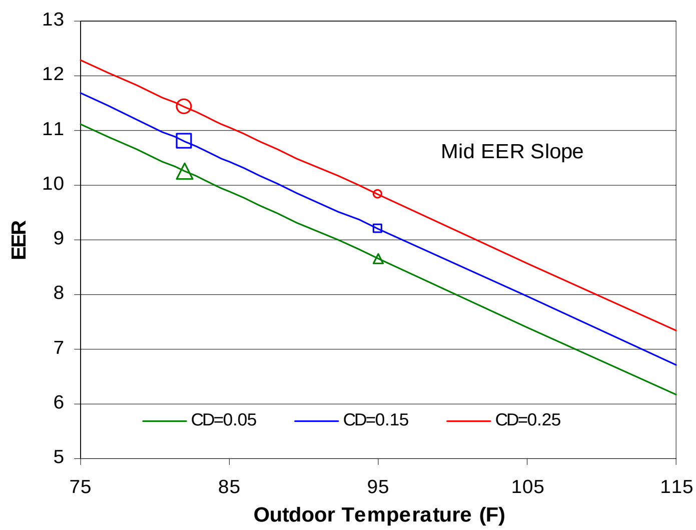

Figure A.3 Effect of C_D on System Performance – SEER 10 Systems

Similarly, Figure A.4 illustrates how a unit's sensitivity to outdoor temperature for same-SEER units impacts its efficiency at peak cooling conditions. In this figure, all units are assumed to have the same cycling loss (C_D value). Because all also have the same SEER rating, each unit would have the same EER_B value (EER at 82º F) from Equation A.1. However, units that are more sensitive to changes to outdoor temperature would have lower operating efficiencies at higher operating temperatures than those that have lower temperature sensitivity. Thus, higher temperature sensitivity in a unit would, all else being equal, result in greater electric demands.

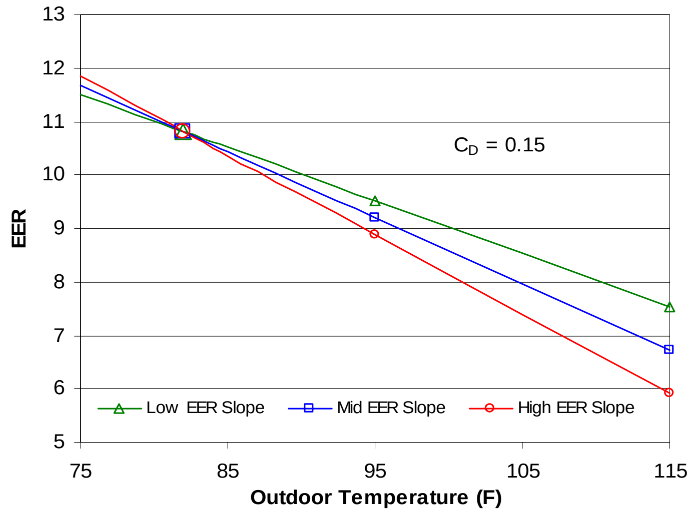

Figure A.4 Effect of Temperature Sensitivity on System Performance – SEER 10 Systems

The importance of these issues was not lost on the developers of the SEER ratings process. The single-speed ratings SEER test procedure requires two temperature tests and one cycling test. These tests provide EER_A, EER_B and C_D ratings values required in the testing of all the "most popular" SEER-rated condenser and evaporator combination. EER_A is the unit's EER at a 95° F outdoor temperature with evaporator entering conditions of 80° F dry bulb and 67° F wet-bulb temperatures. EER_B uses the same evaporator entering condition, but an 82° F outdoor temperature.

Figure A.5 illustrates the impact of temperature sensitivity and cycling losses on rated EER (rated EER refers to the units EER_A value) for nominal SEER 10 air conditioners. Rated EER values are given as their ratio to the units' rated SEER in the figure. For this case, the actual rated EER is found by multiplying the ordinate in Figure A.5 by 10. The abscissa is the cycling loss coefficient, C_D. Each point in the figure represents a single, nominal SEER 10 air conditioner. The rated EER for these units range from just under 8.5 to just above 9.9, covering the full range of expected rated EER's for SEER 10 air conditioners.

Points are color-coded by EER temperature sensitivity. In the figure (and subsequent discussions), "High" represents approximately those units in the upper quartile of units when sorted by temperature sensitivity. That is, 75% of the units not noted as having "High" temperature sensitivity have EER temperature slopes less than those noted as "High". Similarly, units noted as having "Low" temperature sensitivity are approximately the bottom quartile when sorted by temperature sensitivity. Thus, approximately half of the units would be considered to have "Mid" temperature sensitivity. The use of quartiles is preferred over absolute limits because the range of values of temperature sensitivity differs between air conditioners and heat pumps and from one SEER level to another.

The data in the figure is consistent with the trends provided in Figures A.3 and A.4. That is, higher values of C_D produce higher values of rated EER. Also, units with "High" temperature sensitivity (red points) tend to have lower rated EERs than those with "Mid" or "Low" temperature sensitivity (blue and green points) for the same C_D value.

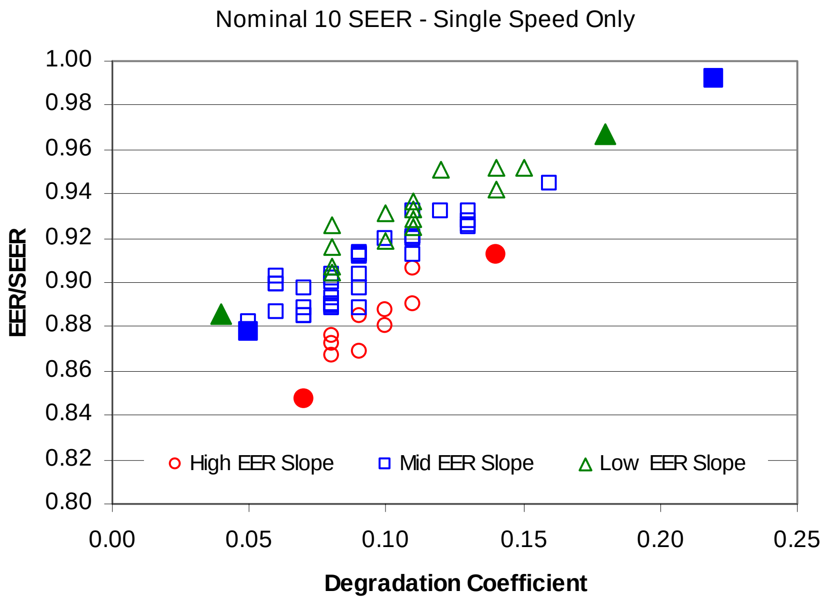

Figure A.5 Selection Procedure – SEER 10 Systems

Using the two metrics of temperature sensitivity and cycling losses, up to nine units were selected from those in the database of single-speed units for each SEER level and each unit type (air conditioner and heat pump). The nine units represent the possible combinations of High, Mid, and Low values of temperature sensitivity and cycling losses. For example, the green triangular symbols shown in Figure A.5 represent units with ”High” temperature sensitivity. Of those units, three were selected that had “High”, “Mid”, and “Low” degradation coefficients. The units with High and Low degradation coefficient were the ones with the highest and lowest values of C_D that had “High” temperature sensitivity. These are shown as solid green triangular symbols in the graph. The unit with “Mid” cycling losses had a C_D value close to the median value of all units with ”High” temperature sensitivity. This was repeated for units with “Mid” and “Low” temperature sensitivity. Where possible, units with “Mid” temperature sensitivity were selected with EER temperature slopes as close to the median value of all “Mid” temperature sensitivity units, with maximum and minimum values of C_D taking precedence. The median value of units with “Mid” temperature sensitivity was also approximately the median value of the dataset. The unit with “Mid” temperature sensitivity and “Mid” degradation coefficient had values of its EER slope and C_D as close as possible to the median value over the entire dataset of each metric. Where there were choices available, a full a mix of different manufacturers was included.

The selection process provided the unit naming convention used in the effort for single-speed equipment. Each name included the type of cooling system; it’s SEER rating; and the qualitative value of its temperature sensitivity and degradation coefficient. For example, a unit noted as SA-10-ML is a split-system (S) air-conditioner (A) with a nominal SEER rating of 10 (10), “Mid” level temperature sensitivity (M), and Low degradation coefficient (L). Possible naming variations are provided in Table A.1. While the full combination of temperature sensitivity and degradation coefficient can produce nine selections, the number of units available for consideration decreases at higher SEER levels. Because of this, there are only six units each considered for nominal SEER 14 and 15 air conditioners and six units each for nominal SEER 14 and 15 heat pumps. Here, the temperature sensitivity is limited to “Mid” and “High” values. “Low”, “Mid”, and “High” categories for the degradation coefficient remain.

Table A.1 Single-speed Naming Convention

Character Position					
	1st	2nd	3rd	4th	5th
	System Arrangement	System Type	Nominal SEER	Temp. Sensitivity	Degradation Coeff.
Possible Values	S – split system	A – A/C H - HP	10, 13, 14 & 15	L – Low M – Mid H - High	L – Low M – Mid H - High

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 need 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.).

Capacity issues do arise for SEER 14 and SEER 15 equipment. In these cases there is a lack of availability of higher capacity, single-speed units (3 ½, 4, and 5 tons). This is most likely associated with the indoor units used in this equipment. Essentially all of the SEER 15 and many SEER 14 units use variable speed indoor fans on the evaporators. These use electronically commutated motors (ECM) that are more efficient than standard split capacitor motors in the fractional horsepower range (half horsepower, or less) associated with units with cooling capacities up to 3 tons. For these systems, the difference in the indoor motor efficiency can produce as much as a half a SEER rating point. The benefit decreases as the motor capacity increases to the point where there is essentially no difference in motor efficiencies at the 1 horsepower range. In addition, higher SEER levels are obtained by coupling higher capacity evaporators with lower capacity condensing units. At a minimum, this too can reduce indoor fan energy requirements by moving less than the design air flow through the fan-coil unit. This design approach is limited by available fan-coil capacity and cannot be applied to larger capacity units where over-sized unit are not available. It is the assumption of this work that these sizing issues will be resolve by future designs or via the installation of multiple, smaller capacity units.

Appendix A References:

A.1. DOE 1979. Test procedures for central air conditioners including heat pumps. Federal Register Vol. 44, No. 249. pp 76700-76723. December 27, 1979.

A.2. Hiller, Carl C, Air Conditioner and Heat Pump Performance Map Database Description and User's Guide, CEC Contract Number 100-98-001, September 2001.