

# Field Study of the Energy Savings Potential of High-SEER Air Conditioning in the Hot-Dry Climate

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## ABSTRACT

Air conditioning loads are generally the largest consumer of energy in a building for the summer season. Most cooling equipment is labeled with a Seasonal Energy Efficiency Ratio (SEER), based on tests outlined by the Air Conditioning, Heating and Refrigeration Institute. The federal government requires all systems to meet standard SEER ratings, and the federal efficiency program ENERGY STAR uses SEER as judgment criteria for systems. However, the SEER rating test is not necessarily reflective of all climate zones, and uncertainty remains about whether SEER ratings are truly effective for planning incentives for energy efficient systems in different regions. In 2011, a large project was deployed around Phoenix, Arizona, to measure the actual field performance of residential air conditioners with a range of SEER ratings. Customer survey information was used to normalize for square footage and other factors. The results of this study helps determine what correlation exists between the shorter-term seasonal efficiency and SEER rating in the hot, dry summer climate, so that appropriate utility incentive programs can be established. The findings of this study will be presented.

## Introduction

In many climates, the summertime load on the electric utility grid is dominated by air conditioning equipment. Air conditioner load shapes tend to track outdoor temperature, and as such, many utilities see their highest demand during the hottest weather of the year. As such, increasing the efficiency and reducing the load variability of air conditioners is a top priority for utilities, which benefit from flat, predictable loads. One way utilities can help reduce air conditioner-driven load peaks is to incentivize highly efficient air conditioners. Perhaps the most common way of doing so is to reference the Seasonal Energy Efficiency Ratio, or SEER [1]. The SEER rating is a single-number rating metric for air conditioners based on a standardized set of tests. In theory, the SEER rating can be used to predict, for the rated air conditioner, how much electricity will be consumed to provide the total cooling load for the year. The energy expected is the total cooling load, in BTU, divided by the SEER in BTU/Watt-hour.

For example, a 120,000 BTU load would be expected to require 10,000 Watt-hours of electricity to a 12 SEER unit. To provide a given amount of cooling, a unit with a higher SEER rating is expected to consume less power than a unit with lower SEER. The expected difference in energy consumption in going from a lower to a higher SEER air conditioner is:

$$1 - \frac{SEER_{low}}{SEER_{high}}$$

Based on the equation above, one would expect a 13 SEER air conditioner to use 8% less energy than a 12 SEER, a 14 SEER air conditioner to use 14% less than a 12 SEER unit, and so on. In reality the difference in energy consumption is more complex. The SEER rating is a single metric for efficiency which weighs results obtained from up to five required test conditions. If the weather in a region does not match the SEER test conditions, it is not clear how well SEER will predict actual energy consumption. The SEER test weighting conditions are summarized in Table 1 below. The indoor test condition is 80°F, with 50.5% relative humidity. It may be noted that the first three SEER temperature bin hours (66.1% of the weight) are below the indoor test temperature.

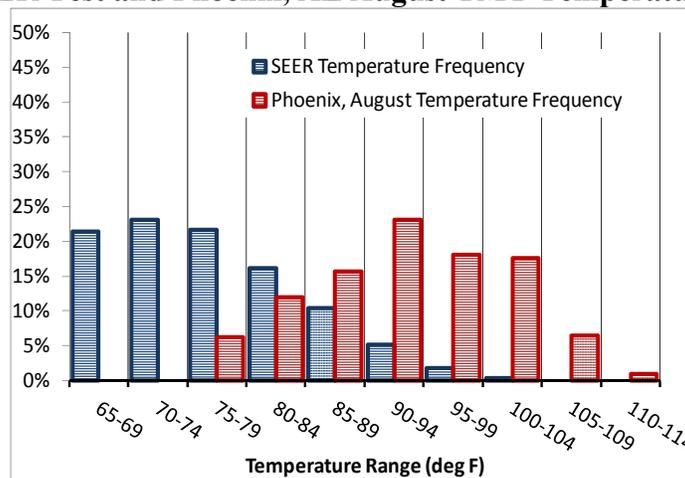
**Table 1. SEER Weighting Conditions**

Bin	Range (deg. F)	Representative Test Point (deg. F)	% total test hours
1	65-69	67	21.4
2	70-74	72	23.1
3	75-79	77	21.6
4	80-84	82	16.1
5	85-89	87	10.4
6	90-94	92	5.2
7	95-99	97	1.8
8	100-104	102	0.4

One objective of this work is to determine how SEER predicts energy and power during intervals of interest. While it is understood that the SEER rating is intended to provide a single metric for the entire cooling season, a more pressing question for electric utilities is how a system with a certain SEER rating will perform during a period of interest, such as the hottest month of the year.

Figure 1 shows the contrast of Phoenix, Arizona weather in the month of August with the SEER temperature bin weights. The weather for Phoenix is Typical Meteorological Year (TMY3) data from the National Renewable Energy Laboratory. As can be seen, the weather bins in August are skewed significantly towards higher temperatures than the SEER test bins.

**Figure 1. SEER Test and Phoenix, AZ August TMY Temperature Bins**



Phoenix has one of the hottest and driest climates in the United States. Since the summer peak in Arizona is driven by weather significantly different than the SEER test conditions, it is important to understand how relevant the ratings are to particular locations in the U.S. A simulation-based study by Fairey et al suggests that the energy benefits of higher SEER system may be reduced by as much as 22% relative to the nameplate rating in hot climates [2].

The SEER rating is extremely important because it is the primary metric by which air conditioners are judged and selected. Federal regulations use the SEER as the standard metric. As of January 1, 2006, all newly manufactured systems must have a SEER of at least 13 [3]. Generally speaking, if a homeowner wants a “more efficient” air conditioning option, they will be directed towards a unit with a higher SEER rating. The ENERGY STAR rating system, which is a federal program to identify particularly efficient appliances, uses SEER (and the related Energy Efficiency Ratio or EER) to select air conditioners.

For electric utilities seeking to implement air conditioning programs, SEER is likely the most readily-available and convenient metric to predict energy savings. Therefore it is critical to understand the efficacy of SEER in distinguishing air conditioner efficiency. In order to understand this, the performance of air conditioners in climates very different from the SEER rating conditions must be understood. This work focuses on the very hot climate of Phoenix, Arizona.

## Study Overview

A large field study was deployed to examine the efficacy of the SEER rating in the Phoenix climate. Salt River Project (SRP) and EPRI are collaborating to monitor more than 340 homes for indoor temperature and air conditioner power in the greater Phoenix area. The sites were selected by SRP after a survey of over 100,000 residential customers. In addition, five homes with variable speed indoor air handlers were found, and those air handlers monitored for power.

The temperature loggers used were HOBO U10 loggers made by OnSet Corporation. The loggers are battery powered with storage capacity for 52,000 measurements and a battery designed to last a year. The loggers were programmed to record data every 15 minutes, and were deployed by SRP employees in May and June, 2011, and collected in November and December by mail or SRP employee pick-up. They were mounted close to the thermostat using an adhesive pad in most homes; if the homeowner did not want to have the logger mounted, it could be placed on a shelf or similarly, as long as it would not be close to sources of hot or cold air such as ovens or supply air ducts. SRP specified and installed metering-grade AMI power meters from Elster Solutions for monitoring the air conditioner condensing unit at each house.

In addition to the hardware described above, SRP conducted a survey of each home pertaining to its thermal loads. Survey questions included the home square footage, the typical indoor temperature set-point, the age of the home and others. The survey was designed by SRP with input from EPRI to provide additional differentiation between homes. Some values, such as square footage, are used to normalize energy data. Others, such as the age of the home and air conditioner, can be used to help identify additional factors in total energy consumption.

## Results Overview

The results of this study to date are shown herein. Data will be viewed for July through September, since most sites were not installed until July, and the cooling season tapers off in October. Unless otherwise specified, SEER will be grouped as SEER 10-11, SEER 12-13, and SEER 14-16 in order to ensure large sample sizes. Finally, data shown with energy or power normalized by square footage will be scaled to the approximate average square footage of the sample, 1780 square feet.

For all data analysis, the sites with SEER 8, 9, 17, 18 and 20 will be filtered out of the data set, for simply having too few units.

Table 2 shows the average daily energy consumption for each month, normalized for square footage for all of the sites in the remaining SEER classes.

**Table 2. Average Daily Energy Consumption (kWh) by Rounded SEER, Normalized for Square Footage**

		SEER						
		10	11	12	13	14	15	16
Month	July	39.9	38.4	38.4	32.3	31.3	28.4	29.7
	August	44.1	42.0	42.4	36.1	35.5	31.0	32.4

	<b>September</b>	28.7	26.1	27.3	23.7	22.2	19.5	21.2
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The above data is filtered to remove under-represented SEER classes, and normalized for square footage. This represents the aggregate energy consumption of the homes selected. However, to understand what energy savings are attributable to the SEER rating, the data set needs to be narrowed down to sites with similar loading. The above makes no account for the differences in indoor and outdoor temperature. The rest of the data in this work is also filtered for indoor temperature.

For each month, the average indoor temperature is computed for all sites and for each individual site. Sites outside of a certain temperature band from the mean are to be filtered out; the band of  $\pm 3^{\circ}\text{F}$  was selected in order to keep greater than ten units per SEER class, while narrowing the data as much as possible. An additional filter can be applied for variance. It is desirable to have a small variance in the 15-minute temperature measurements, but the value must be selected to not remove too many units. Ten units per SEER class were used as the criteria, and a variance of less than  $5^{\circ}\text{F}$  was selected.

The purpose of the above temperature filtering is to seek sites that: Maintain a typical indoor temperature within the same narrow range of temperatures; may allow temperature to fluctuate or use a programmable thermostat, but within a relatively small temperature band; do not have major changes to set-point, schedule or other factors affecting indoor temperature during the month; and represent air conditioners judged to be operating “typically.”

The data which follows is filtered with the aforementioned criteria. The exception is August data, where the variance threshold was increased to  $6.7^{\circ}\text{F}$ , to be inclusive of at least ten units from each SEER class. The data for September shows nine SEER 16 units; the next closest SEER 16 site had a temperature variance of over 10.0, so no further sites were added.

Table 3 shows the summary of data filtered by temperature and variance for each month.

### **Power vs. Temperature Differential**

Since the temperature difference between indoor and outdoor is the main driver of air conditioning loads, the performance of each SEER group for varying temperature differences is of interest. It is important to note that the SEER value is not intended to provide any prediction of power at particular loads. It is explicitly intended to predict integrated energy. However, its relevance to individual conditions can still be investigated.

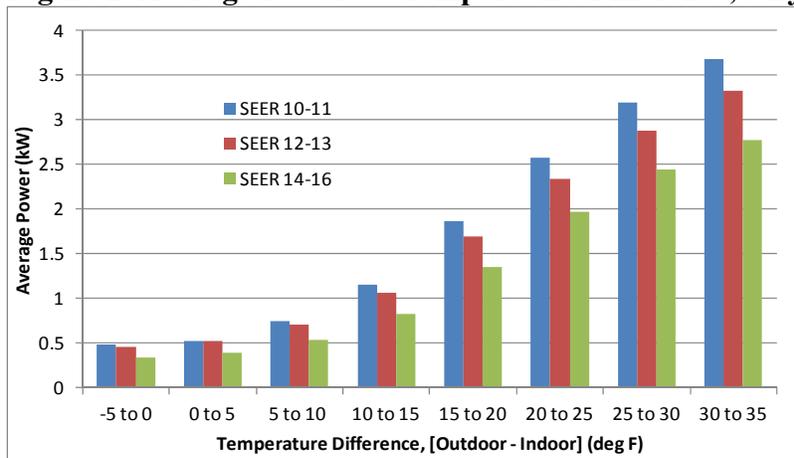
The average hourly power, normalized for square footage, is shown in the following figures for bins of temperature difference. For example the first bin in Figure 2 ( $-5^{\circ}\text{F}$  to  $0^{\circ}\text{F}$ ) indicates periods where the outdoor temperature was lower than the indoor temperature by  $5^{\circ}\text{F}$  to  $10^{\circ}\text{F}$ . The last bin shows periods where the difference is  $30^{\circ}\text{F}$ - $35^{\circ}\text{F}$ . In each month, the highest temperature differential is below  $40^{\circ}\text{F}$ . The highest difference measured was  $39^{\circ}\text{F}$ , in July. Data for which the frequency is lower than 1% of site-hours are excluded.

**Table 3. Selected Sites for July through September**

		SEER 10	SEER 11	SEER 12	SEER 13	SEER 14	SEER 15	SEER 16	TOTAL
July	Count	37	26	64	48	15	12	11	<b>213</b>
	Average Sq. Foot – Survey	1721.6	1784.8	1877.6	1712.7	1806.6	1740.2	1840.3	
	Average Tons	3.9	3.9	4.3	4	4	3.8	4	
	Average ID Temperature	80.6	79.8	80.3	80.3	80.2	79.7	79.9	
August	Count	38	29	68	54	18	13	10	<b>230</b>
	Average Sq. Foot – Survey	1734.1	1787.4	1881.4	1720.6	1823	1779.4	1866	
	Average Tons	3.8	4	4.3	3.9	4	3.9	4	
	Average ID Temperature	80.4	79.9	80.3	80.2	79.9	79.3	79.8	
September	Count	38	28	75	55	18	13	9	<b>236</b>
	Average Sq. Foot – Survey	1718.1	1792.9	1859.7	1697.7	1785.6	1873.6	1867.8	
	Average Tons	3.9	4	4.4	4	3.9	4.1	4.1	
	Average ID Temperature	80.4	79.6	80.1	79.9	80	79.5	79.8	

**Error! Not a valid bookmark self-reference.** shows that in July as expected, the average power increases when the difference in temperature increases. It also shows a trend towards lower power with higher SEER ratings, within each temperature bin. The percentage difference in average power from the SEER 10-11 units to the SEER 14-16 units ranges from 24% to 29%, with larger magnitude reductions, but smaller percentages as the temperature difference increases. The highest percentage reduction was in the -5°F-0°F bin, and the lowest in the 25-30°F bin.

**Figure 2. Average Power vs. Temperature Difference, July**

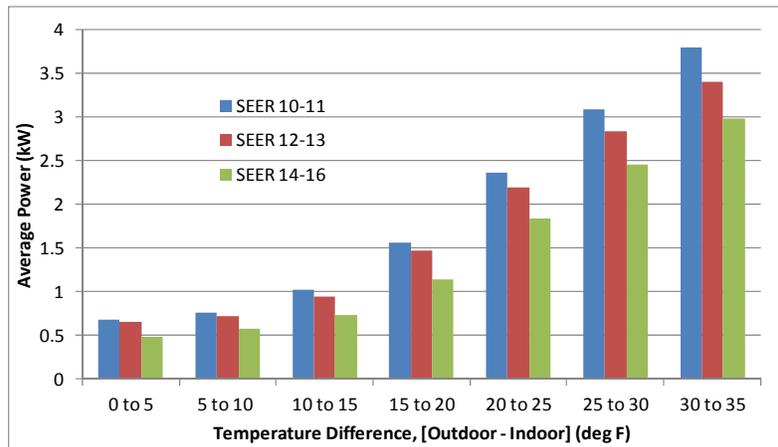


**Figure 3 shows the average power measured in temperature bins for the month of August. The highest temperature difference in the filtered data set was 38°F. The data in**

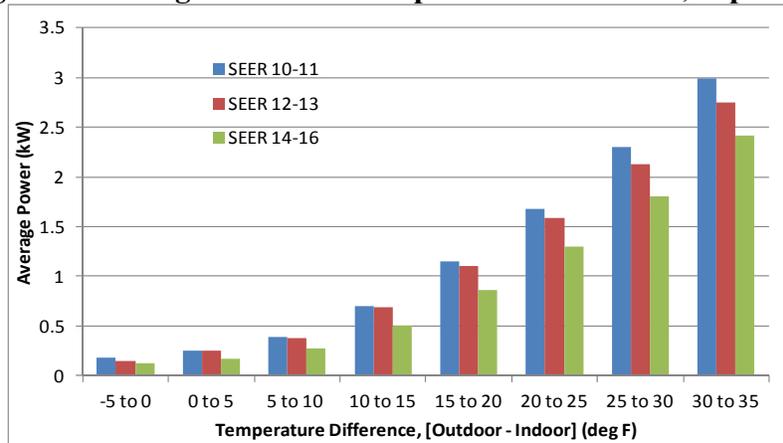
Figure 3 again shows increasing power with increasing temperature difference for each SEER class. It also shows a general trend of decreasing power for higher SEER rating in the same temperature range. In this case the reduction in magnitude was again larger with higher temperatures, at a slightly decreased percentage. The percent reduction from the SEER 10-11 units to the SEER 14-16 units ranged from 21-29%, with 21% reduction in the 25°F- 30°F and 30°F -35°F range and 29% reduction at 0°F to 5°F.

Figure 4 shows the average power for each SEER class at bins of outdoor to indoor temperature differential for September. The expected trend is again seen, with higher temperature differentials leading to higher power, and generally lower power with higher SEER systems for the same temperature differential. The percentage reduction ranged from 19% at 30°F -35°F, to 34% at -5°F to 0°F.

**Figure 3. Average Power vs. Temperature Difference, August**



**Figure 4. Average Power vs. Temperature Difference, September**

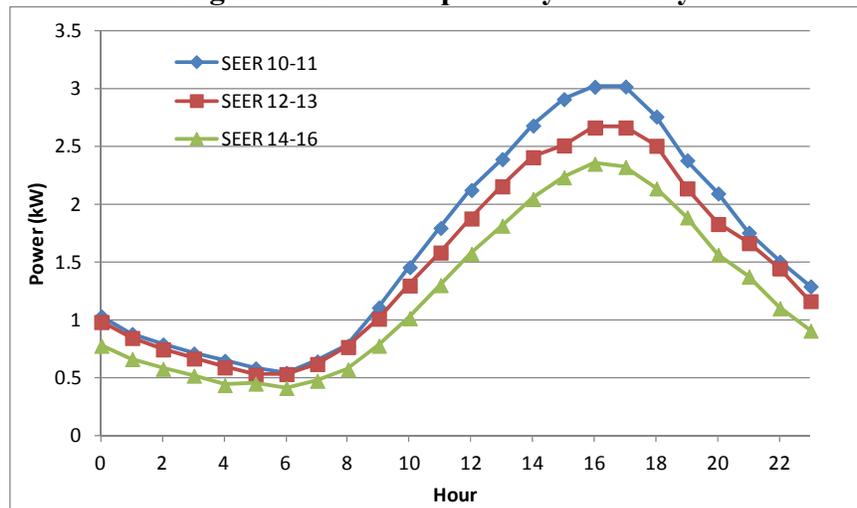


## Load Shapes

Figure 5 shows the load shape for weekdays in the month of July with the aforementioned filters applied. There are several observations to be made from this data. First, the general shape of the load profile is typical of air conditioning equipment in the summer. There is a low point in the data during the coolest part of the night, typically around 4:00 AM to 7:00 AM. The air conditioning load gradually increases as the outdoor temperature and the temperature difference between outdoor and indoor increases, until a peak which occurs around 3:00 PM to 6:00 PM. In the case shown in

Figure 5, the highest individual point occurs with the SEER 10-11 category, with a peak of 3.0 kW at 5:00 PM. The SEER 12-13 units had a peak of 2.7 kW at 4:00 and 5:00 PM. The SEER 14-16 units peaked at 2.4 kW, at 4:00 PM, 20% lower than the SEER 10-11 peak.

**Figure 5. Load Shape - July Weekday**



**Figure 6. Load Shape - August Weekday**

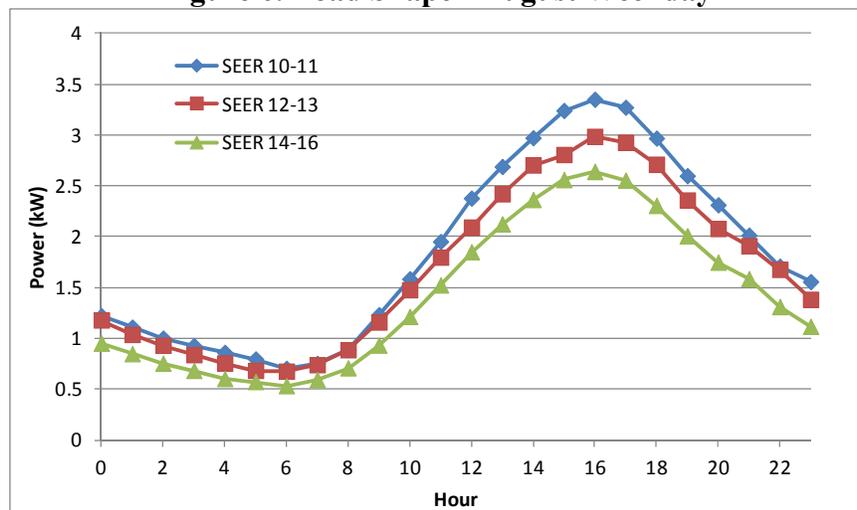
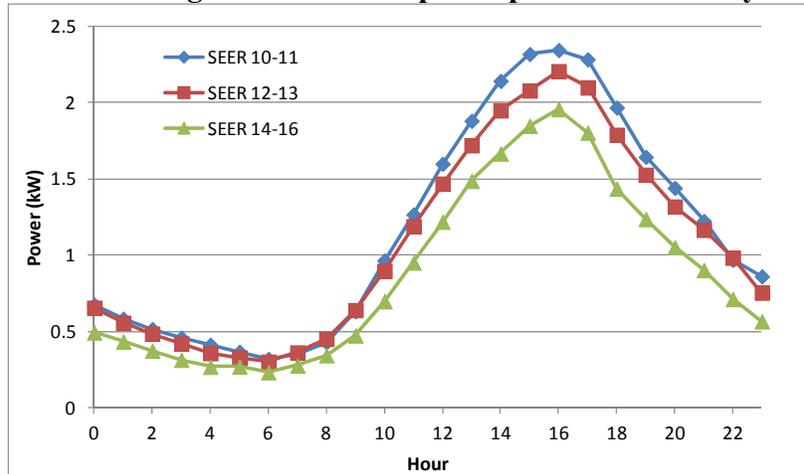


Figure 6 shows the load shape for August weekdays with the indoor temperature and indoor temperature variance filters applied. The highest power was observed for SEER 10-11 systems, with a maximum of 3.3 kW at 4:00 PM. The SEER 12-13 systems had a peak of 3.0 kW, also at 4:00 PM. The smallest peak power value occurred with the SEER 14-16 systems, which had a peak power of 2.6 kW at 4:00 PM. The SEER 14-16 peak is 21% lower than the SEER 10-11 peak.

The load shapes for weekdays in September are shown in

Figure 7. All of the peaks occurred at 4:00 PM. The highest peak was 2.3 kW, for the SEER 10-11 units. The SEER 12-13 units' peak was 2.2 kW. The SEER 14-16 peak was 13% lower than the SEER 12-13 peak, at 2.0 kW.

**Figure 7. Load Shape - September Weekday**



**Figure 8. Load Shape for August 23, 24 and 25**

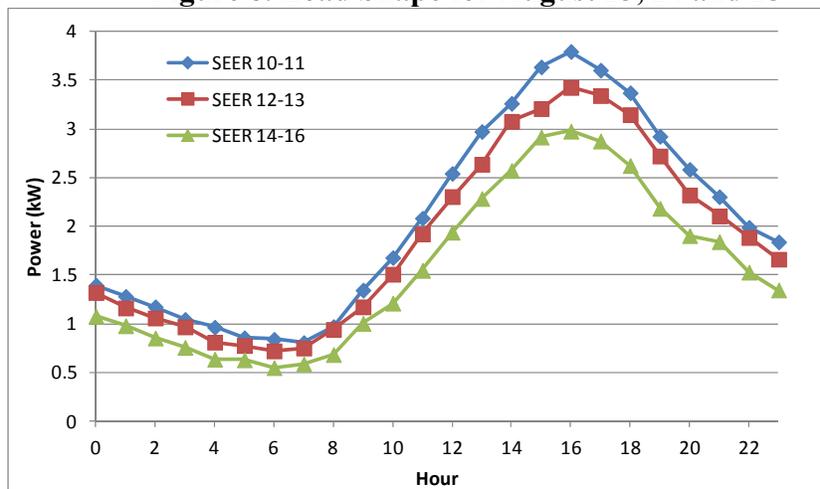


Figure 8 shows the load shape for the SRP 2011 peak day, August 24<sup>th</sup>, as well as the day before and the day after. The peak power during the very hot period of August 23-25 is significantly higher than that of the average for August for every SEER class. The SEER 10-11 peak is 3.8 kW; the SEER 12-13 peak is 3.4 kW and the SEER 14-16 peak is 3.0 kW. The peak was at 4:00 PM for each. The difference between the SEER 10-11 and the SEER 14-16 peaks is 21%.

## Energy

**The reduction in overall energy consumption for each SEER class is also of interest. The following section addresses the average daily energy consumption found for each month, for each SEER grouping, using the filtered data set.**

Table 4 shows the energy consumption for each SEER grouping, for each month along with the percentage decrease compared with the SEER 10-11 group. As can be seen from the table, there is a strong reduction in energy consumption with increasing SEER in each grouping. The SEER 12-13 units used 4.8-9.0% less energy than the SEER 10-11 units, and the SEER 14-16 units used 14.0-18.1% less.

**Table 4. Average Daily Energy Consumption, by SEER, for July, Normalized by Square Footage**

		SEER 10-11	SEER 12-13	SEER 14-16
July	Avg. Daily Energy	39.2	35.6	29.8
	% Reduction vs SEER 10-11	N/A	9.2	24.0
August	Avg. Daily Energy	43.2	40.4	34.8
	% Reduction vs SEER 10-11	N/A	6.5	19.4
September	Avg. Daily Energy	27.5	26.2	21.5
	% Reduction vs SEER 10-11	N/A	4.8	21.8

## Multiple Regression Analyses

A crucial part of this study is to determine if, or the extent to which, the efficiencies for higher SEER units change as the outdoor temperature changes from mild to very hot. Phoenix temperatures were 114 degrees on SRP's August system peak day and 112 degrees on its September peak day. Multiple regression analyses using a multiplicative model were performed to estimate the improvement in efficiency for higher SEER units at different temperatures and different times of day. Efficiency improvement was operationally defined as the percentage decrease in the average demand per ton of the air conditioner (AC) over a three-hour period as the SEER of the unit increased. A three-hour timeframe allows time for the AC unit to cycle on and off as it maintains the desired temperature in the home. A more efficient AC would be expected to cool the home to the desired temperature in a shorter cycle. This would produce a lower average demand for a more efficient AC during the three-hour timeframe.

Twelve three-hour periods were tested for August and September, along with the 3-6 p.m. period for the three highest system peak days in August (i.e., August 23-25) and the highest system peak day in September (i.e., September 1). While it is helpful to have more than one day for the peak day test, only one day in September was hot enough to include in a peak day test. For this test, it is important to make sure the unit was at least running at some point during the three hour period. In-depth analyses of the data revealed that some units literally did not run on some days for long periods of time. Customer reasons for engaging in this AC usage behavior are unknown, but this type of AC usage behavior needed to be excluded from the analyses. Nothing can be learned about the efficiency of different SEER units when the customer has simply decided not to run the unit. The inclusion criteria for these analyses were:

1. The unit had at least 0.1 kW per ton of demand in one of twelve 15-minute intervals.
2. During the day, up to ten of twelve intervals could be zero.
3. During the night, up to eleven of twelve intervals could be zero.
4. For each day, the mean daytime indoor temp for three hours was between 72 and 88.
5. For each day, the mean nighttime indoor temp for three hours was between 70 and 86.
6. The maximum kW per ton for the month was between 0.5 kW and 1.9 kW.
7. The air conditioner tonnage was greater than 2.0.
8. The square footage of the home was between 1100 and 2400.
9. The square feet per ton was between 340 and 580.
10. The SEER rating was between 9 and 16.
11. The customer needed at least 14 days for the month tested that met the criteria above.
12. Customers on one of SRP's time-of-use price plan options were excluded because they significantly alter AC usage during a time when the unit needed to be running.

Based on the inclusion criteria mentioned above, 212 customers qualified for the August analyses and 153 customers qualified for the September analyses. The series of regression analyses produced a consistent pattern of decreases in average demand (kW) per ton as the SEER rating increased. The SEER rating and the average indoor temperature were found to be highly significant in predicting average kW per ton. Other variables tested that were not statistically significant were, square footage, age of home, type of home (house or condo), number of stories, ceiling height, vaulted ceilings and window exposure to direct sunlight. Converting average kW to a "per ton" unit of measurement effectively eliminated the need for square footage, number of stories, ceiling height and vaulted ceilings. Although many socioeconomic/household factors and behaviors affecting AC usage are unknown in this study, SEER and indoor temperature were able to explain a significant amount of the variance in average kW over a three-hour period. The adjusted r-square results range from 0.50 to 0.23 in August and 0.43 to 0.17 in September. In all cases, SEER and indoor temperature were statistically significant beyond the 0.0001 level.

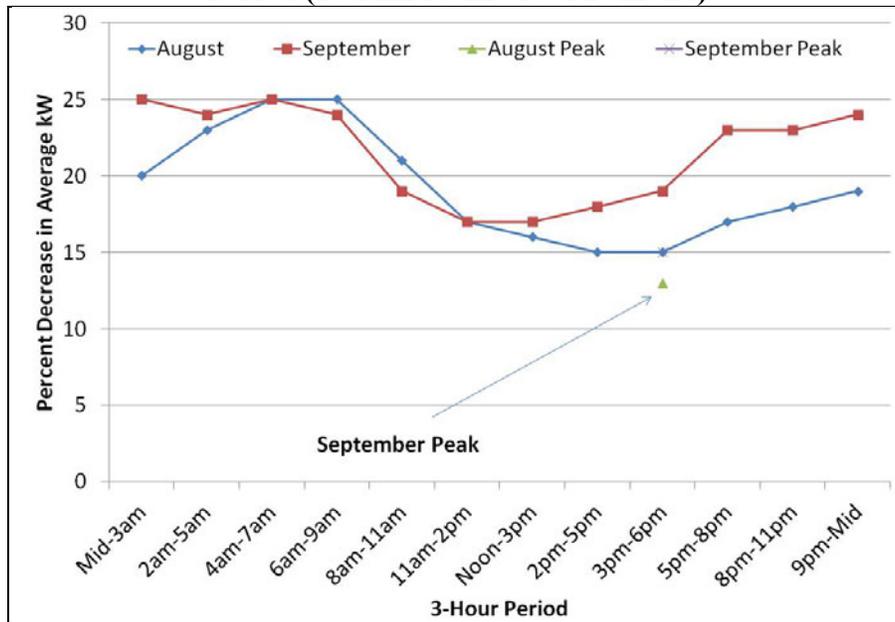
A multiplicative model provided a better fit to the data than a linear model. The multiplicative model is very robust in providing a percentage change estimate based on one regressor in the model that is independent of values derived from other regressors in the model. While one "cross-sectional time-series" model that incorporates indoor and outdoor temperature relationships over time (i.e., different days and different times of day) is being tested, the effect of our sample's very different AC usage behaviors across time-of-day on estimating the specific effect of SEER on average demand has led us to simplify the complexity of the analysis for now. For this analysis, 26 separate regressions of cross-sectional data were performed with respect to time-of-day and month. Each regression analysis for August measured a cross-section of time for the month (e.g., 2-5 a.m., 8-11 a.m., 5-8 p.m.). Regression analyses were performed on the same cross-sections of time in September. Each cross-section of time-of-day in the month has an average outdoor temperature for the month that is constant across all households in the analysis.

As mentioned above, twelve three-hour time periods were tested for August and September with this analytical methodology, along with a peak day analysis. Figure 10 shows the results for comparing SEER 13 to SEER 10. This set of results demonstrates the impact of SEER on average kW per ton for each timeframe. Other SEER comparisons would provide a consistent percentage relationship to these results. The results are reported to the nearest whole percentage

point. One should not place any importance on a result changing by a small percentage point from one timeframe to the next. The important finding is the pattern of results revealed by the series of regression analyses across three-hour segments of time and the comparison of results between August and September.

For August, the percentage decrease in average kW per ton ranges from a high of a 25 percent decrease in the 4 a.m. to 9 a.m. time of day to a low of 13 percent from 3 p.m. to 6 p.m. on the system peak day and the day before and after the peak day. The average high temperature for these three days was 114 degrees. If one ignores the point for the system peak days, there is a clear pattern of decreasing percentages as the temperature increases from relatively mild to hot and then increasing percentages as the temperature decreases from hot to relatively mild. A similar pattern is shown for September, where the percentages decrease from 25 percent to 15 percent and then increase up to 24 percent by the end of the day. Again, ignoring the September peak day percentage, the decreasing and increasing percentages are quite smooth. The average outdoor temperatures reported in Table 6 for each three-hour timeframe can be compared to the results in Figure 10 to see the average outdoor temperature all customers experienced in each timeframe and the relationship between the temperatures and percentage decreases in Figure 10.

**Figure 10. SEER 13 vs. SEER 10 Comparison of % Decrease in Avg kW per Ton in 3-Hour Period (15-Minute Interval Demand)**



**Table 6. Average Outdoor Temperatures for Three-hour Timeframes August and September and Respective Peak Days**

3-Hour Period	Mid-3am	2am-5am	4am-7am	6am-9am	8am-11am	11am-2am	Noon-3pm	2pm-5pm	3pm-6pm	5pm-8pm	8pm-11pm	9pm-Mid
August	92.68	90.70	89.25	91.59	96.90	103.87	105.39	106.91	106.79	104.39	98.46	96.68
September	84.59	82.48	81.12	84.13	90.70	98.46	99.91	100.62	100.00	96.71	90.49	88.69

August Peak (8/24/2011)									112.70			
September Peak (9/1/2011)									110.00			

Although the efficiency of all air conditioners decreases as the difference between the indoor and outdoor temperature increases, the loss of efficiency as outdoor temperatures climbed well above 100 degrees was greater for higher SEER units, which resulted in less difference in average demand between lower-SEER and higher-SEER units during the hottest times of the day. Also, since September evening temperatures are much milder than August evening temperatures, the analyses revealed that the greater system efficiency differences between lower-SEER and higher-SEER units manifested more quickly in September. The results indicate that SRP should expect the performance advantages of higher SEER units to be significantly lower during the hours when SRP’s system peak occurs.

## Conclusions

In order to evaluate the SEER rating as a tool for utilities, SRP and EPRI have deployed monitoring equipment in hundreds of homes in the Phoenix area. The sample of homes, selected by SRP, were instrumented with indoor temperature sensors and power meters on the air conditioning branch circuit in order to gather a large data set during the summer of 2011. The data was collected and analyzed to develop load shapes and energy efficiency correlations. Two separate but interrelated analyses were performed to quantify the difference between ratings classes – a higher-level data overview, and a statistical regression analysis.

The results of this study showed a strong relationship between SEER and monthly energy consumption. From a selection of units with similar indoor conditions, SEER 12-13 units consumed 4.8-9.0% less energy than SEER 10-11 units, and SEER 14-16 units consumed 14.0-18.1% less. Higher SEER ratings also generally corresponded to lower power consumption for all temperature differences, indoor to outdoors. In July for example, the SEER 14-16 units had 24-29% lower power consumption across temperature bins, normalized for square footage, than SEER 10-11 units. This correlation of higher SEER and lower power was true even at large temperature differences, with higher magnitude reductions but lower percentage reductions at high temperature differences.

The regression analysis showed a similar trend, with SEER isolated as the regressor of interest. The predicted percentage reduction in power and energy between a SEER 10 and SEER 13 was shown as an example; the difference in power between SEER 10 and SEER 13 was as high as 25% in August and September during overnight hours, and as low as 13% during the afternoon of the peak cooling days. The results show that utilities in hot climates can expect improved efficiency even during hot weather, but with the relative improvement decreasing as a function of increasing temperature differences. A similar study will be performed in 2012, with a focus on high-SEER units. SRP intends to deploy meters on a set of homes focusing on SEER 15-17 systems, with the goal of providing a larger data set to examine. The Summer 2012 work will enable examination of high-SEER units with a broader data set, and expansion on the findings of this study.



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