Savings Uncertainties in Residential Air Conditioning Rebate Programs

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ABSTRACT

This study presents a methodology for estimating the range of uncertainty on savings from residential AC efficiency programs. This analysis involves building a Crystal Ball[1] model that includes all the performance and data uncertainties that can affect actual savings gained in the field. Sensitivity charts produced by the model show which input uncertainties contribute the most to the uncertainty in kW and kWh savings. They also provide pointers to program evaluators about which aspects of the program should be prioritized for data verification.

This method can help program designers to establish program parameters for requirements such as minimum EER/SEER standards and whether to include minimum installation standards, by looking at the minimum savings needed to make the program cost-effective and the predicted savings for different SEER levels. It can also be useful when making field data collection plans.

The model run for this study used "generic" values for most of the parameters. These would have to be redefined for the particular program being modeled. The inputs should reflect the actual uncertainties present in the program being implemented. For this study, the model showed that:

- Uncertainty in EER and operating conditions mean that demand savings could be up to 2.5 times lower or almost two times higher than predicted; in some cases, they can be negative.
- Uncertainty in energy savings is much lower than uncertainty in demand savings.
- Sensitivity charts show that if EER is not known, it is the variable with the most contribution to variance in demand savings, and that EFLH contributes the most to variance in energy savings.

The Issue of Uncertainty

Residential AC rebate programs have been a staple in many utilities' DSM program portfolios for many years. Accurately calculating the savings gained from these programs is important both to utility managers and energy efficiency program planners. If demand savings are overestimated, then the expected savings will not be realized on peak summer days, making system stresses more likely and reducing the cost-effectiveness of the program.

Performance Uncertainties

Actual performance of the AC unit in the field can fall short of the unit's rated efficiency due to a variety of reasons. These include the following:

- duct leakage
- incorrect refrigerant charging
- incorrect unit sizing (affects both performance and load factor)
- incorrect air flow over the coil
- operating conditions significantly hotter than the conditions in which the unit was rated

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[1] Crystal Ball software is a product of Decisioneering Inc (www.decisioneering.com)

The performance of the unit can be improved by addressing these issues (such as with a quality installation), and by the installation of a thermal expansion valve (TXV).

Data Uncertainties

There are uncertainties that can arise in relation to the data collected on the installed unit. At a minimum, the condenser model number, coil model number, and ARI number should be accurately recorded for each unit installed through the program. Then the unit's rated performance and size, in terms of EER, SEER, and kBtu, can be verified using the Unitary Directory of Certified Product Performance produced by the Air-Conditioning and Refrigeration Institute (ARI).

Actual accuracy levels vary considerably when it comes to data collection, so it can often occur that the model number and/or ARI number in the program database do not match up with the ARI database, or are missing, and then the EER, SEER and size are in doubt. In some cases they may not have been given in the first place. SEER values are always advertised, but EER values are sometimes difficult to obtain from manufacturers.

If the EER value is not known and the model cannot be identified in the ARI database, it must be estimated. However, there is a wide variety of possible EER ratings for a single SEER rating so there is no easy, linear function that relates EER to SEER.

Another data uncertainty is the equivalent full load hours (EFLH) value, which is used to compute kWh savings. This can vary considerably from home to home and thus has a wide range of possible values.

Baseline Upgrade

In most AC programs, the efficiency and size of the baseline unit is unknown (i.e., the unit being replaced), so a baseline is used that represents a replace-on-burnout operation. It is assumed that a customer would replace his or her unit with the minimum standard unit available on the market, if it were not for the program.

The new minimum federal standard of 13 SEER, which came into effect this year, has raised this replace-on-burnout baseline from its previous level of 10 SEER. Because savings due to the program are calculated based on the difference between the efficiencies of the baseline and the energy efficient unit, this potentially reduces program savings when compared to previous years, and means that it is even more important to calculate savings accurately in order to make each installation cost effective.

The Approach

The approach outlined in this paper is to find the full possible range of savings values due to a unit installed through an AC rebate program, taking into consideration all the uncertainties that can affect these savings.

Demand and energy savings are usually calculated using the AC unit's EER and SEER rating with the following formulas:

$$\text{kW savings} = \text{tons} * 12 * (1/\text{EER}_{\text{base}} - 1/\text{EER}_{\text{measure}}) * \text{CF} * \text{LF}$$
$$\text{kWh savings} = \text{tons} * 12 * (1/\text{SEER}_{\text{base}} - 1/\text{SEER}_{\text{measure}}) * \text{EFLH} * \text{LF}$$

Where: EFLH = equivalent full load hours
CF = coincidence factor
LF = load factor

Each of the parameters in these equations may or may not have a range of uncertainty around it.

- If EER and SEER are known and verified, then there is no uncertainty in those inputs; if only the SEER is known, then the EER must be estimated and that adds uncertainty to the kW savings value.
- The load factor is affected by the quality of the sizing calculations done by the contractor; if the unit is oversized, then the load factor will be less than 1. If the quality of the sizing is unknown, the load factor will be unknown.
- The coincidence factor and EFLH value can vary from home to home, so there is almost always some uncertainty in those values when applied to a wide variety of installations.
- The coincidence factor depends on the coincidence of AC use with system peak. This can be estimated for an average household.

For this analysis, each of these inputs used to calculate savings is evaluated for uncertainty. This may involve analyzing the program database to verify: unit SEER, EER, and size, if a proper sizing calculation was done, if a thermal expansion valve (TXV) was installed. From this information, assumptions about degradations in SEER or EER that could occur due to less-than-optimal operating conditions are made.

For example, if no TXV is installed or this information is not known, it can be assumed that not all units will operate at their rated efficiencies due to common problems such as incorrect refrigerant charging and incorrect air flow over the coil. If no information is available on the quality of the sizing, it can be assumed that a certain percentage of units will be oversized (as this is quite common practice), reducing the load factor, and degrading the SEER and EER.

Table 1 below shows the adjustment factors used in this study for such performance uncertainties. [2]

Table 1: Factors Affecting Energy Savings

	Reduction in EER	**Reduction in SEER**	**Reduction in Savings**
No Sizing (efficiency)	6.0%	6.0%	
No TXV	2.5%	6.6%	
No Sizing (Load Factor)			12.0%

Table 2 shows the adjustment factors used in two different cases – TXV and sizing unknown, and TXV and sizing done. These represent a typical high and low uncertainty case.

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[2] These values came from a variety of sources, including an evaluation of Xcel Energy's AC Rebate program, plus the following documents:

1) *Options for a New ENERGY STAR® Specification for Residential Air-Source Heat Pumps and Central Air Conditioners* from the Energy Star website;

2) *Field Measurements of Air Conditioners With and Without TXVs,* by Mowris, Blankenship, and Jones, Robert Mowris & Associates;

3) A report from the Air Conditioning and Refrigeration Institute (ARI), in response to a suggested Federal Standard of TXV's being required on all new air conditioning units;

4) How Contractors Really Size Air Conditioning Systems, by Vieira et. al. (presented at the 1996 ACEEE Summer Study on Energy Efficiency in Buildings).

Table 2: Adjustment Factors for Low and High Uncertainty Cases

	EER min	EER Mean	EER max	SEER min	SEER Mean	SEER max	Load Factor
If TXV and sizing unknown	91.5%	95.8%	100.0%	87.40%	93.7%	100.0%	88.0%
If TXV and sizing exist	97.2%	98.6%	100.0%	95.8%	97.9%	100.0%	100.0%

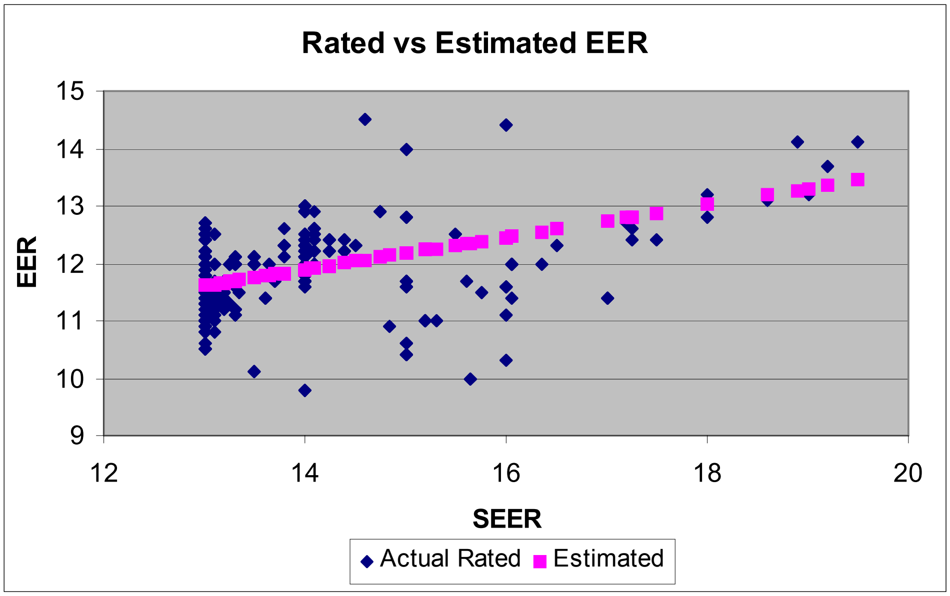
These adjustment factors give the range of possible values, when multiplied by the SEER and EER of the unit.

Uncertainty in Estimating EER

If EER values are not collected by the installers, or are deemed to be inaccurately recorded, they must be estimated. A regression formula can be generated from the CEC or CEE database of available units to enable an EER value to be estimated from the SEER.

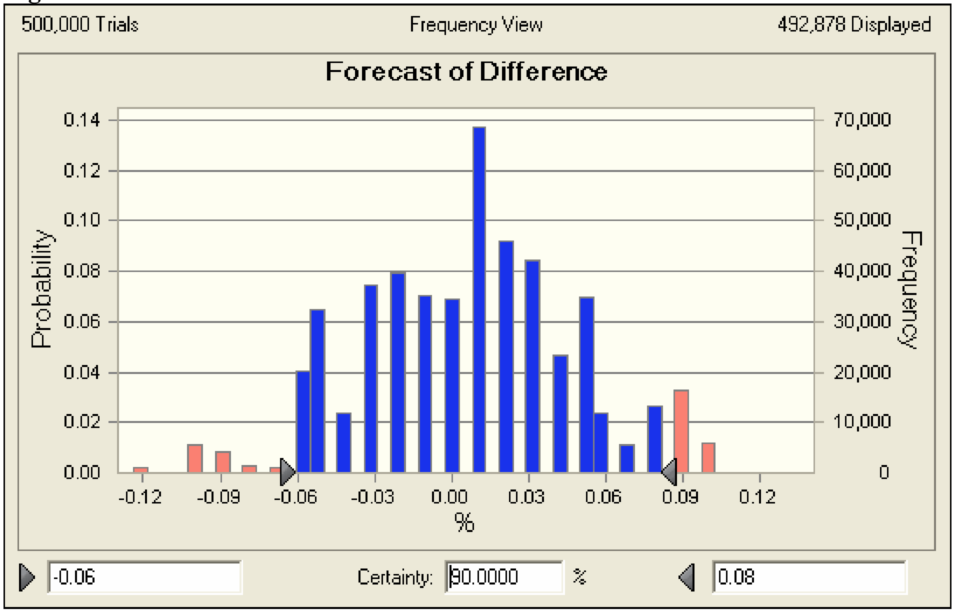
Figure 1 shows a comparison of rated versus estimated values (from regression formula) for a range of units.

Figure 1: Rated vs. Estimated EER



The probability distribution for the percentage difference between estimated and rated EER values was put into Crystal Ball, and a simulation was run. The simulation showed that there is a 90% certainty that the difference will be less than plus or minus 8%. This range was used in the uncertainty model as the range of uncertainty on the EER value if it is not known.

Figure 2: Forecast of Difference between Rated and Estimated EER



-0.06

Certainty: 90.0000 %

0.08

Uncertainty Model

A Crystal Ball model was created that calculates a range of demand and energy savings for units rated SEER 14 to 18. The baseline unit was assumed to be a SEER 13 unit. The model includes probability distributions for the following values:

1) EER value (for high uncertainty case)
2) Coincidence factor
3) Operating hours (EFLH)
4) Local climate
5) Installation of TXU
6) Load factor

The model was run with two cases – high and low uncertainty. It produced a range of forecasted values for kW and kWh, based on a Monte Carlo simulation, for each case.

Adjustments for Climate

Hirsch and Associates performed a study for Southern California Edison that examined the effect of climate on residential AC performance[3]. The report provides adjustment factors for SEER and EER by climate zone for California. These factors reflect the affect of climate on the efficiency of AC units. Rated efficiencies are measured at standard temperatures (82°F for SEER and 95°F for EER) but units will perform at lower efficiencies in higher temperature climates.

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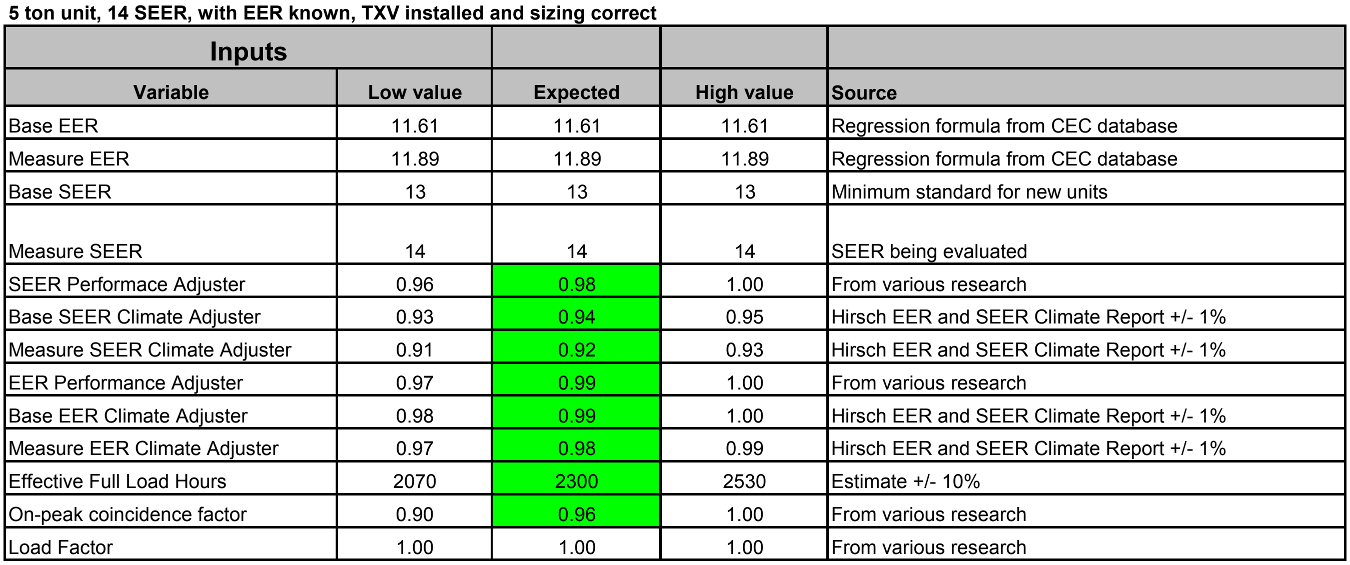
[3] *EER and SEER as Predictors of Residential Seasonal Cooling Performance* prepared by James Hirsch and Associates for Southern California Edison Design and Engineering Services, December 2005. Note that although SEER is a seasonally adjusted efficiency, because it is rated at 82°F it will not be accurate for climates in which the seasonal temperature is significantly higher than this.

These factors can be used to adjust SEER and EER according to the climate when the AC unit is installed. Values range from 0.85 to 1.22 for EER, and 0.71 to 1.2 for SEER. Values for CA zone 12 (moderate) were used in the model.

Uncertainty Inputs

Table 3 shows the inputs for the model for the low uncertainty case. A green cell indicates that it contains a probability distribution. The max and min of the distribution are shown. Triangular distributions were used, but normal distributions could also be used as long as the distribution is terminated at the minimum and maximum.

Table 3: Inputs for SEER 14, Low Uncertainty Case



5 ton unit, 14 SEER, with EER known, TXV installed and sizing correct

Inputs				
Variable	**Low value**	**Expected**	**High value**	**Source**
Base EER	11.61	11.61	11.61	Regression formula from CEC database
Measure EER	11.89	11.89	11.89	Regression formula from CEC database
Base SEER	13	13	13	Minimum standard for new units
Measure SEER	14	14	14	SEER being evaluated
SEER Performace Adjuster	0.96	0.98	1.00	From various research
Base SEER Climate Adjuster	0.93	0.94	0.95	Hirsch EER and SEER Climate Report +/- 1%
Measure SEER Climate Adjuster	0.91	0.92	0.93	Hirsch EER and SEER Climate Report +/- 1%
EER Performance Adjuster	0.97	0.99	1.00	From various research
Base EER Climate Adjuster	0.98	0.99	1.00	Hirsch EER and SEER Climate Report +/- 1%
Measure EER Climate Adjuster	0.97	0.98	0.99	Hirsch EER and SEER Climate Report +/- 1%
Effective Full Load Hours	2070	2300	2530	Estimate +/- 10%
On-peak coincidence factor	0.90	0.96	1.00	From various research
Load Factor	1.00	1.00	1.00	From various research

Table 4 shows the high uncertainty case. The EER has a probability distribution instead of a single value, and the ranges on the SEER performance adjuster and the EER performance adjuster are wider.

Table 4: Inputs and Output for SEER 14, High Uncertainty Case

14 SEER with EER not known, TXV and sizing unknown

Inputs				
Variable	**Low value**	**Expected**	**High value**	**Source**
Base EER	11.61	11.61	11.61	Regression formula from CEC database
Measure EER	10.94	11.89	12.84	Regression formula +/- 8%
Base SEER	13	13	13	Minimum standard for new units
Measure SEER	14	14	14	SEER being evaluated
SEER Performace Adjuster	0.87	0.94	1.00	From various research
Base SEER Climate Adjuster	0.93	0.94	0.95	Hirsch EER and SEER Climate Report +/- 1%
Measure SEER Climate Adjuster	0.91	0.92	0.93	Hirsch EER and SEER Climate Report +/- 1%
EER Performance Adjuster	0.92	0.96	1.00	From various research
Base EER Climate Adjuster	0.98	0.99	1.00	Hirsch EER and SEER Climate Report +/- 1%
Measure EER Climate Adjuster	0.97	0.98	0.99	Hirsch EER and SEER Climate Report +/- 1%
Effective Full Load Hours	2070	2300	2530	Estimate +/- 10%
On-peak coincidence factor	0.90	0.96	1.00	From various research
Load Factor	0.80	0.90	1.00	From various research

Results

Statistics

Table 5 shows the results of the model run, in the form of the statistics for the outputs – kW and kWh saved for a 5 ton unit – for both cases. The minimum and maximum shown are the 10th and 90th percentiles of the forecast.

Table 5: Results from the Model Run

EER known, TXV installed and sizing correct

SEER	min kW savings	max kW savings	avg kW savings	min kWh savings	max kWh savings	avg kWh savings	kW Range	kWh Range
14	0.031	0.107	0.069	370.7	864.5	590.8	0.076	493.8
15	0.043	0.120	0.082	1,231.2	1,869.6	1,537.7	0.077	638.3
16	0.258	0.334	0.296	1,224.5	1,847.1	1,523.9	0.076	622.6
17	0.362	0.439	0.400	1,944.5	2,740.0	2,322.7	0.076	795.5
18	0.368	0.444	0.406	1,965.2	2,748.9	2,322.3	0.076	783.7

EER not known, TXV and sizing unknown

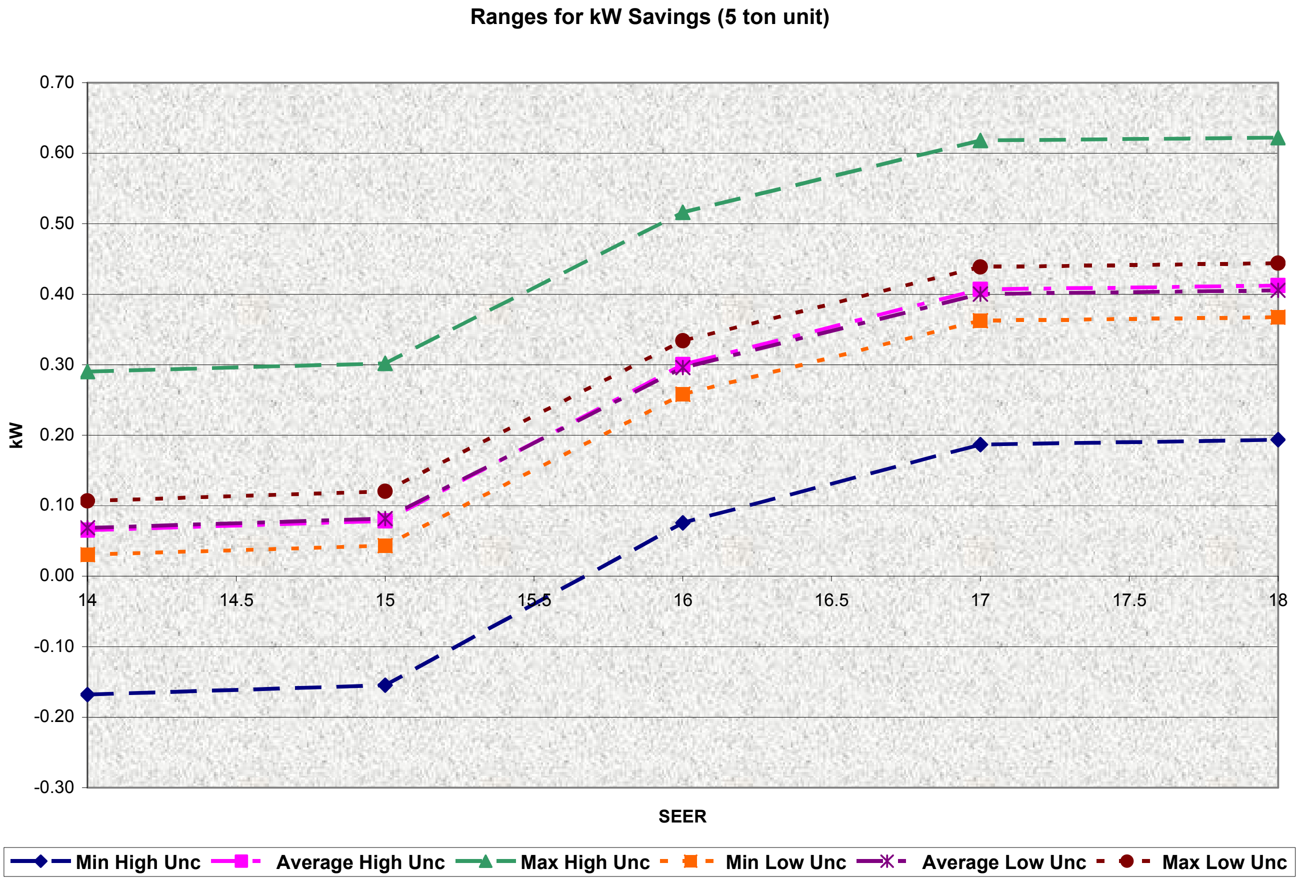
SEER	min kW savings	max kW savings	avg kW savings	min kWh savings	max kWh savings	avg kWh savings	kW Range	kWh Range
14	-0.168	0.290	0.065	359.0	916.3	618.5	0.458	557.3
15	-0.154	0.302	0.078	1,260.8	2,011.1	1,608.2	0.456	750.3
16	0.076	0.516	0.300	1,236.1	2,016.2	1,593.4	0.441	780.1
17	0.187	0.618	0.407	1,975.9	3,012.1	2,427.3	0.432	1,036.2
18	0.194	0.622	0.412	1,947.7	2,975.2	2,427.6	0.428	1,027.5

The uncertainty range (max – min) for the high uncertainty case was higher than the low uncertainty case by an average of 25% for kWh and about 5 times higher for kW saved.

kW Savings

The graph below shows that the averages of the ranges for kW savings, with low and high uncertainty, are fairly close, but the full range for the high uncertainty case (between green and blue lines) is much wider than the low uncertainty case (between brown and orange lines).

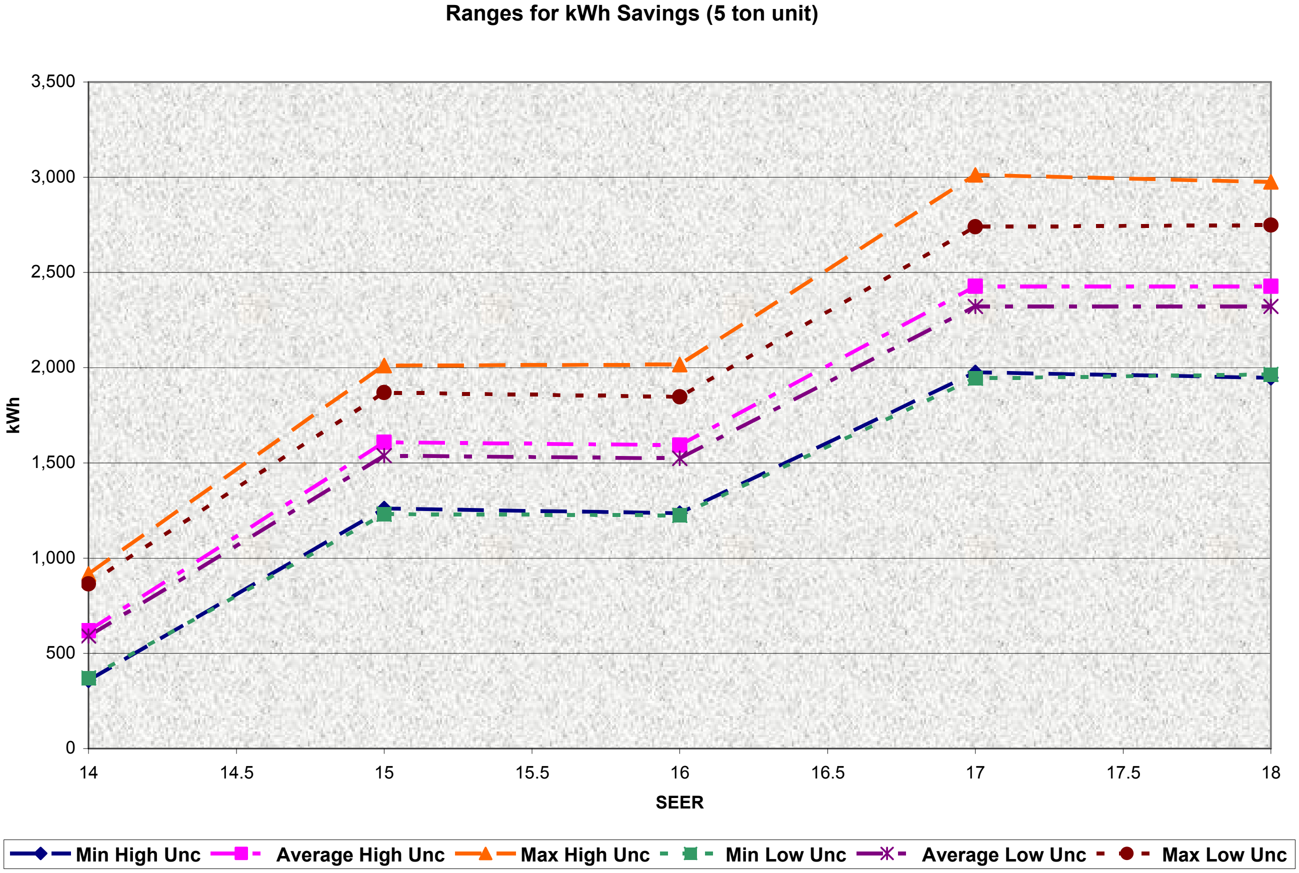
Figure 3: kW Savings



kWh Savings

The averages of the ranges for kWh savings are also very close, and the full range for the high uncertainty case (between orange and blue lines) is wider than the low uncertainty case (between brown and green lines) by a much smaller amount than for kW savings.

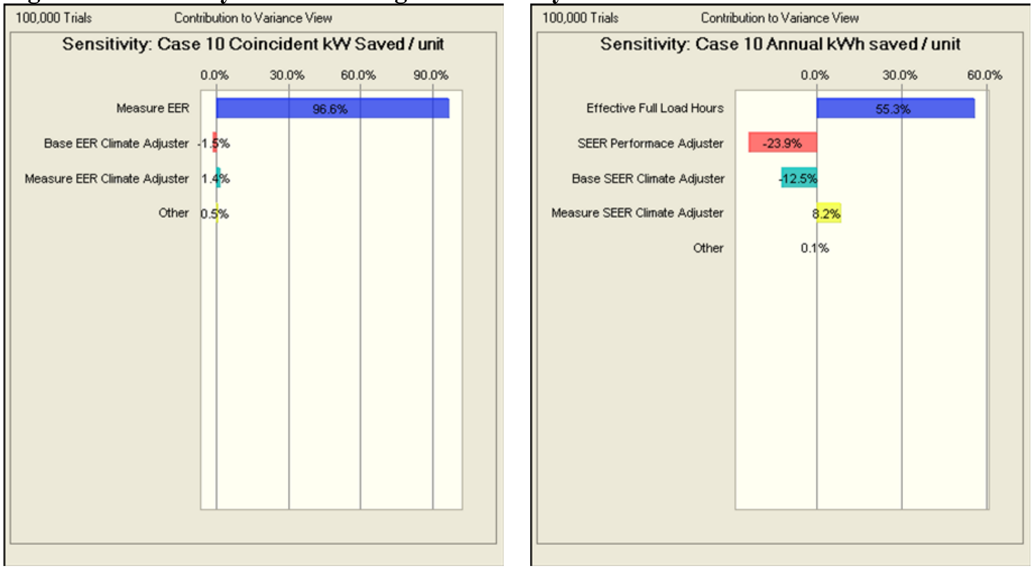
Figure 4: kWh Savings



Sensitivity Charts

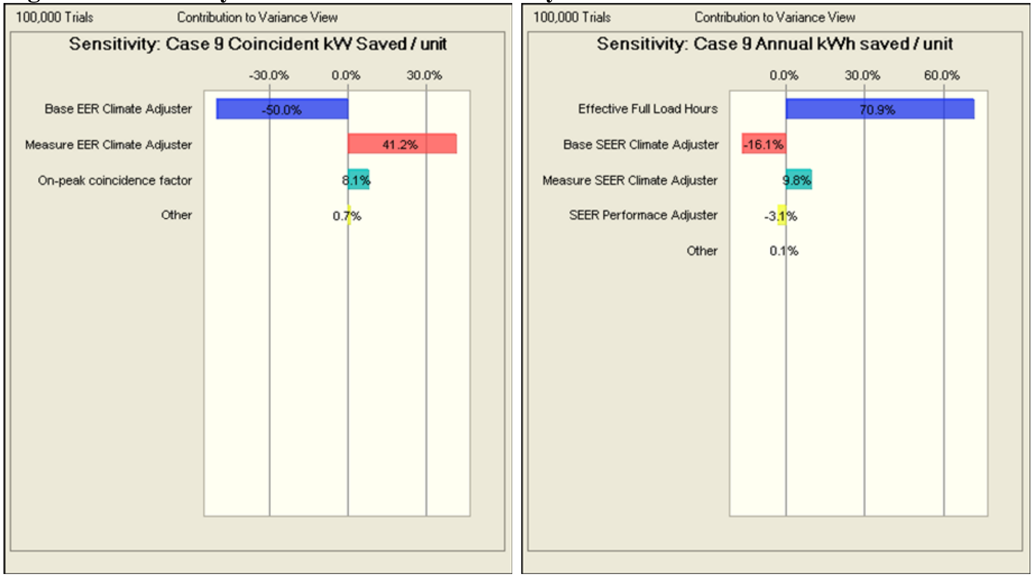
Sensitivity charts show the contribution to variance of the input variables. The charts below are for SEER 18, high uncertainty. It can be seen that if the EER is not known but is estimated, this contributes the most to variance in the kW saved. For kWh, the EFLH value is the highest contributor to uncertainty, followed by the SEER performance adjuster (due to lack of information on sizing and TXV).

Figure 5: Sensitivity Charts for High Uncertainty Case



The charts below are for SEER 18, low uncertainty. The EER climate adjuster is the highest contributor to variance for kW saved, and the EFLH is the highest contributor for kWh saved, as for the high uncertainty case. Because there is less uncertainty about the performance and rating of the unit, the climate adjusters show up much higher in the list of contributors to variance.

Figure 6: Sensitivity Charts for Low Uncertainty Case



Conclusions

The approach presented here provides a way to estimate the range of uncertainty on savings from residential AC efficiency programs. This analysis includes all the performance and data uncertainties that can affect actual savings gained in the field. Sensitivity charts show which input uncertainties contribute the most to the uncertainty in kW and kWh savings and provide pointers to program evaluators about which aspects of the program should be prioritized for data gathering or site inspections, in order to reduce uncertainty in performance.

This method can also help program designers to establish program parameters for requirements such as minimum EER/SEER standards and whether to include minimum installation standards, by looking at the minimum savings needed to make the program cost-effective and the predicted savings for different SEER levels and operating conditions.

It should be noted that this study used “generic” values for most of the parameters. The ranges given to uncertainty parameters were taken from various programs worked on in the past. Most of these parameter ranges would have to be redefined for the particular program being modeled, and some of the parameters would not need probability distributions if they are known. The inputs should reflect the actual uncertainties present in the program being implemented.

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