The Coil & Blade Project: Combining Field Work and Interval Data to Measure Impacts

Kelly Parmenter, Ph.D., Applied Energy Group, Walnut Creek, CA
Joe Prijyanonda, Applied Energy Group, Walnut Creek, CA
Donney Dorton, Oklahoma Gas & Electric, Oklahoma City, OK

ABSTRACT

Residential HVAC tune-up programs often include a set of several maintenance measures, such as adjusting refrigerant charge, replacing air filters, sealing plenums, repairing ducts, and cleaning condenser coils, evaporator coils, and fan blades. Estimating the impacts from these individual measures using deemed savings is challenging because of the many variables involved. To isolate savings impacts and better understand the interaction between maintenance measures, Applied Energy Group (AEG) designed and carried out a multi-phase data collection protocol for measuring energy savings due to HVAC maintenance measures provided by Oklahoma Gas & Electric's (OG&E's) Home Energy Efficiency Program (HEEP). The field data collection incorporated spot measurements and data logging of HVAC system components to measure the impacts of key maintenance measures as a function of the sequence in which they were performed. The primary objective was to collect field data to inform the development of deemed savings appropriate for OG&E's measures and customer base. A secondary objective was to assess the feasibility of estimating HVAC equipment runtimes from 15-minute interval data collected from customers' smart meters. This paper discusses how AEG was able to use the field data to recommend a set of deemed savings for the measures and customers typical to OG&E's service territory. It also explains how AEG was able to assess the viability of using interval data to disaggregate the HVAC equipment from the rest of the loads in the home by directly comparing the logged data of the HVAC system components with the whole-home 15-minute interval data.

Introduction

Background

HEEP provides free HVAC tune-ups and minor air distribution system repairs to OG&E's residential customers with central air conditioning (AC) systems. The HVAC tune-ups include checking and adjusting refrigerant charge, cleaning the condenser coil, checking filters and replacing one air filter per home, and inspecting the plenum, overhead ductwork, and evaporator coil. If contractors identify problems with the ductwork and evaporator coil, the program allows them to perform minor repairs such as plenum sealing, duct repairs, and evaporator coil cleaning. Program-approved qualified HVAC contractors receive rebates from OG&E to perform all eligible improvements. OG&E currently uses deemed savings algorithms to claim savings for the refrigerant adjustment, plenum seal, duct repair, and evaporator coil cleaning measures. However, OG&E does not claim savings for the condenser coil cleaning or filter replacement portions of the tune-up services since they do not have a deemed savings approach for those measures. After a preliminary literature review indicated that fouled coils and filters can have a measurable impact on system efficiency, OG&E initiated a field study with AEG to quantify the energy savings from these measures so that OG&E can claim the savings in future program years.

In addition to studying impacts from condenser coil cleaning and filter replacement, OG&E extended the study to quantify savings from evaporator coil and fan blade cleaning. OG&E claims savings for evaporator coil cleaning already, but wanted to validate the deemed savings algorithm with results from field studies. The tune-up services do not currently include fan blade cleaning, but this could be added in the future as a standard maintenance measure.

Lastly, because OG&E has deployed smart meters in homes throughout their service territory, they wanted to use the present study as a means to investigate the feasibility of disaggregating HVAC equipment operation from 15-minute interval meter data. This type of analysis has potential for far reaching implications. Being able to use interval data to identify when HVAC equipment turns on and off, and accurately quantifying power draw, could help utilities better understand how customers use HVAC equipment and could help pinpoint future opportunities for energy savings without the need for expensive and intrusive logging or end use metering.

Purpose

The primary purpose of this study (known as the "Coil & Blade" study) was to develop, as appropriate, deemed energy and demand savings for the following groups of HVAC tune-up measures during the cooling season using actual field measurements:

1. Condenser coil cleaning and filter replacement
2. Evaporator coil and fan blade cleaning

Due to the study's design, energy savings from plenum seal and duct repair measures was an ancillary outcome. The second main objective of the study was to investigate whether OG&E's interval meter data can also be used to determine HVAC system runtimes and the savings due to these HVAC tune-up measures.

Field Data Collection

Data Collection Plan

OG&E and AEG explored a variety of potential data collection plans and then ultimately settled on the plan presented in this section. The plan involved two groups of OG&E customers—Group A and Group B—and was designed to test three groups of maintenance actions separately from one another to estimate individual savings impacts for each group during the cooling season. Having two groups of customers was necessary for studying the effects of measure interactions and the order in which the measures are implemented. For each group, there were four data collection visits plus a final visit to adjust the refrigerant charge and remove data loggers. The length of data collection for each step was two weeks, which resulted in eight weeks of data collection. The central HVAC systems were in cooling mode during this time period, so they are referred to as "AC systems." The data collection was conducted in Oklahoma during July through September 2014 in conjunction with HEEP activities. The data collection steps for each group are described below and displayed visually in Figure 1:

- **Group A**
  - **Baseline**: Measurements of the 'as-is' AC system.
  - **Evaporator coil and fan blade cleaning**: Measurement of impacts on an 'as-is' AC system. Efforts were made to place homes with evaporator coil blockage of greater than 30% into Group A. Evaporator coils and fan blades were cleaned regardless of how dirty they were.
  - **Plenum seal and duct repair**: Measurement of impacts on AC system that already received the evaporator coil and fan blade cleaning measures. Plenum seal and duct repair were performed as needed.
  - **Condenser coil cleaning and filter replacement**: Measurement of impacts on AC system that already received all other measures, except refrigerant charge adjustment. Condenser coil cleaning and filter replacement are normally performed at every home that participates in HEEP.

- **Refrigerant charge adjustment**: The refrigerant charge was adjusted during the last site visit. Spot measurements were taken after adjusting the charge to measure changes in power draw and unit capacity, but there was no data logging after this step.

- **Group B**
  - **Baseline**: Measurements of the 'as-is' AC system.
  - **Condenser coil cleaning and filter replacement**: Measurement of impacts on an 'as-is' AC system. Condenser coil cleaning and filter replacement are normally performed at every home that participates in HEEP.
  - **Plenum seal and duct repair**: Measurement of impacts on AC system that has already received the condenser coil cleaning and filter replacement measures. Plenum seal and duct repair were performed as needed.
  - **Evaporator coil and fan blade cleaning**: Measurement of impacts on AC system that already received all other measures, except refrigerant charge adjustment. Evaporator coils and fan blades were cleaned regardless of how dirty they were.
  - **Refrigerant charge adjustment**: The refrigerant charge was adjusted during the last site visit. Spot measurements were taken after adjusting the charge to measure changes in power draw and unit capacity, but there was no data logging after this step.

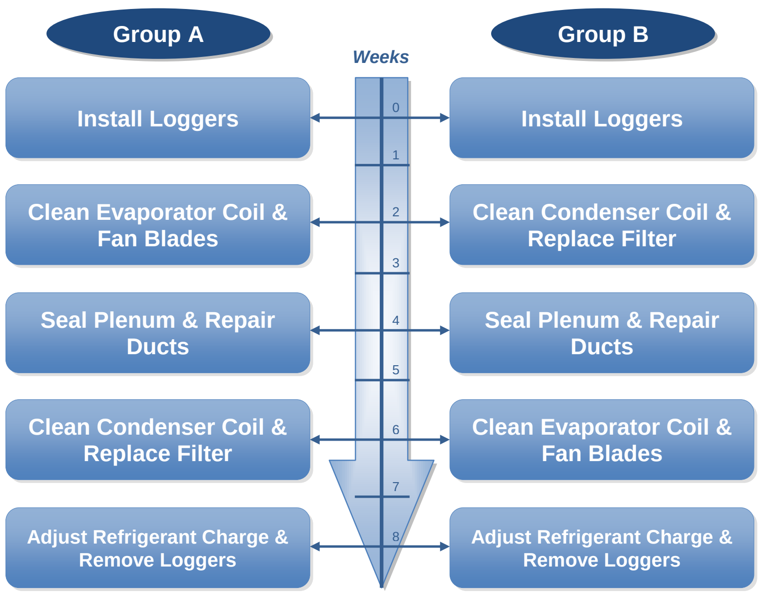

Figure 1. Flow Diagram for Field Data Collection

Although it would have been ideal to have a separate data collection step for each tune-up measure, this was not practical from the project budgeting, data collection timeframe, and customer interaction standpoints. As such, it was necessary to group two measures into each step. OG&E suggested grouping condenser coil cleaning with filter replacement, since both of these maintenance actions are always performed at each home during a tune-up. This grouping allowed for estimation of a combined savings value for condenser coil cleaning and filter replacement that is applicable to all central AC systems undergoing a tune-up. In addition, grouping evaporator coil and fan blade cleaning was another logical choice for two reasons: 1) both system components are located in the same vicinity; and 2) if the evaporator coil is significantly blocked and in need of cleaning, it is likely the fan blade would require cleaning as well. Lastly, grouping plenum seal and duct repair makes sense since these two air distribution measures are closely related.

Field Data Collection Team

AEG subcontracted with CLEAResult and HVAC Solutions to carry out the field data collection. As implementation contractor for HEEP, CLEAResult was well situated to recruit prospective HEEP participants for the study. Also, as a very experienced HEEP-approved HVAC contractor, HVAC Solutions was able to provide the required field services. Figure 2 shows the logistics and division of responsibilities between AEG, CLEAResult, and HVAC Solutions during the study.

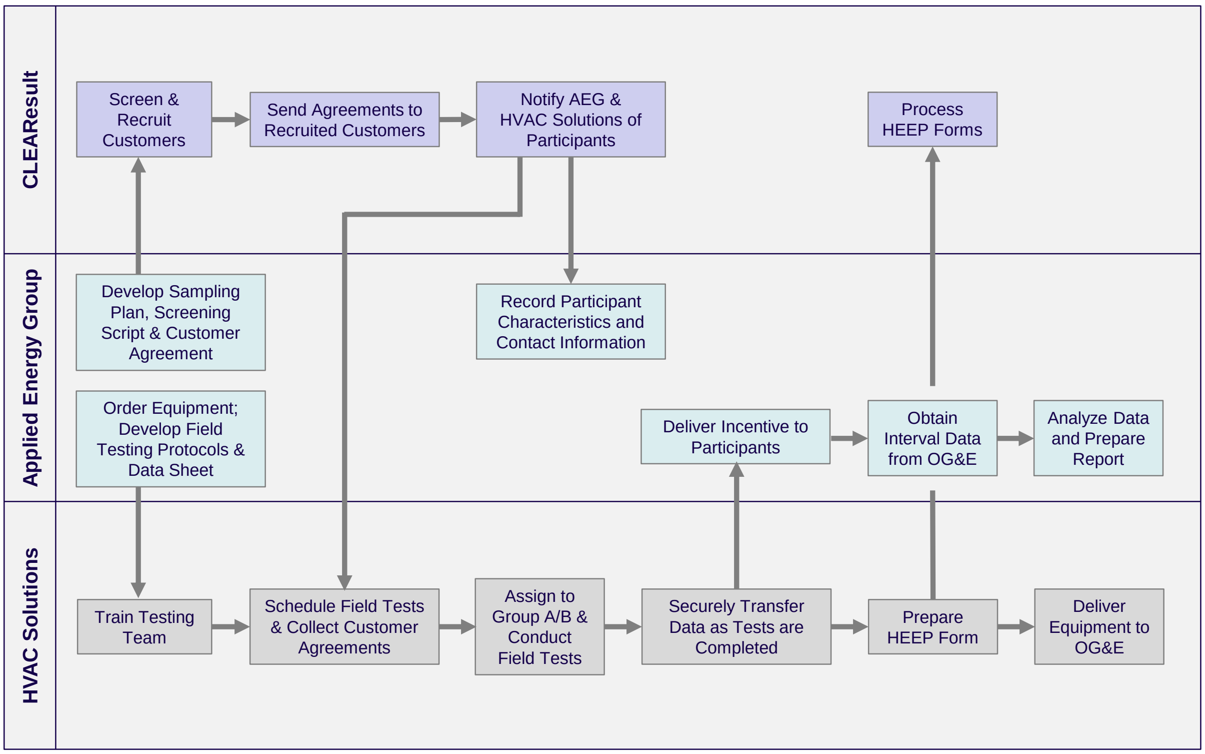

Figure 2. Field Data Collection Responsibilities and Logistics

AEG designed the study, provided hardware, plans, and technical oversight during the field work, analyzed the results, and developed project reports. AEG also delivered incentives to study participants on behalf of OG&E.

CLEAResult screened and recruited study participants and processed program paperwork submitted by HVAC Solutions. AEG provided CLEAResult with a sampling plan, screening script, and customer agreement form as discussed in the next subsection.

HVAC Solutions implemented the HVAC maintenance measures as well as the data logging, spot measurements and other onsite data collection described in the subsections below. AEG provided HVAC Solutions with the data logging hardware, a data collection protocol document that contained detailed instructions for HVAC Solutions to follow during each visit to the customer's home, and a Field Data Collection Form for the purpose of recording the spot measurements and other data collected while onsite.

Sampling Plan and Eligibility Criteria

A traditional sample design was not possible for this study since the pool of potential HEEP participants was not known in advance. Therefore, AEG had CLEAResult follow a randomized approach to assign participants to the sample as they signed up to participate in HEEP. The goal was to have 50 homes assigned to the sample and a total of at least 50 AC systems. In the end, 47 participants representing 52 AC systems completed the study.

CLEAResult called customers on the potential participant list to screen for eligibility to participate in the study using a screening script provided by AEG. One intention of the screening process was to disqualify customers who would be participating OG&E's SmartHours Price Plan during the study period. SmartHours is a Variable Peak Pricing (VPP) program that encourages customers to reduce usage during peak hours from 2 to 7 PM on summer weekdays. It also provides some customers (on an opt-in basis) with a programmable communicating thermostat (PCT) that is set to respond by changing the thermostat set-point during on-peak hours based on the price signals it receives (these are referred to as VPP+ customers). Therefore, since SmartHours participation affects AC system usage, AEG recognized that including SmartHours customers in the study would complicate analysis of the field data. However, 35 SmartHours participants were inadvertently accepted for the study due to a misunderstanding of the screening process; 30 of these participants were VPP+ customers. AEG did not know those SmartHours customers were recruited for the study until after the field work was complete.

Field Measurements and Observations

AEG instructed HVAC Solutions to perform data logging and spot measurements and to collect measure-specific information during the course of the field work. One of their first tasks while onsite was to assign the participant's AC system(s) to either Group A or Group B based on the visual inspection of the evaporator coil condition. Coils with ≥30% blockage were assigned to Group A and coils with < 30% blockage were assigned to Group B, until Group B filled up; then, the remaining were placed in Group A.

Data Logging. For both Group A and Group B, HVAC Solutions installed temporary data loggers to record the current (amperage) drawn by the outside AC compressor and condenser fan. This installation required one 5-50 A split core AC current transformer (CT) feeding into one weatherproof data logger. AEG selected the HOBO U12-008 data logger manufactured by Onset Computer Corporation for this purpose.

For Group A, HVAC Solutions installed a kWh monitoring kit to directly log the energy usage of the evaporator fan. AEG selected a monitoring kit consisting of a HOBO UX90-001 data logger, a 0.2-20 A split-core CT, and a voltage lead kit feeding into a kWh transducer (T-WNB-3D-240) for this purpose. For Group B, the team used a motor runtime logger (HOBO UX90-004) to log the on/off status and runtime of the evaporator fan.

For all data logging equipment, the data recording interval was five minutes. The data loggers remained in place for the entire data collection period at each customer's home, but HVAC Solutions checked the loggers and downloaded the data to a laptop during each visit to the home.

Spot Measurements. HVAC Solutions took spot measurements of system voltage (V), current (A), real power draw (kW), apparent power (kVA), and power factor (PF) of the evaporator fan and compressor/condenser fan. For Group A, the spot measurements were taken twice – once at the beginning of testing (when data loggers were deployed) and once at the end (after refrigerant charge adjustment). For Group B, spot measurements were taken three times – during Step 1 (when data loggers were deployed), Step 4 (after evaporator coil and fan blade cleaning), and Step 5 (after refrigerant charge adjustment). AEG used the spot measurements collected by HVAC Solutions in conjunction with the data from the data loggers to calculate the power draw (kW) and energy use (kWh) for each of the system components.

Measure-Specific Data Collection. HVAC Solutions recorded measure-specific information to identify the measures performed and to assess the condition of the central AC equipment:

- Group assignment (Group A or Group B)
- List of specific measures performed at each home, including dates
- Qualitative indication of the dirtiness of the condenser unit before cleaning
- Qualitative indication of the dirtiness of the filter before replacement
- Qualitative indication of the dirtiness of the fan blades before cleaning
- Estimate of the percentage level of evaporator coil blockage before cleaning

Field Data Analysis Methods

Data Preparation

Field data preparation began with "cleaning" and processing the logger data according to the following steps:

- Removed any problematic data, for example, due to failure of loggers during testing.
- Aligned data to consistent 5-minute intervals.
- Tabulated 5-minute current (A) readings for the compressor/condenser fan units and converted them to 5-minute demand (kW) data using the spot measurements of voltage (V) and power factor (PF).
- Tabulated 5-minute kW and energy (kWh) readings for the Group A evaporator fan units directly from the logger data.
- Converted runtime readings for the Group B evaporator fan units into 5-minute "on" (1) or "off" (0) status. Then, converted to 5-minute kW data using spot measurements of kW from each fan.
- Calculated 5-minute kWh data by multiplying each 5-minute kW data point by 5/60. (This step was automatically done for the kW meters on the Group A evaporator fan units.)
- Determined the maximum kW and average kW during the peak hour of 4-5 PM for each day in the testing period.
- Aggregated the 5-minute kWh data into daily kWh values for each day in the testing period.
- Eliminated the logger installation and removal days, since there was only partial day data on those days.

Other data preparation steps were as follows:

- Identified dates of maintenance steps for each participant.
- Estimated daily cooling degree day (CDD) values (base temperature = 65˚F) during the actual testing period by averaging daily CDD values from weather stations at three Oklahoma City airports: Will Rogers World Airport, Tinker Air Force Base, Wiley Post Airport.[1]
- Estimated average daily CDD value for a normal weather year by dividing the monthly normal CDD values for Oklahoma City by the number of days in each month for June through September.[2]

Analysis of Energy and Demand Trends

AEG studied the logger data for the evaporator fan units and the compressor/condenser fan units to look for trends in energy use, peak demand, and power draw. The data was analyzed as a function of time, CDD, and maintenance steps. This investigation included looking at the data for all participants as a whole as well as for subgroups of participants. Understanding the general trends helped inform the regression analysis approach, including the selection of appropriate variables for the models. Figure 3

[1] Daily CDD data obtained from www.degreedays.net.
[2] Normal monthly CDD data came from http://ggweather.com/normals/cdd.html and was derived using 1981-2010 weather data.

shows an example of one of the plots AEG made to examine the relationship between CDD and power draw for one of the participants.

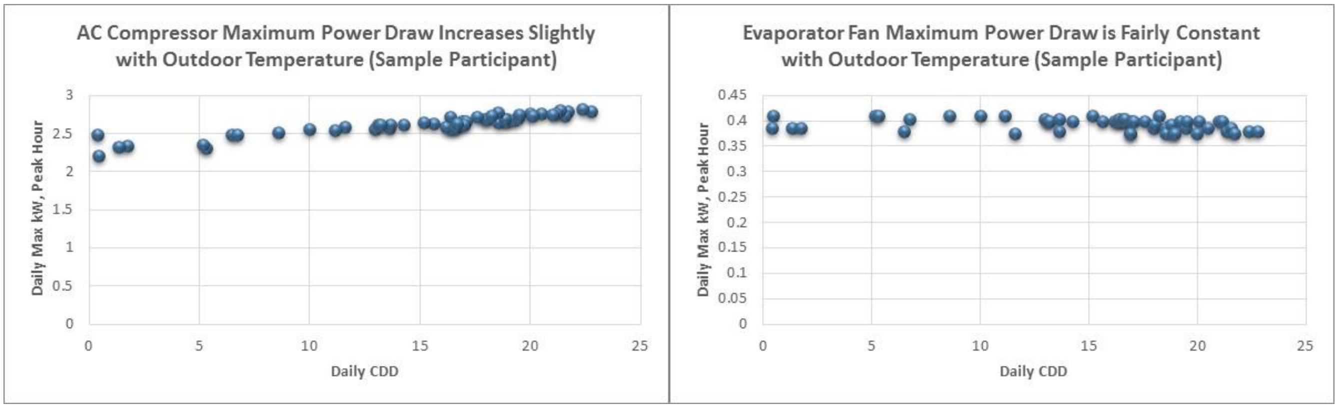

Figure 3. Power Draw during Peak Hour (4-5 PM) vs. Daily CDD (Sample Participant)

Analysis of Energy and Demand Savings

To analyze energy impacts from the maintenance measures, AEG used logger data and statistical regression analysis to estimate how different factors (independent variables) influence energy use (dependent variable). AEG developed four regression models, one for each dependent energy use variable: 1) Group A evaporator fan unit; 2) Group A compressor/condenser fan unit; 3) Group B evaporator fan unit; and 4) Group B compressor/condenser fan unit. The types of independent variables investigated for each model are as follows:

- Maintenance steps
- Current weather
- Previous day's weather
- SmartHours price days
- Customer-specific effects

The regression analysis process looks at the relationship between the dependent variable and the independent variables and returns estimates of the coefficients for the dependent variables and uncertainty or error (indicating statistical significance) of those variables. The result is a mathematical function (model) that predicts how the dependent variable is related to the independent variables.

For each of the four models, the analysis approach included the following steps:

- **Compiled participant data and weather data into a database**: Input consisted of daily logger data, daily weather data, dates of maintenance measures, dates corresponding to SmartHours pricing and events, and other participation features.
- **Created variables and indicators in the database**: Some of the independent variables investigated related to participation in the study, and others did not. Conceptually, information not related to participation went into the model to estimate the baseline energy use, while the participation variables were used to estimate impacts from the maintenance measures.
- **Tested all the individual variables for statistical significance**: One-by-one, AEG removed variables that were not statistically significant, so they did not significantly influence energy use.
- **Selected the most appropriate model for each dependent variable**: To make the savings estimates more stable and consistent, AEG kept the structure of the model consistent across variables related to baseline energy use and each maintenance step. For example, this included interacting the baseline and maintenance step variables with CDDs so that the model quantifies

the relationship between energy use and temperature as well as the relationship between savings from the maintenance measures and temperature.

- **Applied the model to calculate impacts**: AEG applied the model and coefficients to estimate baseline energy use and savings impacts from the maintenance measures for the actual analysis period and for different scenarios (e.g., actual weather, normal weather).

AEG fit the models with the actual CDDs encountered in Oklahoma City during the testing period, and then applied the model to the CDDs in a "normal" cooling season to estimate energy use and savings that would occur during a normal weather year.

Interval Data Collection and Analysis

In parallel to the field data collection, AEG also obtained 15-minute interval meter data from OG&E for all the participants of the study for the timeframe corresponding to the field data collection period.

Data Preparation

There were three main steps to prepare the smart meter interval data for analysis:

- Downloaded 15-minute interval data for the study participants during the study timeframe.
- Removed clearly erroneous data, such as spikes that were more than 20 times adjacent intervals.
- Aggregated 15 minute data to create daily kWh data.

Analysis of Daily Energy Impacts

The method used to analyze savings with daily interval data is similar to the regression analysis process described for the field data model. The only differences in approach are as follows:

- Used daily interval data instead of daily logger data as the dependent variable.
- Created two models: one for Group A participants and another for Group B participants.

Runtime Analysis

A secondary objective of the study was to assess the feasibility of estimating HVAC equipment runtimes from 15-minute interval data collected from the customers' smart meters. The goal was to compare smart meter data with logger data to determine whether interval meter data would provide the level of resolution needed to detect changes in the runtimes of the HVAC system resulting from the maintenance measures. However, AEG was unable to detect changes in runtimes between the maintenance measures using the logger data since the changes were so small, especially relative to changes due to other factors (occupancy, temperature, SmartHours price day, etc.); therefore, being able to detect the changes in the 15 minute interval data was determined to be impractical. Instead, AEG used the smart meter interval data to help validate findings from the logger data.

Energy and Demand Savings

AEG tested and used numerous model specifications to analyze energy and demand savings. AEG analyzed impacts for individuals, subsets of participants, Group A and Group B separately, Group A and Group B together, maintenance steps separately, and maintenance steps together. This section presents the analysis results achieved for all participants using logger data.

Energy Savings

Table 1 and 2 summarize the results of the regression analysis using logger data for the Group A and Group B participants, respectively. The daily kWh savings presented for each measure are the average incremental savings relative to the prior step. The percentage savings are all relative to the average baseline energy use. AEG calculated these results using the average daily CDD value for June through September in a normal weather year (CDD = 14.55) and using the overall distribution of price days encountered during the study period as a proxy for price days during a "normal" year.[3]

Table 1. Average Daily Energy Savings Estimates for Group A

Group A	Baseline Daily Use	Step 1: Evaporator Coil & Fan Blade Cleaning			Step 2: Plenum Seal & Duct Repair			Step 3: Condenser Coil Cleaning & Filter			Total Savings
		Daily Use	Incr. Savings	% Base-line	Daily Use	Incr. Savings	% Base-line	Daily Use	Incr. Savings	% Base-line	
	(kWh)	(kWh)	(kWh)	(%)	(kWh)	(kWh)	(%)	(kWh)	(kWh)	(%)	(%)
Evaporator	4.66	4.94	-0.29	-6.1%	4.88	0.07	1.4%	4.90	-0.02	-0.5%	-5.2%
Comp/Cond	29.65	28.97	0.68	2.3%	30.37	-1.40	-4.7%	28.06	2.31	7.8%	5.4%
Total	**34.30**	**33.91**	**0.39**	**1.1%**	**35.24**	**-1.33**	**-3.9%**	**32.96**	**2.29**	**6.7%**	**3.9%**

Table 2. Average Daily Energy Savings Estimates for Group B

Group B	Baseline Daily Use	Step 1: Condenser Coil Cleaning & Filter			Step 2: Plenum Seal & Duct Repair			Step 3: Evaporator Coil & Fan Blade Cleaning			Total Savings
		Daily Use	Incr. Savings	% Base-line	Daily Use	Incr. Savings	% Base-line	Daily Use	Incr. Savings	% Base-line	
	(kWh)	(kWh)	(kWh)	(%)	(kWh)	(kWh)	(%)	(kWh)	(kWh)	(%)	(%)
Evaporator	6.18	6.22	-0.04	-0.6%	6.41	-0.19	-3.0%	6.17	0.24	3.9%	0.2%
Comp/Cond	25.70	24.39	1.32	5.1%	26.67	-2.28	-8.9%	24.99	1.67	6.5%	2.8%
Total	**31.89**	**30.61**	**1.28**	**4.0%**	**33.08**	**-2.47**	**-7.8%**	**31.16**	**1.91**	**6.0%**	**2.3%**

The tables show that the regression analysis yielded some savings, but the magnitudes are smaller than expected. Based on the literature review of HVAC maintenance measures, AEG expected savings on the order of 5% for the evaporator coil and fan blade cleaning step, 15-30% for the plenum seal and duct repair step, and 5% or higher for the condenser coil cleaning & filter replacement step. (The discrepancy is particularly high for the plenum seal & duct repair step, which shows savings of -3.9% for Group A and -7.8% for Group B. However, plenum seal and duct repair savings were not the focus of the study.)

The evaporator coil & fan blade cleaning step shows energy savings of 1.1% for Group A and 6.0% for Group B. Because Group A participants had greater evaporator coil blockage, the energy savings for this step are expected to be higher for Group A than for Group B. AEG looked at Group A participants with evaporator coil blockage of ≥30% separately to better understand this finding. After completing this analysis, AEG found a lack of statistically significant energy savings for the evaporator coil & fan blade cleaning step for the subgroup of ≥30% blocked evaporator participants. Furthermore, Figure 4 shows it is very difficult to "visually detect" savings in the plot of average daily kWh values for participants with ≥30% evaporator coil blockage as a function of daily CDD for each step in the field testing, which helps validate the lack of energy savings found during the regression analysis. (The lines shown in Figure 4 are linear fits of the data for each step; they are not the results of the multi-variable regression analysis.)

[3] The average daily CDD value for a normal weather year was obtained by dividing the monthly normal CDD values for Oklahoma City by the number of days in each month for June through September. The normal monthly values came from http://ggweather.com/normals/cdd.html and are derived using 1981-2010 data.

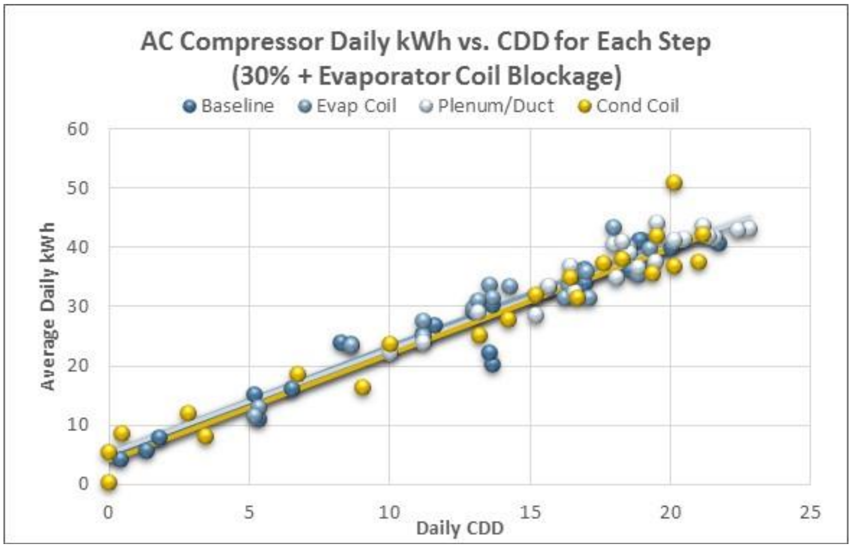

Figure 4. Compressor/Condenser Unit Daily kWh vs. CDD for Each Maintenance Step

The reason for the lack of energy savings for the evaporator coil & fan blade cleaning step for these ≥30% blocked evaporator participants is unclear. Theoretically, the total power draw (kW) may increase after cleaning blocked evaporator coils because 1) fan power increases at higher airflow, and 2) compressor power may increase since the refrigerant has to absorb more heat from a higher flow rate of air passing through the evaporator. Nevertheless, AEG expected the runtime of these AC systems to reduce after cleaning because of the better airflow and improved cooling capacity, in turn yielding a reduction in energy use (kWh). However, it may be possible that increases in power draw outweigh the runtime reductions. This effect may be especially pronounced in systems where the evaporator coil is oversized. Behavioral aspects might also be coming into play. Because this study did not directly control for customer behavior, the analysis does not necessarily compare apples to apples when it comes to the environment in the home before and after the measure. In some of these extreme cases, the customers may have been putting up with less comfortable conditions, but similar runtimes, during the baseline period. There may also be other physical phenomena occurring. For example, even though the analysis accounts for current day and previous day weather effects, the weather during the baseline period for this subset of customers was on average a little cooler (CDD=13.4) than during the two weeks after the evaporator maintenance step (CDD=14.2), and this different weather may influence energy use in different ways than those captured in the model.

In terms of the Group B savings for this step, AEG hypothesizes that "bleeding" of the savings from the earlier plenum seal & duct repair may have occurred in the modeling process, since Group B customers did not have substantially blocked coils (average observed blockage was roughly 8% for Group B). Bleeding of the savings could result from different weather mixes and VPP Price day combinations during the various steps, even though the models try to account for weather by using current day and previous day CDD variables and they also try to account for and remove Price day effects. For example, since temperatures were on average higher during the two weeks after the plenum seal & duct repair step (CDD=18.3) than during the rest of the study period (CDD=13.6), the models may have trouble capturing the plenum seal and duct repair savings at the appropriate time due to the high temperatures and greater overall energy use; instead, the savings may be bleeding into the evaporator coil step when the temperatures and energy use lowered again.

The condenser coil cleaning & filter replacement step shows savings of 6.7% and 4.0% for Groups A and B, respectively. These savings are more in line with expectations and more consistent between the groups than the savings for the other maintenance steps. However, the fact that savings are larger for Group A may also indicate some bleeding of savings from the plenum seal & duct repair step into the Group A condenser step.

Overall, the analysis resulted in average total savings across all measures of 3.9% for Group A and 2.3% for Group B. These percentages equate to average total kWh savings per AC system in the range of 88-165 kWh during the four-month period of June 1 to September 30 in a normal weather year. Because of the large proportion of SmartHours participants and possibility of misallocation of savings due to bleeding across different maintenance steps, AEG does not have high confidence in the absolute magnitudes of the savings; nevertheless, the trends are informative.

Demand Reduction

AEG analyzed peak demand impacts resulting from the maintenance steps by examining changes in the average kW measured each day with the loggers during the peak hour of 4-5 PM. The analysis was carried out for Group A and Group B using regression models that account for (and remove) effects of SmartHours participation on peak demand savings. In the end, no statistically significant savings were detected for the analysis of Group A participants. The analysis of Group B participants resulted in peak demand savings of 11% for the condenser coil cleaning & filter step, -10% for the plenum seal & duct repair step, and 5.5% for the evaporator coil & fan blade cleaning step. Due to the large percentage of SmartHours participants in the study, AEG does not have high confidence in the magnitudes of the peak demand savings results even though SmartHours effects were addressed in the models.

Runtime Analysis

One goal of the study was to see if changes in AC runtime due to the maintenance steps would be discernable from the smart meter 15-minute interval data. Once AEG started analyzing the logger data, it soon became apparent that it was not going to be feasible to accurately detect changes in runtime due to the maintenance measures using the smart meter data because the changes were so small (and hard to detect even with the logger data). However, to more completely address the runtime question (specifically, the question of how well the smart meter data maps to the logger data), AEG carried out additional "visual" analysis for representative participants. For each of these participants, AEG plotted and compared the 5-minute instantaneous kW readings from the logger on the compressor/condenser unit with the 15-minute kW readings from the smart meter data. Figure 5 shows an example of the plots made for a SmartHours VPP+ participant on a Standard price day between 6 AM and 6 PM.

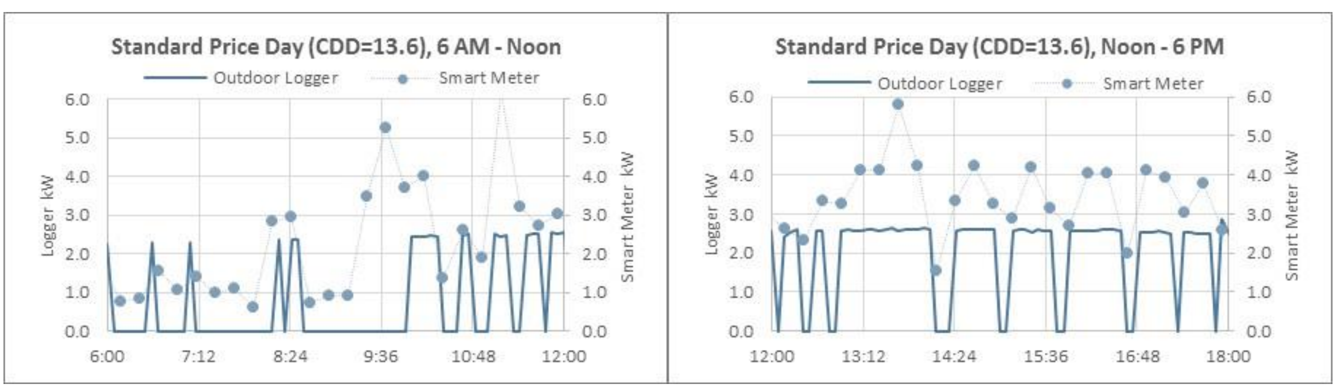

Figure 5. Comparison of Logger and Smart Meter kW Results (Standard Price Day)

Because so much short-interval AC system cycling is going on throughout most of each day, it is very challenging to ascertain the runtimes using the smart meter data. Analyzing the spikes in demand, their duration, and their magnitudes (magnitudes would be needed for spikes that last only one interval) would give approximate values of AC runtime. However, there would be a lot of error because: 1) the resolution in the 15-minute data is just too low, and 2) other end-use equipment also causes spikes.

This analysis shows that smart meter data does track with AC system runtime because of the large influence of AC energy use on whole-home demand. But, it also confirms AEG's conclusion that accurately detecting changes in runtime due to maintenance measures would be unfeasible for individual customers (or small samples of customers) because of the relatively low resolution of smart meter data. Moreover, using smart meter data in conjunction with limited spot measurements of AC system power draw (instead of logger data) would neglect to capture directly the influence of cooling load (weather) on compressor/condenser power draw. However, analysis of smart meter data to measure small impacts for very large samples of customers over longer timeframes is possible, as AEG has demonstrated during past evaluations of behavioral program.

Key Findings and Conclusions

Energy and Demand Savings

Results from the energy and demand savings analysis show the following trends:

- **Overall Savings**: The energy and demand savings detected during the analysis are lower than expected. This was a consistent finding across all models tested. In addition, visual inspection of the data corroborates this since savings were not visually detectable in the logger data.
- **Evaporator Coil & Fan Blade Cleaning Savings**: Overall, the energy and demand savings were inconclusive due to the small sample size (only 10 evaporator coils had blockage of at least 30%). But, the results did indicate that savings for the evaporator coil measure are very small or non-existent. This finding was supported by analysis of the subgroup of participants with ≥30% blockage. Possible explanations for the lack of measurable savings include behavioral changes, oversized coils, or other physical phenomena. Analysis with a larger sample size would be needed to estimate impacts more definitively.
- **Plenum Seal & Duct Repair Savings**: The energy and demand savings were substantially lower than expected for this maintenance step, and savings were actually negative in many of the models AEG investigated. Some of the savings may be bleeding into the other maintenance steps and then being attributed to the wrong measure. There is also the possibility that some of the plenum seals and duct repairs were performed on systems with plenums and ducts in relatively good condition. Note that plenum seals are typically performed for SmartHours VPP+ customers when they receive their PCTs. Since 30 of the participants for this study had received PCTs, their plenums were likely recently sealed.
- **Condenser Coil Cleaning & Filter Replacement Savings**: The logger models consistently detected energy savings for the condenser coil cleaning step for both Group A and Group B, indicating that measurable savings are present for this maintenance action. There was also an indication of peak demand savings since Group B had statistically significant savings for this step as did the subset of non-SmartHours participants. In addition, the power draw analysis suggested a power draw reduction for Group A participants. Nevertheless, the demand impacts were not as consistent or conclusive as the energy impacts.

Runtime Analysis

Detection of changes in HVAC equipment runtimes in smart meter interval data due to maintenance actions proved impractical. Changes in runtime were very difficult to detect even in the 5 minute logger data due to dispersion in the data, variability in weather throughout the study period, effects of price days, and the small magnitudes of savings. Therefore, detection using 15 minute whole home data was all the more challenging. In AEG's review of the literature, most techniques to disaggregate end-use data use dynamic approaches with small intervals such as 30 sec or 1 min.