An M&V Protocol to Evaluate Savings from Rooftop Units – At Last!

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ABSTRACT

Several U.S. utilities use packaged rooftop unit (RTU) servicing programs to acquire energy savings by improving unit efficiency and performance. Engineering estimates and billing analysis have been used with limited success to measure effects of the servicing. More recently, evaluators have used short-term data-logging on individual RTUs to more directly measure the baseline and post-servicing energy usage. We calculate energy savings by extrapolating pre- and post-servicing energy usage to an annual number and subtracting one from the other.

As more utilities adopt these programs and seek to devise their own measurement and verification (M&V) methodologies, we find that accurate analysis hinges on several key questions: how long should we data-log units before and after servicing? Does it make a difference if monitoring occurs in June or July? The Regional Technical Forum (RTF) in the Pacific Northwest formed a subcommittee in 2005 to answer these questions. Initial research throughout the country found several examples of complex research-level monitoring, but it did not uncover a fully developed methodology to apply economically to many units, as a program evaluation requires.

To accurately quantify savings, we need a protocol that ensures proper data collection, and we need a methodology to calculate savings. This RTU M&V protocol needs to extrapolate energy usage from short-term monitoring to normalized annual consumption such that it is possible to develop program-wide savings estimates with 90% confidence and 10% precision. This protocol must minimize costs to ensure a cost-effective program. BPA, in collaboration with RTF subcommittee members, has developed such an M&V protocol. Here, we present our findings on this M&V protocol.

Introduction

Packaged rooftop unit (RTU) servicing programs provide a means to acquire energy savings by improving efficiency and performance of these units. RTU servicing measures include: fixing economizers (damper linkage, sensors, and controllers), adjusting refrigerant charge, cleaning coils, adjusting system and economizer airflow, and upgrading controls (including thermostats).

In 2008 and 2009, the Bonneville Power Administration (BPA) funded pilot projects to study cooling energy savings achieved through RTU servicing. During the Summer 2009 pilot, 150 units were monitored and serviced at a total of 41 sites in the Puget Sound area (Seattle City Light and Snohomish PUD), and in the Tri-Cities area (Benton PUD, Columbia REA, Franklin PUD, and the City of Richland). Under contract with BPA, The Cadmus Group Inc. (Cadmus) conducted all monitoring and analysis.

At the conclusion of monitoring, additional follow-on work was identified to extend the existing project. Seven sites, consisting of 25 units, were selected for long-term metering for a full year, beyond the two-week short-term metering that was performed in the pilot. Examination of these annual data sought to achieve the following goals:

- Quantify and evaluate persistence of savings from 2009 pilot servicing for a one-year period.
- Suggest refinements for savings estimates by analyzing building characteristics, whole-building energy use data and annual RTU energy usage.
- Verify and refine previous versions of annual energy calculations, and measurement and verification (M&V) protocols.

This study determined how well annualized energy calculations from short-term metering predicted actual annual energy usage. Revised calculation outputs were used to inform an M&V protocol for the time of year and duration each unit should be metered to capture sufficient data to achieve the most accurate extrapolations to actual annual usage. Impacts of quarterly servicing and thermostat settings on fan operation and energy usage also proved to be of particular interest, as these two variables potentially could significantly influence realized energy savings.

On-Site Data Collection

From November 2009 to January 2011, 25 RTUs with electric cooling, gas heating, and economizers were monitored in the Puget Sound and Tri-Cities areas. Cooling capacities ranged from 3 to 20 tons, with a median size of 5.5 tons. Data collected in the field included nameplate information such as RTU types, ages, manufacturers, model numbers, and capacities. Field engineers also measured instantaneous supply fan power and compressor power. The following parameters were monitored on all units at one-minute intervals:

- Total unit power;
- Supply air temperature; and
- Outside air temperature (OAT) and relative humidity (one sensor per site).

Annual Energy Estimates

The project sought to evaluate the reliability of extrapolating short-term (two- to four-week) metered data, captured during a portion of the cooling season, to annualized energy estimates. This required fairly precise estimates of total energy used by each unit over the year, as these values represented targets for each extrapolation.

Units' annual energy consumption was based on data from a calendar period spanning 10, 15, 21, or 28 days during the cooling season. First, fan energy was computed from fan power (kW) and fan duty (the percentage of time, on average, the unit operated). Daily fan energy was then fan power (kW), multiplied by fan duty (percent) and by 24 hours per day, assuming unvarying year-round operation.

An equation for compressor energy usage was derived, assuming a linear relationship between total daily energy and outside air temperature. The balance point temperature was then the intersection between the fan energy line and the compressor energy line. An iterative approach was used to ensure the model fit the data.

The study sought to obtain annual energy estimates based on typical unit operation. This required examining all data outliers for each unit, and making a determination as to whether the outlier presented evidence of a recurring event (in which case, its energy impact should be annualized) or a one-time anomaly (in which case, it might be best to eliminate the observation).

Measurement and Verification Methodology

An M&V methodology should specify at what point in cooling season units should be metered and for how long units should be monitored to capture sufficient data to estimate annual energy usage. This section first reviews the energy signature model used to calculate annual energy, and then discusses the M&V protocol elements.

Energy Signature Model. An RTU's fan runs anytime the RTU runs, but the compressor provides mechanical cooling, and only runs as needed. Cooling and fan energy are plotted as a function of average daily outside air temperature; as shown in Figure 1, this is a unit's *energy signature*. The minimum energy a unit uses on a given day is the *fan energy*, and is represented by the horizontal line of points. Days with some compressor cooling are represented by points with a positive linear slope. On warmer days, when both the fan and compressor operate, the unit's total daily energy increase as outside air temperature increases. The *balance point temperature* is the intersection of the fan energy and fan with compressor energy lines.

Annual RTU electric energy is calculated from this signature, using typical meteorological data to annualize consumption. Minimum daily energy usage is driven by fan energy for all days where average OAT fell below a unit-specific balance point temperature.

Above the balance point temperature, compressor energy also adds to daily electric energy consumption.

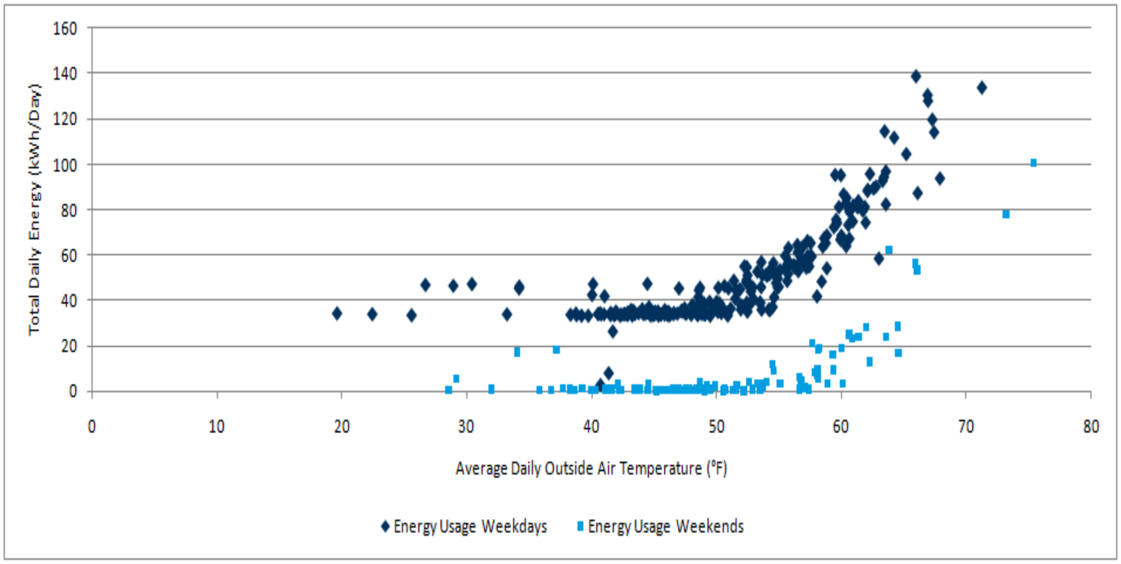

Figure 1. Example RTU Energy Signature

The unit in Figure 1 has two signatures, as it was operated differently on occupied and unoccupied days. This unit's weekend (unoccupied) observations have been plotted as light blue squares, and weekday (occupied) points have been plotted as dark diamonds. This unit's thermostat was set to a higher cooling setpoint temperature on weekends, and the fan was set to operate only as needed (rather than continuously). This control strategy reduced energy usage on unoccupied days in two ways. First, it lowered the fan energy, because the fan operated less. Second, it allowed the RTU to run less frequently as its higher setpoint temperature was above that on occupied days when the unit did not need to provide as much cooling. In some cases, setbacks eliminated compressor energy on unoccupied days.

Refinements to the Annual Energy Calculation. This analysis initially used the same algorithm utilized to calculate savings in the Summer 2009 pilot study. During the course of this analysis, the approach was refined, with three key calculation elements modified.

In the pilot study, the fan energy was first calculated from the fan power and operating times. Daily energy (kWh) was then plotted against average daily outside air temperature (°F) on a scatter plot, and the analyst selected a balance point temperature, based on a visual inspection of this graph. Next, Excel's goal seek function was used to obtain the best linear fit to the sloped portion of the energy signature. Typical meteorological year (TMY) data in 5 °F bins were used to extrapolate to annual energy usage.

In this study, the following modifications were made to the method:

- The balance point was not selected by the user, but was calculated from the data.
- An iterative method was used to find the balance point between fan energy and compressor energy.
- When units were controlled differently based on the day of the week, one signature for unoccupied days and another for occupied days were created and fit to each set of points.

The iterative approach allowed for a better model fit, and the balance point calculation reduced error previously introduced by the former manual selection process. Separate signatures ensured both operated modes were captured correctly.

Timing and Duration of Metering Period. Metering is critical to capture unit operation during the cooling season and calculate the signature's sloped portion. Fan energy can be inferred from cooling season data, even if no fan energy-only days are present, because it is driven by thermostat settings; as long as the thermostat settings remain the same, fan energy is constant throughout the year.

Many parameters need to be considered when determining at which point in the year (and for how long) metering should occur. Occupancy patterns, building loads, and climate all influence how much energy a unit will use. At milder outside air temperatures, economizers can be used to meet setpoint temperatures by opening outside air dampers to allow in outside air and using the fan to send that air into the space. At the hottest part of summer, temperatures during occupied hours are typically too high for economizer cooling; so RTU total daily energy reflects little to no economizer cooling on those days. Conversely, in the spring and fall, temperatures are much cooler, reducing or eliminating the need for compressor cooling.

It is essential to monitor both compressor and economizer cooling patterns to calculate how much energy a unit uses at the full range of cooling season temperatures. In addition, if a unit has different operating schedules for occupied and unoccupied days, enough days must be captured to understand both operating patterns.

In all three climate zones studied, the hottest part of the summer fell in the last two weeks of July and the first week of August (as Figure 2 shows for Pasco, Washington). Average daily temperatures on either side are symmetrical, following a similar slope towards the coldest temperatures in January. The other two climate zones also follow a similar pattern.

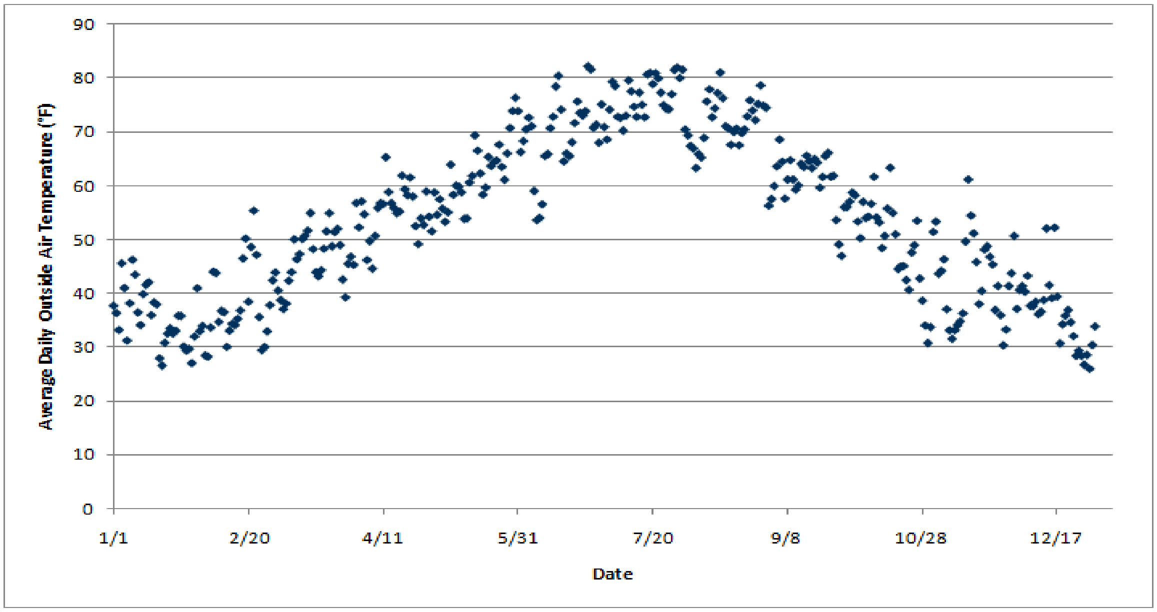

Figure 2. Pasco TMY Average Daily Outside Air Temperatures

To assess the accuracy of the annualized consumption regression methodology, short-term extrapolations of 10-, 15-, 21-, and 28-day subintervals were performed for each week beginning in April and ending in October 2010. Although TMY data typically would be used to extrapolate to annual usage from short-term metering, this analysis used the metered outside air temperatures. This provided an exact comparison for units' short-term extrapolations to their actual annual energy usage from the metered data.

Results were evaluated using the percentage of differences from actual energy usage and by the confidence interval size. A larger confidence interval meant less certainty in the predictions. The metering duration must be sufficient to capture the relatively small savings; savings found in the Summer 2009 pilot were 11 percent, on average.

The 10- and 15-day extrapolations were dismissed. Not only did regressions fail more often than in the longer extrapolations, but predicted estimates tended to be more varied and farther off from actual annual energy usage. Twenty-one day extrapolations were considered, but, because many units operate in setback on weekends, a 21-day metering period would only capture 15 days of weekday usage, rendering it effectively the same as a 15-day extrapolation.

Figure 3 shows 10-day extrapolations for a unit in Snohomish, starting at the dates shown on the x-axis, and with the lower confidence interval a red square, the upper confidence interval a green triangle, and predicted annual energy a blue diamond. The black line shows actual annual energy of 8,025 kWh. For this unit, June 20 was the first successful 10-day regression. Large confidence levels appeared in mid-summer, with the September 5th extrapolation the largest, with an upper confidence limit of 17,013 kWh. The three September regressions have not been included as they also failed.

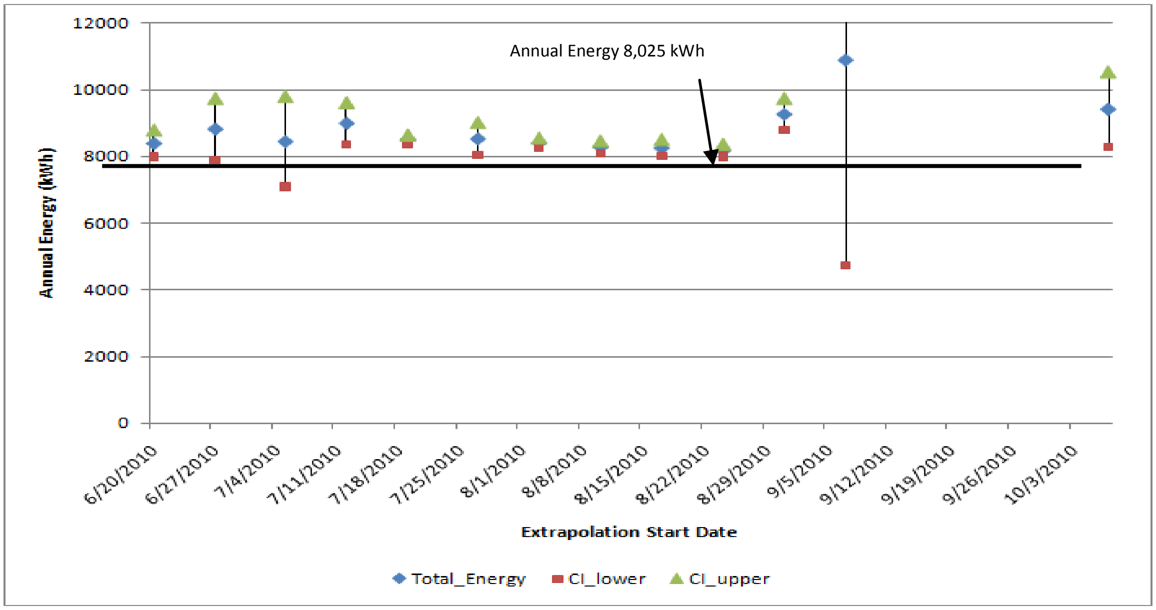

Figure 3. Snohomish Unit 10-Day Extrapolations

In comparison, Figure 4 shows 28-day extrapolations for the same unit, starting at the dates shown on the x-axis. Confidence intervals were much smaller, and many, starting with the May 29 extrapolation (not pictured), contained the actual energy usage, which again is shown with the black horizontal line. Some summer extrapolations did not capture actual energy usage in their confidence intervals; however, this does not necessarily mean the prediction was a poor one. In some cases, the confidence intervals were fairly small, and it was important to examine the percent difference between predicted and actual energy usage. All subinterval estimates, through the one starting August 24, were found to be within 10 percent of actual energy usage, suggesting these were good subintervals to use in predicting annual energy usage.

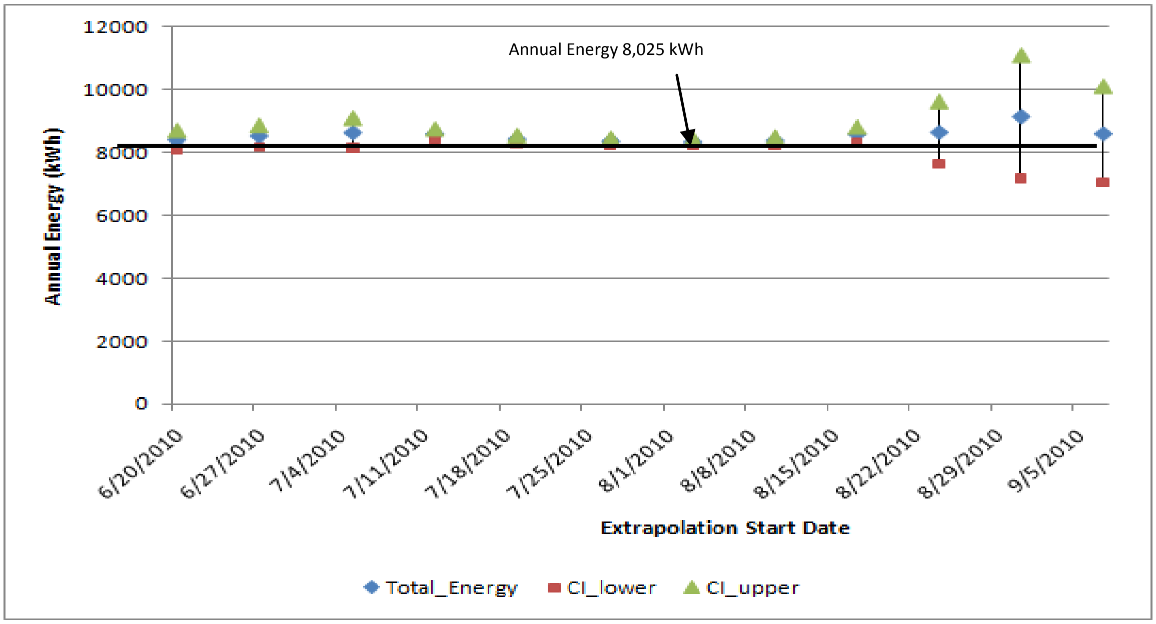

Figure 4. Snohomish Unit 28-Day Extrapolations

Similar patterns were found in other units: the 28-day extrapolations predicted well throughout the summer, within 10 percent of actual energy usage, as shown in Table 1 for Snohomish, except for one unit with two higher predictions at the hottest part of the summer. In the Snohomish units, the most accurate predictions were found when the first day of extrapolation started as early as the beginning of June, and continued for all predictions through a mid-August start date. Tri-Cities units had a longer accurate prediction period, starting early May and through an early-September start date, as shown in Table 2.

Table 1. Snohomish 28-Day Extrapolations Comparison

Extrapolation Start Date	Mean Percent Difference from Actual Energy	Minimum Percent Difference from Actual Energy	Maximum Percent Difference from Actual Energy
5/26/2010	3%	0%	7%
6/2/2010	3%	0%	7%
6/11/2010	2%	-3%	5%
6/18/2010	1%	-4%	4%
6/25/2010	0%	-7%	5%
7/2/2010	-1%	-6%	5%
7/9/2010	-1%	-34%	8%
7/16/2010	3%	-7%	15%
7/23/2010	2%	-10%	12%
7/30/2010	3%	-8%	7%

Extrapolation Start Date	Mean Percent Difference from Actual Energy	Minimum Percent Difference from Actual Energy	Maximum Percent Difference from Actual Energy
8/6/2010	3%	-3%	7%
8/13/2010	2%	-3%	10%
5/26/2010	3%	0%	7%
6/2/2010	3%	0%	7%
6/11/2010	3%	-3%	11%
6/18/2010	1%	-4%	4%
6/25/2010	0%	-7%	5%

Table 2. Tri-Cities 28-Day Extrapolations Comparison

Extrapolation Start Date	Mean Percent Difference from Actual Energy	Minimum Percent Difference from Actual Energy	Maximum Percent Difference from Actual Energy
5/12/2010	3%	0%	8%
5/19/2010	4%	-2%	10%
5/26/2010	3%	-2%	9%
6/2/2010	0%	-4%	3%
6/11/2010	0%	-3%	2%
6/18/2010	-2%	-9%	4%
6/25/2010	1%	-1%	4%
7/2/2010	0%	-8%	6%
7/9/2010	-1%	-4%	2%
7/16/2010	-1%	-7%	7%
7/23/2010	1%	-2%	5%
7/30/2010	1%	-1%	4%
8/6/2010	4%	0%	8%
8/13/2010	2%	-1%	6%
8/22/2010	1%	-5%	4%
8/29/2010	1%	-3%	3%
9/5/2010	-2%	-7%	3%

Conclusions

M&V Methodology Refinement

Changes to annualization calculations provide an improved approach because they reduce error introduced by manual interpretation of data, thus creating a better-fitting energy signature.

Twenty-eight day extrapolations provided the best estimates of annual energy usage, with predicted usage within 5 percent of actual usage, on average. The other periods were too short to accurately estimate annual energy usage, especially for units scheduling different operations on weekdays and weekends.

In the Snohomish units, the most accurate predictions were found when the first day of extrapolation started as early as the beginning of June, and continued for all predictions through a mid-August start date. Tri-Cities units had a longer accurate prediction period, starting in early May, through an early-September start date.

With this sample, building characteristics could not be isolated. The dataset contained 22 gas packs in six buildings, with six different building types and serving nine unique space types. Thus the sample was too small to determine the importance of building envelope characteristics and space types served, although these factors likely influenced usage. Fan energy, which drove annual energy usage, was independent of building characteristics; annual fan energy accounted for 67 percent of total annual energy for these 22 units.

Recommendations for an M&V Protocol

RTU monitoring provides the most robust data for calculating annual energy usage. Billing analysis methods can be used to gauge commercial savings; however, they should be used only if other, more reliable methods (such as end-use metering) are unavailable at a site.

The following M&V protocol elements are recommended to develop reliable estimates of annual RTU cooling and fan energy. This approach seeks to estimate annual energy usage, based on typical unit operations; any clearly abnormal days should not be included in the analysis. To identify abnormal days and outliers, each unit should be examined in detail to determine whether each data point represents normal unit operations.

To extrapolate a short-term interval to total annual energy usage, thermostat schedules and settings were assumed the same year-round as when observed during the metered period.

Energy Signature Model

The updated calculation model should be used to determine annualized cooling and fan energy separately for the baseline data and post-servicing data. Savings then become the difference between the two annual energy numbers.

Metering Period Length

Units should be monitored for at least 28 complete days, both before and after servicing. For units operating in different regimes, such as weekend setbacks, enough data points must be captured to understand the fan energy and balance point in each regime. This duration captures sufficient data points to understand unit operations and identify outliers.

Metering Period Timing

To achieve the highest regression estimate quality, baseline metering should be conducted before the hottest part of summer, and post-servicing metering should be conducted after the hottest part of summer. Only one metering cycle should be conducted per summer. The proposed timing ensures a dataset with both economizer and compressor cooling days. For any climate, servicing should occur in the last two weeks in July or first week in August.

For less extreme climates such as the Puget Sound area, metering equipment should be installed in the first two weeks in June. Post-servicing metering should start no sooner than the first week in August and no later than mid-August. For climates with hotter summers and colder winters more similar to the Tri-Cities area, metering equipment could be installed as early as the beginning of May, with servicing occurring in the same time frame, and post-servicing metering beginning by the end of August.

References:

The Cadmus Group, Inc. *Rooftop Unit Summer 2009 Final Report.* 2009. http://www.bpa.gov/energy/n/emerging_technology/pdf/Roof_Top_Unit_Summer_09_Final_Report_012910.pdf