

2009

BPA RTU Puget Sound Pilot



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Executive Summary

Thousands of existing commercial buildings in the USA are thermally conditioned and ventilated by small packaged rooftop air handling units (RTU). Optimizing the performance of this equipment has significant energy savings potential and can improve the indoor air quality of these buildings. During the summer of 2009, Bonneville Power Administration (BPA) and a number of partner organizations engaged in a Puget Sound area pilot to evaluate the energy savings potential of a select package of optimization services. These services are above and beyond what is normally provided as standard preventative maintenance.

The field pilot included pre- and post-service power consumption data logging, and tracking of as-found conditions and most common modifications and repairs. All service work and support of datalog equipment installation was provided by MacDonald Miller. Service quality assurance was provided by Ecotope and field project management was provided by the Northwest Energy Efficiency Council. Datalogging equipment installation and management was performed by Cadmus and EMP2.

The pilot included 120 datalogged and serviced RTUs, plus 80 RTUs that were only serviced, at a total of 46 sites. Service sites were located over a 40 mile range along the I-5 corridor within both Snohomish PUD and Seattle City Light service territories. The diversity sample included offices, banks, technology and manufacturing facilities, dental offices and a range of retail stores from small to big box.

The majority of the RTUs had received preventative maintenance, but nearly all required some level of adjustment and repairs to the items covered by this service. Since these optimization services are not routine to the industry, specialized training of technicians was required. New refrigeration cycle diagnostic equipment that is not yet prevalent in the industry was also utilized. MacDonald Miller already had experience with this equipment and so specific training was not necessary.

Services provided include two unique protocols. One focused on zone thermostats, outside air intake positions, and economizer assembly functionality. The other evaluated the performance of the refrigeration circuit(s) and included cleaning of the evaporator and condenser coils. These service protocols are referred to as Performance Tested HVAC Service (PTHVAC) and HVAC Service Assistant Tool (FDSI), respectively.

Key findings in the Puget Sound area summer pilot:

- It is important to note that trained service technicians play a critical role in making quick field judgments about where to apply limited time resources for the greatest overall benefit. Their challenge is to attempt to bring all RTUs up to a similar optimized condition when as-found conditions vary widely.
- Pre-qualifying details had to be confirmed for each RTU prior to proceeding with this protocol. The RTU had to have a fully functioning fan and motor that operates at constant volume, properly functioning compressor(s), reasonably clean filters, and healthy belts and shives. It was preferred that the RTU had an economizer assembly, although a small number of non-economizer RTUs were included in the pilot sample.

- The level of effort required to perform all the basic steps in the PTHVAC protocol is two hours. If repair items are found, the time required for these repairs is added to this two hour estimate.
- At initial inspection it is common to find the economizer assembly not functioning as designed.
- Airflow testing and adjustment is the most time consuming component of the PTHVAC protocol. Many packaged RTUs have damper linkages with limited adjustability and it can be difficult to achieve the recommended economizer full open position target of 70% outside air or greater. The average outside air position setting achieved in this pilot was 65%.
- An RTU on the roof with an economizer assembly does not necessarily have the appropriate two-stage thermostat in the space. The thermostat review component of the protocol offers service technicians the opportunity to verify something that they would not normally have the opportunity to do under a preventative maintenance program.
- It is important to note that the PTHVAC protocol represents general recommendations and it is the responsibility of the service technician to determine the best system parameters for the particular building type and customer.
- The FDSI process involves a Pre-Test or “Test In” diagnosis and a Post-Repair or “Test Out” report. Information in the report includes pre- and post- values for energy efficiency and system capacity relative to the rated performance of the RTU, and predicted annual energy cost savings.
- Using the FDSI tool the amount of field time required to diagnose, adjust and repair a refrigeration circuit is considerably variable. If “Test In” reports that no repairs are needed, the basic diagnostics can be done in one hour. If it reports that adjustments or repairs are needed, the necessary procedures often require multiple iterations that increase the amount of time required. A single RTU can take up to a full day to diagnose and repair. The average amount of time required to complete refrigeration cycle optimization using the FDSI Tool is three hours.
- The service technicians typically Pre-Test the RTUs prior to cleaning coils. This way the value of coil cleaning is captured in the Pre-Test to Post-Repair results.
- Seasonal factors include outside air temperatures and cottonwood season. FDSI testing can only be done when outside air temperatures are above 55 degrees F. Cottonwood presents a unique problem with regards to coil buildup and is very prevalent throughout the Puget Sound region. Technicians avoid servicing during this period. These two factors combined can reduce the serviceable period to July through September.
- The FDSI Tool calculates predicted annual energy cost savings based on an estimated number of annual run-time hours of the compressor(s) and the electricity cost per kWh. There is evidence in the documentation that the FDSI Tool does not calculate these cost savings based on local utility rates. This issue has been brought to the attention of FDSI Corporation.
- Although service technicians are able to diagnose the same types of refrigeration circuit problems through traditional field service techniques, in general the refrigeration cycle would have to get further out of its rated performance range before the technician could reasonably diagnose it. The FDSI Tool offers the opportunity to diagnose problems much sooner.

Although the energy saving potential of this service protocol is promising, the challenge is balancing the level of service technician effort with the expected savings. A successful incentive program is one that

will motivate building owners to request this service and adequately compensate service contractors performing this valuable work.

Packaged Rooftop HVAC Unit Service Protocol

This RTU optimization service is comprised of two service protocols. Combined they provide evaluation and adjustment of: zone thermostat setpoints, economizer operation, minimum ventilation air percentage, and refrigeration circuit operation. There are two primary goals of this protocol. One is to utilize free outdoor air for building cooling to the greatest extent feasible. When outdoor conditions are not conducive to outdoor air cooling, mechanical system cooling is required. The second goal is to optimize the performance of the mechanical cooling system so when operating it provides its rated level of energy efficiency.

There were certain pre-qualifying details and minimum preventative maintenance measures that had to be confirmed for each RTU prior to proceeding with this protocol. Otherwise the value of the protocol is diminished. The RTU had to have a fully functioning fan and motor that operated at constant volume, the compressor(s) had to function properly, the filters had to be reasonably clean, and the belts and shives could not be worn. It was preferred that the RTU had an economizer assembly, although there were a small number of non-economizer RTUs included in the pilot sample.

Performance Tested HVAC Service (PTHVAC)

The PTHVAC protocol is modeled after a packaged RTU service program offered by Puget Sound Energy called Premium Service. The primary focus is economizer system optimization. There are four main components to this protocol:

1. ***Zone thermostat evaluation and adjustment*** – There are two key details related to zone thermostat functionality. One is to confirm that the thermostat is capable of two-stage call for cooling to ensure that the system will attempt economizer cooling prior to activating the mechanical cooling system. The second is to confirm or adjust the occupied and unoccupied temperature setpoints so that the system operates within a reasonable deadband between heating and cooling. For occupied hours the optimal deadband is at least 5 degrees F. For unoccupied hours it is preferred to expand the minimum and maximum temperature range to 15 degrees F or greater.
2. ***Outside air positions*** – The minimum ventilation position and the economizer full open position are both important parameters of the economizer system. The recommended minimum percentage of outside air for ventilation is between 10-20% based on ASHRAE Standard 62 guidelines. A set of TruFlow airflow measurement plates are used to determine actual airflow. If necessary the damper positions are adjusted as nearly as feasible to the desired minimum and full open positions.
3. ***Economizer assembly evaluation, adjustment and repairs*** – All economizer assembly components are evaluated for full functionality. This includes the actuator motor, economizer controller, temperature sensors, damper linkages and seals. Components are cleaned, adjusted or repaired, or if not repairable they are replaced. One item of particular interest is dry bulb

sensor made by Honeywell that is common in the industry, but has been reported to adversely affect economizer performance due to issues inherent to the device. In all cases if the service technician finds one of these sensors within an economizer assembly it is replaced with a new Honeywell dry bulb sensor. The economizer control logic is also evaluated. The goal is to confirm or adjust the system changeover setting to 65 degrees F to ensure optimal economizer hour availability.

4. **Coil cleaning** – The protocol requires cleaning of both the evaporator and condenser coils with an environmentally friendly cleaning product.

PTHVAC Field Observations

Even when an RTU has been well-maintained through routine preventative maintenance, many of the items evaluated through the PTHVAC service protocol are often found to require at least adjustment if not repair. For RTUs that receive minimal maintenance - which is the norm in the industry for this type of equipment - it is common to find the economizer assembly not functioning as designed. Outside air dampers that are locked in a fixed position either due to mechanical failure or intentionally are a common occurrence. As are setpoint temperatures set to a minimal deadband and the economizer changeover temperature set to 55 degrees F or even lower. These parameters are often conservatively set to avoid the possibility of comfort complaints at the expense of excessive energy consumption. The intent of the PTHVAC service is to provide the necessary comfort conditions while using the least amount of energy feasible.

Time and Seasonal Factors

The level of effort required to perform all the basic steps in the PTHVAC protocol has been reported to be on average two hours. If repair items are found, the time required to do these repairs are added to this two hour estimate.

In the summer the service technicians try to perform the airflow measurements during the cooler part of the day to avoid introducing hot midday air into the building. For the same reason they prefer to avoid doing airflow testing during cold weather periods to avoid introducing cold air into the building and affecting the occupant's comfort.

Airflow testing is reported by the service technicians to be the most time consuming component of the PTHVAC protocol. This is particularly true for larger RTUs where multiple airflow plates are required to fully cover the outside air intake opening. Once the airflow plates are attached to the RTU a plate is connected to a pressure and fan flow gauge and the values are recorded. This procedure is repeated for each plate and all of the values are added together to determine the total measured outside airflow. The service technician adjusts the damper position and linkage to attempt to achieve the target outside air percentage and then re-measures the airflow. This is repeated until the outside air percentage is measured to be within the target, or it is determined that due to equipment limitations the measured percentage reached is as close to the target as feasible. This process is repeated for both the minimum ventilation position and the economizer full open position. For small RTUs that at minimum ventilation have a very low CFM, the airflow plates may not be able to read this limited airflow. In these cases, the

service technician records only the pressure and outside air temperature and then uses a table provided in the Premium Service documentation to approximate the CFM. This same calculation procedure is also used for large RTUs (over 20 tons) due to the difficulty in fully covering a large outside air intake opening with an array of flow plates.

It is important to note that the PTHVAC protocol represents general recommendations and it is the responsibility of the service technician to determine the best system parameters for the particular building type and customer. This includes deciding when the recommendations in the protocol are not appropriate. For example if the building has some type of activity that creates a high level of indoor air contaminants, such as a manufacturing facility or a veterinary clinic, the recommended minimum ventilation air percentage of 10-20% may be inadequate to maintain good indoor air quality. The service technicians are expected to spend the necessary time needed to make these determinations.

Common As-Found Conditions and Benefits of the PTHVAC Protocol

Many packaged RTUs have damper linkages with limited adjustability and a few manufacturers have damper configurations that do not have linkages at all. Service technicians report that depending on the make and model of the RTU, it can be difficult to achieve the recommended economizer full open position target of 70% outside air or greater. This is not the case of course for all RTUs, however the average outside air position setting achieved in this pilot study was 65%.

If the building has a DDC system controlling their HVAC equipment, the service technician usually cannot review or adjust the occupied and unoccupied thermostat setpoints. They can independently check the wiring at the DDC control module at the RTU to confirm that the Y1 and Y2 wiring is in place, but they cannot check the control logic to confirm that it has been programmed for two-stage cooling. The DDC user interface that the building owner or operations manager (BOM) has access to usually does not provide enough detail to confirm this either. In this situation the service technician informs the BOM of the thermostat setpoint parameters to check and adjust within the user interface. For the economizer control parameters, the service technician informs the BOM of what parameters need to be checked and/or adjusted in the DDC system control logic. Then a DDC controls contractor is hired by the BOM to make the necessary programming adjustments in the control logic.

A packaged RTU on the roof with an economizer assembly does not necessarily have the appropriate two-stage thermostat in the space. And if it does have the correct type of thermostat there is no guarantee that the thermostat is correctly wired to the economizer controller so that two-stage operation can be achieved. Service technicians reported that that the Thermostat Review component of the protocol offers them the opportunity to verify something that they would not normally have the opportunity to do under a preventative maintenance program. This level of evaluation would usually occur under the circumstance of a comfort complaint or equipment replacement.

HVAC Service Assistant Tool (FDSI)

This diagnostic piece of equipment specifically evaluates the performance of the refrigeration circuit in an RTU. If there are multiple circuits in the RTU, each circuit is evaluated separately. The tool is

comprised of several components that include a temperature sensor array, thermocouple clamps, line pressure sensors and a diagnostic Palm Pilot device. Readings from these measurement devices are evaluated by the diagnostic device, which then calculates the following performance indicators:

- differential between liquid and suction pressure
- evaporating and condensing temperatures
- supply, return and outside air temperatures
- condensing above ambient temperature differential
- evaporator and condenser temperature differentials (nominal is 20 degrees F for both)
- suction line superheat (nominal is 20 degrees F)
- liquid line subcooling (nominal is 12 degrees F)

From these indicators the diagnostic device reports the following information as the Pre-Test or “Test In” condition of the refrigeration circuit:

1. Efficiency Index – This value describes the current energy efficiency performance of the refrigeration circuit relative to what its efficiency would be if it were operating at its full rated performance.
2. Capacity Index - This value describes the current total available cooling capacity of the refrigeration circuit relative to what its capacity would be if it were operating at its full rated performance.
3. Pre-Test Diagnosis – The diagnostic device reports either that the Test In condition of the refrigeration circuit is “Acceptable” and no repair is needed, or it will give an “Alert” with a recommendation of what repairs made be needed based on the indicators.

Using all of this information provided by the FDSI Tool, the service technician provides the necessary adjustments and repairs to the system. Common adjustments and repairs include: cleaning the evaporator and condenser coils, adjusting refrigerant charge, adjusting the thermostatic expansion valve (TXV), or replacement of a non-adjustable TXV or fixed orifice type valve. Once completed the diagnostic device provides the following Post-Repair or “Test Out” condition of the refrigeration cycle:

1. Final Efficiency Index
2. Final Capacity Index
3. Realized Savings – This value describes the predicted energy cost savings (in dollars per year) that may be realized as a result of the adjustments and repairs performed.

The Pre-Test and Post-Repair information is uploaded to the FDSI website where the service technician can retrieve and print various reports about the results of the work performed.

FDSI Tool Field Observations

The FDSI Tool provides a straightforward means of diagnosing the performance of the refrigeration cycle of an RTU. The service technicians who have experience with this tool report that they find it to be an asset. There are several field details that should be noted about this process.

Time and Seasonal Factors

When using the FDSI tool the amount of field time required to diagnose, adjust and repair a refrigeration circuit is considerably variable. If the “Test In” reports no repairs are needed, the basic diagnostics can be done in as quickly as one hour. If the “Test In” reports there are problems that require adjustment or repair, a single RTU can take up to a full day to diagnose and repair. This is particularly true if the RTU has multiple compressors as each has to be evaluated separately. For this reason the estimated amount of time required to perform a complete optimization of the refrigeration cycle of an RTU using the FDSI Tool is three hours.

This diagnosis without the FDSI Tool is included in some preventative maintenance programs but is usually part of a more comprehensive package of services, not a basic package. So in either case (with or without the FDSI Tool), it represents additional field time for the contractor and additional cost to the owner. Therefore it is likely that this is a service item that is not routinely done until there is a comfort complaint.

Some of the indicators that the FDSI Tool uses to diagnose the refrigeration circuit requires outside air temperatures in the calculations. If the outdoor air temperature is less than 55 degrees F, then the resulting differentials are inadequate to provide an appropriate evaluation. Therefore in the Puget Sound region the serviceable period is limited to late spring through mid-fall.

When adjusting and testing the refrigeration circuit, the FDSI Tool requires 15 minutes of uninterrupted RTU operation to re-adjust the various parameters. Many of the testing procedures require multiple iterations that can significantly increase the amount of time required to perform the service depending on the condition of the system. So for example if the superheat is reported to be high the likely issue is low refrigerant charge. The service technician notes the superheat and subcool temperatures, adds a recommended amount of refrigerant to the system, waits 15 minutes to allow the system to rebalance, and then checks the superheat and subcool again to see if these indicators have adjusted to within the recommended range. If not, the service technician repeats this process until the desired ranges are achieved. This could involve multiple adjustments. If the superheat and subcool continue to be out of range after refrigerant charge has been added, then the issue may be a faulty TXV or some other issues that needs to be identified and repaired.

On occasion the issue within the refrigeration circuit is a blockage in the liquid or suction line. This is a more extensive repair item that is not included in the FDSI Service Protocol as it involves flushing the system of its refrigerant, disassembling and repairing various components, and then refilling this system with refrigerant.

The service technicians Pre-Test the RTUs with dirty coils. This way the value of coil cleaning is captured in the Pre-Test to Post-Repair results. There are various details that impact how the coil cleaning is performed. If the building owner has not expressed any concerns about the use of chemicals on these coils, and the coil assembly within the RTU is sufficiently accessible, the service technician will perform this cleaning as required by the PTHVAC protocol. If the owner has stated that chemicals are not to be used then the service technician uses only water, preferably with a pressure washer. On occasion they

will use a portable pressure washer when water is not available at the roof. If the coil configuration does not allow for adequate access for a wet cleaning, the service technician will at minimum clean the areas they can reach with a dry brush and pressurized air. Dry brush cleaning alone is not an adequate method.

Time of year is also a factor in coil cleaning. FDSI servicing and coil cleaning should be avoided during the cottonwood season, as this can easily negate the majority of the benefit of the service until the coils are cleaned again. The best timing is after the cottonwood season to ensure a full year of optimized performance after the service. For persistence of energy savings it is recommended to maintain a schedule of regular coil cleaning.

Additional Field Details

One limitation of the FDSI Tool is that if the refrigeration circuit cannot be adjusted or repaired to the point where the various parameters are brought within the minimum values required to be deemed “Acceptable,” then the diagnostic device will not provide a Post-Repair or “Test-Out” report. The refrigeration circuit may have been improved from its as-found condition but not enough for the tool to provide a complete Pre- and Post- report. The diagnostic device requires a 90% level of performance to Test Out.

The diagnostic device calculates the predicted annual energy cost savings based on an estimated number of annual run-time hours of the compressor and the electricity cost per kWh. If the RTU has multiple compressors, each one is assigned a unique number of annual run-time hours. It is important to note that the default settings in the FDSI Tool for run-time hours and electricity cost are for a typical office building located in California. If the default is not updated the Realized Energy Savings value reported from the FDSI Tool will not accurately reflect the local climate conditions, utility rates and facility operating hours. The service technicians report that they do input the zip code of the site into the diagnostic device prior to the Pre-Test or “Test In.” However per FDSI Corporation this step does not update the defaults. At this time it is unclear how to incorporate accurate utility and climate information in these calculations. MacDonald Miller has brought this issue to the attention of FDSI Corporation.

Benefits of the Tool

Before the FDSI Tool was available, technicians would evaluate the performance of the refrigeration cycle by checking the temperature differential across the coils, and check the superheat and subcool. Service technicians reported that although they are able to diagnose the same types of problems through this procedure, in general the refrigeration cycle would have to get further out of its rated performance range before the technician could reasonably diagnose it. The FDSI Tool offers the opportunity to diagnose problems much sooner.

Service technicians comment that they really appreciate having the ability to inform the owner of the predicted energy cost savings that may be realized as a result of the adjustments and repairs performed

immediately after completing the work. It offers a means of quickly communicating the value of the service the owner has purchased.

Pilot Schedule Information

The time period for the BPA RTU service pilot was intended to be consolidated to the following schedule for each RTU:

- Two weeks of pre-service datalogging
- A one week window to schedule and complete service
- Two weeks of post-service datalogging
- Average timeframe – 5-6 weeks

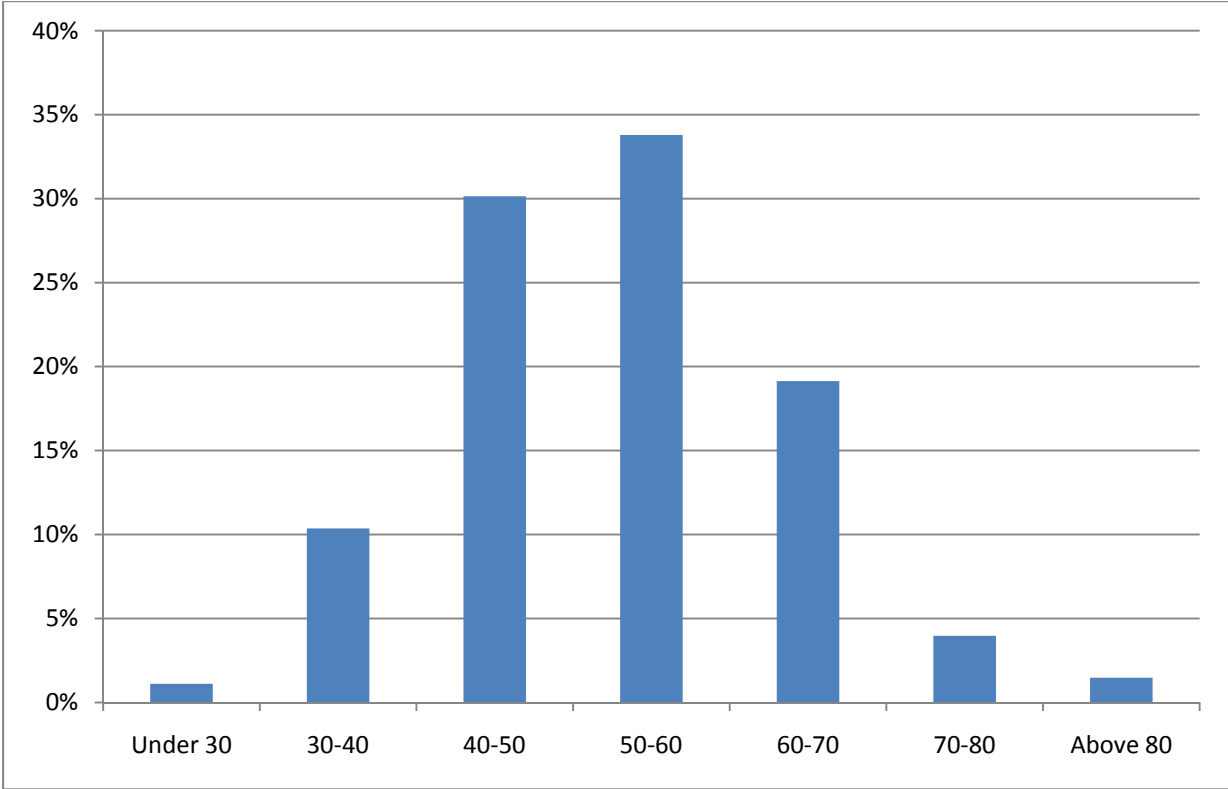
Although this schedule was achievable for many of the sites, there were several sites that required much more effort on the part of the service technicians that complicated the schedule. If during the PTHVAC and FDSI service the technician discovered issues that could not be repaired that same day, they had to make arrangements for a return visit to complete the service. If the necessary repairs were outside the list of items covered under the PTHVAC and FDSI service the technician had to notify the building owner of the added costs, wait for their approval (or in a few cases their decline), and then return to the site to complete the repairs. Lead times for parts and components that were not off-the-shelf items added to the delay. Tracking these vagaries in the schedule proved to be a challenge to all parties involved.

Another issue was the involvement of other service providers outside of the BPA RTU pilot. A few of the building owners included in the pilot either did not have preventative maintenance agreements with MacDonald Miller, or they preferred to use a different service provider for on call emergency maintenance or repairs at their facility. On a few occasions while MacDonald Miller's service technicians were attempting to perform the PTHVAC and FDSI services, they found repair issues that had to be taken care of before the PTHVAC and FDSI services could be completed. Therefore these services and post-service datalogging were delayed until the other service providers went through the process of gaining approval for the repair costs and then completing the repairs.

Conclusion

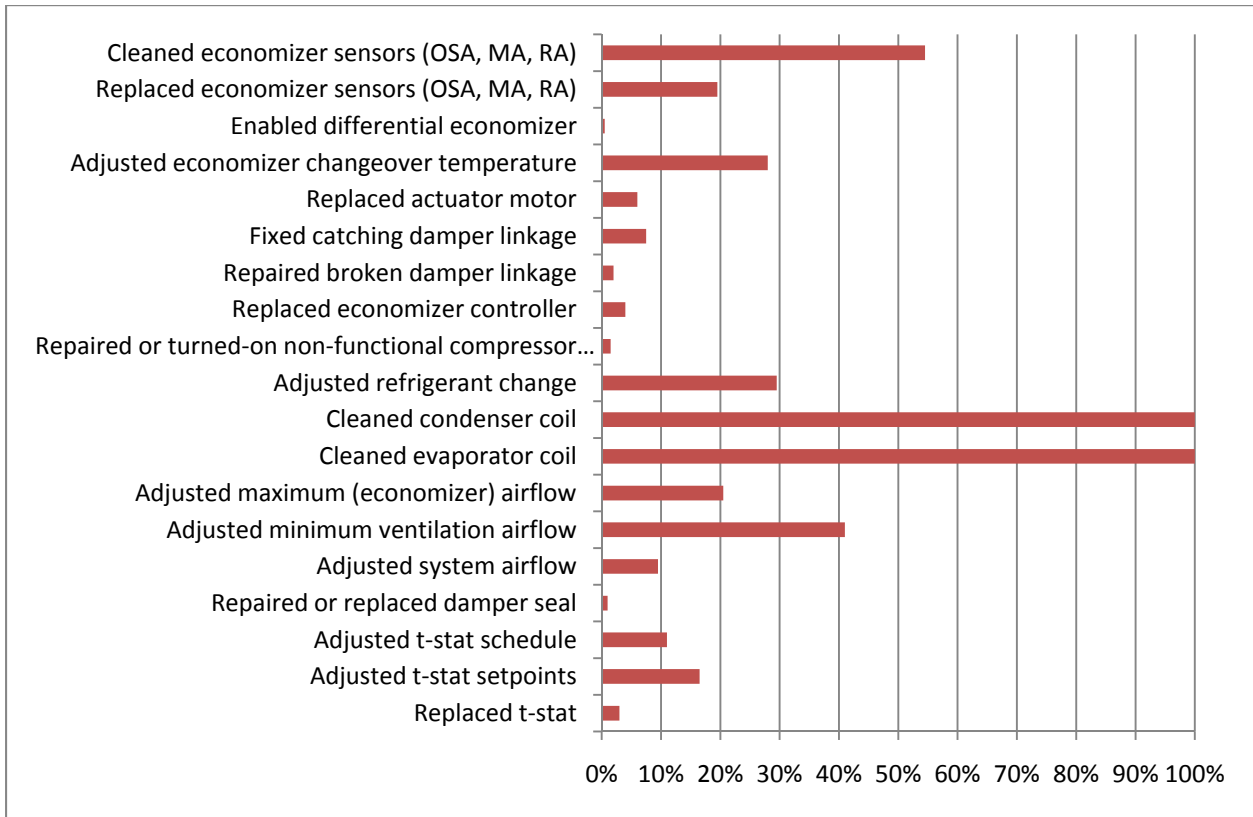
Based on the findings of this summer pilot it is clear that these two RTU service protocols offer value to building owners and promising energy savings potential if developed into a regional incentive program. For this type of program to be successful, the incentives approach has to provide a means of adequately compensating service contractors for their time and materials. Otherwise there will be limited interest in the service provider community to promote the program. The service providers are the vital link to the building owners through their client relationships and technical expertise. Building owners who have this type of equipment on their roof do not necessarily recognize the value of HVAC system optimization. Understanding of value to the owner and sales of these services can be bridged through both incentives and education.

APPENDIX 1



Annual Hourly Outdoor Air Temperatures for Seattle

APPENDIX 2



BPA RTU Pilot Service Items Summary
(Based on 200 RTUs)

APPENDIX 3

Performance Tested HVAC Protocol Form

and

Sample FDSI Report