# Premium Ventilation Package Testing

# Short-Term Monitoring Report – Task 7

**Final Submittal**

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# Table of Contents

## List of Figures

# List of Tables



## Participants & Acknowledgements

PECI is leading the project and coordinated several contributing partners to complete Phase 1, including:

- Portland Energy Conservation, Inc. (PECI): Reid Hart, Ken Anderson, & Dave Moser
- Bonneville Power Administration (BPA): Jack Callahan & Mira Vowles
- Energy Trust of Oregon (ETO): Phil Degens & Nick O'Neil
- Eugene Water & Electric Board (EWEB): Will Price & Chris Wolgamott
- Northwest Power and Conservation Council (NPCC)
- Other interested parties, primarily participants in the NW Regional Technical Forum Rooftop Economizer Committee and other potential participants in Phases 2 & 3.
- The City of Eugene who allowed two units to be retrofit at Campbell Senior Center
- Clark Sheet Metal who allowed two units to be retrofit at their main office

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## Disclaimer

# Executive Summary

## *Proof of Concept Approach and Scope*

### Project Overview

This project represents the first of three phases that are anticipated to vet the Premium Ventilation measure package:

**Field Test**. In one western Oregon location, four units were retrofit with the Premium Ventilation Package. Both gas and heat pump heating units were monitored with the goal of analyze operation before and after retrofit. The field test included development of measure specification, costs, and preliminary savings projections. Phase 2 and 3 plans for expected value savings development and a pilot program with an evaluation plan were also developed.
The purpose of this project is to conduct a field test of a premium ventilation package for rooftop packaged units. That package will include the following measures:

- Optimum start (delayed building warm-up in warmer weather)
- Resistance heat lockout for heat pumps based on outside air temperature
- Ventilation lockout during morning warm-up with improved damper seals
- Economizer control with integration and comparative changeover control
- Demand controlled ventilation (DCV)
- Variable speed drive (VSD) fan control

## *Conclusions*

Several conclusions can be drawn from this work in the areas of functionality, energy savings, and recommended improvements. They are briefly summarized below and explained in more detail in the appropriate report section.

### Functionality

- Analog type controllers and separate components that need to be field wired on the roof are problematic. Reasonably priced stand-alone combination programmable thermostats with DDC controllers should be the focus for future RTU control retrofit programs.
- The lower cost VSDs with integrated controls do function properly, but care must be taken to install them with the appropriate motors.
- While using VSDs can be cost effective, acceptable ventilation at a lower operating and first cost can be provided by cycling the fan off when not needed for ventilation.[1]
- Acceptable air quality for packaged systems that serve only a few rooms can be maintained with a single $CO_2$ sensor located in the return airstream.
- Controlled ventilation provides much better ventilation than a system with the fan in the automatic setting.

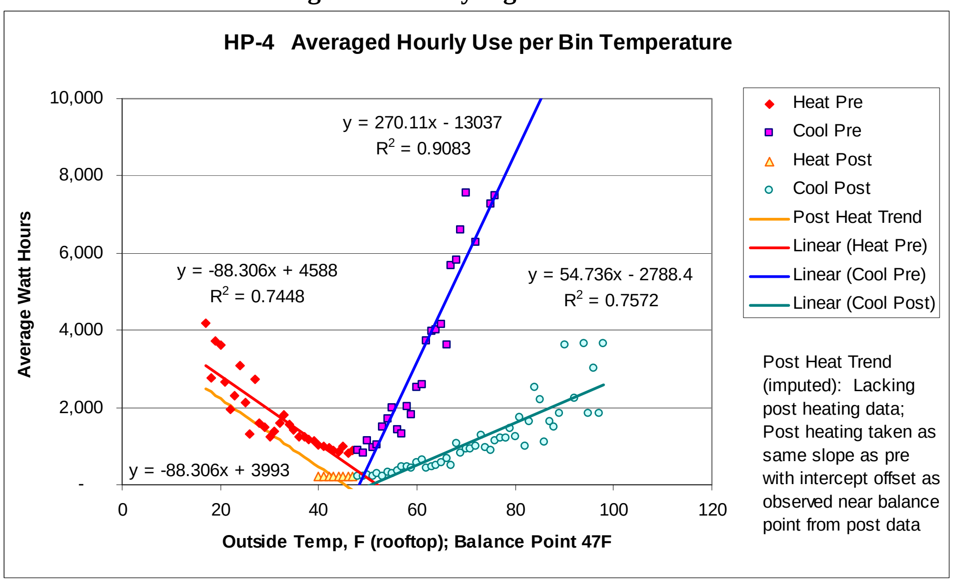
### Energy Savings

- The preliminary estimate of savings appears to be reasonable, although at the one site analyzed there may be other contributors to savings.

[1] Cycling fans under ventilation control is allowed under ASHRAE ventilation standard 90.1 and throughout the Pacific Northwest, but not under current California code.

- The monitored data for one unit was evaluated using four methods.[2] Each method uses the same data, whole unit energy use vs. outside air temperature. The methods are:
  - Daily Energy Signature
  - Hourly Energy Signature (Shown in Figure 1)
  - Inverse Model with three change points
  - Multi-variable regression (addition of occupied period information).
- Monitoring methods based on daily and hourly averages of energy consumption vs. outside air temperature were both found appropriate to evaluate package savings effectiveness.
- Two season savings cannot be verified with a limited 2-week pre- and post-period.
- More sophisticated change point analysis of hourly energy consumption or multi-variable regression did not appear to improve savings projection accuracy.
- The average hourly approach provides more overlap in pre- and post-data for short term monitoring periods than the daily average approach.
- An issue that will be further investigated is the baseline assumption that the fan operates continuously in commercial facilities during occupied periods.[3]

**Figure 1. Hourly Signature Model**




## Recommended Improvements

While there are significant savings resulting from the tested approach, based on lessons learned from the proof of concept testing, the following improvements are suggested:

- The package specification was updated (see Appendix C) to caution about appropriate match of motors and single phase variable speed drives.
- Acceptance testing was improved based on the higher level of complexity of DCV sensors.

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[2] Once additional winter post data is available, the other heat pump will be evaluated in Task 8. The gas-heated units did not have adequate pre-retrofit cooling activity to allow savings analysis.

[3] Around 37% of RTUs have fans cycling during the occupied period and many fans are unnecessarily operating continuously. The fan in auto condition will reduce the actual savings from either VSD or cycling based premium ventilation packages. This loss of savings will likely be offset by continuously operating units that have a proper unoccupied schedule established as part of the package installation. These issues will be evaluated in the Task 8 extended study savings analysis.

- A digital approach using custom programmable DDC thermostats should be tested before pilot program deployment. This should aleviate the difficulties in setting analog or solid state economizer controllers, more reliability and ease of installation could result from a different approach. The DDC-based thermostat integrates economizer, unit, and ventilation control.

## *Next Steps*

### Phase 1 Completion: Added Monitoring and Cycling DCV

Completion of long term monitoring will capture post-period heating for the heat pump units. Data analysis can be completed and savings projections for a premium ventilation package revised.

Based on some of the difficulties in setting analog controllers, the cost of including variable speed drives, and the limited applicability of the low-cost VSDs to some motor types, an alternative approach is suggested for premium ventilation in spaces where fan cycling during occupied hours can be tolerated. A proof of concept test of a digital thermostat integrating DCV integrated fan control and economizer control is planned for this fall.

Once the proof of concept for Digital DCV Integrated Fan Control and the extended analysis are both complete it will be appropriate to pursue several stages of research. These are discussed in more detail later and outlined below:

### Phase 2: Expected Value Savings Development

Two measure packages would be investigated, the original premium ventilation package with variable speed drive and a similar package with DCV integrated fan control. Developing a programmatic expected value of savings requires:

- Revise measure sensitivity analysis as discussed in detail below.
- Complete a small (6-8 units in each climate zone) field pilot of Digital DCV Integrated Fan Control in two climate regions and with at least two controller manufacturers and multiple RTU manufacturers with moderate length monitoring similar to data collected for this proof of concept test.
- Conduct environmental chamber lab tests to simulate a range of climates and operating load conditions.
- With results from the lab tests, as informed by simulations and field tests, conduct parametric analysis and expected value savings to determine programmatic cost effectiveness in multiple climates.

### Phase 3: Pilot Program Development

- In a broad range of climates (depending on partners recruited), deploy simplified field testing in conjunction with a pilot program for retrofit units, new units, and control units.
- A successful program launch will include local contractor training, acceptance testing, data tracking of installations and results, and compilation of findings.
- Complete and deploy an evaluation plan based on the framework in Appendix F. Collect and analyze simplified data (Watt-hours, OAT & SAT) for most units, with some units collecting similar data to that collected for this proof of concept test.
- Compile and publicize evaluation results.

### Phase 4: program launch

- Should savings, feasibility and reliability prove better than existing economizer controllers in the field, launch several utility programs with continuing evaluation.

# Premium Ventilation Package Phase 1 Testing Completion

Beyond the results discussed in this report, the extended monitoring will capture additional heating information, allowing review of projected savings. Further proof of concept testing of an alternative approach using newly available technology will also be undertaken.

## *Experimental Design*

This project represents most of the results from the first of three phases that are anticipated to vet the Premium Ventilation measure package.

**Field Test**. In one western Oregon location, four rooftop packaged units were retrofit with the Premium Ventilation Package, including gas and heat pump heating units. Unit operation was monitored and operations analyzed, specification, costs, and preliminary savings projections were developed. Phase 2 (expected value savings development) and Phase 3 (pilot and evaluation plan) were developed for expanded testing.
The purpose of this project is to conduct a field test of a premium ventilation package for rooftop packaged units. The premium ventilation package will include the following measures:

- Optimum start (delayed building warm-up in warmer weather)
- Resistance heat lockout for heat pumps based on outside air temperature
- Ventilation lockout during morning warm-up with improved damper seals
- Economizer control with integration and comparative changeover control
- Demand controlled ventilation (DCV)
- Variable speed drive (VSD) fan control

Units are monitored pre and post retrofit, and the results compared, primarily to observe observation and develop a proof of concept for the technology included in these measures. The specifications, alternative equipment options, setup and acceptance testing were evaluated. The results are reported in this report.

## *Premium Ventilation Fan Cycling Alternative*

Based on some of the difficulties in setting analog controllers, the cost of including variable speed drives, and the limited applicability of the low-cost VSDs to some motor types, an alternative approach is suggested for premium ventilation in spaces where fan cycling during occupied hours can be tolerated. The revised package is an alternate implementation of Premium Ventilation and includes the following elements:

- Optimum start (delayed building warm-up in warmer weather)
- Resistance heat lockout for heat pumps based on outside air temperature
- Ventilation lockout during morning warm-up with improved damper seals
- Economizer control with integration and optimized changeover control integrated into a digital logic programmable thermostat
- Demand controlled ventilation (DCV)
- DCV integrated fan control – occupied operation of the fan during (and for 2 minutes following) heating and cooling and at least 5 minutes every 30 minutes with longer operation when DCV thresholds are exceeded.

The fan cycling alternative to Premium Ventilation is currently slated for a proof of concept test, using a programmable thermostat with custom DDC programming capabilities. While installations that prefer to have continuous fan operation may choose the VSD option of premium ventilation the fan cycling option is expected to have the following advantages:

- Interface with any staged rooftop unit with an economizer, as there will not be limitations such as split capacitor, single phase motors, or other motor issues for putting the variable speed drives in place.
- The dampers typically provided on RTUs have a fair amount of leakage in the fully closed position. While this is mitigated somewhat by using insulating tape and lower fan speeds in the premium ventilation protocol, turning the fan off when not needed will reduce the negative impacts of closed damper leakage.
- Savings with no motor operation when not needed will be greater than partial savings at low speed with a VSD.
- Lower cost as no VSDs and associated wiring or motor upgrades are required.
- Higher reliability, as electronic (solid-state) controls are replaced with digital logic.

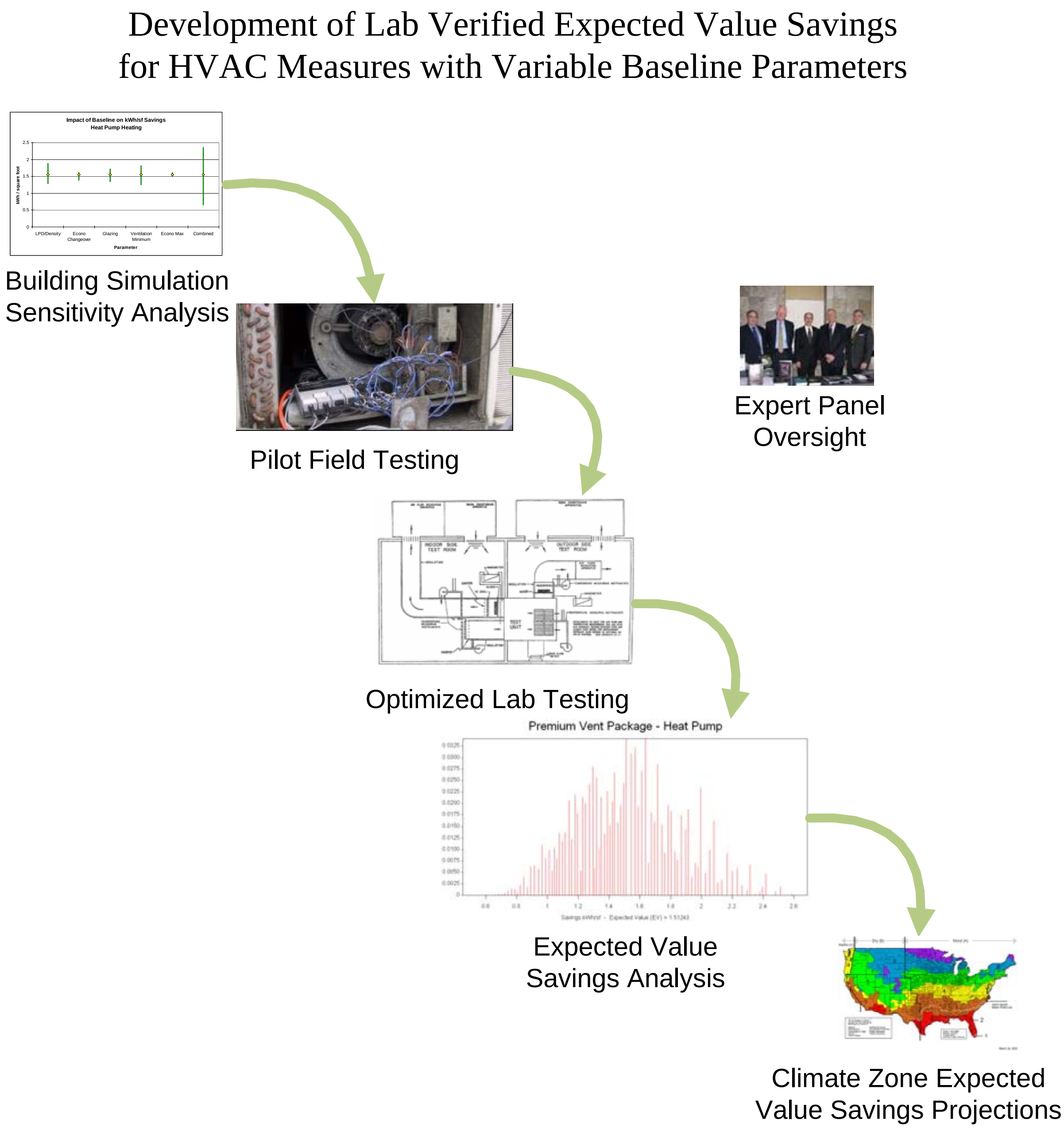
# Phase 2: Expected value Savings Development

Two measure packages would be investigated, the original premium ventilation package with variable speed drive and the package with DCV integrated fan control. The idea of investigating a package of measures, is that all units treated in a program would be brought to a similar end condition, so the variation would exist in the base conditions rather than the final result. It may take different discrete treatments to achieve the uniform final result, but the savings will be related to the final condition, not the discrete measures applied. The approach for the expected value savings development is described below, followed by the rationale for this hybrid savings approach.

## *Expected Value Savings Development Approach*

The purpose of the expected value savings development is to arrive at an appropriate program wide savings for measures that have high variability of sensitive baseline parameters so they can be implemented in a direct-install contractor driven approach. Small unit HVAC measures have this significant range of load variation, as discussed in Appendix I. The expected value savings development would require four steps as seen in Figure 2: Building simulation sensitivity analysis; pilot field testing; environmental lab savings testing, and expected value savings analysis.

**Figure 2. Expected Value Savings Development**




## Building simulation sensitivity analysis

Building simulation sensitivity analysis would follow the methodology described in the Task 5 Matrix report included in Appendix I to find the most sensitive baseline parameters related to the proposed measure packages. Appropriate parameters would be evaluated in DOE2 to determine the range of impacts. Detailed field data from current regional testing would be reviewed to find additional field conditions that should be included. Characteristic studies would be reviewed to determine a range of building type conditions expected. A group of RTU experts would be engaged to determine reasonable probabilities of sensitive parameters where data is lacking. The range of heating and cooling loads from multiple parameter changes such as load density and as-found ventilation and economizer configuration would be determined for a range of building types. The outcome would be identification of the impact of different baseline conditions on measure package savings.

### Field Pilot Testing

Develop refined specifications and acceptance testing forms for both measure packages. In the field, test a moderate sample of about 16 treated units with pre-and post-monitoring in both a western and an eastern Pacific Northwest climate (other climates if additional partners are recruited). The purpose of field testing is to build on the proof of concept testing and further prove reliability and applicability of the specifications, sequences and equipment. It will also gauge the ease of installation for multiple contractors, control equipment manufacturers, and found field conditions. Program specifications and acceptance tests would be further refined.

### Environmental Lab Savings Testing

Complete lab testing of a typical unit with and without the package of measures to establish operation and typical energy use under a range of load and climate conditions. The purpose of lab testing is to rapidly evaluate a range of results under controlled conditions without having to wait for the weather. The zone HVAC load range developed in the building simulation sensitivity analysis would be used to optimize the lab runs and reduce time in the lab to that necessary to project savings for a range of climates and HVAC loads. A group of RTU experts would be engaged to review the lab testing plan in the context of the sensitivity and field pilot testing results.

### Expected Value Savings Analysis

Based on the results of the field pilot testing, building simulation sensitivity analysis, and environmental lab savings testing, results would be combined to develop expected value savings for at least two climate zones (other climates if additional partners are recruited). The expected value approach described further in Appendix I accounts for the probability of occurrence of the identified sensitive building characteristic parameters. In this step, field data, simulation data, lab data, and building stock characteristic data would be evaluated with the guidance of an expert panel to arrive at savings attributes for the range of sensitive parameters. For example, the EER of the lab tested unit would be adjusted for the range and distribution of EERs for units in the field that would be retrofit with the measures. The result will be a projection of the range of savings results expected across a program and the expected value or weighted program average savings per ton of cooling retrofit that will be achieved.

## *Expected Value Savings Approach Rationale*

There are several reasons to develop the expected value savings with the hybrid approach outlined:

- A reasonable range of expected savings can be presented for the decision maker. The range results from the highly variable baseline conditions true in the commercial HVAC market. The expected value approach described further in Appendix I, accounts for the impact and expected distribution occurrence of the identified sensitive building characteristic parameters and projects a program–wide weighted average savings.
- An installing contractor can implement the program expediently, resulting in:
    - Lower administrative costs.
    - Quick single-step sales process that maintains momentum and a higher chance of closing the deal and getting measures installed.
- A single or per-ton expected value savings supports standard rebates, reducing contractor and decision maker confusion and maintaining program consistency.
- Rolling up a region-wide expected value savings result would allow the cost effectiveness of the measure to be evaluated globally. This avoids the measure or package being eligible in

some situations, but not in others—a situation that leads to customer and contractor confusion and negative market feedback in program implementation.

- Contractor-delivered HVAC programs, where the work performed per unit is fairly consistent, can benefit from a standardized savings per ton by major climate zone where a decision-analysis-based expected value of savings is developed based on estimates of field parameters.
- Limiting field testing and combining that method with environmental lab testing has several advantages:
  - Field testing is expensive and provides variable results. Failed monitoring equipment often results in expensive revisits to the site and lost data.
  - Field testing must wait for the weather to be right for the measure being evaluated. Once a limited field pilot is complete, going to the lab allows testing to be accelerated and savings results to be developed more quickly. If multiple rounds of field testing are required, advancement of a new measure may be delayed a year or more.
  - Measures like the proposed ventilation packages will require long pre- and post– monitoring periods to capture both heating and cooling savings.
  - Lab testing provides a controlled environment where a full range of weather and load impacts can be evaluated in a relatively short period of time.
  - When the range of baseline conditions is wide, as it is with packaged rooftop units, a very large sample must be tested to capture the real impact of a program population.
- Including field testing is important to capture a range of field equipment and operating conditions. It will be difficult to include the various anomalies that are discovered in the field in savings results, they should be considered random impacts on program savings, and the program savings be based on a range of typically encountered conditions rather than an outlier.

# Phase 3: Pilot Program Deployment

Develop a pilot program with program specifications, applicability criteria, acceptance testing and simplified test protocol. In a broad range of climates (depending on partners recruited), deploy a pilot program for retrofit units, new units. Complete monitoring and verification based evaluation for a large percentage of these units using simplified field testing (whole-unit power, supply air, and outside air) in conjunction with a more limited sample with a full year's worth of operational data similar to the proof of concept field test conducted here.

## *Evaluation Framework*

An evaluation framework has been developed for a generic roof top unit (RTU) retrofit and tune up services pilot. It is assumed that measure/service specific savings have been estimated through earlier research efforts and that the pilot is testing what measures will be typically installed and to estimate the average RTU savings. The draft evaluation framework can be adapted to pilot implementations in a particular jurisdiction and is included in Appendix F.

# Premium Ventilation Package Description

Each measure is described briefly below with discussion of availability and market placement. Some items like optimum start thermostats, economizer controls, and warm-up cycle are independent of the unit itself, yet there has been an increasing call for factory supplied control packages that have been tested with the unit to verify compatibility. The ability of the unit to perform as intended by the controls is important in several cases, including interaction of outside air damper configuration and seals, exhaust air damper placement to minimize re-entrainment of exhaust air, and response of controls to outside temperatures.

The prior simulation work was completed at EWEB in early 2008 by Reid Hart, Will Price and Dan Morehouse. The savings results of the analysis are shown in Figure 3 below. The basis for savings in Figure 3 is a heatpump RTU. Appendix I includes analysis details and savings for gas heated RTUs. These results include evaporative pre-cooling, but those savings are minimal in the Northwest. When monitoring is completed, savings analysis will be rerun in Task 8 without evaporative pre-cooling and with other modifications based on the proof-of-concept monitoring. The premium ventilation package of measures results in 5 to 25 times the savings of an upgrade from SEER 13 to 15, based on the analysis included in Appendix I.

The premium ventilation package includes the following items:

**Optimum start**. Most programmable thermostats have an optimum start option that slowly increases or reduces the setpoint temperature during building warm-up/cool-down period rather than moving immediately to the occupied setpoint. This saves energy by delaying heating or cooling until needed during the warm-up period.…

**Resistance heat lockout.** This is a simple thermostat control that has been available from heat pump manufacturers for decades. The control simply interrupts the low voltage signal to the resistance heat relay when the outside air is warmer than a set temperature, to increase heating efficiency.

**Ventilation lockout during morning warm-up with improved damper seals**. HVAC units typically start 2 to 3 hours before occupancy with full ventilation provided. This uses a significant amount of unnecessary heating. The measure requires a thermostat with a separate relay signaling actual occupancy period start and an economizer controller allowing this input. Outside air dampers for small package units are also notoriously leaky, with air leakage of 5% to 25%. Properly installed low-leakage dampers can reduce the leaks or adhesive-backed insulation foam can be added to existing dampers.

**Outside air economizer.** The unit simulated here includes an integrated economizer with differential temperature changeover control.[4] Dry-bulb sensors are used in the Western US, and enthalpy sensors in the East. Based on recent testing[5] of analog (solid state) economizer controllers, the manufacturer has developed an improved outside air sensor that is not compatible with differential changeover. If these sensors have an aggressive setting (at least 68°F) then savings is expected to be close to the differential type of changeover.

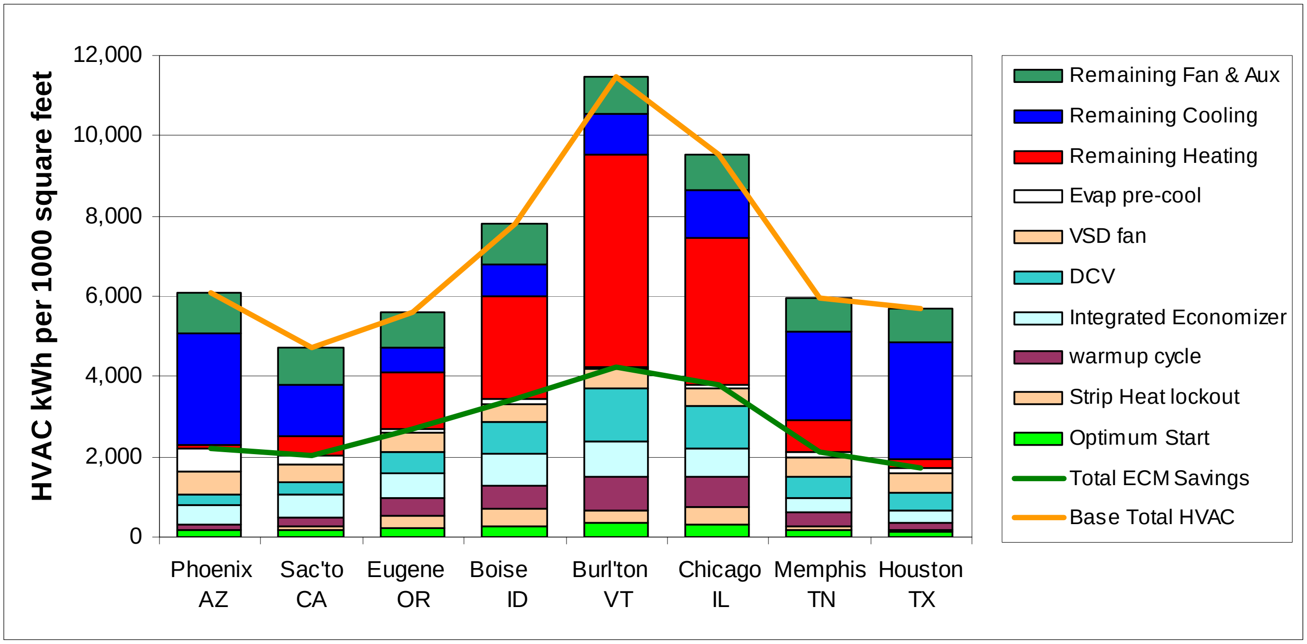
**Demand controlled ventilation.** Demand controlled ventilation (DCV) has traditionally been applied to larger units and areas with dense and variable populations. Because of a reduction in benefit when a properly operating economizer is employed, the measure rarely pays in general density areas with proper system testing, adjusting, and balancing (TAB). Package units do not normally receive proper TAB and ventilation minimums are significantly higher than required (Davis et. al. 2002). Beyond minimum ventilation correction, a DCV system also provides the same benefits of warm-up lockout without the need for a special thermostat. DCV will also adjust ventilation to meet actual load when building occupancy is less than design (almost always). Installation requires a

[4] Reid Hart et al., "The Premium Economizer: An Idea Whose Time Has Come," in *Proceedings of the 2006 ACEEE Summer Study on Energy Efficiency in Buildings* (Pacific Grove, CA: [ACEEE] American Council for an Energy-Efficient Economy, 2006).

[5] David Robison et al., "Field Testing of Commercial Rooftop Units Directed at Performance Verification," in *Proceedings of the 2008 ACEEE Summer Study on Energy Efficiency in Buildings* (Pacific Grove, CA: ACEEE, 2008).

higher quality economizer controller and a carbon dioxide sensor. The cost of $CO_2$ sensors for large-volume contractors continues to drop and is less than $150.[6] If the typical excessive ventilation air is accounted for in the baseline, and the additional benefits of ventilation lockout are considered, DCV is more cost effective.

**Figure 3. Rooftop Unit Savings in Representative Climates**



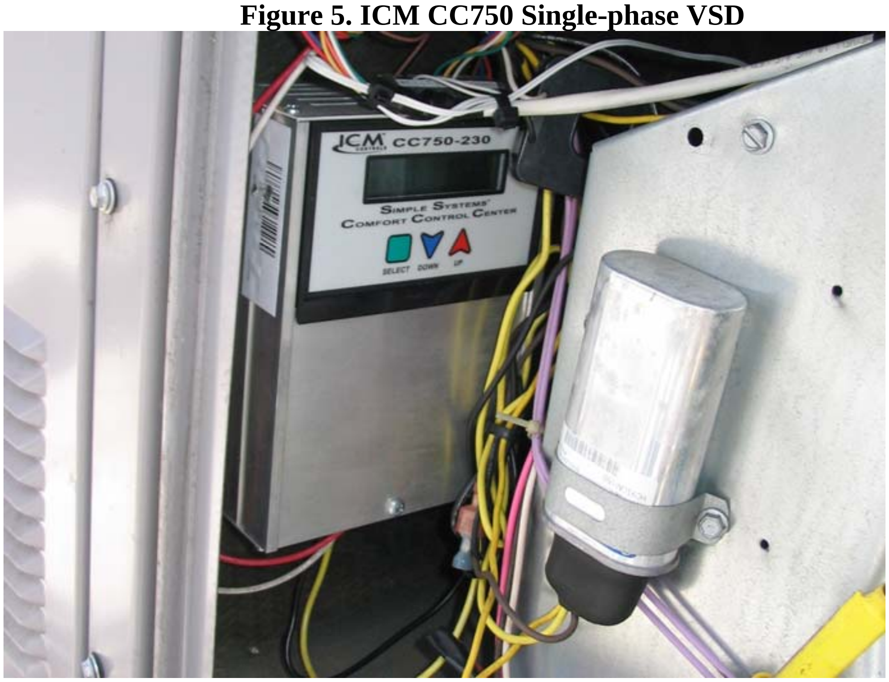

**VSD fan control.** Several manufacturers provide this option in their high-end units marketed to residential customers. There are at least two retrofit products available that contain both a motor speed drive and a control package for fan motors under 10 amps. These units provide significant fan savings and quieter operation by operating at lower fan speeds when the unit is not heating or cooling. They can also improve dehumidification in appropriate climates. These units typically include controls designed to modulate fan speed to maintain discharge air temperature or unit temperature difference within a range, reducing speed to a set minimum when there is no call for heating or cooling. Installation of this measure in a commercial building requires installation of DCV to maintain ventilation when the fan speed is reduced. For this test two units were evaluated: the Fan Handler, shown in Figure 4 and ICM's CC750, shown in Figure 5.

> Note: in future investigations, an alternative approach using DCV integrated fan cycling rather than variable speed drives will be investigated. It is anticipated that savings will be greater with lower costs. This approach is scheduled for 'proof of concept' testing. While acceptable for most occupancies, fan cycling may not be desired in some situations, and the VSD approach would be more appropriate there.

[6] The cost can be substantially higher if a contractor procures a small quantity of $CO_2$ sensors through local distribution channels.

Figure 4. Fan Handler Single-phase VSD


Figure 5. ICM CC750 Single-phase VSD




# Test Site & Equipment Description

The original field test plan for the Premium Ventilation Package included testing up to 6 units. Unfortunately, only four existing units were tested, and no new units were identified by EWEB during the test period. The field test focused on making the units operational with the Premium Ventilation Package and verifying savings on a mode basis at a gross level.

Four units were monitored, each with a 4-ton cooling capacity:

- 2-gas heat/AC retrofits, serving a senior center.
- 2 -heat pump retrofits, serving office space at a conveyor manufacturer.

**Table 1. Units Tested**

| Unit | Heat | Tons | Manufacturer | Model | Area Served |
|---|---|---|---|---|---|
| AC-1 | Gas Furnace | 4.0 | Carrier | 48HJE005-311 | Billiard & Computer Lab |
| AC-2 | Gas Furnace | 4.0 | Carrier | 48HJE005-311 | Craft Classrooms |
| HP-3 | Heat Pump | 4.0 | Lennox | THA048-32BN1p | Office/library – low density |
| HP-4 | Heat Pump | 4.0 | Lennox | THA048-32BN1p | Office – high density |

The following upgrades were made to each unit:

**Table 2. Unit Retrofits Performed**

| Retrofit Performed Site: | Senior Center | | Manuf. Office | |
|---|---|---|---|---|
| Unit: | AC-1 | AC-2 | HP-3 | HP-4 |
| Replace MicroMetl economizer section with new damper section including damper motor and Honeywell W7212 economizer controller | X | X | | |
| Add new Honeywell W7212 economizer controller (Note: the existing damper motor was compatible and the existing economizer was retained) | | | X | X |
| Add new C7660A outside air sensors, set economizer lockout at 68F | X | X | X | X |
| Rework ductwork to improve return air delivery to economizer damper section | | | X | X |
| Install return air barometric relief | X | X | X | X |
| Revise controls to lockout electric resistance heat above 30F OAT | | | X | X |
| Add carbon dioxide sensors (Veris $CO_2$ CDE). Integrate with economizer controller. | X | X | X | X |
| Add foam insulation with adhesive backing in the outside and return air dampers gaps | X | X | X | X |
| Add Fan Handler VSD | X | | | |
| Add ICM's CC750 VSD | | X | | |
| Add ABB VSD with relays to activate set speeds for each operating mode | | | X | X |
| Replace fan motor | | | X | |
| Replace thermostat with Vision Pro IAQ TH8000 series programmable thermostat | X | X | X | X |

# Proof of Concept Functional Review

The primary purpose of this study was to verify field operation of the components installed as a system. Important elements to monitor were the VSD and $CO_2$ sensor installation.

## *Variable Speed Fan Options*

The main proof of concept task for this study was to test commercial application of variable flow fan options designed for residential applications. While similar equipment is used in residential and light commercial, commercial units may have different motor start installations. The following lessons were learned:

- At the senior center, both the Fan Handler and ICM unit worked properly. These fan motors were single-phase and had run-capacitors.
- At the senior center, a relay indicated on the wiring diagram was not installed for the Fan Handler. This extra relay was necessary to provide full speed operation in economizer mode. The ICM controller on the other senior center unit allowed speed for each mode to be set in software.
- At the manufacturer site, one unit was three-phase, and one unit was single-phase with a start-capacitor. Even though the nameplate motor amp draw was within the range of the ICM unit, the ICM unit failed with the single-phase start-capacitor motor. The Fan Handler manufacturer indicated the start-capacitor would be a problem for his device as well. Neither manufacturer documented this in their literature, probably because the start-capacitor configuration is rare in residential equipment.
- At the manufacturer site, the start-capacitor motor was replaced with a surplus 3-phase motor the contractor had in his shop and in both heat pumps, ABB variable speed drives were installed with relays for motor speed control.

### VSD Functional Analysis

- Based on this and prior installation experience, even with quite experienced technicians, analog type controllers and separate components that need to be field wired on the roof are problematic. While they can be made to work, longer term persistence of savings will be supported by a digital controller that is more straightforward to setup and test. Reasonably priced stand-alone DDC controllers that incorporate a programmable thermostat and allow custom programming are now available and should be the focus for future RTU control retrofit programs.
- The lower cost VSDs with integrated controls do function properly, but care must be taken to install them with the appropriate motors.
- While using VSDs can be a cost effective approach where continuous air flow is desired,, acceptable ventilation at a lower operating and first cost can be provided with a DCV Integrated Fan Control approach that cycles the fan off when not needed for ventilation or temperature control. Such an approach is allowed under ASHRAE ventilation standard 90.1 and throughout the Pacific Northwest, but not under current California code.

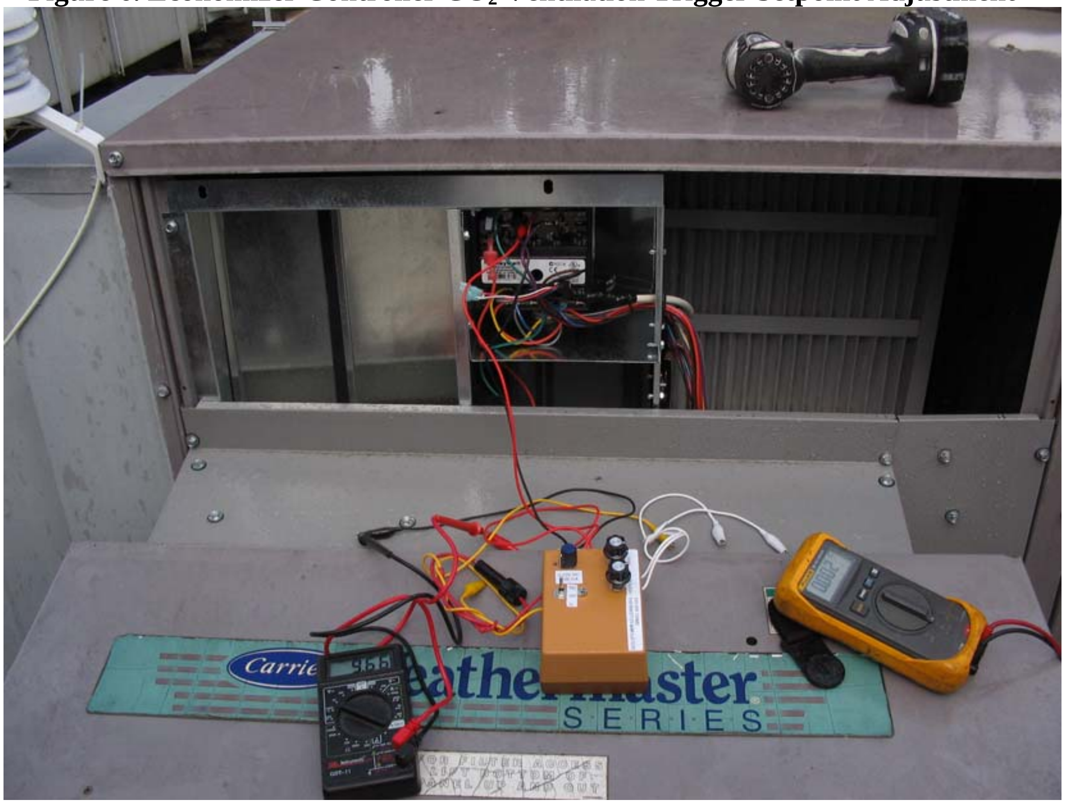
## *Indoor Air Quality Monitoring Issues*

Primary elements of the indoor air quality monitoring or demand controlled ventilation system are a carbon dioxide sensor and calibration of the matching controller. Issues that were found in this installation were as follows:

- There is a lack of contractor awareness of proper $CO_2$ sensor settings. The economizer module ventilation activation point was initially set at 2-volts. This translates to a $CO_2$ concentration of around 400 ppm, or about the same as outside air. A $CO_2$ setting of 1,000 ppm would be more appropriate.
- Important aspects to verify include the sensor output range in voltage related to range in measured $CO_2$, the proper output to match the controller (Volts or milliamps), and appropriate setpoints. It is clear that all items should be individually recorded for proper acceptance testing.

At a May 15, 2009 field verification, a voltage generator was used to change the ventilation activation from 2 volts to 5 volts, to result in a trigger of 1,000 ppm for added ventilation rather than 400 ppm. The voltage generation equipment and setup of the economizer controller is shown in Figure 6. Note that the voltage generator is required during setup to achieve an accurate setpoint with analog (solid state) controllers that do not have digital setpoint capability. It is a relatively simple device with 2-9 volt batteries and a variable resistor. A standard multi-meter is used to verify the voltage output. The voltage generator does not remain as part of the installation.

**Figure 6. Economizer Controller $CO_2$ Ventilation Trigger Setpoint Adjustment**




## *Ventilation Management*

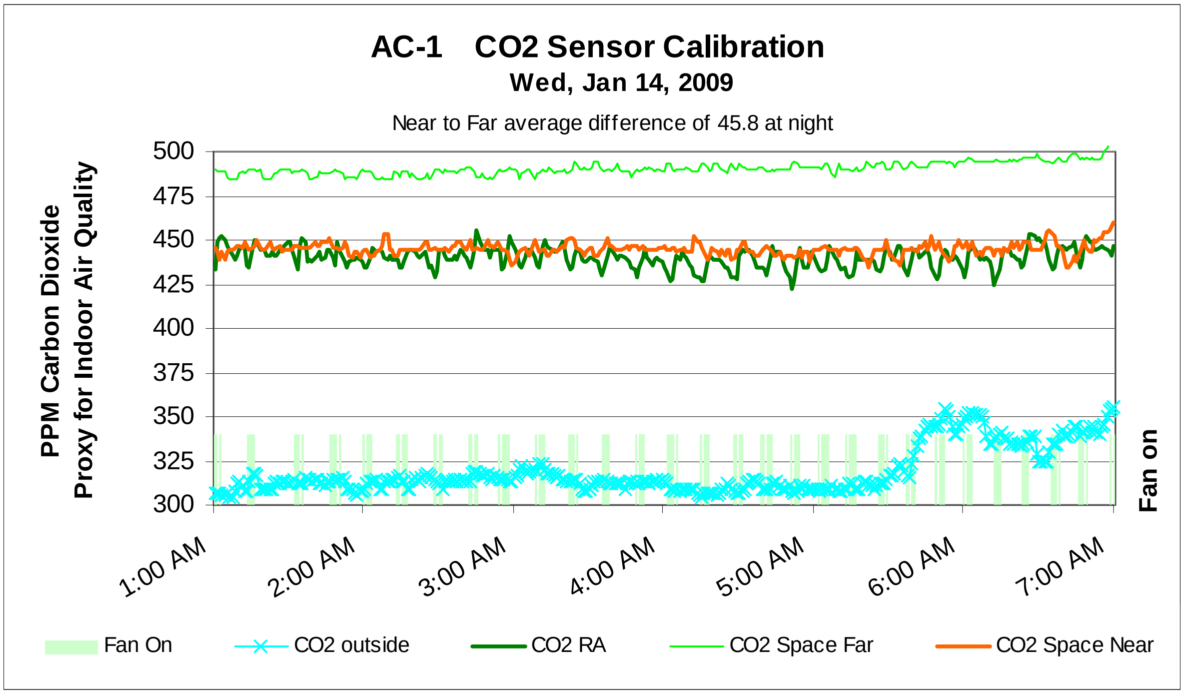
An additional question is the state of ventilation found in existing situations, and the impact that the Premium Ventilation package's DCV measure would have on ventilation. In a recent product test[7] of 15 $CO_2$ sensors, none of the senors met their manufacturer's accuracy statements. In all cases except one, the sensors read higher than actual $CO_2$ concentrations. In the field, this will result in ventilation being slightly higher than desired under a $CO_2$ control strategy. Given these sensor results, it should be understood that $CO_2$ –based control strategies provide a general proxy for ventilation rates, but are not highly precise. Given that ventilation rates recommended under ASHRAE standard 62.1[8] are a committee consensus based on subjective acceptability and are generally not based on precise scientific measurement related to health standards, this level of accuracy is adequate. When comparing sensor results in the following graphs, the average of the differences between sensors to be compared during the unoccupied period was determined and an adjustment made to the higher sensor so that the comparisons would show the proper relative impact. The readings of two sensors in the same space are shown in Figure 7.

---

[7] Gregory Maxwell, "Product Testing Report: Wall Mounted Carbon Dioxide (CO2) Transmitters" (Iowa Energy Center, June 2009), http://www.energy.iastate.edu/Efficiency/Commercial/download_nbcip/PTR_CO2.pdf.

[8] ASHRAE, *ASHRAE Standard 62.1. 2007, Ventilation for Acceptable Indoor Air Quality* (Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 2007).

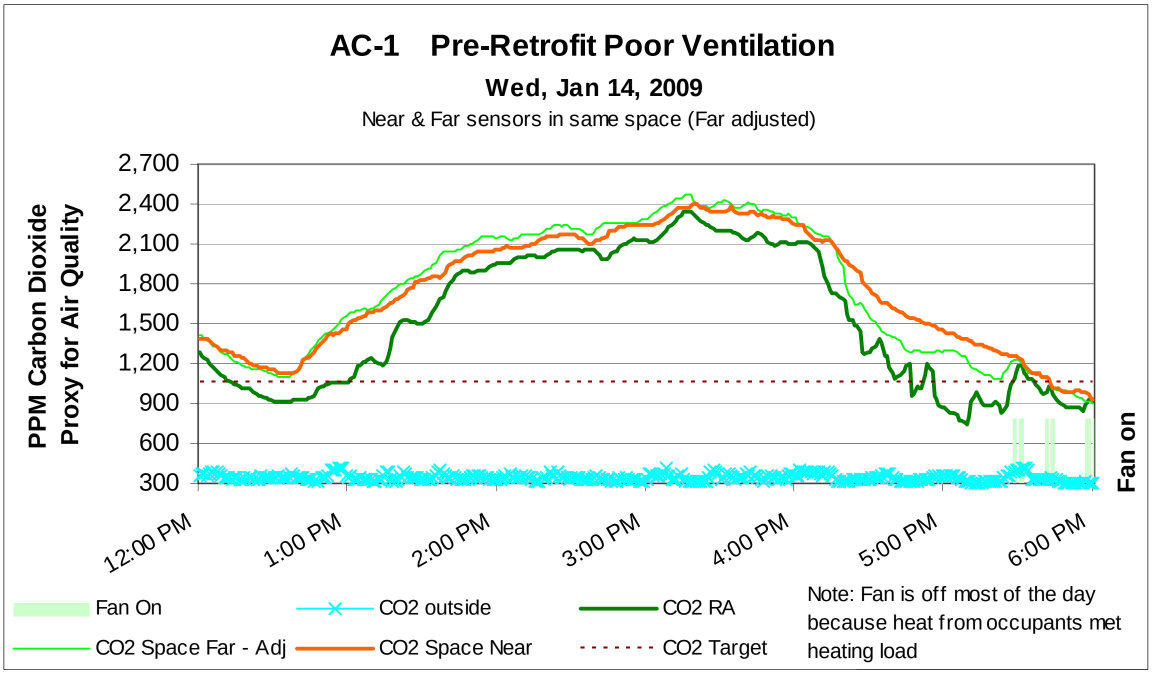
**Figure 7. $CO_2$ Sensor Calibration Adjustment**




The general thinking is that commercial facilities should operate the fan during the occupied period to provide adequate ventilation and comply with ASHRAE Standard 62.1. In fact, section 6.2.6.2 of the 2007 version of Standard 62.1 has provisions for interruption of ventilation over short-term conditions, allowing the ventilation fan to cycle as long as ventilation levels are maintained on an average basis. Continuous ventilation requires the fan switch on the thermostat to be in the "ON" position during the occupied modes. Previous studies have found close to 40% of thermostats have their fan switch in the "Auto" mode resulting in intermittent fan operation.[9] At the senior center the fan operated intermittently, and was off for several hours with significant negative impact on ventilation. When the fan was switched to the "ON" position, occupants would typically switch it back to "Auto", presumably because they did not like either the cold air or the noise of full speed fan operation. During January, heating occurred primarily during the unoccupied period. During the occupied period, people and internal loads heated the building and the fan remained off for several hours. In fact, the $CO_2$ reading in the space was more than double the recommended level as shown in Figure 8. It should be noted that even without fan operation two sensors at different locations in the same room are within 250 ppm of each other.

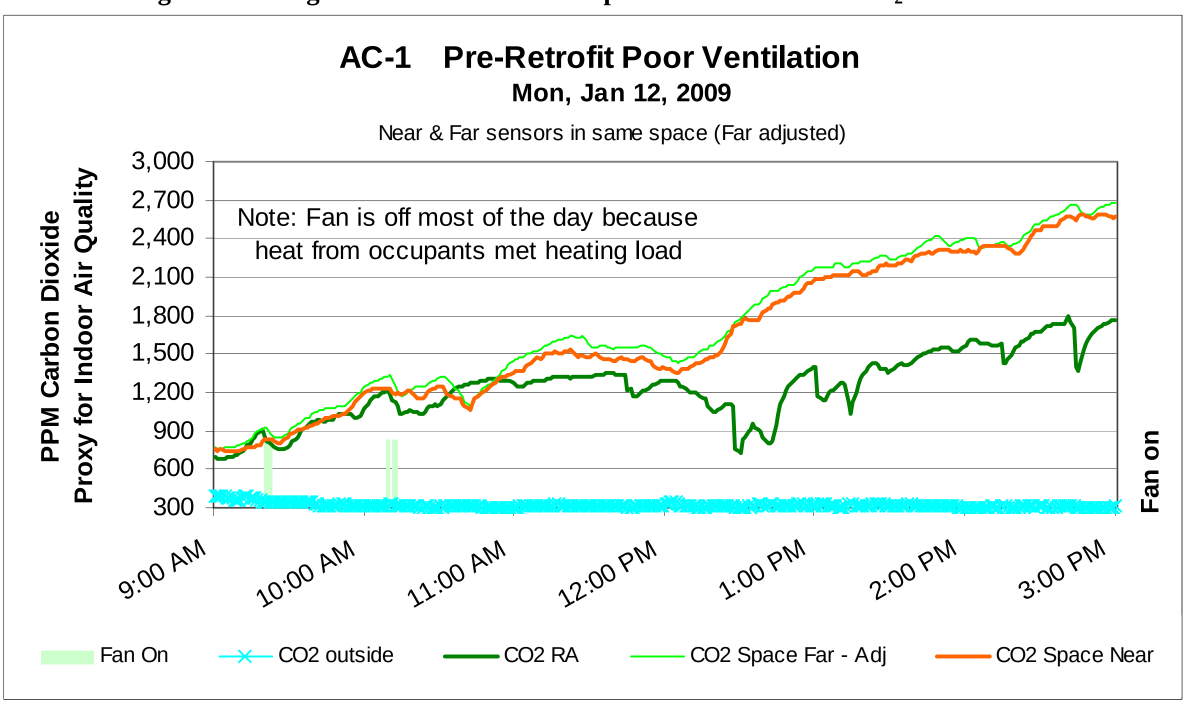
[9] Jacobs, P. Small HVAC Design Guide, CEC-500-2003-082-A-12. Oct 2003, CEC: Sacramento CA

**Figure 8. Poor Occupied Ventilation for AC-1 before Retrofit**




Another example of poor ventilation is shown with even higher levels in Figure 9. In this case, a divergence from the space level is shown in the return air measurement since the fan is not operating. It takes several hours for this divergence to occur. With occasional fan operation, measurement in the return air location is expected to be accurate enough for effective ventilation control. See additional discussion below.

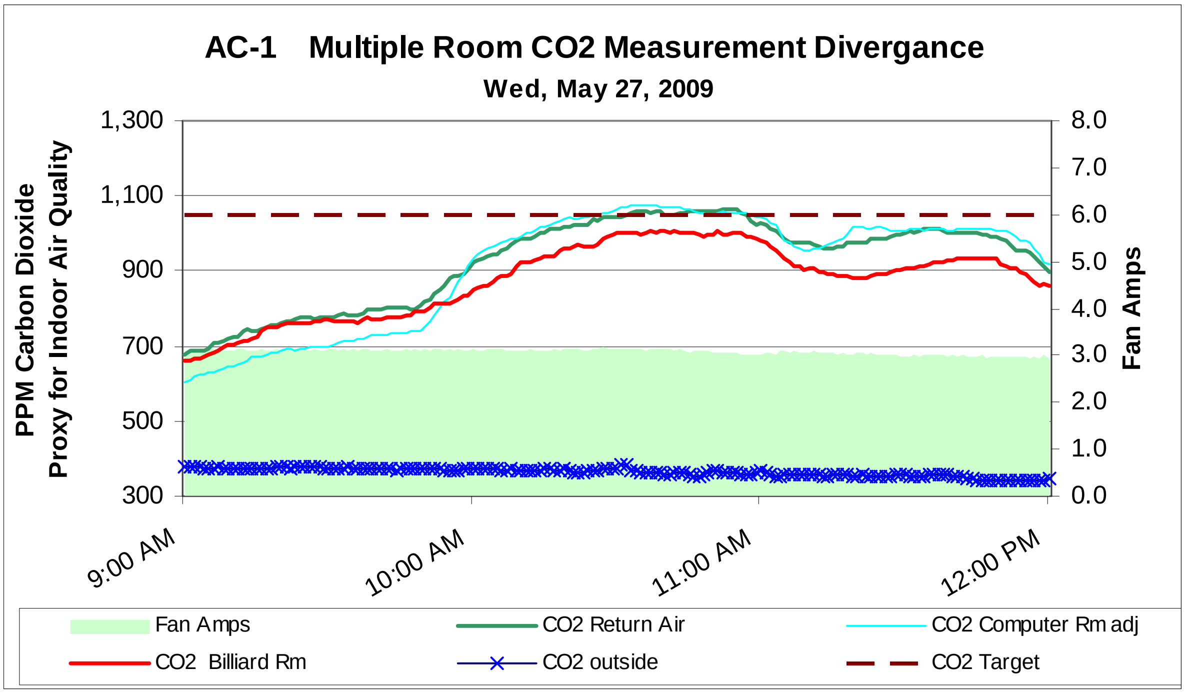
**Figure 9. Divergence of Return Air and Space Measurement of $CO_2$ with Fan Off**



## Premium Ventilation Impact

The premium ventilation package incorporates a $CO_2$ sensor that monitors carbon dioxide levels as a proxy for ventilation rate. The fan runs continuously, slowing down when neither heating nor cooling is required. The slower fan speed reduces energy use and makes fan operation more tolerable to occupants. When carbon dioxide levels increase, indicating more people breathing in the space, the outside air dampers are opened to maintain ventilation at acceptable levels. The test data was scanned to find the highest $CO_2$ concentration in the post-retrofit period. Figure 10 shows one instance where $CO_2$ levels are slightly high, but within an acceptable range of the target, especially compared with the very high levels experienced before the retrofit.

**Figure 10. Ventilation for AC-1 Meeting Target in Both Rooms after Retrofit**




## Ventilation Sensor Location

Straightforward application of a demand controlled ventilation strategy to packaged rooftop units requires that three concerns be addressed:

- The easiest placement of the sensor is in the return air, where wiring to the controller is straightforward. Some studies have indicated that the sensor should be in the room in the breathing zone and California code requires that the ventilation sensor be located there.
- When multiple rooms are served by one unit, an imbalance in ventilation quality may occur when one room is occupied and the other is not.
- When a variable flow strategy is used at the fan, the reduced flow will result in less air throw at the diffuser, and air may not circulate adequately in the room.

There have been recent advocates for placing the $CO_2$ sensor in the breathing zone[10] [11] or for avoiding a $CO_2$ sensor-based approach altogether.[12] The latter arguments are primarily by manufacturers of air-flow measuring equipment who stand to lose sales if $CO_2$ sensor-based approaches are widely adopted. While putting separate sensors in the breathing zone of each room is the most conservative approach, it is difficult to achieve with the controls available for small single zone systems that typically operate with a single $CO_2$ sensor. One proven remedy is an approach that uses a single $CO_2$ sensor in the supply air;[13] however this method will not work with Honeywell solid state controllers that trigger ventilation at a threshold rather than adjusting ventilation to maintain a setpoint.

The setting for AC-1 allowed the concerns around using a single sensor for multiple rooms to be examined based on field testing. AC-1 has two rooms that have moderately high occupancy density served by the same unit. After the retrofit, the second sensor in the billiard room was moved to the computer lab. Data was scanned to find the time when the highest difference between two rooms occurred, as shown in Figure 11. The first observation is that both rooms are well below desired thresholds indicating adequate ventilation. This is due to continuous fan operation, and the fact that the dampers on low end RTU economizers have a moderately high amount of leakage. Hence, the practical minimum ventilation air is around 20%. In this worst-case situation, the difference between the $CO_2$ concentration in the more fully occupied room and the return air measurement is, at most, 150 ppm. Given this fact and expected sensor inaccuracies, a moderately effective job of control can be achieved with a setpoint of about 100-200 ppm below target, or about 900 ppm. Note that in Figure 10, even though there was a similar divergence in the separate room measurements, the $CO_2$ concentration in the more fully occupied room was not significantly above target. For smaller RTUs, a single sensor strategy can be employed, and locating the $CO_2$ sensor in the return air stream certainly provides better control of ventilation than the pre-condition found here where the fan was off for several hours.

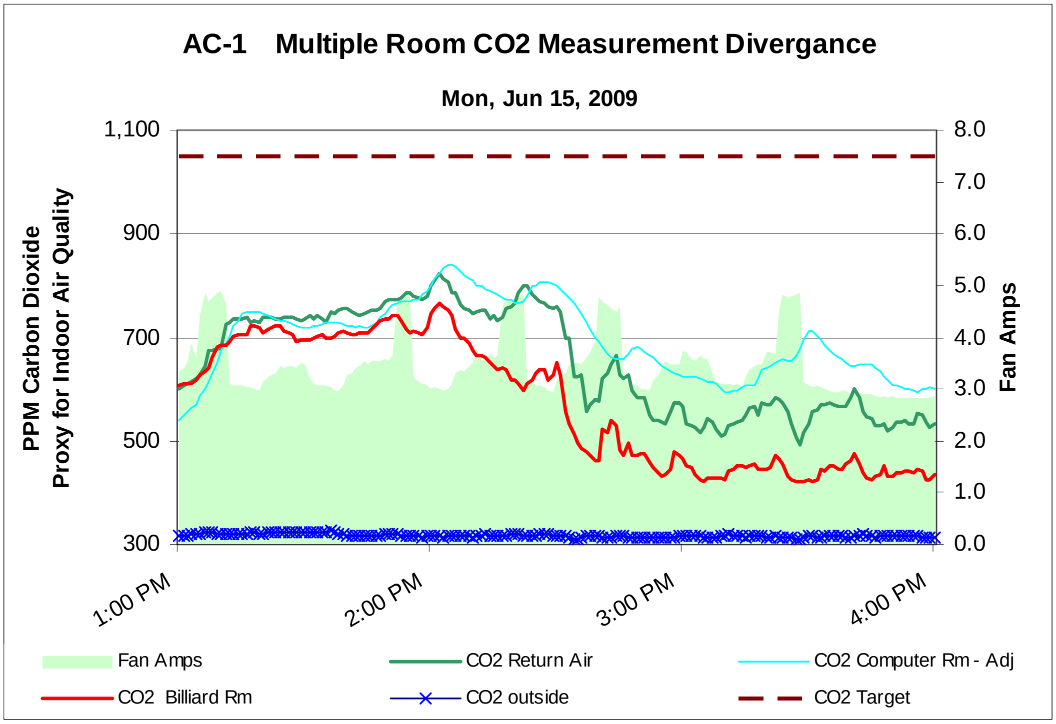
[10] AirTest, "CO2 Control in School Classrooms" (www.airtesttechnologies.com, 8, 2009), https://www.airtesttechnologies.com/support/reference/CO2&SchoolClassrooms.pdf.

[11] Mark Hydeman and Jeff Stein, "Advanced Variable Air Volume (VAV) System Design Guide, 2nd Edition" (Pacific Gas and Electric Co., March 2007), energy design resources, http://tedownloads.com/downloads/guides/EDR_VAV_Guide_5-2-07.pdf.

[12] Leonard A. Damiano, "Greater Use of CO2 is Not Necessarily Better Ventilation," *Automated Buildings*, October 2004, http://www.automatedbuildings.com/news/oct04/articles/ebtron/ebtron.htm.

[13] N. Nassif, S. Kajl, and R. Sabourin, "Ventilation Control Strategy Using the Supply CO 2 Concentration Setpoint," *HVAC&R Research* 11, no. 2 (2005): 239–262.

**Figure 11. Ventilation for AC-1 Diverges in Two Rooms after Retrofit**




## Ventilation Functional Analysis

- Based on results in this study, in systems that serve only a few rooms, the differences between $CO_2$ concentration for the rooms and the return air was much less drastic than conditions experienced in large VAV systems where the critical zones are small relative to the large area served by the system.[14] This finding indicates that acceptable air quality can be maintained with a single $CO_2$ sensor for packaged units. Ventilation control with a return-air $CO_2$ sensor can be effective for RTU systems serving multiple rooms where each room is at least 25% of the floor area served. Maintaining adequate ventilation with one $CO_2$ sensor requires a reduction in ventilation setpoint of about 100 ppm $CO_2$.
- Controlled ventilation certainly provides better ventilation than a system with the fan in the automatic setting.

## Recommended Control Improvements

There are significant savings resulting from the tested approach, but based on some of the difficulties in setting analog or solid state economizer controllers, a non-VSD approach should be explored. This would avoid the cost of including variable speed drives, the limited applicability of the low-cost VSDs to some motor types, along with potential motor problems that were not encountered in this field test. The alternative approach would be developed for premium ventilation in spaces where fan cycling during occupied hours can be tolerated. This approach would vary from the existing approach as follows:

- Controls would be replaced with custom programmable DDC thermostats as discussed earlier. These units are currently available, requiring only application engineering to test a digital approach before pilot program deployment.

[14] Earlier studies have shown the requirement for ventilation sensors in the breating space. Hydeman and Stein, "Advanced Variable Air Volume (VAV) System Design Guide, 2nd Edition."

- Such a DDC-based thermostat would integrate economizer, unit, and ventilation control and significantly improve reliability.  This option is discussed in detail earlier as a remaining task in phase 1.
- As previously discussed, a fan cycling option for premium ventilation meets ASHRAE Standard 62.1 ventilation requirements and would provide significantly better ventilation than units with their fan controls set to cycle based on temperature needs during the occupied period.

## *Acceptance Testing Checklist*

A general acceptance checking approach was used, modeled after acceptance testing protocols used in California under the energy code.  It was found that subtleties were missed and after viewing the monitoring data, multiple field visits were necessary to correct operational issues.  This occurred due to new technology being introduced—even though the installing technician was known to be experienced and to provide quality installations with EWEBs premium economizer program.  Some issues still remain that are under investigation.  A preliminary updated and more detailed acceptance checklist supplement is included in Appendix A.  There are two significant improvements to this checklist that should improve operation:

- While avoiding manufacturer specific operation, spell out the individual items that need to be checked as individual items.
- Where possible require a unique data entry be made by the installing contractor that indicates the test was really performed in the field.

# Monitoring Results

## *Monitored Points*

The following points were recorded on a one-minute time interval for each unit:

1. Supply air (SA) temperature, degrees F & RH
2. Return air (RA) temperature, degrees F & RH
3. Total unit power, Watt-hours (include power supply to fan and compressor)
4. Cooling thermostat call, volts (0-24 VAC, usually yellow to blue or ground)
5. Return air $CO_2$ sensor output (0-10 VDC)
6. Fan amps

The following additional points were monitored at one site:

7. For one space, with moderate occupancy:
    a. $CO_2$ in the return duct
    b. $CO_2$ in the room at 60-inches high near the diffuser
    c. $CO_2$ in the room at 60-inches high far from the diffuser (this sensor was later moved to another room)
8. Outside air temperature measured near the hood intake, but outside the hood with a radiation shield.
9. Outside $CO_2$

## *Data Issues, Adjustment and Processing*

Data equipment and tracking subscription was provided and initially installed by BPA using Onset hobo loggers with remote cell phone acquisition.  This was an early experience with this technology, and there was shaking out required.  Unfortunately, this led to delays in getting accurate pre-retrofit cooling data at the senior center.  Fortunately at the manufacturer site, metering was operational sooner and the internal loads were sufficient to provide good pre-retrofit cooling data. Specific problems noted that may be avoided in the future are:

- Watt hour meters have different configurations for 3-phase and single-phase and will not record useful information if connected in the wrong configuration.
- During initial testing, uploads to verify configuration changes may exceed the data hosting contract limit and that can lead to delays in completing sensor and acquisition setup.
- Data visualization spreadsheets were not set up in advance to allow easy viewing of modal operation to detect difficulties in data collection or control operation. Having these visualization tools available during the shake out phase of data collection and retrofit installation would speed discovery of issues that need resolution.
- Three parties were involved in monitoring setup and analysis: BPA, EWEB, and PECI. While this had advantages in terms of using in-kind services to reduce contract cost, it led to some lack of clarity over roles in verifying data acquisition, and delays in reconfiguring sensors to correct problems. During the initial installation, adequate monitoring equipment was not delivered to the site, shifting the installation load from BPA to EWEB.
- Field monitoring sensor configuration took longer than expected as the system was unfamiliar to EWEB, who carried most of the load of setup and verification of monitoring output with hand-held equipment.
- The contractor was not educated on the data acquisition scheme, leading to relocation of some sensors during retrofit installation. Notably, the return air temperature sensors at the manufacturer site were relocated outside resulting in two weeks of missed data.
- Once the monitoring setup issues were resolved, the ONSET automated data collection process missed several minutes of data in the early morning hours on a regular basis.
- The separate fan current transformer downstream of the VSD was included for redundancy. In the past, the modal analysis relied on the whole unit power to determine fan operation, with one threshold for fan operation and one threshold for unit operation. With the VSD in place, the threshold for fan operation was no longer clear at the whole unit level, and the separate fan current transformer proved essential for fan operation mode identification.

## Data Adjustment

Data adjustments were made to allow for processing based on the notes in Appendix H.

## Data Processing

A batch spreadsheet process was used to process one minute data into hourly results and daily results. In this analysis, minute-by-minute modes were identified including:

- Heating
- Economizer operation called for based on thermostat signal
- Economizer impact without thermostat call due to minimum ventilation
- Fan operation without significant supply air temperature impacts, indicating fan operation during non heating and cooling modes.
- Mechanical cooling operation
- Fan off operation

These modal results were rolled up on an hourly or daily basis so the following results could be analyzed:

- Unit energy use by different mode (Heating vs. cooling vs. fan only)
- Minutes of operation by mode

- Degree-hours based on duration and sensible temperature difference between return and supply air. This metric was not as valuable here due to the impact of variable speed fans on actual delivered quantity (Q) of heat energy to airstream.

## *Data Visualization for Controls Troubleshooting*

The processing spreadsheets allowed a view of daily, hourly, or minute-by-minute system operation. While outside the scope of this measure review, the ability to quickly see problems when the data is visualized argues for more development of low-cost data visualization and fault diagnostics. These types of systems are starting to be developed.

### Daily

The daily view of pre-retrofit operation demonstrates excessive operation in a particular mode, improperly set schedules in the programmable thermostat, and the relation between heating and cooling on a seasonal basis. The modal view in Figure 12 shows hours per day in different modes, while the daily energy use view in Figure 13 shows that there was not an excessive energy penalty associated with long hours of fan operation now that a variable speed drive was installed. Daily figures in full size format are included for all four units in Appendix B.

**Figure 12. HP-4 Shows Excessive Fan Operation in Post Period**

Thumbnail shown here; See Appendix B for full size format

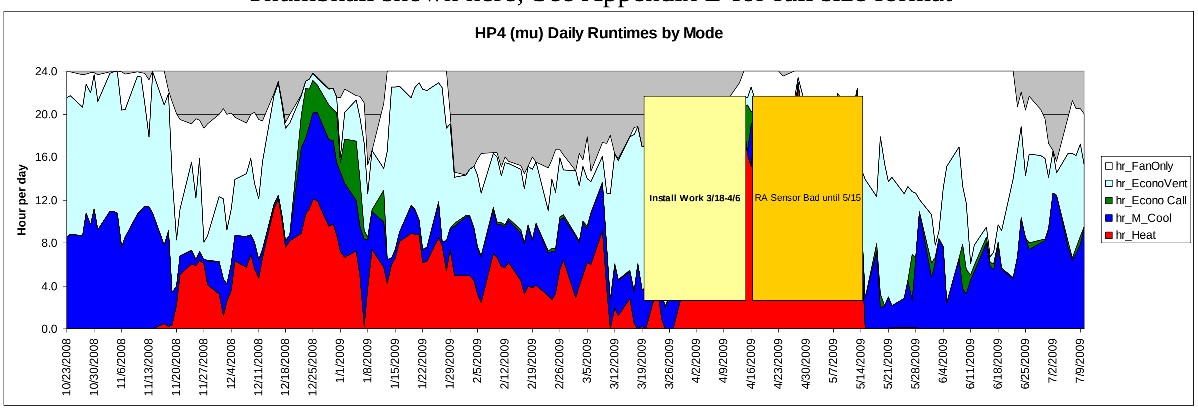
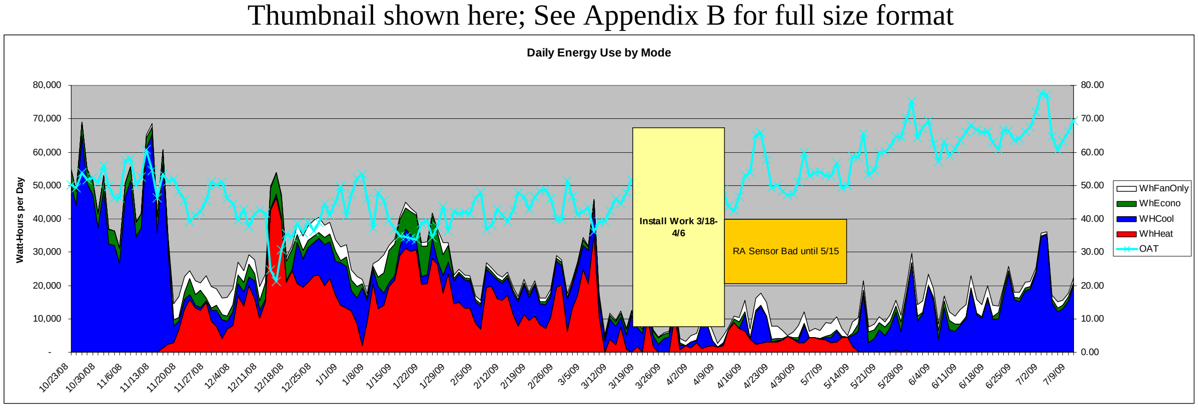



**Figure 13. HP-4 - Excessive Fan Operation Mitigated by VSD**

Thumbnail shown here; See Appendix B for full size format



## Hourly

The hourly views of pre-retrofit data allow more detailed investigation of system temperatures and modal energy use. Modal results from one-minute data are averaged or summed to find hourly values. For example, Figure 14 shows multiple supply air temperatures for some hours because separate averages are formed in each hour for the time the unit is economizing, cooling, heating, or operating with the fan on. In Figure 14 an interesting anomaly is discovered. Each weekday, at the end of the occupied period around 5:00 pm, heating ramps on full then tapers off over the course of 2-3 hours. While it cannot be verified, it is suspected that use of a residential programmable thermostat led to setting a post occupancy period with a heating setback of 80F rather than using that for the cooling setback.

**Figure 14. HP-4 Pre Period Excessive Heat Following Occupied Period**

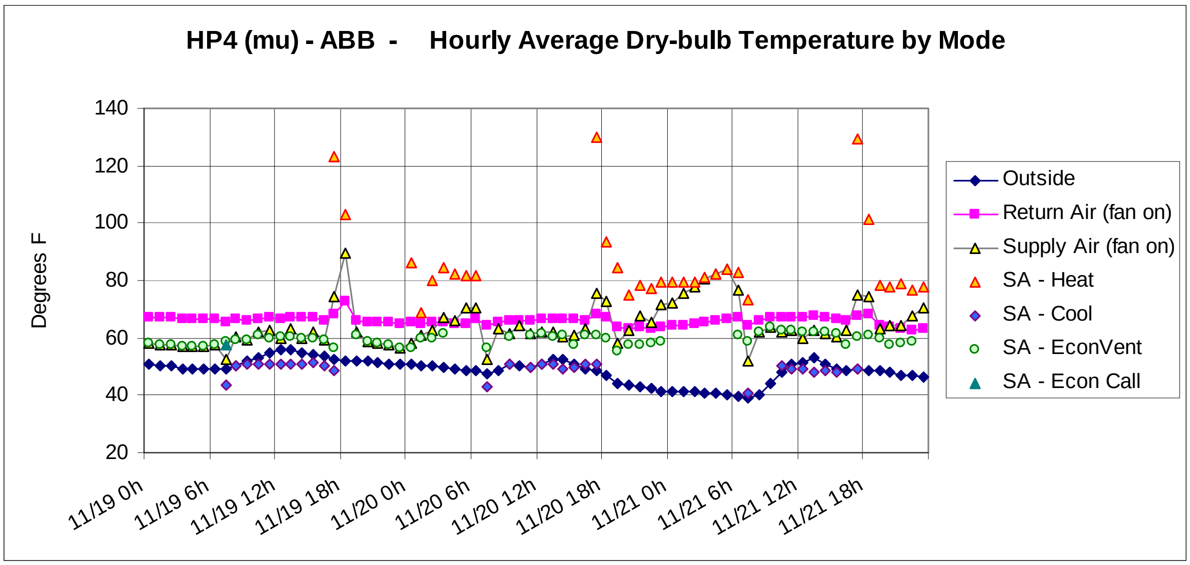
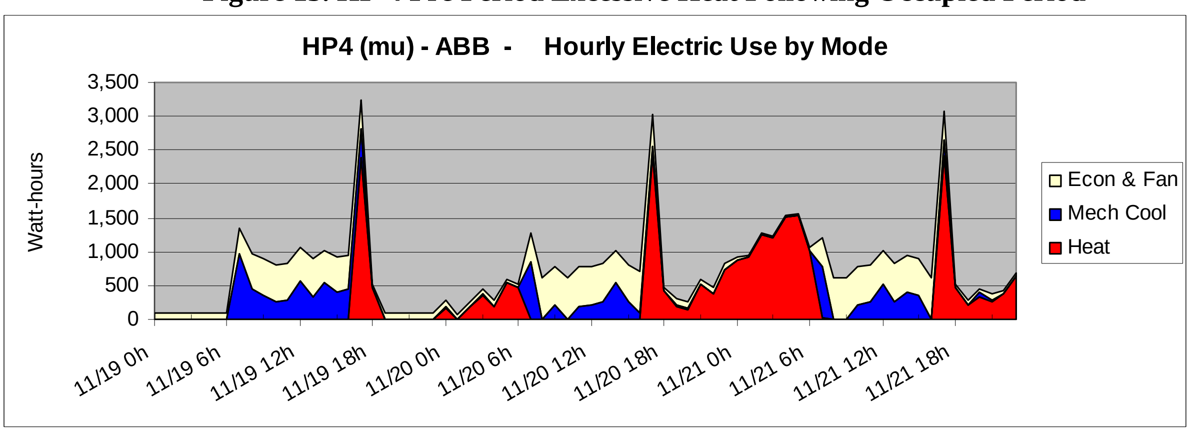



Figure 15 shows the energy impact of this operation, which is much more significant that the extended fan operation in the earlier example. The hourly energy mode also shows the comparison between occupied period fan and unoccupied period fan.

**Figure 15. HP-4 Pre Period Excessive Heat Following Occupied Period**




The unintentional after-hours fan operation may have contributed to the higher than expected savings, shown in Figure 12 for HP-4. While unoccupied fan operation is normally considered inappropriate, during the post-retrofit period the unoccupied fan operation resulted in a night flush effect seen as low pre-occupancy supply temperatures in Figure 16. While this does produce savings during the months in question, if it had continued into hotter weather, the energy impact may have been negative.

**Figure 16. HP-4 Unintended Night Flush Effect with Continuous Fan in Post Period**

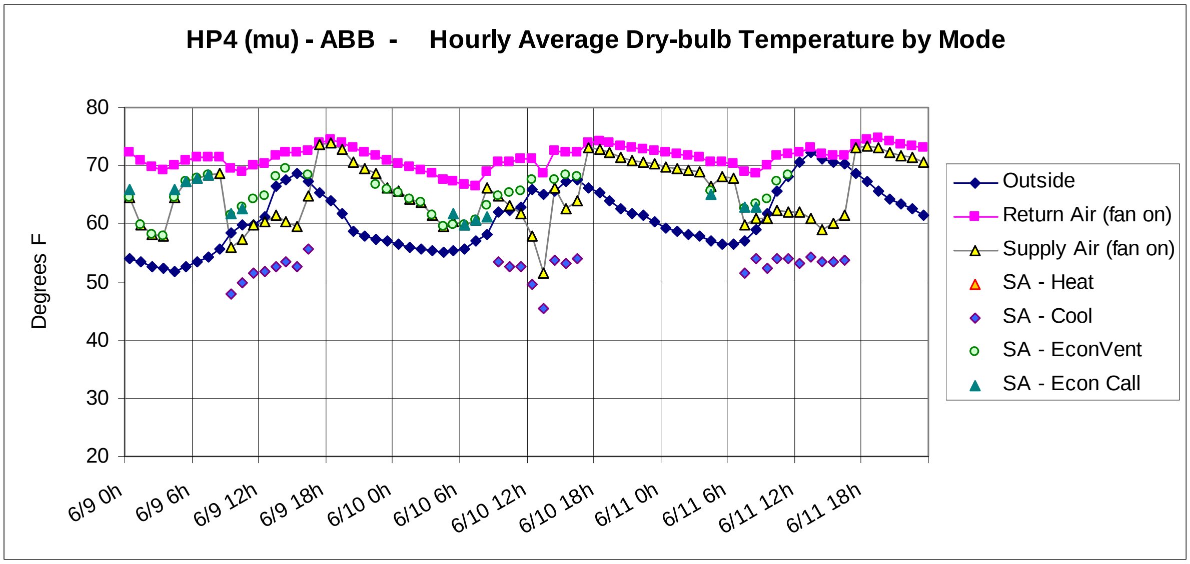



Figure 17 shows the energy impact of this unintended strategy. While there is an increase in fan energy overnight, it is offset by reduced cooling during the early part of the day since the space temperature was reduced compared with the normal unoccupied cooling setpoint that would otherwise have occured.

**Figure 17. HP-4 Energy Impact of Unintended Night Flush Effect with Continuous Fan**

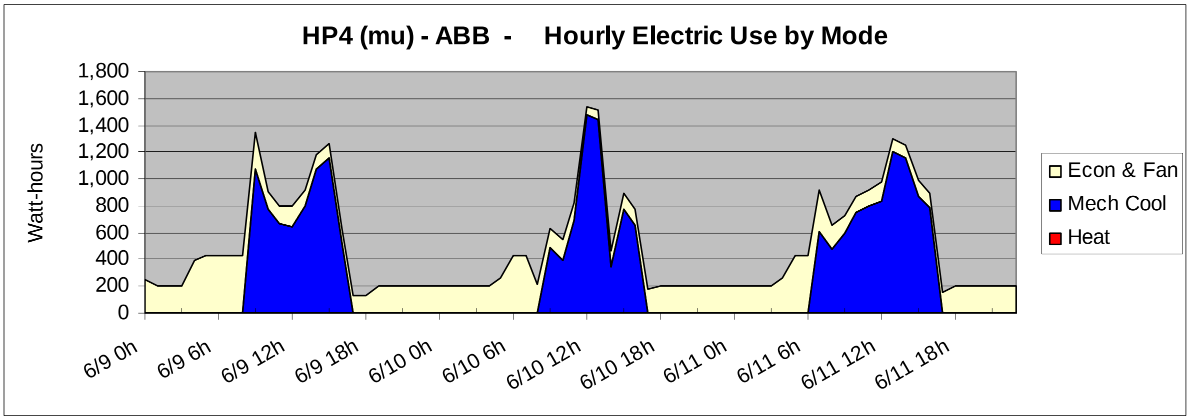



Figure 18 demonstrates more typical operation with the fan off during the unoccupied period until the space warms up to the unoccupied cooling setpoint. In this operating mode, the need for cooling is held off for several hours. Later in the early morning, when outside air temperatures have reduced, we see some intentional economizer operation, although not as much as would be expected.

**Figure 18. HP-4 Fan Operation Off until High Night Limit**

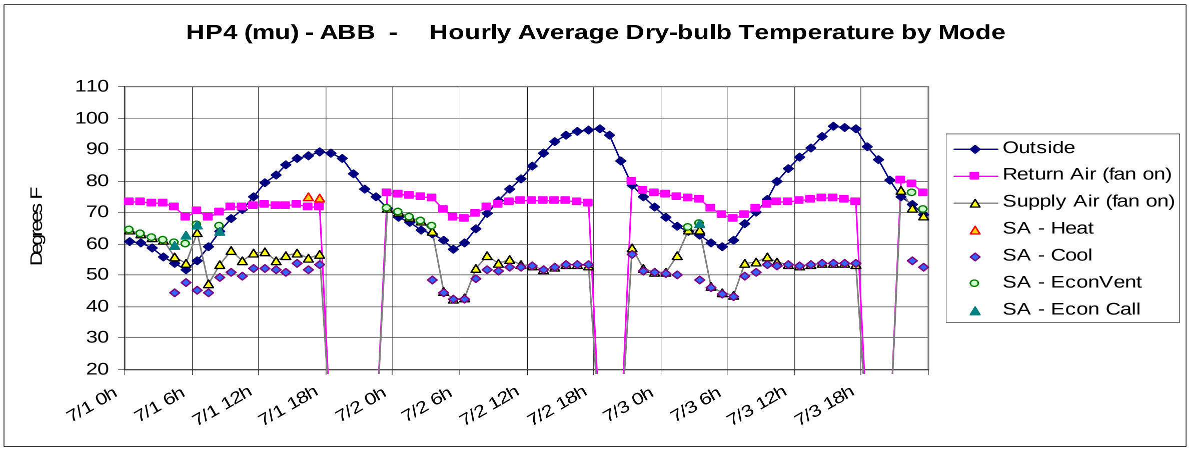
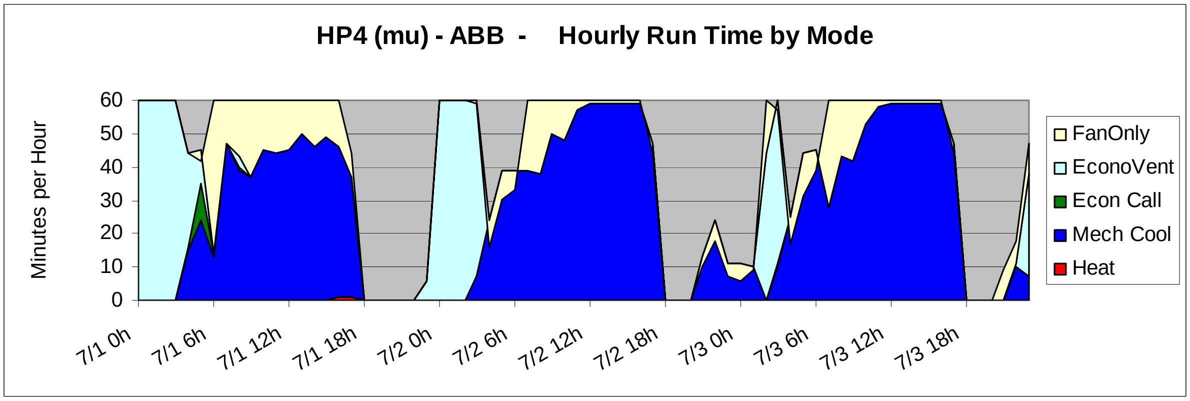



Figure 19 shows hourly runtime by mode and more clearly illustrates the ventilation effect of economizer operation.

**Figure 19. HP-4 Runtime by Mode – Post Period**




## Minute-by-Minute

Once a particular operating mode is detected in the hourly views, a closer look can be made to the minute-by-minute data. Here unit cycling can be observed, and more immediate control results reviewed. Figure 20 shows that there is some economizer effect being provided during the post period in early June. Figure 21 shows unintentional night flush occurring.

**Figure 20. HP-4 some Economizer Effect with Continuous Fan in Post Period**

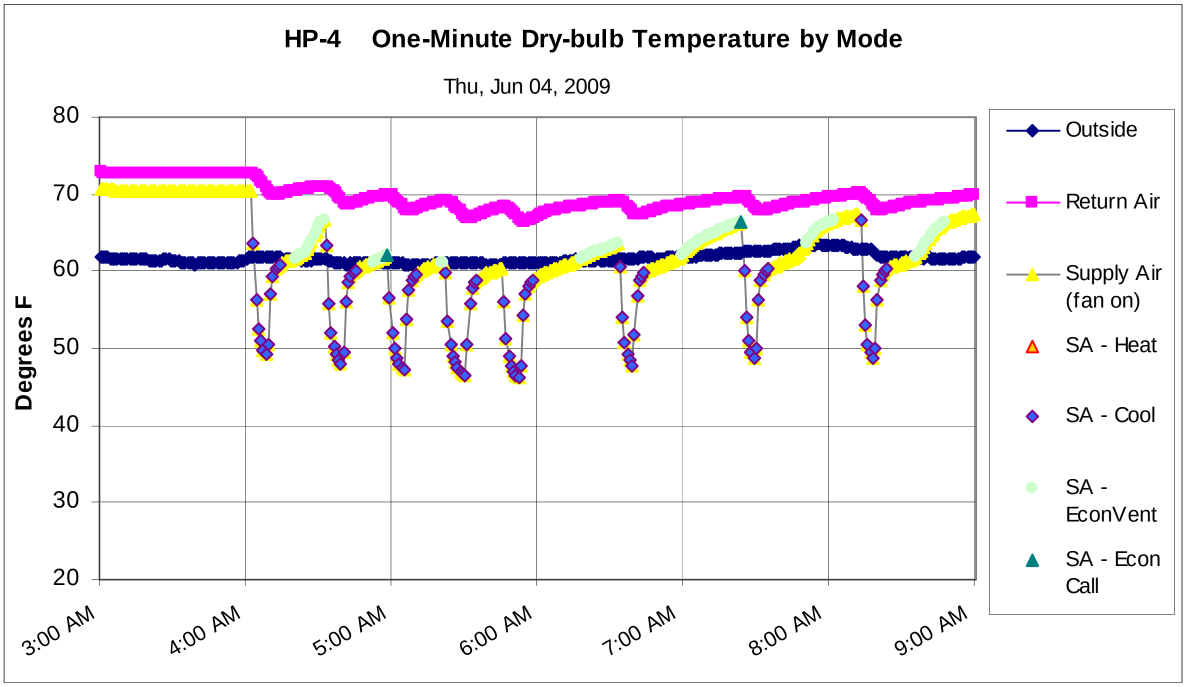
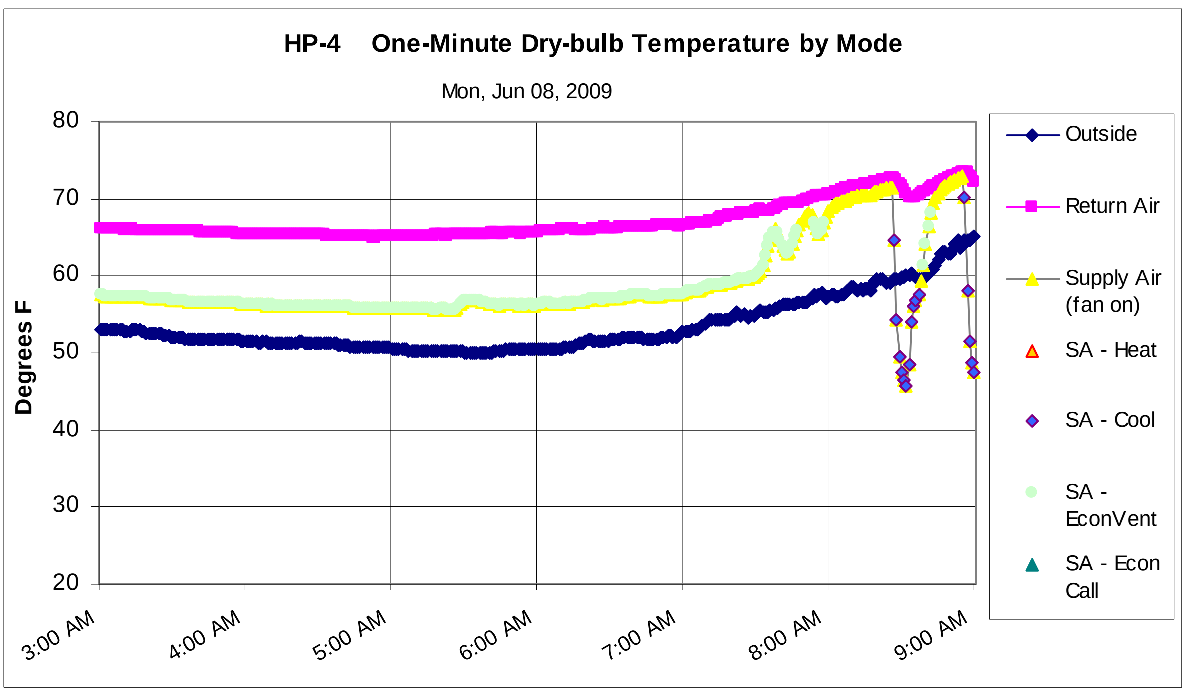



**Figure 21. HP-4 Unintended Night Flush Effect with Continuous Fan 60% OA**




While the retrofit process was intended to improve economizer operation, Figure 22 shows a situation where outside conditions were conducive to economizer operation, but significant economizer operation was not engaged. Although it should be noted that the discharge temperature below 45F indicates that the mixed air temperature was significantly lower than the return air temperature. Figure 23 shows that there is some thermostat-called economizer operation in the post period.

Figure 22. HP-4 lack of Economizer Operation in Post Period

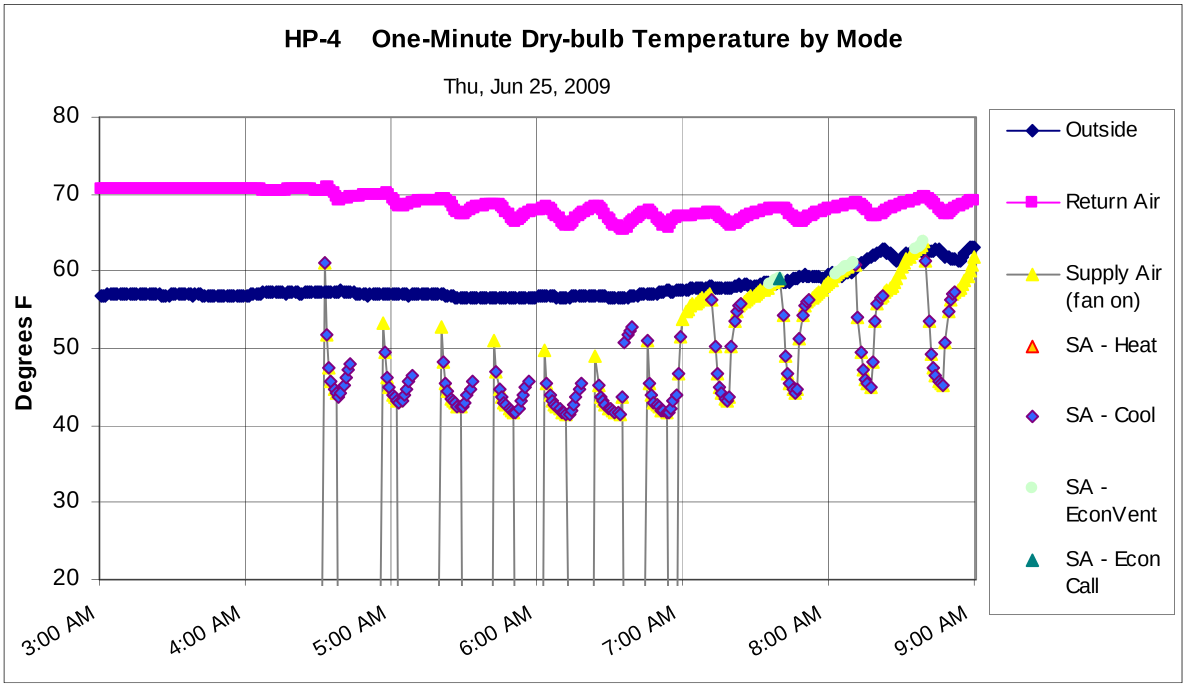
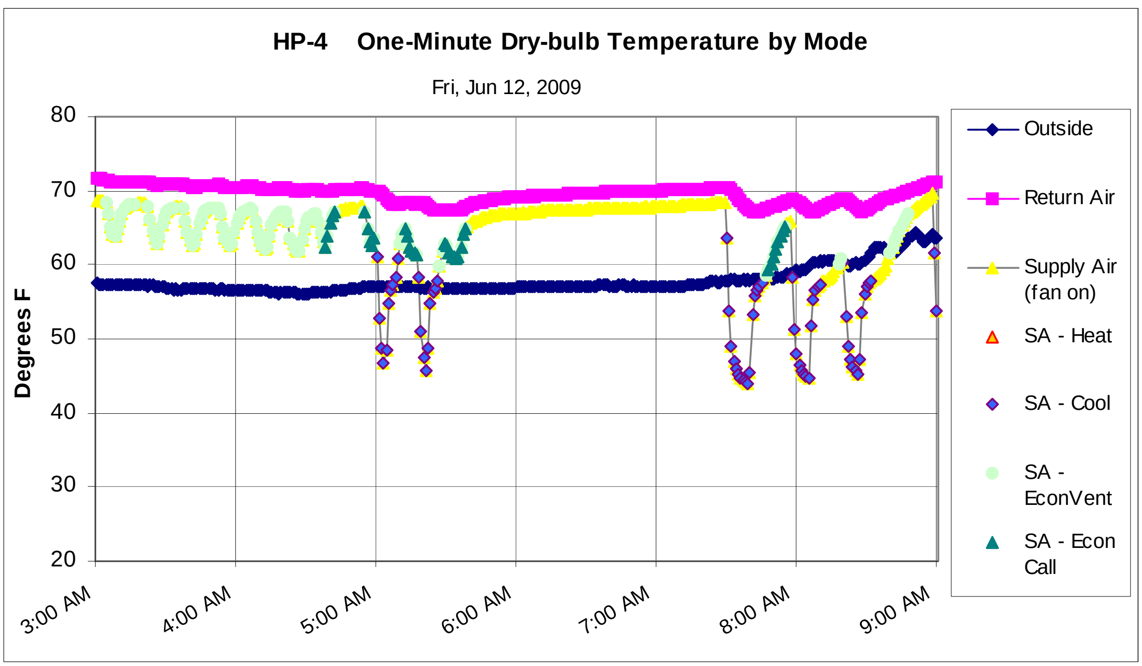



Figure 23. HP-4 Intentional Economizer Operation in Post Period



# Specification Update

## *Recommended Premium Ventilation Changes*

At this point, it is determined that language around the motor limitations of single-phase VSD products should be included in the specification. These changes are made in a revised specification included as Appendix C. While difficulties in implementing these products as a general measure package make a fan cycling alternative potentially more desirable as discussed below, there will be some situations where a variable flow fan is preferred over a fan cycling sequence, and in these instances, the Premium Ventilation Package with VSD specification should be installed.

## *Alternative Measure Package: DCV Integrated Fan Control*

Based on some of the difficulties in setting analog controllers, the cost of including variable speed drives, and the limited applicability of the low-cost VSDs to some motor types, an alternative package is suggested for premium ventilation where fan cycling can be tolerated. The alternate package, termed "Demand Controlled Ventilation with Integrated Fan Control" (DCV-IFC), is currently slated for a proof of concept test, and would primarily feature all control sequences integrated into a digital logic programmable thermostat with custom programming capabilities. The following sequence elements would be included:

- Optimum start (delayed building warm-up in warmer weather)
- Resistance heat lockout for heat pumps based on outside air temperature
- Ventilation lockout during morning warm-up
- Economizer control with cooling compressor integration and optimized changeover
- Demand controlled ventilation (DCV) of minimum ventilation
- DCV integrated fan control – occupied operation of the fan during (and for 3-5 minutes following) heating and cooling and at least 5 minutes every 30 minutes with longer operation when DCV thresholds are exceeded.
- The above Demand Controlled Ventilation with Integrated Fan Control would be accomplished using a programmable thermostat with custom programming capabilities.

Additional components beyond the digital custom programmable thermostat would include:

- Added or improved damper seals
- Indoor or return air $CO_2$ sensors
- Outside air temperature sensor
- Replace damper motor where necessary for compatibility
- Replacement of thermostat wiring where needed

There may be other optional items such as occupancy sensor setpoint adjustment and night flush, although these will not be included in the first phase proof of concept testing.

## *Updated Opinions of Cost*

### Initial Opinion of Probable Cost

There is a wide range of probable cost for this package of measures. The biggest variable is the pre-existence of a standard economizer. In this cost estimate the basis is that about one-third will require the addition of economizers and that 25% of the units will receive commissioning. The field test will be a very good opportunity to get good feedback about actual contractor costs for installing this set of measures. It may be that once actual costs are in hand, it makes sense to restrict the measure to units that are already equipped with outside air economizers.

**Table 3. Original Opinion of Probable Cost**

| | |
|---|---|
| Materials | **$ 1,057** |
| Low voltage wiring | **$ 125** |
| Installation | **$ 405** |
| OH&P | **$ 317** |
| Commissioning (25% sample) | **$ 240** |
| Total | **$ 2,144** |

### Revised Opinion of Probable Cost – Premium Ventilation

Actual contractor costs from the retrofits were reviewed against estimating manuals and supplier material costs and found to be accurate. The scope has been revised from the original cost scope as follows:

- Slightly higher costs for heat pump resistance heat lockout are included with weighting based on Pacific Northwest simple system heating type distributions.
- The measure cost is based on only units with existing economizers receiving this treatment, although an assumption is included that 20% of the units will require wholesale economizer replacement or major ductwork to make the economizer effective.
- An allowance is made for larger VSDs and associated control interfaces being installed on larger units.
- Evaluation costs such as commissioning are not included, but a detailed supplemental acceptance test by the contractor is.

**Table 4. Revised Opinion of Probable Cost**

| Configuration | | Gas heat | Electric Heat | Heat Pump | Average |
|---|---|---|---|---|---|
| RTU heat type distribution from 6th power plan: | | 70.5% | 14.3% | 15.2% | Cost |
| Typical measure with No economizer upgrade: | | | | | |
| Small VSD with integrated controls | 28.5% | $2,070 | $2,070 | $2,140 | $2,080 |
| Large VSD, with programming & relays | 51.5% | $2,270 | $2,270 | $2,340 | $2,280 |
| Unusual case with economizer or ductwork replacement | | | | | |
| Small VSD with integrated controls | 7.1% | $2,510 | $2,510 | $2,580 | $2,520 |
| Large VSD, with programming & relays | 12.9% | $2,710 | $2,710 | $2,780 | $2,720 |
| Expected Programmatic Average | | | | | **$2,300** |

### Opinion of Probable Cost – DCV Integrated Fan Control

While a detailed cost for the DCV integrated fan control is beyond the current scope, it is expected to result in a $250 to $400 reduction over the premium ventilation package with VSD. There is also expected to be an increase in reliability and potential to expand the energy saving sequences. There will be higher applicability, since fan motor issues will not impede deployment of the package.

# Energy Savings

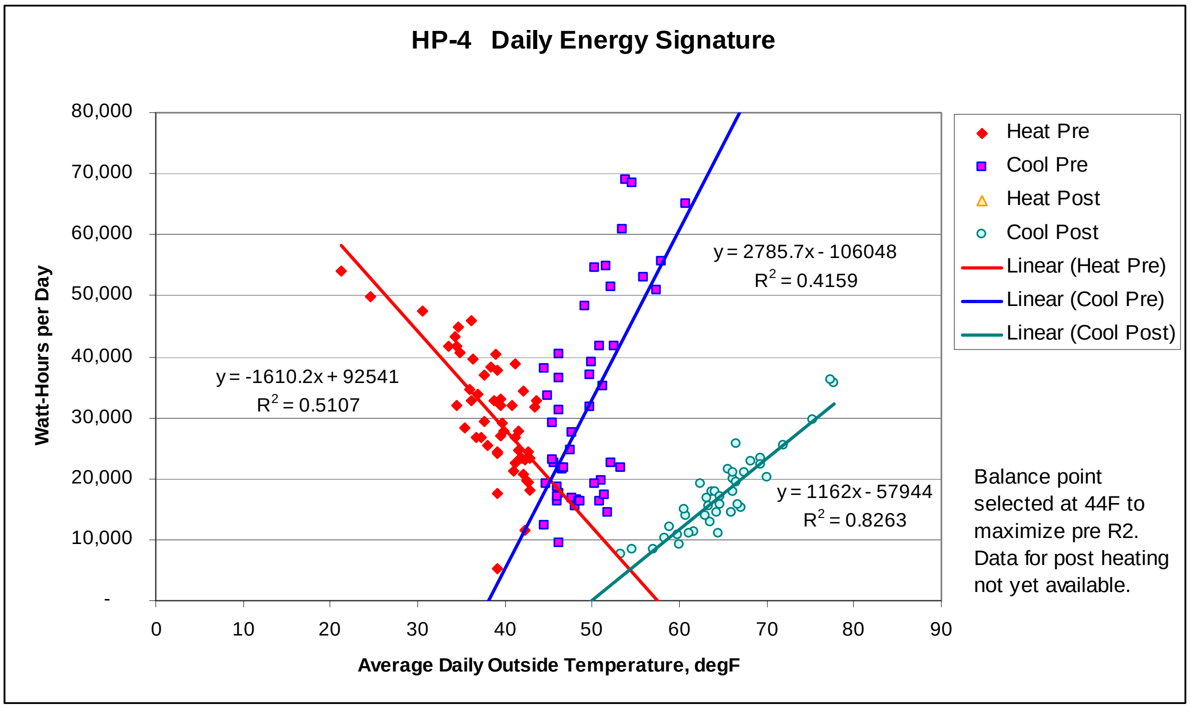
## *Monitoring Based Analysis Procedures*

While there are many possible ways to analyze monitored data, four were investigated at this stage of results: Daily Energy Signature, Hourly Energy Signature, an Inverse Model with three change points, and a multi-variable regression. At this point, each model engages the entire data set and HP4 was the example used as it had clear savings and good pre and post cooling energy use. For the final analysis both HP3 and HP4 will be investigated. There will also be an exploration of separating occupied and unoccupied periods. AC-1 and AC-2 cannot be analyzed as they are lacking pre-period cooling use.

## Daily Energy Signature

**Daily Energy Signature**. This method is based on a comparison of daily average outside temperature vs total RTU Watt-hours. Regression lines for the pre and post period are established around an apparent balance point. For units without electric heat, the regression below the balance point is typically taken as horizontal. For heat pumps, the slope increases at outside temperature decreases. The method is developed by Howard Reichmuth at New Buildings Institute.[15] The data and regression lines for unit HP-4 are shown in Figure 24 with the exception of the post-period heating line as data was not yet available.

**Figure 24. Daily Energy Signature Model**

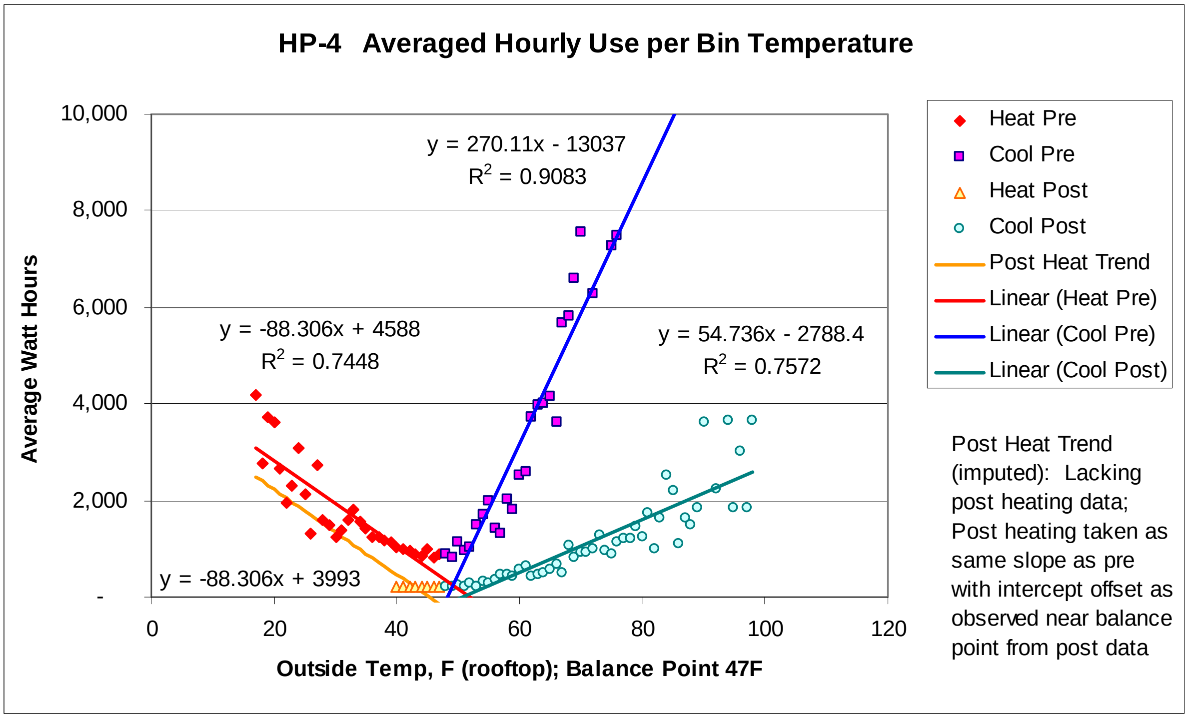



## Hourly Energy Signature

**Hourly Energy Signature.** Hourly average outside temperature vs total RTU Watt-hours. This method is developed in the context of the current project as an alternative approach. Hourly energy use for the pre- and post-period is averaged by one-degree outside temperature bins. In a similar fashion to the Daily Energy Signature, regression lines are developed separately for the heating and cooling range of temperatures as shown in Figure 25. While adequate post-period heating data is not available for an accurate model, there is adequate data in the hourly model to develop a base offset near the balance. This can be used to develop a conservative line parallel to the pre-period heating line. The actual post-period heating use is expected to be represented with a lower slope due to reduced ventilation.

[15] Howard Reichmuth and Mark Cherniack, "Commercial Rooftop HVAC Energy Savings Research Program: Final Project Report – Phase 2" (New Buildings Institute, March 2009).

**Figure 25. Hourly Signature Model**



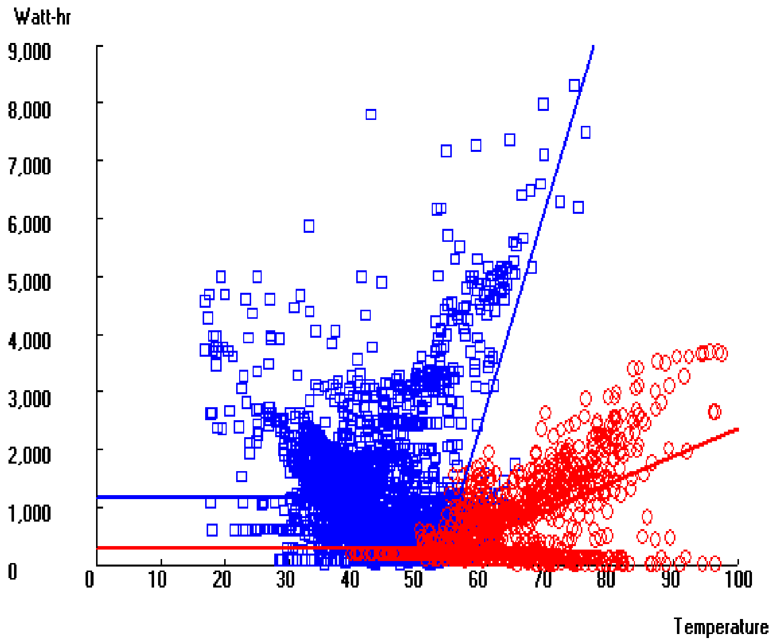

## Inverse Model with Three Change Points

Inverse Modeling with change points was developed under ASHRAE research project RP-1050[16] and is an accepted method under ASHRAE Guideline 14.[17] The inverse modeling approach analyzes the data and finds separate optimized liner regression models for the pre and post period and for heating, cooling, and possibly intermediate modes of operation. Here, the Energy Explorer computer program is used to find results for 2, 3, 4 and 5 point models as included in Appendix F. The 3-point model was selected for comparison here, because it produced the most acceptable results with the data given. When there is more complete post-heating data, a 5-point model is expected to be more accurate. The results are shown in Figure 26.

[16] J. K. Kissock, J. Haberl, and D. E. Claridge, "Inverse Modeling Toolkit (1050RP): Numerical Algorithms," *ASHRAE transactions* 109, no. Part 2 (2003): 425–434.

[17] ASHRAE, *ASHRAE Guideline 14-2002 Measurement of Energy and Demand Savings* (Atlanta, GA: ASHRAE, 2002).

**Figure 26. Change Point model**




## Hourly Multi-variable Regression

A multi-variable regression model was developed with hourly outside air temperature as the primary independent variable. An additional variable that proved significant was the 5-day average outside temperature, included to account for the fact that the seasonal impact affects HVAC energy use beyond the immediate hourly temperature.

A review of hourly pre and post heating and cooling energy use shown in Figure 27, demonstrates that the unoccupied and occupied periods have a big impact on energy use; hence the regression model has an occupied categorical variable. The importance of this variable is shown by the high codetermination with Watt-hours of both the Occupied variable and the Occupied*OAT interactive variable.

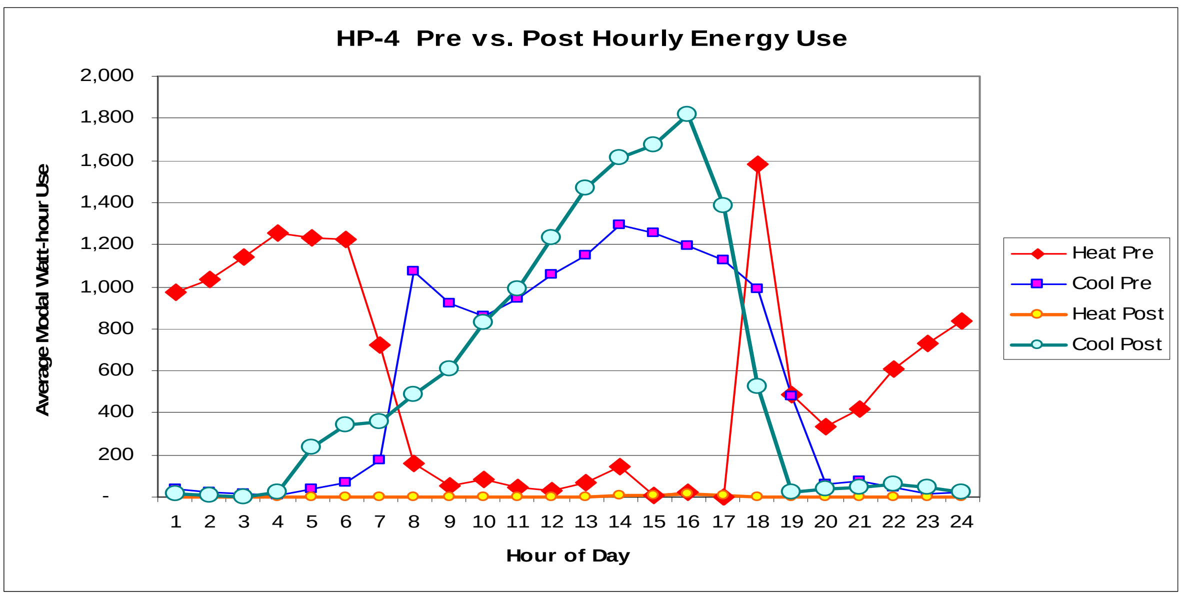
One problem with representing data with an obvious "V" shape with increasing energy use at both higher and lower temperatures is resolved by the inclusion of a categorical variable representing "heating." Interactive variables are included where significant. The overall interactive regression analysis has an $R^2$ of 0.452 as compared with an $R^2$ of 0.188 when interactive variables are not included.

**Table 5. Multi-Variable Regression Analysis**

| *Independent Variable* | *Explanation* | *Coefficients* | | *Codetermination with Watt-hours* | *Interactive P-value* |
|---|---|---|---|---|---|
| | | *separate* | *interactive* | | |
| Intercept | | -3678.79 | -4371.17 | | **6.7E-39** |
| ECM | A categorical variable 0 for the pre condition and 1 for the post condition after retrofit | -807.16 | 2434.48 | **5.1%** | **1.9E-16** |
| Occupied | A categorical variable: 0 for unoccupied periods and 1 for occupied periods based on a general schedule | 576.77 | -3569.57 | **7.9%** | **1.5E-107** |

| | | | | | |
|---|---|---|---|---|---|
| OAT Seasonal | The moving average of the outside temperature for the previous 5 days to give the impact of season on the building similar to the daily average approach | 75.35 | 74.01 | 1.8% | **1.6E-42** |
| OAT (Avg Hr) | The outside air temperature for the hour | 20.53 | 28.49 | 0.1% | **6.4E-07** |
| Heating | A categorical variable 0 when outside air is above an assumed balance point and 1 when below. The balance point can be taken from a review of binned baseline results, although that is not strictly independent. The seasonal winter average temperature is a good proxy and is strictly independent | 510.59 | 6182.69 | 0.8% | **2.9E-85** |
| ECM*Heat | Interactive impact of ECM*Heat | | -929.74 | 0.2% | **1.1E-03** |
| ECM*Occ | Interactive impact of ECM*Occupied | | -1618.97 | 0.3% | **3.1E-55** |
| ECM*OAT | Interactive impact of ECM*OAT | | -50.73 | **3.3%** | **3.2E-19** |
| Heat*OAT | Interactive impact of Heat*OAT | | -133.83 | 0.2% | **6.0E-81** |
| Occ*OAT | Interactive impact of Occupied*OAT | | 91.57 | **10.6%** | **1.1E-137** |

**Figure 27. Pre and Post Energy Use by Hour of Day**




## Comparison of Alternative Annualized Results

While the primary purpose of this study is proof of concept, the various monitor-based models are compared in Table 6. It should be noted that the first three models are based on a dataset that excluded weekends, while the multivariable regression accounts for occupied and unoccupied periods so the projection adjusts for weekends. To provide better comparison, the first three model results are adjusted, based on weekend energy savings being much less than occupied period savings. Annual energy use for baseline and measure is projected as follows:

- Daily Energy Signature regressions are applied to annual single-degree bin hours of average daily temperatures based on TMY hourly weather data.
- Hourly Energy Signature and Inverse Model Signature regressions are applied to annual single-degree temperature bin hours based on TMY hourly weather data.

- The multi-variable regression is applied to TMY hourly weather data with an hourly and 5-day moving average of outside temperature along with a presumed schedule of occupied periods based on observation of the system shown in Figure 27.

**Table 6. Comparison of Annualized Results from Four Data Models**

| | Monitored Period (kWh) | | TMY Annual Projection (kWh) | | | | | |
|---|---|---|---|---|---|---|---|---|
| Method | Pre | Post | Pre | Post | Savings | | Adjusted Savings** | |
| Actual Monitoring | 3,201 | 711 | | | | | | |
| Day Signature* | 3,201 | 709 | 17,072 | 2,434 | 14,638 | 86% | 12,152 | 71% |
| Hour Signature | 2,948 | 761 | 20,570 | 4,336 | 16,234 | 79% | 13,477 | 66% |
| ChangePoint (3) | 3,166 | 711 | 21,492 | 3,850 | 17,642 | 82% | 14,645 | 68% |
| MV Regression | | | 16,224 | 7,410 | 8,814 | 54% | 8,814 | 54% |

*Day signature did not have post heating use calculated

**First 3 models are adjusted since weekends and holidays were not included in base data

- Monitor-based model projections of annual adjusted savings range from 2200 to 3600 kWh per ton of installed cooling based on this particular 4-ton heat pump.
- Original estimates were 470 to 900 kWh per ton in Eugene Oregon, based on expected value adjusted hourly simulations.[18]
- This particular unit, HP-4, has high savings for two possible reasons. The pre-period had excessive post-occupancy heating starting in late November (see Figure 14 and Figure 15). The thermostat was set for continuous fan operation for all but the final weeks of the post period, resulting in a beneficial—if unintended—night flush effect that reduced cooling energy use as seen in Figure 16 and Figure 17.
- HP-3 also has pre-period cooling and will be investigated in the final report after fall data is collected.

## Energy Savings Results

- At one site where adequate pre- and post-data was available, the preliminary estimate of savings appears to be reasonable, although at this site, other contributors to savings were present.
- The monitored data was evaluated using four methods. Once additional winter post data is available, the other heat pump will be evaluated in Task 8. The gas-heated units did not have adequate pre-retrofit cooling activity to allow savings analysis. Each method uses the same data, whole unit energy use vs. outside air temperature. The multi-variable regression adds occupied period information. The methods are:
    - Daily Energy Signature
    - Hourly Energy Signature
    - Inverse Model with three change points
    - Multi-variable regression.
- Monitoring methods based on daily and hourly averages of energy consumption vs. outside air temperature are both appropriate to evaluate package savings effectiveness; however, collecting enough data when there are heating savings can be challenging. Two season savings cannot be verified with a limited 2-week pre- and post-period. A more sophisticated change point of hourly energy consumption vs. outside air temperature or multi-variable

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[18] Reid Hart, "Premium Ventilation Package Testing: Decision Framework Matrix Report – Task 5" ([PECI] Portland Energy Conservation, Inc, October 2008), for [BPA] Bonneville Power Administration.

regression did not appear to improve savings projection accuracy. The multi-variable analysis did show that occupancy was highly significant, and an hourly average approach with separate occupied and unoccupied periods may be the approach of choice. Such an approach will be tested in Task 8 once there is adequate post-period heating data. The average hourly approach does provide more overlap in pre- and post-data for short term monitoring periods than the daily average approach.

- A significant issue for the premium ventilation package savings is the baseline assumption that the fan is on in commercial facilities during occupied periods. Large field studies[19] have indicated around 37% of RTUs have fans cycling during the occupied period. The same studies found that many fans are unnecessarily operating continuously. This condition will reduce the actual savings from either VSD or cycling based premium ventilation packages. This loss of savings will likely be offset by units that have a proper unoccupied schedule established as part of the package installation. The impact on savings will be evaluated in the Task 8 extended study savings analysis.

# Conclusions

Several conclusions can be drawn from this work:

- Based on this and prior installation experience, even with quite experienced technicians, analog type controllers and separate components that need to be field wired on the roof are problematic. While they can be made to work, longer term persistence of savings will be supported by a digital controller that is more straightforward to setup and test.
- The lower cost variable frequency drives do function properly, but care must be taken to install them with the appropriate motors. While this can be a cost effective approach where continuous air flow is desired; acceptable ventilation at a lower cost can be provided with a DCV Integrated Fan Control approach that cycles the fan when not needed for ventilation or temperature control.
- The difference between $CO_2$ concentration for a small number of rooms and the return air was much less drastic than conditions experienced in large VAV systems where the critical zones are small relative to the large area served.
- Ventilation control with a return-air $CO_2$ sensor can be effective with a minor adjustment in setpoint. Controlled ventilation certainly provides better ventilation than a system with the fan in the automatic setting.
- At one site where data was available, the preliminary estimate of savings appears to be reasonable, although at this site, other contributors to savings were present.
- Monitoring methods based on daily and hourly averages are appropriate for a range of units; however, collecting enough data when there are heating savings can be challenging. A more sophisticated change point or multi-variable regression did not appear to add accuracy. The multi-variable analysis did show that occupancy was highly significant, and an hourly average approach with separate occupied and unoccupied periods may be the approach of choice. Such an approach will be tested once there is adequate post-period heating data.
- There is significant savings resulting from this approach, but now that custom programmable thermostats are available, a digital approach should be tested before pilot program deployment.

[19] Pete Jacobs and Archetectural Energy Corporation (AEC), *Small HVAC system design guide* (Sacramento, Calif.): California Energy Commission, 2003), http://openlibrary.org/b/OL17622999M/Small-HVAC-system-design-guide.

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# Appendix A: Supplemental Acceptance Testing Checklist

The enclosed supplemental acceptance testing checklist is preliminary and has not been field tested. It would be field tested and revised during the field pilot portion of the Expected Value Savings Development.

## Appendix A: Supplemental Acceptance Testing Checklist

Note: preliminary version; requires field testing with multiple contractors

| Premium Ventilation Package<br>Functional Test Procedure<br>Supplement to standard acceptance testing | | | | | |
|---|---|---|---|---|---|
| **Mode of Operation** | **Step** | **Premium Vent Component Tested** | **Test Procedure** | **Data, or pass/fail** | **Initials, date, time** |
| | 1 | | Note the programmed operating schedule of the unit, and the occupied / unoccupied temperature setpoints. | 'On' schedule: ________________<br>Occ setpoints: ___ºF clg, ___ºF htg<br>Unocc setpoints: ___ºF clg, ___ºF htg | |
| | 2 | | Does the operating schedule match the occupied period? (y=pass, n=fail, note differences) | | |
| | 3 | | Note the as-found economizer lockout setpoint. | Setpoint: ____ºF | |
| Warm-Up | 4 | | Put the system in unoccupied (off) mode. Adjust the night setback setpoint as necessary to trigger the warm-up cycle. Note the actual space temperature and night setback setpoint. | Space temp: _____ºF<br>Setback setpoint: _____ºF | |
| | 5 | | Is the fan on? (y=pass, n=fail) | | |
| | 6 | | Note the speed of the fan. | ____ rpm, or ____ Hz | |
| | 7 | Ventilation lockout | Is the outside air damper closed? (y=pass, n=fail) | | |
| | 8 | Ventilation lockout | Are damper seals installed on the outside air damper to limit leakage during morning warm-up? (y=pass, n=fail) | | |
| | 9 | Optimum Start | Is the thermostat's optimum start setting activated? (y=pass, n=fail) | | |
| Normal Occupied | 10 | | Program the schedule so that the unit is operating in occupied mode. Return the temperature setpoints to the as-found condition, noted in step 1. | | |
| Occupied, no heat or cool | 11 | VSD | Disable any call for heating or cooling. Note the speed of the fan. | ____ rpm, or ____ Hz | |
| | 12 | VSD | Is the fan speed less than the speed noted in step 6? (y=pass, n=fail) | | |

| Mode of Operation | Step | Premium Vent Component Tested | Test Procedure | Data, or pass/fail | Initials, date, time |
|---|---|---|---|---|---|
| Occupied, heating | 13 | Resistance heat lockout | Simulate a call for heating by raising the thermostat setpoint. Simulate an outside air temperature greater than 35ºF, or note the outside air temperature if it is already above 35ºF. | OAT: ____ºF | |
| | 14 | | Is the electric resistance heat locked out? (y=pass, n=fail) | | |
| | 15 | DCV | Note the range of the CO2 sensor output, and the corresponding CO2 levels. For example, "0-10 volt sensor output. 0 volts at 0 ppm CO2, 10 volts at 5,000 ppm CO2." | volts or milliamps, and CO2 levels | |
| | 16 | DCV | Note the demand controlled ventilation (DCV) activation setting (volts or milliamps). | ____ volts, or ____ milliamps | |
| | 17 | DCV | Calculate the corresponding CO2 level related to this setting. | ____ ppm CO2 | |
| | 18 | DCV | Is CO2 level between 900 ppm and 1,000 ppm? (y=pass, n=fail) | | |
| | 19 | DCV | Note the location of the CO2 sensor. | | |
| Occupied, heating, high CO2 | 20 | DCV | Lower the DCV activation setting to below the current CO2 level, or simulate a high CO2 level using a voltage / milliamp source. Note the activation level. | CO2: ____ or volts: ____ or milliamps: ___ | |
| | 21 | DCV | Is the outside air damper 100% open? (y=pass, n=fail) | | |
| | 22 | DCV | Is the return air damper 100% closed? (y=pass, n=fail) | | |

| Mode of Operation | Step | Premium Vent Component Tested | Test Procedure | Data, or pass/fail | Initials, date, time |
|---|---|---|---|---|---|
| Occupied, cooling, hot OAT, low CO2 | 23 | | Raise the DCV activation setting to the maximum setting possible, to temporarily lock out the DCV. Alternatively, simulate 0 ppm CO2 using a voltage / milliamp source. Note the activation level. | CO2: ____ or volts: ____ or milliamps: ___ | |
| | 24 | min OA | Simulate a call for cooling. Lower the economizer lockout setpoint to below the current outside air temperature (to simulate hot OA temp). Note the space temperature and the outside air temperature. | Space temp: ____ºF<br>OAT: ______ºF | |
| | 25 | min OA | Note the position of the outside air damper (visual estimate). | % open: _______ | |
| | 26 | min OA | Adjust the minimum damper position setting / dial, visually verify that the damper moves in response. (moves=pass, doesn't move=fail) | | |
| | 27 | min OA | If the outside air temperature is below 60ºF or above 85ºF, note the return air, outside air, and mixed air temperatures. | RAT: ____ºF<br>OAT: ____ºF<br>MAT: ____ºF | |
| | 28 | min OA | Calculate the % minimum outside air using the following equation: % OSA = (MAT-RAT) / (OAT-RAT) * 100 | % OSA: ______ | |
| | 29 | min OA | Is the mechanical cooling operating? (y=pass, n=fail) | | |
| | 30 | VSD | Is the fan speed the same as the speed noted in step 6? (y=pass, n=fail) | | |
| Occupied, cooling, cold OAT, low CO2 | 31 | | Return the economizer lockout setpoint to its normal position (step 3). | | |
| | 32 | Economizer | Simulate cool outside air conditions (<55ºF) by either adjusting the lockout setting to below the current OAT, using a cold spray on the OAT sensor, or make no adjustment if the actual OAT<55ºF. Note the method of simulation. | Simulation method (circle one):<br>- Adjust lockout setting<br>- Cold spray<br>- Actual OAT ___ºF. | |
| | 33 | Economizer | Simulate a call for cooling. Does stage one cooling activate the economizer? (y=pass, n=fail) | | |
| | 34 | Economizer | Is the mechanical cooling operating during stage one cooling? (n=pass, y=fail) | | |
| | 35 | Economizer | Is the fan speed the same as the speed noted in step 6? (y=pass, n=fail) | | |
| Return to normal | 36 | DCV | Return the DCV activation setting to a setting that corresponds to 1,000 ppm. Note the activation setting (volts or milliamps). | ____ volts, or ____ milliamps | |
| | 37 | | Return the system to 'auto'. Return the operating schedule and occupied / unoccupied temperature setpoints to the as-found condition (step 1). Return the economizer lockout setting to the as-found condition (step 3). | | |

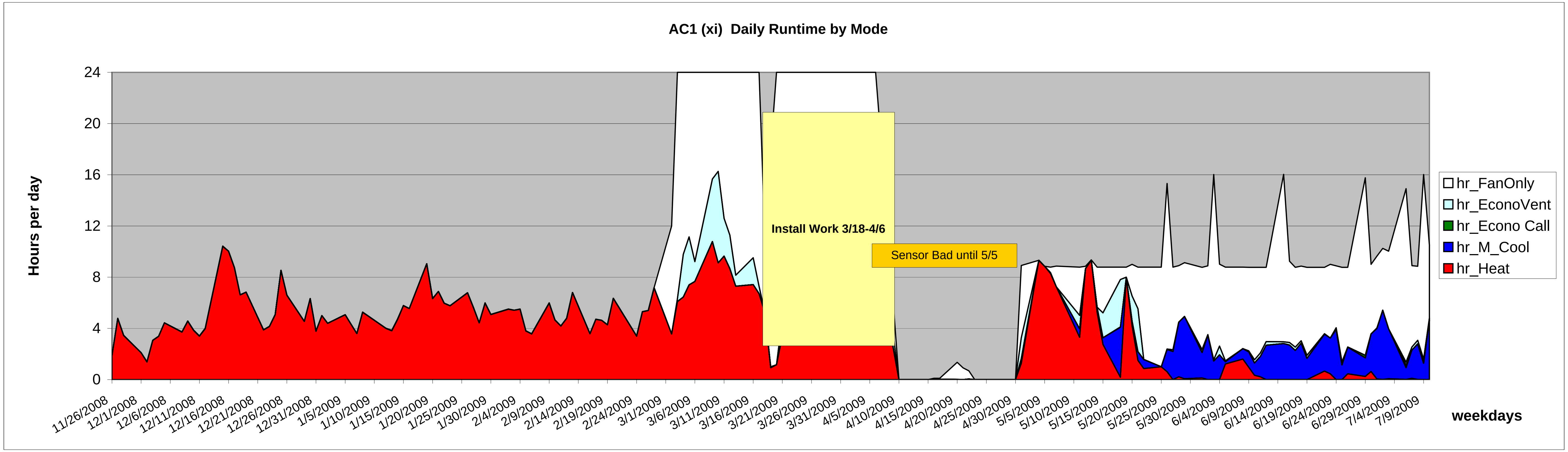
# Appendix B: Daily Data Visualization

Daily data visualization graphs for the entire monitoring period to date are included for the four monitored units:

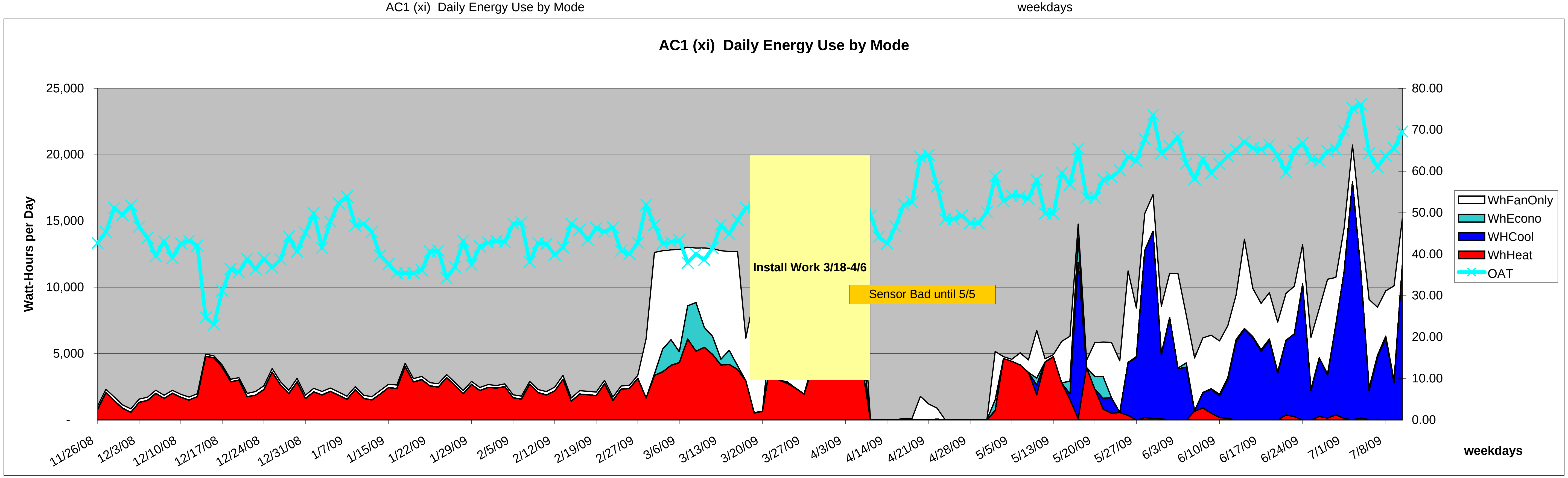
AC-1, AC-2, HP-3, HP-4

Note: the HP-4 page has full-size graphics for
Figure 12. HP-4 Shows Excessive Fan Operation in Post Period
Figure 13. HP-4 - Excessive Fan Operation Mitigated by VSD

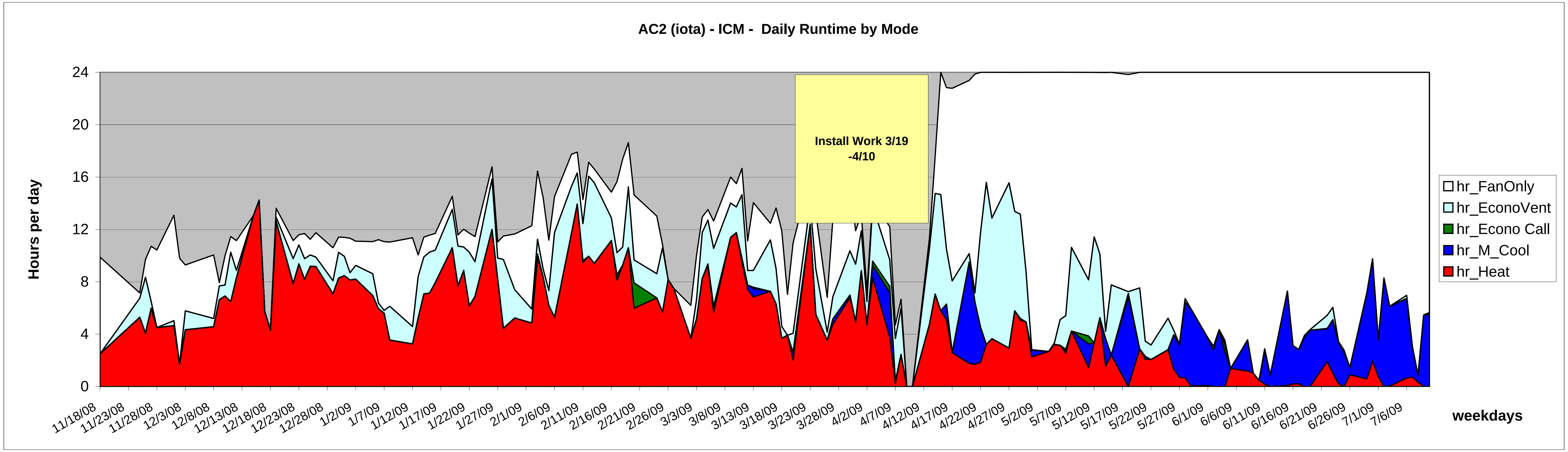
CSC-RTU-1 Unit: **AC1 (xi)** AC1 (xi) Daily Runtime by Mode **weekdays**



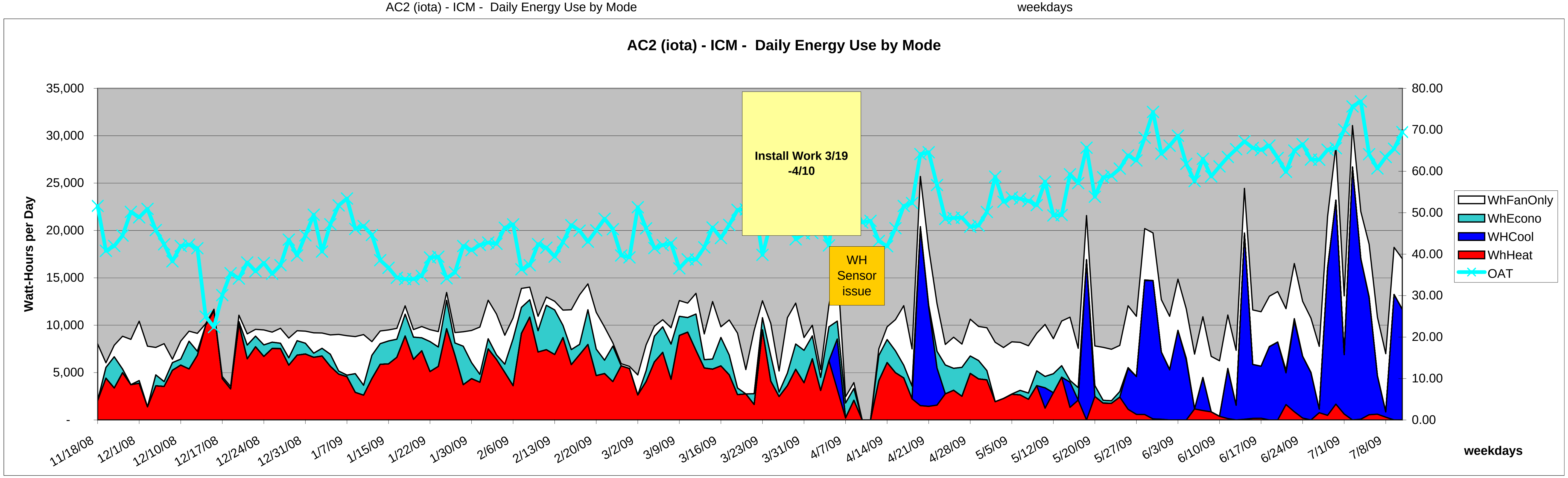

AC1 (xi) Daily Energy Use by Mode weekdays



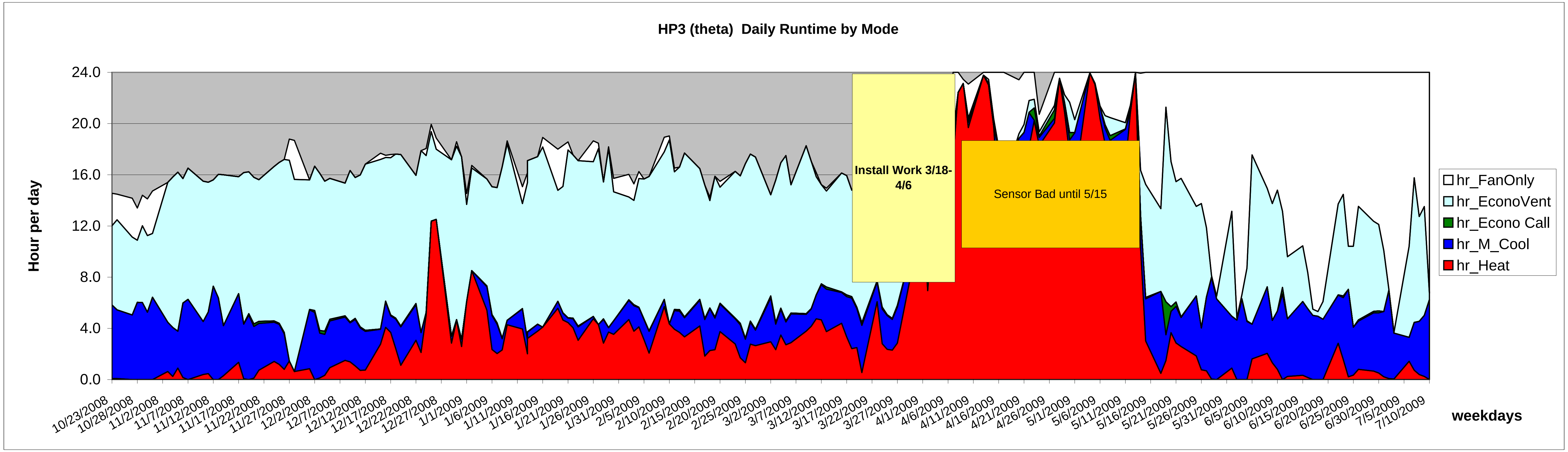
CSC-RTU-2-Iota Unit: **AC2 (iota) - ICM -** AC2 (iota) - ICM - Daily Runtime by Mode **weekdays**



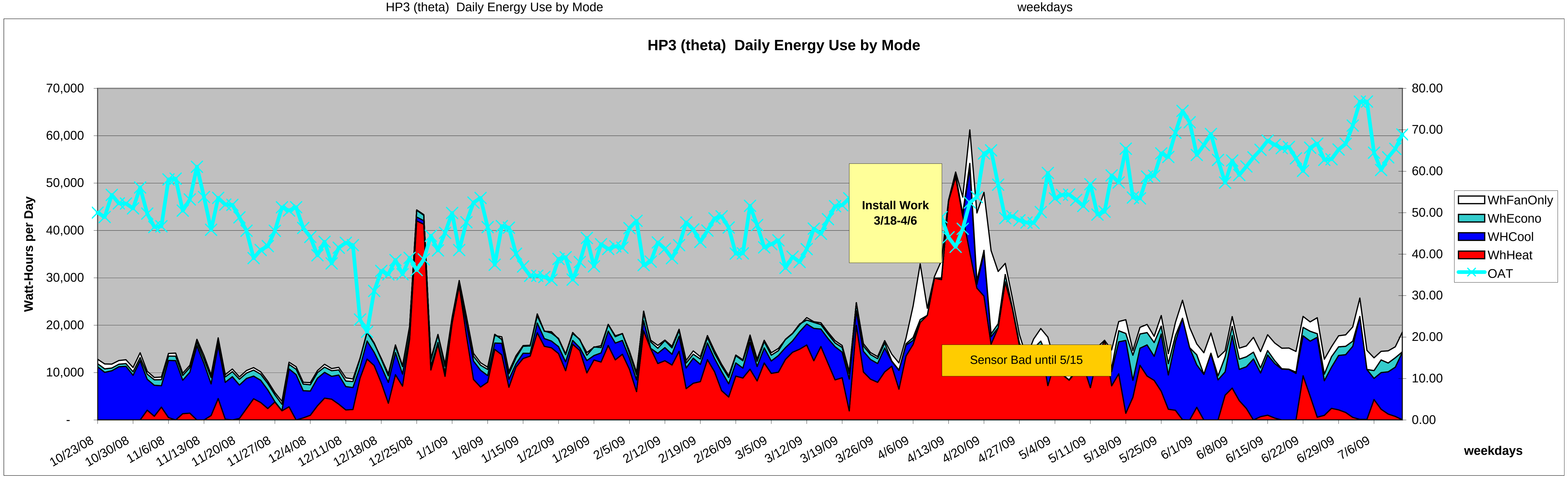

AC2 (iota) - ICM - Daily Energy Use by Mode weekdays

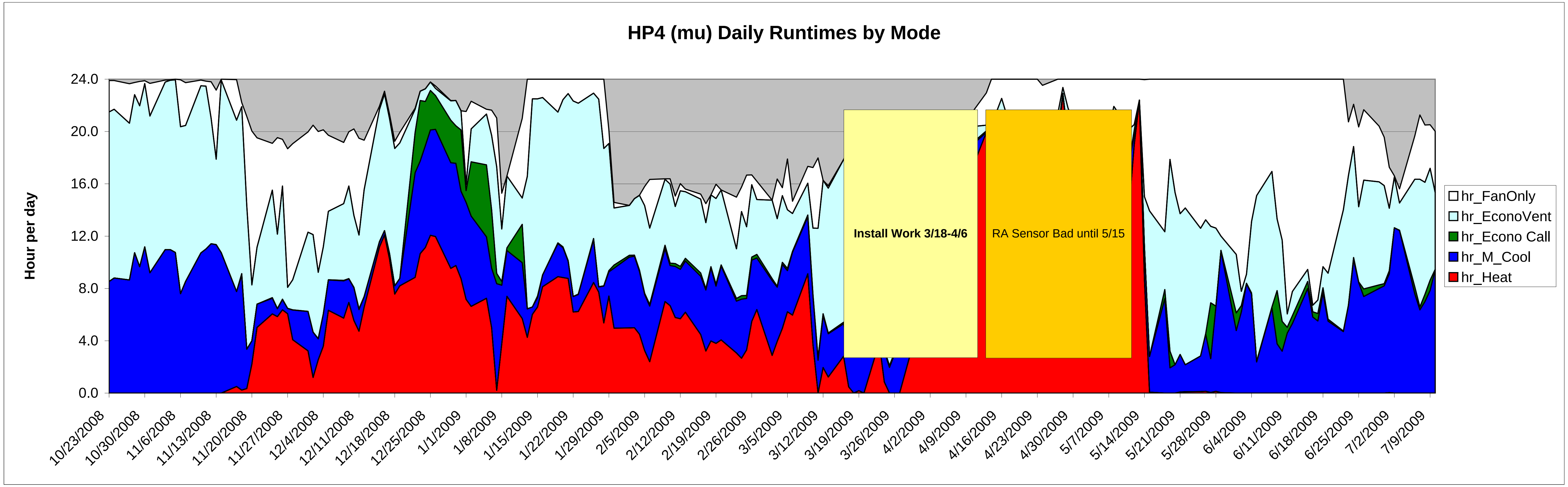


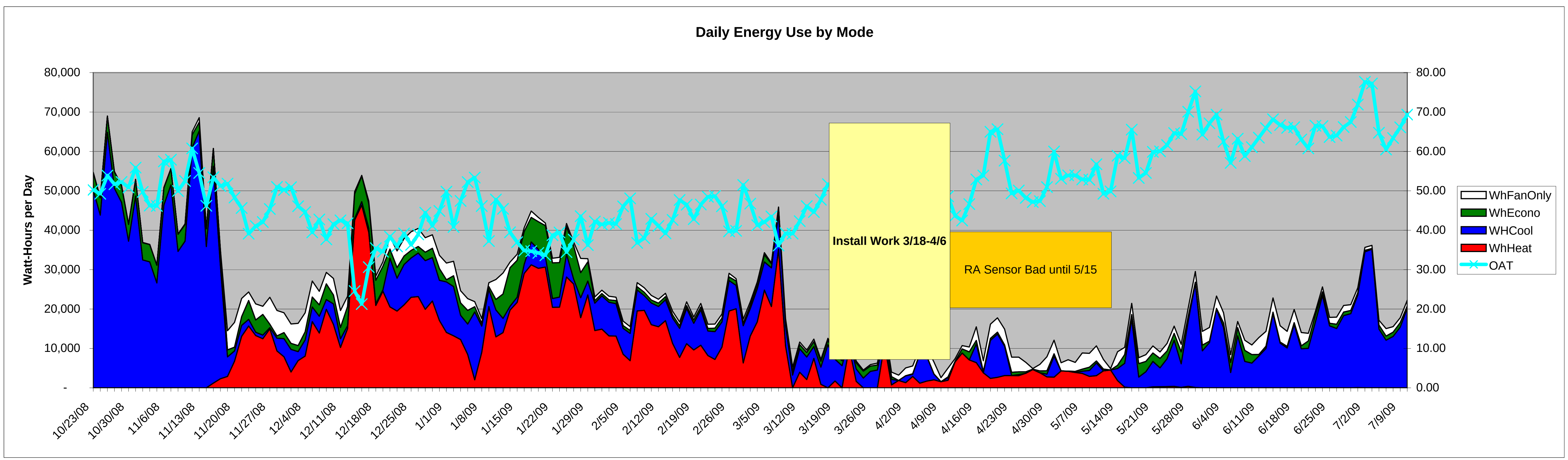
CSM-RTU-3 Unit: **HP3 (theta)** HP3 (theta) Daily Runtime by Mode **weekdays**




HP3 (theta) Daily Energy Use by Mode weekdays




HP4 (mu) Daily Runtimes by Mode
Hour per day
Install Work 3/18-4/6
RA Sensor Bad until 5/15
hr_FanOnly
hr_EconoVent
hr_Econo Call
hr_M_Cool
hr_Heat


Daily Energy Use by Mode
Watt-Hours per Day
Install Work 3/18-4/6
RA Sensor Bad until 5/15
WhFanOnly
WhEcono
WHCool
WhHeat
OAT

# Appendix C: Revised Premium Ventilation Specification

## *Premium Ventilation Package Outline Specifications*

The following basic items and checks must be included to meet requirements:

- Fully modulating damper motor with outside and return air dampers
- Proportional damper control
- Coordinated control, that is, the economizer only operates on a call for cooling
- Relief air damper in return ductwork upstream of return air damper-barometric or motor driven

### Western Premium OSA Economizer Requirements

The following items and checks must be included to meet requirements for a *Western Premium Economizer*:

- Dedicated thermostat cooling stage for economizer
- Dry-bulb changeover (not enthalpy)
- Differential changeover with both return and outside air sensors; hysteresis for outside air reset shall be 2°F or less. For Honeywell analog controllers, single outside changeover with the selectable C7660 sensor shall meet requirements.
- Primary sensor for damper control placement: in the discharge air position with a DX coil, and in the mixed air position with a chilled-water coil
- Low-ambient OSA compressor lock out, set to lock out mechanical cooling when outside air is less than 60°F
- Advanced documented checkout
- Cooling coil delta (split) temperature no more than 25°F and no less than 10°F when mechanical cooling is operating

### Premium Ventilation Package Requirements

These requirements are in addition to the *Western Premium Economizer* requirements:

- Return air and outside air dampers have low-leakage seals for new units. For retrofits, any visible damper gaps greater than 1/8" will be sealed with UV rated adhesive backed foam insulation
- Demand controlled ventilation via $CO_2$ sensor, set to activate ventilation no lower than 900 ppm $CO_2$
- Variable speed fan control with integrated controls or relays and VSD setup to lower speed to half or lower when heating, cooling, and economizer are not active. When economizer cooling is called for,
- Premium ventilation supplemental acceptance testing

## *Typical Equipment Requirements*

While there may be variation in equipment to upgrade a particular installation, the following items are typically needed. Suggested items for a unit with gas furnace and air conditioning are listed:

- Replace economizer controller with Honeywell W7212A, or controller with equal capabilities
- Where necessary, replace damper actuator motor for compatibility with controller. For Honeywell M7415 actuator motor, replace with M7215.

- Equip with changeover temperature sensors, including outside and either return air or space temperature. For Honeywell analog controllers, require single outside air selectable temperature sensor Honeywell C7660.
- Optional solar radiation shield for OSA sensor: Ambient Weather SRS100LX Temperature and Humidity Solar Radiation Shield; Davis 7714 - Passive Radiation Shield (may require modification); or equal. Note that Honeywell C7660 sensor must be mounted in airstream for proper operation.
- Upgrade thermostat to a programmable thermostat with optimum start, 7-day programming, and one more stage of cooling control than the number of stages in the rooftop unit.
- Replace thermostat wiring if necessary.
- Provide, install and wire $CO_2$ sensor with 0 to 10 VDC output or other output that matches economizer controller requirements: Honeywell C7242, AirTest eSENSE 9290-L or 9291, Veris CO2 CDE, BAPI BA/AQS-D-10 or BA/AQS-R-10 or equal.
- Provide, install and wire VSD fan drive
    - For fan motors 1.5HP or less not equipped with start capacitors, use VSD with integrated control and sensors: ICM CC750, Fan Handler FAC-120/240 or equal. Fan handler will require additional relay to operate the fan motor at full speed during economizer operation.
    - For larger fan motors, use compatible VSD by ABB or equal. Utilize relays wired to activate appropriate fan speed setting during economizer, heating, or cooling modes and activate low (40% to 50%) fan speed when fan operation is called for otherwise.
- In some cases a VSD motor combination will result in excess noise and the motor will need replacement. Baldor (among others) makes specially designed blower motors for speed control applications ranging from ¼ HP to 1 HP size, equipped with ball bearings, electrically reversible, 48 frame, 1075 rpm, 3-speed, 50° rise.
- Install foam weather stripping seals on damper blade edges or where there are gaps between damper edge and damper casing if seals are not present.
- Check out and complete supplemental acceptance testing of unit.

## Recommended Settings

- Schedule: match business hours and enable optimum start
- Fan: On during occupied and cycle during unoccupied
- Heating Temperature setpoint: 70$^{o}$F occupied; 60$^{o}$F unoccupied.
- Cooling temperature setpoint: 76$^{o}$F occupied; 80$^{o}$F unoccupied.
- Outside air changeover for economizer: 68 $^{o}$F or 73 $^{o}$F if not differential
- Outside air minimum: cfm/square foot served by RTU based on occupancy type. Note that this minimum airflow may be met with damper leakage in the closed position. See ASHRAE Standard 62.1 for occupancy categories not listed:
    - Office building, warehouses, public assembly: 0.06 cfm/square foot
    - Classrooms, libraries, retail sales: 0.12 cfm/square foot
    - Dining, day care, laboratories, workshops: 0.18 cfm/square foot
- Demand controlled ventilation activation point:
    - 1000 parts per million $CO_2$ for units serving single rooms or multiple rooms with low density occupancy
    - 900 parts per million $CO_2$ for units serving multiple rooms that are likely to have high density occupancy (more than 20 people per 1000 square feet) such as conference rooms, classrooms, dining rooms, etc.

- Where occupancy is low density, or where any single room that may have high density occupancy is more than 25% of the floor area served, a single $CO_2$ sensor may be located in the room where highest density is anticipated or the return air (except in California). Where high density areas are less than 25% of the floor area served, separate $CO_2$ sensors should be located in the breathing zone of each space where high density is expected, and the highest $CO_2$ reading be used for ventilation control.
- Maximum ventilation. Many DCV controllers are equipped with a maximum ventilation setpoint to avoid lack of capacity during transient states or when a $CO_2$ sensor is subjected to direct exhale in the breathing zone. This setpoint should allow ventilation up to the airflow amount required by ASHRAE Standard 62.1 if all rooms served are fully occupied.

# Appendix D: Updated Opinion of Probable Cost

**Basecase 'RTU':**
Electric cooling, gas heating rooftop unit

**Basecase 'HP':**
Electric cooling, gas heating rooftop unit

**ECM case:**
Unit with premium ventilation package

Costs in table below represent the cost of retrofitting a basecase unit with the Premium Ventilation package measures.
The Premium Ventilation package includes the following measures:
- Optimum start
- Resistance heat lockout (for heat pumps)
- Morning warm-up ventilation lockout with improved damper seals
- Integrated economizer, differential dry bulb control
- Variable speed drive (VSD) on supply fan (Fan Handler or ICM CC750)
- Demand controlled ventilation (DCV)

| | | | Materials | | Labor | | | |
|---|---|---|---|---|---|---|---|---|
| **Item Description** | **Quantity** | **Units** | **Unit Price** | **Amount** | **Unit Price** | **Amount** | **Total** | **Source of prices** |
| Honeywell IAQ programmable thermostat | 1 | ea | $240 | $240 | $0 | $0 | $240 | Climate Control quote, backed out O&P |
| Western Premium Controls | 1 | ea | $167 | $167 | $0 | $0 | $167 | Climate Control quote, backed out O&P |
| CO2 sensor | 1 | ea | $379 | $379 | $0 | $0 | $379 | Climate Control quote, backed out O&P |
| Supply fan speed control (Fan Handler or ICM CC750) | 1 | ea | $369 | $369 | $0 | $0 | $369 | Climate Control quote, backed out O&P |
| Economizer damper controller and motor | 1 | ea | $406 | $406 | $0 | $0 | $406 | Adjusted Climate Control quote, backed out O&P |
| Labor | 1 | ea | $0 | $0 | $163 | $163 | $163 | Adjusted Climate Control quote, backed out O&P |
| Electric heat lockout sensor (Basecase 'HP' only) | 1 | ea | $56 | $56 | $0 | $0 | $56 | Climate Control quote, backed out O&P |
| | | | | | Subtotal | | $1,724 | |
| **Basecase 'RTU'** | | | | | Overhead and profit | 20% | $345 | |
| | | | | | **Total Cost** | | **$2,069** | |
| | | | | | Subtotal | | $1,780 | |
| **Basecase 'HP'** | | | | | Overhead and profit | 20% | $356 | |
| | | | | | **Total Cost** | | **$2,136** | |

**Basecase 'RTU':**
Electric cooling, gas heating rooftop unit

**Basecase 'HP':**
Electric cooling, gas heating rooftop unit

**ECM case:**
Unit with premium ventilation package

Costs in table below represent the cost of retrofitting a basecase unit with the Premium Ventilation package measures.
The Premium Ventilation package includes the following measures:
- Optimum start
- Resistance heat lockout (for heat pumps)
- Morning warm-up ventilation lockout with improved damper seals
- Integrated economizer, differential dry bulb control
- Variable speed drive (VSD) on supply fan (Fan Handler or ICM CC750)
- Demand controlled ventilation (DCV)

| | | | Materials | | Labor | | | |
|---|---|---|---|---|---|---|---|---|
| **Item Description** | **Quantity** | **Units** | **Unit Price** | **Amount** | **Unit Price** | **Amount** | **Total** | **Source of prices** |
| Honeywell IAQ programmable thermostat | 1 | ea | $240 | $240 | $0 | $0 | $240 | Climate Control quote, backed out O&P |
| Western Premium Controls | 1 | ea | $167 | $167 | $0 | $0 | $167 | Climate Control quote, backed out O&P |
| CO2 sensor | 1 | ea | $379 | $379 | $0 | $0 | $379 | Climate Control quote, backed out O&P |
| Supply fan speed control (Fan Handler or ICM CC750) | 1 | ea | $369 | $369 | $0 | $0 | $369 | Climate Control quote, backed out O&P |
| Economizer | 1 | ea | $657 | $657 | $0 | $0 | $657 | Climate Control quote for RTUs, backed out O&P |
| Labor | 1 | ea | $0 | $0 | $283 | $283 | $283 | Climate Control quote for RTUs, backed out O&P |
| Electric heat lockout sensor (Basecase 'HP' only) | 1 | ea | $56 | $56 | $0 | $0 | $56 | Climate Control quote, backed out O&P |
| | | | | | Subtotal | | $2,095 | |
| **Basecase 'RTU'** | | | | | Overhead and profit | 20% | $419 | |
| | | | | | **Total Cost** | | **$2,514** | |
| | | | | | Subtotal | | $2,151 | |
| **Basecase 'HP'** | | | | | Overhead and profit | 20% | $430 | |
| | | | | | **Total Cost** | | **$2,581** | |

**Basecase 'RTU':**
Electric cooling, gas heating rooftop unit

**Basecase 'HP':**
Electric cooling, gas heating rooftop unit

**ECM case:**
Unit with premium ventilation package

Costs in table below represent the cost of retrofitting a basecase unit with the Premium Ventilation package measures.
The Premium Ventilation package includes the following measures:
- Optimum start
- Resistance heat lockout (for heat pumps)
- Morning warm-up ventilation lockout with improved damper seals
- Integrated economizer, differential dry bulb control
- Variable speed drive (VSD) on supply fan (ABB VSD)
- Demand controlled ventilation (DCV)

| | | | Materials | | Labor | | | |
|---|---|---|---|---|---|---|---|---|
| **Item Description** | **Quantity** | **Units** | **Unit Price** | **Amount** | **Unit Price** | **Amount** | **Total** | **Source of prices** |
| Honeywell IAQ programmable thermostat | 1 | ea | $240 | $240 | $0 | $0 | $240 | Climate Control quote, backed out O&P |
| Western Premium Controls | 1 | ea | $167 | $167 | $0 | $0 | $167 | Climate Control quote, backed out O&P |
| CO2 sensor | 1 | ea | $379 | $379 | $0 | $0 | $379 | Climate Control quote, backed out O&P |
| Supply fan speed control (ABB VSD) | 1 | ea | $536 | $536 | $0 | $0 | $536 | Climate Control quote, backed out O&P |
| Economizer damper controller and motor | 1 | ea | $406 | $406 | $0 | $0 | $406 | Adjusted Climate Control quote, backed out O&P |
| Labor | 1 | ea | $0 | $0 | $163 | $163 | $163 | Adjusted Climate Control quote, backed out O&P |
| Electric heat lockout sensor (Basecase 'HP' only) | 1 | ea | $56 | $56 | $0 | $0 | $56 | Climate Control quote, backed out O&P |
| | | | | | Subtotal | | $1,890 | |
| **Basecase 'RTU'** | | | | | Overhead and profit | 20% | $378 | |
| | | | | | **Total Cost** | | **$2,269** | |
| | | | | | Subtotal | | $1,946 | |
| **Basecase 'HP'** | | | | | Overhead and profit | 20% | $389 | |
| | | | | | **Total Cost** | | **$2,336** | |

**Basecase 'RTU':**
Electric cooling, gas heating rooftop unit

**Basecase 'HP':**
Electric cooling, gas heating rooftop unit

**ECM case:**
Unit with premium ventilation package

Costs in table below represent the cost of retrofitting a basecase unit with the Premium Ventilation package measures.
The Premium Ventilation package includes the following measures:
- Optimum start
- Resistance heat lockout (for heat pumps)
- Morning warm-up ventilation lockout with improved damper seals
- Integrated economizer, differential dry bulb control
- Variable speed drive (VSD) on supply fan (ABB VSD)
- Demand controlled ventilation (DCV)

| | | | Materials | | Labor | | | |
|---|---|---|---|---|---|---|---|---|
| **Item Description** | **Quantity** | **Units** | **Unit Price** | **Amount** | **Unit Price** | **Amount** | **Total** | **Source of prices** |
| Honeywell IAQ programmable thermostat | 1 | ea | $240 | $240 | $0 | $0 | $240 | Climate Control quote, backed out O&P |
| Western Premium Controls | 1 | ea | $167 | $167 | $0 | $0 | $167 | Climate Control quote, backed out O&P |
| CO2 sensor | 1 | ea | $379 | $379 | $0 | $0 | $379 | Climate Control quote, backed out O&P |
| Supply fan speed control (Fan Handler or ICM CC750) | 1 | ea | $536 | $536 | $0 | $0 | $536 | Climate Control quote, backed out O&P |
| Economizer | 1 | ea | $657 | $657 | $0 | $0 | $657 | Climate Control quote for RTUs, backed out O&P |
| Labor | 1 | ea | $0 | $0 | $283 | $283 | $283 | Climate Control quote for RTUs, backed out O&P |
| Electric heat lockout sensor (Basecase 'HP' only) | 1 | ea | $56 | $56 | $0 | $0 | $56 | Climate Control quote, backed out O&P |
| | | | | | Subtotal | | $2,262 | |
| **Basecase 'RTU'** | | | | | Overhead and profit | 20% | $452 | |
| | | | | | **Total Cost** | | **$2,714** | |
| | | | | | Subtotal | | $2,318 | |
| **Basecase 'HP'** | | | | | Overhead and profit | 20% | $464 | |
| | | | | | **Total Cost** | | **$2,781** | |

# Appendix E:  Change Point Analysis

## Program Description

Energy Explorer is a tool for the analysis of building and facility energy use data. It integrates the previously laborious tasks of data processing, graphing and statistical modeling in a user-friendly, graphical interface. Energy Explorer' easy to use features will help you quickly and accurately determine baseline energy use, understand factors that influence energy use, calculate retrofit savings and identify operational and maintenance problems.

Energy Explorer includes with a full package of statistical models specifically designed for analyzing building and facility energy use. Models include mean, median, simple and multiple-linear regression. In addition, specially-developed 2, 3, 4 and 5-parameter change-point models allow the user to precisely and easily quantify relationships between building energy use, weather and other energy drivers. Change-point models accurately model the non-linear energy use patterns characteristic of whole building electric, steam, heat-pump, and cooling energy use data. Modeling results are displayed numerically and graphically to facilitate a quick and complete understanding of the model and its fit to the data. In addition, retrofit savings and Lean Energy Breakdowns can be calculated from the regression models with a few simple keystrokes.

Energy Explorer is an analysis software tool developed by Dr. Kelly Kissock from the University of Dayton.  The algorithm used by Energy explorer to determine change-points is the same process used in the ASHRAE Inverse Modeling Toolkit and the methodology is supported by ASHRAE Guideline 14.

Results of multiple model runs include:

| | baseline model | | post model | |
|---|---|---|---|---|
| **Model Type** | **CV-RSME** | **R2** | **CV-RSME** | **R2** |
| All Data 2P | 91.6% | 0.01 | 84.6% | 0.34 |
| **All Data 3P** | **82.4%** | **0.20** | **83.9%** | **0.35** |
| All Data 4P | 79.6% | 0.25 | 83.4% | 0.36 |
| All Data 5P | 78.9% | 0.26 | 84.3% | 0.36 |
| Occ Data 2P | 81.1% | 0.20 | 44.6% | 0.47 |
| Occ Data 3P | 75.7% | 0.31 | 44.6% | 0.48 |
| Occ Data 4P | 75.2% | 0.32 | 43.7% | 0.50 |
| OCC Data 5P | 75.4% | 0.31 | 43.7% | 0.50 |
| UnOcc Data 2P | 69.3% | 0.33 | 94.0% | 0.02 |
| ~~UnOcc Data 3P~~ | ~~69.3%~~ | ~~0.33~~ | ~~92.9%~~ | ~~0.04~~ |
| UnOcc Data 3PH | 64.7% | 0.42 | 94.0% | 0.02 |
| UnOcc Data 4P | 64.7% | 0.42 | 92.2% | 0.05 |
| UnOcc Data 5P | 64.1% | 0.43 | 92.3% | 0.05 |

**Glossary of Model Parameter terms used in the program extractions below:**

N: number of observations used in the model
Ymean: mean of dependent (Y) variable.
Yint: model parameter indicating the y intercept
Xn: model parameter corresponding to the nth independent variable.
LS: model parameter corresponding to the left slope of a multiple slope model
RS: model parameter corresponding to the right slope of a multiple slopemodel
Xcp: model parameter indicating the x change-point of a multiple slope model
Xcp1: model parameter indicating the left x change-point of a multiple slope model
Xcp2: model parameter indicating the right x change-point of a multiple slope model
Ycp: model parameter indicating the y change-point of a multiple slope model

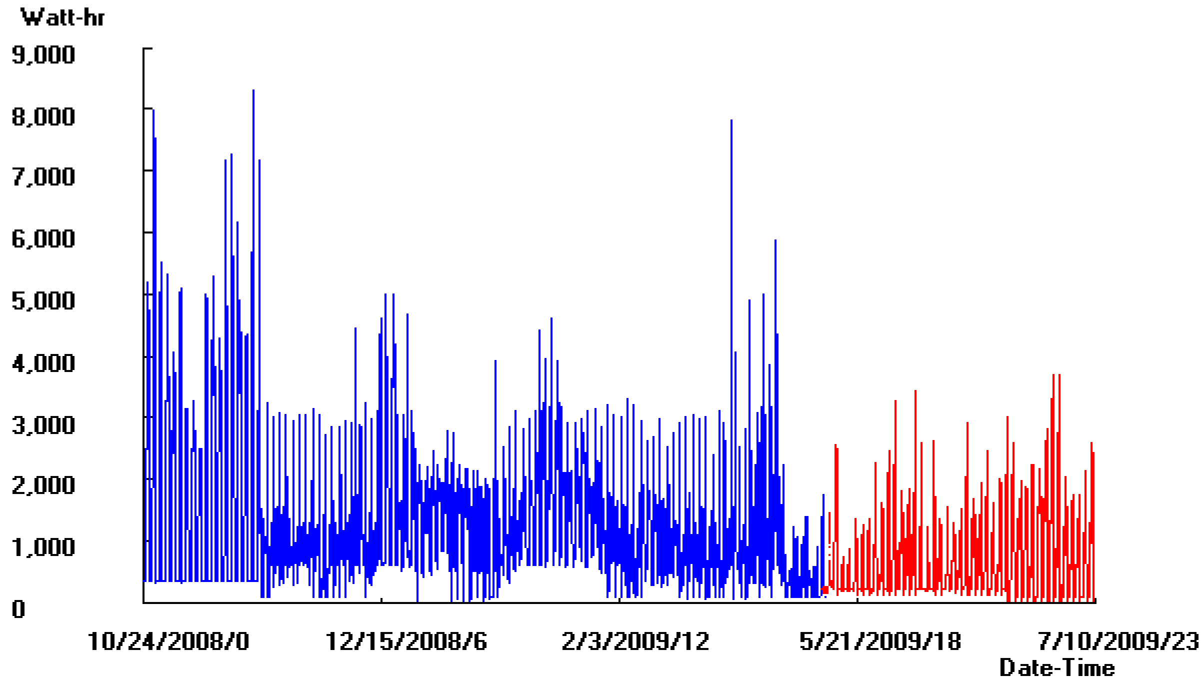



**Figure 1: Time Series Plot (all data)**

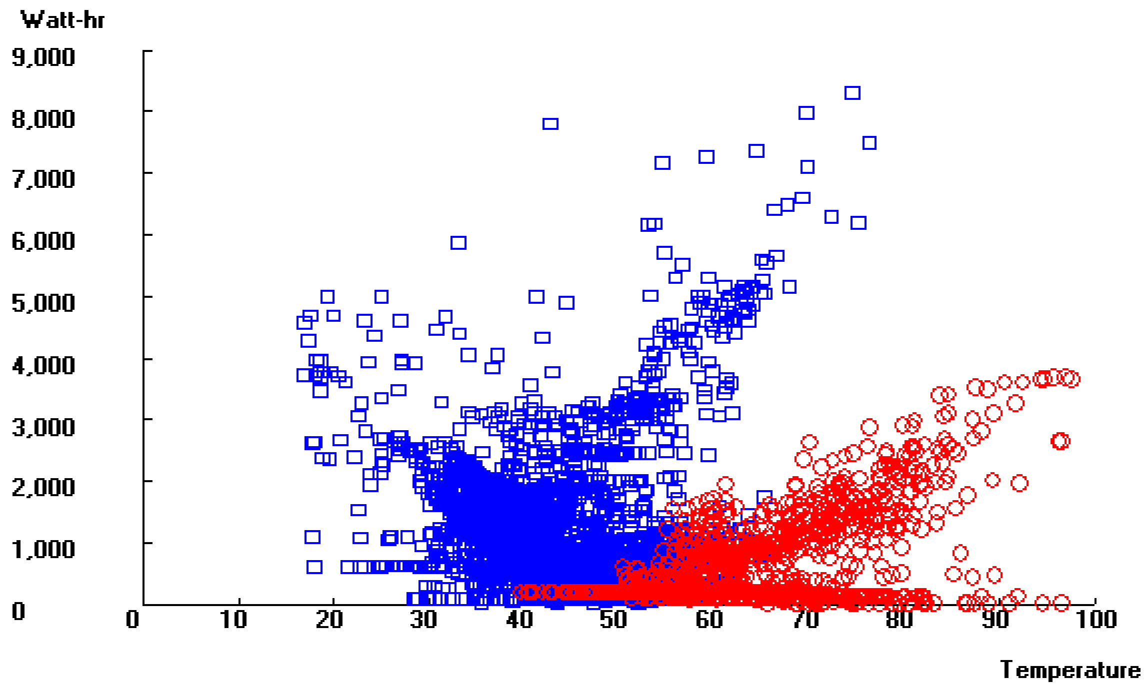
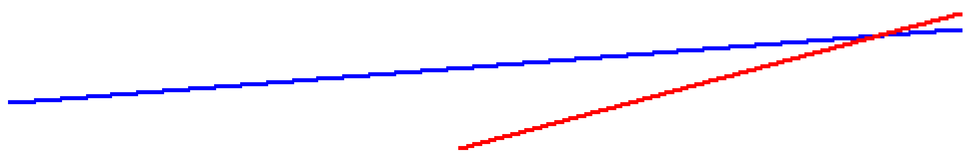


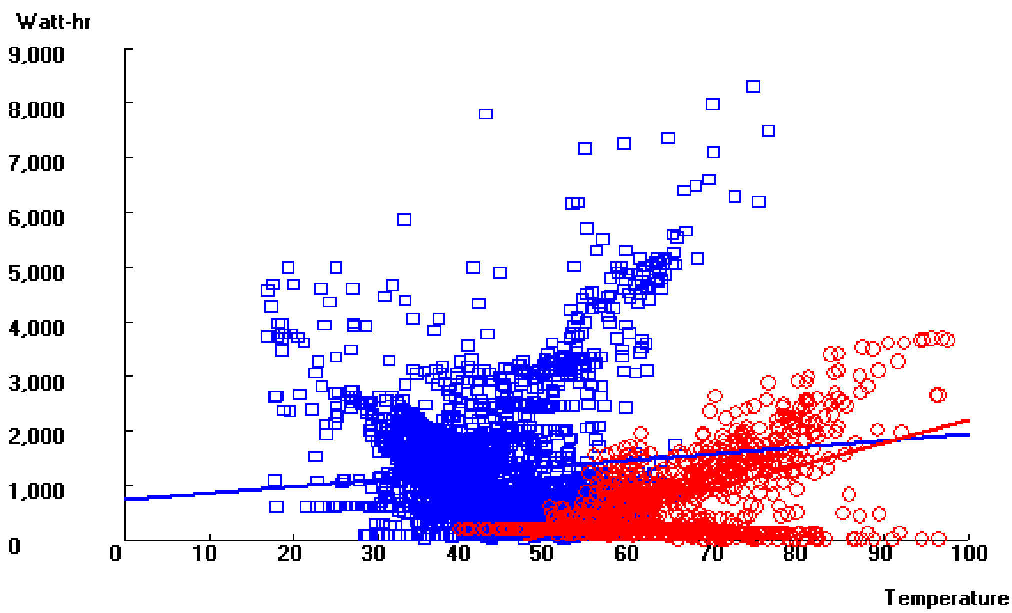

**Figure 2: X-Y scatter**

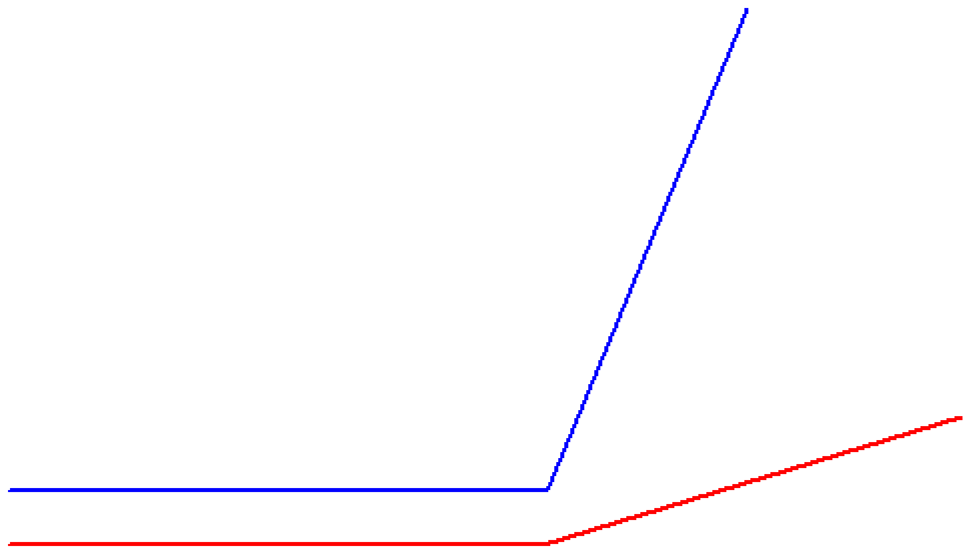


BPA ACP CHANGEPOINT_ALL DATA.TXT G1 2P model N = 2496 R2 = 0.01 RMSE = 1162.7303 CV-RMSE = 91.6%
Yint = 748.3032 (122.5550) Slope = 11.8897 (2.7491)
Model: Watt-hr = 748.30 + 11.89 Temperature

BPA ACP CHANGEPOINT_ALL DATA.TXT G2 2P model N = 984 R2 = 0.34 RMSE = 611.4868 CV-RMSE = 84.6%
Yint = -1962.9874 (121.1416) Slope = 41.4545 (1.8454)
Model: Watt-hr = -1,962.99 + 41.45 Temperature

**Figure 3: 2-P Model (all data)**

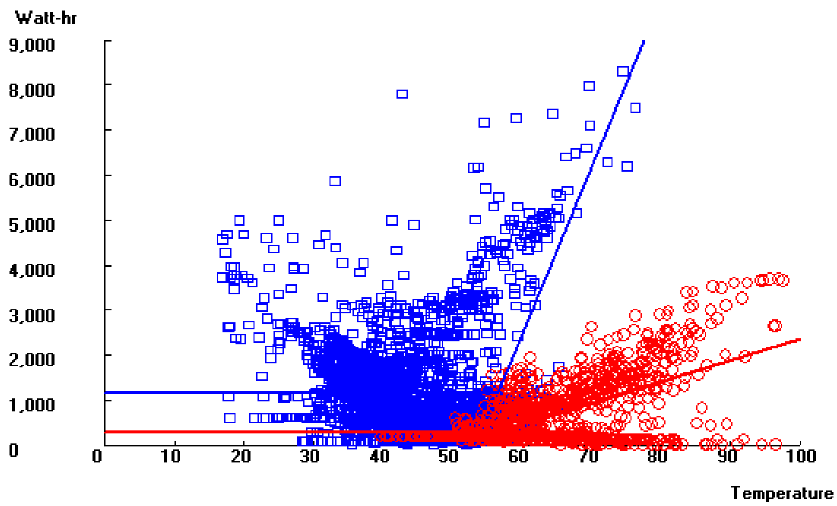


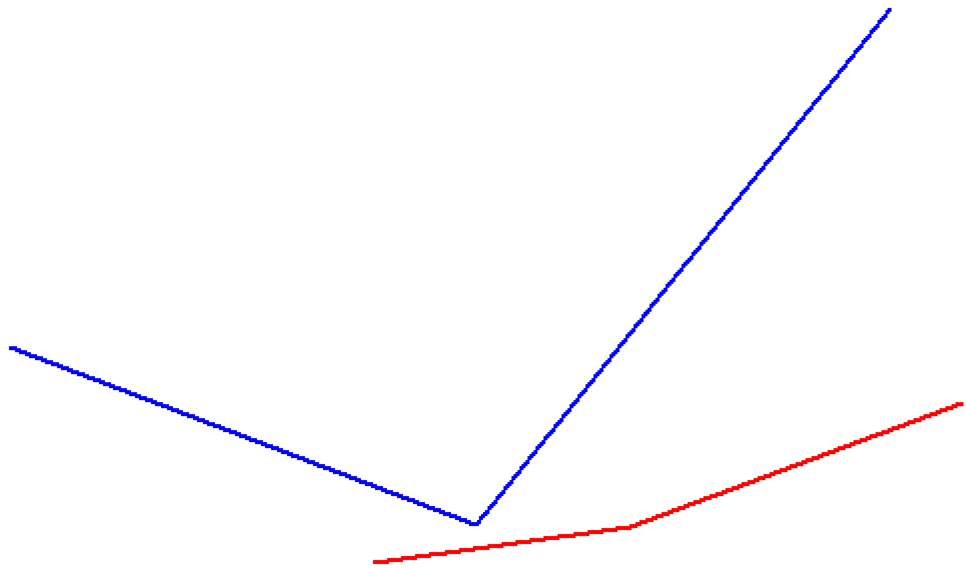


BPA ACP CHANGEPOINT_ALL DATA.TXT G1 3P model N = 2496 R2 = 0.20 RMSE = 1045.0670 CV-RMSE = 82.4%
Ycp = 1166.7576 (21.3173) Xcp = 56.5341 (0.0119) LS = 0.0000 (0.0000) RS = 372.9170 (15.0208)
Model: Watt-hr = 1,166.76 - 0.00 (56.53 - Temperature)+ + 372.92 (Temperature - 56.53)+

BPA ACP CHANGEPOINT_ALL DATA.TXT G2 3P model N = 984 R2 = 0.35 RMSE = 606.2737 CV-RMSE = 83.9%
Ycp = 270.1407 (27.5675) Xcp = 56.1941 (0.0116) LS = 0.0000 (0.0000) RS = 47.5265 (2.0639)
Model: Watt-hr = 270.14 - 0.00 (56.19 - Temperature)+ + 47.53 (Temperature - 56.19)+

**Figure 4: 3-P changepoint model (all data)**

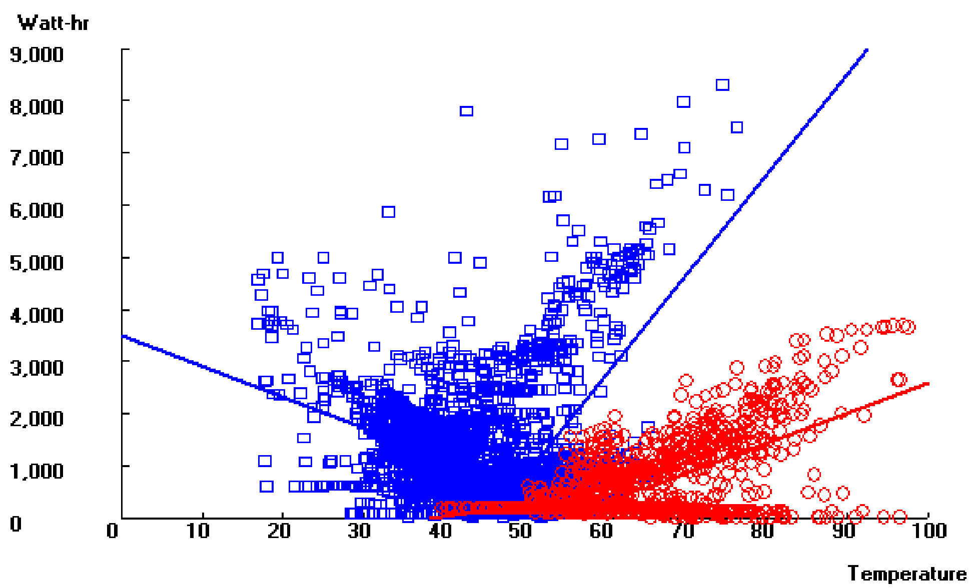


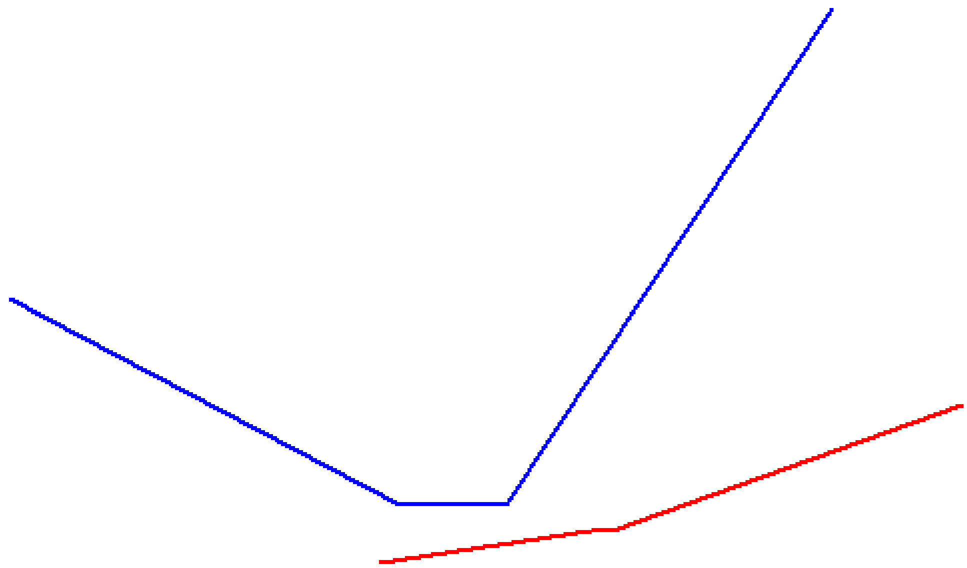


BPA ACP CHANGEPOINT_ALL DATA.TXT G1 4P model N = 2496 R2 = 0.25 RMSE = 1010.0173 CV-RMSE = 79.6%
Ycp = 612.8554 (221.0332) Xcp = 48.9300 (1.1900) LS = -58.6448 (3.4392) RS = 192.9471 (9.4744)
Model: Watt-hr = 612.86 - -58.64 (48.93 - Temperature)+ + 192.95 (Temperature - 48.93)+

BPA ACP CHANGEPOINT_ALL DATA.TXT G2 4P model N = 984 R2 = 0.36 RMSE = 602.8092 CV-RMSE = 83.4%
Ycp = 578.9885 (360.2748) Xcp = 65.0760 (1.1580) LS = 21.4998 (4.1010) RS = 57.1358 (7.7397)
Model: Watt-hr = 578.99 - 21.50 (65.08 - Temperature)+ + 57.14 (Temperature - 65.08)+

**Figure 5: 4-P Changepoint model (all data)**

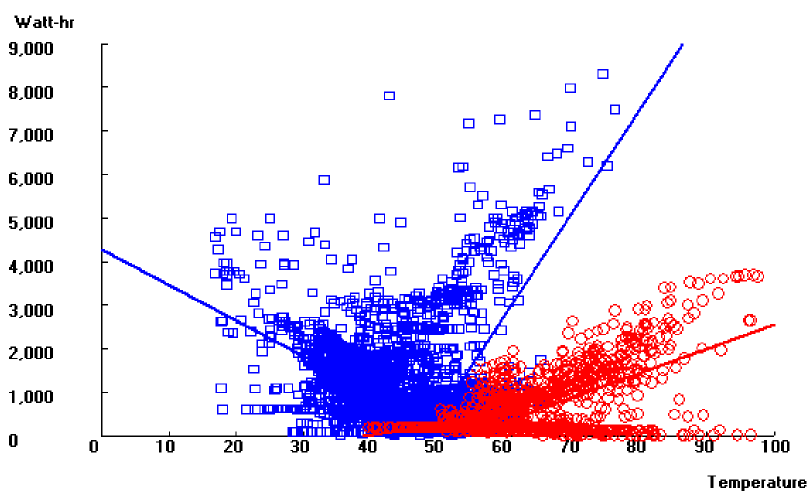




BPA ACP CHANGEPOINT_ALL DATA.TXT G1 5P model N = 2496 R2 = 0.26 RMSE = 1000.8903 CV-RMSE = 78.9%
Ycp = 916.6634 (24.2322) Xcp1 = 41.0363 (2.2015) Xcp2 = 52.0637 (2.2015) LS = -82.0787 (5.1390) RS = 235.4811 (8.5024)
Model: Watt-hr = 916.66 - -82.08 (41.04 - Temperature)+ + 235.48 (Temperature - 52.06)+

BPA ACP CHANGEPOINT_ALL DATA.TXT G2 5P model N = 984 R2 = 0.36 RMSE = 602.6881 CV-RMSE = 83.4%
Ycp = 495.5236 (30.3001) Xcp1 = 61.0423 (2.1423) Xcp2 = 63.1910 (2.1423) LS = 22.3327 (5.2186) RS = 55.5626 (2.9177)
Model: Watt-hr = 495.52 - 22.33 (61.04 - Temperature)+ + 55.56 (Temperature - 63.19)+

**Figure 6: 5-P Changepoint model (all data)**



Occupied Data

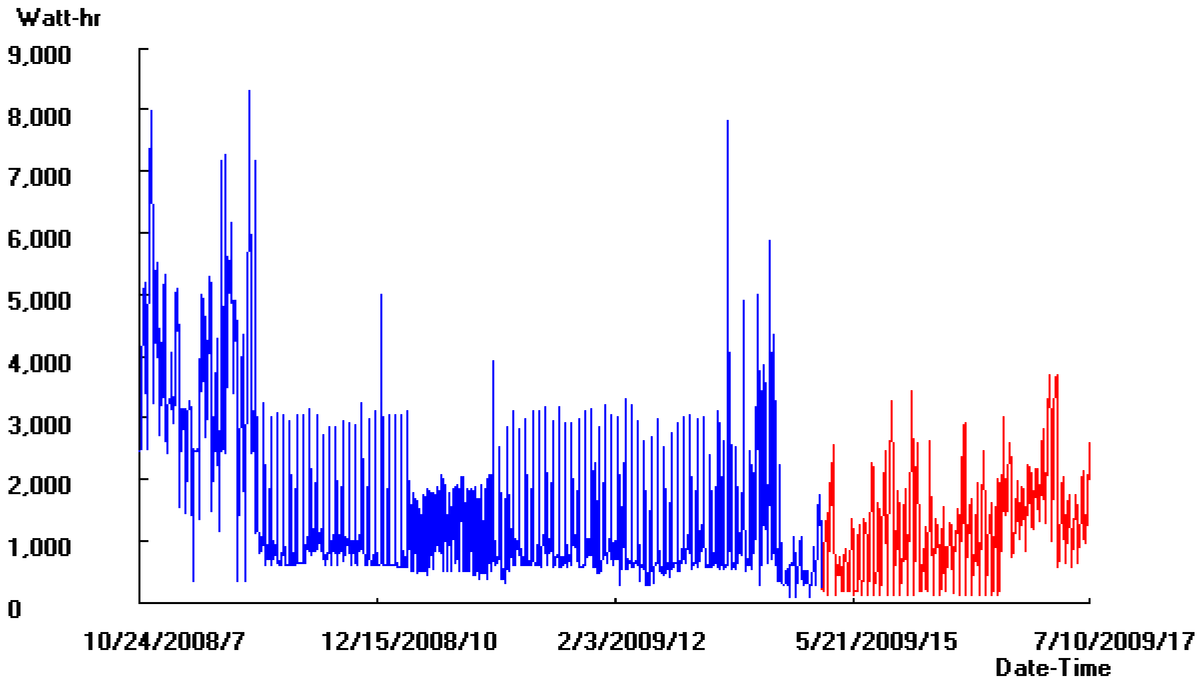



Figure 7: Occupied Time series

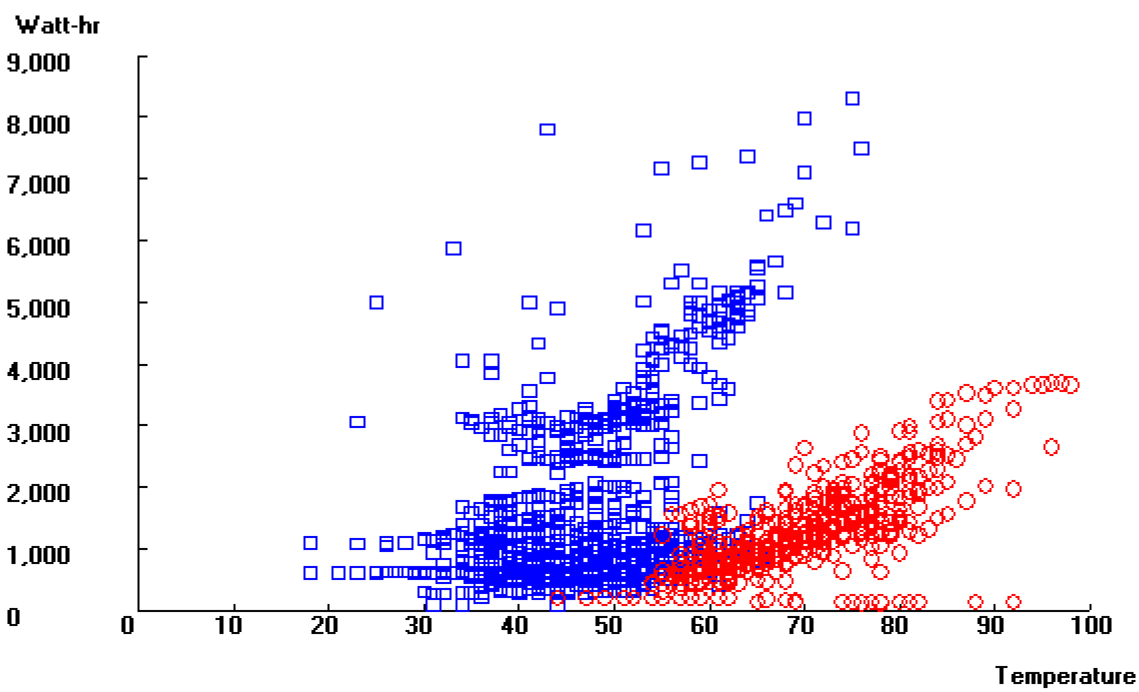
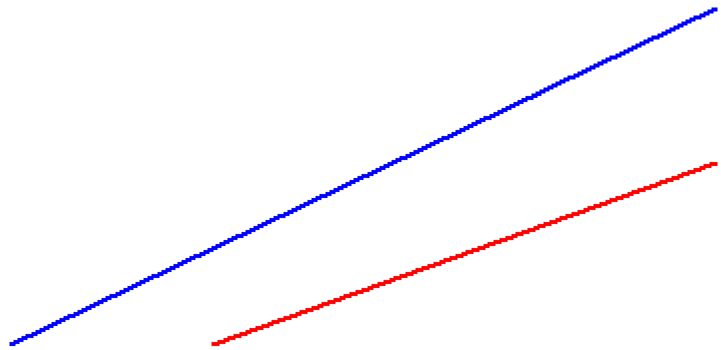


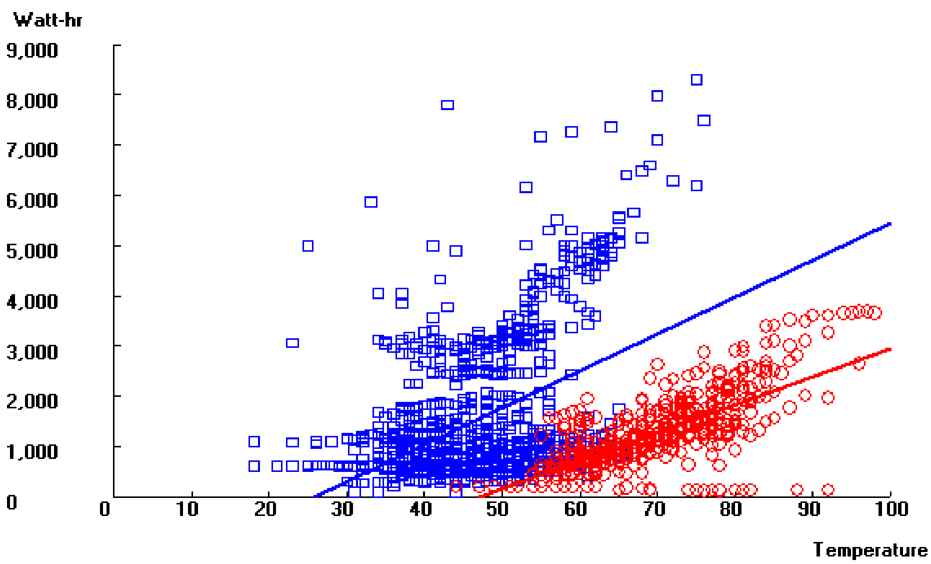

Figure 8: Occupied X-Y Scatter

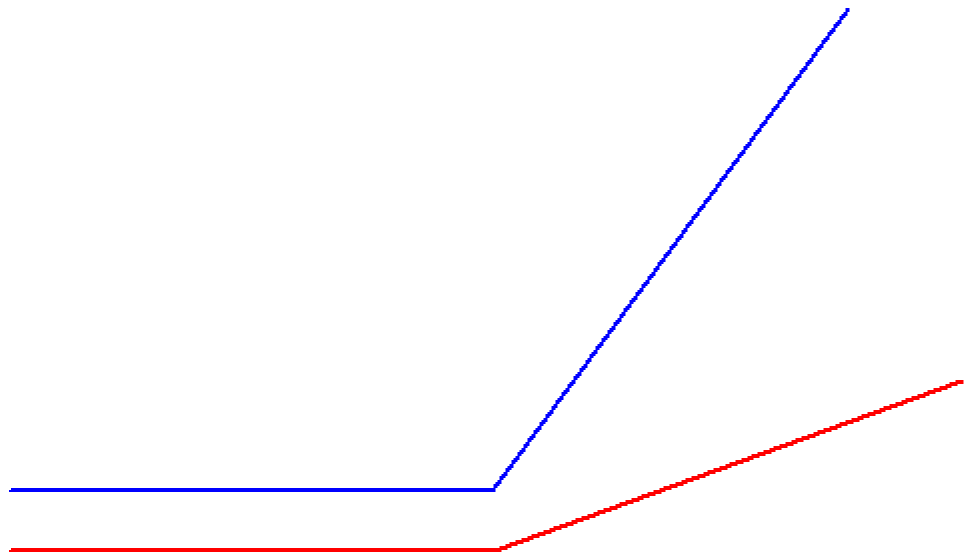


BPA ACP CHANGEPOINT_OCC.TXT G1 2P model N = 1144 R2 = 0.20 RMSE = 1231.2480 CV-RMSE = 81.1%
Yint = -1888.3886 (202.2135) Slope = 73.2395 (4.2755)
Model: Watt-hr = -1,888.39 + 73.24 Temperature

BPA ACP CHANGEPOINT_OCC.TXT G2 2P model N = 451 R2 = 0.47 RMSE = 566.4773 CV-RMSE = 44.6%
Yint = -2612.7181 (194.5985) Slope = 55.5078 (2.7557)
Model: Watt-hr = -2,612.72 + 55.51 Temperature

**Figure 9: 2-P Model Occupied**

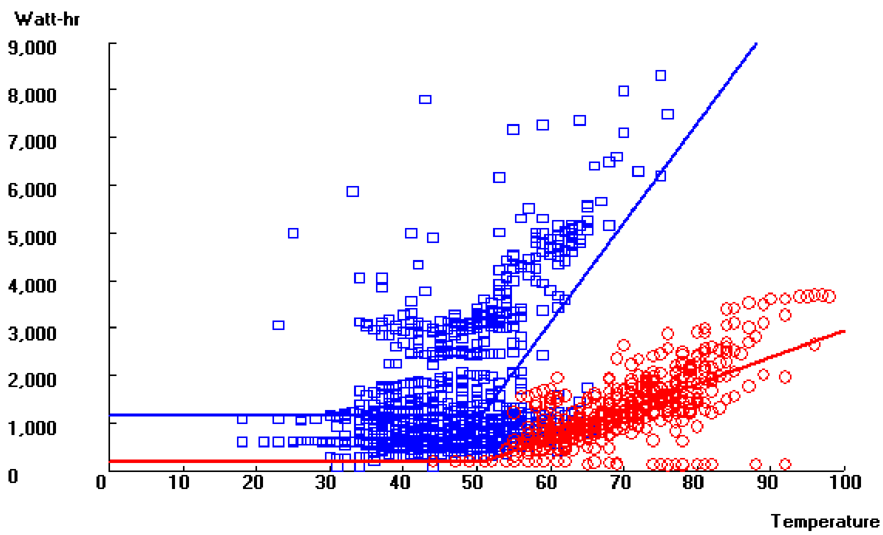


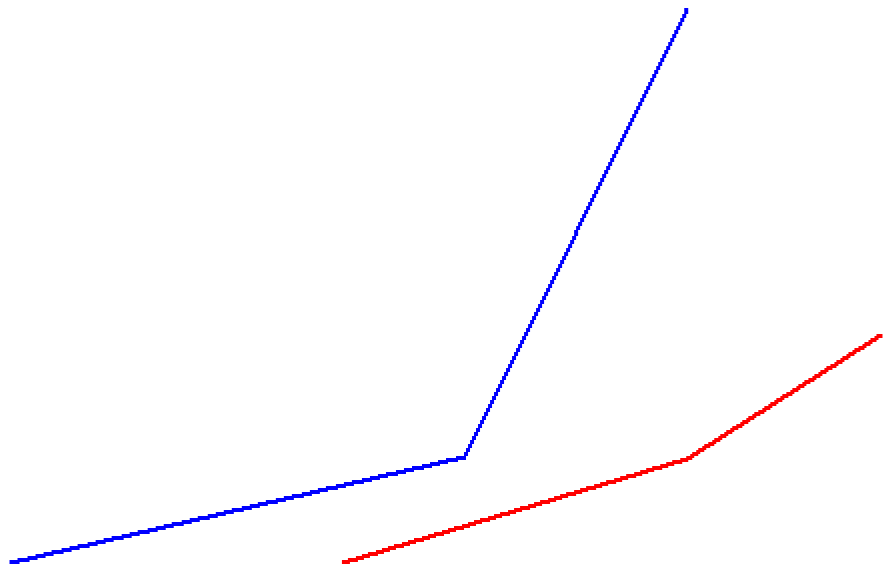


BPA ACP CHANGEPOINT_OCC.TXT G1 3P model N = 1144 R2 = 0.31 RMSE = 1150.0703 CV-RMSE = 75.7%
Ycp = 1153.8988 (37.6953) Xcp = 50.6192 (0.0116) LS = 0.0000 (0.0000) RS = 209.5616 (9.3418)
Model: Watt-hr = 1,153.90 - 0.00 (50.62 - Temperature)+ + 209.56 (Temperature - 50.62)+

BPA ACP CHANGEPOINT_OCC.TXT G2 3P model N = 451 R2 = 0.48 RMSE = 566.0761 CV-RMSE = 44.6%
Ycp = 198.6482 (59.4228) Xcp = 50.8364 (0.0108) LS = 0.0000 (0.0000) RS = 55.9613 (2.7741)
Model: Watt-hr = 198.65 - 0.00 (50.84 - Temperature)+ + 55.96 (Temperature - 50.84)+

**Figure 10: 3-P Change point (occ)**

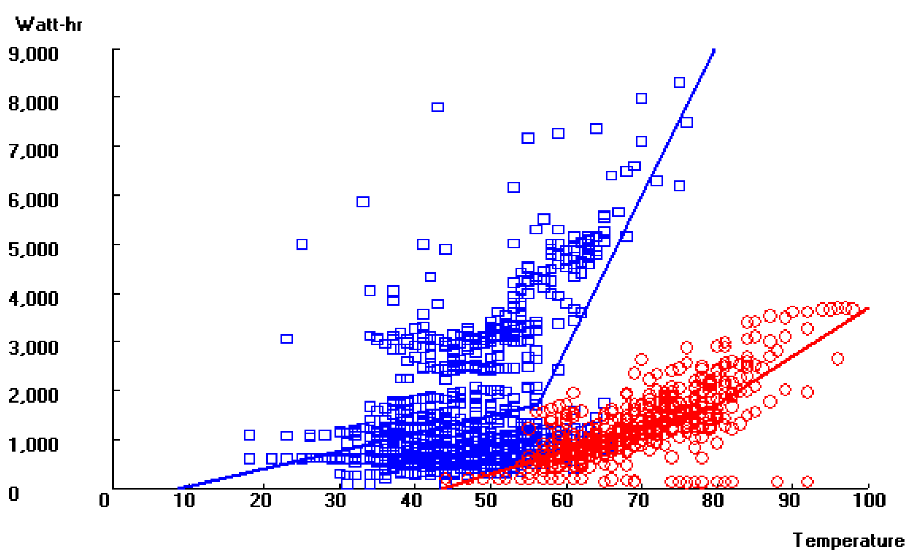


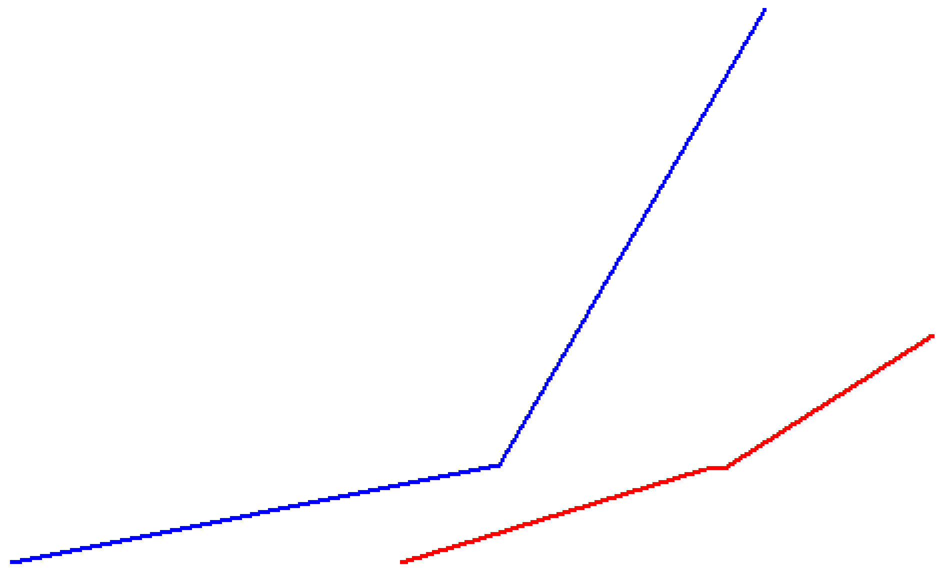


BPA ACP CHANGEPOINT_OCC.TXT G1 4P model N = 1144 R2 = 0.32 RMSE = 1142.7435 CV-RMSE = 75.2%
Ycp = 1718.3660 (349.8117) Xcp = 56.2800 (1.1600) LS = 36.0143 (4.8216) RS = 311.0583 (20.8021)
Model: Watt-hr = 1,718.37 - 36.01 (56.28 - Temperature)+ + 311.06 (Temperature - 56.28)+

BPA ACP CHANGEPOINT_OCC.TXT G2 4P model N = 451 R2 = 0.50 RMSE = 555.4104 CV-RMSE = 43.7%
Ycp = 1674.8172 (359.8306) Xcp = 79.6400 (1.0800) LS = 46.3282 (3.4233) RS = 99.2767 (12.5985)
Model: Watt-hr = 1,674.82 - 46.33 (79.64 - Temperature)+ + 99.28 (Temperature - 79.64)+

**Figure 11: 4-P change point (occupied)**

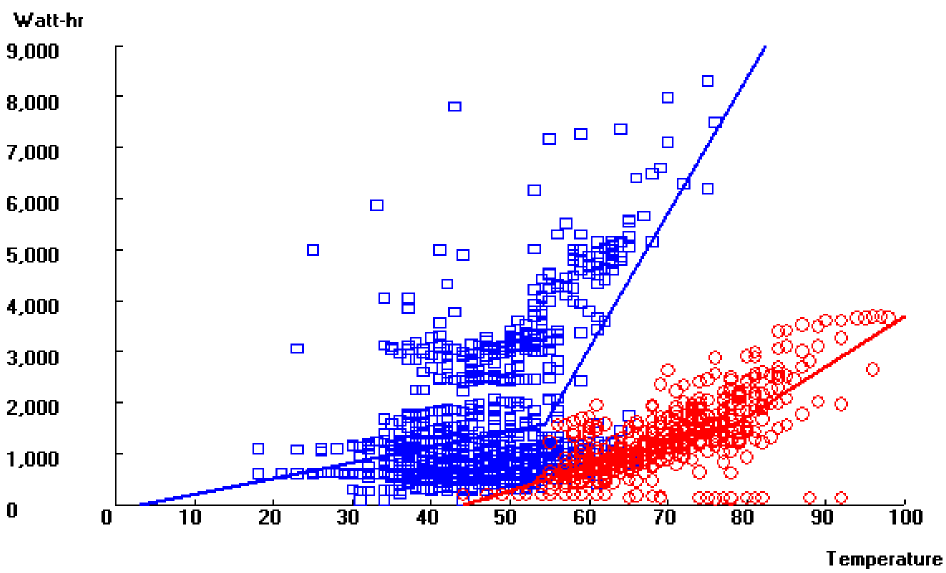




BPA ACP CHANGEPOINT_OCC.TXT G1 5P model N = 1144 R2 = 0.31 RMSE = 1144.8693 CV-RMSE = 75.4%
Ycp = 1576.0216 (60.8898) Xcp1 = 54.5142 (2.1460) Xcp2 = 54.5207 (2.1460) LS = 30.6234 (5.0904) RS = 265.3512 (14.8651)
Model: Watt-hr = 1,576.02 - 30.62 (54.51 - Temperature)+ + 265.35 (Temperature - 54.52)+

BPA ACP CHANGEPOINT_OCC.TXT G2 5P model N = 451 R2 = 0.50 RMSE = 554.3565 CV-RMSE = 43.7%
Ycp = 1525.5613 (43.0954) Xcp1 = 75.9980 (1.9980) Xcp2 = 78.0020 (1.9980) LS = 47.7492 (3.8114) RS = 98.1943 (8.8531)
Model: Watt-hr = 1,525.56 - 47.75 (76.00 - Temperature)+ + 98.19 (Temperature - 78.00)+

**Figure 12: 5-P changepoint model (occupied data)**



Unoccupied Models

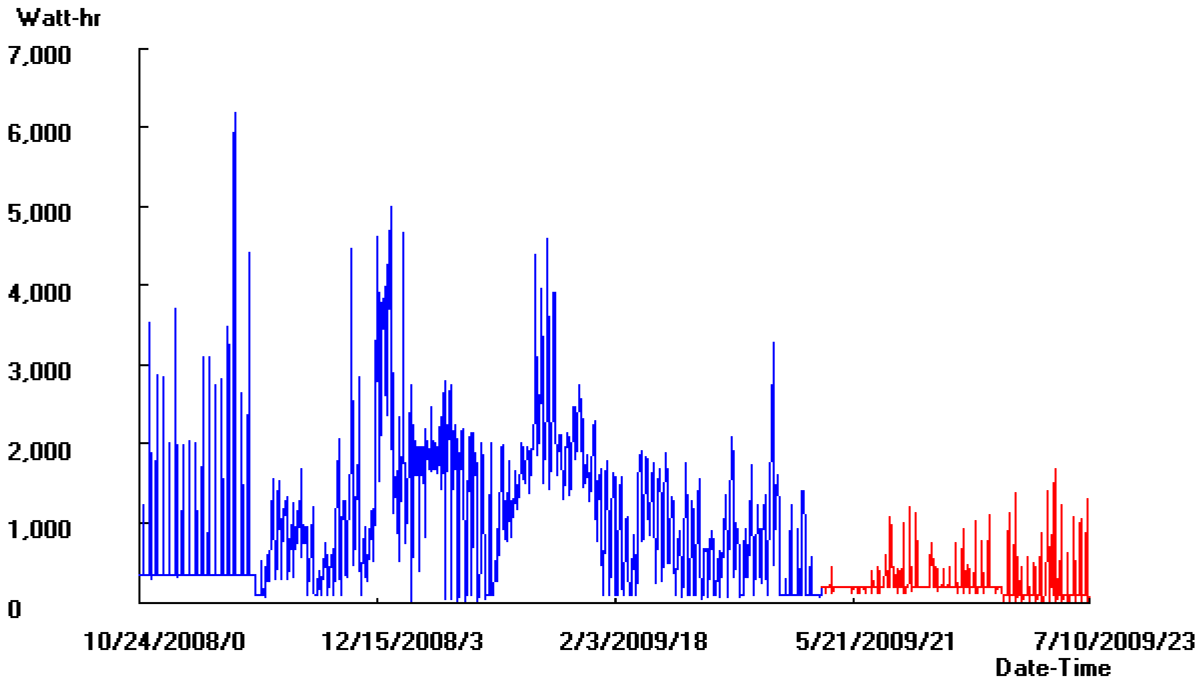



Figure 13: Unoccupied time series

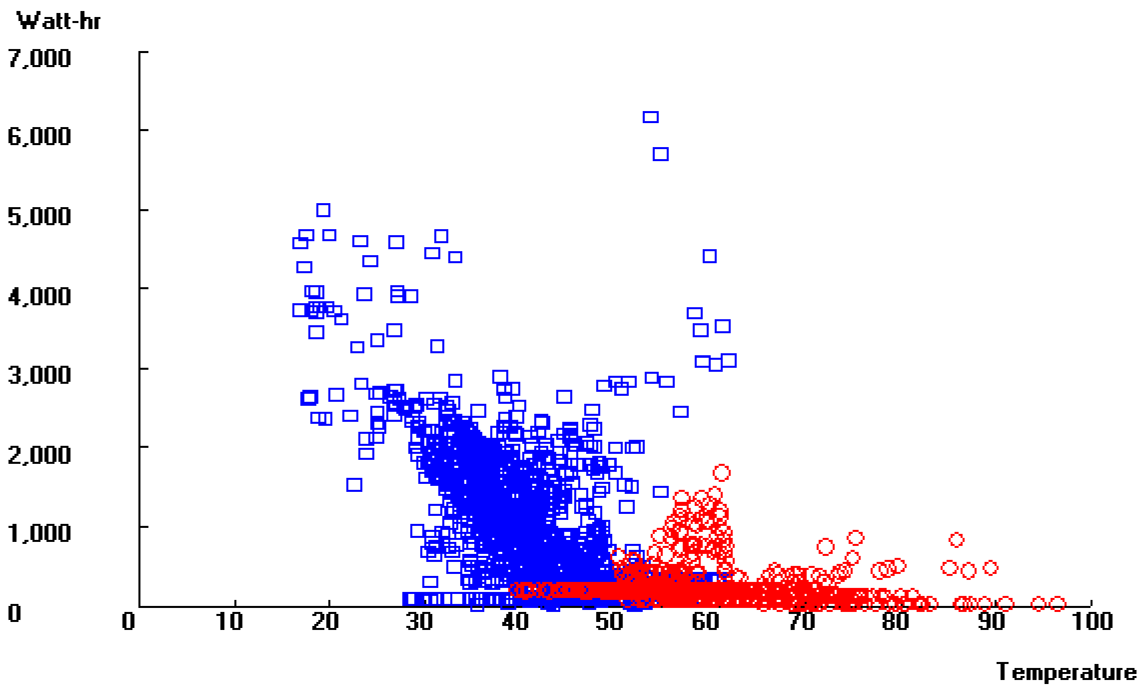
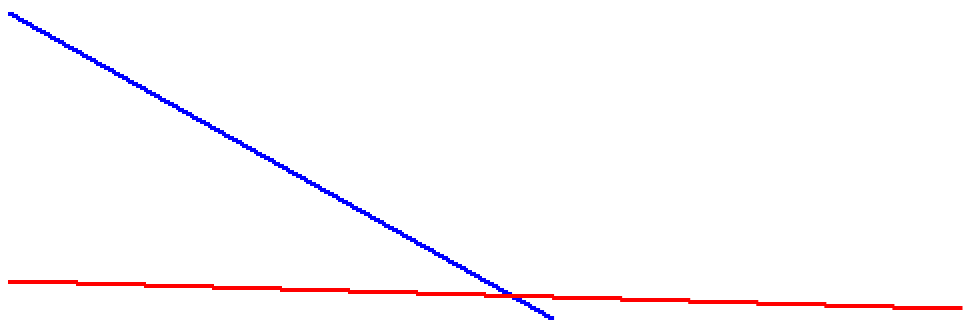


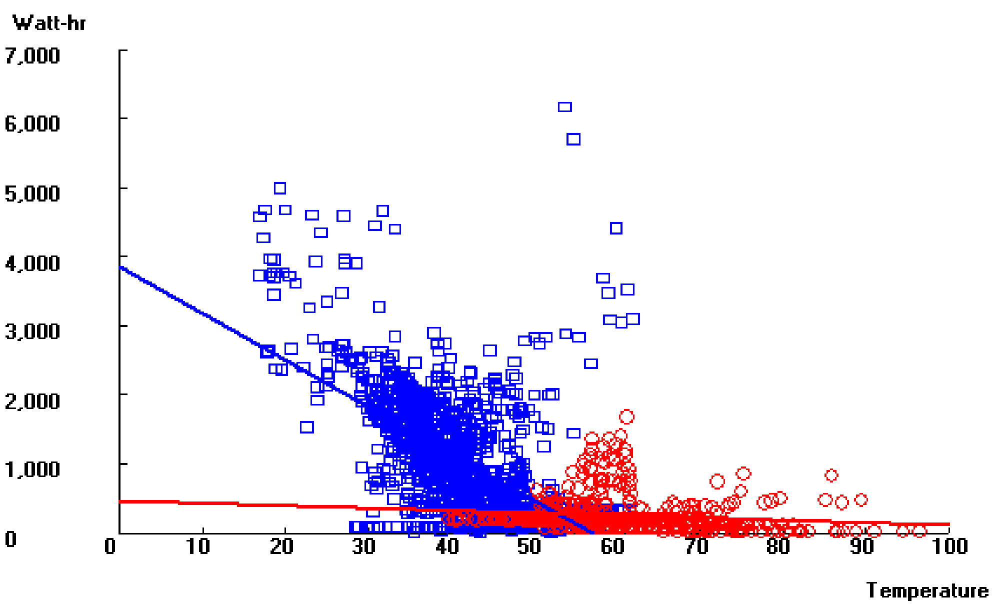

Figure 14: Unoccupied X-Y Scatter

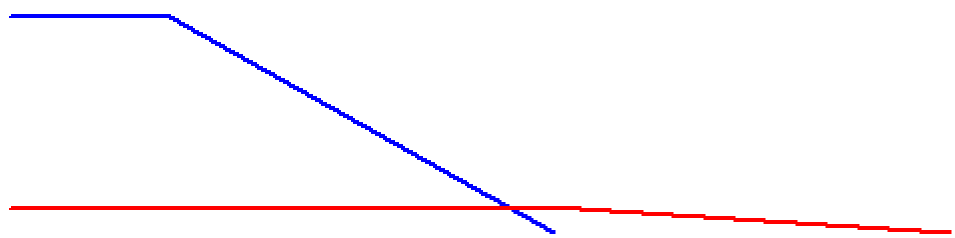


BPA ACP CHANGEPOINT_UNOCC.TXT G1 2P model    N = 1352   R2 = 0.33   RMSE = 732.5357   CV-RMSE = 69.3%
Yint = 3854.1632 (109.2033)     Slope = -67.5138 (2.5912)
Model: Watt-hr = 3,854.16  +  -67.51 Temperature

BPA ACP CHANGEPOINT_UNOCC.TXT G2 2P model    N = 533   R2 = 0.02   RMSE = 243.7994   CV-RMSE = 94.0%
Yint = 464.0729 (70.0551)     Slope = -3.3887 (1.1463)
Model: Watt-hr = 464.07  +  -3.39 Temperature

**Figure 15: 2-P model (unoccupied data)**

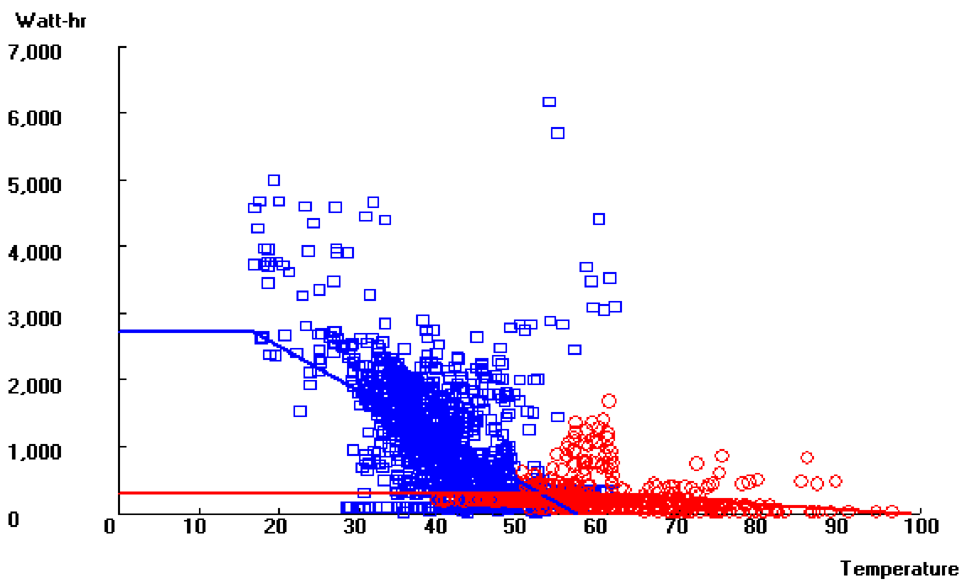


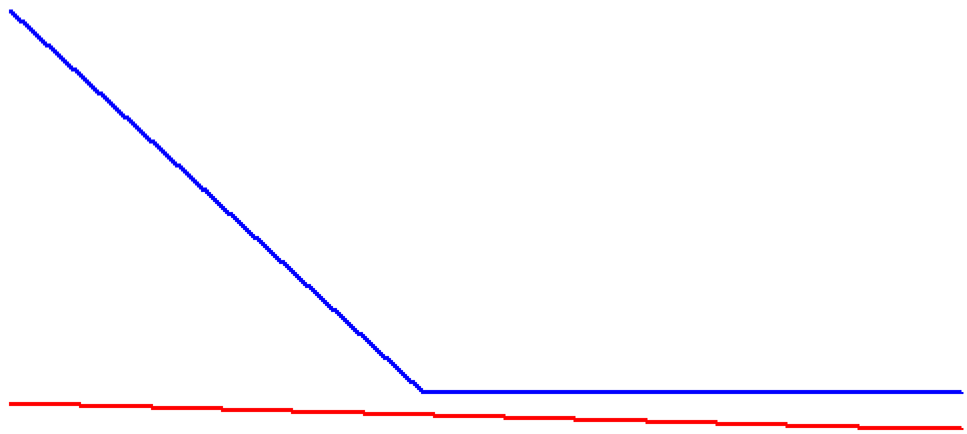


BPA ACP CHANGEPOINT_UNOCC.TXT G1 3P model N = 1352 R2 = 0.33 RMSE = 732.5374 CV-RMSE = 69.3%
Ycp = 2719.3245 (66.8534) Xcp = 16.8090 (0.0090) LS = 0.0000 (0.0000) RS = -67.5139 (2.5912)
Model: Watt-hr = 2,719.32 - 0.00 (16.81 - Temperature)+ + -67.51 (Temperature - 16.81)+

BPA ACP CHANGEPOINT_UNOCC.TXT G2 3P model N = 533 R2 = 0.04 RMSE = 241.0523 CV-RMSE = 92.9%
Ycp = 286.7598 (12.0254) Xcp = 59.9019 (0.0114) LS = 0.0000 (0.0000) RS = -7.3785 (1.6059)
Model: Watt-hr = 286.76 - 0.00 (59.90 - Temperature)+ + -7.38 (Temperature - 59.90)+

**Figure 16: 3-P change point (unoccupied)**

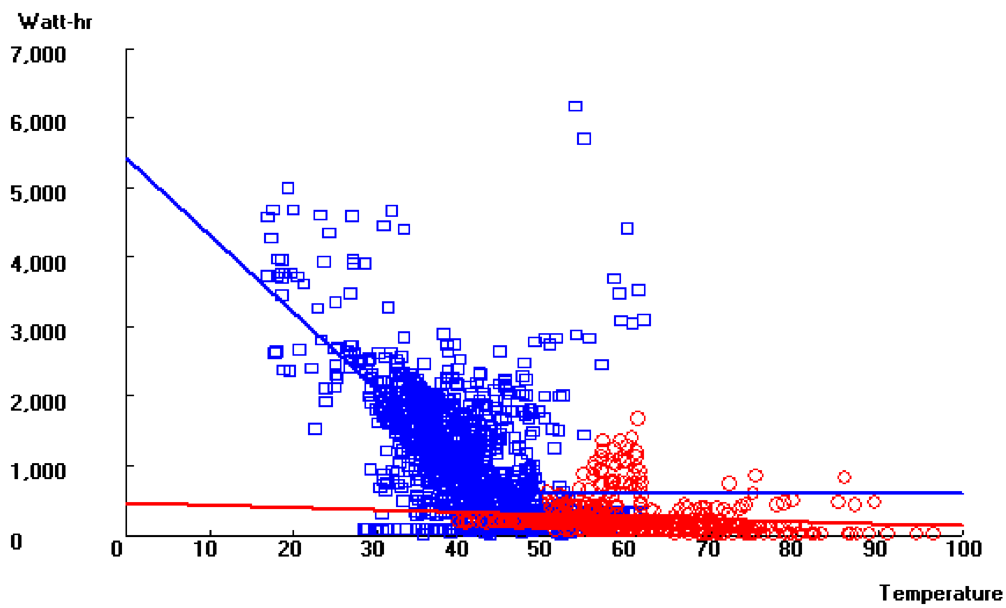


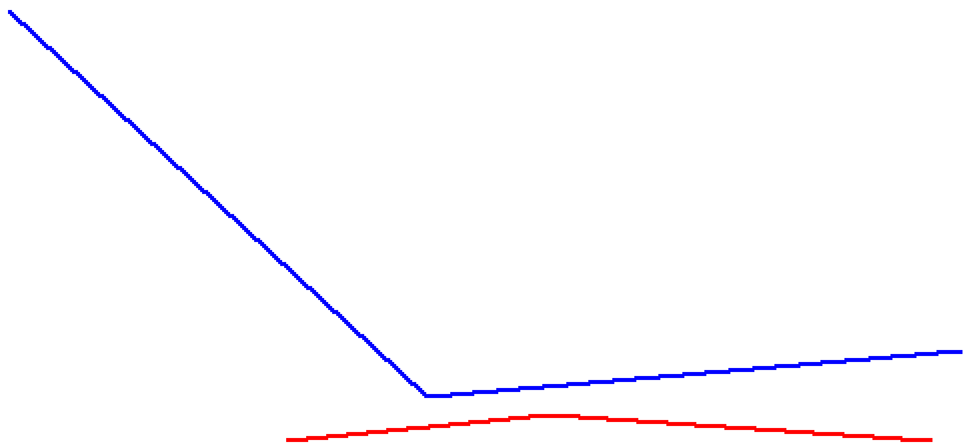


BPA ACP CHANGEPOINT_UNOCC.TXT G1 3P model N = 1352 R2 = 0.42 RMSE = 683.3853 CV-RMSE = 64.7%
Ycp = 590.4622 (23.8091) Xcp = 43.4721 (0.0090) LS = -111.0302 (3.5445) RS = 0.0000 (0.0000)
Model: Watt-hr = 590.46 - -111.03 (43.47 - Temperature)+ + 0.00 (Temperature - 43.47)+

BPA ACP CHANGEPOINT_UNOCC.TXT G2 3P model N = 533 R2 = 0.02 RMSE = 243.7994 CV-RMSE = 94.0%
Ycp = 137.0971 (42.6825) Xcp = 96.4886 (0.0114) LS = -3.3888 (1.1464) RS = 0.0000 (0.0000)
Model: Watt-hr = 137.10 - -3.39 (96.49 - Temperature)+ + 0.00 (Temperature - 96.49)+

**Figure 17: 3-P heat mode (unoccupied)**

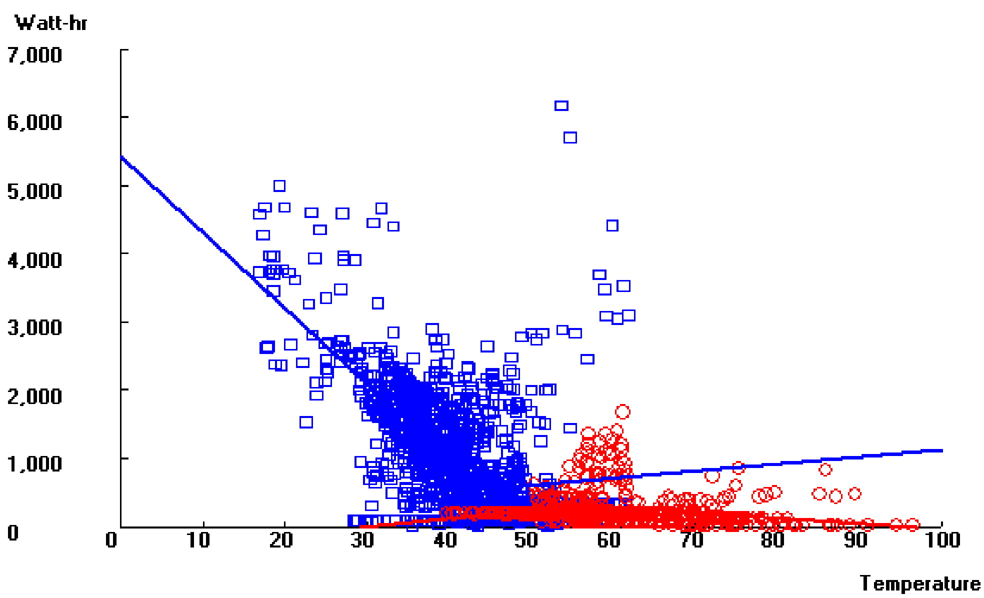




BPA ACP CHANGEPOINT_UNOCC.TXT G1 4P model N = 1352 R2 = 0.42 RMSE = 683.1005 CV-RMSE = 64.7%
Ycp = 540.6750 (228.7591) Xcp = 43.8600 (0.9020) LS = -111.6420 (3.9255) RS = 10.2891 (9.4063)
Model: Watt-hr = 540.68 - -111.64 (43.86 - Temperature)+ + 10.29 (Temperature - 43.86)+

BPA ACP CHANGEPOINT_UNOCC.TXT G2 4P model N = 533 R2 = 0.05 RMSE = 239.1938 CV-RMSE = 92.2%
Ycp = 322.9615 (269.2495) Xcp = 56.6700 (1.1380) LS = 11.7063 (3.4339) RS = -8.0200 (5.4561)
Model: Watt-hr = 322.96 - 11.71 (56.67 - Temperature)+ + -8.02 (Temperature - 56.67)+

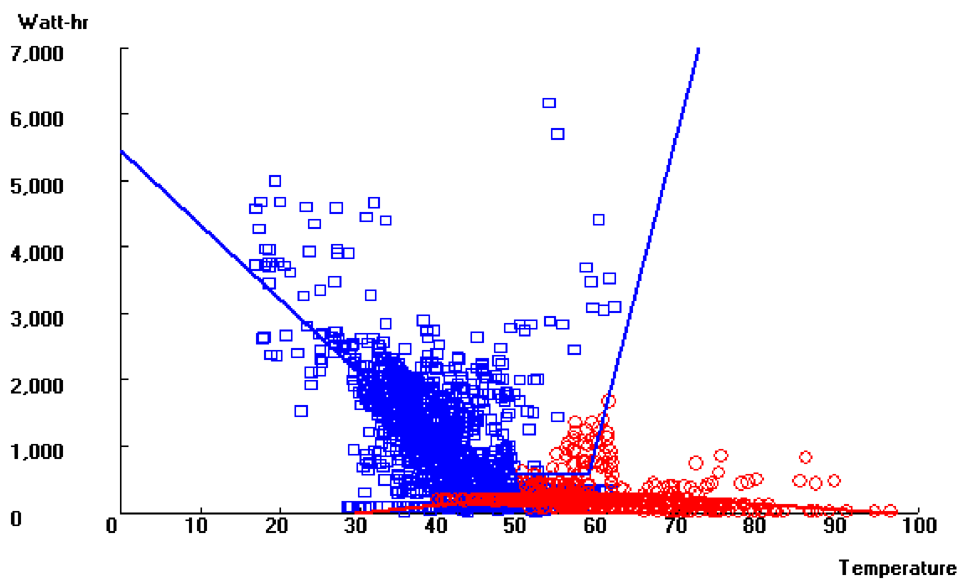
**Figure 18: 4-P change point (unoccupied data)**



BPA ACP CHANGEPOINT_UNOCC.TXT G1 5P model N = 1352 R2 = 0.43 RMSE = 677.4967 CV-RMSE = 64.1%
Ycp = 573.9130 (23.8249) Xcp1 = 43.5243 (1.6687) Xcp2 = 58.5576 (1.6687) LS = -112.0295 (3.5135) RS = 458.9253 (92.5614)
Model: Watt-hr = 573.91 - -112.03 (43.52 - Temperature)+ + 458.93 (Temperature - 58.56)+

BPA ACP CHANGEPOINT_UNOCC.TXT G2 5P model N = 533 R2 = 0.05 RMSE = 239.3060 CV-RMSE = 92.3%
Ycp = 322.7376 (15.6693) Xcp1 = 56.4550 (2.1053) Xcp2 = 56.4614 (2.1053) LS = 11.8948 (3.5111) RS = -7.8845 (1.4909)
Model: Watt-hr = 322.74 - 11.89 (56.46 - Temperature)+ + -7.88 (Temperature - 56.46)+

**Figure 19: 5-P changepoint model (unoccupied data)**



# Appendix F: Phase 3 Evaluation Framework

## *Draft* Evaluation Framework for Roof Top Unit Retrofit and Tune-Up Services Pilot

*Phil Degens 9-29-2009*

**Background:**

This evaluation framework has been developed to for a generic roof top unit (RTU) retrofit and tune up services pilot. It is assumed that measure/service specific savings have been estimated through earlier research efforts and that the pilot is testing what measures will be typically installed and to estimate the average RTU savings.

It is assumed that the pilots are performed on a group of fairly homogenous RTU's (e.g. RTU's with heat pumps will be studied separately as will RTU's that have gas packs). It is also assumed that obtaining metered data for a year before participation is not possible the first year of the pilot but that two weeks of pre-installation metering is possible (This may change in the second year if comparison group RTU's that have a year of metered data receive program services).

**Impact Evaluation:**

The level of impact analysis may vary depending on the needs of the organization. For estimating overall average savings, 15 minute metered data for the whole RTU is sufficient. For researching and disaggregating the source of the savings, more detailed sub metering is required.

*One Season Savings:*
Participant N: 20 units at 10 or more sites
Comparison N: 15 units at same or comparable sites

Metering and monitoring protocols:
Length and type of metering:
One season savings: Two weeks pre- and two weeks post-data.
Data type and frequency: 15 minute load data during (season of interest)

One season savings estimation:
One season savings: pre/post analysis will be performed controlling for temperature, and projected to a full season's savings. Comparison group savings (as a mean and as a percent) will be used to adjust for secular non-programmatic trends

*Two Season savings*
Participant N: 20 units at 10 or more sites
Comparison N: 20 units at same or comparable sites

Cooling Season savings: Two weeks pre- and two weeks post-data.
Data type and frequency: 15 minute load data during (season of interest)

Heating Season savings: Pre/post billing and post/post meter analysis
Data type and frequency: 15 minute load data for the heating season
RTU's with gas heating will require data logging of run-time hours with appropriate time stamps. Modulating units

will require a time stamp data for stage RTU was in.
One year of pre- and one year of post monthly billing data.
(If available 15 minute AMI data)

Two season savings estimation:
Cooling season savings: pre/post analysis will be performed controlling for temperature, and projected to a full season's savings. Comparison group savings (as a mean and as a percent) will be used to adjust for secular non-programmatic trends

Heating season savings: Analysis of participant and comparison group post energy consumption analysis will be performed controlling for temperature and space served by RTU. Pre/post billing analysis bills will also be used to adjust these savings.

**Process Evaluation:**

*Interview 1*: Post installation interviews occurring within a month after 80% of the retrofits have been completed:
Interview HVAC service technicians, HVAC Firm Owners/managers, building owners/managers and program staff.
Acquire feedback on retrofit installation process, expectations, costs, marketability, and satisfaction to obtain information on retrofit barriers and opportunities as well as improvements to the pilot offerings and implementation processes.

*Interview 2*: Post-one/two season operations interviews occurring after one/two seasons of HVAC operations
Interview HVAC service technicians, HVAC Firm Owners/managers, building owners/managers and program staff.
Feedback on ease of servicing retrofit units, satisfaction with features, and other issues associated with the HVAC to obtain information on longer term operating conditions and issues.

**Expected Evaluation Costs**:

Process and impact evaluation costs are estimated below from recent RTU metering studies and pilot and program process evaluations. Actual costs are expected to vary depending on a wide variety of factors such as the number of RTU's at a site, the frequency of reading the data, local costs of evaluation and installation contractors, or the number of times the interview guides are reviewed.

**Impact evaluation**

Detailed metering: One minute to 15 minute load metering, Supply air and outside air temperatures, return air, mixed air temperatures, fan amps, cooling (heating) stage and economizer damper signals.

Estimated cost per RTU: $2,500 for equipment and installation.

Basic metering: 15 minute load meter, cooling (heating) stage and economizer damper signals, NOAA weather data.

Estimated cost per RTU: $1,200 for equipment and installation.

*One Season Savings (35 total units):*
Basic Metering Cost: $42,000
Detailed Metering: $87,500

*Two Season Savings (35 total units)*:
Basic Metering Cost: $48,000
Detailed Metering: $100,000

Analysis and reporting: $15,000-$20,000

Impact Evaluation Total: $57,000-$120,000

**Process Evaluation**

Evaluation work plan and management: $5,000
Survey/interview instruments design: $3,000
Interviews 1: $5000 ~ 10-15 interviews
Interviews 2: $5000 ~ 10-15 interviews
Report: $10,000

Process Evaluation Total: $28,000

# Appendix G:  Custom Programmable Thermostats

Product sheets for Alerton's VisualLogic Display and KMC's Flexstat are included.  These devices combine the capabilities of a commercial programmable thermostat and a stand-alone DDC controller.

ALERTON

## VisualLogic™ Display (VLD)

### Features and highlights

- **Capable**
  Internal temperature and humidity sensors, 3 universal inputs, 6 binary outputs and 2 analog outputs.
- **Interoperable**
  BACnet-compliant on MS/TP LAN at up to 76.8 Kbps.
- **Versatile**
  Fully DDC programmable, capable of standalone or integrated operation.
- **Flexible**
  Fully programmable, configurable display, easy to locate wireless sensors.
- **Powerful**
  Offers control of a second VLC using peer-to-peer commands. Modes of operation allow control based on occupancy or schedules.
- **Fast**
  Internal DDC logic loop of 100 msec.
- **Visually appealing**
  Based on industry standard platform, sleek sophisticated design with touchscreen display.


Alerton's BACnet®-based VisualLogic® Display (VLD) is a communicating, intelligent sensor-controller combination with built-in temperature and humidity sensors that targets common controls applications such as roof top units, fan-coil units and heat pumps. It provides a cost-effective solution to meet in-room hotel requirements—an easy-to-use interface, easy-to-see digital display, and Celsius/Fahrenheit change over—where you already have Alerton systems in public or common areas. A versatile wireless addition provides door and occupancy sensor function. Direct digital control (DDC) enables powerful control of units, sophisticated, customizable displays, and a superb user interface.

The VLD combines a configurable display and a VisualLogic controller, making it ideal for retrofits of thermostat installations and places where a single-piece combination is easier to install.

The VLD communicates over an MS/TP LAN so it operates as a fully-functioning BACnet controller and easily integrates with the building automation system. Alerton can also provide seamless integration with hotel reservation and check-in systems with the BCM-HOTEL.

Based on an established industry platform and a sleek, sophisticated design that millions of people have already installed in their own homes, the VLD is a single, cost competitive unit with a familiar and user-friendly interface, so it's an easy to use choice for your customers. The VLD is compatible with Alerton's wireless occupancy kit so you can offer a plug-and-play wireless solution for applications needing motion or door sensing, such as hotel rooms.

6670 185th Avenue Northeast, Redmond, WA 98052 USA • Tel: 425.869.8400 • Fax: 425.869.8445 • www.alerton.com
1 of 2
LTBT-VLD Rev. 0001

## BAC-10000 Series
# FlexStat™ BACnet Programmable Thermostats

### Description and Application

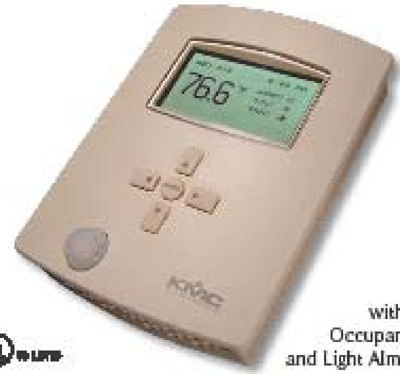
The KMC FlexStat series of flexible, intelligent temperature/humidity/occupancy-sensing, wall-mounted, thermostat/controllers are native BACnet Advanced Application Controllers (B-AAC) for connection with a BACnet system. The set-and-forget FlexStat simplifies networked zone control for common packaged HVAC equipment, such as single- and multi-stage packaged, unitary, and split systems (including high SEER/EER variable speed packaged equipment), as well as factory-packaged and field-applied economizers, water-source and air-to-air heat pumps, fan coil units, central station air handling units, and other similar applications.

In addition, an on-board library of programs permits a single model to be rapidly configured for a wide range of HVAC control applications. Thus, a single "one size fits all" FlexStat model can replace multiple competitor models. A single BAC-10163CW, for example, can be configured for any and all of these application options:

- Air handling unit, with proportional heating and cooling valves, and with optional economizer, dehumidification, and/or fan status
- Fan coil unit, 2-pipe or 4-pipe, proportional or 2-position valves, with optional dehumidification (w/ 4-pipe option) and/or fan status
- Heat pump unit, with up to two compressor stages, and with optional auxiliary heat, emergency heat, dehumidification, and/or fan status
- Roof top unit, with up to two H/C stages, and with optional economizer, dehumidification, and/or fan status

FlexStats also provide the capability to customize the standard library of sequences using KMC's BAC-stage programming tool. This enables a local authorized KMC installing contractor to adapt the standard library to the unique site needs and application specific requirements of a particular project.

Standard hardware options include a mix of output configurations (relays and universal outputs), optional on-board humidity/occupancy sensing, and inputs for additional remote external sensors such as outside air temperature and $CO_2$ sensors.




(Shown with Optional Occupancy Sensor and Light Almond Case)

### Features

#### Interface and Function

- User-friendly, 64 x 128 pixel, dot-matrix LCD display and 5 buttons for data selection and entry
- Six On/Off and independent heating and cooling setpoint periods per day
- Schedules can be set uniquely for each day, 5-1-1, or 5-2 daily schedules
- Easy copy function for rapid schedule programming in stand-alone and small network applications
- Built-in, factory-tested libraries of configurable application control sequences
- Integral energy management control with optimum start/stop, energy deadband heating and cooling setpoints, and other advanced features
- Three levels of password-protected access (user/operator/administrator) prevent disruption of operation and configuration
- Integral CMOS temperature and (on relevant models) humidity sensing for accurate operation
- Optional occupancy sensor (shown in photo above)
- Model choices enable "best fit" of sequence in new and retrofit applications with other field devices, such as proportional or 3-wire "floating" actuators and staged equipment; functionally replace most Viconics and other competitors' products
- All models have 72-hour power (capacitor ) backup and a real time clock for network time synchronization or full stand alone operation

*Specifications and design subject to change without notice.*

# Appendix H: Data Correction Log

This is a summary of the data issues noted during transfer, processing, storage, and graphing. In some cases (short gaps) the missing data could be replaced with data from similar times but where too much data is missing a whole day is removed from analysis. There is a general problem on many days where several minutes of data are missing in the original files around 4:00 am. In these cases data from a similar day is used for replacement.

**Campbell-Sr-Center-AC-1-Xi**

All available data file name: "EWEB PremVent_Campbell_Senior_Center-AC-Unit_1-Xi-10-08-to-07-13-09.xls" This is the only unit with $CO_2$ outside data and this was translated to the other three RTUs. This site has three indoor $CO_2$ sensors. The $CO_2$ inside (CO2i) is in the return air vent. $CO_2$ near and $CO_2$ far were in the same room until May 21$^{st}$ when the "far" sensor was relocated to the computer lab.

| Tab | Notes and Issues on raw data files (Note: Most gaps filled in whole day workbook) |
|---|---|
| October | 10-27-19:53 to 10-31-23:59 with no gaps, Date/Time format problem, **No RTU data,** Tstat stuck at 21.794; fan not running much. |
| November | **No RTU data until 11-26-6:24**, large data gap 11-26-00:00 to 04:59 filled, RTU max 10 Wh/min, Fan runs 3 minutes, Tstat stuck at 21.784 until 11-26 then stuck -0.003, |
| December | No data gaps, RTU values 0 to 10 Wh/Min, Fan 0 to 2.1Wh/Min, Tstat stuck at -0.003, |
| January | Data gap 1-9-12:02 to 12:25 filled, Tstat stuck at -0.003 or -0.004, RTU hit 31 Wh/min |
| February | Data gap 2-23-4:27 to 2-23-5:25, Tstat stuck at -0.004 all month, RTU 10.5 Wh/min |
| March | No Gaps RTU 10.5 Wh/min, Tstat stuck -0.004, RTU 10.5. On 3/31 at 14:13 $CO_2$ near sensor goes to all 1's into April. |
| April | Gap 4-8-18:39 to 4-9-01:36, From 11/26 to 4/13, RTU never exceed 10.5 Wh/min t **RTU was to zero 4/8 to 4/13, then RTU jumped to max of 62 Wh/Min**, Tstat stuck -0.004 all month. 4/1 the $CO_2$ near sensor is all 1's from 00:00 to 13:18. |
| May | Gap 5-8-17:33 to 5-9-00:29, May 8$^{th}$ was left out of whole day sheet by May 9 was filled. Tstat -0.004, RTU max 66.5 Wh/min, May 21$^{st}$ at 2pm $CO_2$ sensor (Col G) (Far from SA) went random, at 2:38 it returned to normal. $CO_2$ far sensor is most often 30 to 100 PPM higher than $CO_2$ near although for a few minutes it was lower. On 5/21 **Tstat started working at 2:28pm,** RTU 66.5 Wh/min. 5/18 17:26 to 17:36 all $CO_2$ went to 1's. |
| June | No gaps in data, RTU 64.5 Wh/min |
| July | No gags, data ends 7-13-12:51, RTU max 69.5 Wh/min |

**Campbell-Sr-Center-AC-2-Iota**

Most available data file name: "EWEB PremVent_Campbell_Senior_Center-AC-Unit_2-Iota-10-29-to-07-13-09.xls"

| Tab | Notes and Issues on raw data files (Note: Most gaps filled in whole day workbook) occasionally have -888 in a cell this was not cleaned out. |
|---|---|
| October | 10-29-16:15 to 10-31-23:59, Date/Time format all months**, t-stat is stuck on**, fan continuous during day, **No RTU data,** No gaps in data |
| November | Data gap 11-16-7:34 to 11-16-13:11, s-stat and RTU data starts at 11/17 12:43, RTU data good except for a max **115 Wh/min. some where.** |
| December | Data gap 12-4-21:38 to 12-5-5:28, RTU max 15 to 16 Wh/min for all months |
| January | Data gap 1-28-23:49 to 1-29-7:53, t-stat stuck off |
| February | No gaps, t-stat stuck off, RTU max 15 Wh/min |
| March | Data gap 3-25-00:26 to 3-25-09:12, t-stat stuck off, **RTU max jumped to 58.5** Wh/min |
| April | No gaps, tstat stuck off, RTU max 64 Wh/min, **fan started running continuously 4/14 7:24 am,** CO2 sensor 2000 4-9-13:48, dropped to 850 to 835 by 4-9-19:30 and stayed until stopped (1) on 4-29-1:40 |
| May | Data gap 5-19-3:29 to 5-19-11:36, t-stat started working, fan running continuously, CO2 sensor back at 5-21-14:36, RTU max 67.5 Wh/min |
| June | No data gaps, all sensors working fine, fan running continuously |
| July | RTU max 72.5 Wh/min, fan running continuously |

**Clark Sheet Metal-HP-3-Theta**

Most available data file name: "EWEB PremVent_Clark-sheet-Metal-HP-3-Theta-10-08-to-07-13-09-filled.xls"

| Tab | Notes and Issues on raw data files (Note: Most gaps filled in whole day workbook), RTU, Fan and CO2 had faulty multipliers-column added with corrected value. |
|---|---|
| October | 10-22-16:38 to 10-31-23:59, No data gaps, Date/Time format problem, **RTU data double,** Fan 15.5 times high, CO2 1000 times low. T-stat not working stuck off |
| November | Data gap 11-18-8:06 to 11-18-14:54, after gap RTU, Fan, t-stat, and CO2 fixed. |
| December | No gaps, all sensors working |
| January | Data gap 1-13-17:34 to 1-1401:59, t-stat seems to hit and miss, |
| February | Data gap 2-20-14:29 to 2-20-16:18, t-stat hit and miss |
| March | Data gaps 3-8-1:59 to 3:00 and 3-30-00:15 to 3-30-8:34, |
| April | No gaps, 4-6-16:24 **fan and RTU running continuously at night, on 4-24 RTU drops to 4 Wh/min and fan to 1.4 Wh/min (half) evening and cycle up and down. On 4-25 at 5am RTU on then off. Fan never goes off** |
| May | Data gap 5-25-13:44 to 22:23, Fan goes from 1.4 to 2.7 but never to 0! RTU 2.5 to 63 but never 0. |
| June | No data gaps, looks like May |
| July | No data gaps |

**Clark Sheet Metal-HP-4-Mu**

Most available data file name: "EWEB PremVent_Clark-sheet-Metal-HP-Unit_4-Mu-10-08-to-07-13-09-7-20-a.xls"

| Tab | Notes and Issues on raw data files (Note: Most gaps filled in whole day workbook) |
|---|---|
| October | 10-22-16:52 to 10-31-23:59, No data gaps, Date/Time format problem, **RTU data double,** Fan 15.45 times high, CO2 1000 times low. T-stat not working stuck off |
| November | Data gap 11-18-8:04 to 15:19, after gap RTU, fan, T-stat, and CO2 sensor constants fixed. |
| December | No data gaps, t-stat hit and miss, fan on and off til 12-2-7:02 to 12-2-17:59 full speed continuos, RTU 10 to 60 then 200 12-2-17:48, all off 12-2-18:00, 12-3 intermittent at night, 7:00 am continuous full speed fan, RTU 10 to 45 until 18:00, intermittent again. T-stat and RTU power up |
| January | Data gap 1-12-5:38 13:07, RTU hits 200, 1-1-00:00 fan and RTU on til 17:45, fan on occupied, intermit unoccupied |
| February | Data gap 2-18-1:34 to 3:55, **Fan started intermittent occupied & unoccupied, all month** |
| March | Data gap 3-8-12:21 to 15:29, 3-31- 17:33 return air sensor drops to 50F same as OSA temp |
| April | No data gaps, Return air sensor goes from 35F to 85F over the month. 4-10 fan goes part power 1.8, **4-11** to 1.3 Wh/min and constant on occupied and intermittent unoc., 4/13 fan went continuous unoccupied and stayed on |
| May | Data gap 5-2-9:55 to 18:56, Return air sensor colder than OSA temp. 5-14-8:22 Return air temp back to normal, fan ran continuously whole month at 1.2 to 1.9Wh/min |
| June | No data gaps, Fan on continuous half power unit 6-23-17:42 went intermittent unocup and continuous occupied. |
| July | No data gaps, Fan intermit unoc and continous occ. |

# Appendix I: Decision Framework Matrix Report

The Task 5 Report, submitted on October 24, 2008 is included as background for the next phase plan. The expected value approach discussed is part of the Phase 2 Deemed Savings Development plan.

Note that the page numbers and contents in the Task 5 report are separate from this report.

# Premium Ventilation Package Testing

## DECISION FRAMEWORK MATRIX REPORT – TASK 5

**Final Submittal**

**October 24, 2008**

**Prepared by: Reid Hart, PE**

**Delivered via electronic copy to BPA and partners.**

**Contract No. 00038702**
**RTU AirCarePlus & Premium Ventilation Program**

PORTLAND ENERGY CONSERVATION, INC

# Table of Contents



# List of Tables

# List of Figures



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## Scope for Task 5 Item: Decision Framework Matrix

Provide Decision Framework Matrix for one climate location identifying significant variables. The decision framework matrix shall be a simplified example of a possible path to developing a parametric path for deemed savings evaluation based on different conditions encountered in the field with up to four (4) parametric variables analyzed. While it shall be based on actual DOE2 simulations, it is not intended to have the rigor required for actual use, but instead to is be an example to help frame discussion with the RTF economizer sub-committee for development of an appropriate method in the future.

## Disclaimer

# Executive Summary

This report reviews relevant parameters that impact savings for the premium ventilation measure package, available saving methodologies, parametric sensitivity analysis, and looks at two particular deemed savings methods: the matrix approach and an expected value approach.

Investigation found a matrix approach using parameter input to select savings to be a reasonable approach; however, input requirements are similar to a parametric based spreadsheet that would provide more customized results for each site. The alternative expected value deemed savings approach avoids the need for input outside the servicing contractor's expertise and provides a good weighted deemed savings for work in one climate zone. With this simplicity and reduced administration cost the weighted deemed approach may be more desirable than a parametric input approach when the program design does not include a site visit by an energy expert.

# Decision Framework Matrix

In the Pacific Northwest, there are three paths to acknowledging savings for commercial energy saving measures incorporated into utility integrated resource plans that can be credited by BPA:

- Custom savings. These require pre-review and a high level of custom analysis not efficient for smaller projects.
- Lighting savings. This method uses a regionally approved calculation spreadsheet and allows individual site calculation without the need for method pre-approval and extensive custom simulation.
- Deemed measures & unit rebates. These measures have deemed savings per unit and while the regional technical forum (RTF) has established an extensive list of residential measures, the list of commercial sector HVAC measures has been relatively short. This is due in part to the more highly variable nature of parameters impacting HVAC savings in the commercial sector. Per fixture lighting rebates are one example of a deemed measure.

The goal of this work was to provide a Decision Framework Matrix for one climate location identifying significant variables. The decision framework matrix is a simplified example of a possible path to developing a parametric path for deemed savings evaluation based on different conditions encountered in the field. We also explore an alternative method to find a single deemed savings per major climate zone, called *expected value deemed savings*. This method provides a good estimate of regional savings based on relevant parameter variation, but has the simplicity of a single deemed savings.

For the analysis, a premium ventilation measure package for packaged rooftop HVAC units is evaluated, as described in detail in Appendix A. The measure package includes a western premium economizer upgrade, optimum start thermostat, variable speed fan motor, and demand controlled ventilation (DCV).

## *Relevant Parameters*

Relevant parameters are those which impact the same end uses that the measure will impact. Note that while the measure package under consideration does not impact lighting directly, lighting energy use in the baseline has a large impact on heating and cooling load, so it is considered a relevant parameter. Multiple parameters that were expected to have an impact on measure savings are listed below. These are grouped as meta-parameters, analyzed parameters and other parameters.

## Drawbacks of Building Type as a Primary Parameter

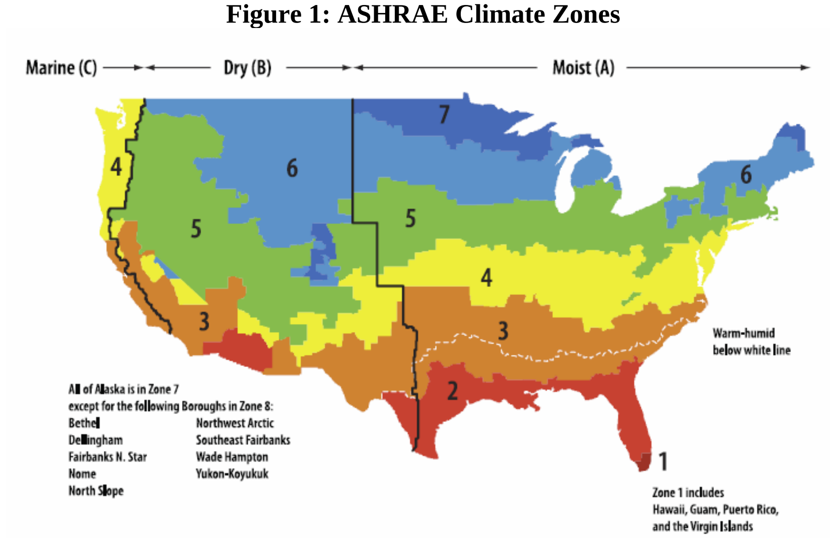
Note that building type is not among the parameters analyzed. While this is a common approach, both in the DEER[1] database in California and in many other measure characterization systems, there are flaws. Often the building types are limited in number. As a result, convenience stores might be included with small retail. This results in buildings with very different energy impacts getting lumped together. Some small retail shops have short hours, low occupancy and very low internal loads. Others, like a jewelry store, have high lighting loads, while some have very high internal loading and refrigeration use, such as a convenience store. Each of these can be characterized by parameters better than by type. Relevant parameters may include internal loads and operating hours. If the relevant parameters are found for a particular measure, or measure package, then the range of energy savings response will be better articulated than with building types, unless many sub-building types are included. If the sub-building type approach is taken, it may result in much more analysis than just focusing on the relevant parameters. The other problem with building type and vintage approach is that buildings with similar occupancies, vintage, and type may have widely different energy use, depending on whether these buildings have undergone an energy upgrade, such as a lighting retrofit, that significantly reduces internal gains.

## Meta-Parameters

Meta-parameters typically require a separate analysis and separate treatment in savings allocation, although this is not always the case.

- Major climate: in the Pacific Northwest, measures are typically analyzed separately for the western area and eastern area, corresponding to ASHRAE climate zones 4 and 5 respectively. Areas in climate zone 6 are typically lumped with climate zone 5, as the climate zone 6 areas are low in population. This level of distinction typically results in adequate differentiation in results. ASHRAE climate zones are typical of major climate zones. Portland vs. Boise proxies are used in this analysis as proxies for the western and eastern regional climates. A single run with all typical settings was included for Boise, Idaho.

**Figure 1: ASHRAE Climate Zones**




[1] The **Database for Energy Efficient Resources** (DEER) is a California Energy Commission and California Public Utilities Commission sponsored database designed to provide well-documented estimates of energy and peak demand savings values, measure costs, and effective useful life.

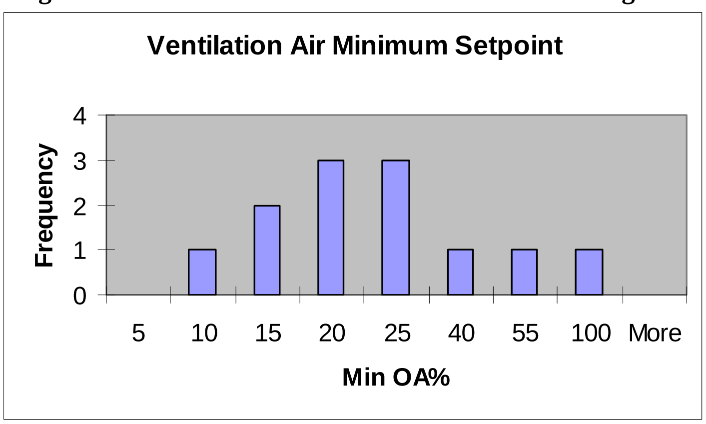
- Heating type: when the heating type changes fuel sources, a separate analysis is required to capture unit savings by fuel type.

## Analyzed Parameters

The baseline parameters analyzed for this example, with the settings included, are listed. The typical or neutral setting for each parameter is bolded.

- Internal loads, primarily as indicated by lighting density: lights 1.0 Watts per square foot; **lights 1.8 Watts per square foot**; call center density: lights 1.8 Watts per square foot + double plug load (1.5 Watts per square foot) + density (100 sf/person)
- Envelope: quality glass, double pane low-e argon filled (2668); **standard glass – double pane tinted (2203 #2)**; Poor glass curtain wall, single pane (1001)
- Economizer found changeover: failed (or none); **55°F(D);** 65°F(C); full 75°F(B)
- Minimum outside air (OSA) setting found (includes damper leakage):
  25% = 37.6 cfm/person; **20.6% = 31.0** cfm/person**;** 15% =22.6 cfm/person
  Note that most measure analysis of this type would assume a code baseline of around 10-15% ventilation air setting. This measure takes credit for setting the ventilation minimum using DCV, so it is much lower than the typically found setting. The typically found setting is higher than code requires, based on a field study in the Eugene, as seen in Figure 2.

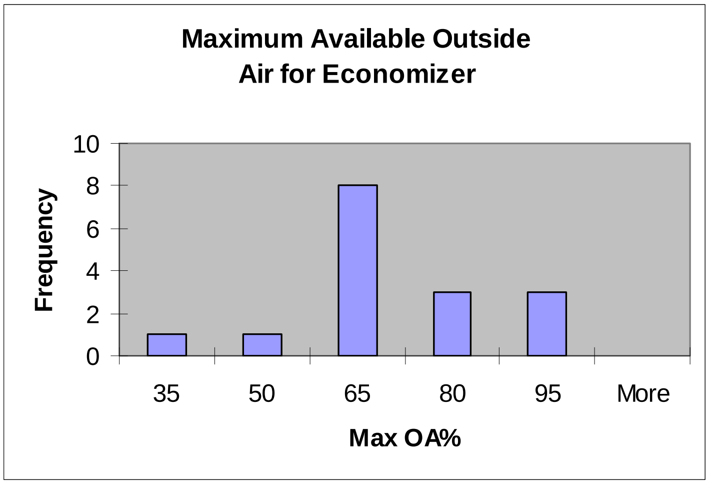
**Figure 2: Distribution of Minimum Ventilation Settings**




Source: Ecotope EWEB study – 2001

- Economizer maximum OSA flow: 50%, **65%,** 80%. Note that while the study results shown in Figure 3 indicate 65% is typical, the EWEB study focused on units smaller than 5 tons. Conversations with Mike Kennedy indicate that when larger units are included, such as in the Puget Sound Energy program, 80% is more typical.

**Figure 3: Distribution of Maximum Ventilation Capability**



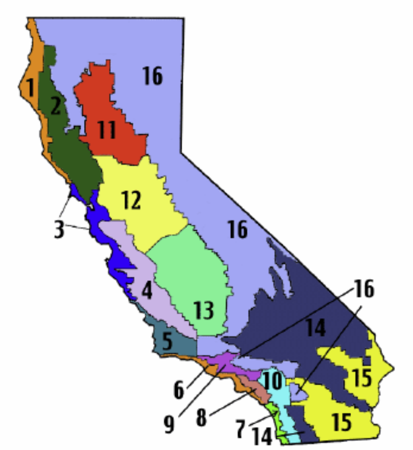

Source: Ecotope EWEB study – 2001

## Other Relevant Parameters

The following parameters are thought to be relevant to the investigation. They were not included here due to budget considerations, but should be included in a final review of this measure package.

- Hours of operation: brief 9 hours per day, 5 days per week; **office 11 hours per day, 6 days per week**; 2-shift call center 18 hours per day, 7 days per week; 24/7.
- Perimeter ratio: 3000 square feet, single storey; **25**,000 square feet, two storey; 50,000 square feet three storey.
- Base case measure overlap. Where some measures in a package may already be included in the base case condition, the impact on total savings can be modeled based on estimates for the occurrence of those measures.
- Measure reliability. One difficult to measure item is the actual savings performance of measures involving tune-up of controls or variable reliability of control operation. Once a robust sample of units has been monitored for actual performance, probabilities and performance levels can be entered as an influence in a decision model analysis as discussed later in the paper.
- Minor climate zones: for some measures, there may be meaningful impacts from different local climate zones. California is one example where 16 climate zones seen in Figure 4 have been implemented over the range of 4-5 major climate zones. With minor climate zones, the range of impact on savings is likely to be less than the impact of other parameters, and such impacts can be treated in the decision analysis in a similar manner.

**Figure 4: California Climate Zones**



- The impact of market transformation effects and delivery improvements over time can be included as a parameter, improving the realized savings in balance to the reliability issue parameter previously discussed. It is important to understand the impact of market transformation effects so a valid long-term program strategy can be developed.

## *Savings Methodology Approaches*

There are multiple approaches to analyzing or predicting program savings for energy measures. These are listed below from the most site-specific analysis to program-wide single deemed savings. Each method can have varying degrees of sophistication and hence presumed accuracy. For example a custom eQUEST (DOE2)[2] analysis can be run with or without calibration, and with custom envelope development or a simplified architectural configuration; parametric approaches can have a few or many parameters input; and deemed approaches can have a simplified or complex model behind the development of the deemed savings. Typical methodology approaches include:

- Custom analysis – this requires a model for each individual application and results in relative high accuracy. Too expensive for most contractor-delivered programs, it slows down the process when a contractor is trying to make a sale, as an energy analyst must visit the site first and complete the analysis. The level of custom analysis can range from a simplified or approximate method to an analysis that is fully calibrated to site energy bills. DOE-2 is commonly used, although a full range of modeling programs can be found at: http://apps1.eere.energy.gov/buildings/tools_directory/subjects_sub.cfm

- Field-based monitoring approach – there have been some attempts to collect field data for HVAC systems pre- and post-retrofit and use that data to generate savings. So far, this method has been elusive, and the sample sizes or time of data collection have been too small to generate data that can be used to generate savings with a high degree of confidence.

- Field-driven model approach – this method obtains field data for primary parameters and feeds that data into a simplified model to generate savings. This method uses inputs that are familiar to the field technician and makes assumptions about the remaining inputs based on building type. Among examples of this approach is the Savings Estimator,[3] developed at Purdue University.

- Energy-bill-based parametric tool – this type of parametric tool looks at billing data for a site and resolves a parametric model to the data, sometimes correlated with average monthly temperature. One example is EZ Sim (www.ezsim.com). Similar approaches are used by web-based auditing tools produced by Nexus and Apogee. While an attractive method for whole building analysis, when savings for one rooftop unit among many at a site is desired, savings or energy impacts can be difficult to see in the site energy data.

- Parametric tool – a parametric tool requires much less effort per site than a custom analysis; however, the parameters required are often outside the expertise of an installing

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[2] eQUEST is a widely used front end for DOE-2, an accepted building energy analysis program that can predict the energy use and cost for all types of buildings. DOE-2 uses a description of the building layout, constructions, operating schedules, conditioning systems (lighting, HVAC, etc.) and utility rates provided by the user, along with weather data, to perform an hourly simulation of the building and to estimate utility bills.

[3] A public version of the Savings Estimator called the Ventilation Strategy Assessment Tool (VSAT) with California climate zones is available at:
http://www.archenergy.com/cec-eeb/P3-LoadControls/P3-1_Reports.htm

HVAC contractor. Making accurate judgments about the lighting density, footprint-to-wall ratio, or glazing type will probably require an energy analyst to visit the site. Reporting for the parametric tool would be implemented similar to the current lighting spreadsheet or Energy Smart grocery program in the Pacific Northwest. Certain parameters, even within the skill of the HVAC contractor, require measurement such as baseline ventilation airflow. These measurements can be difficult to achieve accurately in a timeframe appropriate for the value of the savings. The parametric tool can be isolated to a particular unit, or attempt a whole building approach with the addition of building meter energy data.

- Simplified analysis – this is typically a spreadsheet tool that has relatively simple inputs. The lighting analysis spreadsheet used regionally is an example. Here lighting inputs are very specific, while any HVAC interaction is limited to adjustment factors based on gross system type.
- Matrix method – similar to a parametric tool, except that it would result in a "high, medium, or low" savings output, depending on certain key parameters. The original expectation was that this method would be recommended here; however, this approach is most useable only one or two field parameters are significant in the savings variation equation. In the case of the premium ventilation measure package, there are at least three input parameters that need to be attended to.
- Deemed savings by building type, vintage by measure and climate (California DEER database approach) – this method results in a very straightforward (if long) pick list of deemed values, based on multiple custom analyses of "typical" conditions. Somewhat flexible, except that a particular building may not reflect the typical building type at all. For example, an older vintage building that has been retrofitted with efficient lighting will have a completely different interaction with HVAC systems than the original with high internal loads, and there can be significant difference between sub types within a building type.
- Unit rebate – often used with lighting programs, assigns a fixed savings to unit measures such as a lighting fixture replacement. Easy to implement on a program basis, but not as well matched to control & HVAC measures, as the savings can vary widely based on unit size.
- Expected value deemed savings – this approach results in one expected value of savings for the measure or package, with the caveat that multiple results have to be generated when there are large changes in savings resulting from different meta-parameters, such as major climates or heating type changes. Does not require any site-specific input and maintains regional savings accuracy as long as installations occur with parameter variation similar to the original probability inputs to the model.

For purposes of illustrating methods that have not typically been used, this analysis explores a Matrix Method and Weighted Expected Value Approach. It should be noted that while representative parametric analysis with eQUEST was completed, the intention was to generate values for an example approach and not a final analysis of the premium ventilation package. To develop a field useable expected value, more investigation into different typical parameter values and the probability of occurrence for each value would be undertaken.

## *Parametric Run Results*

Building on prior analysis performed by EWEB for the premium ventilation package, parametric analysis was performed with eQUEST version 3.62c for selected parameters, listed in Table 1.

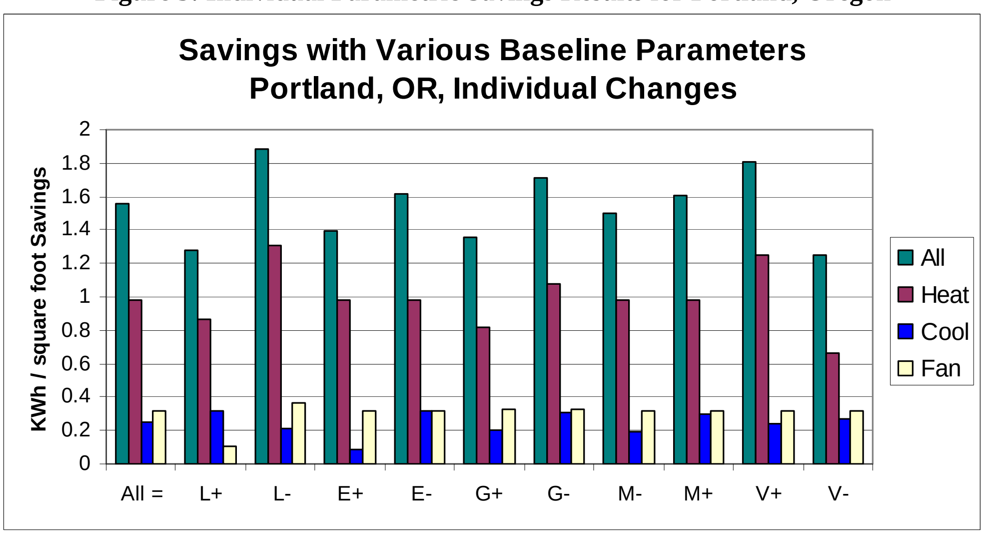
The same ECM parameters used in the EWEB premium ventilation package measure were maintained. Note that the premium ventilation package excludes the evaporative condenser pre-cooling in the earlier analysis, as this measure was found to be too expensive relative to savings except in hot/dry climates, as a plumbing trade must be involved for proper installation.

**Table 1: Baseline Parameter Variations Applied & Symbols**

| Parameter | Sym | Parameter variation in baseline BEFORE measure is installed |
|---|---|---|
| Internal Load | L+ | 1.8 LPD, 1.5 plug, 100 sf/person |
| LPD | = | 1.8 w/sf LPD; eQuest defaults |
| Density | L- | 1.0 w/sf LPD; eQuest defaults |
| Ventilation | V+ | 37.6 cfm/person |
| Minimum | = | 31 cfm/person (typical) |
| | V- | 22.6 cfm/person |
| Glazing | G+ | Low-e Argon, double pane |
| Type | = | Double pane, solar Bronze |
| | G- | Single Pane |
| Economizer | E++ | B, double stage |
| Changeover | E+ | C, single stage |
| | = | D or Snap Disk |
| | E- | Failed Economizer |
| Economizer | M+ | 80% Max OSA |
| Max OSA | = | 65% Max OSA |
| | M- | 50% Max OSA |

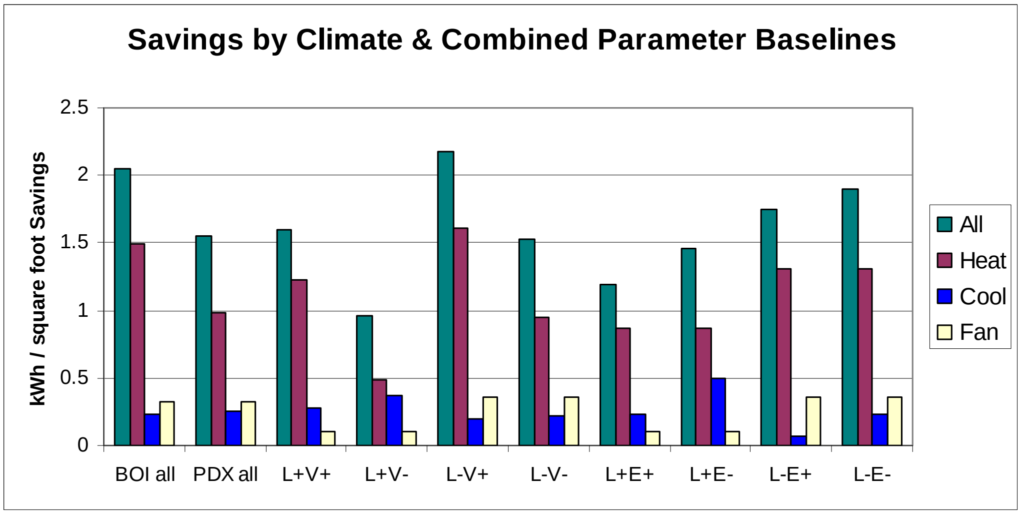
The overall savings on a building area basis when individual parameter values were changed is shown in Figure 5.

**Figure 5: Individual Parametric Savings Results for Portland, Oregon**




When parameters are varied together, they can either cancel each other out or amplify their impact. Figure 6 shows the total savings for Boise and Portland, along with variation for combinations of lighting (internal loads) and ventilation (L,V) and combinations of lighting and economizer baseline changeover (L,E). Note that there are often cases where heating or cooling move opposite each other or the fan savings, but the overall savings is similar.

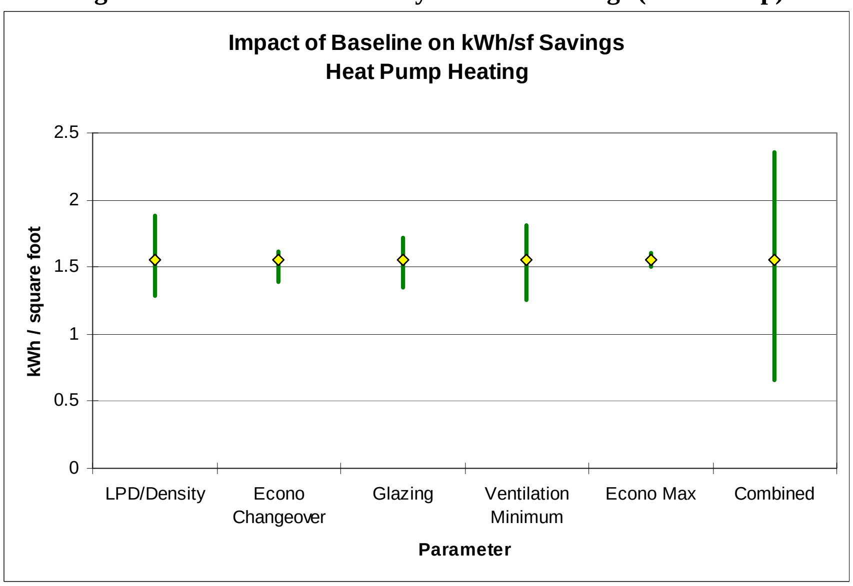
**Figure 6: Combined & Climate Parametric Savings Results**




## *Parametric Analysis*

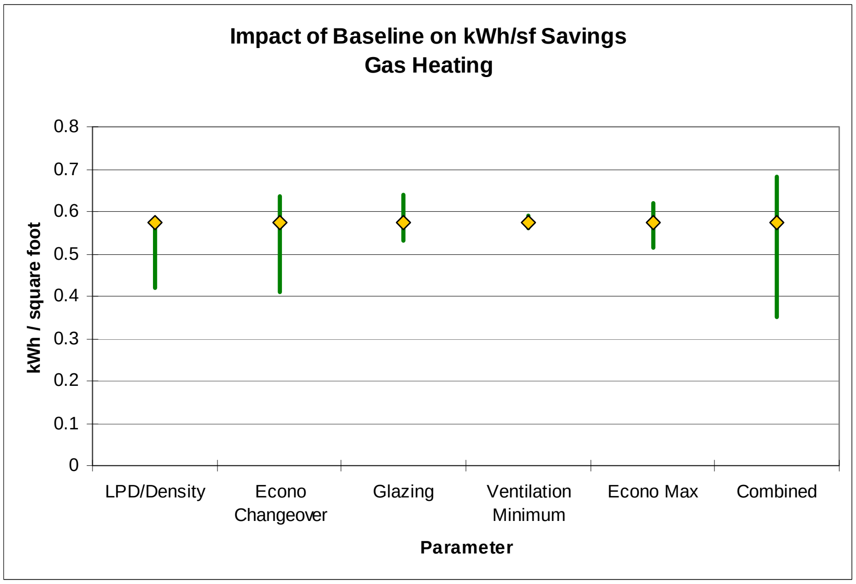
Results from changing analyzed parameter values in both directions from the neutral case are shown in Figure 7. The variation when all parameter values are changed together is also shown. Note that for total energy savings impact the lighting (internal load) and ventilation minimum parameters create the most change.

**Figure 7: Parameter Sensitivity for Total Savings (Heat Pump)**




When a similar analysis is performed for a gas-furnace heated system, the electric results show different sensitivities. In Figure 8, since electric savings no longer include heating, the economizer changeover condition becomes the most important parameter, with lighting (internal load) the second most important. Hence, attempts to reduce the analysis cost by limiting the number of parameters analyzed may result in misleading results unless sensitive parameters are determined for all meta-parameters.

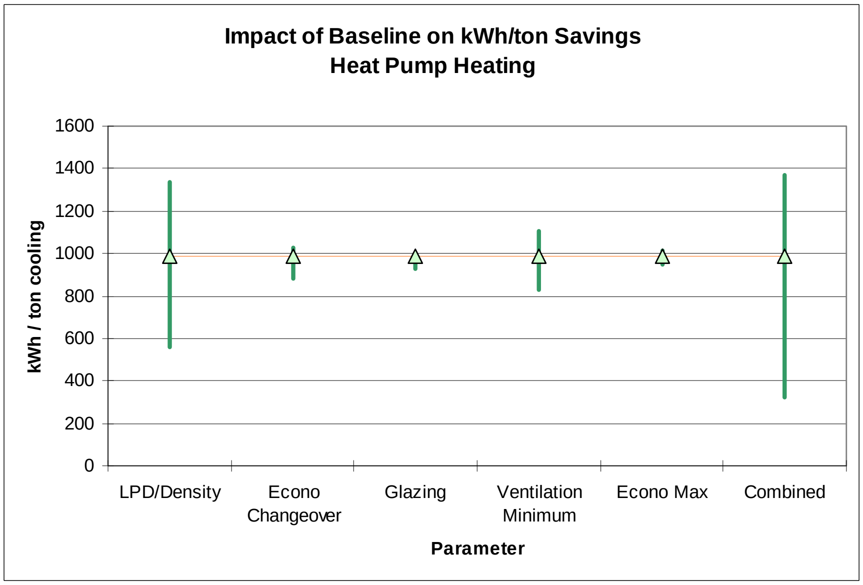
**Figure 8: Parameter Sensitivity, Electric Savings for Gas Heating**




## Impact of Reported Units

Savings have been compared on a building area basis so far. For HVAC program design, it is often popular to base incentives or rebates on unit tonnage. This reduces the impact of certain parameters. In comparing Figure 9 with Figure 7, we see that the savings are less sensitive to the impact of glazing type, and probably to other envelope parameters. This is because a unit for a building with a less efficient building envelope will be sized to handle the greater cooling load.

**Figure 9: Parameter Sensitivity When Reported as kWh/Ton (Heat Pump)**




Note that using either savings per building area or per unit size will require accurate collection of that data at each site. Some programs have been developed that assume an average or set mix of unit sizes and postulate a fixed savings for the measure. This can be attractive for measures or packages like the premium ventilation package where the cost does not vary by unit size but is similar for a wide range of unit sizes. While a unit-based (RTU-based in this case) deemed savings works well for a region over time, it may not reflect the results for a specific utility in a specific program year. This can result from utilities serving urban areas having a higher average unit size than more rural utilities or a particular delivery contractor focusing more on larger or smaller units. Based on this reality, reporting savings for these measures on a per-ton basis makes the most sense. The rebate can be designed to be uniform per unit, since essentially the same work gets done, or the rebate can be on a per-ton basis, with a cap to avoid windfalls on larger units. Whatever approach is taken, it will be best to implement regional consistency to avoid confusing contractors who serve multiple utility areas. It will also be best on the marketing side of the program to prepare customer savings estimates that are based on a typical unit rather than savings per ton.

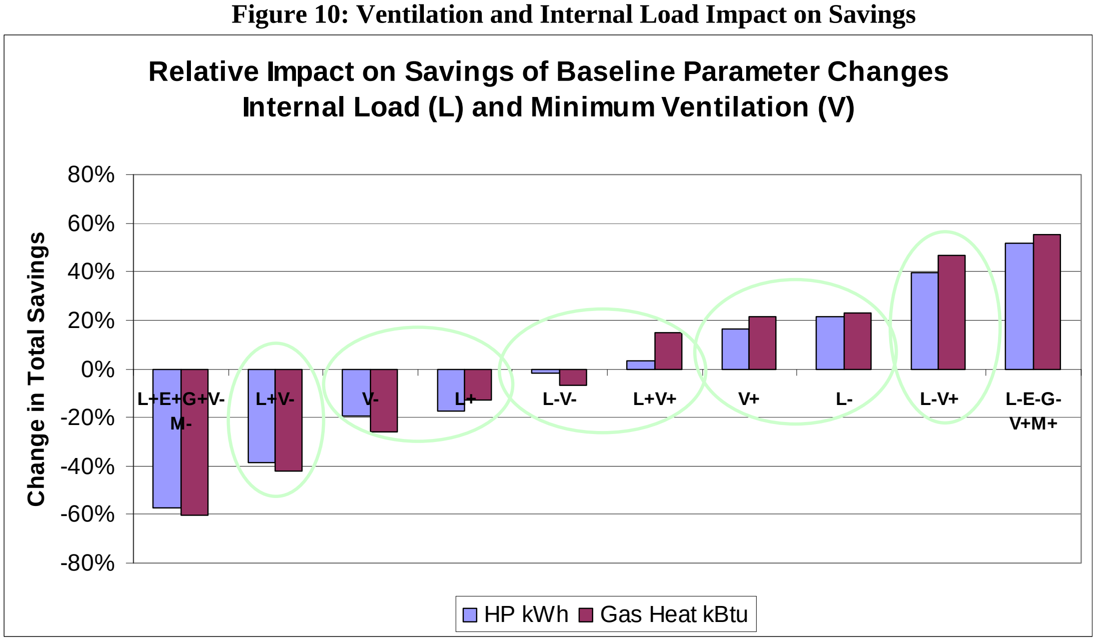
# Two Savings Methods Explored

This work develops two savings methods: a *Decision Framework Matrix* and *Expected Value Deemed Savings.* Both methods react to significant parameters. The decision framework matrix is a simplified example of a possible path to developing a parametric path for deemed savings evaluation based on different conditions encountered in the field. The *Expected Value Deemed Savings* provides a good estimate of regional savings based on relevant parameter variation but has the simplicity of a single deemed savings and no need for site specific parameter input.

## *Decision Framework Matrix Savings Method*

The purpose of a matrix savings method is to look at the most relevant parameters, place them in a matrix, and then group results that are similar to reduce the number of "line items" that must be maintained as separate measures in the RTF database. In Figure 10, the total saving results from all combinations of parameter values for lighting (L) and ventilation minimum (V) are shown. In addition, the results when all five parameters are changed together in a way that pushes the results in a common direction are shown. While changing parameter values for lighting and ventilation minimum capture most of the savings variation, there is some additional change when all parameters move together. Fortunately, the cases where all parameters move savings in the same direction are likely to be low probability situations.

**Figure 10: Ventilation and Internal Load Impact on Savings**



The results in Figure 10 are circled where the saving results are similar. These parameters are matrixed in Table 2, where for each combination of lighting and ventilation, one of five "savings conditions" is assigned

**Table 2: Savings Condition Based on Combined Parameters**

| | | | Internal Density | | |
|---|---|---|---|---|---|
| | Base Condition Savings Matrix | | L- 1.0 w/sf | L= 1.8 w/sf | L+ call center |
| Ventilation Minimum | V- | ≈15% | = | - | - - |
| | V= | ≈20% | + | = | - |
| | V+ | ≈25% | ++ | + | = |

Then these savings conditions can each be assigned a deemed savings as shown in Table 3.

**Table 3: Deemed Savings Matrix Based on Savings Conditions**

| Condition From Table Above | Deemed Savings | | |
|---|---|---|---|
| | Gas Heat | | HP Heat |
| | Gas therms/ton | Electric kWh/ton | Electric kWh/ton |
| - - | 36 | 214 | 433 |
| - | 27 | 182 | 557 |
| = | 44 | 363 | 985 |
| + | 63 | 406 | 1336 |
| ++ | 75 | 384 | 1479 |

The matrix demonstrated shows a possible approach for two parameters with three states each. In this case, nine possible savings results are reduced to five. If the matrix were expanded to more variables, then it is expected that the reduction in required outcomes would be a greater percentage. Note that the sensitive parameters were selected based on total savings results for heat pump heating. In the case of gas heating, electric savings requires economizer changeover condition to be considered as well.

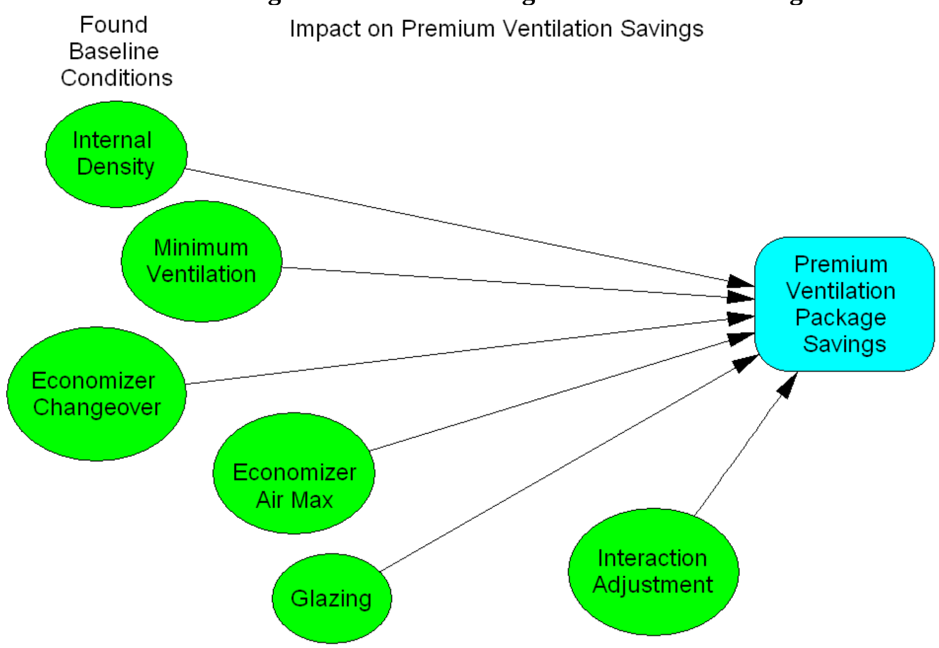
## *Expected Value Deemed Savings Method*

For most energy savings measures or measure packages, determining the savings is not as straightforward as a typical run for each building type and climate as done for the DEER database in California. Multiple parameters impact the savings, and each parameter may interact with others. A discrete savings impact for a particular building type will be an estimate at best and may not reflect the actual weighted impact of multiple parameters. Using expected value analysis, it is possible to make an expert projection of what the likely states for parameters might be with a reasonable estimation of their probability. This approach is complicated by the influence of multiple parameters that interact with each other. While a multiple variable regression approach could be applied with this method, a simplified approach that requires fewer simulation runs may be just as effective in projecting the overall program or regional impact of savings from a measure or measure package.

The approach taken here is to use Decision Programming Language (DPL)[4] in conjunction with eQUEST (DOE 2) results. DPL has been used to analyze a wide variety of decision problems including branding and marketing decisions, market entry strategies, capital investment decisions, capital allocation decisions, environmental restoration decisions and multi-attribute decision applications. These decisions have been analyzed in numerous industries including oil & gas, power, pharmaceuticals, financial services, media, sport, and technology as well as for various areas of government such as defense, regulation and community services. Though DPL is extremely powerful and flexible, it is also easy to use for less complex decisions. The decision applications have ranged from quite complex with many uncertainties and a high degree of asymmetry, to real options applications with learning models, to the relatively straightforward decisions. Here the "decision" is whether or not to implement the measure package, and the thrust of the analysis is to determine an expected value of savings. The advantage of a probability based expected value analysis is that it is very forgiving regarding accuracy of a particular parameter value or probability. This is unlike a custom analysis, where a single incorrect input can result in a very inaccurate savings projection for a particular site.

An influence diagram for this package of measures is shown in Figure 11. The value of each of the analyzed parameters is expected to influence the expected weighted value of savings for the measure package on a program basis. The interaction adjustment provides a simple method to deal with parameter interaction and is discussed later.

**Figure 11: Influence Diagram for Electric Savings**

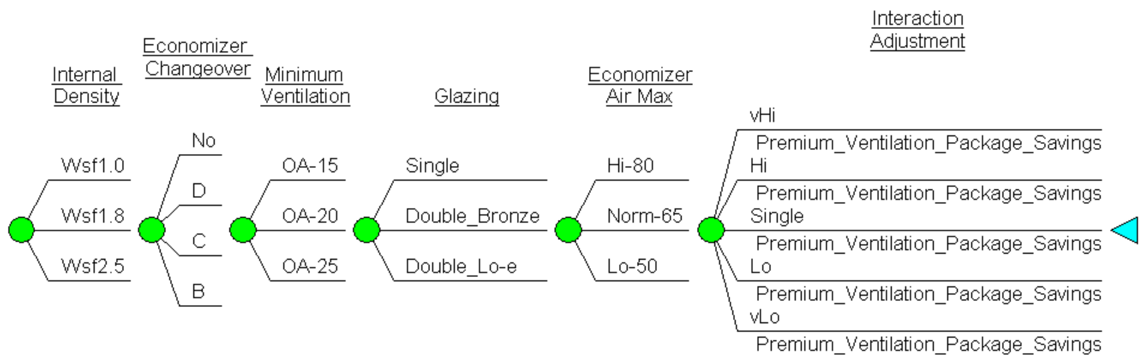



[4] An early version (3.1) of DPL was used for this analysis. There are reasonably priced shareware spreadsheet add-in calculators to determine expected value from a decision tree using similar methodology.

## Probability and Factor Assignments

The influence diagram is resolved into a decision tree, as shown in Figure 12. For each of the chance nodes (green circles), state assignments are made for each state. Each state is assigned a probability and a value that cascades through to the final result. The assigned factors and probabilities are shown in Table 4. For this example, a simplified approach is taken where the results of the individual parameter variation eQUEST runs were used to determine a factor that, when multiplied by the neutral case energy savings, results in the high or low case energy savings. Note that for the neutral case runs the factor is 1.0.

**Figure 12: Decision Tree for Combined Saving Analysis**




The probabilities in Table 4 are rough estimates used for this exploratory view of the method. In actual use, the probabilities would be based on building characteristic surveys or field investigations and could be enhanced by having a group of experts meet to agree on a set of probabilities for a particular measure or package.

**Table 4: Parameter Impact on Savings Condition and Parameter Variation Probabilities**

| Parameter | Sym | Parameter variation in baseline BEFORE measure is installed | Probability | Factors for % of neutral savings | | |
|---|---|---|---|---|---|---|
| | | | | Gas Heat | | HP Heat |
| | | | | Gas | Electric | Electric |
| Internal Load | L+ | 1.8 LPD, 1.5 plug, 100 sf/person | 20% | 0.909 | 0.732 | 0.825 |
| LPD | = | 1.8 w/sf LPD; eQuest defaults | 45% | 1.000 | 1.000 | 1.000 |
| Density | L- | 1.0 w/sf LPD; eQuest defaults | 35% | 1.295 | 1.0003 | 1.212 |
| Ventilation | V+ | 37.6 cfm/person | 25% | 0.659 | 1.027 | 1.162 |
| Minimum | = | 31 cfm/person (typical) | 50% | 1.000 | 1.000 | 1.000 |
| | V- | 22.6 cfm/person | 25% | 1.282 | 0.979 | 0.806 |
| Glazing | G+ | Low-e Argon | 10% | 0.861 | 0.929 | 0.869 |
| Type | = | Double Bronze | 40% | 1.000 | 1.000 | 1.000 |
| | G- | Single Pane | 50% | 1.079 | 1.118 | 1.103 |
| Economizer | E++ | B, double stage | 5% | | 0.500 | 0.750 |
| Changeover | E+ | C, single stage | 30% | | 0.715 | 0.895 |
| | = | D or Snap Disk | 45% | | 1.000 | 1.000 |
| | E- | Failed Economizer | 20% | | 1.109 | 1.040 |
| Economizer | M+ | 80% Max OSA | 20% | | 0.897 | 0.964 |
| Max OSA | = | 65% Max OSA | 70% | | 1.000 | 1.000 |
| | M- | 50% Max OSA | 10% | | 1.082 | 1.029 |

## Simplified Parameter Combination Impact Approach

For this analysis, a simplified approach was used to account for combinations of parameters. A run was completed for the neutral case for all parameters, and then runs were completed changing each individual parameter to its other conditions. Finally, two runs were done to find the overall impact of changing all parameters at once to the condition that either increases or reduces savings. Then the result of multiplying all individual parameter factors in Table 4 was compared to the actual result of the "all parameters" separately for the increased savings and reduced savings cases. An example of developing these combination adjustment factors for the premium ventilation package with heat pump heating is shown in Table 5.

**Table 5: Simplified Combination Adjustment Factors – Heat Pump**

| Compare to Neutral | LPD/ Density | Econo Changeover | Glazing | Ventilation Minimum | Econo Max | *Factor of All* | Combined Run | Combination Adjustment |
|---|---|---|---|---|---|---|---|---|
| Plus | 1.212 | 1.040 | 1.103 | 1.162 | 1.029 | *1.663* | 1.517 | **0.912** |
| Minus | 0.825 | 0.895 | 0.869 | 0.806 | 0.964 | *0.499* | 0.424 | **0.850** |

A high and low adjustment factor was determined that would make the product of all parameter factors equal the actual high or low case, and this is shown bold in Table 6 as the Lim+ and Lim-. A neutral case where only one parameter changes receives an interactive factor of 1.0, and an intermediate factor is the average of 1.0 and the limit factor. Each of the 5 cases is assigned a probability.

**Table 6: Parameter Combination Impacts and Probabilities**

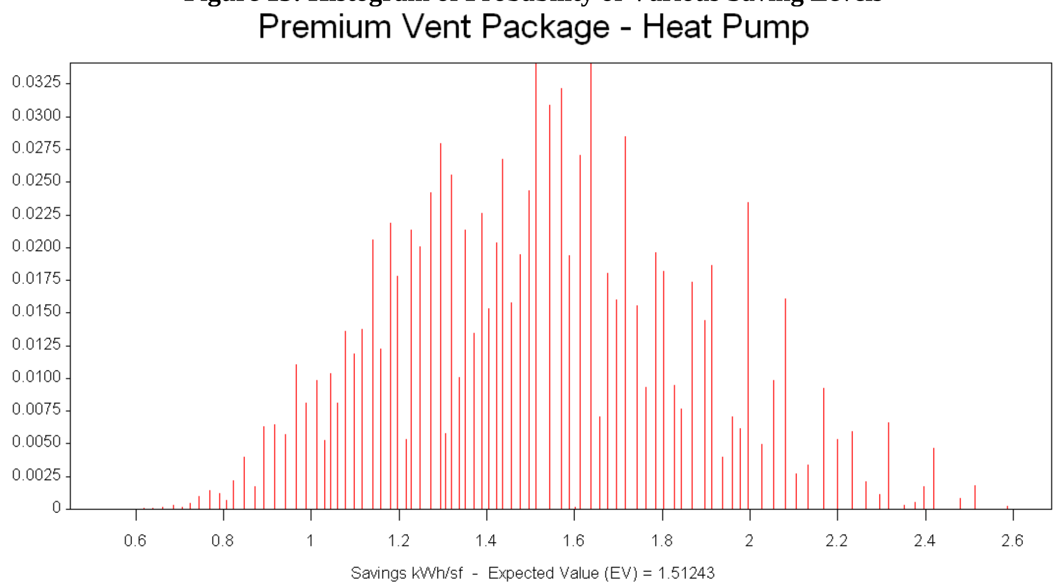
| *Simplified approach to adjust for combination impact from multiple parameter changes* | | | | | | |
|---|---|---|---|---|---|---|
| | | Parameter Combination | Probability | Gas Heat | | HP Heat |
| | | | | Gas | Electric | Electric |
| Interaction | **Lim+** | All parameters increase | 10% | **0.865** | **0.924** | **0.912** |
| factors | avg() | | 25% | 0.932 | 0.962 | 0.956 |
| from full | 1 | Single Parameter change | 30% | 1.000 | 1.000 | 1.000 |
| combination | avg() | | 25% | 1.215 | 0.825 | 0.925 |
| | **Lim-** | All parameters decrease | 10% | **1.430** | **0.649** | **0.850** |

This simplified adjustment method has the advantage of requiring the fewest number of runs. For a given climate and heating system type, one run is needed for each parameter state, plus two runs for the high and low savings impact cases. An alternative approach is to develop multiple runs with all possible combinations of parameters and use these results in a weighted fashion to develop a multiple regression model that can be called from the decision analysis model. While this may produce more accurate results, the increase in accuracy may be minimal related to the extra work.

## Program or Regional Expected Value of Savings

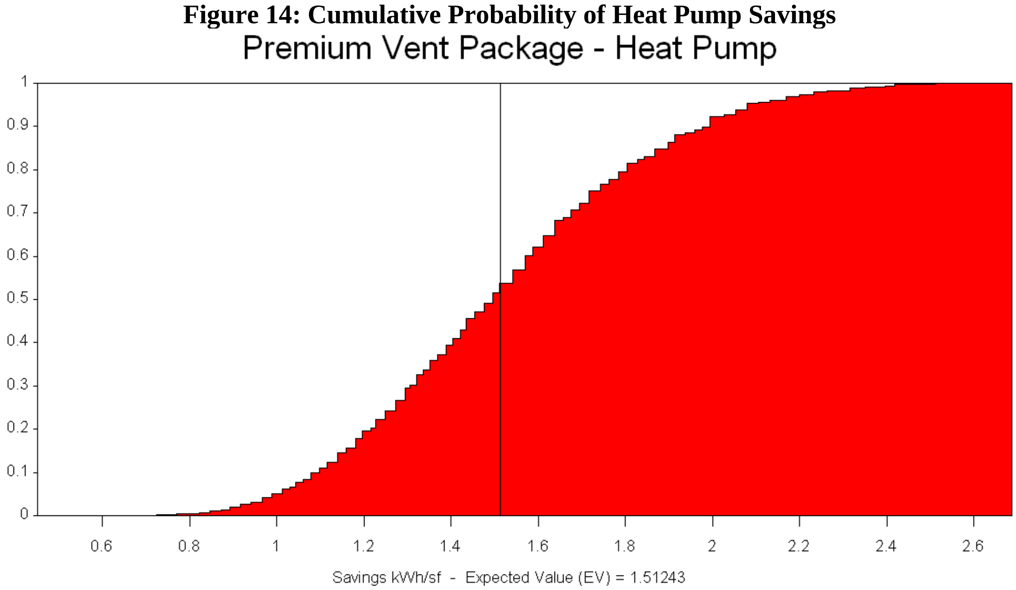
When all the possible combinations of parameter states are explored, a resulting savings for each combination is determined. The probability of occurrence of various savings results can be seen in the histogram in Figure 13.

**Figure 13: Histogram of Probability of Various Saving Levels**




The histogram can be recast as a cumulative probability as shown in Figure 14. The cumulative probability of possible individual savings results is shown, and the ability to view results in a certain "risk range" is improved. For example, the range of savings that occurs between 0.2 and 0.8 probability can be easily reviewed. The expected value (EV) is the product of each combination result and its probability (the product of all node probabilities down the tree for that case) is shown as a vertical line in Figure 14. Expected value analysis shows the range of results that can occur in individual cases as well as the expected value for the program or region as a whole.

**Figure 14: Cumulative Probability of Heat Pump Savings**




While it is true that the range of individual savings results goes from close to half the EV to almost double the EV, the EV does represent a good estimate of savings for the region as a whole, given all the analyzed parametric changes. Overall results for the west side (Portland, Oregon) are shown in Table 7 for two heating system types. The expected value can be compared with the "typical case" with all parameter states at a neutral or typical value.  For this particular measure the heat pump heating overall savings is about the same for the neutral measure and the decision tree analysis.  For a gas heated system, the gas savings is higher and the electric savings is lower than the neutral parameter case.

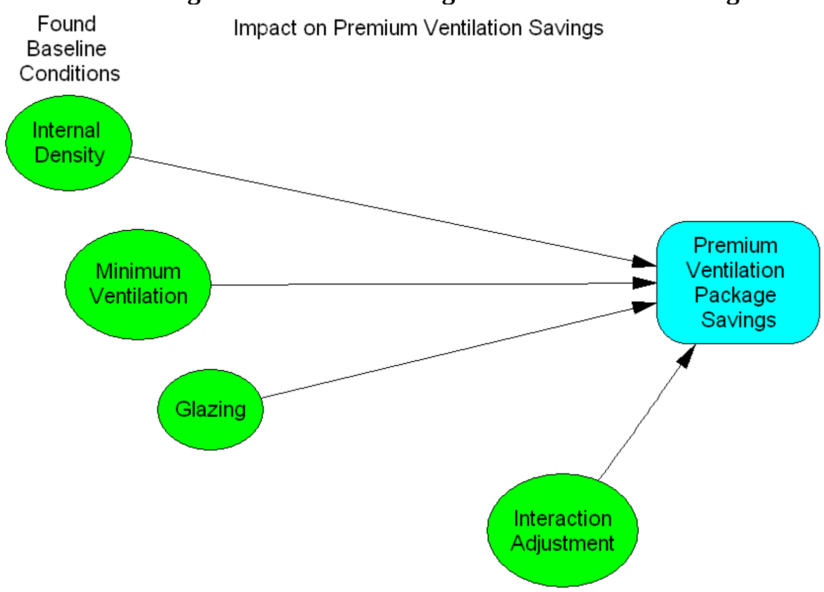
**Table 7: Neutral Parameter Case vs. Expected Value of Savings**

| Premium Ventilation Package | Gas Heat | | HP Heat |
|---|---|---|---|
| Portland, Oregon | Gas | Electric | Electric |
| Energy Saving units | kBtu/sf | kWh/sf | kWh/sf |
| Neutral (=) parameter energy savings case | 6.893 | 0.573 | 1.555 |
| Expected Value with probable adjustments | **8.191** | **0.465** | **1.512** |

## Gas Savings – Fewer Variables

While for a rigorous analysis separate gas runs would be completed, in this case, heat pump and supplemental resistance heating were converted to gas use with a flat efficiency.  Because the cooling and fan savings are electric, the influence diagram shown in Figure 15 is less complex for the gas case than it is for the electric case.

**Figure 15: Influence Diagram for Gas Heat Savings**




The cumulative probability curves for the electric and gas savings with a gas-heated system are shown in Figures 16 and 17 respectively.  The curves show the wide range of possibilities for individual site savings. While there is a small probability that there will be a very high or low savings for individual cases, the range of savings shown between 0.20 and 0.80 cumulative probability is a good reflection of the individual savings a customer might expect.

**Figure 16: Cumulative Probability of Electric Savings with Gas Heat**

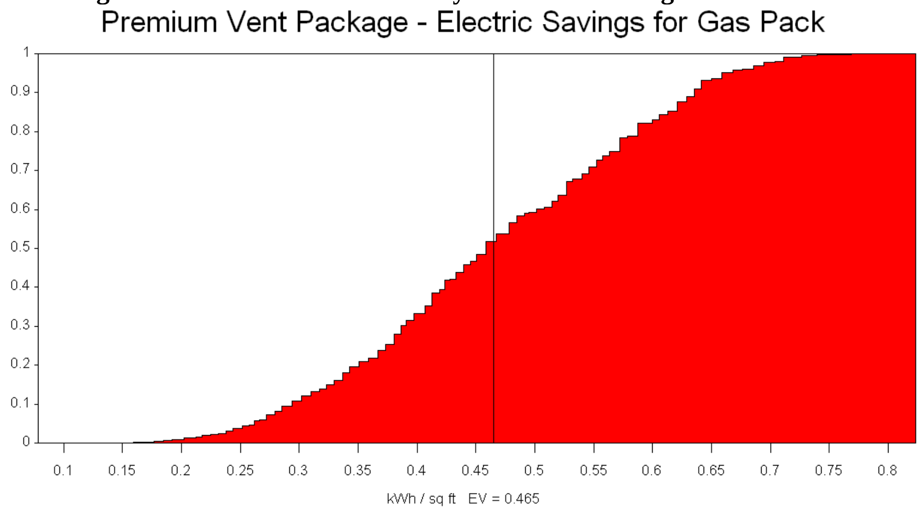
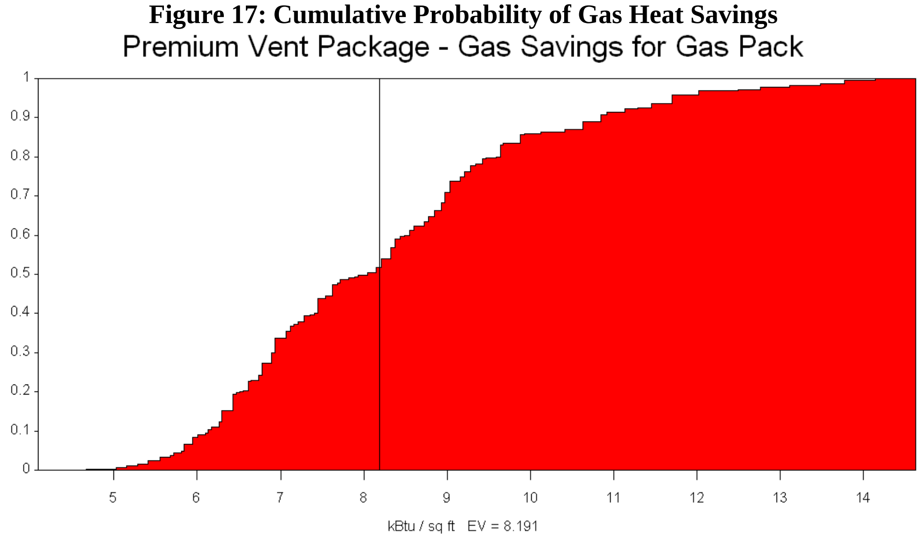



**Figure 17: Cumulative Probability of Gas Heat Savings**




## *Method Comparison*

With a low number of parameters, there is not a significant difference in the number of runs required to develop a *Decision Framework Matrix* or parametric tool versus an *Expected Value Deemed Savings.* Assuming that a baseline and ECM run are required in two climate zones for two heating types with three states per parameter, the number of cases and analysis runs are shown in Table 8. There is a big difference in the number of analysis runs required once four or more parameters are considered. It is true that automated methods have been developed to generate multiple runs and that initial sensitivity analysis can reduce the parameters investigated, but some expert attention is required to vet the results from the runs and verify that parameter variations are producing expected results. The "number of runs" question extends to parametric-based models designed for particular measure groups.

Especially in the early stages, a more reasonable analysis investment may favor the *Expected Value Deemed Savings* approach. The decision analysis model can be updated with information collected under pilot programs to improve the accuracy of state variables, especially reliability and market transformation effects.

**Table 8: Analysis Run Requirements by Method**

| Parameters of Interest | Regression-based Parametric model or Matrix | | Expected Value Deemed Approach | |
|---|---|---|---|---|
| | Cases | Runs | Cases | Runs |
| 2 | 9 | 72 | 6 | 48 |
| 3 | 27 | 216 | 8 | 64 |
| 4 | 81 | 648 | 10 | 80 |
| 5 | 243 | 1944 | 12 | 96 |
| 6 | 729 | 5832 | 14 | 112 |
| 7 | 2187 | 17496 | 16 | 128 |

# A Regional Path Forward

There have been delays in identifying acceptable regional deemed savings for HVAC measures in the commercial sector, with the exception of a lighting approach and a few measures added to the list over the last few years. Consequently, approaches for HVAC savings in the commercial sector have relied on custom analysis. It is important to develop a reasonable method that provides a good projection of regional savings combined with an easier program implementation path.

## *The Analysis Quandary*

On the surface, it seems that the most attractive approach is to provide the most accurate savings on a site-by-site basis. This accuracy comes at the cost of increased administrative costs to provide the analysis and may reduce implementation rates from the program point of view. Negative marketing impacts result from delays in the authorization process that can dissuade customers who do not meet a perfect payback threshold or confuse customers who do not fully understand the subtleties of energy conservation measure implementation and savings estimates. Approaches can range from fully custom to fully deemed. The various approaches to analysis discussed previously are:

- Custom analysis
- Field-based monitoring approach
- Field-driven model approach
- Energy-bill-based parametric tool
- Parametric tool
- Simplified analysis
- Matrix Method (parametric selection of a range of deemed savings)
- Deemed savings by building type, vintage by measure and unit rebate
- Weighted expected value deemed savings

While there may be varying balances of result accuracy vs. program effectiveness to be considered for each of these approaches, the custom approach vs. a single deemed approach are broadly compared to provide a context for recommendations.

## Custom Site Analysis – Pros and Cons

Individual site analysis, as provided with a custom analysis, a parametric input spreadsheet model, a parametric based matrix model or other suitable methods will provide the following impacts:

Advantages:

- A site-specific custom savings result is determined to inform the decision maker.
- Site based savings are reported for regional results, avoiding any skew that might occur if the implemented measures did not match deemed assumptions.
- Involvement of expert auditors may result in identification of other savings or referral to other energy programs.

Disadvantages:

- An energy expert is usually required to develop appropriate inputs:
  - Higher administrative costs.
  - If parameters or custom inputs are generated by service contractors who implement energy efficiency programs directly, they are unlikely to get proper input variables correct when they are outside their specialty, for example HVAC contractors will have difficulty estimating internal loads or glazing type.
  - At this time, well trained energy auditors are difficult to find in the industry.
  - Important parameters may require testing or monitoring.
- Differing site savings are likely to result in different rebates or incentives, although this may vary depending on the type of measure to be installed:
  - For lighting measures, varying incentives may be appropriate, as the quantity of material installed at different sites will vary widely.
  - For measures like the premium ventilation package, the work per unit is fairly constant; hence, a single rebate per unit or per ton may be preferable in program design to varying the rebate with custom calculated savings, as varying rebates can cause contractor confusion.
- For the sites where savings is lower than an expected value average, the lower savings may result in the simple payback falling below an inappropriately low business case threshold and the measure not being approved for installation.
- Typically, the custom analysis must be prepared for and delivered to the customer, resulting in a multi-step sales process that results in loss of momentum and a lower measure realization rate.

## Deemed Savings – Pros and Cons

Advantages:

- A reasonable range of expected savings can be presented for the decision maker.
- An installing contractor can implement the program expediently:
  - Lower administrative costs.
  - Quick single-step sales process that maintains momentum and a higher chance of closing the deal.
- A single or per-ton deemed savings supports standard rebates, reducing contractor and decision maker confusion and maintaining program consistency.
- Rolling up a region-wide deemed savings result would allow the cost effectiveness of the measure to be evaluated globally. This avoids the measure or package being eligible in some situations, but not in others—a situation that leads to customer and contractor confusion and negative market feedback in program implementation.

Disadvantages:

- There could be a skew in reported savings if the measures actually implemented in a particular territory or time period did not match the weighted probabilities used in the deemed analysis.
- A deeper relationship with expert auditors is not developed, limiting consideration of measures to the specific program and limiting the possibility of selling more sophisticated measures in a later trip.
- For the sites where savings is higher than an expected value average, the lower deemed savings may result in the measure not being approved for installation.

## *Recommendations*

Based on the work so far, there are method recommendations specific to program type and also recommendations for further research.

### Methodology to Fit Specific Programs

The best savings methodology for commercial buildings depends on the program approach.

- Complex measures with large savings should receive some level of custom analysis.
- Contractor-delivered lighting programs, where there is a large variation in work performed at each site, are best served by a simple spreadsheet approach with simple adjustments for heating system type.
- Contractor-delivered HVAC programs, where the work performed per unit is fairly consistent, can benefit from a standardized savings per ton by major climate zone where a decision-analysis-based expected value of savings is developed based on estimates of field parameters.
- Programs that rely on a marketing approach involving visits by a field energy analyst, benefit from using a parametric model that customizes savings to the site.
- A matrix method to select from multiple deemed savings does not provide significant advantages over a parametric model approach, although it may be less costly to develop.

### Further Research

If the RTF is interested in developing the *Expected Value Deemed Savings* method, further research should be undertaken to fully vet the method.

- This measure package should be further explored to determine deemed expected values in a process that includes research into extant characterization data and a "committee of experts" process to develop probabilities for the parameter variations that have a more solid consensus footing.
- Evaluate the differences in expected value and range of results for unit basis (kWh/unit) versus floor area basis (kWh/sf) versus size basis (kWh/ton) results.
- A regression model for high impact parameters should be developed for inclusion in the decision analysis model to determine the acceptability of the less costly simplified interactive method used in this work.
- Other software tools for a multiple node expected value analysis should be explored to make recommendations on effective methods to the energy community.
- A more in-depth review of how program impacts change as programs and technology mature. For many parameter state probabilities we need to rely on data from short-run efforts. Once we understand how past programs impacts have changed as they mature and economy of scale takes hold, we can apply anticipation factors to the projections over longer time frames.
- Develop a step-by-step *Expected Value Deemed Savings* method for use in the region.

# Appendix A: Summary of Prior EWEB Simulation Work

This simulation work was completed in preparation for a paper[5] presented at ACEEE in 2008 by Eugene Water & Electric Board (EWEB), a municipal utility in Eugene, Oregon. The simulations and specification form the basis for the analysis of the premium ventilation package of measures.

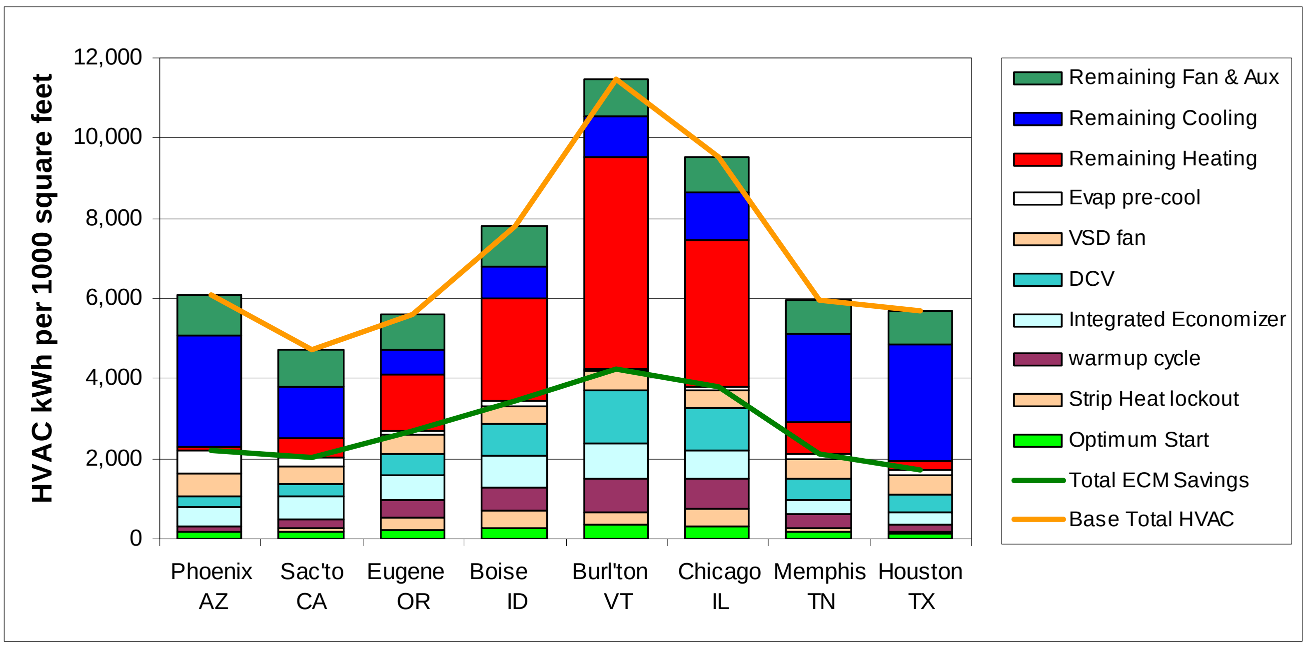
[5] Hart, R., D. Morehouse, W. Price, J. Taylor, M. Cherniack & H. Reichmuth. "Up on the Roof: From the Past to the Future." *Proceedings of the ACEEE 2008 Summer Study on Energy Efficiency in Buildings*. Washington, D.C.: American Council for an Energy-Efficient Economy (ACEEE).

# Summary of prior EWEB simulation work

The prior simulation work was completed at EWEB in early 2008 by Reid Hart, Will Price and Dan Morehouse. The savings results of the analysis are shown in the figure below. These results include evaporative pre-cooling, but those savings are minimal in the Northwest. The premium ventilation package of measures results in 5 to 25 times the savings of an upgrade from SEER 13 to 15. The technologies in the premium ventilation package include:

- Optimum start
- Resistance heat lockout for heat pumps based on outside air temperature
- Ventilation lockout during morning warm-up with improved damper seals
- Economizer control with integration and comparative changeover control
- Demand controlled ventilation (DCV)
- VSD fan control

**Rooftop Unit Savings in Representative Climates**




Reworking the numbers as previously analyzed for just the Premium Ventilation Package (excluding the evaporative pre-cooling of the condenser) for climates of interest shows the following expected results:

| **Heat Pump kWh saved /2000 sf** | **Sacram. CA** | **Eugene OR** | **Boise ID** | **ECM Cost** |
|---|---|---|---|---|
| Optimum Start | 343.3 | 424.3 | 557.2 | $378 |
| Strip Heat lockout | 203.8 | 665.3 | 856.5 | $282 |
| Warmup cycle | 426.5 | 810.1 | 1,184.9 | $528 |
| Integrated Economizer | 1,118.9 | 1,243.3 | 1,523.0 | $995 |
| DCV | 669.0 | 1,131.4 | 1,602.5 | $611 |
| VSD fan | 896.9 | 898.7 | 879.4 | $636 |
| **Premium Ventilation kWh** | **3,700** | **5,200** | **6,600** | **$2,144** |

| | | | | |
|---|---|---|---|---|
| $/kwh | 0.083 | 0.048 | 0.033 | |
| Annual Savings | $307 | $249 | $220 | |
| Simple Payback | 7.0 | 8.6 | 9.8 | |
| Incentives @ 0.15/kWh | 555 | 780 | 990 | |
| Net Customer Cost | $1,589 | $1,364 | $1,154 | |
| Net payback | 5.2 | 5.5 | 5.3 | |

| **Analysis for Gas Pak** | **Sacram. CA** | **Eugene OR** | **Boise ID** |
|---|---|---|---|
| Electric Savings, kWh | 1967 | 1511 | 1607 |
| Gas Savings, Therms | 94 | 203 | 278 |
| $/kwh | 0.083 | 0.048 | 0.033 |
| $/therm | 1.344 | $1.25248 | 0.901 |
| Annual Savings | $290 | $327 | $304 |
| Simple Payback | 7.4 | 6.6 | 7.1 |
| Incentives @ 0.15/kWh | $295 | $227 | $241 |
| Net Customer Cost | $1,849 | $1,918 | $1,903 |
| Net payback | 6.4 | 5.9 | 6.3 |

## *Unrecognized Technologies Old & New*

There are multiple strategies available for small rooftop technologies that go beyond straight efficiency (SEER/EER). Many of these have been commercially available for decades but have not had a testing procedure available to allow them to be reliably compared. Table 1 summarizes the technologies that are candidates for an efficiency test procedure, indicates why they save energy, and indicates their status in the smaller packaged unit marketplace. Features that provide maintenance benefits or are difficult to test in a standard procedure are not listed.

**Table 1. Technologies Considered**

| Technology | Savings Rationale | Status |
|---|---|---|
| **Readily available items:** | | |
| Optimum start | Reduces energy use during building startup with moderated space temperatures | Established - in most thermostats |
| Resistance heat lockout for heat pumps based on outside air temperature | Reduces electric energy used for heat pump units by restricting use of resistance heating to colder ambient temperatures | Established as an option – often not installed |
| Ventilation lockout during morning warm-up with improved damper seals | Reduces energy use during building startup with less heating (sometimes less cooling) of ventilation air | Established option – rarely installed |
| Economizer control with integration and comparative changeover control | Reduces mechanical cooling by using outside air when appropriate to reduce mixed air temperatures | Established option – full application is rare |
| Demand controlled ventilation (DCV) | Reduces energy use during weather extremes with less heating or cooling of ventilation air, as quantity of ventilation is reduced to match actual occupancy requirements. | Established as an option – rarely installed |
| **Limited availability items:** | | |

| | | |
|---|---|---|
| VSD fan control | Reduces fan energy use and impacts from duct leakage by reducing airflow when the unit is not actively heating or cooling. | Rarely installed in commercial; two known manufacturers |

Each measure is described briefly below with discussion of availability and market placement. Some items like optimum start thermostats, economizer controls, and warm-up cycle are independent of the unit itself, yet there has been an increasing call for factory supplied control packages that have been tested with the unit to verify compatibility (AEC 2005). The ability of the unit to respond properly to the controls is important in several cases, including interaction of outside air damper configuration and seals, exhaust air damper placement to minimize re-entrainment of exhaust air, and response of controls to outside temperatures.

The baseline building for savings analysis is a 20,000 square foot 2-story office building primarily using the Title 24 eQuest defaults, with an increase in unoccupied lighting and equipment loads to reflect reality and higher than required ventilation (31 cfm/person or 13%) to reflect field observation of ventilation minimums greater than 20% (Hart, Mangan & Price 2004; Davis et. al. 2002). Packaged single zone units with a SEER rating of 13.0 were simulated.

**Optimum start**. Most programmable thermostats have an optimum start option that slowly increases the setpoint temperature during building warm-up rather than moving immediately to the occupied setpoint.

**Resistance heat lockout.** A simple thermostat control that has been available from heat pump manufacturer's for decades. Typical installation simply interrupts the low voltage signal to the resistance heat relay when the outside air is warmer than a set temperature.

**Ventilation lockout during morning warm-up with improved damper seals**. HVAC units typically start 2 to 3 hours before occupancy with full ventilation provided. This uses a significant amount of unnecessary heating. The measure requires a thermostat with a separate relay signaling actual occupancy period start and an economizer controller allowing this input. Outside air dampers for small package units are also notoriously leaky, with air leakage of 5% to 25%. Properly installed low-leakage dampers can reduce the leaks and could be tested with the proposed testing procedure.

**Outside air economizer.** Outside air economizers have been marketed for decades, but no testing procedure has ever been fully developed. Modifying the test apparatus to allow interaction of the unit with the simulated outside environment will verify operation and impacts of these controls. The unit is simulated here with integration and differential changeover control. Dry-bulb sensors are used in the Western US, and enthalpy sensors in the East.

**Demand controlled ventilation.** Demand controlled ventilation (DCV) has traditionally been applied to larger units and areas with dense and variable populations. Because of a reduction in benefit when a properly operating economizer is employed, the measure rarely pays in general density areas with proper system testing, adjusting, and balancing (TAB). Package units do not normally receive proper TAB and ventilation minimums are significantly higher than required (Davis et. al. 2002). Beyond minimum ventilation correction, a DCV system also provides the same benefits of warm-up lockout without the need for a special thermostat. DCV will also adjust ventilation to meet actual load when building occupancy is less than design (almost always). Installation requires a higher quality economizer controller and a carbon-dioxide sensor. The cost of sensors for large-volume contractors continues to drop and is less than $150. If the typical excessive ventilation air is accounted for in the baseline, and the additional benefits of ventilation lockout considered, DCV is cost effective.

**VSD fan control.** Several manufacturers provide this option in their high-end units marketed to residential customers. There are at least two retrofit products available that contain both a motor speed drive and a control package for fan motors under 10 amps. These units will provide significant fan savings and quieter operation during the ventilation cycle when the unit is not heating or cooling. They can also improve dehumidification in appropriate climates. These units typically include controls designed to modulate fan speed to maintain discharge temperatures within a range or unit temperature difference in a range, reducing speed to a set minimum when there is no call for heating or cooling. Installation of this measure in a commercial building requires installation of DCV to maintain ventilation when the fan speed is reduced.

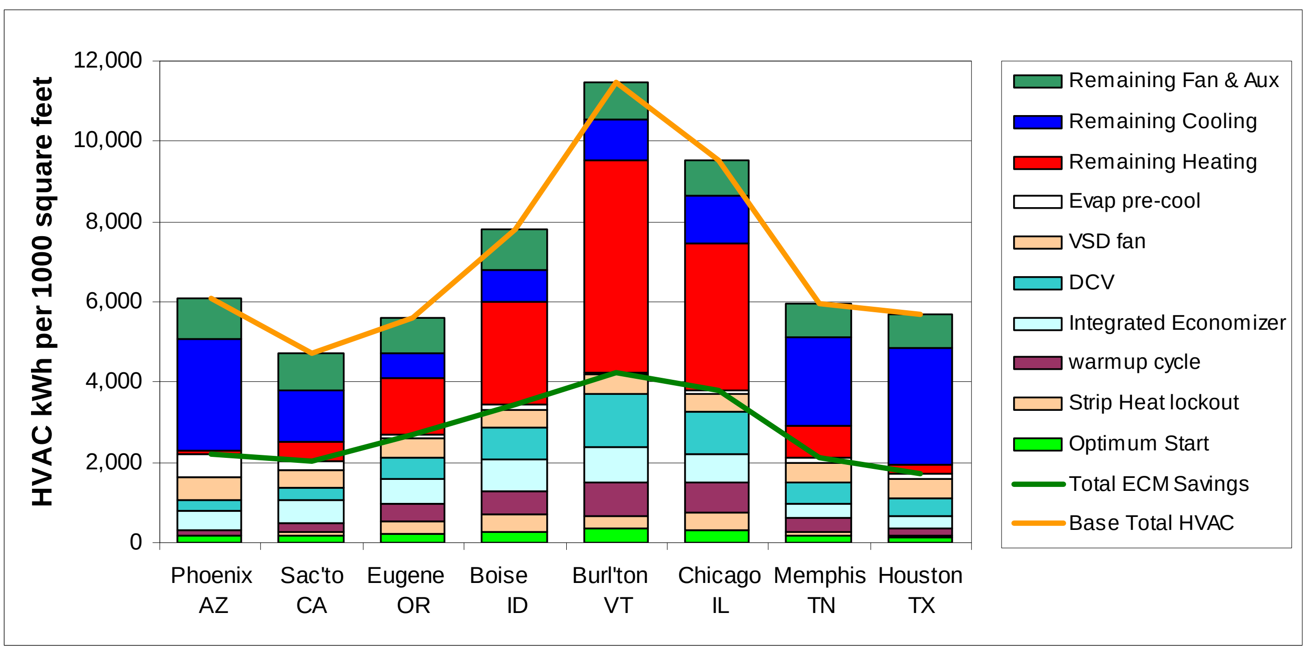
## *Premium Ventilation Rooftop Package Potential Savings*

Measure items included:

- Optimum start
- Resistance heat lockout for heat pumps based on outside air temperature
- Ventilation lockout during morning warm-up with improved damper seals
- Economizer control with integration and comparative changeover control
- Demand controlled ventilation (DCV)
- VSD fan control
- Evaporative assist condenser pre-cooling (not included in Premium Ventilation Package).

Measure savings were analyzed using DOE 2.2 for eight cities in the United States, covering a range of climate zones. Heat pump systems on a typical small office building were analyzed so all results would be electric for easy comparison. The allocated interactive[5] measure saving results from the DOE2 analyses are shown in Figure 6, along with remaining HVAC energy use after all measures are completed.

**Figure 6: Rooftop Unit Savings in Representative Climates**




[5] For individual saving results in Figure 6 the interactive package savings are allocated using the share of savings for each measure's independent results (shown in Table 4). This method eliminates order of consideration issues inherent in a rolling baseline calculation.

Overall interactive results for the comprehensive package of measures are shown in Table 2 along with a conversion of heat pump heating to natural gas furnace heating. It is interesting to note that this package of measures results in 5 to 25 times the savings of an upgrade from SEER 13 to 15.

**Table 2. Overall Package Measure Results & Climate Zone Information**

| **Savings for composite run:** | **Phoenix AZ** | **Sac'to CA** | **Eugene OR** | **Boise ID** | **Burltn VT** | **Chicago IL** | **Memphis TN** | **Houston TX** |
|---|---|---|---|---|---|---|---|---|
| Percent Total Savings | 36.0% | 42.3% | 47.9% | 43.9% | 37.0% | 39.5% | 34.9% | 29.9% |
| **KWh/SqFt ECM Savings** | **2.2** | **2.0** | **2.7** | **3.4** | **4.3** | **3.8** | **2.1** | **1.7** |
| Compare to 15 SEER savings | 0.42 | 0.22 | 0.15 | 0.17 | 0.17 | 0.19 | 0.29 | 0.37 |
| SqFt/Ton Cooling Installed | 249 | 340 | 427 | 355 | 355 | 321 | 256 | 260 |
| KWh/Ton ECM Savings | 552.5 | 685.9 | 1,151.3 | 1,219.9 | 1,507.3 | 1,213.3 | 539.2 | 450.4 |
| Annual savings for recast of heat pump heating to gas heating at 78% AFUE: | | | | | | | | |
| KWh/SqFt, all measures | 2.0 | 1.2 | 0.9 | 0.9 | 0.7 | 0.7 | 1.1 | 1.3 |
| Therm/SqFt, all measures | 0.012 | 0.047 | 0.102 | 0.139 | 0.200 | 0.171 | 0.057 | 0.024 |
| ASHRAE Climate Zone | 2 | 3 | 4 | 6 | 6 | 5 | 4 | 2 |
| ASHRAE Moisture Area | Dry | Dry | Marine | Dry | Moist | Moist | Moist | Humid |
| East vs. West | West | West | West | West | East | East | East | East |

## *Cost Effectiveness and Premium Ventilation Package*

Measure cost effectiveness will vary by climate zone and building characteristics. The intent of this analysis is to demonstrate that potential savings exist. Individual measure results are shown in Table 5 as a range based on the greatest and smallest climate zone savings, along with an expected cost range. The basis is 1500 square feet per unit, as the measure cost is per rooftop unit. The payback range is fairly wide, indicating that measure packages should be developed for different climates. The average payback is reasonable for most measures, with the average package payback of less than five years.

There are significant advantages to incorporating the control measures into a "Premium Ventilation Package." This package includes all measures except the evaporative pre-cooler for the condenser. For example, economizer savings potential has been attractive, but unreliable unless commissioned. The payback on a small unit may not be attractive when the cost of commissioning was included. When multiple measures are combined—all of which require commissioning—the cost of commissioning is not much more than for one measure, so the overall cost for a combined measure with commissioning is much more attractive.

**Table 5. Measure Savings, Cost & Simple Payback**

| Energy Conservation Measures | Savings Range kWh/Unit | | Savings Range $/Unit/Year | | Cost Range | | Simple Payback Range, yr | | Average Payback, years |
|---|---|---|---|---|---|---|---|---|---|
| Optimum start | 250 | 850 | $20 | $119 | $300 | $450 | 2.5 | 22.5 | 5.4 |
| OSA strip heat lockout | 50 | 1,000 | $4 | $140 | $250 | $350 | 1.8 | 87.5 | 4.2 |
| OSA warm-up lockout | 250 | 1,950 | $20 | $273 | $400 | $650 | 1.5 | 32.5 | 3.6 |
| Economizer control | 600 | 1,950 | $48 | $273 | $800 | $1,200 | 2.9 | 25.0 | 6.2 |
| Demand controlled ventilation | 550 | 3,000 | $44 | $420 | $500 | $750 | 1.2 | 17.0 | 2.7 |
| VSD fan control | 900 | 1,100 | $72 | $154 | $500 | $750 | 3.2 | 10.4 | 5.5 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Evap. condenser pre-cooling | 150 | 1,100 | $12 | $154 | $450 | $650 | 2.9 | 54.2 | 6.6 |
| **Comprehensive Package** | **2,600** | **6,400** | **$208** | **$896** | **$2,050** | **$3,050** | **2.3** | **14.7** | **4.6** |
| **Premium Ventilation Package** | **1,950** | **6,700** | **$156** | **$938** | **$1,700** | **$2,550** | **1.8** | **16.3** | **3.9** |

## *Initial opinion of probable cost*

There is a wide range of probable cost for this package of measures. The biggest variable is the pre-existence of a standard economizer. In this cost estimate the basis is that about one-third will require the addition of economizers and that 25% of the units will receive commissioning. The field test will be a very good opportunity to get good feedback about actual contractor costs for installing this set of measures. It may be that once actual costs are in hand, it makes sense to restrict the measure to units that are already equipped with outside air economizers.

| | |
|---|---|
| Materials | **$ 1,057** |
| Low voltage wiring | **$ 125** |
| Installation | **$ 405** |
| OH&P | **$ 317** |
| Commissioning (25% sample) | **$ 240** |
| Total | **$ 2,144** |

The parameters used to simulate each measure are shown in Table 3 along with non-interactive savings averaged across the eight climate zones. Individual measure results for each climate zone shown in Table 4.

**Table 3: Measure Parameters and Potential Non-Interactive Savings**

| **Technology** | **Baseline Parameters** | **Measure Parameters** | **Average US Savings kWh/SF/yr** |
|---|---|---|---|
| Optimum start | Setpoint to Occupied 2 hours before occupancy; fan on | Setpoint ramps 33% during 3 hours before occupancy with fan cycling | 322.9 |
| OSA strip heat lockout | Strip heat operates as needed and during warm-up | Strip heat locked out above 30F OSA, heat pump compressor allowed to DOE2 default (10°F) | 322.4 |
| OSA vent lockout during morning warm-up with improved damper seals | Ventilation (31 cfm/person) begins 2 hours before occupancy with fan on; damper leakage at 8%. | OSA dampers closed before occupancy; at occupancy 31 cfm/person provided. Infiltration ACH/hr at DOE 2 defaults, Damper leakage at 4%. | 619.4 |
| Economizer control with integration and differential changeover control | No economizer; 31 cfm/person ventilation air during occupancy reflecting field discovered excess ventilation settings | Differential changeover (drybulb west 75°F high limit, enthalpy east 34 Btu/lb high limit) and 65% maximum air available on cooling demand. Ventilation to 20.5 cfm/person reflecting commissioned airflow setting | 829.1 |
| Demand controlled ventilation (DCV) | Ventilation at 31 cfm/person reflecting field discovered excess ventilation settings | Ventilation to 15 cfm/person to reflect typical occupancy below design; equivalent of maintaining 20 cfm/ actual person | 968.9 |

| | | | |
|---|---|---|---|
| VSD fan control for smaller rooftop packaged units. | Fan "ON" during occupied | Supply airflow reduced to 30% when heating or cooling not required; 15 cfm/person ventilation maintained | 667.1 |
| Evaporative assist condenser pre-cooling. | Air cooled evaporator at ambient dry-bulb | DOE2 standard measure, condenser type changed to evaporative | 237.6 |

**Table 4: Non-interactive Measure Savings by Climate**

| Energy Saving Technology | kWh/1000 sf/year savings, non-interactive | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Phoenix AZ** | **Sac'to CA** | **Eugene OR** | **Boise ID** | **Burl'ton VT** | **Chicago IL** | **Memphis TN** | **Houston TX** |
| Optimum start | 219.0 | 235.0 | 309.0 | 403.0 | 551.5 | 449.0 | 241.0 | 175.5 |
| OSA strip heat lockout | 19.5 | 139.5 | 484.5 | 619.5 | 412.5 | 670.0 | 164.5 | 69.0 |
| OSA warm-up lockout | 153.0 | 292.0 | 590.0 | 857.0 | 1,311.0 | 1,058.5 | 444.0 | 249.5 |
| Economizer control | 595.0 | 766.0 | 905.5 | 1,101.5 | 1,315.5 | 1,025.0 | 515.5 | 409.0 |
| Demand controlled ventilation | 369.0 | 458.0 | 824.0 | 1,159.0 | 1,995.0 | 1,554.5 | 773.5 | 618.0 |
| VSD fan control | 726.0 | 614.0 | 654.5 | 636.0 | 726.0 | 659.5 | 660.0 | 661.0 |
| Evap. condenser pre-cooling. | 726.5 | 256.5 | 156.5 | 200.0 | 88.5 | 121.0 | 176.0 | 176.0 |
| Package Interactive Savings | 2,221.0 | 2,016.5 | 2,694.0 | 3,440.0 | 4,250.5 | 3,785.5 | 2,103.0 | 1,729.5 |

# Appendix B: Western Premium Economizer Background

## Important Pending Revision:

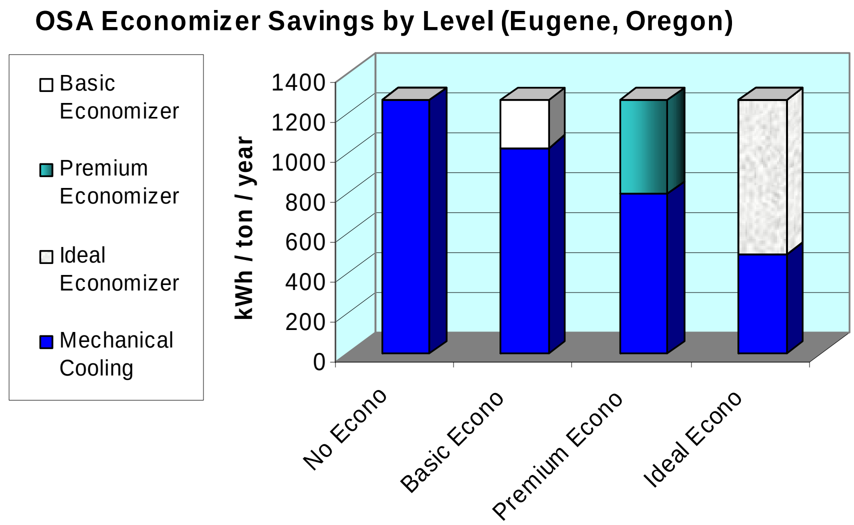
Since development of the Western Premium Economizer specification, problems have come to light with the dry-bulb sensors for the prime manufacturer.[6] As a result, this product is being replaced with a dry-bulb sensor with a smaller switching differential and more accuracy. As this new product will not operate in the comparative or differential changeover mode, the Western Premium Economizer specification is being revised to allow single point sensible changeover. In conjunction with a variable speed fan motor it is appropriate to run the fan at full speed in economizer mode only when the outside air is at least 5°F below return air.

The following specification has not been updated for this change in technology.

[6] Robison, D., R. Hart, W. Price, & H. Reichmuth. "Field Testing of Commercial Rooftop Units Directed at Performance Verification." *Proceedings of the ACEEE 2008 Summer Study on Energy Efficiency in Buildings*. Washington, D.C.: American Council for an Energy-Efficient Economy (ACEEE).

# Western Premium Economizer Background

**Why a *Western Premium Economizer*?** Several field studies completed around the country have found that more than half of outside air economizers are not providing optimal savings, either because dampers or controls have failed, changeover is set incorrectly, or the improper type of controls for the local climate have been installed. The graph at the right shows the potential savings increase from upgrading an economizer to premium specifications. The following *Western Premium Economizer* requirements are designed to improve reliable operation and increase energy savings in the Pacific Northwest.




**Outside Air Economizer Savings Principles.** The basic idea behind an outside air economizer is to use cool outside air instead of mechanical cooling to cool the space. Where there are cooling loads at the same time outside air temperatures are cool, significant savings of 20% to 60% can be achieved. To work properly, the economizer must **coordinate** or **interlock** with the cooling so that it is only used when there is a call for cooling. An economizer is also equipped with some type of **changeover** control that returns the outside air damper to a minimum ventilation position when the outside air is too warm to provide cooling. An **integrated** economizer takes full advantage of outside air before mechanical cooling is used. Over the years, numerous ways to provide economizer controls have been created. The *Western Premium* outside air economizer uses readily available technology to provide a system that doubles the savings compared with a basic economizer that is typically provided in today's HVAC market place.

**Understanding OSA Economizer Attributes**. Many items can be adjusted to change the operation, effectiveness, cost, and potential savings of an outside air economizer. These can be grouped into five general attributes:

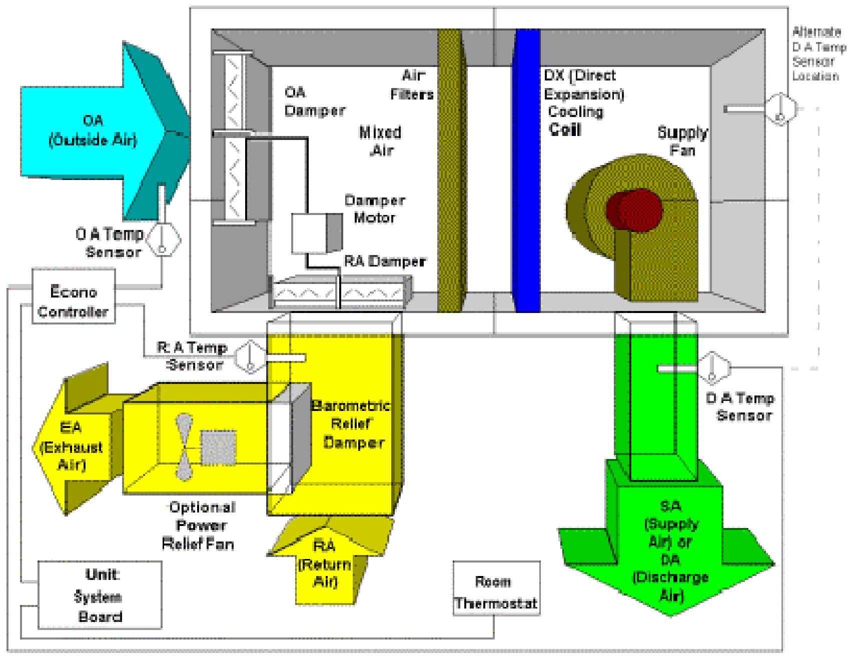
- Economizer configuration: How many dampers and what can they do?
- Economizer activation: When does the economizer come on?
- OSA high limit or "changeover" sequence: When is it too hot to economize?
- Level of Integration: Does mechanical cooling work together with free cooling?
- Minimum ventilation airflow amount and how activated.

**1. Economizer configuration** includes the number and relationship of dampers and relief/exhaust air characteristics, as well as the type of mixed air or discharge air temperature control. The basic questions are: "How many dampers does the economizer control?" and "What damper control options do I have?" Damper Control options include:

- Number of dampers. Typically, smaller units have outside and return air dampers. Exhaust or relief can be omitted, provided by barometric dampers or motor controlled exhaust air dampers. On larger units, a relief fan can be added to assist exhaust. Smaller units have parallel blade or single dampers. On larger units, opposed blade dampers with seals improve control.

- Damper movement can be manual, two-position with only open or closed positions; three-position with full, minimum, and closed positions; or fully modulating with the ability to locate to any percentage open position.
- Fully modulating automatic dampers are typically controlled by a primary sensor or low limit temperature control. Usually the proportional controller maintains air between 50°F and 56°F. The sensor can be located in either the mixed air (MA) position or the discharge air (DA) position. One point of confusion is that this is often called a "mixed air" sensor by manufacturers. Mixed air is the proper primary sensor location for fully modulating chilled water coils, but to maintain comfort and avoid coil icing with a direct-expansion cooling system, the primary economizer sensor should typically be located downstream of the cooling coil in the discharge air position.

**Packaged Unit (DX cooling) Outside Air Economizer**



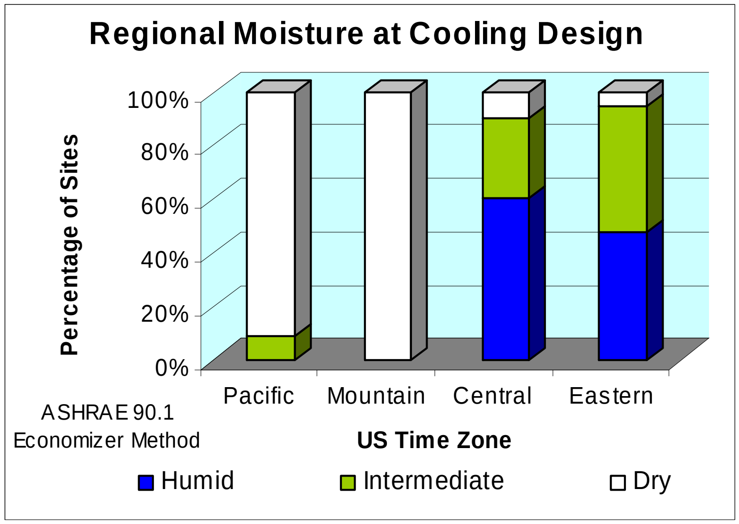

**2. Economizer activation** includes how or if the economizer operation is interlocked with cooling call. The basic question is: When does the economizer turn on? Activation of the economizer can be:

- "Wild" or full open. This can be manual or automatic. Automatic operation usually includes a lock-out that closes the economizer if OSA is too cold.
- Fixed mixed air cycle that always maintains a set mixed air temperature (55°F typical).
- Coordinated or interlocked with a call for cooling. Activation on an actual call for cooling is preferred, as other methods can result in excessive heating costs.

**3. OSA high limit or "changeover" sequence** determines when is it too hot outside to use the economizer. Changeover type is distinguished by both choice of mode and sensor type. The sensor type should match the climate. Three types of sensors are available:

- Dry-bulb sensors measure temperature only.
- Enthalpy sensors adjust for the heat energy of moisture content in air.
- Separate dry-bulb and humidity sensors measure moisture more accurately and are also referred to as enthalpy control.

The graph shows the share of humid vs. dry climate cities by time zone in the U.S. In the western half of the country, there are no humid climate sites and dry-bulb sensors will do the job at a lower cost with better reliability.

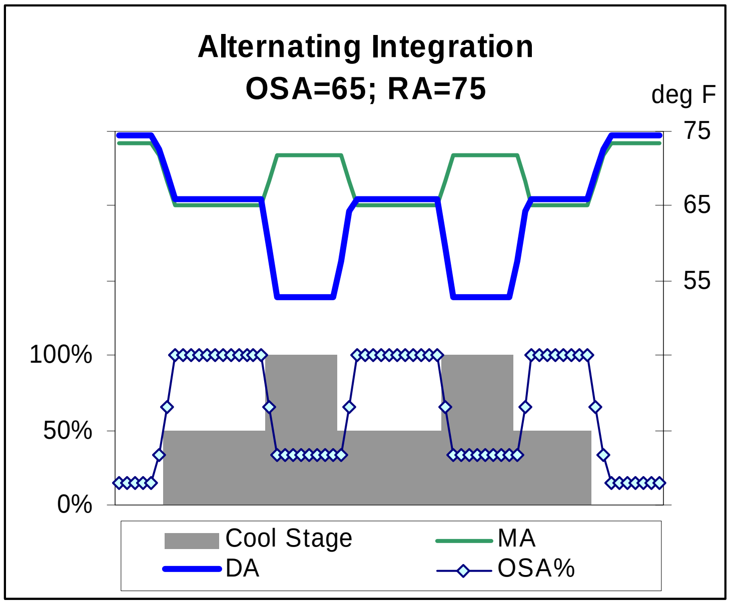



The mode of control can be a single (OSA only) fixed (snap disc) sensor for dry-bulb, a single (OSA only) adjustable (analog) sensor for either sensor type, or a set of differential or comparative (OSA vs. RA) sensors. A differential changeover uses outside air until it is warmer or contains more energy than return air. Differential changeover allows the economizer to take better advantage of integration strategies discussed below. Some will advocate using a single OSA sensor with a higher setpoint, but the assumed return air temperature will be a guess at best. Even a good guess will fail when the return air temperature varies or the cooling setpoint is changed. So, with single-sensor changeover, there will be times when either (a) the economizer is not used when it could be or (b) the economizer operates when outside air is too warm. Differential changeover takes the guesswork out of field adjustments and provides a more reliable economizer changeover. Most economizer controllers are typically equipped with the logic for differential control and it just takes a return air sensor to achieve this superior changeover method.

**4. Level of integration** determines if the economizer operates in conjunction with the cooling coil or separately. The first two options can use a single-stage cooling thermostat, while the final three require a dedicated thermostat stage for economizer:

- **Non-integrated or exclusive operation**: Below the changeover temperature, only the economizer operates. Above the changeover setting, only the cooling coil operates. They never operate at the same time. To maintain comfort, a non-integrated economizer changeover is usually set for OSA above 50°F or 55°F, although with experimentation, some spaces can achieve comfort with changeover settings around 60°F.
- **Time-delay integration**: On a call for cooling, the economizer operates for a set time (usually 5 minutes). Then if there is still a need for cooling, the cooling coil operates and the economizer modulates to near minimum to keep discharge air from getting too cold. When the cooling call is satisfied, both the coil and economizer are off and the dampers return to the minimum ventilation position. This strategy can be implemented with differential changeover or a higher single-sensor changeover setting.

- **Alternating integration**: This is the best integration that can be achieved with a single-stage direct-expansion cooling unit. As shown in the graph, the first cooling stage from the thermostat activates the economizer. When the temperature rises further, the second thermostat stage is activated and the cooling compressor operates. With the coil on and the primary sensor in the discharge air position, the economizer controller modulates the outside air dampers closed (usually to or near the minimum ventilation position) to keep discharge air from getting too cold for comfort and to prevent coil icing. When the space temperature drops and the second stage is satisfied, the compressor stops and the economizer opens again to provide maximum outside air economizing until the first stage of cooling is satisfied or the second stage is activated again. Note that in the graph example, the OSA damper does not close all the way to the minimum position; if the OSA were cooler or the return air warmer, it would.




- **Partial integration**: With a multiple-stage direct-expansion cooling unit, integration is improved. Operation is similar to alternating integration, except that when the second stage of cooling is called for, the partial cooling provides only a 5- or 10-degree temperature drop from mechanical cooling. The economizer is able to do more of the cooling with outside air while maintaining a comfortable discharge temperature. When the second stage cooling call is satisfied, the economizer returns to full outside air similar to the alternating integration. For a two-stage cooling unit, partial integration can be achieved with a two-stage thermostat:
    - below the changeover setting, stage one is the economizer and stage two is the first stage of compressor cooling, and
    - above the changeover setting, stage one is the first stage of compressor cooling economizer and stage two is the second stage of compressor cooling.
- **Full integration**: A hydronic chilled-water cooling coil can be modulated to any cooling output. This allows the economizer to be fully open when outside air is above the discharge air setpoint (usually 55$^{o}$F) and add only the amount of mechanical cooling that is actually needed. For full integration to be achieved, a differential changeover strategy is required.

**5. Minimum outside airflow for ventilation** is typically controlled by the economizer controller. While not technically part of the economizer strategy for cooling, energy can be saved by paying attention to when and how much ventilation air is used. Excessive ventilation air increases heating and cooling use when the economizer is not active. Too little ventilation air results in odors or unhealthful conditions in the space. When the economizer controller is set up, the quantity of ventilation air can be determined one of four ways:

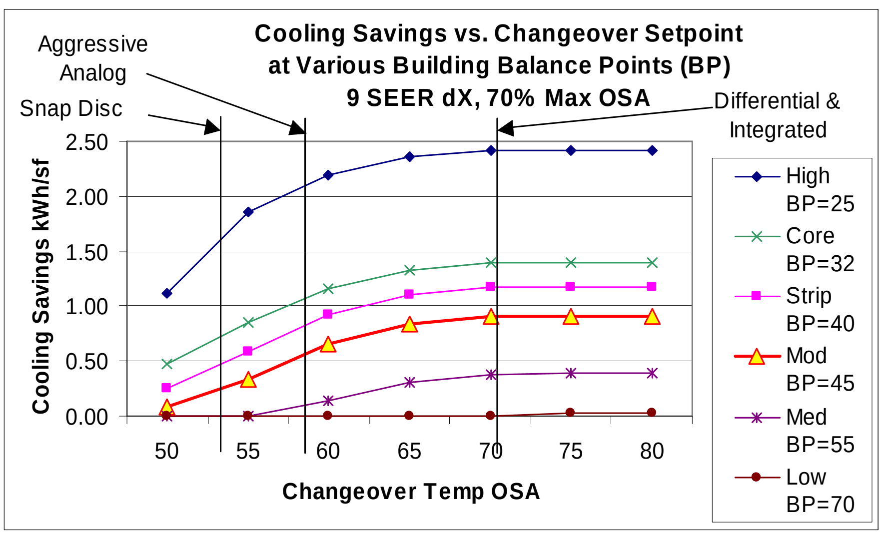
- Estimated by observed damper position
- Estimated by temperature measurement
- Flow measured with flow plate, velometer, or duct traverse
- Varied with demand controlled ventilation by $CO_2$ sensor

How the economizer controller is wired determines when the ventilation air is activated. Ventilation air dampers can be:

- Always open (no automatic control)
- Open whenever the fan is on
- Open when the fan is on and the return air is warm (>68 $^{o}$F; called a warm-up cycle)
- Open with the "occupied" schedule in the thermostat
- Open when an occupancy sensor detects occupancy in the room
- Open with demand controlled ventilation

**Economizer Integration.** The major method to increase savings is to achieve some level of integration of the economizer with mechanical cooling. **Integration** means that the outside air is used to full advantage before mechanical cooling is used. With a modulating chilled-water cooling coil, full integration can be achieved. Outside-air dampers remain full open until outside air is warmer than return air (differential changeover) and only as much chilled-water cooling is used as is needed. With direct expansion cooling using multiple stages or a variable speed compressor, partial integration can be achieved. With a single stage direct expansion unit, alternating integration can be achieved. Basic economizers installed today are typically not integrated. They use single-sensor changeover, which means the economizer is turned off at a set outside air temperature when the technician thinks the compressor may be needed. This changeover is controlled by a snap disc set around 55 degrees or an adjustable sensor that may be set even lower. Single-sensor changeover economizers can save more by increasing the changeover setpoint to around 60 degrees (B+ on the A-D scale).

Getting as much integration as possible is important because there are many occupied hours during the year in the 55 to 70 degree range where integration applies. There is also a trend of reducing internal building loads. New lighting technologies and flat-screen computer displays put less heat into the space. This means that balance temperatures are increasing. The balance temperature is the outside air temperature when no cooling is required. The graph at right shows that most savings occur when the economizer is integrated and differential changeover is used.




***Western Premium Economizer* Designation.** To avoid confusion with manufacturers who may have different specifications for a "premium" economizer, EWEB uses the term *Western Premium* to specify an integrated economizer with a dry-bulb differential changeover.