B O N N E V I L L E   P O W E R   A D M I N I S T R A T I O N

RTU Premium Ventilation: Proof of Concept Field Test

Final Report: May 2012

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Contract No. 38702

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Citation

Hart, R., K. Falletta, and B. Lipscomb (2012). “RTU Premium Ventilation: Proof of Concept Field Test.” PECI for Bonneville Power Administration (BPA).

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Executive Summary

Project Overview

This report presents results of a proof of concept field test of the Premium Ventilation Package, an innovative array of control strategies developed to improve indoor air quality and reduce energy consumption of unitary HVAC systems, typically rooftop units (RTUs). The focus of the testing was verifying proper functioning of multiple manufacturer implementations of Premium Ventilation, as the sample size was too small and occupancy type was not appropriate for a meaningful pre and post test of energy usage. Also included are tests of a partial implementation of Premium Ventilation with a Digital Economizer Controller.

This package of strategies addresses the fact that RTUs provide heating and cooling for more than half of commercial building space yet they regularly use excess energy by running more often than necessary (TIAX 2003). Many RTUs function with intermittent fan control and as a result, frequently fail to provide adequate ventilation.

Previously completed work investigated the Premium Ventilation package of strategies through a field test, focusing on the application of demand controlled ventilation (DCV) with a variable frequency drive (VFD) (Hart 2009, Hart 2010). VFD installations proved to be costly to implement in certain scenarios, so an alternative approach using fan cycling was proposed. In this study, the premium ventilation package with fan cycling was installed on five RTUs. This report presents the proof of concept results of a field study of premium ventilation package implementations by multiple manufacturers.

The field study described in this report also incorporates new controls enhancements that were not previously tested in the field. These enhancements provide more ventilation and energy savings benefits than the prior premium ventilation specification. The strategies in this expanded version of the Premium Ventilation package can be grouped into five groups: economizer enhancements, ventilation enhancements, fan control upgrades, basic temperature control enhancements, and advanced temperature control enhancements. The premium ventilation package includes all the strategies, although some manufacturer implementations include a subset. The full premium ventilation package strategies are listed below with more detail included in Section 1.1.

1. Economizer enhancements
    - Stable economizer control
    - Differential economizer lockout
    - Economizer refurbishment (where required)

2. Ventilation enhancements
    - Demand Control Ventilation (DCV)
    - Damper leakage improvement
    - Acceptance testing including DCV setup

3. Fan control upgrades
    - Fan cycling or
    - Fan motor variable speed drive

4. Basic temperature control enhancements
    - Optimum start
    - Resistance heat lockout

- Ventilation lockout during morning warm-up
- Fan Ventilation Priority
- Occupancy sensor standby mode (this item optional)
- Set-point limiting
- Unoccupied temporary override with elimination of "hold" mode

5. Advanced temperature control enhancements
   - Robust optimum start
   - Short-time switch-mode lockout
   - Night flush cooling
   - Duty cycle option during warm-up to reduce winter demand
   - Stand-alone setpoint adjustment demand response
   - Stand-alone pre-cooling with demand response

The strategies above may be implemented partially or fully. To coordinate with other regional initiatives and clarify measure naming conventions, the following combinations of strategies are identified:

- **Standard Demand Controlled Ventilation** or **Standard DCV** includes strategies 1 and 2. This is measure 1 in the DCV application guide.
- **Demand Controlled Ventilation with Fan Cycling** or **DCV with Fan Cycling** includes strategies 1, 2, and 3. Fan cycling is included and typically requires an integrated digital controller. This is measure 2 in the DCV application guide.
- **Demand Controlled Ventilation with Fan Variable Speed Drive** or **DCV with Fan VSD** includes strategies 1, 2, and 3. Fan speed is controlled by a speed controller driving a VSD. This is measure 3 in the DCV application guide.
- **Enhanced Ventilation** is a more generic measure name and includes strategies 1, 2, and 3. Fan control may be either with a VSD or integrated controller with fan cycling. The savings for the two fan control options are similar.
- **Enhanced Ventilation and Temperature Control** includes strategies 1, 2, 3, and 4. Fan control may be either a VSD or an integrated controller with fan cycling. While **DCV with Fan VSD** could be implemented with an economizer controller replacement and CO_2 sensor, the temperature control aspects require an advanced programmable thermostat or integrated digital controller.
- **Premium Ventilation** includes strategies 1, 2, 3, and 4 and multiple items from strategy 5. Premium ventilation requires an integrated digital controller making robust optimum start, night flush and demand control options possible. At a minimum, robust optimum start and setpoint limiting is included, with optional inclusion of occupancy sensor standby, night flush, duty cycling, optimum stop and demand response. For reference, the programmatic specification in Appendix A refers to premium ventilation measures as ECM 4 with fan cycling and ECM 5 with a VSD.

The field tests of the Premium Ventilation Package were conducted at a recreation community center in Eugene, OR, referred to as "Site A" in this report. At Site A, five heat pump RTUs were retrofit with the fan cycling version of the Premium Ventilation package. Data sensors and loggers were installed that monitored fan run time rates, CO_2 concentrations, economizer utilization, and RTU power. Monitoring started in May 2010 with measure installation in December 2010. Troubleshooting and acceptance testing was completed in April 2011 with monitoring concluded in July 2011. As is typical in monitoring projects, there were periods when some data was not acquired due to sensor or monitoring failure. The resulting data was then used to analyze the functional performance of the package.

In addition to the premium ventilation package, the **Enhanced Ventilation and Temperature Control** strategy was tested. This strategy was implemented with a digital economizer controller.

One was located at Site A, while two were located at a technology office in Vancouver, WA, referred to as “Site W” in this report. Data from three other economizers at site W were analyzed. The tested digital economizer is the recently released Honeywell JADE or W7220 controller. The digital economizer combined with an advanced thermostat was tested and compared to the full implementation of the premium ventilation package since it is less costly to install and provides a large share of Premium Ventilation Package energy savings.

Proof of Concept Test Findings

Key findings from this field study include the following.

- A DCV strategy that utilizes fan cycling maintains an average ventilation rate equal to or better than the prescriptive rate of ASHRAE Standard 62.1-2010 and eliminates insufficient ventilation.
- Fan cycling strategies implemented as part of DCV result in 71% less fan operation during occupied hours compared to the code minimum without DCV and 22% less fan operation during total hours. When compared to fan operation as-found at Site A (4 fans in “Auto” and one fan on continuously) there was a slight increase in fan use.
- Economizer enhancements resulted in an average 54% more sensible cooling provided by the economizer and showed improved economizer use in all 7 cases analyzed.
- Heating control enhancements resulted in reduced resistance electric heater operation.
- Simple payback for the Premium Ventilation package application to an office building with 5-ton units is estimated to be 5.9 years for Boise, Idaho and 6.1 years for Eugene, Oregon, based on the low bid in the field test and DOE2 analysis.
- While this sample is too small to draw a valid population conclusion, in all cases the retrofit economizer controls (both and premium ventilation package) produced increases in sensible economizer cooling.

In addition to the operational findings of the Premium Ventilation installations at Site A and Site W, the experience of recreation staff at Site A with the advanced control units was also documented. Key observations include the following:

- The Innotech and Alerton units displayed a single setpoint in the middle of the dead band between heating and cooling setpoints. This creates confusion for users and a programming work around was found with the Innotech unit.
- Users were frustrated by the long delay from when the override button was activated until the system responded. In a programming revision, fan activation was made immediate and setpoint changes were temporarily amplified to provide a faster system response.
- For the advanced programmable thermostat (Honeywell T7351 / JADE) users were able to adjust the fan settings. This resulted in the fan setting often being changed to “auto”, resulting in inadequate ventilation. It is recommended that the thermostat be set up to lock out user access to fan settings.
- Users found the Honeywell advanced programmable thermostat to be the most intuitive to use, followed by the Innotech unit. This stemmed from the fact that these units are very similar to the programmable thermostats that users were already accustomed to using.
- Properly installing an integrated digital control system requires a contractor familiarity with the system and facility staff training on the software. On the other hand, the advanced programmable thermostat and economizer controller (Honeywell/JADE) can be readily installed and configured by a contractor and user without significant training.

Recommended Next Steps

The Premium Ventilation advanced controls strategies investigated in this study show promising ventilation and energy savings benefits. This study's demonstration of the control strategies' functionality should serve as a base for developing the necessary infrastructure to deploy the measures.

There are currently a number of components that are recommended for the Premium Ventilation measures deployment. Chief among these are measure standardization and establishing several contractors who are trained to implement the measures.

The study demonstrates how Premium Ventilation can be implemented across multiple manufacturers, without compromising overall functionality.

The following steps are recommended for Premium Ventilation deployment:

- Verify energy savings for the Premium Ventilation package. The study described in this report was designed to understand measure functionality, so the sample size was not large enough to draw statistically significant conclusions about energy savings and monitoring was not set up for a focus on pre and post measurements, as Site A was not a common building type.
- Determine appropriate target customer or building types for **Enhanced Ventilation and Temperature Control** vs. full implementations of Premium Ventilation. . Due to the fact that **Enhanced Ventilation and Temperature Control** uses an advanced thermostat that a wider range of contractors are familiar with, this reduced scope measure may provide a more expansive impact in the marketplace even though it achieves less comprehensive energy savings than the full premium ventilation implementation.
- Study the value of utilizing networked controllers or web based thermostats for remote monitoring to aid in achieving persistent RTU savings.
- Review available technology to see if there are additional manufacturers who have products suitable for the premium ventilation sequence.
- Standardize savings estimates. Premium Ventilation savings could be incorporated into the DCV savings calculator tool. (Hart & Falletta 2012).
- Conduct analysis and field tests to verify operation of demand control during warm-up for electric heat, summer peak demand limiting, and night flush. Select a site with greater internal load to verify the value of these additional extended sequences.
- Develop training materials and an application guide to aid in training the first group of contractors.
- Train contractors to implement the Premium Ventilation measures.

A pilot or soft program launch could create the infrastructure for a potential full-scale program offered to BPA commercial customers, while providing the opportunity to work on the steps listed above.

Introduction

Premium Ventilation strategies have a large potential for energy savings, and were investigated at Site A with two goals (1) verifying that multiple manufacturers could implement the sequence of operation and (2) developing an acceptance testing process for the sequence with an HVAC contractor in the field. The report is organized as follows:

- The introduction presents background of RTU issues in the commercial sector, a history of research related to premium ventilation, the field testing undertaken, and a summary of advancements produced as a result of this field testing.
- Section 1 includes a detailed description of Premium Ventilation strategies.
- Section 2 includes discussion of the Premium Ventilation field test; control configurations; manufacturer solutions; site conditions; monitoring lessons learned; and sequence testing lessons learned.
- Section 3 includes discussion of the functional testing results; sequence compliance; hardware and installation; and premium ventilation measure results.
- Section 4 includes discussion of user interactions; setpoints displays; overrides: creating feedback; fan settings: user preference; user interface.
- Section 5 includes discussion of prototype savings and cost; premium ventilation savings potential; and cost effectiveness.
- Section 6 includes discussion of key findings; program readiness and recommended next steps.
- Section 7: References.

RTUs serve over 40% of commercial space and commonly run reliably and provide comfort for many years with minimal maintenance (TIAX 2003). However, multiple field studies (Hart et al. 2011) have found pervasive performance problems related to improper settings and failed controls that result in poor ventilation and excess energy use. One field survey of over 300 packaged units found 91% with at least one problem and 64% with two or more problems (Cowan 2004). Many of the control problems seen in the field can be traced to older style analog and electro-mechanical controls on RTUs that have excessive or deficient ventilation settings. Thermostats are often set in the “Auto” or “On” position, resulting in the RTU either not providing adequate ventilation during the occupied period or wasting energy during unoccupied periods.

To date, utility HVAC programs, codes, and green standards have focused on higher efficiency units or unit tune-ups that lead to the exclusion of ventilation and control upgrade opportunities. However, hourly simulation over a range of eight U.S. climates show that a comprehensive package of RTU control retrofits produced HVAC savings between 18% and 44% - ten times the savings from incrementally higher efficiency unit replacement (Hart et. al. 2008). The two climate zones included in this study in or near the BPA service territory, Eugene, OR and Boise, ID, showed 44% and 41% savings, respectively.

The Premium Ventilation package of strategies addresses RTU performance problems by implementing a series of advanced control strategies related to ventilation, economizer operation, and temperature/heating enhancements. At its base, implementing Premium Ventilation as an integrated package of strategies has two primary benefits: more effective ventilation and more appropriate RTU operation. More effective ventilation is achieved by improved ventilation rates when a space needs it most, resulting in CO_2 concentrations below target thresholds and improved indoor air quality (IAQ). More appropriate RTU operation is achieved by accounting for occupancy and outside air conditions when ventilating, heating and cooling a space, resulting in energy savings from reduced fan operation and less heating or mechanical cooling.

There have been a number of past studies that have investigated the specific strategies that are part of the Premium Ventilation package. The spotlight on improving RTU efficiency began with the economizer unit. In 1999, research on a limited sample of units indicated that 50% of economizers had at least one major fault (Lunneberg 1999). Subsequent research obtained similar findings (Davis Energy Group 2001) and prompted the idea that RTU economizer improvement strategies had significant energy savings potential. A selected list of premium ventilation research follows:

- In the early 2000s, Eugene Water & Electric Board worked with Ecotope, Inc. to explore the possibility for incorporating RTU maintenance and optimization into existing HVAC technician practices. They conducted a field study that confirmed RTU ventilation and economizer improvements had a high potential for energy savings, but that more research was needed to understand the level of potential (Davis et al. 2002a). At the same time, research conducted on over 500 RTUs documened that economizers have performance issues in over 64% of the units studied (Cowan 2004).
- The findings of these early studies prompted research in designing a more efficient economizer that could be retrofit to existing systems. The resulting "Western Premium Economizer" program[1] utilized dry bulb economizer activation, differential changeover, and integration to provide better functionality. This project required some contractor training which improved the local skill set in Eugene, Oregon. However, testing of the upgraded economizer proved it to be tricky to implement in the field and further research was needed to develop methods for quality assurance (Hart et al. 2006).
- Potential savings in RTUs generated interest in expanding the scope of research beyond economizer function, to an expanded controls package of strategies that could obtain even deeper savings. A 2008 study compiled available controls technologies and estimated the potential savings associated with each one by climate zone. The cumulative results of the package of strategies showed the possibility for reliable RTU savings between 5 to 25 times the savings of an RTU upgrade from SEER 13 to 15. This package of strategies was coined the "Premium Ventilation Package" (Hart et al. 2008).
- In 2008, Bonneville Power Association funded PECI to conduct field tests of the proposed Premium Ventilation package, which included DCV and VSDs on the fan motors. Field tests determined that VSDs may be difficult or costly to install in some situations so it was proposed to cycle fans as an alternative to installing a VSD. This study also showed that current analog controls were too difficult to commission, and that Premium Ventilation would greatly benefit from the use of an integrated DDC controller (Hart 2009).
- A proposed lab testing protocol was initially suggested as part of developing an approach to programmatic savings for DCV and Premium Ventilation. A lab testing approach to projecting savings for varying loads and baseline control conditions is likely to be a less costly option compared to testing RTU control strategies on the roof, given the wide range of load and as-found control conditions. Development of a load-based method of test is part way through the research funding process at ASHRAE.

The cumulative research conducted to date on the Premium Ventilation package has led to the scope of this field study: a field test at Site A of multiple manufacturer implementations of the Premium Ventilation package with application of DDC controls, a fan cycling algorithm, and expanded controls strategies including robust optimum start, electric resistance heat lockout, night flush and occupancy sensor temperature standby. Review monitoring data to determine functionality and compliance with the premium ventilation sequence. The study will also review

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[1] EWEB Western Premium Economizer contractor training & program 2004-Present

operation of an **Enhanced Ventilation and Temperature Control** measure with digital economizer installations at Site A and Site W.

The following advancements in RTU control have occurred during the course of this study and are a direct result of BPA sponsorship of this work.

- An acceptance testing tool was developed and contractor tested, to ensure proper and efficient setup of RTUs that receive a premium ventilation or DCV upgrade.
- Premium Ventilation sequences were tested and major revisions made to allow software from three manufacturers to reliably implement the Premium Ventilation package.
- New products have been advanced by manufacturers in response to the sequence and study results.
    - KMC developed a next generation FlexStat model that includes the fan cycling portion of the developed sequence as a standard option in their production product.
    - Innotech developed a rooftop controller that has increased memory to allow for more complex sequences, along with a smart space sensor that allows schedule programming from the space and improves setpoint management.

1. Premium Ventilation Strategies

The Premium Ventilation package of strategies grew out of an EWEB premium economizer utility program in Oregon (Hart et al. 2006). The suite of strategies requires a comprehensive controls upgrade for existing RTUs that includes multiple strategies that reinforce each other. The strategies can be grouped into five groups: 1) economizer enhancements, 2) ventilation enhancements, 3) fan control upgrades, 4) basic temperature control enhancements, and 5) advanced temperature control enhancements. The strategies may be implemented partially or fully. To coordinate with other regional initiatives and clarify measure naming conventions, the following combinations of strategies are identified:

- **Standard Demand Controlled Ventilation** or **Standard DCV** includes strategies 1 and 2. This is measure 1 in the *DCV Application Guide*.
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Premium Ventilation includes strategies 1, 2, 3, and 4 and multiple items from strategy 5. Premium ventilation requires an integrated digital controller making robust optimum start, night flush and demand control options possible. Full implementation of the premium ventilation measure package requires an integrated digital controller that has direct control of the economizer dampers. An integrated digital controller has all the program functionality in one controller or in networked controllers and is able to fully integrate temperature, schedule, and economizer control. Three of the manufacturer products tested met this fundamental requirement. The Honeywell JADE economizer control unit combined with an advanced thermostat was also tested, and the functions that combination achieved are discussed at the end of this section. The JADE is a separate economizer controller and does not have full Premium Ventilation capability because temperature, fan, and schedule control functions are in a separate thermostat. The JADE can be combined with an advanced programmable thermostat, fan speed controller, and VSD to provide the control strategies of groups 1 through 4 or **Enhanced Ventilation and Temperature Control,** but does not have the fully integrated control required of the Premium Ventilation specification.

1.1 Economizer Enhancements

Outside air economizers typically have low quality outside air temperature sensors, such as snap discs, with simple dry bulb change-over in the Western U.S. and enthalpy sensors in the East. The Premium Ventilation economizer enhancements use an integrated economizer with differential temperature change-over control (Hart et al. 2006). The specific economizer enhancement strategies in the Premium Ventilation package include stable economizer control, space differential economizer lockout, and economizer refurbishment for retrofit situations.

1.1.1 Stable Economizer Control

Outside air economizers are notorious for unstable operation at low outside air temperatures due to large changes in system gain.[2] Typically a Proportional Integral (PI) control loop is used to control damper position. To achieve stability at low temperatures, the loop typically needs to be tuned for slow damper response. Tuning the dampers to open over a period of up to 45 minutes is not uncommon to maintain stability[3] at low temperatures. To avoid this, multiple approaches can be taken:

- Adaptive gain parameters can be utilized so the loop is more sensitive at moderate temperatures. This approach was taken by KMC and Alerton and a similar proprietary approach is used in the Honeywell JADE controller.
- Simple algorithm control with PI trim (SAC_PIT) uses a simple algorithm (percent damper position as a linear function of outside temperature). Limited PI action is added as a slow trim feature to adjust toward the desired setpoint. This combination allows the approximate damper position to be quickly obtained, and then final adjustments made to get closer to a mixed air setpoint. This was implemented in the Innotech controller.
- Wide proportional band control can also be stable over a wide range of conditions, although there is a significant sacrifice in accuracy.

Different manufacturers favored different approaches, and all were implemented. Unfortunately, the test site did not include zones with high internal loads that would require economizer cooling at low outside temperatures, so the actual reduction in unstable operation could not be verified through monitoring. The existence of one of the stable economizer control methods was verified in all the units tested and they are expected to operate properly under higher load conditions.

1.1.2 Differential Economizer Lockout

Economizers are only effective during specific outdoor temperature ranges, usually between 50 and 70 degrees Fahrenheit. Outside of that range, the outside air must be significantly heated or cooled before being supplied into the occupied area. Desirable economizer controls use a dry bulb high limit to enable economizer operation only when the outside air temperature is low enough to provide cooling (Hart, Price & Morehouse 2006). The differential approach results in better economizer operation because it operates relative to actual return air or space conditions, not an assumed setpoint.

There are two differential high limit approaches that can be effectively used:

- A return-to-outside air temperature differential dry bulb high limit control operates on the difference between outside air and return air, which requires an additional return air sensor. This is the recommended option for an economizer controller that is not integrated with the space temperature control, like the JADE.
- In implementation of the Premium Ventilation package, targeted primarily at single zone units, a differential between space temperature and outside temperature was used. This avoided the need for an additional return air sensor. A 5°F differential was used, so that economizer-delivered outside air was cool enough so the cooling savings offset the cost of fan energy.

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[2] Gain is amplification. An economizer has higher gain at low outside temperatures because the same change in economizer position results in a bigger change in the controlled variable, mixed air, at the lower outside air temperature.

[3] Stability indicates that a control loop is operating without hunting or feedback cycling.

1.1.3 Economizer Refurbishment

- When premium ventilation is retrofit to existing systems, economizer refurbishment is often required. Refurbishment includes repairing or adjusting dampers and linkages for smooth operation and full cycle (closed to open) operation, verifying wiring and damper motor operation.
- In most cases, a new economizer controller or integrated digital controller will require a new damper motor, because older damper motors are not compatible with the 2-10 VDC signal required for operation with most new controllers.

1.2 Ventilation Enhancements

The Premium Ventilation package enhances ventilation through demand controlled ventilation and damper leakage reduction strategies. These strategies both relate to minimum ventilation.

1.2.1 Demand Controlled Ventilation

Demand Control Ventilation (DCV) adjusts ventilation rates to meet but not exceed the load required by a zone's real-time occupancy rate, which is typically less than the full design rate. Energy savings are achieved by reducing the heating or cooling of ventilation air. Installation requires a DCV controller and a CO_2 sensor. Indoor air quality can be improved through DCV since the amount of space ventilation more closely matches real-time occupancy requirements.

RTUs with a properly operating economizer limit the benefit of DCV in zones with consistent occupancy assuming the RTU had proper system testing, adjusting, and balancing (TAB). Unfortunately, RTUs do not normally receive proper TAB so ventilation is often significantly higher than required (Davis et. al. 2002). RTUs that have excess minimum ventilation can benefit from a DCV system even without high or variable occupancy.

For measures that include fan control strategies, some form of DCV or other ventilation adjustment is required to maintain ventilation rates at lower fan speeds.

1.2.2 Damper Leakage Improvement

Closed, outside air dampers for RTUs typically have leakage of 5% to 25% and sometimes more (the range of damper leakage for the 6 units tested in this field test was 2% to 39%). When closed damper leakage is high, it is difficult to achieve ventilation control with DCV, as the space will often be over ventilated when the fan is on. High outside air leakage can be curtailed in some units with the application of adhesive-backed closed-cell insulation foam to damper blade edges, and it is recommended that this step be taken whenever closed-damper leakage is found to be greater than 20% and the damper configuration is appropriate.

1.3 Fan Control Upgrades

The fan control upgrade measure group has two options: fan cycling or fan motor variable speed drive (VSD). Basic DCV implementation controls ventilation by adjusting the opening of the outside air damper. Further energy savings may be realized by enabling the system to turn down or turn off the supply air fan during these periods with reduced ventilation requirements. As mentioned above, the scope of this field test is limited to the fan cycling approach to fan control.

1.3.1 Fan Motor Variable Speed Drive

Fan energy use reductions can be achieved by installing a VSD on the fan motor and a fan speed controller that ramps down the fan motor speed when there is no heating or cooling requirement.. For unitary systems, the fan must operate at a high speed whenever the heating or cooling is operating so that supply air temperatures stay within a reasonable range. Because most RTUs have on/off heating and cooling, the fan speed and heating/cooling output does not track loads proportionally as they would in larger hydronic systems. The VSD operates in a multi-speed mode. Speeds can either be set for different modes, or the control sequence can target a desired discharge air temperature (DAT) for each mode. Table 2 indicates recommended settings.

Table 1. Fan Speed and DAT limits by RTU Mode

Mode	Default VSD Speed	DAT limit setpoint
Fan Only	20%-40%*	N/A
Heat Stage 1	80%	max 170°F
Heat Stage 2	85%	max 170°F
Cool Single Stage	95%	min 50°F
Cool Stage 1, Interlaced Coil	80%	min 53°F
Cool Stage 1, Split Coil	90%	min 58°F
Cool Stage 2	95%	min 50°F
Economizer	95%	min 53°F

* Fan speed shall be less than 40% for existing motors, 30% for replacement motors, 20% for PMM; Target 25% "Fan only" speed if motor accommodates; Increase "Fan only" speed as required to match exhaust airflow or maintain space pressurization.

1.3.2 Fan Cycling

Fan cycling is a DCV fan control method that turns the fan motor on and off as needed to provide ventilation. Using fan cycling provides similar savings to a VSD. The alternative fan cycling approach was developed due to difficulties uncovered in earlier field tests (Hart 2009) with matching low-cost VSDs with some motor types. Fan cycling was field tested in in this study as an alternative fan control strategy. The scope of this functional analysis report is limited to DCV using the fan cycling approach. The fan cycling approach requires an integrated digital controller combined with a programmable thermostat-like interface or space setpoint interface. The basic idea of the fan cycling approach is to provide a high ventilation rate for a brief period of time so that the average ventilation rate matches what is required in the occupants in the space. The averaging approach is allowed by ASHRAE ventilation Standard 62.1 and cycling the fan off for up to 30 minutes has been recently confirmed in an ASHRAE interpretation. So, the system provides a high ventilation rate during intermittent heating and cooling operation, and cycles the fan off when not needed. The sequence uses the CO_2 sensor signal to determine how long to run at a high ventilation rate. When thermal loads do not call for heating and cooling, the fan cycles on every half-hour to maintain acceptable indoor air quality. The strategy is further discussed in Section 3.3.3.

1.4 Basic Temperature Control Enhancements

The basic temperature control enhancement measure group includes strategies that impact the timing and setpoints related to ventilation and mechanical heating and cooling. These strategies are designated as "basic" because they are capable of being implementing by a stand-alone economizer controller and advanced programmable thermostat, such as the Honeywell T7351/JADE unit tested (see section 2.2).

1.4.1 Optimum Start

Optimum start adjusts the warm-up or cool-down period so that desired space setpoints are just achieved by the programmed start time. This prevents the space from reaching the desired setpoint too early and wasting energy. Optimum start is likely the most commonly available energy saving control sequence; it is readily available in DDC systems and most commercial programmable thermostats. Unfortunately, optimum start is likely one of the most disabled options in control systems as well. Disabling occurs because facility operators may not trust the automated algorithms, they may not take the time to properly set up the system, or they may have experienced optimum start failing to warm up a space by the occupied time. As discussed under Robust Optimum Start, standard programmable thermostat optimum start without outside air temperature input is likely to fail during extreme weather.

1.4.2 Resistance Heat Lockout

This control strategy locks out resistance heat when it is warm enough for the heat pump to meet warm-up load, typically around 30°F. This strategy not only uses a more efficient heating source, but can also reduce electric demand charges several months a year.

1.4.3 Ventilation Lockout during Morning Warm-up

HVAC units typically start two to three hours before occupancy for morning warm-up and employ full ventilation during that period, resulting in unnecessary heating of outside air. This measure locks out ventilation during morning warm-up by utilizing a separate thermostat relay that closes the ventilation dampers. This enables the system to warm up faster by only heating warmer return air and not outside air.

1.4.4 Fan Ventilation Priority

The premium ventilation standard removes the fan "Auto" option so that during the occupied period the fan operates continuously with a VSD or is never off more than 30 minutes with fan cycling. This ensures proper ventilation will occur.

1.4.5 Occupancy Sensor Standby Mode

This controls capability relaxes setpoints and suspends ventilation when a space is scheduled to be occupied but is actually empty (standby mode). For example, if an RTU serving a conference room is scheduled for occupancy from 9 AM – 5 PM, but is only actually occupied from 1 PM – 5 PM. The space would then be in standby mode from 9 AM – 1 PM. To be effective and maintained, the standby setback should be between 1 and 2 degrees offset from the standard setpoints, not the unoccupied setback setpoints.

Note that savings from this strategy is not due to reduced envelope conduction, but suspension of system fan operation and ventilation when the space is unoccupied. Attempting to offset the standby setpoints more than 2°F will likely result in user dissatisfaction due to extended recovery time to achieve occupied setpoints. To improve user acceptance, it is beneficial to initiate a ventilation cycle when the occupancy sensor is activated, even if the space temperature is within the standard setpoint dead band, as this lets the user know the system is responding.

There are some important design and commissioning considerations related to this measure:

- Using lighting occupancy sensors has been proposed to reduce cost for this measure. This approach is not recommended due to different activation mechanisms between lighting and HVAC controls. The trend in lighting control is toward turning lights off with an occupancy sensor but requiring the user to manually turn the lights on. Since the ventilation sensor must activate every time the space is occupied, coupling HVAC controls with this approach will not meet ventilation requirements if occupants fail to manually turn on the lights. It will often be less expensive to install a 24 VAC-powered occupancy sensor dedicated to the HVAC system, because a lighting sensor with a separate 'dry contact' for HVAC control costs more than a standard sensor, and there is an added cost for coordination of trades.
- A minimum time-out delay (i.e. delay after last occupancy is sensed before ventilation ceases and setpoints are relaxed) should be utilized. A 30 minute delay was adequate for HVAC occupancy control. The occupancy sensor may not cover the entire zone, but there is usually some activity that can be sensed within 30 minutes if the space is still occupied. There is a time out setting in the sensor, as well as usually one in the program sequence, so it is important that they both be set to result in a total time out of about 30 minutes.
- For meeting and conference rooms it's recommended to add a delay to occupancy mode activation of two minutes. This avoids activating occupied mode when there is only a brief entrance into a room.

1.4.6 Set-point Limiting

This strategy entails limiting the high heating setpoint and low cooling setpoint so that users will not heat or cool the building to unreasonable levels and waste energy. When making setpoint adjustments, most users tend to significantly exaggerate the setpoint with the (false) hope that the system will respond faster. A reasonable approach is to limit the heating setpoint to no greater than 72°F and the cooling setpoint to no lower than 73°F. Some owners with more aggressive energy policies may opt for a heating limit of 70°F and a cooling limit of 76°F. One compromise is to have non-adjustable standard settings and allow limited override with the more relaxed settings.

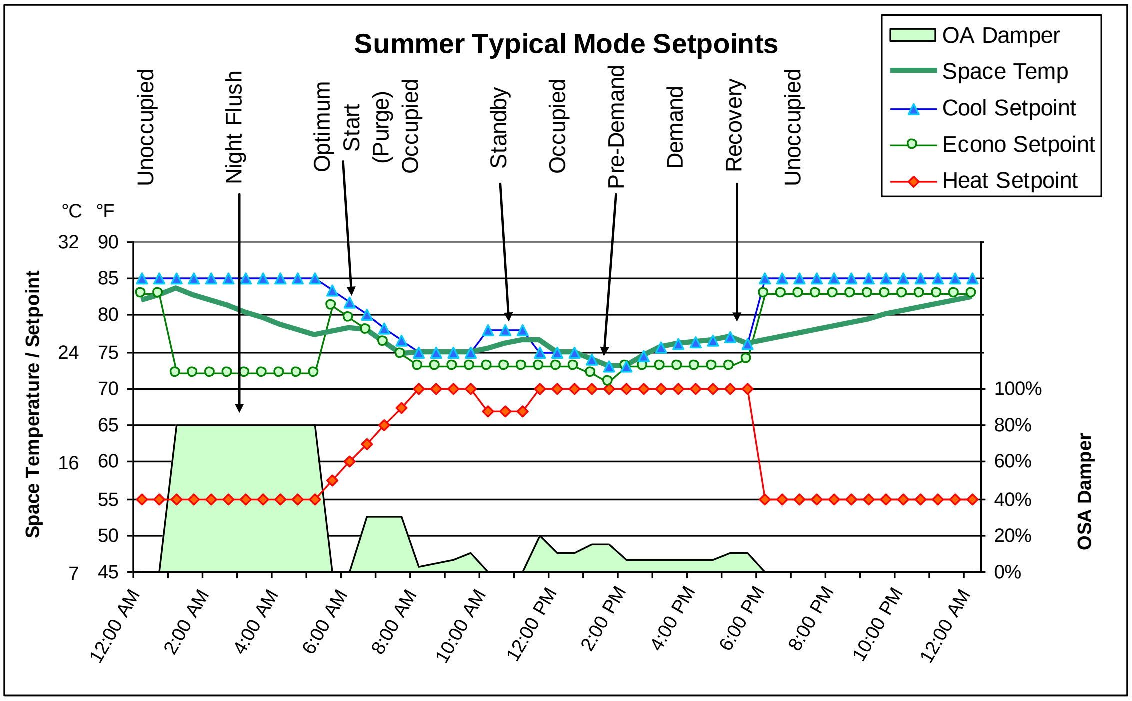
1.4.7 Unoccupied Temporary Override with Elimination of "Hold" Mode

Most programmable thermostats are equipped with a temporary override mode so that after hours occupancy does not require resetting the schedule. Older thermostats have a "hold" button that maintains the override temperature until pressed again. Unfortunately field surveys have found a large number of thermostats in the "hold" position, defeating the unoccupied setback saving features of the thermostat (PECI 2008).

This strategy limits the override period to two or three hours, depending on owner policy. After that time, the controls return to the unoccupied setpoints and a repeated setpoint override is needed to maintain the override.

shows how setpoints and the ventilation rate vary throughout a typical summer day as the premium ventilation sequence moves through several modes. The optimum start, standby, and unoccupied setback strategies are part of the Basic Temperature Control Enhancements, while night flush and demand response belong to the Advanced Temperature Control Enhancements.

Figure 1. Premium Ventilation Typical Sequence Modes and Setpoints



1.5 Advanced Temperature Control Enhancements

The advanced temperature control enhancement measure group includes strategies that impact the timing and setpoints related to ventilation and mechanical heating and cooling. These strategies are designated as "advanced" because they require an integrated digital controller. The Alerton, KMC, and Innotech control units tested are capable of implementing the advanced temperature control enhancement strategies, although not all strategies were tested in this field study.

1.5.1 Robust Optimum Start

Typical RTU control configurations rely only on space temperature to determine optimum start. Whether they have internal "learning" algorithms or they rely on a set response related to design conditions they will eventually fail to achieve the desired space temperature by occupancy start due to a cold snap. Basing the setback on space temperature gives no indication of the larger startup load required when outside conditions are extreme. Robust Optimum Start addresses this issue both by accounting for outside air temperature and using a setpoint ramp.

A setpoint ramp is used to gradually move the setpoint from the setback condition toward the desired occupied setpoint at the occupancy time. In this example, we will consider heating; however the approach is applicable to cooling as well. If outdoor conditions are mild and the space temperature has not dropped to the setback condition, then the system will be delayed in starting until the space temperature reaches the setpoint. This gradual response results in a reasonable demand reduction for electric systems and avoids using resistance heating alongside heat pumps unless necessary to meet load.

To account for extreme outside conditions and avoid a warm-up failure, the setpoint ramp approach is enhanced by starting the ramp earlier when it is colder outside. Since outside air temperature is needed by the system for economizer control, the sensor can be used for the optimum start system as well.

1.5.2 Short-time Switch-mode Lockout

This controls measure entails delaying the initiation of heating or cooling mode when the system is switching from heating to cooling, or vice versa, for a minimum of five minutes. This results in a smoother RTU response and prevents it from needlessly switching back and forth between the two modes.

1.5.3 Night Flush Cooling

Night flush utilizes cool outside air in the early morning hours to pre-cool the space when mid-day temperatures are anticipated to require mechanical cooling. This can reduce cooling needs during the day due to the reduced temperature of the thermal mass in the building. This strategy is most effective in buildings with unoccupied internal loads, such as unavoidable or poorly controlled plug loads. The control sequence requires multiple components to be effective:

- A seasonal or temperature enable. While a calendar-driven approach could be used, the Premium Ventilation sequence uses an outside temperature-based enable. Once outside temperature exceeds 75°F, the night flush sequence is enabled, as there is likely to be cooling required. The temperature enable continues until outside air temperature falls below 45°F, allowing the sequence to alternate as appropriate during swing seasons.
- A temperature differential allows night flush only when the outside temperature is at least 5°F cooler than the inside temperature. This differential ensures the sensible cooling gained offsets the fan energy used.
- A time of day start is often employed, allowing the cycle to begin only after midnight and preventing it from starting or continuing during occupied periods.
- A low limit is necessary to prevent the need to re-heat the space in the morning. A conservative approach is to stop night flush when the space temperature drops down to the standard occupied heating setpoint. A more aggressive approach allows a few more degrees drop, ramping up to meet the occupied heating setpoint by occupancy. The subcooling allows a slight reduction in thermal mass temperature, absorbing more heat later in the day. In either case, night flush benefits will be much greater if the occupied heating setpoint is lowered several degrees during the cooling season to allow a lower pre-cooling temperature without causing morning heating. The lower setpoint can be accomplished manually or automatically and is usually tolerated by occupants in summer months. If this strategy is employed, occupant awareness and cooperation is helpful to avoid morning occupant override of the heating setpoint.

1.5.4 Duty Cycle Option during Warm-up to Reduce Winter Demand

This strategy entails cycling a series of RTUs alternating in sequence to reach a heating setpoint during morning warm-up instead of allowing them to all run simultaneously. This results in lower total demand during the warm-up period. This was an optional measure that was not implemented in this field study.Stand-Alone Setpoint Adjustment Demand Management

This control strategy raises the cooling setpoint during periods of peak cooling load as a demand response mechanism. The sequence is enabled based on morning outside air temperature used to predict high demand days or via a utility demand response signal. The strategy was not tested in this field study.

1.5.5 Stand-Alone Pre-cooling with Demand Response

An advanced version of the previous strategy can also pre-cool the building with mechanical cooling before the peak period. The sequence can be activated either on a utility demand response signal, or activated when the morning outside temperature exceeds a set value. The strategy was not tested in this field study.

1.6 Advanced Economizer Controller and Thermostat Option

While the Honeywell T7351 and JADE economizer control unit are capable of implementing many of the Premium Ventilation package strategies, the segregated economizer controller does not allow for several functions. Missing functions include:

- Fan cycling with average ventilation maintenance
- Night flush
- Demand response control strategies
- Duty cycling
- Robust optimum start

2 Premium Ventilation Field Test

The results in this paper are based an extended field test of the Premium Ventilation package and advanced economizer on six RTUs at the Site A in Eugene, Oregon. The Premium Ventilation package was implemented using three manufacturers: Alerton, KMC, and Innotech. The economizer and basic temperature control enhancements were tested with Honeywell's new JADE Economizer controller and their T7351 advanced thermostat.

The field testing included implementing the control modes described in **Error! Reference source not found.** to better understand the effectiveness of each control strategy. This chapter discusses the specific RTU control configurations utilized, manufacturers of the control systems tested, site conditions, monitoring plan, monitoring lessons learned, and sequence testing lessons learned.

2.1 RTU Control Configurations

This study tested three control configurations, defined by the location of RTU control elements. The location of the components can have a significant impact on field wiring and retrofit cost, as running additional wires from the space to the unit can be expensive. The three configurations described below are summarized inTable 2.

Table 2. Configuration Overview

Config	Space User Interface	Setpoint and Schedule Control	Econ Controller	Manufacturer Tested	Capabilities
1	Setpoint Adjustment	Controller in RTU		Innotech[1]	Premium Ventilation, Networkable
2	Integrated in Space Controller	Controller in Space		KMC, Allerton	Premium Ventilation, Networkable
3	Thermostat	Thermostat in Space	In RTU	Honeywell	Economizer Upgrade

[1] Allerton was also tested in configuration 1; however that test required two controllers and did not allow use of existing thermostat wires, so that application is not commercially viable.

In each of the configuration diagrams, the following abbreviations were used:

OAt: Outside air temperature

DAt: Discharge air temperature

CO_2: Carbon dioxide sensor

Occ: Occupancy sensor

HMI: Human machine interface

RGWYO: Standard RTU thermostat wire connections (R: Red/ 24VAC Hot, G: green/fan, W: white/ heat, Y: yellow/compressor, O: orange/reversing valve)

Note that in almost all control configurations, replacement of the existing economizer damper motor is necessary to provide the capability to accept a 2-10 VDC control signal. There are optional workarounds to a new motor that involve an adaptor and separate transformer, but the cost is similar to the cost of a new motor and the proper wiring of the adaptor is challenging. A new damper motor is a beneficial addition regardless as this component is subject to runtime failure. A new motor extends the life and persistence of the control system upgrade.

2.1.1 Configuration 1: Roof Controller; Space Interface

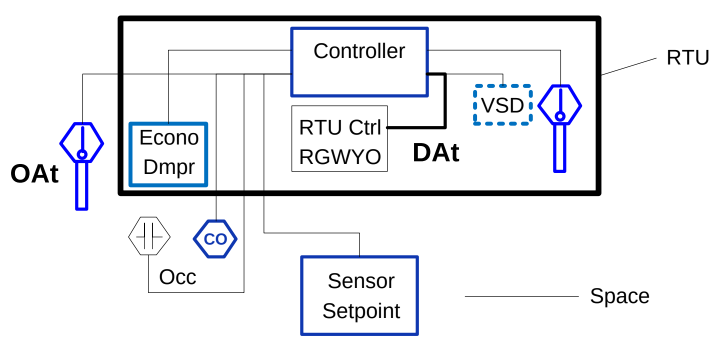
Configuration 1 includes a controller on the roof and an interface and space sensors in the space interior. It was used for the Innotech control unit, as the Innotech unit requires this configuration. It was also used for one version of the Alerton installation using two controllers (one in the space and one on the roof). A test of this configuration was planned for a KMC setup, but abandoned after consultation with KMC technical staff.

The goal of this configuration is to reuse the existing thermostat wires for the space to RTU connection. This additional wiring can be costly; a deductive bid alternate for this test project ranged from $100 to $290 per unit. For buildings with drop ceilings and partial height walls, the additional wiring is straightforward. However buildings with a hard ceiling, like the test site, the additional cost can be even more than the high bid for the added wiring alone.

The controller to space interface connection over existing wires was attempted with the Alerton installation, but failed due to poor communication. An additional shielded communication wire was required for proper installation. Reuse of the thermostat wires was not attempted with the Innotech and KMC units. KMC technical staff offered feedback that a shielded communication would be needed for their equipment. Innotech technical staff indicated that unshielded wiring had worked in some situations where there was low electrical interference, but that it was very situation dependent.

The conclusion of these tests and manufacturer feedback is that currently, additional wiring from the space to the RTU will be required for installation of advanced control units. There is a new space interface available from Innotech that may be able to use existing thermostat wires, however, this has not yet been tested. In general, communication links from the controller to a space interface will require shielded wiring, so the idea of re-using thermostat wires to reduce installation should not be further considered. As more robust wireless solutions are developed, these can be investigated.

Figure 2. Control Configuration 1



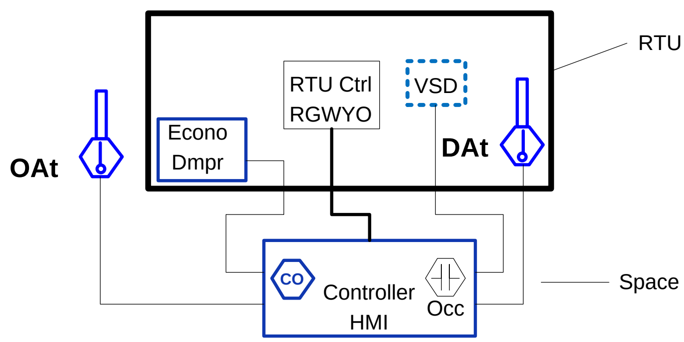
2.1.2 Configuration 2: Space Controller with Sensors

The most common configuration for advanced controllers designed to replace space thermostats is control configuration 2, shown in Figure 3. The KMC and Alerton control units were tested using configuration 2.

In this configuration the controller resides in the space, and all sensors and controlled components need to be wired to the controller. This results in a greater number of wires returning to the controller. This is not necessarily a disadvantage to the configuration, as the test of reusing wires for the space interface to rooftop controller in configuration 1 failed. There are variations in what sensors are included in the space controller. For example:

- The Alerton VLD controller contains the space temperature sensor, so separate occupancy sensors or CO_2 sensors are required.
- The tested KMC FlexStat model includes an occupancy sensor, which reduces additional wiring. However, it should be noted that the occupancy sensor included is a passive infrared type (PIR) with limited coverage, so for large rooms and multiple room zones, additional occupancy sensors will be required.
- The next generation FlexStat includes both the occupancy sensor and the CO_2 sensor.

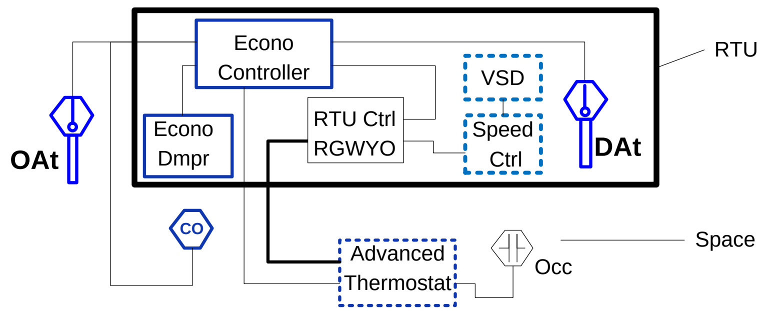
Figure 3. Control Configuration 2



2.1.3 Configuration 3: Space Controller with Economizer Controller on Roof

Configuration 3 is the most traditional approach, with standard thermostat wiring connecting the thermostat to the roof and a separate economizer controller in the RTU. While this provides an easier retrofit to existing units, it should be noted that because the economizer controller and space temperature and schedule control are not integrated, the full benefit of all premium ventilation package options cannot be realized. The Honeywell T7351 and JADE economizer control unit utilize this configuration.

Figure 4. Control Configuration 3

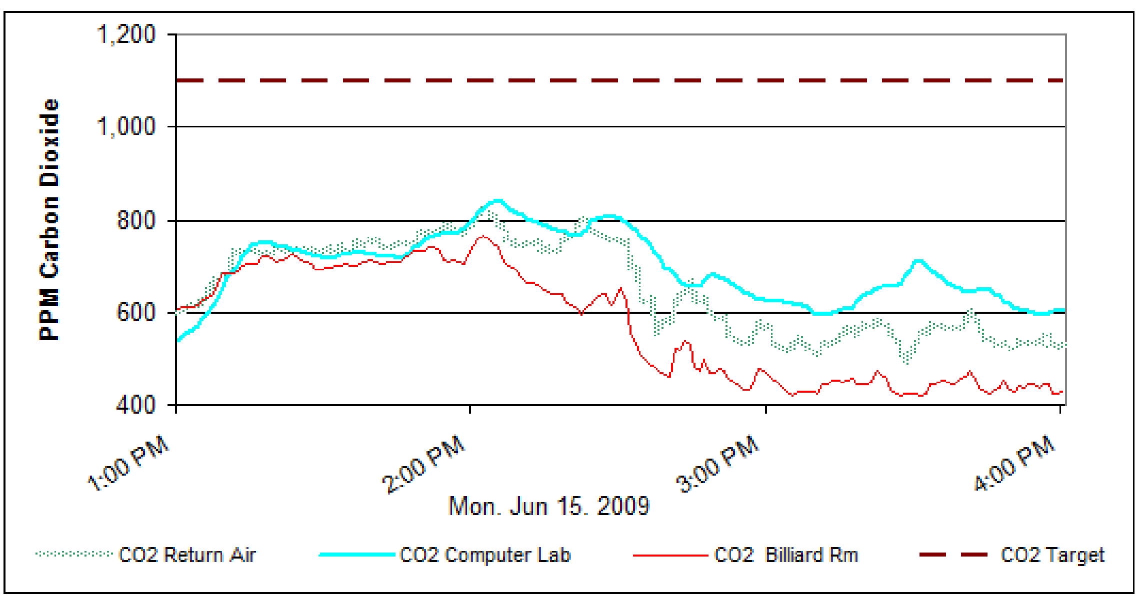


2.1.4 <u>CO_2 Sensor Location Placement for RTUs</u>

Different control configurations result in placement of CO_2 sensors in differing locations. Typically CO_2 sensors are placed to reduce wiring to the control unit interface, which minimizes retrofit cost. For example, in this field test the control CO_2 sensors were installed in the space with the KMC and Alerton installations, and return air CO_2 sensors were installed for the Innotech units. In all cases, the monitoring was done in the return air, and values only used when the fan was running.

Field test results from the Premium Ventilation VSD study (Hart 2009), presented in Figure 5, shows the measurements of CO_2 sensors in three different locations: return air stream, billiards room, and computer lab. The results show that the maximum difference between the CO_2 concentration in the room with the highest CO_2 concentration and the return air is never more than 150 ppm. This difference is much less than differences experienced in large VAV systems where the critical zones are small relative to the large area served by the system (Hydeman & Stein 2007). Readings within 150ppm are accurate enough for ventilation control, indicating placement of CO_2 sensors in the return air for two or three rooms is an acceptable approach.

Figure 5. CO_2 Sensor Placement Results



2.2 Manufacturer Solutions

The control configurations described above can be achieved by control units from various manufacturers. To better understand the capabilities, strengths, and weaknesses of potential control units, a literature search was conducted to find potential manufacturers. Based on findings, the following manufacturers were recruited and their units tested with the Premium Ventilation package of strategies.

- Alerton VLD
- KMC FlexStat BAC-11063CW
- Innotech MicroMax

An advanced economizer and programmable thermostat option was also tested:

- Honeywell T7351 & JADE economizer

In all the pictorial diagrams , connection to the existing RTU and economizer damper are omitted for clarity. These are shown in the schematic diagrams in the previous configuration discussion (Section 2.1).

2.2.1 <u>Alerton VLD</u>

The Alerton VLD unit follows control configuration 2, with the exception that the occupancy and CO_2 sensors are not included inside the controller. The components necessary for retrofit are shown in Figure 6. There was also an attempt to simulate control configuration 1 with the Alerton unit, using both a space controller and a controller at the RTU. Detailed submittals for the installation tested are included in Appendix H.

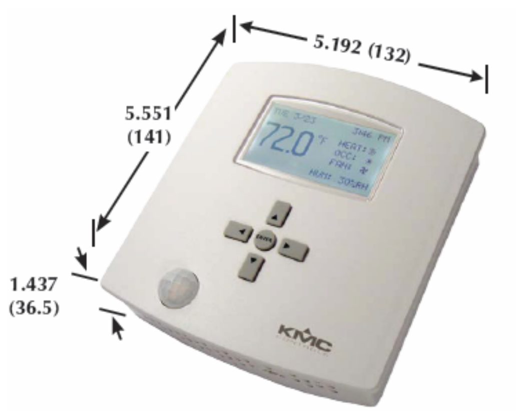
Figure 6. Alerton VLD Control Unit

2.2.2 KMC

The KMC FlexStat BAC-11063CW was tested at the site and follows configuration 2, with the exception that the CO_2 sensor is not included inside the controller. This control unit was tested with a separate CO_2 sensor installed in the space. The next generation FlexStat model BAC-131163CW are shown in Figure 7. This unit includes both the occupancy sensor and CO_2 sensor in one package, reducing field wiring.

There was also a plan to test control configuration 1 with the KMC unit using both a space controller and a controller at the RTU; however, it was abandoned when it was determined that existing thermostat wires could not be used for the space-to-roof data connection. Detailed submittals for the installation tested are included in Appendix F.

Figure 7. KMC BAC-131163CW Control Unit



Temperature Sensor and Schedule/Setpoint Adjustment

with built in CO_2 Sensor and Occupancy Sensor

2.2.3 Innotech

The Innotech MicroMax unit follows configuration 1. The components necessary for retrofit using the next generation innTOUCH space sensor are shown in Figure 8 . An optional mini-port human machine interface (HMI) (not shown) can be located in the RTU on the roof, or anywhere with a network connection. This allows for easier access to setup, schedule and setpoint changes. The configuration was tested with an industry standard BAPI setpoint interface. The new innTOUCH space sensor (shown in the pictoral diagram) provides the basic interface needed for schedule and setpoint changes, so a separate HMI should not be necessary. Access to other settings can be made with a RS485 computer interface during setup or commissioning.

Note that with a gateway option, all controller parameters, trends, setpoints, and schedules can be remotely accessed from a computer with free software. Detailed submittals for the Innotech unit tested are included in Appendix G. This control configuration is typical of many manufacturers of small scale DDC system components.

Figure 8. Innotech Control Components

Temperature Sensor and Setpoint CO_2 Sensor Occupancy Sensor

2.2.4 Honeywell T7351 & JADE economizer

The Honeywell advanced thermostat option follows configuration 3, the typical industry approach to RTU control with economizers. This approach includes a T7351 programmable thermostat with occupancy sensor in the space. A separate JADE economizer unit is located inside the RTU with a CO_2 sensor in the return air space. The components necessary for retrofit are shown in Figure 9. Detailed submittals for the units tested are included in Appendix I.

Figure 9. Honeywell T7351 & JADE economizer Control Unit

CO_2 Sensor and Digital Economizer Controller

Occupancy Sensor and Advanced Programmable Thermostat

2.2.5 Manufacturer Solutions Summary

Table 3 details the four manufacturers' models tested, their next generation model, and the control configuration that the units use.

Table 3. Control Units and Configurations Tested

Options	Alerton	Innotech	KMC	Honeywell
Model tested	VLD	MicroMax	BAC-11063CW	T7351/JADE
Next gen model	N/A	+ innTOUCH	BAC-131163CW	N/A
Configuration	2 (1)	1	2	3

2.3 Site Conditions

The six heat pump RTUs tested as part of this study were located at the Site A in Eugene, OR. The characteristics of the six RTUs, including design ventilation setpoints, and the zones they serve are included in Table 4 .

Table 4. Test RTU Ventilation Design Setpoints

Bldg	Unit Tag	Estimated Supply Airflow (CFM)*	Zone Use (Occupancy Category)	Typical Peak Occupancy (people/ksf)	OSA area CFM	OSA full CFM	OSA% area	OSA% full
A	HP-3	2400	Gym (Daycare)	20	110	310	5%	13%
B	HP-4	900	Crafts (Art Class)	20	160	360	18%	40%
B	HP-5	1500	Clay (Art Class)	18	160	340	11%	23%
C	HP-6	1300	Dance (Music)	37	60	250	5%	19%
C	HP-7	1300	Dance (Music)	32	50	210	4%	16%
C	HP-8	1100	Conference	22	30	140	3%	13%

**Supply Airflow estimated based on unit cooling capacity.*

During setup and acceptance testing (see section 3.2.2 for details), the following ventilation setpoints were implemented on the test RTUs. Note that in many cases, leakage with the outside dampers fully closed exceeded the area level of ventilation required, so actual ventilation rates were generally higher, and in some cases much higher, than needed. The three-temperature method was used to calculate commissioned outside air percentage.

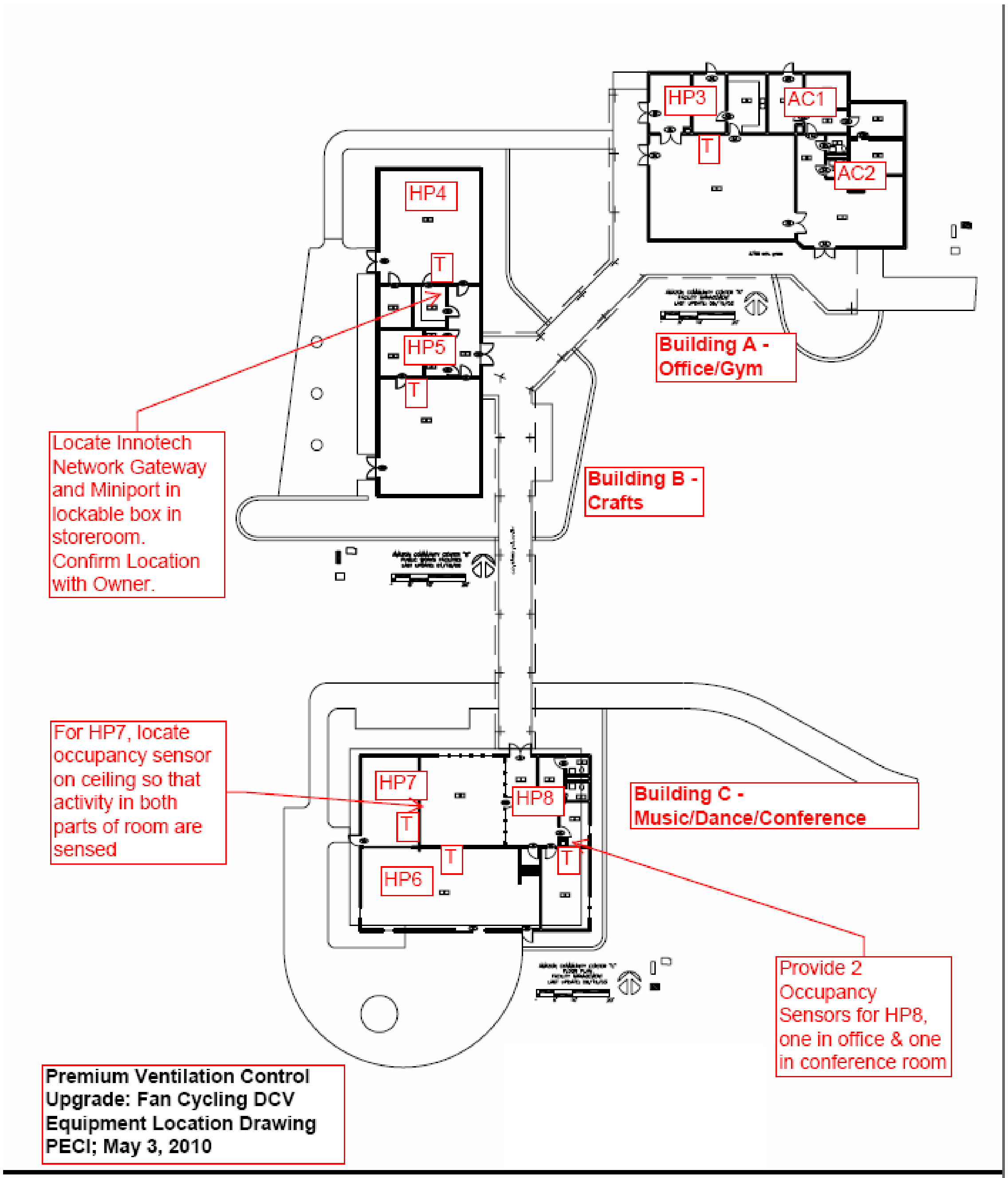
Table 3. Test RTU Commissioned Setpoints

Unit Tag	Total RTU Supply Airflow			Design		Commissioned	
	Nominal (CFM)*	Actual (CFM)*	Actual (CFM/ton)	OSA% area	OSA% full	OSA% area	OSA% full
HP-3	2500	2250	360	5%	13%	39%	40%
HP-4	1000	900	360	18%	40%	16%*	24%*
HP-5	1600	1150	284	11%	23%	10%	23%
HP-6	1400	1250	357	5%	19%	7%	21%
HP-7	1200	1430	250	4%	16%	15%	18%
HP-8	1100	1430	475	3%	13%	13%	18%

** Due to manual entry error, airflow requirements were underestimated for HP-4; revised versions of the acceptance testing spreadsheet check parameters by space type reducing the chance of this error in the future. Also, the space requirements were reset when changed out with a JADE controller at the conclusion of the test.*

The site plan of the Site A, showing units and work requirements is shown in Figure 10 .

Figure 10. Site A Site Plan



2.4 Monitoring Plan

The monitoring plan was developed by PECI and outlines the purpose and approach to monitoring the RTUs tested as part of this field study.

2.4.1 Purpose of Monitoring

This field study is designed to verify operation of the Premium Ventilation package of strategies on heat pump RTUs. There are two purposes of this field test:

- To ensure the controls components work together and function with the expected sequence of operation.
- To investigate the strategies' impact on RTU operation, including fan run time and cooling provided by the economizer.

2.4.2 Equipment Monitored

Monitored equipment included the six heat pump RTUs at the Site A. The RTU models, controller manufacturer tested, and controls configuration implemented are shown in Table 5 .

Table 5. Site A Monitored Heat Pumps

Bldg	Unit	Tons	Baseline Economizer	Tested Control Manuf.	Occu-pancy Sensors	Configuration
A	HP-3	6.5	Trane Voyager	Honeywell / JADE T7351	1	3: Thermostat with economizer controller
B	HP-4	2.5	Honeywell W7359	Innotech	1	2: RTU controller with space sensor (ICS)*
B	HP-5	4.0	Honeywell W7359	Innotech	1	2: RTU controller with space sensor & interface (miniport)*
C	HP-6	3.5	Honeywell W7359	KMC Controls	1(In FlexStat)	1: Space controller
C	HP-7	3.5	Honeywell W7359	Alerton	1 Ceiling Mount	2: RTU controller (VLC) with space sensor (VLD)
C	HP-8	3.0	Honeywell W7359	Alerton	2	1: Space controller (VLD)

* Tested Innotech units require network gateway and wiring for battery backup of date/time; Next generation provides battery backup through INNtouch interface.

2.4.3 Monitoring Points

Monitoring points as part of this field study included the points in Table 6.

Table 6. Monitoring Points

Point	Units	Location
Supply air	°F and relative humidity	RTU
Return air	°F and relative humidity	RTU
Mixed air	°F	RTU, 2 points adjacent to coil
Total RTU power	Watts	RTU
Fan power	Watts	RTU fans
CO_2 sensor	0-10 VDC	Return air duct
Outside air dry bulb temperature	°F and relative humidity	- Near hood intake (outside radiation shield)
Occupancy Sensor	Occupied/Unoccupied	In Space

2.4.4 Monitoring Equipment

HOBO data loggers with remote cell phone communication capability, manufactured by AEC, were provided by BPA and Eugene Water & Electric Board (EWEB). EWEB led the effort to install the data loggers and download the resulting data, and then sent the raw data to PECI for analysis.

2.4.5 Analysis of Monitoring Results

The resulting data from the monitoring exercise at the Site A was analyzed to determine the operational characteristics of pre and post retrofit conditions. The following points were considered:

- CO_2 concentration
- Fan run time
- Sensible cooling provided by economizer (determined by the return air to supply air temperature difference)
- Resistance heat operation during warm-up

An additional analysis investigating operational performance of the Honeywell/JADE economizer control unit was completed at the Site W in Vancouver, WA (see section 3.3 for details). The following points were considered for this analysis:

- Sensible cooling provided by economizer
  - Pre and post Honeywell JADE controller installation
  - Side by side comparison of Honeywell JADE controller and analog economizer controllers

- Estimated annual energy savings from changes in fan and mechanical cooling operation

2.5 Monitoring Lessons Learned

Monitoring was completed with HOBO U-30 system equipment. While Hobo provides a generally acceptable monitoring and data storage system, there were several issues with the equipment. Lessons learned from these issues may make future research more productive:

- A U-30 shuttle would greatly simplify troubleshooting on the roof since it provides a way to review data in the field.
- HOBO requires a current version of their software to interface with the U-30 monitoring modules. While this is available under the license, it was difficult for EWEB staff to update without administrator rights.
- The TRMS module, required for single CT monitoring, has a known interference issue with the HOBO U-30 cell phone (used for data acquisition), requiring significant distance separation. This information was not available from HOBO during planning.
- Reading 24 VAC thermostat signals with the HOBO voltage reading devices proved problematic. An RTU control relay can be falsely triggered with this device, resulting in the voltage readings not being maintained. In the future, setting up a web connection to a controller network would be preferable.
- It would have been worthwhile to monitor space temperature. In this test there were recurring comfort issues and discrepancies between displayed setpoint and actual setpoint that could have been resolved with space temperature records.
- HOBO monitoring continues to have brief periods of missing data on downloaded data files.

2.6 Controls Field Testing Lessons Learned

Testing new control units often resulted in errors that could not be detected before actual use. As a result, testing them in an occupied building sometimes resulted in lack of function for users and comfort issues. It is recommended that for future testing, one of two approaches be taken for pre-testing controller sequences before they are tested in an occupied building.

- A quasi-environmental test chamber and bench testing arrangement could be set up to test variable conditions. A full range environmental chamber designed for accurate steady state unit measurements would not be necessary, but simply a reasonable range of hot and cold conditions controlled by a computer lab card so that daily weather and occupancy profiles could be tested.
- An emulated system that uses a computer simulation to generate system load and weather response in a simulation that is controlled by actual outputs from the controller connected with a lab interface card. Responses would be trended for evaluation of control response.

There were many more revisions of software than expected in setting up the control sequences. It would have been helpful to have all the test controllers connected to gateways and the internet. This would have allowed more immediate response to comfort or other issues at the site and reduced the time for engineer review and upload of new programming. It would also have provided direct access to manufacturer staff for troubleshooting sequenced.

3 Functional Testing Results

The results of this field test are presented in the section below. Sequence compliance results are first presented, detailing which control sequences were successfully implemented by each controller. Next, experience from the field test in installing the control units and interfacing with the units' hardware is discussed. Finally, the functional results of each measure group are presented and discussed.

3.1 Sequence Compliance

Table 7 details which of the Premium Ventilation strategies or control sequences were included in the programming for each of the four control units tested.

Table 7. Sequence Compliance

Measure Group	**Sequence**	**KMC FlexStat**	**Innotech MicroMax**	**Alerton VLD**	**H'well T7351/ JADE**
1. Economizer enhancements	Stable economizer control	Yes	Yes	Yes	Yes
	Space temperature vs. OSA differential economizer lockout	Yes	Yes	Yes	N/A
	Differential economizer lockout return air vs. outside air	N/A	N/A	N/A	Yes
2. Ventilation enhancements	Demand controlled ventilation	Yes	Yes	Yes	Yes
	Fan ventilation priority	Yes	Yes	Yes	**No**
	Damper leakage improvement	Yes	Yes	Yes	Yes
	Fan cycling	Yes	Yes	Yes	**No**
	Fan variable speed drive (VSD)	Not Tested	Not Tested	Not Tested	Not Tested
4. Basic temperature control enhancements	Optimum Start	Yes	Yes	Yes	Yes
	Resistance heat lockout	Yes	Yes	Yes	Yes
	Ventilation lockout during morning warm-up	Yes	Yes	Yes	Yes
	Occupancy sensor standby mode (temperature and ventilation)	Yes	Yes	Yes	Yes
	Set-point limiting	Yes	Yes	Yes	Yes
	Unoccupied temporary override with elimination of "hold" mode	Yes	Yes	Yes	Yes
5. Advanced temperature	Robust optimum start	Yes	Yes	Yes	**No**

Measure Group	Sequence	KMC FlexStat	Innotech MicroMax	Alerton VLD	H'well T7351/ JADE
control enhancements (some optional)	Short-time switch-mode lockout	Yes	Yes	Yes	**No**
	Night flush	Yes	Yes	Yes	**No**
	Duty cycle option during warm-up to reduce winter demand	**No**	**No**	**No**	**No**
	Stand-alone setpoint adjustment demand response	**No**	**No**	**No**	**No**
	Stand-alone pre-cooling with demand response	Not Tested	**No**	Not Tested	**No**

It's important to note that all of the control units tested do not have a "Hold" setting, but instead a temporary override. Many programmable thermostats have a "Hold" button that indefinitely maintains override temperature settings. Once the "Hold" button is pressed, the temperature setbacks previously programmed will not occur. Table 8 shows data on as-found thermostat hold condition collected between 2006 and 2008 in RTU tune up programs in California (PECI 2008).

Table 8. "Hold" Button Use

Thermostat Condition	Sample n	Percent
Normal Programmable Condition	1220	75%
"Hold" button activated (thermostat in permanent override)	414	25%
Total	1634	100%

A temporary override setting, on the other hand, limits the override period to a reasonable time range. After two hours[4] the temporary override times out, and the previously programmed settings are restored. In addition, if the "Hold" button is activated during unoccupied hours, the unoccupied settings are restored after the override period times out. This feature avoids users changing control settings that would result in reduced energy savings potential of the strategies dependent on standby mode temperature setbacks.

3.2 Hardware and Installation

In the field test, custom controllers from three manufacturers (Alerton, Innotech, and KMC) were tested in addition to a high-end programmable thermostat with digital economizer controller

[4] The default timeout in the Honeywell T7351 thermostat is 3 hours and was reset to 2 hours for this test. The other controllers were programmed for a 2 hour default timeout per the sequence of operation.

(Honeywell/JADE). All manufacturers were given the same controls sequences to program into their controllers.

All three of the custom programmable controllers had network capabilities, although they were installed in a stand-alone mode. They all also required connection to a laptop computer with the manufacturer's monitoring software to setup and commission the control units. This task is usually performed by a contractor who has an established relationship with the manufacturer as an authorized dealer and has prior experience with using the commissioning software.

In this field test for setup and commissioning, the Alerton unit was accessed directly by a local manufacturer's representative , and KMC and Innotech were accessed with software provided to PECI with telephone field support from the manufacturer. For Innotech, the configuration and setup software is available to any user for free download from the manufacturer's site. It is of note that even though the installing contractor was considered to have more knowledge about controls than a typical HVAC technician, they were not interested in using the setup software. The city maintenance staff, who operate Site A, was also not interested in using the software.

Properly installing one of the controls systems requires a commitment by facility staff to training on the software, as well as the local availability of an installing contractor familiar with the system. This was not an issue for the high end programmable thermostat and economizer controller (Honeywell/JADE) that can be readily installed and configured by a contractor and user without significant training.

Table 9. Control Unit Characteristics

Options	Alerton VLD	Innotech MicroMax	KMC BAC-11063CW	Honeywell T7351/JADE
User Acceptance*	Moderate -	Moderate	Moderate +	High
User Issues*	Single setpoint midway between Heat and cool	Separate HMI for Schedule and Setpoint**	Button sequencing is awkward	Too easy for occupant to switch fan to Auto
Setpoints	Single	Biased Single	Heat/Cool	Heat/Cool
Schedule	At Unit	HMI or PC*	At Unit	At Unit
Setup/Cx	Computer	Computer	Computer	Moderate
Software	Dealer	Free	Dealer	N/A
Simulation	Yes/Dealer	Yes/Free	No	N/A
Programming	Block/Limited	Block	Line	Fixed
Fan savings	High	High	High	Limited
Multiple/ DT Occ Sensor	Yes	Yes	No***	Yes
Monitoring/Trend Capability	Need Gateway/ Network	Need Gateway/ Network /Software; has Spare I/O	Need Gateway/ Network/ BacNet Software	No
3-Wire Output (Trane Voyager compatible)	No	Yes	Requires custom programming and accessory relay	No

*User acceptance and Issues noted is based on an anecdotal assessment by the PECI engineer interactions with recreation staff and managers at the site.

**Next generation innTOUCH interface includes scheduling capability and does away with the need for separate HMI.

***Next generation Flexstat provides standard program for additional occupancy sensors.

3.2.1 Retrofit Wiring

One of the barriers to retrofitting thermostats with advanced control capabilities is the number of wires that are needed to connect the controller to the RTU. Replacing wiring from the existing thermostat to the unit can cost several hundred dollars in many instances. Since connections for outside air, discharge air, and economizer control need to be routed to the controller, the number of wires available from an existing thermostat installation are typically fewer than the number needed for the advanced controller.

A potential solution was tested where the separate controller was installed in the RTU with the space controller communicating to it through the existing thermostat wires, simulating configuration 1. Discussions with KMC during design revealed that this configuration could not be supported, as a shielded network connection was required. With the Alerton configuration 1, the use of the thermostat wires for communication was attempted, but failed, and a shielded network communication wire was installed. For the Innotech unit, the controller was located in the RTU and a room sensor was installed. The thermostat wires could have been reused for the interface connection, but this approach was not field tested.

With the exception of a controller mounted in the RTU with a space sensor (configuration 3), the current generation of technology cannot reuse the existing thermostat wires for communication between a controller in the space and one at the RTU. A typical non-programmable thermostat for single stage heating and cooling requires 4 wires and 7 wires are required for a heat pump. Thermostat cable is available in 4, 5, 6, and 8 conductors, and it is typical to install with spare conductors. Devices are available[5] that allow sharing of a wire for two non-simultaneous signals, such as heating and cooling.

Table 10. Retrofit Wiring Requirements

	Alerton VLD	**Innotech MicroMax**	**KMC FlexStat**	**Honeywell T7351/JADE**
Configuration Diagram	2	1	2	3
Number of wires needed: *space to RTU (single stage HP, CO_2 in RA for config 1)*	10	6	10	8

3.2.2 Acceptance Testing

A comprehensive acceptance testing process is essential for proper set up of DCV and premium ventilation. Unfortunately, many RTUs do not receive complete testing, adjusting and balancing (TAB)or commissioning at start up. A streamlined system check-out and set-up procedure was developed and tested as part of this study. The Premium Ventilation Acceptance Testing tool, an Excel file, is available at the BPA or PECI web site in conjunction with the BPA *DCV Application Guide for Unitary HVAC* (Hart & Falletta 2012). This tool allows a contractor to calculate ventilation requirements and document measured data at the site. The tool calculates required damper positions for area and full ventilation, based on a heating temperature split airflow test and a closed damper leakage test. Use of the tool documents setup for proper DCV system and RTU operation, proper thermostat or controller schedule and setpoint setup and provides verification of upgrade installation for receipt of utility incentives.

[5] Two such multiplexing devices are Venstar "Add-a-Wire" and Robertshaw INT-43.

Contractor Feedback

The installation contractor had difficulties installing the Innotech unit, which has multiple controller units and network connections between units. Note that this issue has been solved with Innotech's next generation innTOUCH interface and its real time clock. The control unit can now be installed without networking or a gateway if desired.

The contractor found the KMC to be the simplest unit to install, except that 10 wires were needed between the RTU and controller. Alerton had a similarly simple installation, however the programming was not correct the first few times and there were significant delays getting responses from the manufacturer's representative to update the program.

The acceptance testing process was fairly straight forward, the use of a laptop computer on the roof is unusual for HVAC contractor staff. The computer provides real time feedback after the airflow and leakage test so that damper positions can be set properly for maximum efficiency. As controls become more complex and small building DDC systems become more commonplace, contractors will have a higher acceptance of laptop computer use in the field. Note that the acceptance testing spreadsheet is designed so it can be used on a smart phone with a spreadsheet application.

A computer is also not commonly used by most HVAC contractors to set up commissioning points. For setup and commissioning, the contractor worked with the PECI engineer in the case of KMC and Innotech and the manufacturer's representative in the case of Alerton. For this field test, custom programmable controllers were used and the use of a connected computer enhances the setup and commissioning process. Contractors familiar with installing networked DDC systems are more familiar with using a computer interface in the field. The next generation KMC flexstat has all required commissioning points on setup screens on the controller. Setting up the Honeywell T7351 and JADE was the most straightforward, although the connection of the occupied relay to the economizer was missed in the original installation by the contractor multiple times. It should be noted the T7351/JADE combination does not include the fan controls that provide most of the electrical savings.

3.3 Premium Ventilation Measure Results

The following section presents the results of the field study's functional analysis of Premium Ventilation strategies. The results are organized by measure group, as presented in Section 1: economizer enhancements, ventilation enhancements, fan control upgrades, and temperature control enhancements. Note that the results for basic and advanced temperature control enhancements have been grouped into the same section.

3.3.1 Economizer Enhancements

The economizer enhancement strategies maximize the amount of cooling achieved by utilizing outside air when temperatures are appropriate. Leveraging this "free" cooling contributes to reduced mechanical cooling loads. While the ultimate result of this is reduced energy consumption, the percent sensible cooling provided by economizer can be used as a proxy for actual energy savings impacts.

This analysis investigates the percent sensible cooling provided by economizers at the Site Aand Site W in Vancouver, WA.[6] The field test at Site W was limited to installation of the Honeywell

[6] Data for HP-4 could not be analyzed because there was no Pre-period data. The original monitoring plan at Site A did not include pre-data setup and pre-data was available on the other units only due to delays in the bidding and installation process.

T7351 / JADE economizer control unit. In addition to the percent sensible cooling results, the Site W analysis also includes projected annual energy savings from reduced fan and cooling energy use.

Sensible Cooling Provided by the Economizer

The use of improved economizer or integrated controllers with differential or higher economizer changeover temperature setpoints resulted in a greater percentage of sensible cooling to be provided by the economizer. The improved controllers also include a feature called integration, which allows for economizer operation while the mechanical cooling compressor is operating, maximizing the time that the economizer operates.

Percent sensible cooling provided by the economizer was calculated by summing the dry-bulb temperature differential between supply air and return air (SA-RA) for all the minutes that the economizer was operating alone, and dividing by the sum of the temperature differential for all cooling hours. Figure 11 and Table 11 shows the percentage of sensible cooling provided by the economizer both pre and post installation during the cooling season (see Appendix D for analysis period details). The average period temperatures of the pre and post installation periods were similar. All but one unit had average temperatures within 1°F of each other and HP-7 within 3°F. This analysis found that there was a 50% average increase in percent sensible cooling provided by the economizer, demonstrating that the Premium Ventilation economizer enhancements functioned properly and had greatly increased economizer contribution to cooling. Table 9 is organized to show separate average results for the JADE economizers vs. the premium ventilation installations; however, the sample size is too small to draw conclusions about the difference in these products. It should be noted that for all units there was a large increase in percentage of cooling by economizer as compared with the older existing economizer controllers.

Figure 11. Percent Sensible Cooling Provided by Economizer

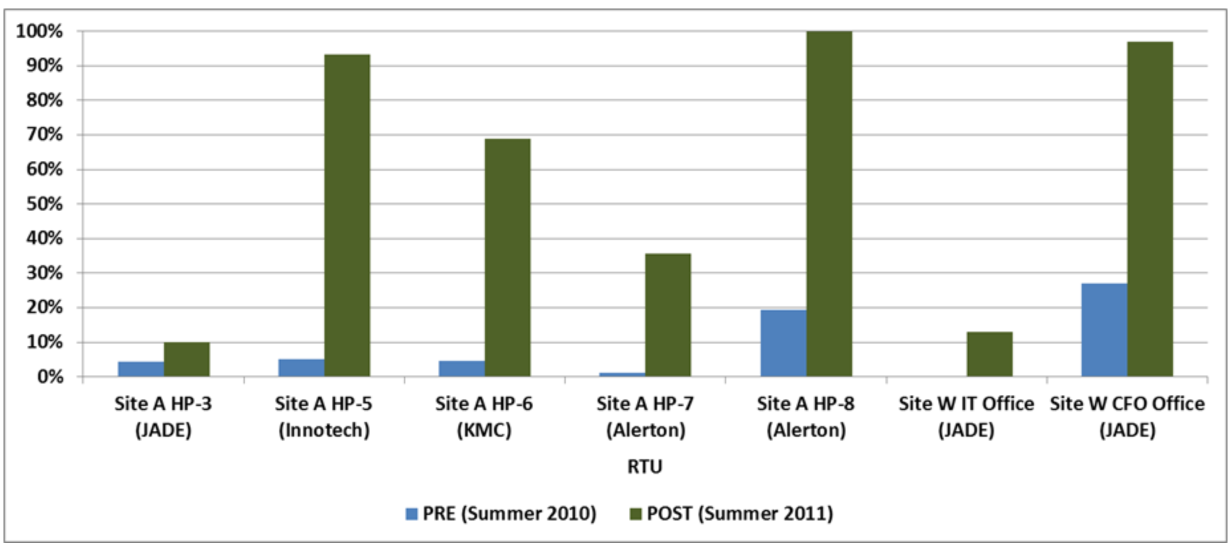


Table 11. Percent Sensible Cooling Provided by Economizer

RTU	Pre Econo Control	Post Econo Control	Pre % Sensible Cooling by Economizer	Post % Sensible Cooling by Economizer	% Increase in Sensible Cooling by Economizer
Site A HP-5 Crafts	W7459	Innotech	5%	93%	88%
Site A HP-6 Dance/Yoga	W7459	KMC	5%	69%	64%
Site A HP-7 Waiting	W7459	Alerton	1%	36%	35%
Site A HP-8 Conference	W7459	Alerton	20%	100%	80%
Premium Ventilation Average			**8%**	**75%**	**67%**
Site A HP-3 Gym	Voyager	JADE	4%	10%	6%
Site W IT Office	W7459	JADE	0%	13%	13%
Site W CFO SW Office	W1212	JADE	27%	97%	70%
JADE Economizer Controller Average			**10%**	**40%**	**30%**
Overall Average			**9%**	**60%**	**51%**

JADE economizer Control Unit Performance

Additional analysis on the Honeywell JADE economizer control unit was undertaken to better understand the operational and energy savings impact of this new product. While the JADE economizer control unit does not have the full Premium Ventilation capabilities of the advanced control units tested, it provides a significant improvement over legacy analog economizer controllers. The improvement is shown in the delivered cooling results and by the more precise setup and testing available in a digital economizer controller. Test RTUs for this analysis were located at Site W in Vancouver, WA. Table 12 shows the RTU characteristics included in the study. Note that two of the five tested RTUs had JADE control units installed; the other three had analog Honeywell economizer controllers. The results of these two control unit groups are compared below.

Table 12. Equipment Monitored - Site W

Zone	Tons	Mfg	Pre-retrofit Honeywell Control	Post-retrofit Honeywell Control	Economizer Control Type	Fan
IT Office	6	Carrier	W7459	JADE	Dry Bulb Temp.	Continuous
CFO SW Office	4	Carrier	W7212	JADE	Fixed Enthalpy	Continuous
Server Room	3	Carrier	W7212	N/A - no retrofit	Diff.Enthalpy	Continuous
SQA Lab Room	4	Trane	W7459	N/A - no retrofit	Dry Bulb Temp.	Cycling
Eng Office 235	7.5	Trane	W7459	N/A - no retrofit	Dry Bulb Temp.	Continuous

Investigation into JADE control unit performance included the following analyses:

- Side by side comparison of percent sensible cooling by economizer between RTUs with JADE control units installed and RTUs with analog Honeywell controllers installed.
- Pre and post comparison of percent sensible cooling by economizer for RTUs installed with JADE control units. JADE and non-JADE units from the Site A results are also presented.
- Projected annual cooling and fan energy usage – pre and post JADE installation.

Percent Sensible Cooling – Side by Side

The analysis of percent sensible cooling between RTUs with and without JADE control units gives an indication of which controllers performed well and which controllers did not take advantage of opportunities to economize as much. The results of this analysis are shown in Table 13. The JADE economizer controlers provided an average of 99% sensible cooling with economizers, compared to on average 59% of sensible cooling by earlier generation Honeywell economizer controllers; an increase of 40%. Note that the W7212 is an analog controller and the W7345 has both digital and analog elements. Again, this sample is too small to draw statistically significant conclusions about improvements.

Table 13. Percent Sensible Cooling Provided by Economizer - Site W

Zone/Thermostat	Tons	Mfg	Honeywell Econo. Model	% Sensible Cool by Econo.
IT Office	6	Carrier	JADE	100%
CFO SW Office	4	Carrier	JADE	98%
Server Room	3	Carrier	W7212	1%
SQA Lab Room	4	Trane	W7345 OEM	100%
Eng Office 235	7.5	Trane	W7345 OEM	75%

The period for which this analysis was performed was during mostly cool and cold months (10/28/2010 – 2/12/2011), so when cooling was needed there was usually ample opportunity to economize. Both of the JADE units and the SQA Lab RTU with the W7345 economizer module used nearly 100% economizer cooling. The Engineering Office RTU also had fairly high economizer usage.

The Server Room had almost no economizer usage and was mechanically cooling for most of the time period. There are two possible explanations for the low economizer cooling in the Server Room. One possibility is that the economizer was unable to meet the load in the space so the compressor had to run almost constantly. When the compressor is running, economizer use is limited to maintain comfortable discharge temperatures and avoid coil freezing. The other possibility is that the sensors used to perform differential enthalpy high limit were poorly calibrated and incorrectly indicated that the air was too warm and moist to economize.

This analysis indicates that the JADE economizer modules performed as intended and provided a high percentage of economizer cooling. While one of the OEM economizer modules also achieved nearly 100% economizer cooling, another unit using the same module and dry bulb limit control achieved only 75% economizer cooling. This could indicate a lower level of reliability for the W7345 economizer module or problems with the sensors that have been shown to have reliability problems in the past, (Robison et al. 2008) although the sample size is too small to validate this conclusion with any degree of statistical certainty.

Percent Sensible Cooling – Pre & Post

Table 14 presents the impact of sensible cooling provided by the economizer before and after the installation of the JADE control units at Site W, as well as the JADE unit results from Site A. While this sample is too small to draw a valid population conclusion, in all cases the retrofit economizer controls (both JADE and premium ventilation package) produced increases in sensible cooling provided by the economizer.

Table 14. Percent Sensible Cooling Provided by Economizer, Pre and Post Analysis – Site W & Site A Units

RTU	Tons	Post Model	Pre % Sensible Cool by Econo	Post % Sensible Cool by Econo	% Increase in Sensible Cool by Econo
Site W IT Office	6	Honeywell / JADE	0%	13%	13%
Site W CFO SW Office	4	Honeywell / JADE	27%	97%	70%
Site A HP 3	6.5	Honeywell / JADE T7351	4%	10%	6%
Avgerage of 3 JADE units	5.5	Honeywell / JADE	10%	40%	30%
Avgerage of 4 premium ventilation units at Site A	3.3	Innotech, KMC, Alerton	8%	75%	67%

Projected Annual Energy Savings

To analyze the cooling and fan energy impacts of the JADE economizer controller installation, hourly energy usage data was regressed against outside air temperature data for the analysis period at Portland International Airport, which is approximately 5 miles from Site W for each hour of the day.[7] The regressions for each hour were then driven with hourly temperature bin data generated with typical meteorological year (TMY2) weather data for Portland International Airport resulting in projected annual energy usage for a typical meteorological year. The purpose of this analysis was to quantify energy savings on an annual basis as a result of upgrading to the JADE economizer controller.

Since the energy usage data available was limited to cooling and fan energy use of the RTUs, the analysis was restricted to weekday hours in the afternoon when the majority of cooling was taking place in both the pre and post periods. The hours that were considered in the analysis period were Noon to 7:00 PM for the IT Office RTU, and Noon to 6:00 PM for the CFO Office RTU on weekdays. Usage was projected annually only for these hours, so the resulting projected annual energy usage is for cooling and fan energy during weekday afternoons. There may be additional economizer savings on summer mornings. See Appendix D for further details on the pre and post analysis periods. Table 15 shows projected annual energy usage impacts for these two RTUs.

[7] There was not adequate pre and post data available to reliably conduct the daily temperature average protocol for these units, so hourly analysis of afternoon occupied hourly data was conducted.

Table 15. Projected Annual Energy Usage - Afternoon

Unit	Pre kWh	Post kWh	Savings kWh	Savings %
IT Office	1,453	1,212	241	17%
CFO Office	2,161	1,235	925	43%

This analysis indicates that the addition of the JADE economizer controller resulted in annual energy savings for both of the units, and that the CFO Office savings are significantly higher than the IT Office savings. This is consistent with the percent economizer cooling analysis above, which shows a much larger increase in economizer cooling for the CFO Office than the IT Office.

While 43% energy savings for the CFO Office seems high for economizer savings, it is important to remember that this analysis is only for the weekday afternoon time period. If the analysis period was modified to include additional fan hours in the morning and evening occupied hours, as well as fan energy due to heating in the unoccupied period, the percent savings would be lower, likely in the range of 30%.

The annual results can be viewed graphically in Figure 12 and Figure 13. This is an annual projection of pre and post energy use based on hourly results **from the limited sampling periods**. In both cases the post cooling use is lower than the pre use, indicating improved economizer operation.

Figure 12. Annual Cooling Projection, Site W IT Office

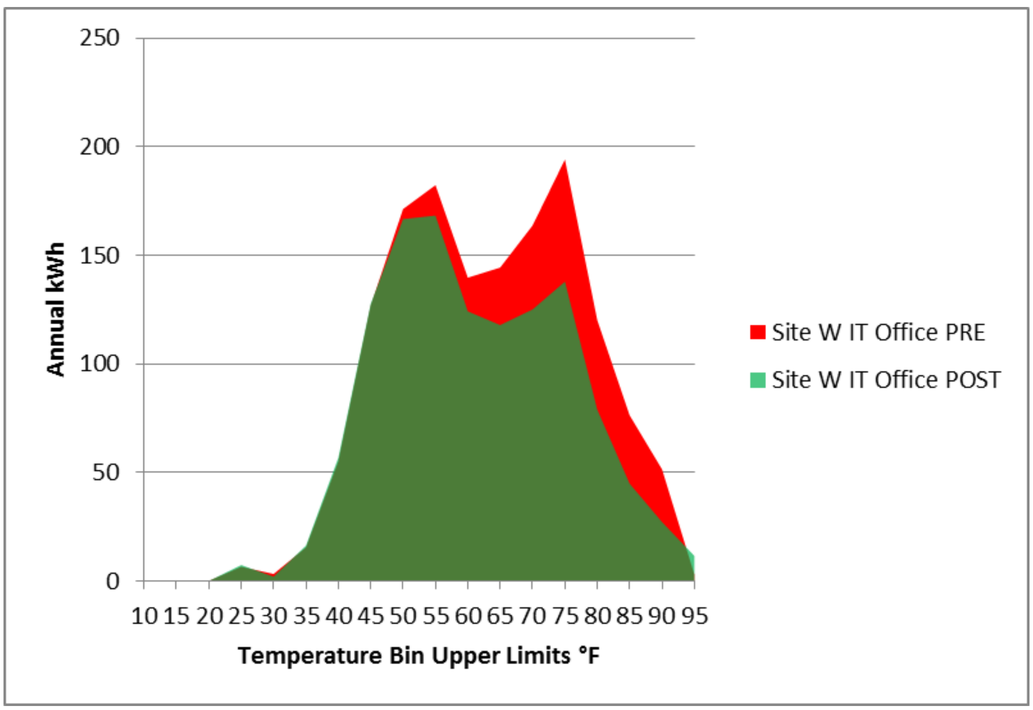
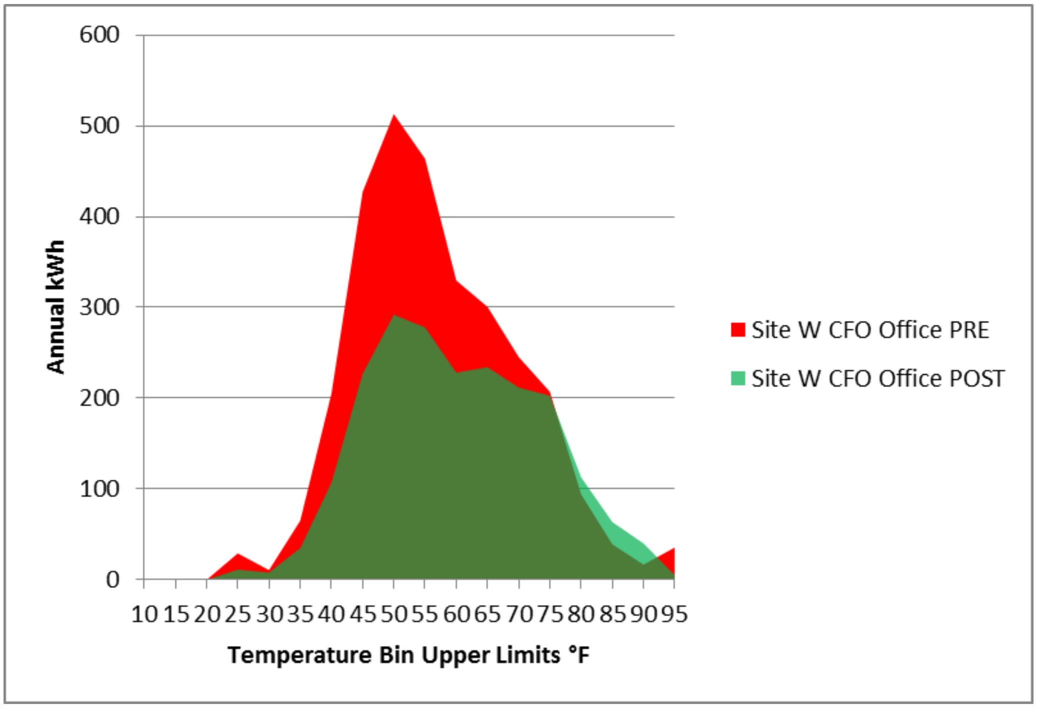


Figure 13. Annual Cooling Projection, Site W CFO Office



3.3.2 Ventilation Enhancements

The ventilation enhancement strategies impact the amount and timing of ventilation provided by the economizer controls. In this section, the impact on CO_2 concentration in the space is presented as the key results metric for DCV. Note that results specific to the damper leakage improvement strategy was not investigated due to lack of adequate pre and post data.

CO_2 Concentration Impact of DCV

The purpose of DCV is to reduce the amount of outside air ventilation supplied to a space while maintaining an acceptable level of ventilation as required by the space and its occupants. Return air CO_2 levels were analyzed for periods of time with similar average outdoor air temperatures before and after DCV installation (see Appendix D for analysis period details). For each unit several CO_2 concentration bins were developed and histograms generated that show the percent of time the CO_2 concentration was within each bin. Each unit has a target threshold of CO_2 concentration based on the expected occupancy density and space type. This threshold is calculated in the Acceptance Testing process based on ASHRAE Standard 62.1. The goal of the DCV system is to reduce excess ventilation, but rarely exceed the target threshold.

In all of the cases analyzed the distribution of CO_2 concentration shifted downwards slightly after DCV was installed. In each of the histograms below, the target threshold (CO_2 setpoint) is indicated by a vertical line. In all premium ventilation fan cycling cases the addition of fan cycling DCV maintains levels below the target threshold. In the case of HP-5, inadequate baseline ventilation is eliminated by the premium ventilation DCV system. For all the premium ventilation installations, proper fan cycling and CO_2 ventilation control was enforced during occupied scheduled times and could not be eliminated by the user.

For the advanced economizer option (JADE) with DCV in HP-3, the number of hours above the threshold is reduced. It should be noted that the fan control on the T7351 thermostat for HP-3 was switched by users from “fan on” during occupied to intermittent or “auto” multiple times, creating an inadequate ventilation issue. The T7351 does have an advanced setup mode that locks out fan and system control options; however scheduling is also locked out in this mode and a special access key sequence is required. This lockout was not implemented to allow easier scheduling by site staff.

Figure 14. HP-3 with JADE, Percent of Occupied Minutes by CO_2 Concentration

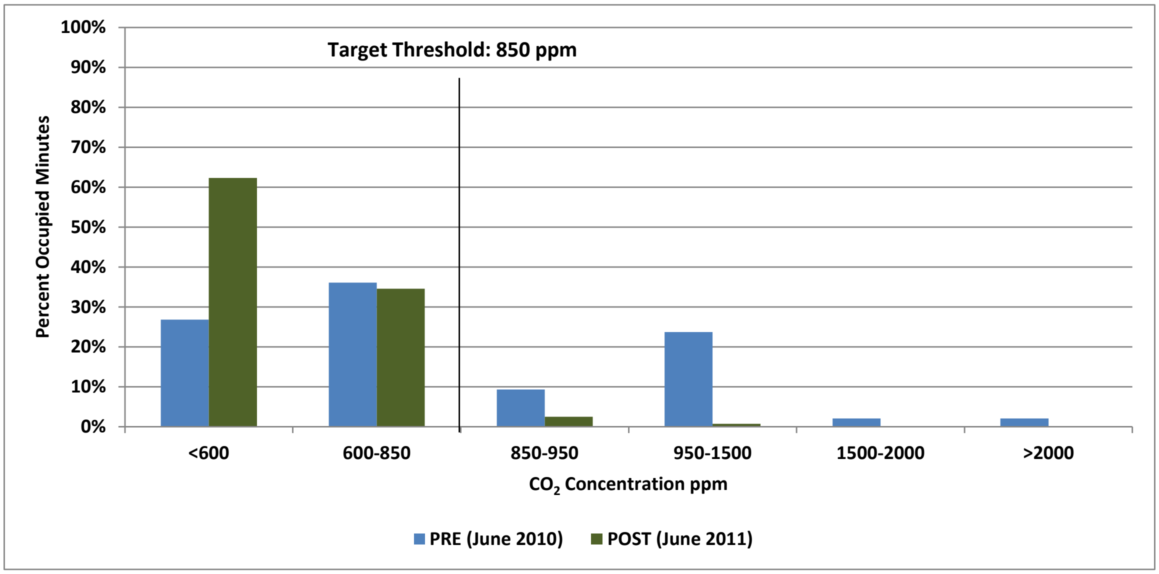


Figure 15. HP-5 with Innotech, Percent of Occupied Minutes by CO_2 Concentration

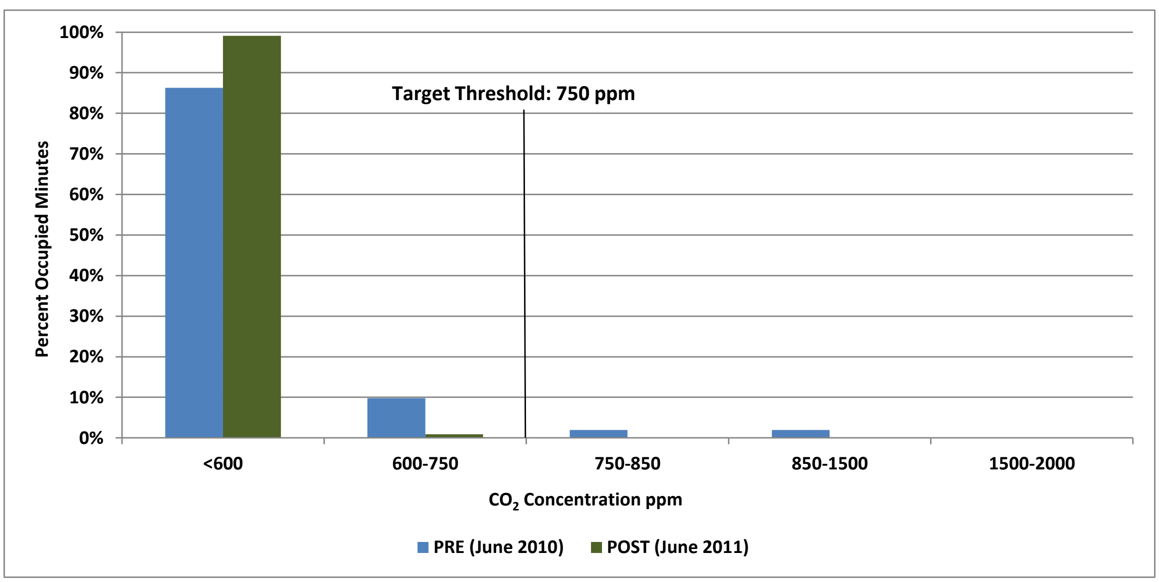


Figure 16. HP-6 with KMC, Percent of Occupied Minutes by CO_2 Concentration

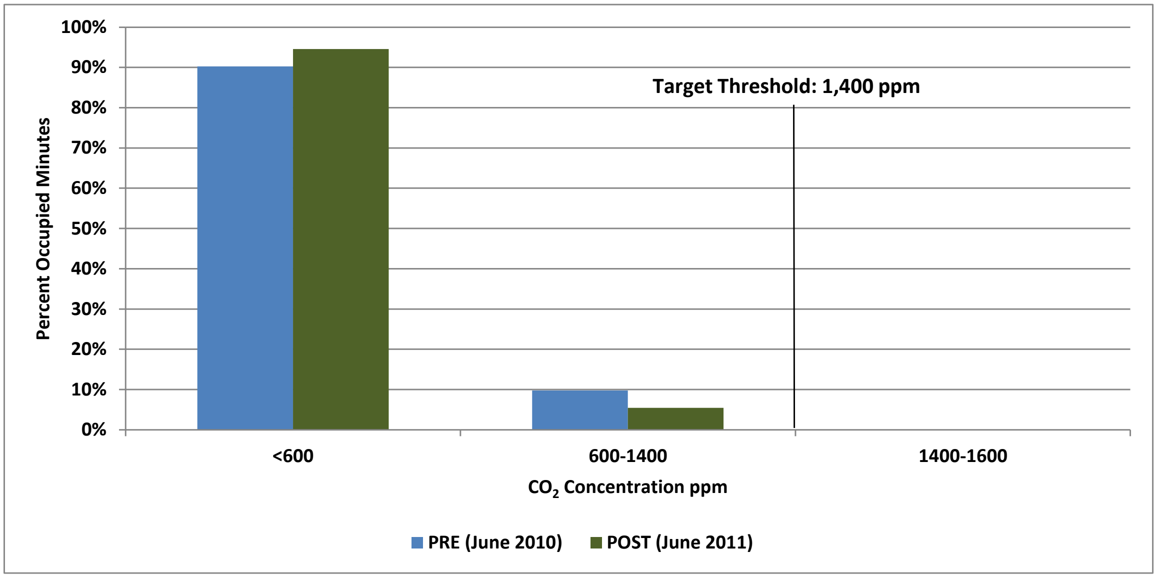


Figure 17. HP-7 with Allerton, Percent of Occupied Minutes by CO_2 Concentration

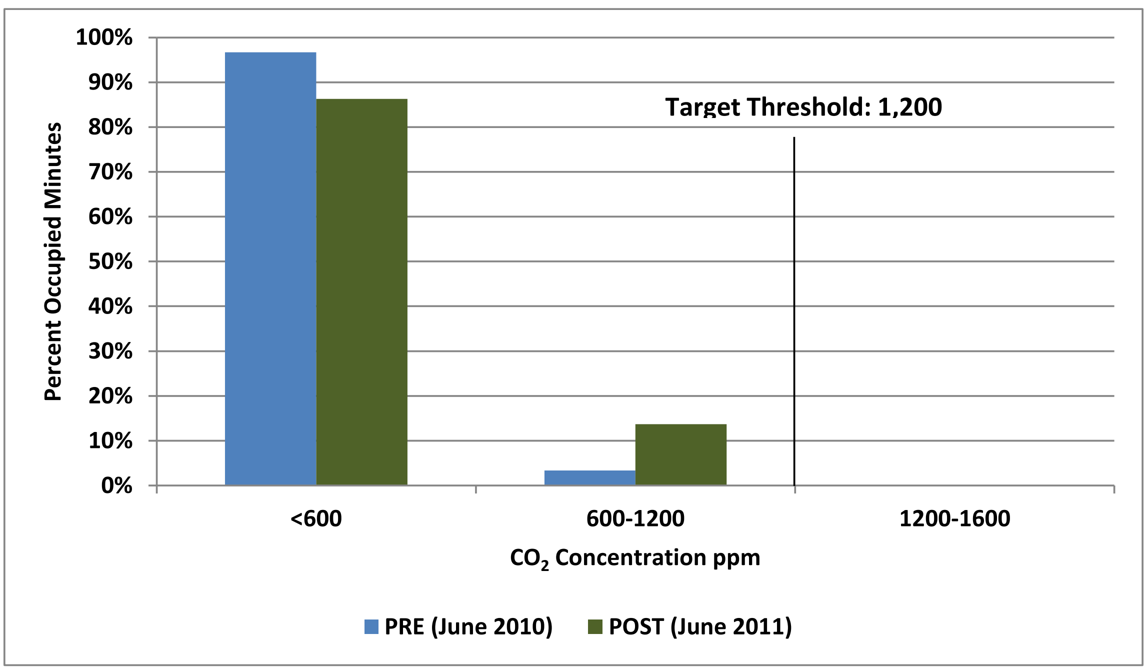


Figure 18. HP-8 with Allerton, Percent of Occupied Minutes by CO_2 Concentration

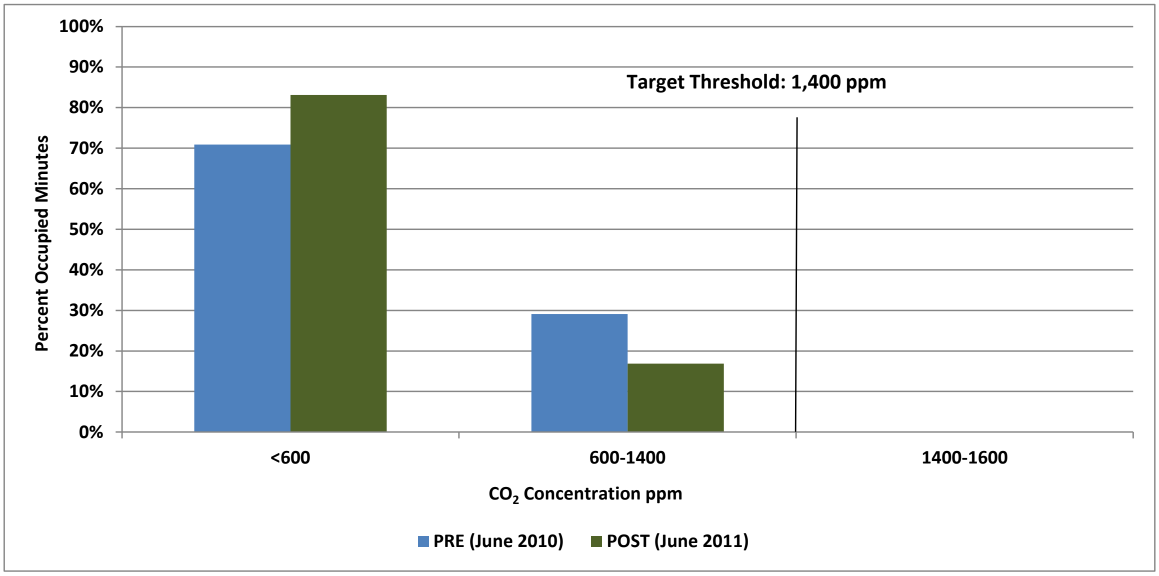


Table 16 compiles the occupied time spent above the target CO_2 threshold for all RTUs, and compares pre and post results. The impact of DCV was to reduce the amount of time spent above the target CO_2 threshold to zero for the Premium Ventilation controls with fan cycling. The gym area with the advanced thermostat and JADE controls exceeded the ventilation threshold 6.4% of the time. It should be noted that only two of the five units had time above the CO_2 threshold in the pre period. While the monitoring plan did not include measurement of baseline outside air percentages, observation noted that they were generally quite high. In addition these older buildings have a moderately high level of infiltration, so the pre ventilation was not fully dependent on fan operation.

Table 16. Total Percent Occupied Minutes Above and Below Target Threshold

Site A RTU	Economizer Controller		Occupied period minutes above CO_2 Target Threshold		
	Pre	Post	Pre %	Post %	% decrease
HP-5 Crafts	W7459	Innotech	3.9%	0.0%	3.9%
HP-6 Dance/Yoga	W7459	KMC	0.0%	0.0%	0.0%
HP-7 Waiting	W7459	Alerton	0.0%	0.0%	0.0%
HP-8 Conference	W7459	Alerton	0.0%	0.0%	0.0%
Premium Ventilation Average			**0.98%**	**0.0%**	**0.98%**
HP-3 Gym	Voyager	JADE	29.0%	6.4%	22.6%
JADE Economizer Controller Average			**29.0%**	**6.4%**	**22.6%**
Overall Average			**16.5%**	**1.3%**	**9%**

Note: Pre data for HP-4 was not available and was not part of the monitoring plan.

It is important to note that similar CO_2 concentration improvements have been achieved with a DCV approach that uses a VSD as opposed to fan cycling (Hart 2009). The percentage of time outside the CO_2 threshold was not analyzed for VSD installations in this earlier study, but based on review of graphic representation of CO_2 concentration the ventilation was found significantly inadequate in the base case for multiple units and significantly improved after installation of the DCV and VSD. Both fan control strategies provide better ventilation than the as-found condition from the field study where a fan set in the "auto" position is completely off for most of some days.

3.3.3 Fan Control Upgrades

The fan control upgrade strategy in this field study was limited to the fan cycling measure. As discussed, both fan cycling and a VSD are effective fan control strategies, but the scope of this report only includes fan cycling. This section demonstrates how fan cycling can be effectively used to meet ASHRAE Standard 62.1 requirements while potentially reducing fan run time.

DCV Fan Cycling and ASHRAE Standard 62.1

General thinking assumes that commercial facilities require continuous supply air fan operation during all occupied periods to comply with ASHRAE Standard 62.1. On the contrary, section 6.2.6.2 of Standard 62.1-2010 (ASHRAE, 2010b) has provisions for short-term interruption of ventilation, allowing the ventilation fan to cycle as long as steady-state average ventilation levels are maintained equal to the prescriptive method. This has been confirmed by 62.1 committee INTERPRETATION IC 62.1-2010-3 approved January 21, 2012.

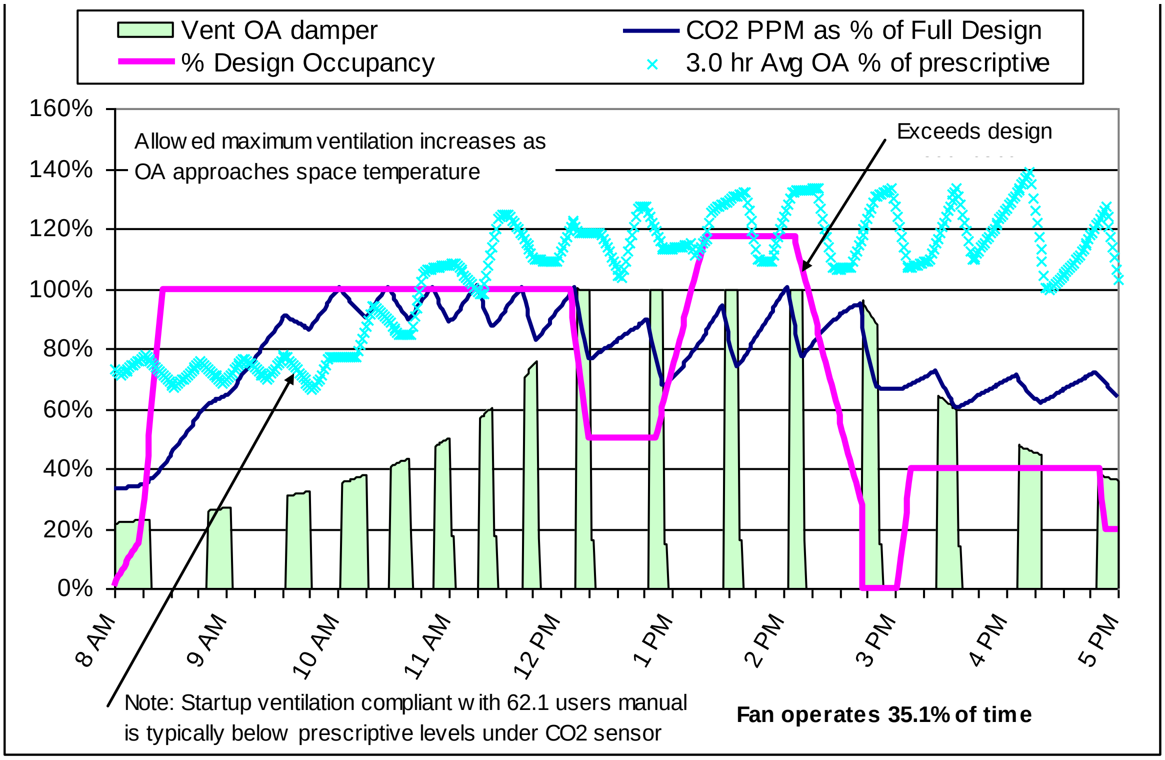
Standard 62.1-2010, section 6.2.6.2 states, "If it is known that peak occupancy will be of short duration and/or ventilation will be varied or interrupted for a short period of time, the design may be based on the average conditions over a time period."

Figure 19 is a simulation of the premium ventilation fan cycling sequence that shows how an average ventilation rate can be achieved equal to the prescriptive rate. In conjunction with the fact that the fan cycling premium ventilation for HP-5 improved ventilation and none of the premium ventilation controlled units had any hours above the threshold CO2 level, this demonstrates ASHRAE 62.1 compliance.

In the premium ventilation fan cycling sequence, the control system increases ventilation during the time immediately following a fan off cycle. Whenever heating or cooling is initiated, or if the supply fan has been off for 30 minutes, the fan automatically starts and a ventilation recovery mode begins. In the recovery mode, the controller opens the outside damper 100% when outside conditions are temperate. So a higher ventilation rate is provided for a shorter time period, resulting in the same average ventilation rate. The shorter time of fan operation means fan energy use is reduced compared with constant fan operation and ventilation at a low rate.

As outside temperatures move beyond the range acceptable for supply air, the outside air volume is reduced and ventilation times are extended. Figure 19 shows how a cool morning and warm afternoon result in reduced outside air damper positions with longer fan run times at the beginning and end of the day. The fan run time is shown as the green area, with the white background in between indicating the fan is off. The height of the green bars indicate how far the damper is open. Based on the damper position and how long the fan has been off, the time in recovery mode is adjusted to provide average ventilation equal to the CO_2 ventilation sequence in the 62.1-2010 user's manual (ASHRAE 2010a).

Figure 19. Fan Cycling Ventilation (cycles shown to meet ventilation only)



After the recovery period, if fan operation is still required for heating or cooling, the damper returns to a standard demand controlled ventilation cycle, positioned proportionately between the "area" and "full" ventilation positions depending on the CO_2 sensor reading. To help offset the lag time it takes CO_2 sensing to come to steady-state, at the start of the occupied period, the supply fan operates with the ventilation damper open to the ventilation recovery mode position for 20 minutes. Under typical operation, the thermostat calls for heating or cooling about every 10 minutes and ventilation will occur. If there is no call for heating or cooling, the fan will operate in ventilation recovery mode a minimum of 5 minutes every 30 minutes.

Fan Cycling Controls Effect on Fan Run Time

The premium ventilation sequence shuts the fan completely off when an occupancy sensor indicates that the space is unoccupied, thus saving fan energy, especially in spaces that are occupied intermittently. Without an occupancy sensor, code requires ventilation to be provided whenever the space is scheduled to be occupied.[8]

At this site, for all but one of the baseline RTUs the monitoring data indicates the fans were in "auto" mode, meaning the supply fan would only run if the unit was heating or cooling. Due to the limited run time (fan operating only during heating and cooling), "Auto" mode uses the least fan

[8] ASHRAE INTERPRETATION IC 62.1-2010-4 (January 2012) indicates a shift in 62.1 committee direction, and requires the area ventilation rate whenever a space is expected to be occupied. This shift is in conflict with Standard 90.1 provisions that allow occupancy sensors as schedule control, and it is expected that a vacant area ventilation proposal will be considered to address building pollution issues while reducing energy use. Such a proposal has been accepted for the next round of Title 24 in California.

energy of any control strategy, but it is also not code compliant; as the fan is often unable to provide adequate ventilation in this mode. As such, it is not a good baseline for post-retrofit fan run time.

While almost all baseline RTU fan settings in this field study were set in “Auto”, there are two other common fan settings often found in the field: Continuous 24/7 “On”, and “On during occupied hours.” A fan cycling approach leads to reduced fan energy consumption for both of these fan settings due to reduced fan run time.

Previous studies have found that the “On during occupied” feature, while available on advanced thermostats, is rarely installed, and almost all commercial installations use less expensive residential programmable thermostats that do not have this feature. In a California RTU performance investigation, 37% of thermostat fan controls were set for intermittent operation during the occupied period and 30% had continuous operation during unoccupied periods. (Jacobs 2003). In cases where the fan is intermittent during the occupied period, the addition of fan cycling controls will increase fan run time over the baseline (due to the nature of “Auto” mode discussed above); however, in all cases fan run time was decreased compared to a code compliant baseline. For the units that have continuous operation during the unoccupied period, there will be a significant decrease in fan operation and unoccupied ventilation. The extra savings from reducing continuous fan operations is likely to offset the lost savings from increased fan use in the units with baseline fan control in the auto position. Figure 20 and Table 17 shows fan operation as a percent of scheduled occupied hours for several units at Site A during spring and summer months. During the post period, fans operated an average of 29% of occupied hours. This is a 71% run time reduction from the 100% run time required by code minimum without DCV.

Figure 20. Percent of Fan “On” Time During Occupied Hours

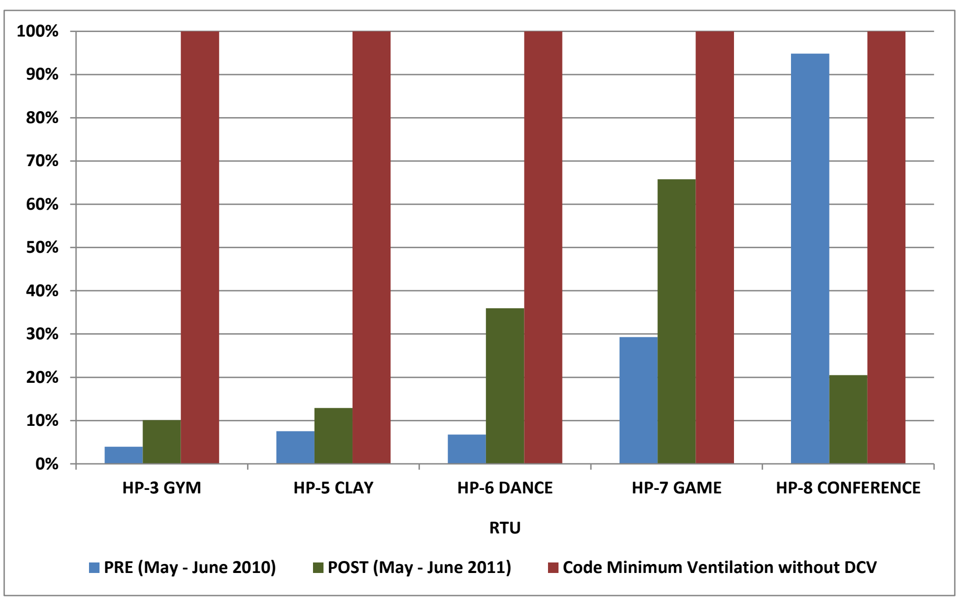


Table 17. Fan "On" Percent of Occupied Hours

RTU	Pre-retrofit	Post-retrofit	Code Minimum Ventilation without DCV
HP-3 GYM	3.9%	10.1%	100%
HP-5 CLAY	7.5%	12.9%	100%
HP-6 DANCE	6.7%	36.0%	100%
HP-7 GAME	29.3%	65.8%	100%
HP-8 CONFERENCE	94.8%	20.5%	100%
Average	28.5%	29.0%	100%

Note: Pre data for HP-4 was not available and was not part of the monitoring plan.

In the winter, unoccupied heating results in much more unoccupied fan use than for cooling. As a result there was after-hour fan operation for fans in intermittant mode, and a review of total fan hours can provide another view of differences in fan operation. Figure 21 and Table 18 shows fan operation as a percentage of total hours for three units that had available data in the winter months. In all cases the advanced controls reduced run time over the code baseline, and in two of the three cases, the advanced controls (POST) reduced run time over the baseline (PRE) case. For both of the premium ventilation cases analyzed, there was a reduction in fan operation, while the advanced thermostat had an increase. During the post period, fans operated an average of 24% of total hours. This is a 22% run time reduction from the average 46% run time required by code minimum without the fan cycling controls.

Figure 21. Percent of Fan "On" Duration for Total Hours

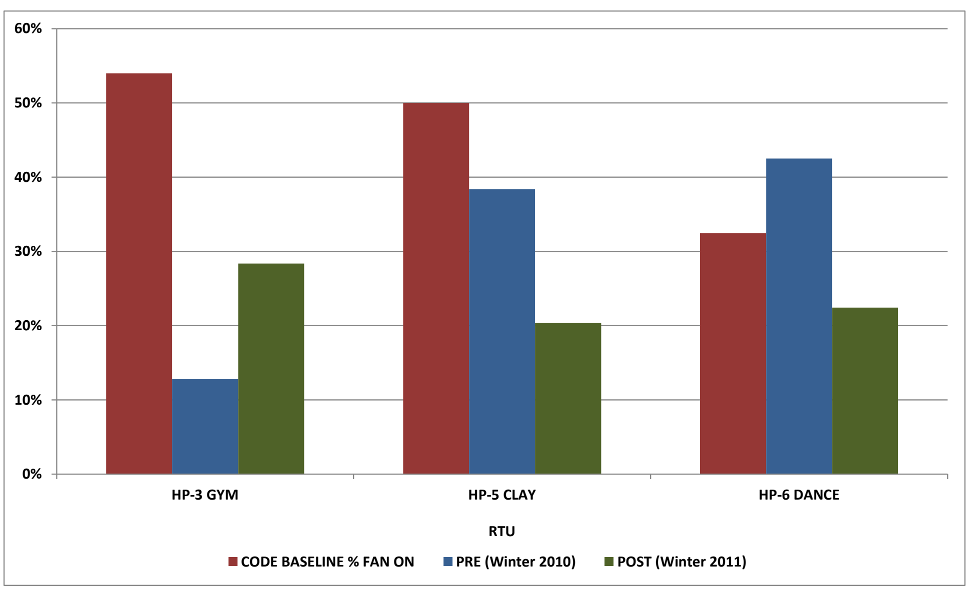


Table 18. Fan "On" Percent of Total Hours

RTU	Pre-retrofit	Post-retrofit	Code Minimum Ventilation without DCV
HP-3 GYM	13%	28%	54%
HP-5 CLAY	38%	20%	50%
HP-6 DANCE	43%	22%	32%
Average	31%	24%	46%

Note: Only units with adequate winter data are shown. Pre data was not part of the monitoring plan.

Although running the fan in "Auto" mode will result in the lowest fan energy use for occupied hours, properly controlling the fan during unoccupied hours can also reduce fan run time and energy use. In Figure 22, the fan in the baseline case for RTU HP-7 appears to be in "Auto" mode with little or no unoccupied temperature setback, producing fan operation that follows the sinusoidal oscilation of daily temperature. In this case, the total fan runtime was reduced, but fan operation was increased during occupied hours which likely led to the reduced CO_2 levels shown in the CO_2 histogram for HP-7.

Figure 22. RTU HP-7 Average Minutes Fan Operation by Hour

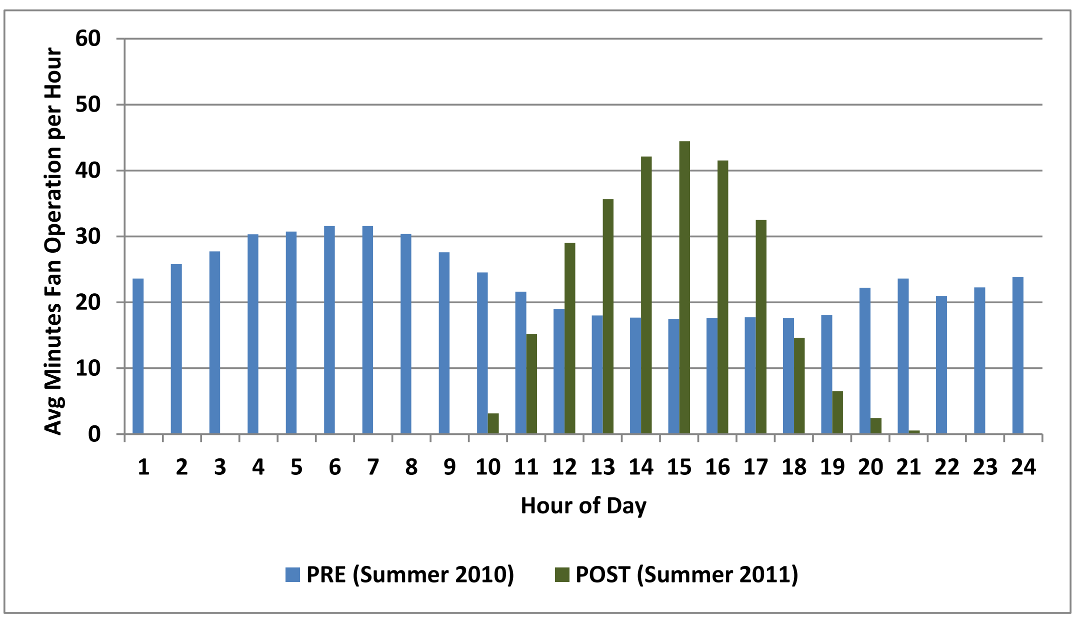
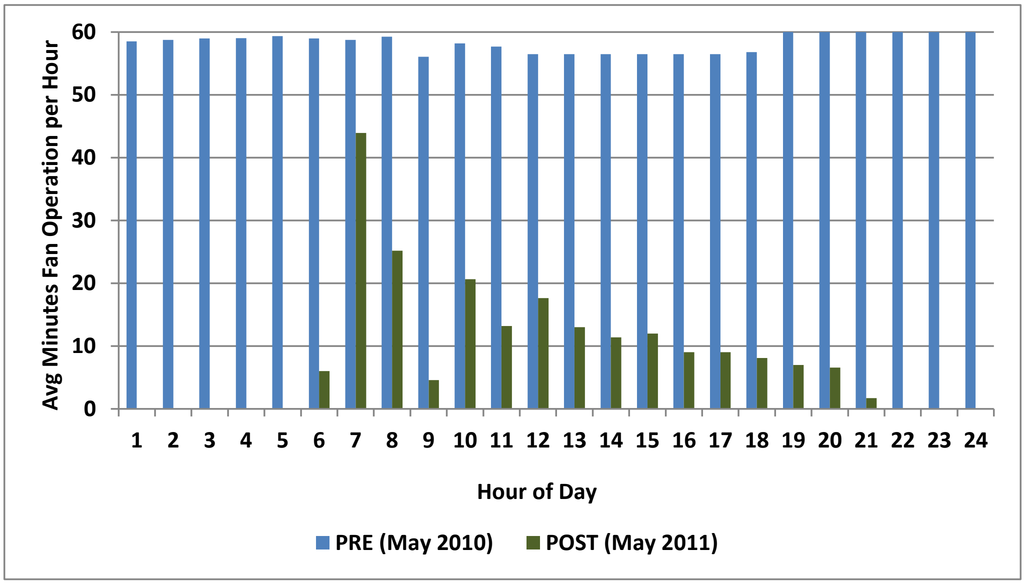


Figure 23 illustrates fan reduction impact when the fan in the baseline is running nearly continuously for all hours of the day. The minutes shown are an average over 18 days and for a few of those days the fan was in intermittant mode. Addition of the cycling controls and occupancy sensors cuts fan operation considerably for both occupied and unoccupied hours when most of the baseline fan operation is in the intermittant mode.

Figure 23. RTU HP-8 Average Minutes Fan Operation by Hour



3.3.4 Temperature Control Enhancements

The Premium Ventilation temperature control enhancements aim to reduce the amount of mechanical heating and cooling delivered by the RTU. The results presented in this section include the impact of the resistance heat lockout and robust optimum start, as well as a discussion of duty cycle during warm-up to reduce winter demand.

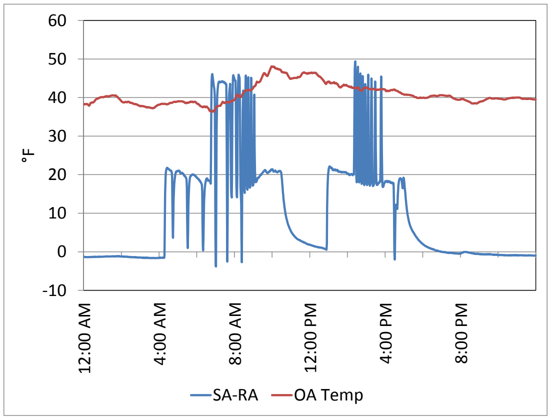
Resistance Heat Lockout & Robust Optimum Start

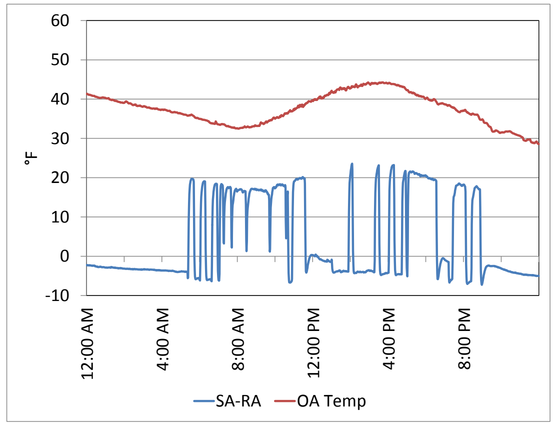
Premium Ventilation reduces electric resistance heat use in winter months by dynamically locking out the electric resistance heaters above an outdoor air temperature of 30°F (resistance heat lockout),and providing optimum start to use heat pump heating earlier in the morning and allowing it to run without the aid of the strip heaters (robust optimum start). Resistance heat is not only less efficient than heat pump heating, but also contributes to higher demand charges for the customer.

These strategies should enable the heat pump to more regularly meet the desired setpoint without the use of the resistance heater, reducing energy consumption. Determining the difference in energy use was not part of the monitoring plan; however, a couple of comparative cases can demonstrate the functionality of the resistance heat lockout.

Figure 24 and Figure 25 show the temperature difference between supply and reaturn air (SA-RA) that shows whether or not the resistance heat is on. If SA-RA is between 15 and 25°F the unit is operating in heat pump mode. If SA-RA is greater than 30°F the unit is using resistance heat in addition to the heat pump, based on measurements during acceptance testing.

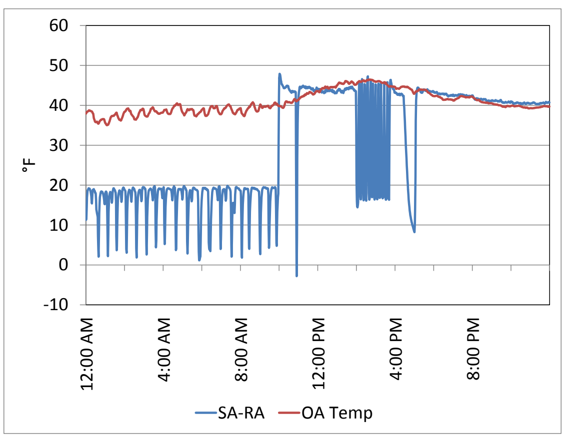
Figure 24. HP-6 Heating Mode, Pre (11/19/10) and Post (2/1/2011)

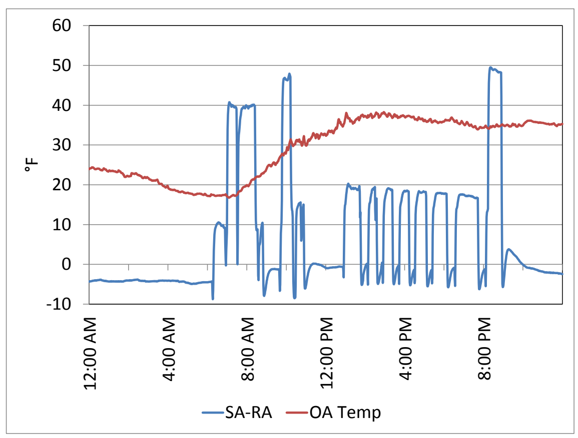




Average OAT: 40.9°F *Average OAT: 37.5°F*

Figure 25. HP-6 Heating Mode, Pre (12/5/10) and Post (2/26/2011)





Average OAT: 40.8°F *Average OAT: 29.2*

In each of the comparisons average outside (OA) temperature is lower in the post period, and resistance heat usage is also lower, indicating the resistance heat lockout and optimum start sequences reduced resistance heat usage.

In the first case (Figure 24) the strip heat comes on in the morning of the baseline period. In the post period the OA temp is colder in the morning, but the unit brings the space temperature up and maintains it throughout the day without using resistance heating. In the second case (Figure 25) OA temp is much colder during warm-up and throughout the day in the post period, but less resistance heat is used.

Robust Optimum Start

In early testing, one of the controllers was programmed with the robust optimum start control sequence and did not have trouble reaching occupied temperature on time. The same controller in an adjacent room used the manufacturer's standard optimum start learning algorithm based solely on indoor air temperature, which resulted in complaints due to the space not reaching the desired setpoint on time. So to be successful, an optimum start algorithm must take outside air temperature into account.

While the robust optimum start was successful in warming up the space on time, there continued to be more resistance heat use during startup than desired. In fact, even with the heat pump cycling, the resistance heat would come on. The first adjustment made to avoid this was increasing the warm up period, which was unsuccessful as seen in the left side of *Figure 26*. A different approach was then attempted where the inter-stage differential was increased and a dynamic resistance low limit was utilized. This approach was effective in reducing the use of resistance heat during warm up as seen in the left side of *Figure 26*.

Increasing the inter-stage differential requires a greater temperature drop below setpoint before the resistance heat can operate. Maintaining a larger differential between heat pump heat and resistance heat of 3F during optimum start warmup and following standby reduces the chance that resistance heat will be used. A dynamic low limit lockout is an alternative approach to increasing the inter-stage differential. It uses the typical resistance heat lockout as discussed above based on an outside air setting, but lowers that setting during the optimum start warm up period and standby recovery, prioritizing use of the heat pump heat. Dynamic lockout is another innovation created during the experimentation in this field test. This sequencing has a more stringent lockout at the beginning of the optimum start warm up period. Full availability of strip heat is allowed at a reasonable temperature as occupied time arrives. This allows the heat pump to provide more of the heating early in the warm-up period, but allow the resistance heat to be applied if necessary late in the warm up period in the event that the heat pump has not met the warm-up heating load. When the setpoint moves out of standby to full during the occupied period, the strip heat has a more stringent requirement during that recovery period. This implementation was made on the innotech unit and a screen shot of the dynamic reset is shown in Figure 27. The Y axis represents minutes after the start of the occupied period, with negative numbers representing minutes before start.

Figure 26. Robust Optimum Start Impact on Resistance Heat

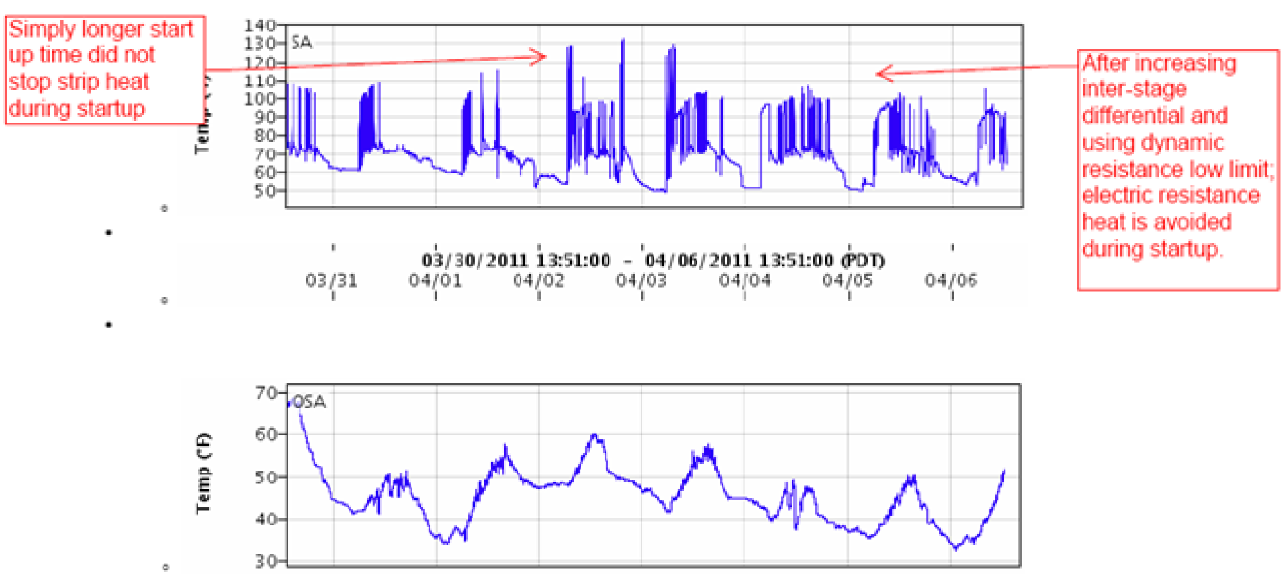
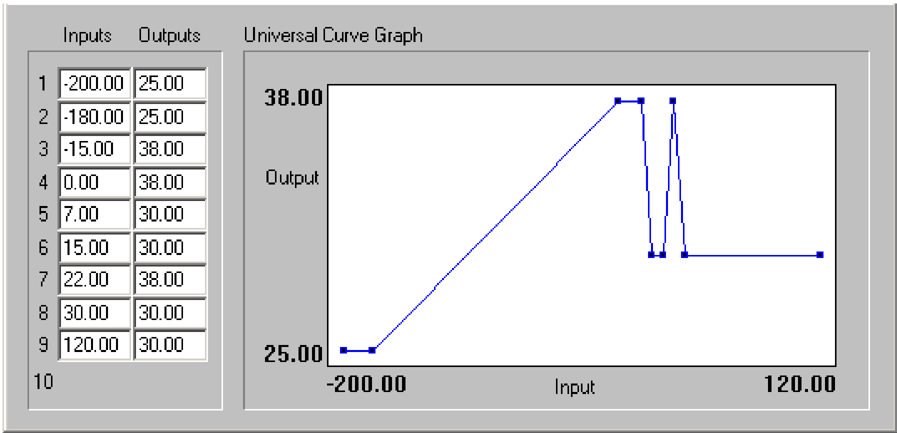


Figure 27. Dynamic Resistance Heat Lockout Sequence



Duty Cycling

An alternative approach to reducing demand impact from resistance heat usage is to utilize a duty cycle strategy during warm up. This approach requires less fine-tuning setup adjustments at each site compared to resistance heat lockout and robust optimum start. Duty cycling was included in the sequence as an optional method, but it was not fully implemented or tested at the site in this field test.

There are two ways duty cycling provides significant savings to the customer. First, the peak use of electricity is managed during electric heat warm up and during cooling, since duty cycling guarantees that only 1/3 to 2/3 of the units operate at any given time, depending how the staggered duty cycling is set up. Second, adaptive duty cycling will adjust the unit operation time in each cycle depending on a variable related to load, like outside temperature. Adaptive duty cycling allows peak demand to occur only in peak heating or cooling months, and reduces demand during shoulder months.

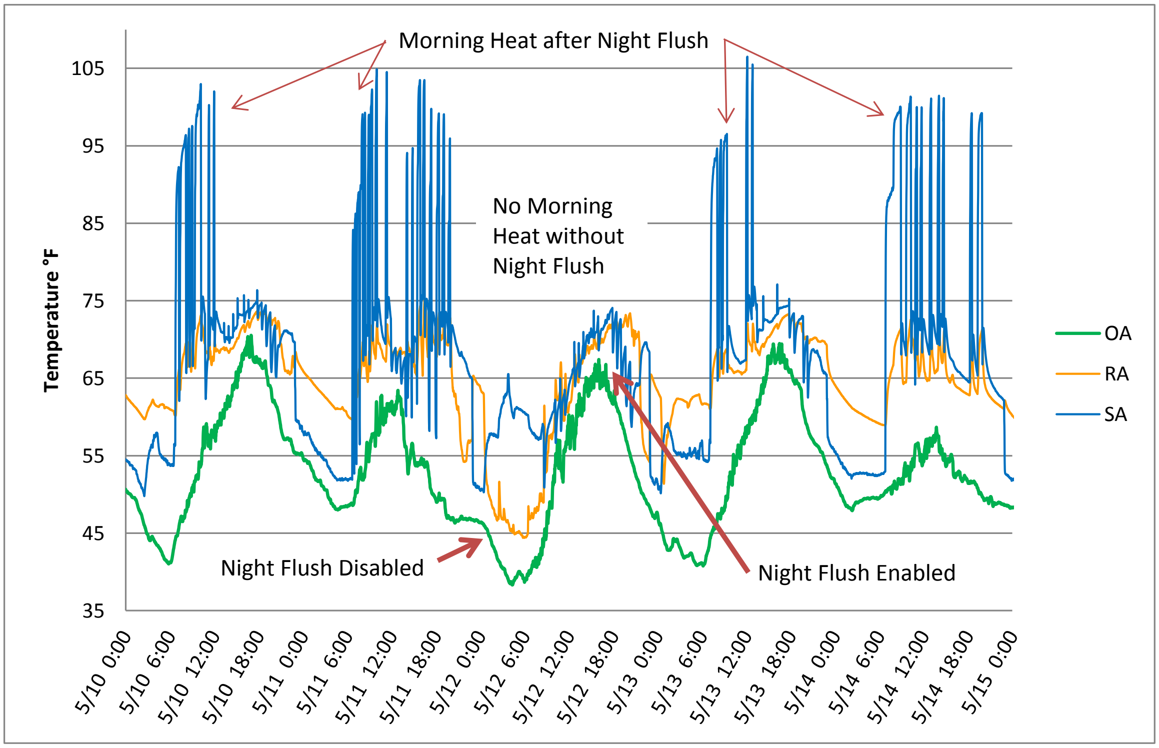
Night Flush Cooling

A sequence element included in the Premium Ventilation package but not included in the scope of this field test was night flush cooling. Prior testing by MacDonald Miller (Cadmus 2010) implemented a variation to night flush cooling where a simple stair step cooling setpoint adjustment results in mechanical cooling during the morning cool-down. This approach did not show energy savings because of the additional fan use and mechanical cooling use at a lower setpoint. A true night flush cooling strategy uses outside air for cooling.

Site A site was not an ideal candidate for night flush, because the general assembly and classroom type occupancies did not have unoccupied internal loads. The building is also of an older vintage and has relatively high infiltration rates, resulting in significant air movement through the building at night without night flush. Newer, better insulated buildings with occupancies (e.g. office) that have a base internal load due to computers and other equipment operating during the unoccupied period have a higher need for heat removal during the unoccupied period.

While comprehensive testing of night flush was not included, some observations were made. Proper operation of the night flush sequence as specified can be seen in Figure 28, when night flush was disabled around midnight on 5/12 as the outside air temperature dropped below 45°F. The following day (5/13), the daytime outside air temperature rose above the threshold (70°F) to activate night flush for the following night. Note that the controlling outside air for HP-5 was in a location with more solar gain than where the shown site outside air was monitored. Night flush operation and the resulting supply air temperature drop can be seen in the early hours of 5/13, and again on 5/14. However, the supply air temperature indicates heating was required in the morning, so night flush was not appropriate at this time, or the heating setpoint should have been lowered to make it effective.

Figure 28. Night Flush Cooling in May

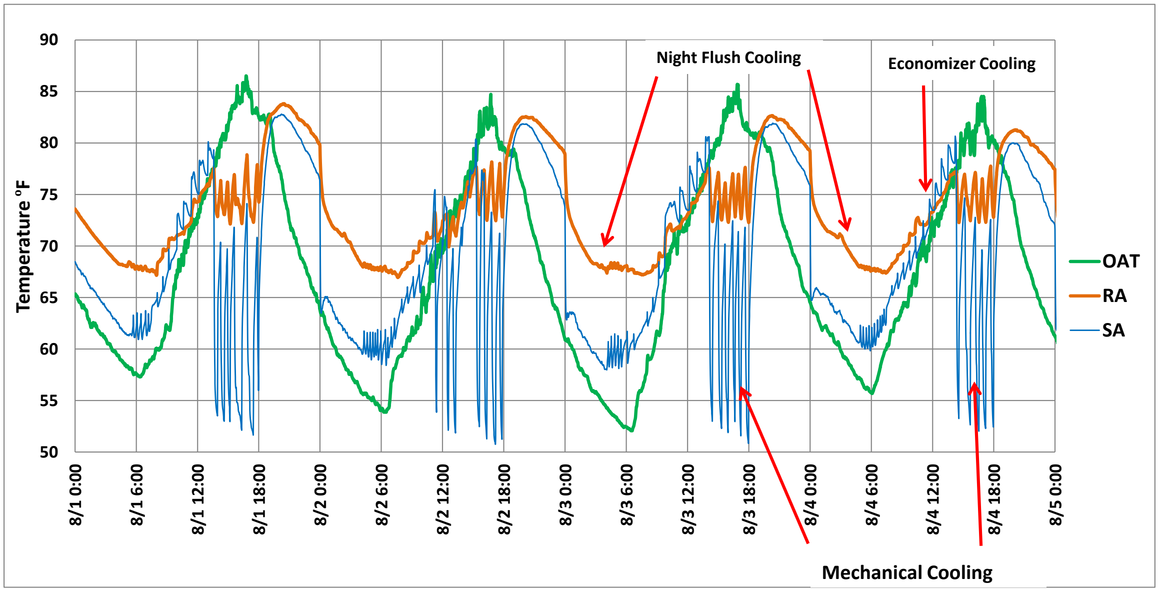


Adjustment of some night flush parameters could result in less morning heating, but it may be more appropriate to provide a lock out of night flush cooling if there has been any heating in the last 24 hours. In addition, development of guidelines for what building types are appropriate for night flush cooling would be beneficial. When properly applied, night flush cooling provides reduced peak summer demand and a significant reduction in mechanical cooling.

To avoid morning heating, a programming change was made in August to reduce both the heating setpoint and change the night flush trigger setpoint to 68°F (i.e. night flush is activated if outside air temperature reaches at least 68°F during the day). This revised night flush approach allowed about a 7°F drop in space temperature nightly, as can be seen in the return air temperature drop starting at midnight. The night flush extended morning economizer use as shown in Figure 29. Space temperature was not directly monitored, and the differential is imputed from return air temperature.

Further investigation of night flush sequences in a building type with more unoccupied building loads along with simulation of night flush operation is appropriate to properly gage the savings potential.

Figure 29. Night Flush Cooling in August



There are other enhanced temperature control strategies that were implemented and observed to operate properly. These are minor contributors to electrical savings, so no attempt was made to directly analyze savings effects. Sequences for these items are included in Appendix A. They include:

1. Ventilation lockout during morning warm-up.
2. Occupancy sensor standby mode.
3. Set point limiting.
4. Unoccupied temperature override with elimination of “hold” mode.
5. Short time switch mode lockout.

4 User Interaction Observations

The field study indicates that the Premium Ventilation strategies improve indoor air quality, increase sensible cooling completed by the economizer, and reduce fan run time and mechanical heating and cooling to save energy. These are significant benefits, but they will not be maximized unless individuals that interface with the control units find them to be intuitive and user-friendly. The following section discusses the users' experience operating the control units and managing their HVAC system with Premium Ventilation strategies installed, as observed by the PECI engineer in interactions at the site. Four specific areas are investigated: setpoints, overrides, fan settings, and control interface. It should be noted that these are anecdotal observations based on impromptu feedback of a limited number of users at one site. It should also be kept in mind that multiple different controllers were installed in an experimental field test at one site, and user response would likely be better if all the units at the site were converted to the same type of controller and there was a more long term commitment to a new control system.

4.1 Setpoints: Displaying the Truth?

Programmable and standard thermostats utilize different methods to separate heating and cooling setpoints. The Alerton and Innotech control units allow users to enter a single setpoint in the middle of the dead band between heating and cooling setpoints. The problem with this approach is that when a five degree deadband is enforced, the actual space temperature (displayed on the space interface) will never match the setpoint. In cooling mode, the actual space temperature will always be 2-3 degrees higher than the displayed setpoint and in heating mode 2-3 degrees below setpoint. When the temperature is floating in the deadband mode, it will sometimes match the displayed setpoint. This approach is reasonable for a DDC system where the setpoint and space temperature are not displayed on the thermostat or space interface, but it creates confusion for users when these parameters are displayed and ultimately lowers their trust of the control unit.

This issue was addressed during this study by making a programming adjustment to the Innotech controller so the displayed setpoint showed the heating setpoint when the outside air temperature was below 65F and the cooling setpoint when outside air temperature was above 75F.This displayed setpoint would ramp linearly between the heating and cooling setpoints when the temperature was between 65 and 75 degrees. Based on staff feedback, this change reduced user confusion with operation of the Innotech unit.

Attempts were made to change the Alerton VLD user interface, but the setpoint interface was fixed unless several other necessary interface components were deactivated, so the "setpoint in the middle" was retained.

For the KMC FlexStat and Honeywell T7351 the setpoint that is reset by the user was the setpoint for the last active mode (heating or cooling). This did occasionally create problems when the last mode was heating and users were uncomfortably warm. Even when the cooling setpoint was higher than the cooling setpoint limit, it could not be lowered until after the unit entered the cooling mode at the uncomfortable setpoint.

An additional observation from the users related to setpoints was that 2°F was the maximum acceptable standby (vacant during occupied schedule) temperature setback. Larger standby setbacks result in users manually adjusting the setpoint once a space was occupied. This adjustment resulted in excess heating or cooling operation.

4.2 Overrides: Creating Feedback

Initial implementations of the sequence resulted in several minutes of delay[9] from when the user hit the override button to adjust the setpoint until there was a reaction by the system. This resulted in user dissatisfaction and a perception that the system was not responsive. In a revised protocol, the fan was activated within 15 seconds of when a user setpoint adjustment was made, and the setpoint change was temporarily (for 2-5 minutes) amplified to move past the differential and provide a system reaction. This resulted in less user frustration with the system, as they hear the fan operation in response to their adjustment. An extension of this approach that could be applied to future implementations would be to trigger the fan immediately after the occupancy sensor activation.

4.3 Fan Settings: User Preference

For the advanced programmable thermostat (Honeywell T7351) allowed users to select a fan cycling setting, as opposed to an "on during occupied" mode. Note that for the other three advanced control units, users do not have manual control over fan settings; a ventilation-based fan control cycle is the default when the Premium Ventilation package is implemented. User preference for the "auto" mode that results in fan cycling may result from either a desire for less fan noise, or discomfort due to drafts induced by the moving air.

In multiple site visits, the advanced thermostat was left with the fan in the "on" mode. In this mode, the fan operated when the occupancy sensor detected occupancy, and cycled based on heating and cooling needs when the sensor was not active. Each time, the users reset the fan to "Auto" so it only operated when there was a thermal demand for either heating or cooling. As a result, the advanced thermostat combined with the JADE economizer had CO_2 above the desired threshold 6.4% of the time (see Figure 14). The conclusion is that users at this site preferred a thermally driven cycling fan (that may not provide adequate ventilation) to a fan that ran continuously**.** The Honeywell control unit can be setup to not allow manual control of fan settings, which would avoid the possibility of the fan being set to "Auto;" however, this setup also locks out user access to programming the schedule.

4.4 User Interface

Users found the Honeywell advanced programmable thermostat to be the most intuitive to use. The space sensor approach with display provided by the Innotech unit ran a close second. Users found that these two interfaces were most like the programmable thermostats that they were already accustomed to using.

Users found the Alerton and KMC units to have interfaces that were difficult to navigate. Many of the touch screen options of the Alerton unit in custom mode were not functional, making the work around to avoid a single setpoint in the middle of the dead band (Section 4.1) not feasible. The buttons of the KMC unit were overly generic, similar to a programmable logic controller, and resulted in user confusion, even after training.

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[9] The control loops were set up and tuned to provide gradual and stable responses. Consequently, the thermal change took several minutes from setpoint change until the control loop recognized an actual call for heating or cooling.

5 Prototype Savings and Cost Effectiveness

When viewed in the context of comprehensive HVAC savings, including energy for fans, heating and cooling, simulations indicate that the premium ventilation control upgrade can save a significant share of HVAC energy.

5.1 Premium Ventilation Savings Potential

DOE2.2 energy models of the Premium Ventilation package showed savings for eight cities covering a range of U.S. climate zones (Hart 2008). The strategies in the energy model match the strategies investigated in this report with the exception that VSDs were included in the energy modeling analysis as opposed to fan cycling. Further analysis has verified that fan cycling and VSDs produce very similar savings (Hart et al. 2012). Therefore, the savings from the prior analysis is valid for the package of strategies presented here.

Energy savings for the package of strategies ranged regionally from 18% to 44% of HVAC use, substantially higher than the savings of 1.5% to 6.7% from upgrading RTUs from SEER 13 to 15 (Hart et al. 2008). RTU baseline models used parameters from field studies of the typical as-found condition of smaller RTUs. For example, baseline ventilation rates used a minimum outside air of 13% of supply rather than the code required 7%, based on field observation (Davis et al. 2002).

To estimate savings, a simulation of heat pump RTUs on a small office building with the VSD fan version of the Premium Ventilation Package was used. The total height of bars in Figure 30 represents baseline office RTU HVAC energy use in eight national climate zones. Interactive measure savings from the analyses are shown in the sections at the bottom of the bars. The remaining HVAC energy use after all strategies are implemented is shown in the top three portions of the bars: remaining heating, remaining cooling, and remaining fan and auxiliary.

Figure 30. Premium Ventilation Energy Modeling Results

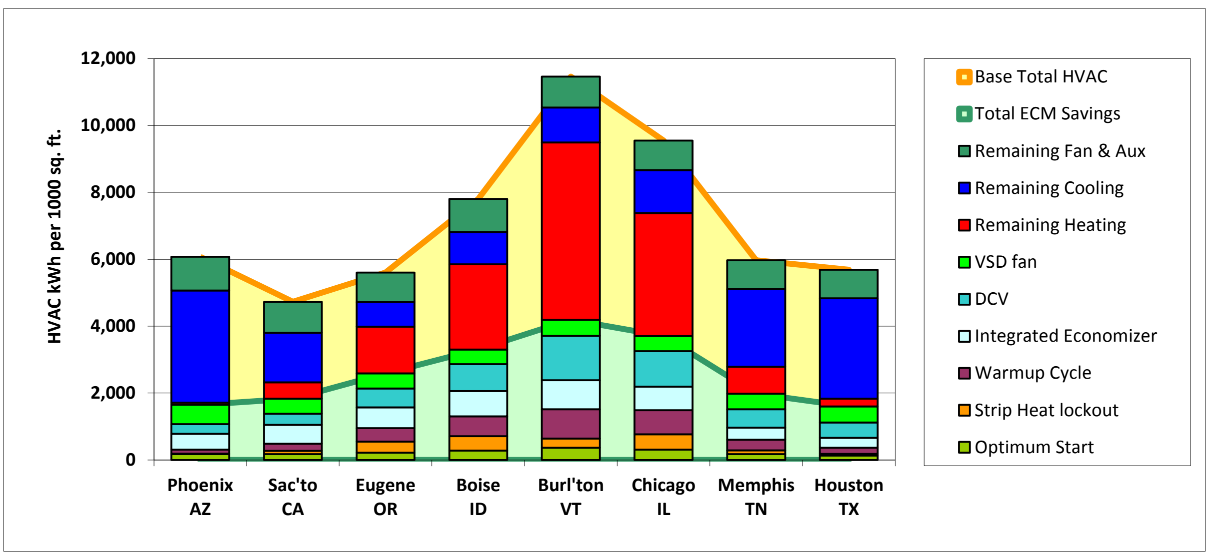


Table 19 shows the same office building heat pump results re-characterized into measure savings for a gas furnace RTU. Gas furnace RTUs are more prevalent in commercial buildings. The savings have been re-calculated from the original heat pump DOE2 end use outputs and separated by fuel type. Results are put into multiple measure groups and normalized by typical tons of cooling. Heat pump specific strategies such as strip heat lockout were eliminated from the savings. The strategies represent a stepwise addition of control features as follows:

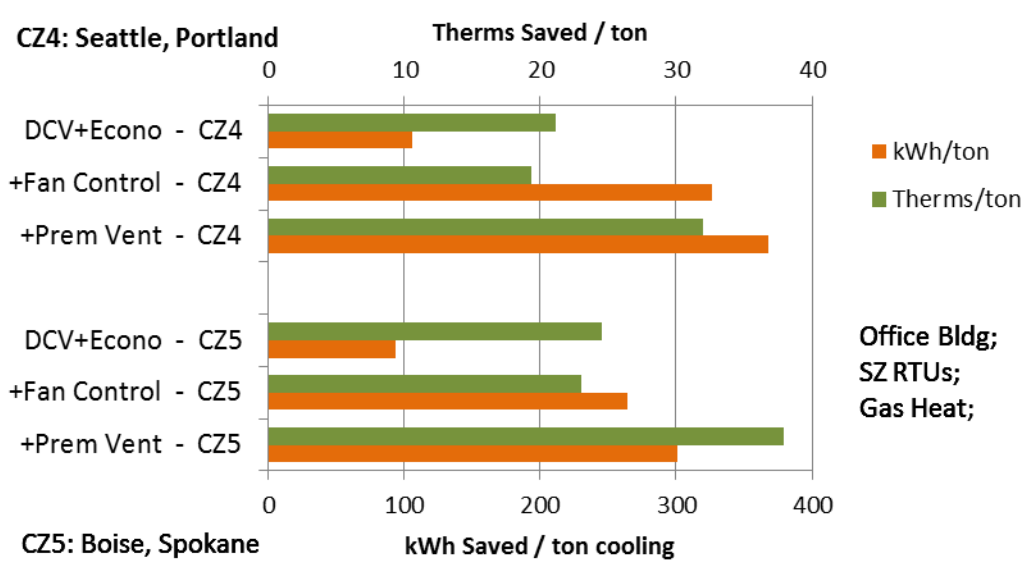
- **DCV + Econo**. Add demand controlled ventilation and upgrade to a digital economizer with differential high limit control. In the process reduce excess baseline ventilation with acceptance testing on setup.
- **+ Fan Control.** Add fan control, either VSD or fan cycling to reduce fan energy use.
- **+ Premium Vent.** To the above measures, add robust optimum start, ventilation lockout during warmup, occupancy sensor standby, and temperature setpoint limits.

Table 19. Premium Ventilation Savings Results

Office Building Savings	Phoenix AZ	Sac'to CA	Eugene OR	Boise ID	Burl'tn VT	Chicago IL	Memphis TN	Houston TX
kWh/ton								
DCV + Econo	161	150	106	94	14	28	81	137
+Fan Control	311	326	326	264	185	177	218	274
+Premium Vent	342	359	368	301	221	208	239	293
Therms/ton								
DCV +Econo	1.4	8.0	21.1	24.5	40.5	28.5	7.8	3.1
+Fan Control	1.3	7.4	19.3	23.1	37.8	26.6	7.5	3.0
+Premium Vent	2.7	12.9	32.0	37.9	59.7	42.8	12.4	5.4

A graph of savings for Pacific Northwest climate zones is shown in Figure 31. Fan control savings are higher on the West side due to more idle time.

Figure 31. Pacific Northwest Measure Package Savings Results



5.2 Cost Effectiveness

A low administrative cost is important to maintain cost effectiveness when per RTU savings are small. Calculating individual savings for items like optimum start thermostats, economizer controls, fan controls, and demand controlled ventilation can be independently selected for each unit, but a package of strategies provides the synergy of addressing common problems together and building installer expertise and efficiency with installing a set package of strategies.

Premium Ventilation measure synergies include capturing economizer savings that have not been fully realized with existing controls due to poor control setup and unreliable equipment. Because many RTUs are in the 4-5 ton range, unit savings are not high enough to support customized controls, multiple CO_2 sensors, and full scale commissioning. To reduce costs to the level needed to make smaller RTU retrofits cost effective, standardized practices with a reasonably effective control approach and appropriate acceptance testing must be applied.

The goal for Premium Ventilation is a practical and cost effective package of strategies that will provide improved performance of existing RTUs. Field tests have led to improvements, including the addition of DDC controls and verification of fan cycling. While not appropriate for all spaces, the lower cost fan cycling approach provides improved ventilation compared with “auto” fan cycling, the typical setting for more than a third of RTUs (Hart 2008).

In this field test with custom controllers, the total bid upgrade cost including controllers, replacement damper operators, new control wiring and labor ranged from $2,198 to $3,551, depending on manufacturer. These costs are offset by the measure savings, providing a payback from 2.0 to 6.1 years for 5 to 15 ton units in Eugene, OR and 2.0 to 5.9 years in Boise, ID.

Costs for various strategies based on the control units tested in this field study are listed in Table 20 . Bid results for individual manufacturers are included in Appendix C. The costs shown have been adjusted from the original bids to account for for next generation equipment changes where appropriate. For example, the new KMC Flexstat includes a CO_2 sensor, reducing installation labor with a slight increase in material costs. An estimate was obtained from the bidding contractor for the “DCV + economizer” option, as the site installation included a smart thermostat not required for DCV and economizer alone. Savings from the analysis in section 5.1 for an office building are shown for both 5 and 15 ton units with paybacks for both low and high bid costs. Cost savings are based on EIA regional utility rates of $0.0748 per kWh and $1.10 per therm.

Table 20. West side PNW Payback

ASHRAE Climate Zone 4c	Installed Cost		Modeled Office Savings		Annual $	Simple Payback	
(Seattle, Portland)	Low	High	kWh	therms	Savings	Low	High
5-ton Cooling Unit							
DCV + Economizer	$1,300	$1,500	500	105	$150	8.7	10.0
DCV + Econo + VSD	$3,300	$5,200	1,600	95	$220	15.0	23.6
Premium Ventilation Cycle	$1,900	$4,300	1,800	160	$310	6.1	13.9
15-ton Cooling Unit							
DCV + Economizer	$1,300	$1,500	1,500	315	$460	2.8	3.3
DCV + Econo + VSD	$4,200	$6,100	4,800	285	$670	6.3	9.1
Premium Ventilation Cycle	$1,900	$4,300	5,400	480	$930	2.0	4.6

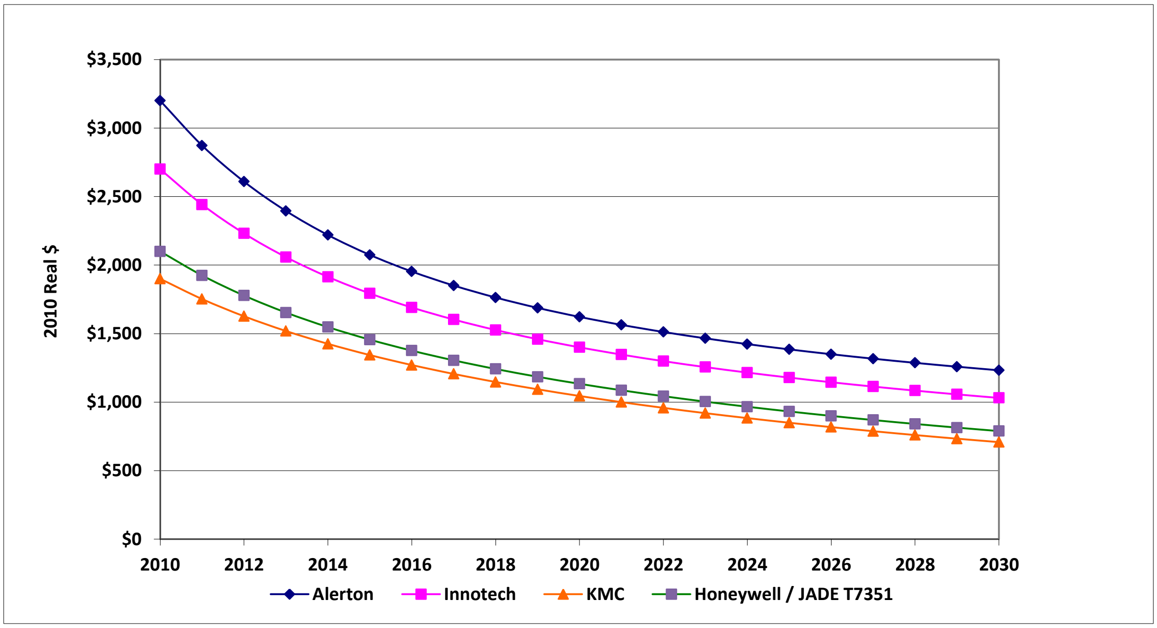
Table 21 includes similar results for an office building in ASHRAE climate zone 5, covering Boise or Spokane. Costs are the same as the East side analysis, but savings vary for this climate based on the prior DOE2 analysis.

Table 21. East side PNW Payback

ASHRAE Climate Zone 5b	Installed Cost		Modeled Office Savings		Annual $	Simple Payback	
(Boise, Spokane)	Low	High	kWh	therms	Savings	Low	High
5-ton Cooling Unit							
DCV + Economizer	$1,300	$1,500	500	125	$170	7.6	8.8
DCV + Econo + VSD	$3,300	$5,200	1,300	115	$220	15.0	23.6
Premium Ventilation Cycle	$1,900	$4,300	1,500	190	$320	5.9	13.4
15-ton Cooling Unit							
DCV + Economizer	$1,300	$1,500	1,500	375	$520	2.5	2.9
DCV + Econo + VSD	$4,200	$6,100	3,900	345	$670	6.3	9.1
Premium Ventilation Cycle	$1,900	$4,300	4,500	570	$960	2.0	4.5

Materials and labor associated with installing Premium Ventilation are expected to reduce over time due to larger demand and refining the installation process. As shown in Figure 32, the development of a more dedicatated control product and larger scale implementation would reduce manufacturing and labor costs which would shrink the payback period, paybacks for this package of strategies. An example of cost reduction is shifting from a custom programmable controller like the ones used in this test (Allerton, KMC, Innotech) and moving to a controller with the sequence burned into memory, like a programmable thermostat. Projected retrofit costs below are based on a 5% annual labor reduction and 14% annual hardware reduction that is based on long term cost reduction for computing equipment.

Figure 32. Control Unit Projected Retrofit Cost



6 Findings Summary and Conclusions

This field study investigating the Premium Ventilation package of strategies demonstrates promising potential to improve IAQ while saving energy through smarter ventilation control strategies. RTUs serve 40% of commercial building space but significant control problems have been documented. Many units have leaking dampers and excessive or deficient ventilation settings. Thermostats are often set in the “Auto” or “On” position so the RTU either does not provide adequate ventilation during the occupied period or wastes energy during unoccupied periods.

The Premium Ventilation package of strategies addresses these issues by combining economizer enhancements, ventilation enhancements, fan control upgrades, and temperature control enhancements to more intelligently control when and how a space is heated, cooled, and ventilated.

6.1 Key Findings

Key findings from this field study include the following.

- A DCV strategy that utilizes fan cycling maintains an average ventilation rate equal to or better than the prescriptive rate of ASHRAE Standard 62.1-2010.
- Implementation of DCV eliminated insufficient ventilation, leading to CO_2 levels below the target threshold. Compared to the baseline, DCV resulted in 9% less occupied time spent above the target CO_2 threshold.
- Fan cycling strategies implemented as part of DCV result in 71% less fan operation during occupied hours compared to the code minimum without DCV and 22% less fan operation during total hours. When compared to fan operation as-found at Site A (4 fans in “Auto” and one fan on continuously) there was a slight increase in fan use from 28.5% to 29.0% of the time.
- Economizer enhancements resulted in an average 54% more sensible cooling provided by the economizer and showed improved economizer use in all 7 cases analyzed.
- Heating control enhancements resulted in reduced resistance electric heater operation.
- Simple payback for the Premium Ventilation package application to an office building with 5-ton units is estimated to be 5.9 years for Boise, Idaho and 6.1 years for Eugene, Oregon, based on the low bid in the field test and DOE2 analysis.
- While this sample is too small to draw a valid population conclusion, in all cases the retrofit economizer controls (both and premium ventilation package) produced increases in sensible cooling.
    - The four premium ventilation units, with the economizer controls integrated into the controller produced 67% more sensible economizer cooling compared to the replaced economizer controls.
    - Three RTUs with JADE economizers utilized the economizer on average for 30% more sensible cooling compared to the replaced economizer controls.
    - For two RTUs with JADE economizers at site W, annual savings during weekday afternoons were 40 kWh per ton and 230 kWh per ton.

In addition to the operational findings of the Premium Ventilation installations at Site A and Site W, the experience of recreation staff at Site A with the advanced control units was also documented. Key observations include the following:

- The Innotech and Alerton units displayed a single setpoint in the middle of the dead band between heating and cooling setpoints. This creates confusion for users and a programming work around was found with the Innotech unit.
- Users were frustrated by the long delay from when the override button was activated until the system responded. In a programming revision, fan activation was made immediate and setpoint changes were temporarily amplified to provide a faster system response.
- For the advanced programmable thermostat (Honeywell T7351 / JADE) users were able to adjust the fan settings. This resulted in the fan setting often being changed to "auto", resulting in inadequate ventilation. It is recommended that the thermostat be set up to lock out user access to fan settings.
- Users found the Honeywell advanced programmable thermostat to be the most intuitive to use, followed by the Innotech unit. User satisfaction with these units stemmed from them being most similar to the programmable thermostats that they were already accustomed to using. Unfortunately the Advanced thermostat/JADE combo does not provide fan savings.
- Properly installing one of the integrated digital control systems requires a commitment by facility staff to training on the software, as well as the local availability of an installing contractor familiar with the system. This was not an issue for the advanced programmable thermostat and economizer controller (Honeywell/JADE) that can be readily installed and configured by a contractor and user without significant training.

6.2 Program Readiness & Recommended Next Steps

The Premium Ventilation advanced controls strategies investigated in this study show promising ventilation and energy savings benefits. This study's demonstration of the control strategies' functionality should serve as a base for developing the necessary infrastructure to deploy the measures.

There are currently a number of components that are recommended for the Premium Ventilation measures deployment. Chief among these are measure standardization and establishing several contractors who are trained to implement the measures.

The study demonstrates how Premium Ventilation can be implemented across multiple manufacturers, without compromising overall functionality.

The following steps are recommended for Premium Ventilation deployment:

- Verify energy savings for the Premium Ventilation package. The focus of the current study was to understand measure functionality, so the sample size was not large enough to draw statistically significant conclusions about energy savings and monitoring was not set up for a focus on pre and post measurements, as the available recreation site was not a common building type.
- Determine appropriate target customer or building types for **Enhanced Ventilation and Temperature Control** vs. full implementations of Premium Ventilation. . Due to the fact that **Enhanced Ventilation and Temperature Control** uses an advanced thermostat that a wider range of contractors are familiar with, this reduced scope measure may provide a more expansive impact in the marketplace even though it achieves less comprehensive energy savings than the full premium ventilation implementation.

- Study the value of utilizing networked controllers or web based thermostats for remote monitoring to aid in achieving persistent RTU savings.
- Review available technology to see if there are additional manufacturers who have products suitable for the premium ventilation sequence.
- Standardize savings estimates. Premium Ventilation savings could be incorporated into the DCV savings calculator tool. (Hart & Falletta 2012).
- Conduct analysis and field tests to verify operation of demand control during warm-up for electric heat, summer peak demand limiting, and night flush. Select a site with greater internal load to verify the value of these additional extended sequences.
- Develop training materials and an application guide to aid in training the first group of contractors.
- Train contractors to implement the Premium Ventilation measures.

A pilot or soft program launch could create the infrastructure for a potential full-scale program offered to BPA commercial customers, while providing the opportunity to work on the steps listed above.

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