Premium Ventilation Package Testing

Pre-Installation Report – Task 5

Final Submittal

August 29, 2008

Prepared by: Reid Hart, PE

Delivered via electronic copy to BPA and partners.

Contract No. 00038702
RTU AirCarePlus & Premium Ventilation Program

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Project Overview

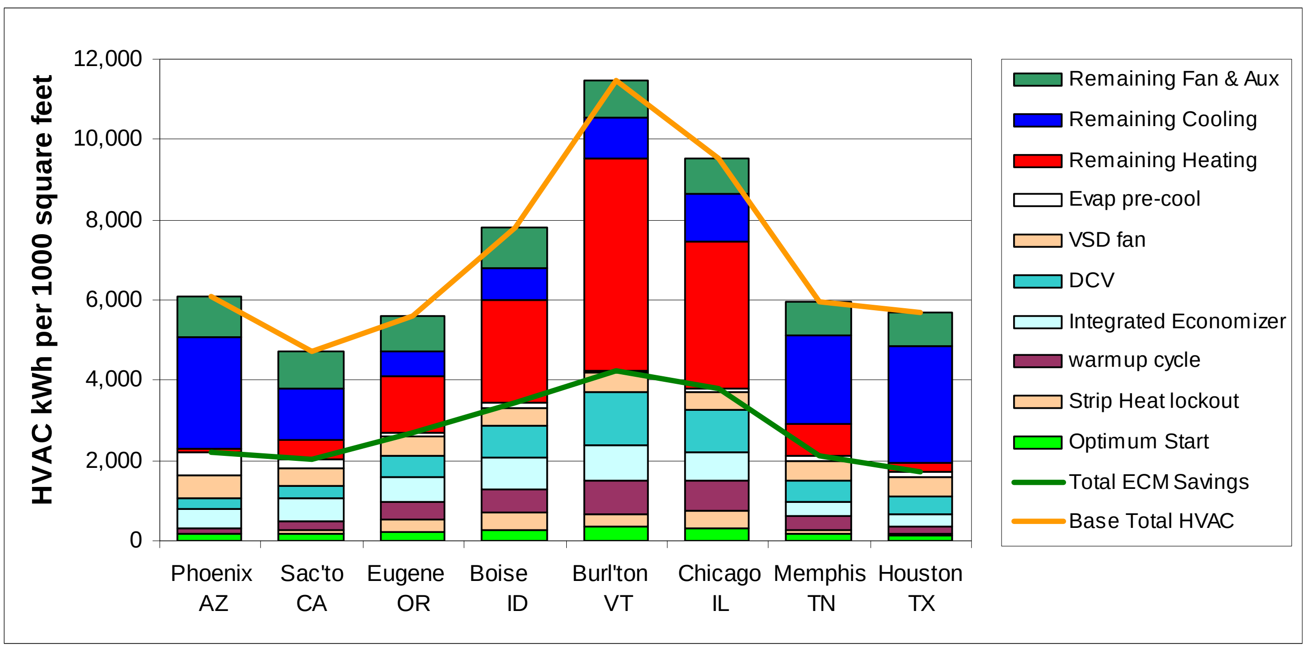
The purpose of this project is to conduct a field test of a premium ventilation package for rooftop packaged units. That package will include the following measures:

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

Cost Effectiveness

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

Rooftop Unit Savings in Representative Climates



Based on the previous analysis by EWEB for the Premium Ventilation Package (excluding the evaporative pre-cooling of the condenser), for climates of interest we find the following expected results:

- A preliminary cost for the total package is around $2,200. This engineering estimate will be significantly improved through actual bids and contractor feedback in the test project.
- This compares favorably with the cost of putting in individual measures at $3,430. The package allows cost savings due to more effective use of contractor time on the roof and with synergies where one measure provides the impact of another.

- The savings and cost projections for the package result in a simple payback of 8 to 10 years, reduced to close to 5 years from the customer view when typical incentives are considered.

Since this initial work by EWEB, two significant changes in approach are anticipated when undertaking further analysis:

- The variable fan flow was originally modeled using standard code words that simulate a load-based variable flow approach that is different from actual operation. Sideline calculations were completed in that analysis to ensure reasonable results; however, further research has shown that more specific DOE2 code words are available to simulate the actual operation of the simplified variable speed controllers employed in packaged rooftop units. These will be applied in future analysis efforts.
- The base case taken for analysis was no economizer. While some standard economizer implementations are very low in realized savings, future analysis will produce more accurate portfolio results if they look at the anticipated frequency of different base conditions extrapolated from the field tests available in the literature.

Testing Project Scope & Schedule

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

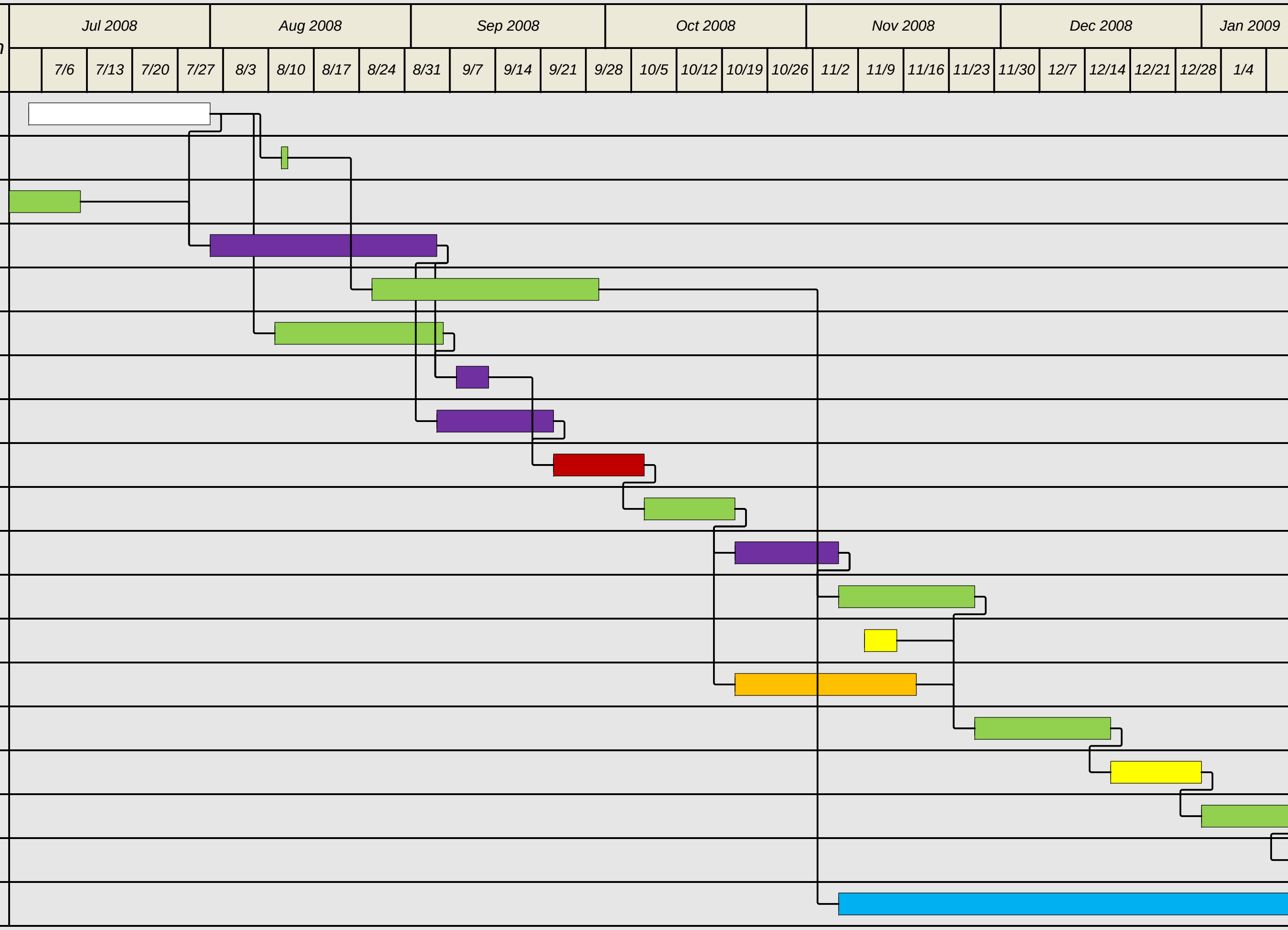
1. **Field Test**. In one western Oregon location, test about 6 units in the field, including gas, heat pump, heating, retrofit, and new units. Monitor and analyze operation, develop specification, costs, and preliminary savings projections. Develop evaluation plan and scope for expanded testing.
2. **Field & Lab Evaluation**. Test a larger sample of treated and control units in both a western and an eastern Pacific Northwest climate (other climates if additional partners are recruited). Complete lab testing of a typical unit with and without the package of measures to establish operation under a range of conditions. Develop preliminary deemed savings for four to eight commercial proxy types. Develop a pilot program with acceptance testing and simplified test protocol for Phase 3 testing.
3. **Pilot Program Deployment.** In a broad range of climates (depending on partners recruited), deploy simplified field testing in conjunction with a pilot program for retrofit units, new units, and control units. Collect and analyze full year data.

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

- Portland Energy Conservation, Inc. (PECI)
- Bonneville Power Administration (BPA)
- Energy Trust of Oregon (ETO)
- Eugene Water & Electric Board (EWEB)
- Northwest Power and Conservation Council (NPCC)
- Other interested parties, primarily participants in the NW Regional Technical Forum Rooftop Economizer Committee and other potential participants in Phases 2 & 3.

The schedule for Phase 1, except for the extended data collection and analysis task, is shown on the next page.

ID	Task Name	Duration
1	Develop Scope & Contract	4w
2	5a: Review Scope	.2w
3	5b: Recruitment Guidance	1.8w
4	5b: Recruit Units & Contractors	5w
5	5c: Decision Framework Matrix	5w
6	5d:Spec & Monitoring Plan	4w
7	Contractor Bids	1w
8	Pre-Monitoring	2.4w
9	Installation	2w
10	6e: Functional Review; Troubleshoot	2w
11	Post-Monitoiring	2.4w
12	7f: Data Analysis/ ST field test report	3w
13	RTF Economizer Protocol (NBI)	1w
14	Phase 2 Evaluation Plan Development	4w
15	7gh: Draft Report, Phase 2 Scope	3w
16	7i: “Big Tent” Phase 2 Scope Review	2w
17	7j: Final Report & RTF presentation	2w
18	7k: Phase 2 Study Recruit Partners	4w
19	8l: Phase 1B extended monitoring	52w



Note: Plan as shown is optimistic with a 50% chance of hitting target dates; final execution will likely include delays between tasks due to number of parties involved.

Deliverable Schedule

Lead Premium Ventilation Package research work

a) Pre-Installation Report - due on or before September 1, 2008.

b) Provide Decision Framework matrix for one location - due on or before October 1, 2008.

c) Short-term Field Test Report - due on or before December 1,2008.

d) Provide Phase 2 Scope Draft Report, including Scope, Monitoring Plan and Evaluation Plan - due on or before September 1, 2008. [Should be Jan 1, 2009]

e) Present Final Phase 2 Scope to RTF - due at January or February 2009 RTF meeting.

f) Recruit phase 2 partners and provide a report detailing parties contacted and response of each party due on or before May 1, 2009.

g) Provide Extended Field Test Report - due within 45 days after completion of one calendar year of metering data is collected, or by December 1, 2009 at the latest.

Task Lead

- BPA
- PECI
- EWEB
- ETO
- NWPCC
- Contr

Rooftop Vent Package Phase 1 Field Test

PECI	8/11/2008

Rooftop Ventilation Package:

- Premium Economizer
- VSD Fan Control
- Demand Controlled Ventilation DCV (provides OSA setting & warmup lockout)
- Optimum Start
- Strip Heat Lockout (HP)

Recruitment Guidance

Delivered July 7, 2007 & reviewed with EWEB August 12, 2007

Recruitment of units in EWEB service territory:

For the purposes of a field test of the Premium Ventilation Package, we are looking for up to 6 units. It is preferable if the units are at one or two sites (for the purposes of long term monitoring that requires a separate data collection computer). The field test will focus on getting the units operational and verify savings on a mode basis at a gross level.

Short term monitoring with be:
2-3 weeks prior to installation
2-3 weeks after installation (with a check at 24-48 hours to verify proper operation)

We are looking for the following units for upgrade:
2-gas heat/AC retrofits,
2-heat pump retrofits,
2-units for replacement with new units, one gas heat, one heat pump if possible

The following are desirable qualities for all the rooftop units to be upgraded or replaced:

- Equipped with outside air economizer
- Equipped with barometric relief dampers
- Honeywell economizer controllers for the retrofit units
- Unit size from 3 to 10 tons
- Significant cooling load and operating hours in zones served by unit.

Monitoring points will be similar to the earlier Western Premium Economizer testing with the following minimum points for each unit:
Supply Air Temperature, degrees F
Return Air Temperature, degrees F
Total unit power, Watts (include power supply to fan and compressor)
Cooling Thermostat Call, volts (0-24 VAC), (Usually yellow to blue or ground)

There will be additional points at each site, and possibly at each unit, to be determined during the pre-installation phase of the project.

At startup we will want to measure the following:
Actual power vs. current for each operating mode
Total unit airflow using flow plates for each operating mode
Outside & total airflow at OSA dampers closed, minimum, open

Meeting: Rooftop Premium Ventilation Package Field Test Kickoff Meeting
Date: August 12, 2008, via teleconference

Attendees:
Jack Callahan, BPA
Nick O'Neil, ETO
Charlie Grist, NPCC/RTF
Will Price, EWEB
Chris Wolgamott, EWEB
Reid Hart, PECI
Karen Des, PECI
Francisco Gadea, PECI
Kathy Hile, PECI

Unavailable:
Mira Vowles, BPA
Fred Gordon, ETO
Bob Lorenzen, EWEB

Meeting Notes:
Reid Hart reviewed the schedule for the project that was sent out before the meeting.

- The objective is to field test a premium ventilation package for rooftop units. The package is expected to save three times the energy of a premium economizer. Retrofits of gas furnace & air conditioning and heat pump units will be tested, and if available new unit replacements will be tested up to a total of 6 units.
- A draft testing plan and specification will be issued this week, with the deadline for the final the end of August.
- Recruitment is underway, and the goal is to complete the short-term testing by early November with a draft analysis report in early December.
- The report and phase 2 testing plan will be reviewed by the RTF economizer committee in December.
- Extended monitoring will continue through summer and possibly early fall of 2009.
- Partners will be sought for phase 2 testing in early 2009.

The scope and partnership arrangements were also reviewed per the scope document sent out before the meeting.

- EWEB and ETO will coordinate on mutual funding and internal purchasing arrangements to cover installation costs of the prototype measures.
- EWEB wanted to know if ETO required bids for the contractor services, and Nick indicated he would check with Fred.
- Jack indicated that BPA will be able to purchase the final long term monitoring equipment in time to be used for the short term monitoring.

In discussion the following comments were made:

- Jack indicated that a good monitoring plan will be important. He was not available to review before the draft went out, but will review with Reid before the plan is finalized. He wanted Tim Steele included. Once feedback is received, a phone conference including Reid, Jack, Tim, Will, and Nick will convene to finalize the monitoring plan.
- Charlie would like to have key members of the economizer subcommittee copied on the meetings and draft testing plan, including Bob Davis at Ecotope, Dave Robison at Stelar, and Mark Cherniack at NBI.
- Concerns were expressed about capturing the heating situation during the short pre-period. Reid indicated that the purpose of testing was to determine functionality, and full energy savings analysis would follow the long-term testing.
- Charlie asked if the new Honeywell selectable sensor will be used, and Reid indicated that Honeywell had committed to providing 6 prototypes.
- Since it will likely not be possible to get replacement units coordinated in time for the fall testing–as this project will not cover the full cost—those units would be delayed until a replacement was in play, with the four retrofit units getting started for this fall.

Monitoring Plan

The monitoring plan outlines the purpose and approach to monitoring the units included in the premium ventilation package field test.

Purpose of Monitoring

This is an initial field test designed to verify operation of a package of available technology. The sample size is too small to make meaningful projections of overall energy savings. There are five purposes of this field testing:

- To make sure the components work together and function with the expected sequence of operation.
- To verify reduced power due to fan speed reduction with specialized package unit VSD's.
- To collect more data on typical unit airflows, and verify the minimum airflow provided by damper leakage.
- To generate preliminary projections of potential savings - from the longer term testing, enough experience in various weather conditions will be accumulated so the results can be combined with either bin or hourly simulation.
- To collect enough data to determine the relative percentage of cooling load provided by the economizer versus mechanical cooling.

Equipment to be Monitored

For the purposes of a field test of the Premium Ventilation Package, we are looking for up to 6 units. It is preferable if the units are at one or two sites (for the purposes of long term monitoring that requires a separate data collection computer). The field test will focus on making the units operational and verifying savings on a mode basis at a gross level.

We are looking for six packaged rooftop air conditioning units with 3 to 10 tons of cooling and the following characteristics for upgrade:

- 2-gas heat/AC retrofits,
- 2 -heat pump retrofits,
- 1-unit for replacement with new unit, OR one unit to be controlled by DDC
- 1-unit for replacement with new unit, gas heat

Installation	**Heating**	**VSD**	**Economizer**
Retrofit	Gas Furnace	ICM	Hny W7212
Retrofit	Gas Furnace	Fan Handler	Hny W7212
Retrofit	Heat Pump	ICM	Hny W7212
Retrofit	Heat Pump	Fan Handler	Hny W7212
Retrofit	Any	TBD	DDC
New	Any	Factory	Factory

The following are desirable qualities for all the rooftop units to be upgraded or replaced:

- Equipped with outside air economizer
- Equipped with barometric relief dampers
- Honeywell economizer controllers for the retrofit units except for the DDC unit
- Unit size from 3 to 10 tons
- Significant cooling load and operating hours in zones served by unit

Monitoring Points

Monitoring points will be similar to the earlier Western Premium Economizer testing.
The following points are required for each unit:

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

Site points—monitor the following at each site:

7. For one space, with moderate occupancy: Separate CO_2 sensors could be monitored to compare readings in the different locations. (on micro-data logger) place sensors in
    a. the return duct
    b. the room at 60-inches high near the diffuser
    c. the room at 60-inches high far from the diffuser
8. Outside air temperature to be measured near the hood intake, but outside the hood with a radiation shield.
9. Outside humidity or wet-bulb temperature.

The following optional unit points can be added, although they are not required for the planned analysis:

10. Mixed air – as this is difficult to measure accurately, 2-3 points degrees F & RH should be recorded or a series parallel averaging sensor be made up of 9 or 16 thermistors.
11. Relative air flow – again, a difficult item to measure in packaged units. A hot-wire anemometer in the discharge ductwork could be used and calibrated to startup flow measurements. Dedided not to monitor this.
12. Outside air temperature inside the hood where the economizer outside air sensor is located.

Monitoring Equipment

Monitoring equipment will be provided by BPA and EWEB. BPA's current plan is to provide HOBO data loggers, manufactured by AEC, with remote cell phone communication capability and a database which will be set up to capture information.

Sensor Type		Sensor Location		
Required Sensors Per Unit & Site				
	Per Unit		For 4 units	For 6 Units
Temp DB/RH	2	Return Air (RA), Supply Air (SA)	8	12
Watts	2	Fan, Total or Compressor	8	12
0-24 VAC	1	First Stage Cool Thermostat Call	4	6
0-10 VDC	1	CO2 Sensor	4	6
	Per Site		For 2 sites	For 4 Sites
Temp DB/RH	1	Outside Air with radiation shield	2	4
Special Ventilation Monitoring for One Unit				
	One Zone			

CO2	3	Duct, Space near diffuser, Space distant from diffuser	3	
Optional Monitoring per Unit				
Mixed Air Temp DB/RH	3	3 points adjacent to coil	12	18

Planned Analysis

To put the monitoring in context, the planned monitoring will be focused on determining the relative energy impact of each mode.

- The data will be analyzed to determine when the units operate in cooling or economizer modes. The average weekday operation by mode[1] for the pre and post period will be determined.
- The share of total sensible cooling (on a degree-hour[2] basis) provided by the economizer[3] will be determined. This approach will provide a good indicator of savings difference from the economizer upgrade. Application to a situation with an upgrade from no economizer to an economizer will require the ventilation related cooling to be calculated and subtracted from the base and improved case.
- Total unit power in the different modes will be determined relative to differential temperature and outside air temperature.
- Humidity impacts will be reviewed for the pre- and post-period to verify that latent impacts are similar.

[1] Economizer cooling will be only credited when the thermostat calls for cooling. Ventilation cooling effect will be separately calculated since it will vary based on ventilation air minimum settings and would be provided by a unit without an economizer.

[2] Sensible cooling degree hours are calculated each minute as (RA – DA)/60 then summed for the mode period analyzed.

[3] Economizer share (%) of cooling degree hours will be used for comparison, as it is independent of cooling loads, unit size, or hours of cooling operation. The percentage share of economizer cooling is the economizer cooling provided compared to the sum of economizer and mechanical cooling. A larger "economizer share of sensible cooling" indicates more savings.

Preliminary Decision Framework Matrix

Note, to expedite specification delivery the decision framework matrix will be developed as a separate deliverable. It will contain:

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

Retrofit Specifications and Sequence

Premium Ventilation Package Outline Specifications

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

- Fully modulating damper motor
- Proportional damper control
- Coordinated control
- Relief air and return air damper

Western Premium OSA Economizer Requirements

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

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

Premium Ventilation Package Requirements

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

- Return air and outside air dampers have low-leakage seals (experiments will be held for retrofit seals using foam weather stripping)
- Demand controlled ventilation via CO_2 sensor
- Variable speed fan control

Typical Equipment Requirements

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

- Replace economizer controller with Honeywell W7212A
- Equip with outside air selectable temperature sensor C7660 (the C7600 selectable sensor is not yet available through normal distribution channels; Honeywell will provide sensors for this test)
- Solar radiation shield for OSA sensor: Ambient Weather SRS100LX Temperature and Humidity Solar Radiation Shield; Davis 7714 - Passive Radiation Shield (may require modification); or equal.
- Either replace M7415 actuator motor with M7215 OR use Q769C adaptor with separate 24VAC transformer.
- Upgrade thermostat to a programmable thermostat with optimum start, 7-day programming, and one more stage of cooling control than the number of stages in the rooftop unit.
- Replace thermostat wiring if necessary.

- Provide, install and wire CO_2 sensor with 0 to 10 VDC output; Honeywell C7242, AirTest eSENSE 9290-L or 9291, BAPI BA/AQS-D-10 or BA/AQS-R-10 or equal.
- Provide, install and wire VSD fan drive with integrated control and sensors ICM CC750, Fan Handler FAC-120/240 or equal.
- In some cases a VSD motor combination will result in excess noise and the motor will need replacement. Baldor (among others) makes specially designed blower motors for speed control applications ranging from ¼ HP to 1 HP size, equipped with ball bearings, electrically reversible, 48 frame, 1075 rpm, 3-speed, 50° rise.
- Install foam weather stripping seals on damper blade edges if seals not present.
- Check out and acceptance test unit with engineer present, including operating controls to allow measurement of air flow rates using either flow measuring equipment or temperature sensors with the following measurements:

OSA damper	**Heat**	**Cool**	**Deadband**
Fully open	Sysem cfm & OSA cfm	Sysem cfm & OSA cfm	Sysem cfm & OSA cfm
Minimum position	Sysem cfm & OSA cfm	Sysem cfm & OSA cfm	Sysem cfm & OSA cfm
Fully closed	Sysem cfm & OSA cfm	Sysem cfm & OSA cfm	Sysem cfm & OSA cfm

Recommended Settings

- Schedule: match business hours
- Heating Temperature setpoint: 70°F occupied; 60°F unoccupied.
- Cooling temperature setpoint: 76°F occupied; 80°F unoccupied.
- Outside air changeover for economizer: 73 °F if not differential
- Outside air minimum: _____(varies by building type) cfm/square foot – see ASHARE Standard 62—note that this minimum airflow may be met with damper leakage in the closed position.
- Demand controlled ventilation activation point: 1000 parts per million CO_2.

Requirement Discussion

Fundamental Requirements. There are several fundamental requirements:

- **Fully modulating damper motor.** A fully modulating damper motor is necessary to allow proper mixed air temperature control and for the economizer to operate the most hours possible. The motor modulates to any position necessary to maintain the discharge air or mixed air temperature around 55°F. Three-position or staged damper motors are available that do not meet this requirement. Modulating motors that operate in conjunction with micro-switches at set damper positions or controls that rely on a low (about 40°F) outside air lockout for the economizer do not qualify.
- **Proportional damper control.** An analog sensor must be located in either the mixed air or discharge air to control the modulating dampers. The sensor must be connected to an appropriate mixed air or economizer controller to provide proportional control of the mixed air dampers. PI or PID controls are allowed.
- **Coordinated control.** The economizer needs to be wired so it is only active when there is a call for cooling. On larger systems serving multiple zones, the economizer should coordinate with the discharge air or primary air temperature control. When a heat pump is involved, a relay needs to be provided with any separate economizer controller, so that the economizer is activated only when cooling is called for.
- **Relief air and return air damper**. To qualify for a rebate, EWEB requires a modulating return air damper and a method to relieve exhaust air from the building. Otherwise, higher

percentages of outside air will pressurize the building: doors may stand open and the economizer will not be able to do its job. Relief air can be provided with a barometric damper in the return air duct before the return air damper, a motorized exhaust air damper, or a powered relief/exhaust fan that is activated when the economizer reaches about 50-70% open.

- **Documented checkout**. For rebates, EWEB requires that the installer complete the “supplemental economizer information” sheet for each economizer installed and fully check out operation at the time of installation. The supplemental economizer information sheets are available from EWEB. Be sure to use the current (April 2004) version. Note that the documentation for a basic economizer has fewer requirements than the documentation for a *Western Premium Economizer*.

Western Premium Economizer. In addition to the fundamental requirements, *Western Premium Economizers* have these requirements:

- **Dedicated thermostat stage for economizer.** To get the most benefit, the economizer needs to provide cooling first, before the cooling compressor is engaged. This requires a separate thermostat cooling stage for the economizer. A premium economizer requires a thermostat with at least two stages of cooling control properly wired to the economizer controls. When there are two stages of compressor cooling, it is acceptable to set up the economizer so that only one compressor stage operates when the economizer is active, and both stages are available when the changeover has activated. Some manual heat pump thermostats may appear to have two stages of cooling, when actually the first stage is for the reversing valve; these thermostats need to be replaced.
- **Differential changeover.** Most controllers have differential logic built in; it just takes the addition of a dry-bulb return air sensor to get more savings from economizer changeover. A differential changeover allows the economizer to operate whenever outside air is colder than return air. This is called an “integrated” economizer, since the economizer cooling is integrated with the compressor cooling. Another advantage of integrated differential control is that there is no confusion about where to set the changeover and there will be fewer comfort callbacks for contractors. A premium economizer requires both return air and outside air dry-bulb sensors. For differential changeover, the changeover selector is set to the “D” position. Snap-disc temperature sensors for changeover do not qualify. Snap discs need to be removed and replaced with two analog sensors. For Honeywell analog controllers, single outside changeover with the selectable C7660 sensor shall meet requirements. The changeover temperature should be typically set at 68^{o}F or 73^{o}F or 2^{o}F to 4^{o}F below the expected cooling temperature setpoint. Because fan speed is reduced when the economizer is not operating, the outside air should be a few degrees below room temperature when the economizer is activated.[4]
- **Dry-bulb changeover.** Many manufacturers recommend enthalpy sensors for changeover control and refer to a differential enthalpy control as a premium economizer. In our western climate, we rarely experience high humidity near changeover temperatures. There is no additional advantage to the enthalpy sensors. Enthalpy sensors are more expensive and less reliable. For upgrades, if an existing outside air sensor is the enthalpy type, then replace it with a dry-bulb sensor when installing the return air dry-bulb sensor. Because enthalpy sensors easily go out of calibration and are less reliable, they do not meet our *Western Premium* requirements except by pre-approval for humidity sensitive spaces such as bowling alleys with wood floors.
- **Primary control placement.** Determine the type of cooling you have and make sure the primary (or low-limit) sensor is in the right location.

[4] Research by Honeywell in the ASHRAE HVAC&R Research showed that fan energy was offset when the temperature difference was 5^{o}F or more.

- o With a direct-expansion (DX) cooling coil (no chiller) you can get coil freezing problems and very cold discharge air if the primary control sensor is in the mixed air position and differential changeover is used. With a DX coil, the primary controller should be located after the cooling coil, either between the coil and fan or in the discharge air position in the supply air duct after the fan.
- o If you have a chiller and a chilled-water coil, it is appropriate to have the primary control sensor in the mixed air position, before the cooling coil. Mixed air is often stratified and difficult to measure so an averaging sensor or multiple sensors should be used. If the primary sensor is after the cooling coil, you are missing some energy savings.

- **Low-ambient OSA compressor lockout.** This control stops the compressor from operating when the outside air is below setpoint (55^{o}F to 60^{o}F recommended, 50^{o}F minimum). Below this temperature, the economizer can handle the full cooling load. Many economizers will fail due to mechanical damper wear or improper control operation. The failure often goes undetected. With the low-ambient compressor lock out, an economizer failure may result in a high temperature comfort complaint and service request so the economizer is more likely to get needed service. Some manufacturers provide low-ambient compressor lock-outs at 35^{o}F to 40^{o}F, but they do not meet EWEB's requirements.
- **Minimum airflow.** Without adequate airflow, economizers cannot deliver adequate cooling and both DX cooling efficiency and comfort suffer. The cooling coil split temperature in full cooling must be less than 25^{O}F, indicating that airflow is adequate.

Premium Ventilation Package Requirements. In addition to the *Western Premium Economizer* requirements, the Premium Ventilation Package requires these items:

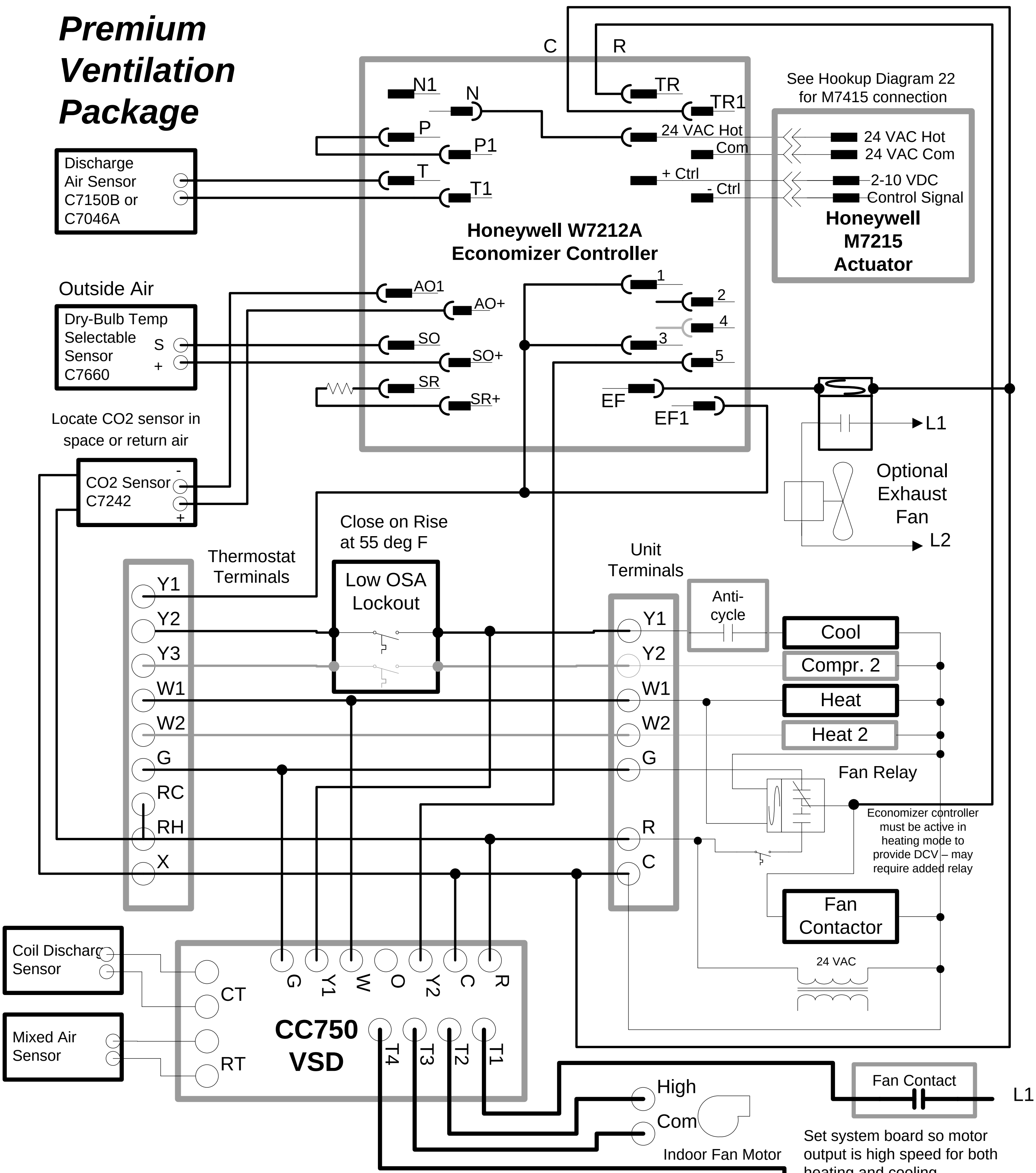
- **Fan variable speed drive.** Incorporating a speed control for the supply fan will save significant energy. In most western climates, the fan uses one third the energy of the rooftop package unit due to the requirement that it continue operating to provide ventilation when the building is occupied.
- **Demand controlled ventilation.** Improve the control of minimum ventilation air with a controller and CO_2 sensor to regulate the amount of minimum ventilation air depending on the number of people in the space.
- **Programmable thermostat.** Getting automatic setback of temperatures and fan control can save significant energy. When a thermostat is upgraded to provide the staging needed for a premium economizer, replacement with a programmable thermostat makes sense. In addition, it is important to set up the optimum start control and make sure the schedule is optimized to match actual occupancy.

Retrofit Hookup Diagrams

Hookup Diagram Index

Hookup Diagram	Unit Type	Thermostat	Econo Controller	VSD Controller	Other Controls	Min OSA Activation	Actuator	Comments
21	Gas/Cool	Mech/Pgm	W7212 (W7215)	ICM CC750	Anti-cycle	Demand Controlled Ventilation (DCV)	M7215	Exhaust/ Relief Fan
22	Gas/Cool	Mech/Pgm	W7212 (W7215)	Fan Handler FAC	Post Purge	Demand Controlled Ventilation (DCV)	M7415	Need two transformers
23	Heat Pump	Mech/Pgm	W7214	ICM CC750		Demand Controlled Ventilation (DCV)	M7215	

For Heat Pump and Fan Handler, consult both diagrams 22 and 23.



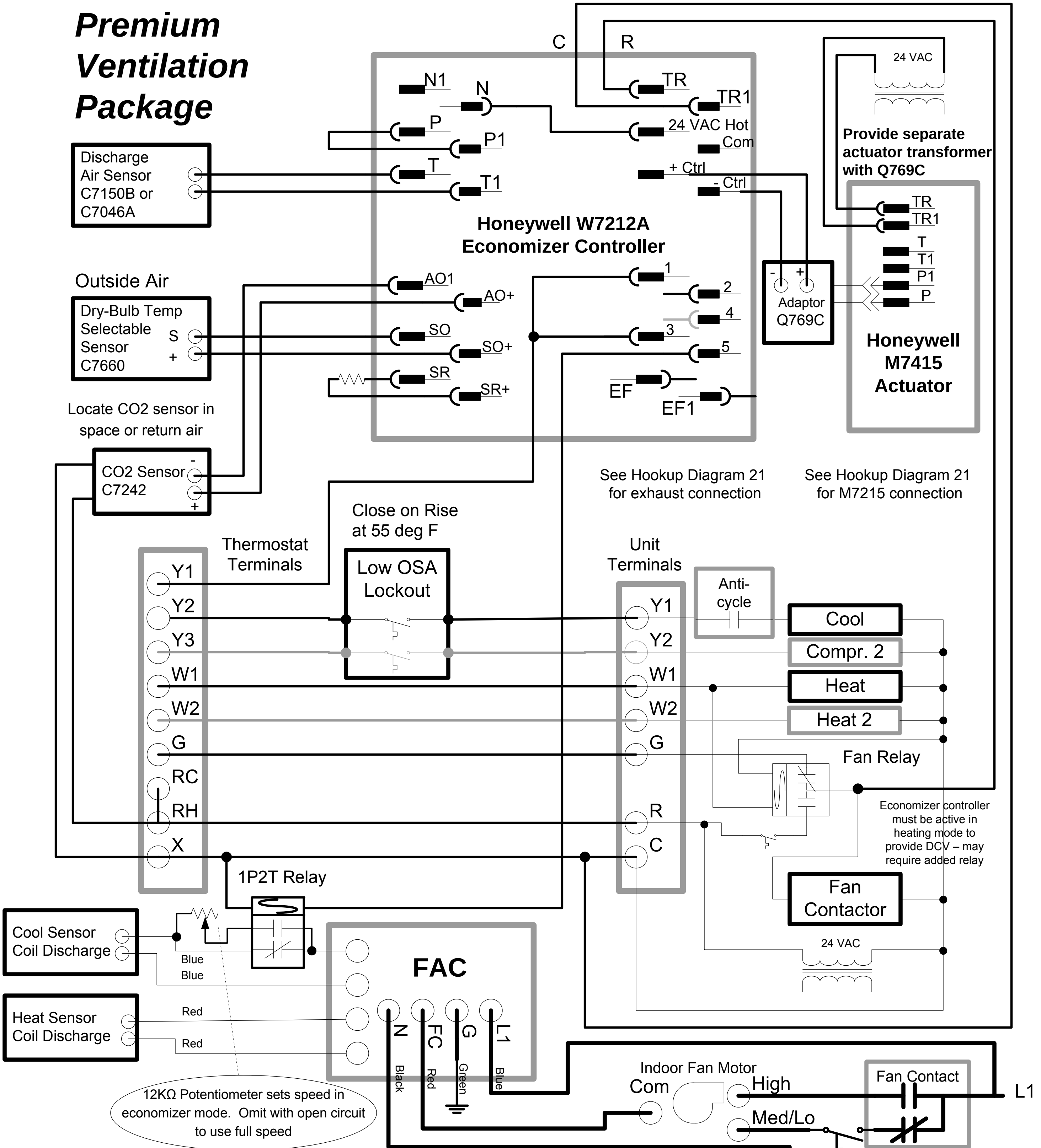
Hookup 21: Gas Furnace/AC – ICM CC750 – Honeywell W7212A

W7212A Economizer Controller with 2-stage Thermostat, ICM VSD, Demand Ventilation (DCV) Low-Ambient Compressor Lockout, and Dry-Bulb Set Switch Changeover

PECI provides suggested wiring for education only. Installer and customer to determine suitability for specific products and application. 8/2008

PECI (Hart) 503-961-6142

Premium Ventilation Package



Hookup 22: Gas Furnace/AC – Fan Handler – Honeywell W7212A

W7212A Economizer Controller with 2-stage Thermostat, FH VSD, Demand Ventilation (DCV) Low-Ambient Compressor Lockout, and Dry-Bulb Set Switch Changeover

PECI provides suggested wiring for education only. Installer and customer to determine suitability for specific products and application. 8/2008

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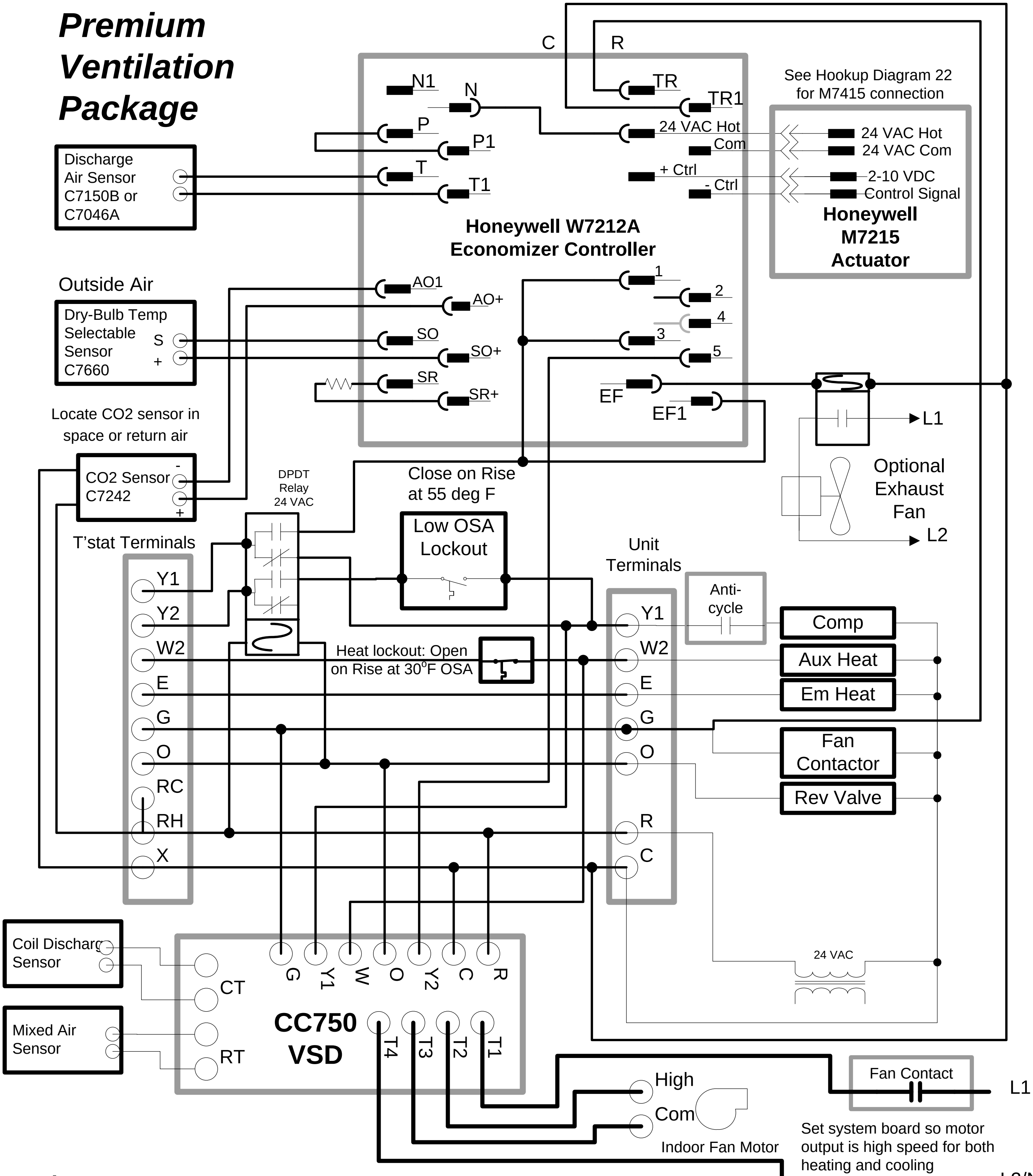
Premium Ventilation Package



Hookup 23: One Stage Heat Pump – ICM CC750

Honeywell W7212A Economizer Controller with
2-stage Thermostat, ICM VSD,
Demand Ventilation (DCV),
Low-Ambient Compressor Lockout, and
Dry-Bulb Set Switch Changeover

Requires 2-stage HP thermostat. "Normally heating" reversing valve shown. For "B" (normally-cooling reversing valve), reverse contact positions shown in relay.

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New Unit Specifications and Sequence

Note, to expedite retrofit specification delivery the new unit specification and sequence will be developed as a separate deliverable.

The new unit specification is in development. At this point several units have been identified that meet the specification. In many cases variable speed fans are more available on residential units, and we are working with contractors in the Eugene area to determine what specific units meet the combination of requirements in the Premium Ventilation Package.

Sequence for Direct Digital Control (DDC) Applications

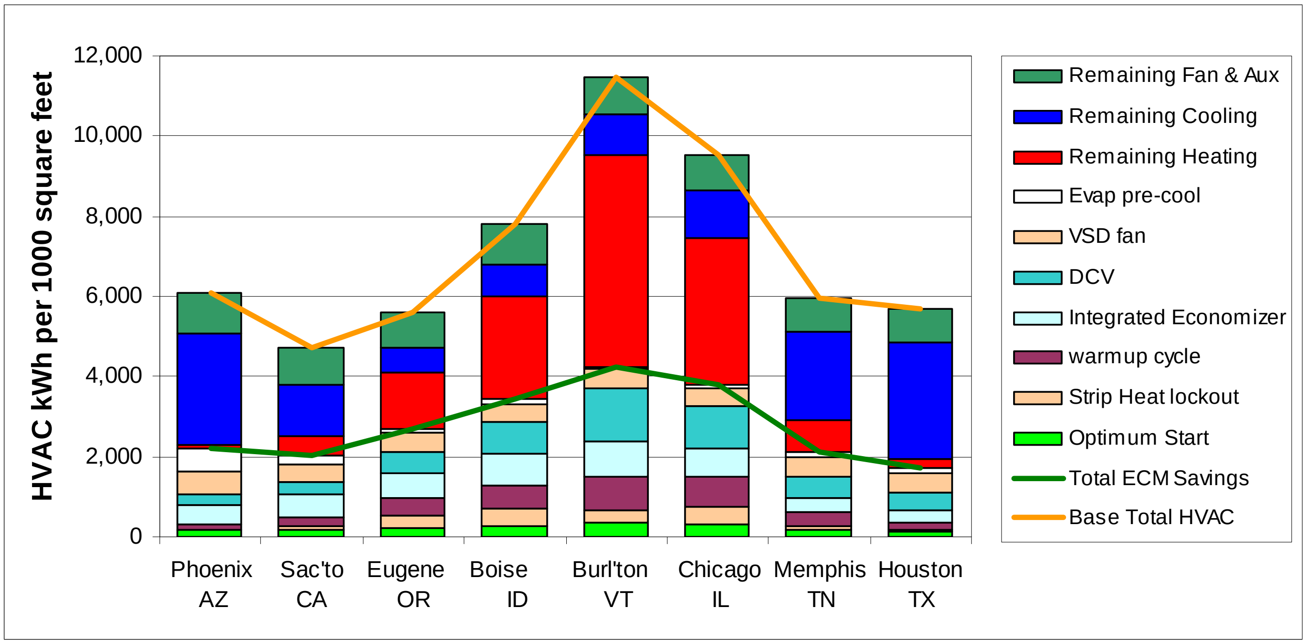
Note, to expedite retrofit specification delivery the DDC sequence will be developed as a separate deliverable. A rough draft was included in the draft pre-installation report.

Summary of prior EWEB simulation work

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

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

Rooftop Unit Savings in Representative Climates



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

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

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

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

Unrecognized Technologies Old & New

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

Table 1. Technologies Considered

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

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

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

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

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

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

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

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

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

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

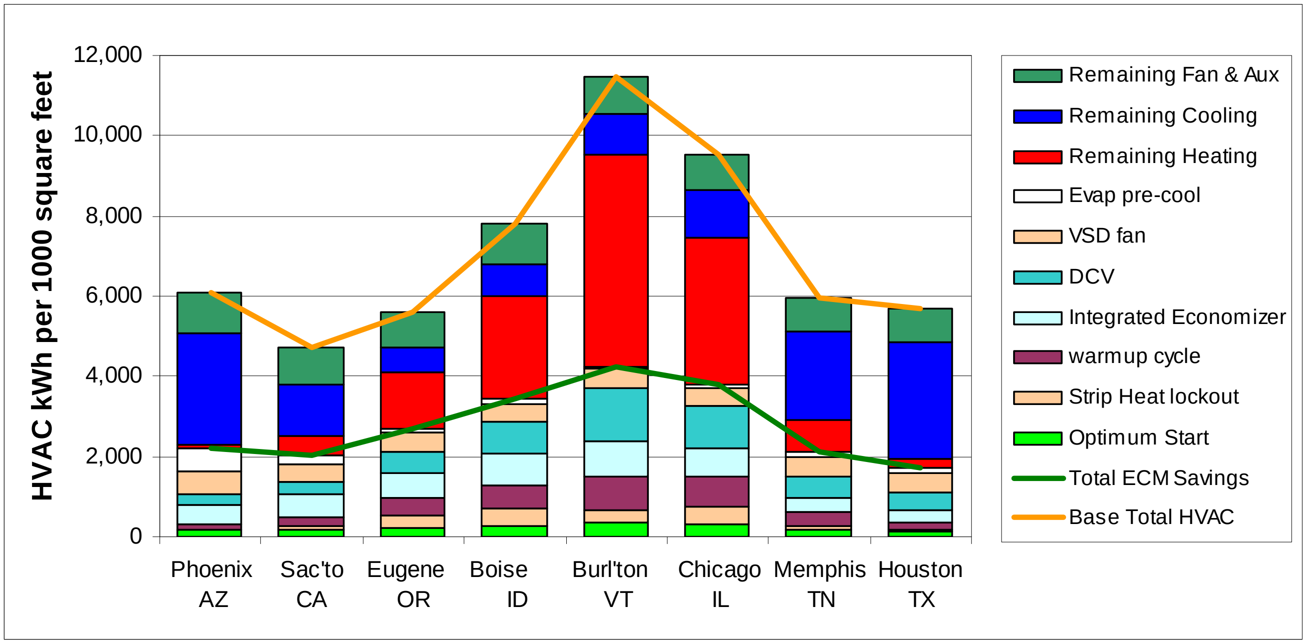
Premium Ventilation Rooftop Package Potential Savings

Measure items included:

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

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

Figure 6: Rooftop Unit Savings in Representative Climates



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

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

Table 2. Overall Package Measure Results & Climate Zone Information

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

Cost Effectiveness and Premium Ventilation Package

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

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

Table 5. Measure Savings, Cost & Simple Payback

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

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

Initial opinion of probable cost

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

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

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

Table 3: Measure Parameters and Potential Non-Interactive Savings

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

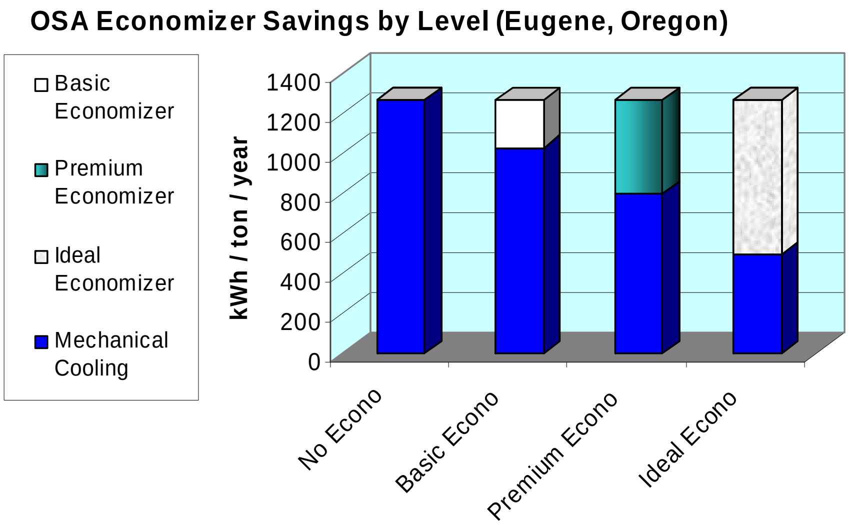
VSD fan control for smaller rooftop packaged units.	Fan “ON” during occupied	Supply airflow reduced to 30% when heating or cooling not required; 15 cfm/person ventilation maintained	667.1
Evaporative assist condenser pre-cooling.	Air cooled evaporator at ambient dry-bulb	DOE2 standard measure, condenser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

Table 4: Non-interactive Measure Savings by Climate

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

Western Premium Economizer Background

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



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

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

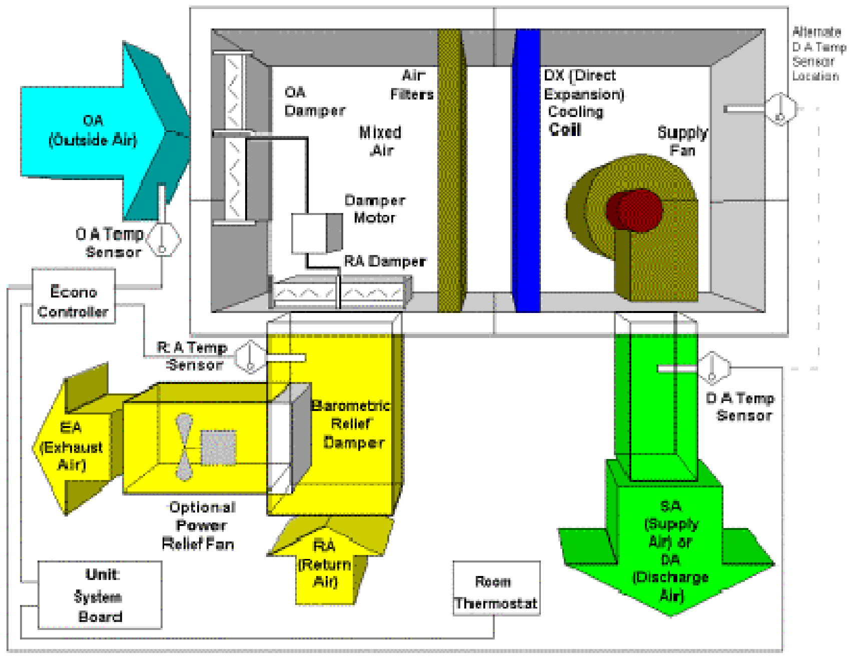
- Economizer configuration: How many dampers and what can they do?
- Economizer activation: When does the economizer come on?
- OSA high limit or "changeover" sequence: When is it too hot to economize?
- Level of Integration: Does mechanical cooling work together with free cooling?
- Minimum ventilation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

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

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

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

Packaged Unit (DX cooling) Outside Air Economizer



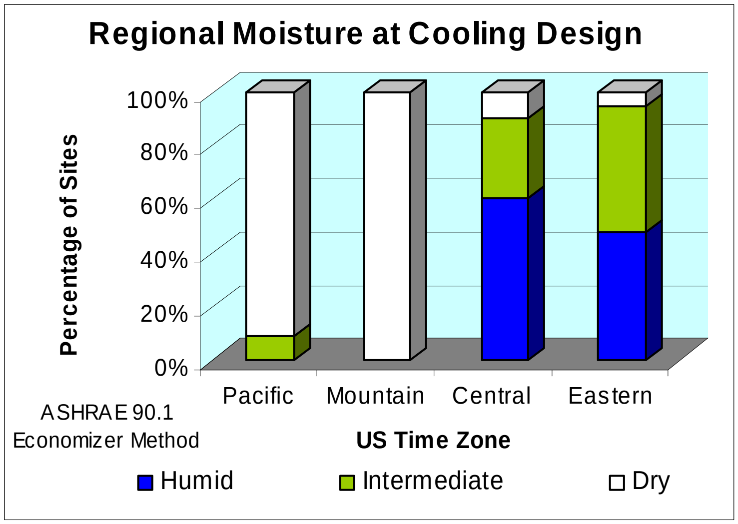
2. Economizer activation includes how or if the economizer operation is interlocked with cooling call. The basic question is: When does the economizer turn on? Activation of the economizer can be:

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

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

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

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

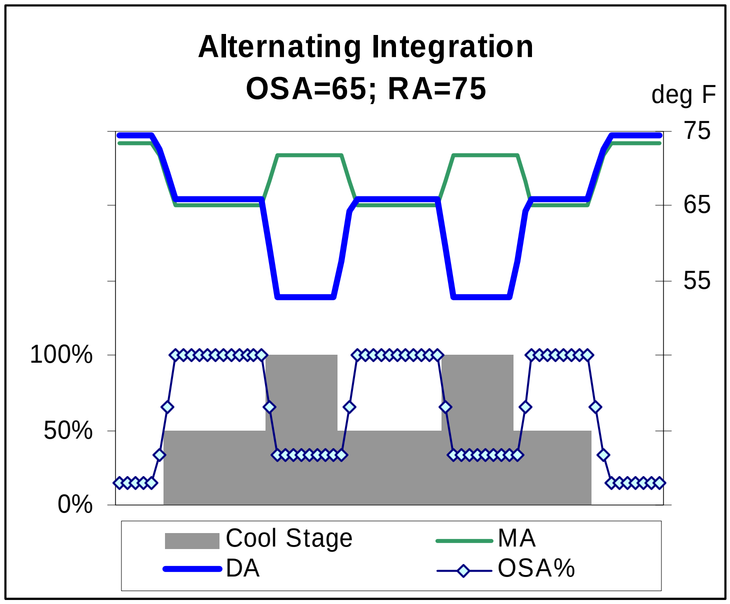


The mode of control can be a single (OSA only) fixed (snap disc) sensor for dry-bulb, a single (OSA only) adjustable (analog) sensor for either sensor type, or a set of differential or comparative (OSA vs. RA) sensors. A differential changeover uses outside air until it is warmer or contains more energy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

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

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

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



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

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

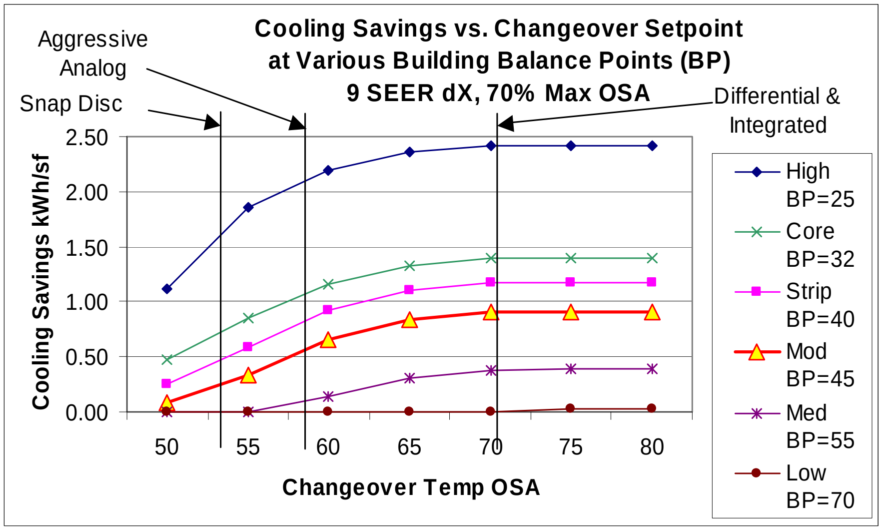
- Estimated by observed damper position
- Estimated by temperature measurement
- Flow measured with flow plate, velometer, or duct traverse
- Varied with demand controlled ventilation by CO_2 sensor

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

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

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

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



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

Preliminary Acceptance Testing Checklist

During the field check out of the prototype installations, the goal will be to use existing checklists in an acceptance procedure, and develop how these checklists should be modified for future use with this measure. The developed checklists will be delivered along with the short-term monitoring report.

Sample sources of similar acceptance checklists and procedures are attached on the following pages.

2005 ACCEPTANCE REQUIREMENTS FOR CODE COMPLIANCE

Economizer Acceptance Document — MECH-4-A

NJ.7.1 — **Form __ of __**

PROJECT NAME		DATE
PROJECT ADDRESS		
TESTING AUTHORITY	TELEPHONE	
AIR ECONOMIZER NAME / DESIGNATION		Checked by/Date Enforcement Agency Use

Intent: Verify that an HVAC system uses outside air to satisfy space cooling loads when outside air conditions are acceptable.

Construction Inspection

1 Instrumentation to perform test includes, but not limited to:
  a. Hand-held temperature probes
  b. Multi-meter capable of measuring ohms and milliamps

2 Test method (check one of the following):
- ☐ Economizer comes from HVAC system manufacturer installed by and has been factory calibrated and tested. **Attach documentation and complete certification statement. No equipment testing required.**
- ☐ Economizer field installed and field tested.

3 Installation (check **all** of the following first level boxes)
- ☐ Economizer high limit setpoint complies with Table 144-C per Standards Section 144(e)3
- ☐ System controls are wired correctly to ensure economizer is fully integrated (i.e. economizer will operate when mechanical cooling is enabled), if all boxes are checked for Standalone Control or EMS Control

  Stand-alone Control Systems:
  - ☐ HVAC unit has two-stage thermostat and the economizer is wired to be the first stage of control
  - ☐ First stage of cooling (Y1) from thermostat is separately wired to Y1 at HVAC unit
  - ☐ Second stage of cooling (Y2) from thermostat is separately wired to Y2 at HVAC unit
  - ☐ Two stages of cooling are not jumpered or wired together

  EMS Controlled Systems:
  - ☐ Control sequence of operations will allow economizer to be integrated with cooling coil
- ☐ Economizer high limit control sensor(s) are properly installed
- ☐ System is provided with either barometric relief or powered relief (a relief fan or a return fan)
- ☐ Sensor(s) used for economizer high limit control has factory calibration certificate or is field calibrated. Sensors include: outside air sensor only if single-point changeover; both outside and return air sensors if differential changeover control. Field calibration is not necessary if economizer is factory installed.

Certification Statement: I certify that all statements are true on this MECH-4-A form including the PASS/FAIL Evaluation. I affirm I am eligible to sign this form under the provisions described in the Statement of Acceptance on form MECH-1-A

Name: ____________________________________

Company: ____________________________________

Signature: ____________________________________ Date __________________

: _ _

2005 ACCEPTANCE REQUIREMENTS FOR CODE COMPLIANCE

Economizer Acceptance Document — MECH-4-A

NJ.7.1 — **Form __ of __**

PROJECT NAME	DATE

A. Equipment Testing	
Step 1: Simulate a cooling load and enable the economizer (check and verify the following)	
☐	Economizer damper modulates open to maximum position to provide 100% of design supply air quantity as outside air
☐	Return air damper modulates closed and is completely closed when economizer damper is 100% open
☐	Economizer damper is 100% open before mechanical cooling is enabled
☐	Relief is provided through barometric damper or powered relief (relief or return fan and exhaust damper)
☐	Mechanical cooling is only enabled if cooling space temperature setpoint is not met with economizer at 100% open
☐	There are no signs of building overpressurization
Step 2: Simulate a cooling load and disable the economizer (check and verify the following)	
☐	Economizer damper closes to minimum position
☐	Return air damper opens to normal operating position
☐	Relief fan (if applicable) shuts off or barometric relief dampers close. If system uses a return fan, the exhaust damper is shut.
☐	Mechanical cooling remains enabled until cooling space temperature setpoint is met
Step 3: System returned to initial operating conditions	Y / N

B. Testing Results	**PASS / FAIL**
Step 1: Simulate cooling load and enable the economizer (all check boxes are complete)	
Step 2: Simulate cooling load and disable the economizer (all check boxes are complete)	

C. PASS / FAIL Evaluation (check one):	
☐	PASS: All **Construction Inspection** responses are complete and all **Testing Results** responses are "Pass"
☐	FAIL: Any **Construction Inspection** responses are incomplete *OR* there is one or more "Fail" responses in **Testing Results** section. Provide explanation below. Use and attach additional pages if necessary.

Energy Smart Services
Supplemental Economizer Information
(Expires December 31, 2008)

This form shall be completed by the installing technician and submitted to EWEB along with the HVAC Coupon before an economizer rebate can be paid. Please complete a checklist for each economizer installed.

____
Facility Name

______________________________ ______________________________
Installing Technician Contractor Name

Western Premium Economizer

Area Served by Economizer:________________________________HVAC Tag#:____________________
(Specify: restaurant, computer area, interior zone, etc.)

Economizer Control Manufacturer/Model #: ____
Thermostat Manufacturer/Model #: ____

☐ Installed according to manufacturers recommendations.

☐ Complete economizer cycle observed; dampers operate freely, linkage adjusted properly.
- ☐ OSA damper closes completely when unit is off.
- ☐ ✷Has Modulating Motor
- Damper coordination: ☐ Linkage ☐ Gear Driven Direct Drive

☐ Compressor staged appropriately during economizer cycle.
- ☐ ✷Thermostat has Dedicated Economizer Stage
- Cooling type: ☐ 1 Stage Direct Expansion (DX) ☐ ____Stage DX ☐ Chilled Water
- Primary air sensor location: ☐ Discharge/Supply Air ☐ Mixed Air Before Cooling Coil

Method of return air building pressure relief:____
(Specify: powered fan, actuated damper, barometric/gravity damper)

Total system cfm:__________________
- System cfm determined by: ☐ Nameplate ☐ Measured
  - Describe:____

Minimum Outside Air (OSA) setting_______________________percent or _________________cfm.
- OSA percent method: ☐ Calculated ☐ Measured ☐ Temperature Split
  - Explain:____
- ☐ OSA sensor connected and located in outside air stream and not subject to condenser heat.
- ☐ ✷Has both OSA and RA Sensor (Differential/Comparitive Changeover Type)
- ☐ ✷Dry Bulb Type OSA and RA Sensor (No Snap Disc)
- OSA changeover sensor setting (✷D):_______________
- OSA compressor lockout temperature setting ✷_____F

Signed & Certified: ____ Date: ________________________

✷ Denotes requirements for Western Premium Economizer installations

____
Facility Name

_________________________________ _________________________________
Installing Technician Contractor Name

Standard Economizer (Expires December 31, 2008)

(Western Premium Economizers provide a higher rebate—use the form on the front for them.)

Area Served by Economizer:______________________________HVAC Tag#:__________________
(Specify: restaurant, computer area, interior zone, etc.)

Economizer Control Manufacturer/Model #:____

Thermostat Manufacturer/Model #: ____

☐ Installed according to manufacturers recommendations.

☐ Complete economizer cycle observed; dampers operate freely, linkage adjusted properly.
- ☐ OSA damper closes completely when unit is off.
- Motor type: ☐ Modulating Motor ☐ Staged
- Damper coordination: ☐ Linkage ☐ Gear Driven Direct Drive

☐ Compressor staged appropriately during economizer cycle.
- Thermostat type: ☐ One-Stage Cooling ☐ Two-Stage Cooling ☐ Dedicated Economizer Stage
- Cooling type: ☐ 1 Stage Direct Expansion (DX) ☐ ____Stage DX ☐ Chilled Water
- Primary air sensor location: ☐ Discharge/Supply Air ☐ Mixed Air Before Cooling Coil

Method of return air building pressure relief:____
(Specify: none, powered fan, actuated damper, barometric/gravity damper)

Total system cfm:_________________
- System cfm determined by: ☐ Nameplate ☐ Measured
  - Describe:____

Minimum Outside Air (OSA) setting______________________percent or _________________cfm.
- OSA percent method: ☐ Calculated ☐ Measured ☐ Visual Inspection ☐ Temperature Split
  - Explain:____
- ☐ OSA sensor connected and located in outside air stream and not subject to condenser heat.
- OSA changeover type: ☐ OSA Only ☐ Differential/Comparitive (OSA & RA)
- OSA/Return air sensor type (check one): ☐ Dry Bulb ☐ Enthalpy ☐ Snap-Disc
- OSA changeover sensor setting (A, B, C, D):________________
- OSA compressor lockout temperature setting _____F ☐ N/A

Signed & Certified: ______________________________________ Date: ____________________

EWEB
Eugene Water & Electric Board
Energy Management Services
500 East 4th Avenue
P.O. Box 10148

This functional testing guidance is designed to aid in developing test procedures for a specific project by describing the steps involved in testing. The guidance should be adapted as necessary to address the control sequences, configuration, and performance requirements of the particular system being tested. Additionally, codes may require specific testing procedures that may not be addressed in this document. All tests based on this guidance should be reviewed carefully to ensure that they are complete and appropriate.

Test Procedure: Large Packaged HVAC Systems

Overview

The objective of testing a packaged HVAC system is to ensure that each component is working correctly, and that they all work together as a system to satisfy zone heating, cooling, and ventilation requirements. Additional objectives of testing are to assess the response to, and recovery from, a power failure, and to test the interlock with the fire/life safety system. The test guidance outlined below covers both constant and variable volume units.

System Description

A packaged HVAC system typically includes a wide array of individual components, subsystems, or related systems, including: supply fan, DX compressor/condenser, heating element (natural gas, electricity, heat pump, etc.), outdoor and return dampers/actuators, relief dampers, temperature sensors, and safeties/interlocks. Large package HVAC systems may also include return fans, power relief fans, volume control devices (such as VFD, inlet vanes, etc.) and additional control sensors

In many respects, a large packaged HVAC system is very similar to a built-up air handling unit and utilizes many of the same components and control features. The functional test procedures described below apply to large packaged HVAC systems, which typically have the following characteristics:

- All aspects of system operation and control are provided by either an internal microprocessor controller or a central DDC system.
- Outdoor, return, and relief dampers are controlled by individual actuators and are capable of modulating between fully open and fully closed for economizer operation and to meet minimum ventilation requirements.
- Economizer control strategy is executed through the internal microprocessor controller or central DDC system. If the economizer is controlled by a stand-alone controller provided by the manufacturer, then the *Small Package HVAC System* test guidance should be followed.
- DX compressors are staged to meet varying cooling loads. The economizer should be fully integrated with mechanical cooling.
- Return or relief fans (if applicable) can be controlled many ways, including but not limited to, supply fan tracking, building pressure, or limit switches on the outdoor air dampers (limit switch control is typically associated with relief fans).
- For constant volume systems, heating, economizer, and mechanical cooling control is based on satisfying space temperature setpoint through the use of a 2-stage thermostat or zone temperature sensor. For variable air volume systems, heating is generally only used during a morning warm-up cycle, and the economizer and mechanical cooling are modulated as necessary to maintain discharge air temperature setpoint.

Sample Test

The following test was not created based on this test guidance but serves as a sample of similar tests. It is available at www.ftguide.org/ftct/testdir.htm.

- Large Packaged Rooftop DX Unit Test. ID#: 302

Test Procedure Outline

1. Preparation

1.1 Create a test form

1.2 Determine acceptance criteria

1.3 Provide instructions/precautions

1.4 Specify participants and roles/responsibilities

2. Large Packaged HVAC System Test Guidance

2.1 Confirm that all system prefunctional checklists are complete

2.2 Verify warm-up operation

2.3 Verify heating operation during occupied hours

2.4 Verify economizer operation during occupied hours

2.5 Verify mechanical cooling operation during occupied hours

2.6 Verify economizer high limit lockout control during unoccupied hours

2.7 Verify system operation during unoccupied hours

2.8. Return system to normal operations

3. Smoke Control Test Procedures

3.1. Verify system fire shutdown control sequence (if applicable)

3.2. Verify pressurization control sequence

3.3. Verify evacuation control sequence

3.4. Verify smoke purge control sequence

4. Recovery from Power Failure Test Procedures

4.1. Verify system status when power is lost

4.2. Verify system operation when power is returned

5. Trending System Operation

5.1. Verify system operation through trending

1. Preparation

1.1. **Create a test form**. Testing will be easier if the test procedure is thought through and documented before conducting the test. Developing a test form will assist in data collection and subsequent evaluation, as well as allow less experienced staff to execute the test.

1.2 **Determine acceptance criteria.** Acceptance criteria are based on design sequence of operations implemented to control the packaged HVAC system. In general, temperatures should be maintained within ±3°F of setpoint without excessive hunting or cycling between heating and cooling.

1.3 **Provide instructions/precautions.** If performing the test during subfreezing atmospheric conditions, ensure proper care is taken to prevent freezing of the coil(s) when verifying economizer interaction. Be sure to have an emergency “exit” strategy in place should the test need to be aborted prior to completion. If a test fails, the source of the failure should be identified and conveyed to the proper authority. The system should be retested once the repairs are complete.

1.4 **Specify participants and roles/responsibilities.** The testing guidance provided in this document can assist in verifying proper system performance in both new construction and existing building applications. At a minimum, the following people should participate in the testing process. Refer to the *Functional Testing Basics* section of the Functional Test Guide for a description of the general role and responsibility of the respective participant throughout the testing process. The roles and responsibilities should be customized based on actual project requirements.

New Construction Project	Existing Building Project
Commissioning Provider Mechanical Contractor Control Contractor Fire/Life Safety Inspector Electrical Contractor	Commissioning Provider Building Operating Staff Controls Contractor Fire/Life Safety Inspector

2. Large Packaged HVAC System Test Guidance

2.1 **Confirm that all system prefunctional checklists are complete.** Prior to performing any functional tests, the commissioning pre-start, start-up, and verification checklists should be completed, as well as applicable manufacturer's pre-start and start-up recommendations. Prefunctional checklist items include, but are not limited to, the following:

2.1.1 Supply fan spins in the right direction and is free of unusual noise and vibration.

2.1.2 Supply fan belt tension, alignment, and condition are OK (if applicable).

2.1.3 Return and/or powered relief fan spins in the right direction and is free of unusual noise and vibration (if applicable).

2.1.4 Return and/or powered relief fan belt tension, alignment, and condition are OK (if applicable).

2.1.5 Outdoor, return, and relief dampers stroke freely with minimum play.

2.1.6 Damper assemblies are clean of any construction debris, dirt, or other foreign materials.

2.1.7 Evaporator coil is clean and fins are in good condition.

2.1.8 Condensate trap/drain is piped per manufacturer’s specification.

2.1.9 Compressor(s) has no unusual noise or vibration.

2.1.10 Condenser coil is clean and fins are in good condition.

2.1.11 There is adequate clearance around condenser for proper air flow.

2.1.12 All field-mounted sensors are installed per manufacturer’s specification and calibrated (either field calibration or calibration certificates).

2.1.13 All safeties and interlocks are functional (i.e. freezestat, compressor lockout, static pressure limit switches, etc.).

2.1.14 Appropriate occupied, unoccupied, and holiday schedules are programmed in the DDC system or microprocessor.

2.2 **Verify warm-up operation.** Most variable air volume and some constant volume units may utilize a warm-up sequence to bring a space up to temperature prior to occupancy. The control strategy is generally based on satisfying a return air temperature setpoint. Note that excessive leaks in the building envelope may allow outdoor air to infiltrate the return air plenum (if applicable), which can have an adverse impact on the warm-up cycle control. In order to test the control sequence, simulate an unoccupied condition by either setting the schedule in the DDC system or microprocessor to include the actual time the test is being performed or adjusting the time to be within the unoccupied schedule and adjusting the warm-up setpoint(s) as necessary to trigger the warm-up cycle.

Check the following:

2.2.1 Supply fan (and return fan if applicable) is operating.

2.2.2 Outdoor and relief air dampers are fully closed.

2.2.3 Return air damper is wide open.

2.2.4 Power relief fans (if applicable) are not operating.

2.2.5 DX compressor and condenser are not enabled.

2.2.6 Heating is enabled and staged as necessary to satisfy control setpoint.

2.2.7 Allow unit to enter an "occupied" mode while still in warm-up mode. Verify that heating terminates when the warm-up setpoint is achieved and that the unit does not go back into warm-up mode.

2.3 **Verify heating operation during occupied hours.** Constant volume systems generally stage heating elements as necessary to maintain space temperature setpoint, but many variable air volume (VAV) systems do not have a heating mode other than morning warm-up. Heating for a packaged VAV system is generally provided by reheat coils in the terminal units that serve their respective zones. However, the unit may have an "occupied heating mode" option that must be selected in order to enable the control strategy.

Simulate an occupied condition by either setting occupancy schedule in the DDC system or microprocessor to include actual time the test is being performed or adjusting the time to be within the occupied schedule. Raise either the space temperature setpoint or heating temperature setpoint (if occupied heating mode in a VAV unit is selected) to be 10°F above current ambient conditions in order to generate a call for heating.

Check the following:

2.3.1 Supply fan (and return fan if applicable) is operating.

2.3.2 Outdoor air damper is at minimum ventilation position. Minimum position should be set based on the measured outdoor air flow rate meeting design.

2.3.3 Relief fan (if applicable) should not be operating.

2.3.4 DX compressor and condenser are not enabled.

2.3.5 Heating is enabled. Note of precaution – raising space temperature above ambient conditions may have adverse impact on workers or equipment located in the zone being tested.

2.4. **Verify economizer operation during occupied hours.** The economizer will typically be the first stage of cooling in both constant and variable air volume systems. Some constant volume units are controlled by a zone thermostat, which will simply enable the economizer when the Y1 circuit is energized (first stage call for cooling) and outdoor air conditions are adequate to economize. Other constant volume systems may modulate the economizer as necessary to meet a discharge air temperature setpoint if space temperature exceeds cooling setpoint. Most variable air volume systems typically control cooling operation by maintaining a discharge air temperature setpoint as space temperature deviates from the cooling temperature setpoint.

Leave the system in the occupied mode and lower zone cooling temperature setpoint to be 5°F below current ambient temperature to generate a call for cooling. Based on the type of system and control strategy employed, the following should occur:

- In a thermostat application, the Y1 circuit will be energized.
- In non-thermostat applications, the microprocessor or central DDC system initiates the cooling sequence in order to satisfy zone temperature setpoint.
- In thermostatically-controlled constant volume systems, the economizer is enabled to satisfy the first stage call for cooling.
- In non-thermostat applications or in VAV units, the economizer modulates to meet the discharge air temperature setpoint. Hence, the discharge air temperature setpoint should be adjusted to be only about 1°F or 2°F below outdoor air temperature to ensure the economizer will modulate fully without enabling mechanical cooling.
- Regardless of system type, adjust the economizer high-limit lockout setpoint to be above current ambient conditions. If a simple changeover strategy is used, this may include raising the setpoint. If a differential control strategy is used, it may include overwriting the return air temperature signal to be above ambient conditions. An alternative, but less desirable, method is to use a substance like tech spray on the outdoor air sensor to simulate a “cold” condition. However, the “cold” condition may not last long enough to fully check out the economizer if the outdoor air temperature is extremely high, because an enthalpy sensor may not respond appropriately.

Check the following:

2.4.1 Supply fan (and return fan if applicable) is operating.

2.4.2 Outdoor air damper modulates to 100% open position.

2.4.3 Return air damper modulates to fully closed position. This is critical because leakage past return dampers will reduce the effectiveness of the economizer.

2.4.4 DX compressor and condenser are not enabled.

2.4.5 Heating is not enabled.

2.4.6 Power relief fan (if applicable) is enabled when system goes to full economizer position. Control may be based on building pressure or possibly a limit switch located on the outdoor air damper.

2.5. **Verify mechanical cooling during occupied hours.** Compressor operation is typically the second stage of cooling if the outdoor air conditions are adequate for economizing. Constant volume units controlled by a zone thermostat will stage mechanical cooling ON when the thermostat energizes the Y2 circuit, while constant volume systems will stage compressor operation as necessary to meet a discharge air temperature setpoint. Again, most variable air volume systems typically control cooling operation based on maintaining a discharge air temperature setpoint as space temperature deviates from the cooling temperature setpoint.

Leave the system as outlined in step 1.4 above and lower the zone cooling temperature setpoint to 10°F below current ambient temperature. This magnitude of deviation from setpoint should be adequate to energize the Y2 circuit in a thermostat application and ensure that the call for cooling remains in non-thermostatically controlled constant and variable air volume systems. Also, lower the discharge air temperature setpoint to 10°F below outdoor air temperature to ensure that mechanical cooling will be enabled to meet the new setpoint.

Check the following:

2.5.1 Supply fan (and return fan if applicable) is operating.

2.5.2 Outdoor air damper stays at 100% open position.

2.5.3 Return air damper stays at fully closed position.

2.5.4 DX compressor and condenser are enabled.

2.5.5 Heating is not enabled.

2.5.6 Power relief fan (if applicable) is still enabled.

2.6. **Verify economizer high limit lockout control.** Leave the system as outlined in step 1.5 above. Adjust the economizer high-limit lockout to be below current ambient conditions.

Check the following:

2.6.1 Supply fan (and return fan if applicable) is operating.

2.6.2 Outdoor air damper returns to minimum ventilation position.

2.6.3 Return air damper opens.

2.6.4 DX compressor and condenser are enabled.

2.6.5 Heating is not enabled.

2.6.6 Power relief fan (if applicable) turns off.

2.7. **Verify system operation during unoccupied hours.** Simulate an unoccupied condition by either setting schedule to include actual time the test is being performed or adjusting the time to be within the unoccupied schedule. Follow the same procedures outlined in steps 1.3 and 1.5, except adjust the unoccupied heating and cooling setpoints to verify night low/high limit operation. There is no need to recheck economizer operation or cooling staging since these control sequences have already been verified.

Check the following:

2.7.1 Supply fan (and return fan if applicable) cycle ON when a call for either heating or cooling is established, and OFF when the load is satisfied.

2.7.2 Outdoor air damper closed when supply fan is OFF and modulates as necessary when system is enabled.

2.7.3 Return air damper follows outdoor air damper in reverse.

2.7.4 DX compressor and condenser cycle on and off as necessary.

2.7.5 Heating cycles on and off as necessary.

2.7.6 Relief fan (if applicable) is OFF when the supply fan is OFF and operates as necessary when the system is enabled.

2.8 **Return system to normal operation.** Return system to normal operating conditions by enabling correct time and schedules, removing all overrides, and adjusting all setpoints to the values specified in the design sequence of operations.

3. Smoke Control Test Procedures

Many large package HVAC systems can be operated in different modes to execute various smoke control strategies. In most cases, implementation of the various smoke control modes requires installation of after-factory switches and relays to selectively interrupt and override the standard factory control sequences. The most common modes include: 1) fire shutdown; 2) pressurization; 3) evacuation; and 4) smoke purge. Each control strategy would typically be initiated manually at

2005 ACCEPTANCE REQUIREMENTS FOR CODE COMPLIANCE	MECH-3-A

Packaged/Split HVAC Systems Acceptance Document

NJ.4.1	Form _____ of ______

PROJECT NAME		DATE
PROJECT ADDRESS		
TESTING AUTHORITY	TELEPHONE	
PACKAGED HVAC NAME / DESIGNATION		______________ Checked by/Date Enforcement Agency Use

Intent: Verify that under a specific load whether in occupied or unoccupied condition, the system meets a specific sequence of operation.

Construction Inspection

1 Instrumentation to perform test includes, but not limited to:
   a. None required
2 Installation
   - ☐ Thermostat or zone temperature sensor is located within the zone that the HVAC system serves
   - ☐ Thermostat or sensor is wired to the HVAC system correctly
3 Programming (check **all** of the following)
   - ☐ Heating and cooling therm[illegible]s are capable of a 5°F deadband where cooling and heating are at a minimum (§122(b)3)
   - ☐ Occupied, unoccupied, and holiday schedule have been programmed.
   - ☐ Pre-occupancy purge (at least lesser of minimum outside air or 3 ACH for one hour prior to occupancy) programmed (§121(c)2)
   - ☐ Set up and set back setpoints have been programmed as required

Certification Statement: I certify that all statements are true on this MECH-3-A form including the PASS/FAIL Evaluation. I affirm I am eligible to sign this form under the provisions described in the Statement of Acceptance on form MECH-1-A

Name: ______________________________

Company: ______________________________

Signature: ______________________________ Date: ________________

2005 ACCEPTANCE REQUIREMENTS FOR CODE COMPLIANCE MECH-3-A

Packaged/Split HVAC Systems Acceptance Document

NJ.4.1 **Form _____ of ______**

PROJECT NAME	DATE

B. Equipment Testing Requirements — Operating Modes

A = Heating load during occupied condition
B = No-load during occupied condition
C = Heating load during unoccupied condition
D = No-load during unoccupied condition
E = Manual override
F = Cooling load during occupied condition
G = Cooling load during unoccupied condition

	Check and verify the following for each simulation mode required	A	B	C	D	E	F	G
1	Supply fan operates continually	☐	☐			☐	☐	
2	Supply fan turns off				☐			
3	Supply fan cycles on and off			☐				☐
4	System reverts to "occupied" mode to satisfy any condition					☐		
5	System turns off when manual override time period expires					☐		
6	Gas-fired furnace, heat pump, or electric heater stages on	☐		☐				
7	Neither heating or cooling is provided by the unit		☐		☐			
8	No heating is provided by the unit		☐		☐		☐	☐
9	No cooling is provided by the unit	☐	☐	☐	☐			
10	Compressor stages on						☐	☐
11	Outside air damper is open to minimum position	☐	☐			☐	☐	
12	Outside air damper closes completely				☐			
13	System returned to initial operating conditions after all tests have been completed: Y/N							

C. Testing Results	A	B	C	D	E	F	G
Indicate if Passed (P), Failed (F), or N/A (X), fill in appropriate letter							

Note: Shaded areas do not apply for particular test procedure

D. PASS / FAIL Evaluation (check one):

☐ PASS: All **Construction Inspection** responses are complete and all applicable **Testing Results** responses are "Passed" (P)

☐ FAIL: Any **Construction Inspection** responses are incomplete *OR* there is one or more "Failed" (F) responses in **Testing Results** section. Provide explanation below. Use and attach additional pages if necessary.

This functional testing guidance is designed to aid in developing test procedures for a specific project by describing the steps involved in testing. The guidance should be adapted as necessary to address the control sequences, configuration, and performance requirements of the particular system being tested. Additionally, codes may require specific testing procedures that may not be addressed in this document. All tests based on this guidance should be reviewed carefully to ensure that they are complete and appropriate.

Test Procedure: Demand-Controlled Ventilation

Overview

A demand-controlled ventilation (DCV) control strategy adjusts the quantity of outdoor ventilation air supplied to a zone by a central air handling unit based on the ventilation rate required to provide adequate indoor air quality. A significant amount of heating and cooling energy can be saved by supplying just enough ventilation air to satisfy zone load requirements. The objective of testing the demand-controlled ventilation control strategy is to ensure that outdoor ventilation air is adjusted as necessary to meet zone loads as they vary with time. The following procedures will assist with:

- Ensuring all system prefunctional checklists are complete prior to executing system tests
- Verifying demand-controlled ventilation control strategy operates as intended for both constant and variable air volume zones and air handling systems
- Verifying zone minimum ventilation air requirements are met under varying operating conditions
- Verifying that zone demand-controlled ventilation control strategy interacts with zone terminal units and air handling units' economizer control sequence correctly

Control Strategy Considerations

The amount of outdoor air that must be included in the supply air stream is generally determined by a combination of varying and non-varying factors.

Non-varying requirements:

- Make-up requirements for direct exhaust from the zone(s) served
- Design excess air for building pressurization
- Amount of air necessary to dilute non-occupant sources of contaminants (i.e. glues, solvents, cleaning solutions, carpeting, fabrics and materials, office equipment, water vapor and other particulates)

Varying requirements:

- Amount of air necessary to dilute occupant-based contaminants like bio-effluents (i.e. body odors)

Non-Varying Outdoor Air Requirements

For most building types, the amount of outdoor air necessary for exhaust make-up and design excess air for building pressurization are fixed values that do not vary over time. The off-gassing from materials like carpets, fabrics, adhesives, and furnishings will initially be very high when the building is new, but typically decrease to a much lower steady-state (i.e. fixed) emission rate over time as the building ages. In addition, odors and contaminants from cleaning products and solvents, office equipment and materials, or off-gassing from new products (merchandise in a retail store for example), may not vary over time and require a constant volume of outdoor air to maintain adequate indoor air quality. The sum of these three variables will set the *base minimum* ventilation requirement for the system. Note however, if the quantity of direct exhaust air exceeds the design, non-occupant pollutant air flow rate, it will not be necessary to introduce any additional ventilation air into the supply air other than the amount needed to offset the air exhausted from the building.

Varying Outdoor Air Requirements

The amount of air necessary to dilute occupant-based contaminants varies with the number of occupants and their activity levels. The total *design minimum* ventilation rate is the sum of the *base minimum* ventilation rate (described above) and the occupant-based ventilation requirements. The *base minimum* ventilation rate is typically about 20% to 30% of total *design minimum* ventilation. Most building codes and standards require that minimum ventilation flow rate be adequate to satisfy a design occupant load and typically refer to meeting ASHRAE Standard 62.1-2004 requirements. However, design occupant load is rarely achieved under normal building operation. Hence, buildings tend to be over-ventilated which wastes a significant amount of energy over time. In response, DCV is becoming more widely accepted across the HVAC industry because it varies the amount of outdoor air provided depending on demand within the building.

Demand for Ventilation in Zones

It is exceedingly difficult, if not impossible, to directly measure the demand for outdoor air. Some control strategies may vary ventilation air flow rate based on whether particular zones are occupied via occupancy sensors. If various zones are unoccupied, the ventilation rate can be reduced. Once the zone is occupied, the ventilation rate would most likely be increased to design ventilation air flow requirements regardless of whether the zone is at design occupancy. This control strategy can be effective but it is not optimum since the ventilation air flow rate is not varied based on actual demand with the respective zones.

The most common parameter used to estimate actual demand is the concentration of carbon dioxide (CO_2) within respective zones. CO_2 is generated by humans at varying rates based on age, diet, and physical activity. When the ventilation rate per occupant is low, the concentration of contaminant gases and particulates, as well as CO_2, begin to build up within the space. Although carbon dioxide is not considered a contaminant at the concentration levels typically found in most buildings, a high CO_2 concentration indicates insufficient ventilation. And since the concentration of CO_2 gas is easily measured, it can be used to vary the ventilation rate to maintain acceptable indoor air quality.

Appropriate CO_2 Setpoints

Building codes and standards typically require that a specific outdoor ventilation air flow rate (in CFM/person) be provided to a building based on the occupancy category of the zone(s) being served. For example, ASHRAE Standard 62.1-2004 stipulates an overall ventilation rate of 17 CFM/person for an office environment in order to dilute both occupant-based human bio-effluents and non occupant-based contaminants generated within the space. The mass balance method outlined in Appendix C of ASHRAE Standard 62.1-2004 demonstrates that a steady-state CO_2 concentration of approximately 700 parts-per-million (PPM) above the concentration in the outdoor air (typically ranging between 300 PPM and 500 PPM), is equivalent to a ventilation rate of approximately 15 CFM/person. To be conservative and account for variations among people and activity levels, maintaining an absolute CO_2 concentration setpoint ranging between 900 PPM and 1100 PPM within the zones served by each air handling unit will provide adequate ventilation for the typical office. Refer to Appendix C of ASHRAE Standard 62.1-2004 for a detailed derivation and rationale for minimum ventilation requirements based on CO_2 concentration. Additional analysis may be necessary to ensure adequate indoor air quality as well as satisfy applicable codes and standards if the activity level, ventilation rate, or outdoor CO_2

concentration for a specific project is different than the mass balance calculation outlined in Appendix C of ASHRAE Standard 62.1-2004.

Constant Volume System Considerations

A demand-based ventilation control strategy can be applied to both constant volume and variable air volume air handling systems. In a constant volume application, the outdoor air dampers are typically modulated between the *base minimum* and *design minimum* ventilation flow rates to maintain a CO_2 concentration setpoint, which is a fairly simple control strategy to implement.

Note that the economizer control loop will interact with the demand-controlled ventilation control loop. Whichever control loop is calling for the highest amount of outdoor air should take precedence. For example if the economizer loop is driving the outdoor air dampers open to provide free cooling, the dampers should not close because zone CO_2 concentrations are below setpoint. In contrast, the outdoor air dampers should be driven toward the *design minimum* ventilation flow rate if any zone CO_2 concentration exceeds setpoint even if free cooling is neither available nor needed (i.e. economizer is locked out or the economizer loop output signal is zero). This control strategy is illustrated in Figure 1.

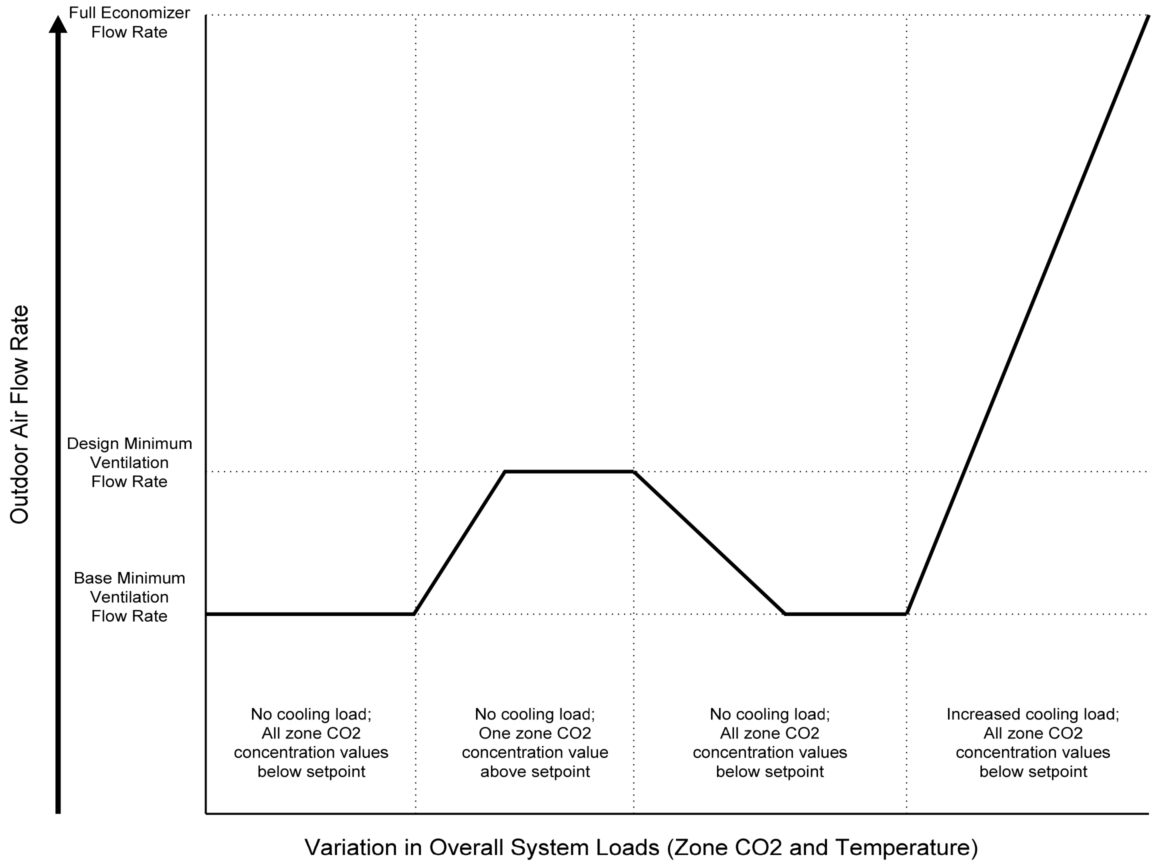


Figure 1 Outdoor Air Damper Control with Demand-controlled Ventilation

Variable Air Volume System Considerations

In a variable air volume system, the minimum air flow rate delivered by an individual VAV box to its respective zone is typically based on providing adequate ventilation for the occupants within that zone. The overall minimum outdoor air flow rate added to the supply air stream at the central air handling unit is determined by the ventilation requirements of all the zones served.

Hence as building occupancy varies within each zone, the individual VAV box damper as well as the central air handling unit outdoor air damper can be adjusted to satisfy ventilation requirements based on CO_2 concentration.

VAV Box Control

When the CO_2 concentration for an individual zone is below setpoint, the minimum ventilation flow rate setpoint for that VAV box is reset to its *base minimum* ventilation flow rate value. As occupancy increases and the CO_2 concentration within the zone begins to rise above setpoint, the minimum ventilation flow rate setpoint is reset upwards toward its *design minimum* ventilation flow rate value to satisfy the CO_2 setpoint.

Note that CO_2 concentration only impacts the <u>minimum</u> ventilation flow rate setpoint for the VAV box. Actual flow rate delivered by the VAV box to the zone will be controlled based on maintaining zone temperature setpoint. Typical VAV box control is illustrated in Figure 2. Also keep in mind that the *base minimum* ventilation flow rate value for a VAV box is dependent on the minimum flow rate to which the particular VAV box can be controlled, as well as any specific operating requirements. For example, the minimum air flow rate necessary for an electric reheat element to become and remain enabled may exceed the minimum flow determined by the demand-controlled ventilation control loop. In this case, the CO_2 control loop output may be overridden if the zone is calling for heat.

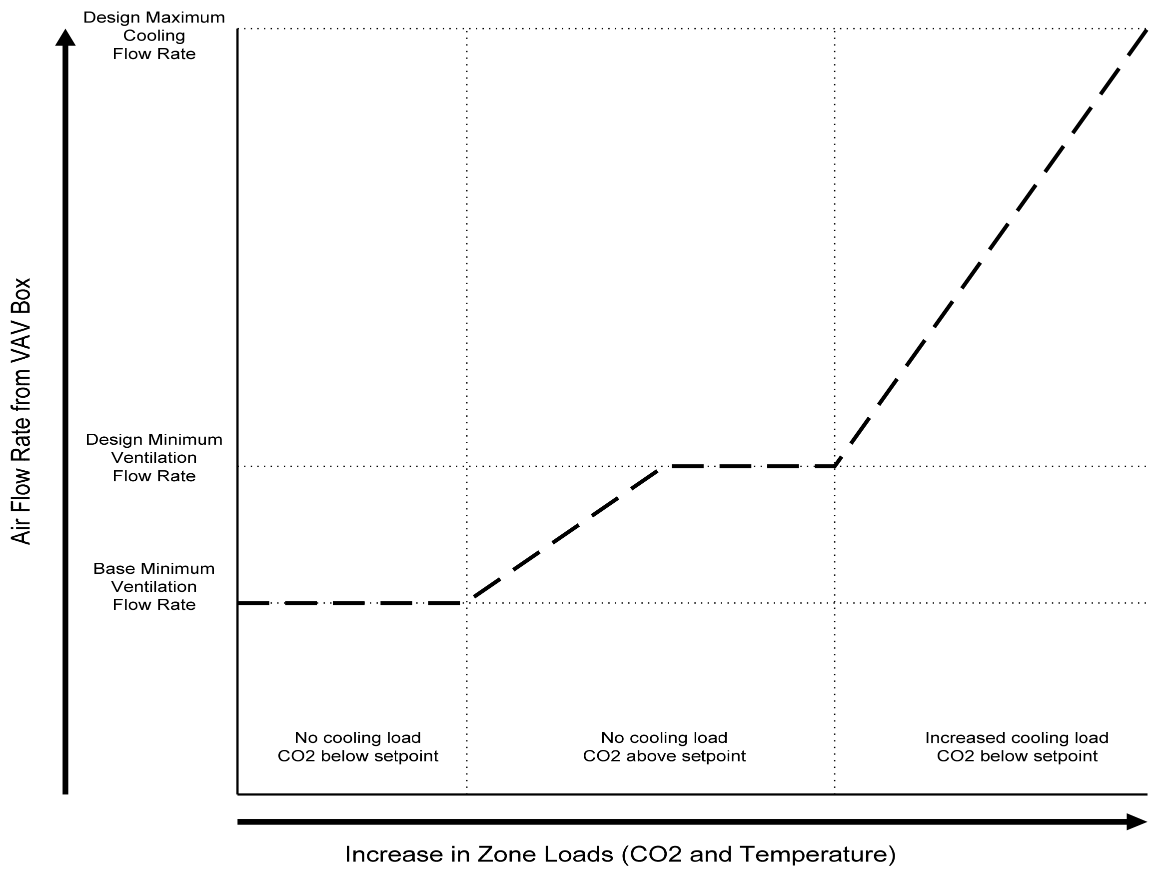


Figure 2 VAV Box Control with Demand-controlled Ventilation

AHU Outside Air Damper Control

Control of the outdoor air damper in a variable air volume system is very similar to that of a constant volume system. The outdoor minimum ventilation setpoint is at the *base minimum* ventilation flow rate value until one VAV box is at its *design minimum* ventilation flow rate value and zone CO_2 concentration continues to rise. At this point, the outdoor air ventilation setpoint will be reset upwards towards the *design minimum* ventilation flow rate value and the outdoor air damper will modulate open.

As with a constant volume system, CO_2 concentration only impacts the minimum ventilation flow rate. The economizer control loop takes precedence over the demand-controlled ventilation control loop (refer to Figure 1). However, resetting the minimum damper position in a variable air volume system is significantly more complicated than in a constant volume system depending on the actual control strategy employed to regulate outdoor air intake (common control strategies include fan tracking, flow tracking, direct flow measurement, mixed plenum pressure, injection fan, and energy balance method). Due to the increased complexity of the control sequences, some designers may opt for just controlling the VAV box and leave the minimum ventilation setpoint for the air handler fixed at the *design minimum* value.

An example operating sequence for controlling both the VAV box and outdoor air damper in a variable air volume system is illustrated below.

- The minimum ventilation flow rate setpoint for each VAV box is at its respective *VAV base minimum* ventilation flow rate value when zone CO_2 concentration is below setpoint. The minimum outdoor ventilation flow rate setpoint for the central air handling unit is at the *AHU base minimum* ventilation flow rate value when **ALL** zone CO_2 concentrations are below setpoint. As an individual zone CO_2 concentration increases above setpoint, the minimum ventilation flow rate setpoint for that VAV box is reset linearly from the *VAV base minimum* to *VAV design minimum* ventilation flow rate value as the CO_2 control loop output value ranges between 0% and 50%. The minimum outdoor ventilation flow rate setpoint at the central air handling unit remains at the *AHU base minimum* ventilation flow rate value. If the CO_2 control loop output value for **ANY** zone exceeds 50%, the minimum outdoor ventilation flow rate setpoint is reset linearly from the *AHU base minimum* to *AHU design minimum* ventilation flow rate value as the CO_2 control loop output value ranges between 50% and 100%.

The control strategy is graphically represented in Figure 3.

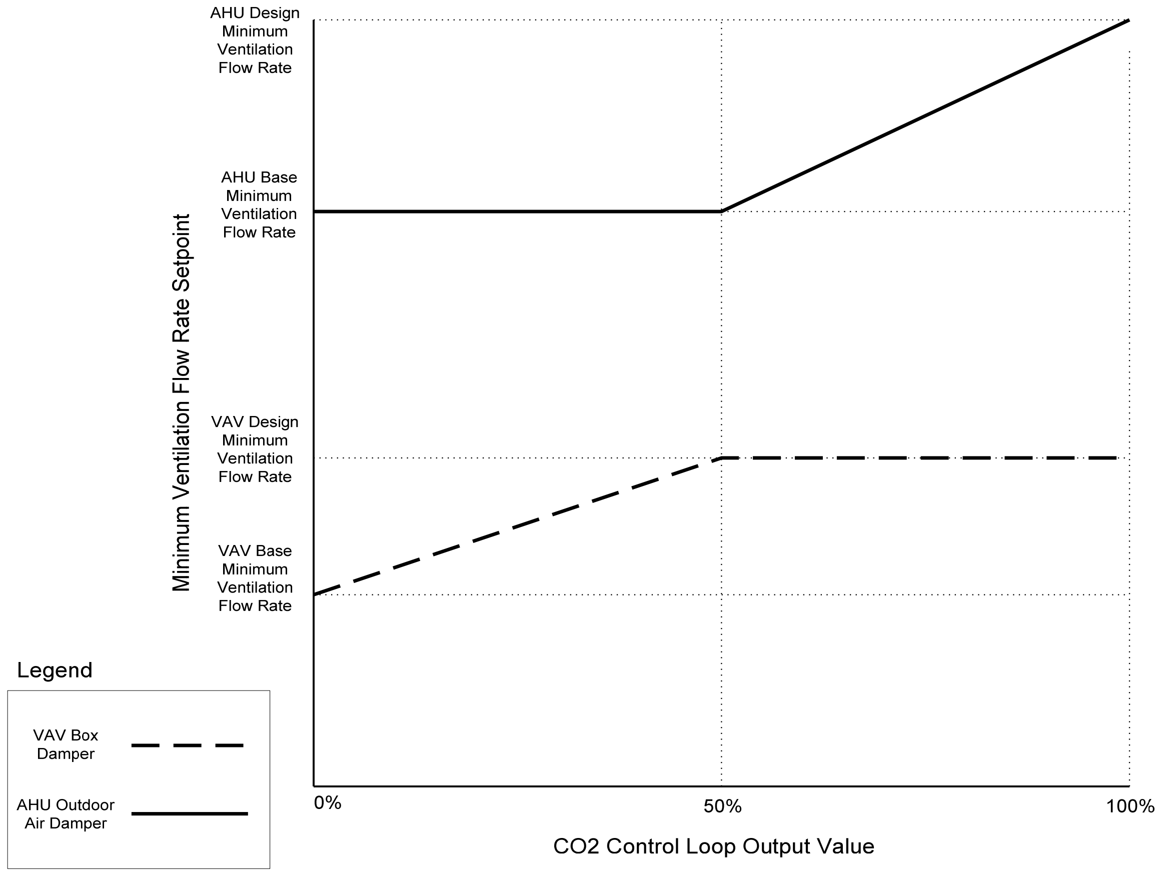


Figure 3 VAV Box and AHU Outdoor Air Damper Control

Sensor Location

Regardless of system type, location of the CO_2 sensor can significantly impact overall control and system performance. Examples of the common locations are provided below.

- **Return Air CO_2 Measurement.** A common strategy is to install a single CO_2 sensor in the return air stream of the air handling unit. This method can be effective if the unit is serving large open spaces where concentration levels are uniform across the entire zone – for example large office spaces, theaters, lecture halls, classrooms, or churches. It will be less effective if the unit serves multiple spaces, especially if some are enclosed with the potential for temporary high occupancy loads (i.e. conference rooms, lunch rooms, assembly areas, etc.). The reason is that transient CO_2 concentration in these zones may exceed safe limits, but the ventilation rate might not be adjusted if total return air concentration is below setpoint (due to dilution from other over-ventilated zones). This method is also ineffective at controlling minimum ventilation rates at the zone level in variable air volume applications.
- **Critical Zone(s) CO_2 Measurement**. An alternate method is to install CO_2 sensors in all of the critical zones served by the central air handling unit. The critical zone(s) can be any enclosed space with the potential for temporary high occupancy loads. The local sensor(s) will ensure that the ventilation rate is adjusted as necessary to meet the requirements of the zone with the highest concentration, and the general return air sensor can be used to set overall minimum ventilation rates or control VAV boxes serving "open areas," especially if the building is in partial use during unoccupied periods. This method will be more expensive since additional sensors, wiring, and control points must be installed. In addition, the control

sequences will require additional programming, but will yield better indoor air quality. This is the recommended control option for multi-zone constant volume systems and variable air volume air handling systems.

Test Conditions

The test can be performed under any condition. Care should be taken when verifying economizer interaction if the outdoor air temperature is below freezing. Ensure the freezestat or similar safety/interlock is functioning correctly to protect the air handling unit during the test. The test can be performed regardless of building occupancy.

Test Equipment

The following equipment may be necessary to conduct this test procedure.

- Cylinder with a known concentration of CO_2 to calibrate sensor
- Air flow measurement device (Shortridge, anemometer, etc.)
- Digital temperature measurement device

Test Procedure Outline

Preparation

1.1 Create a test form

1.2 Determine acceptance criteria

1.3 Provide instructions/precautions

1.4 Specify test participants and roles/responsibilities

General System Inspection

2.1 Review all prefunctional checklists for completeness

DCV Test Procedures – Constant Volume Systems

3.1 Verify base minimum outdoor air ventilation flow rate

3.2 Verify design minimum outdoor air ventilation flow rate

3.3 Verify economizer interaction

3.4 Return system to normal

DCV Test Procedures – Variable Air Volume Systems

4.1 Verify base minimum VAV box ventilation flow rate

4.2 Verify design minimum VAV box ventilation flow rate

4.3 Verify base minimum AHU outdoor air ventilation flow rate at reduced supply fan speed

4.4 Verify base minimum AHU outdoor air ventilation flow rate at full supply fan speed

4.5 Verify design minimum AHU outdoor air ventilation flow rate at reduced supply fan speed

4.6 Verify design minimum AHU outdoor air ventilation flow rate at full supply fan speed

4.7 Verify economizer interaction

4.8 Return system to normal

Test Procedure

1. Preparation

1.1 **Create a test form.** Testing will be easier if the test procedure is thought through and documented before conducting the test. Developing a test form will assist in data collection and subsequent evaluation, as well as allow less experienced staff to execute the test.

1.2 **Determine acceptance criteria.** In a constant volume system, the outdoor air minimum ventilation setpoint should be reset between the base minimum and design minimum ventilation flow rate values in order to maintain CO_2 concentration setpoint. For variable air volume systems, each VAV box minimum ventilation setpoint should be reset between its respective base minimum and design minimum ventilation flow rate values in order to maintain zone CO_2 concentration setpoint. In addition, the outdoor air minimum ventilation setpoint may also be reset between the base minimum and design minimum ventilation flow rate values based on the zone with the highest CO_2 concentration. All measured flow rates should be within ±10%1 of setpoint. Flow measurements can be made by many methods including but not limited to duct traverse, measuring air velocity across intake, reading measurements from installed flow meters (if factory or field calibrated), or using a hand-held flow device like a hot-wire anemometer.

1.3 **Provide instructions/precautions.** If performing the test during subfreezing atmospheric conditions, ensure proper care is taken to prevent freezing of the coil(s) when verifying economizer interaction. Be sure to have an emergency "exit" strategy in place should the test need to be aborted prior to completion. If a test fails, the source of the failure should be identified and conveyed to the proper authority. The system should be retested once the repairs are complete.

1.4 **Specify participants and roles/responsibilities.** The testing guidance provided in this document can assist in verifying proper system performance in both new construction and existing building applications. At a minimum, the following people should participate in the testing process. Refer to the Functional Testing Basics section of the Functional Test Guide for a description of the general role and responsibility of the respective participant throughout the testing process. The roles and responsibilities should be customized based on actual project requirements.

New Construction Project	Existing Building Project
Commissioning Provider	Commissioning Provider
Mechanical Contractor	Building Operating Staff
Control Contractor	Controls Contractor

2. General System Inspection

2.1 **Review all prefunctional checklists for completeness.** Prior to performing any functional tests, the commissioning pre-start, start-up, and prefunctional checklists

[1] note the 10% value is from California Title 24 acceptance testing requirements

should be completed, as well as applicable manufacturer's pre-start and start-up recommendations.

Prefunctional checklists include, but are not limited to, the following:

- CO_2 sensor(s) has either calibration certificate from the manufacturer or is field calibrated
- Sensor(s) is installed per the location specified on the plans
- All air handling unit(s) being tested have been functionally tested and are capable of serving normal operating loads
- All terminal unit(s) being tested have been functionally tested and are capable of serving normal operating loads
- Air system has been balanced per design
- All safeties and interlocks have been tested and are operational
- All sequence of operations are programmed per design

3. DCV Test Procedures – Constant Volume Systems

3.1 **Verify base minimum outdoor air ventilation flow rate.** Prior to performing the test, disable the economizer control loop to prevent unwanted interaction. Simulate a low CO_2 concentration by raising the setpoint for all CO_2 sensors significantly above the zone CO_2 level.

Check the following:

3.1.1 The outdoor air damper modulates to the base minimum damper position as determined when the air handling system was balanced.

3.1.2 The measured outdoor air ventilation rate is within ±10% of the specified value.

3.2 **Verify design minimum outdoor air ventilation flow rate.** Continuing from step 3.1, leave the economizer control loop disabled. Simulate a high CO_2 concentration by lowering the setpoint for one of the CO_2 sensors significantly below the zone CO_2 level.

Check the following:

3.2.1 The outdoor air damper modulates to the design minimum damper position as determined when the air handling system was balanced.

3.2.2 The measured outdoor air ventilation rate is within ±10% of the specified value.

3.3 **Verify economizer interaction.** Simulate a low CO_2 concentration by raising the setpoint for all carbon dioxide sensors installed well above the zone CO_2 level. Re-enable the economizer control loop and adjust the economizer lockout setpoint as necessary depending on the control strategy used so that the economizer will not become disabled during the test. For dry-bulb or enthalpy single-point changeover strategy, raise the economizer lockout setpoint significantly above current outdoor air conditions. For dry-bulb or enthalpy differential changeover strategy, raise the measured return air condition value significantly above current outdoor air conditions. Simulate a call for cooling by lowering the cooling control loop setpoint (typically discharge air temperature) or, if applicable, the independent economizer control loop setpoint (which is typically based on mixed air temperature) to 50°F.

Check the following:

3.3.1 The outdoor air damper starts from the base minimum damper position as determined when the air handling system was balanced.

3.3.2 The outdoor air damper modulates toward a full open position (refer to Figure 1).

3.4 **Return system to normal.** Once all tests are complete, return all control parameters back to original setpoints and conditions per the design sequence of operations.

4. DCV Test Procedures – Variable Air Volume Systems

4.1 **Verify base minimum VAV box ventilation flow rate.** Simulate a low CO_2 concentration by raising the setpoint for each CO_2 sensors significantly above the zone CO_2 level. To simulate a low cooling load without enabling reheat, adjust zone cooling temperature setpoint 5°F above current space temperature and zone heating temperature setpoint (if applicable) 5°F below current space temperature.

Keep in mind that each VAV box must be tested individually. Hence, this step must be repeated until all VAV boxes that are employing DCV have been tested.

Check the following:

4.1.1 The VAV box damper modulates to the base minimum damper position as determined when the air handling system was balanced.

4.1.2 The measured VAV box flow rate is within ±10% of the specified value.

4.2 **Verify design minimum VAV box ventilation flow rate.** Continuing from step 4.1, keep the zone cooling temperature setpoint 5°F above and zone heating temperature setpoint (if applicable) 5°F below current space temperature. Simulate a high CO_2 concentration by lowering the setpoint for each CO_2 sensors significantly below the zone CO_2 level. Again, this step must be repeated until all VAV boxes that are being controlled have been tested.

Check the following:

4.2.1 The VAV box damper modulates to the design minimum damper position as determined when the air handling system was balanced.

4.2.2 The measured VAV box flow rate is within ±10% of the specified value.

4.3 **Verify base minimum AHU outdoor air ventilation flow rate at reduced supply fan speed.** Release all of the zone temperature setpoint changes. Command all VAV box dampers being controlled by CO_2 to their respective base minimum ventilation flow setpoints and command all non-controlled VAV boxes to their respective minimum damper positions. This should simulate a low cooling load and allow the supply fan speed to slow down. Simulate a low CO_2 concentration by raising the setpoint for all CO_2 sensors significantly above the zone CO_2 level.

Check the following:

4.3.1 Supply fan speed slows down towards minimum speed.

4.3.2 The measured outdoor air ventilation rate is within ±10% of the specified base minimum ventilation flow rate value.

4.4 **Verify base minimum AHU outdoor air ventilation flow rate at full supply fan speed.** Continuing from step 4.3, leave CO_2 setpoint significantly above the zone CO_2 level. Command all VAV box dampers (those controlled and not controlled by CO_2) to their respective maximum ventilation flow setpoints. This should simulate a full cooling load and allow the supply fan speed to increase.

Check the following:

4.4.1 Supply fan speed increases to full speed.

4.4.2 The measured outdoor air ventilation rate is within ±10% of the specified *base minimum* ventilation flow rate value.

4.5 **Verify design minimum AHU outdoor air ventilation flow rate at reduced supply fan speed.** Command all VAV box dampers being controlled by CO_2 to their respective design minimum ventilation flow setpoints and command all non-controlled VAV boxes to their respective minimum damper positions. This should simulate a low cooling load and allow the supply fan speed to slow down. Simulate a high CO_2 concentration in one zone by lowering the respective CO_2 setpoint significantly below the zone CO_2 level.

Check the following:

4.5.1 Supply fan speed slows down towards minimum speed.

4.5.2 The measured outdoor air ventilation rate is within ±10% of the specified design minimum ventilation flow rate value.

4.6 **Verify design minimum AHU outdoor air ventilation flow rate at full supply fan speed.** Continuing from step 4.5, leave CO_2 setpoint for the selected zone significantly below the zone CO_2 level to simulate a high CO_2 concentration. Command all VAV box dampers (those controlled and not controlled by CO_2 to their respective maximum ventilation flow setpoints. This should simulate a full cooling load and allow the supply fan speed to increase.

Check the following:

4.6.1 Supply fan speed increases to full speed.

4.6.2 The measured outdoor air ventilation rate is within ±10% of the specified design minimum ventilation flow rate value.

4.7 **Verify economizer interaction.** Simulate a low CO_2 concentration by raising the setpoint for all CO_2 sensors significantly above the zone CO_2 level. Re-enable the economizer control loop and adjust the economizer lockout setpoint as necessary depending on the control strategy used so that the economizer will not become disabled during the test. For dry-bulb or enthalpy single-point changeover strategy, raise the economizer lockout setpoint significantly above current outdoor air conditions. For dry-bulb or enthalpy differential changeover strategy, raise the measured return air condition value significantly above current outdoor air conditions. Simulate a call for cooling by lowering the cooling control loop setpoint (typically discharge air temperature) or, if applicable, the independent economizer control loop setpoint (which is typically based on mixed air temperature) to 50°F.

Check the following:

4.7.1 The outdoor air damper starts from the base minimum damper position as determined when the air handling system was balanced.

4.7.2 The outdoor air damper modulates toward a full open position (refer to Figure 1).

4.8 **Return system to normal.** Once all tests are complete, return all control parameters back to original setpoints and conditions per the design sequence of operations.