CODES AND STANDARDS ENHANCEMENT INITIATIVE (CASE)

Outside Air

2013 California Building Energy Efficiency Standards

California Utilities Statewide Codes and Standards Team, October 2011

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1. Overview

Eight code change proposals are summarized in the following tables. The title of each measure has been categorized by type and listed below.

Measures to Support Energy Savings for DCV and VAV systems

- Require factory calibration of CO_2 sensors and eliminate field calibration option.
- Add field verification of CO_2 sensors to acceptance testing of demand control ventilation systems.
- Explicitly require and confirm during acceptance testing that outdoor air rates are dynamically controlled for variable air volume systems.

Acceptance Testing Changes for Improved Indoor Air Quality

- Verify proper location of outdoor air ducts in plenum systems.
- Confirm pre-occupancy purge for all system types.

Simple Corrections and Clarifying Language

- Correct CO_2 sensor mounting height in Nonresidential Compliance Manual.
- Add guidance for measuring outdoor air ventilation rates during acceptance testing.
- Encourage reduction of outside air during partial occupancy.

a. Measure Title	Require factory calibration of CO2 sensors and eliminate field calibration option.
b. Description	This measure eliminates the option to field calibrate CO2 sensors used in demand control ventilation systems. Instead, certificate of factory calibration would be required for all CO2 sensors. Although demand control ventilation has large energy savings potential, these savings are often not realized due to CO2 sensors that are not calibrated or non functional. Studies show that many CO2 sensors have large errors in the field and that many sensors do not easily allow for field calibration, if at all.
c. Type of Change	This measure would change the acceptance testing for CO2 sensors and would require modifications to the NA7.5.5 Demand Control Ventilation Systems Acceptance Form (MECH-6A) as well as the Nonresidential Compliance Manual.
d. Energy Benefits	No benefits will be realized above energy savings already established for demand control ventilation (DCV) systems in prior CASE Initiatives. Improving sensor accuracy through factory calibration, however, will help ensure that installed DCV systems are working properly and delivering these calculated energy savings.
e. Non-Energy Benefits	Eliminating field calibration should simplify acceptance testing and increase CO2 sensor reliability.

f. Environmental Impact

The recommendation has no additional measureable impacts on water, water quality or environmental contaminants.

Material Increase (I), Decrease (D), or No Change (NC): (All units are lbs/year)

	Mercury	Lead	Copper	Steel	Plastic	Others (Indentify)
Per Unit Measure[1]	NC	NC	NC	NC	NC	
Per Prototype Building[2]	NC	NC	NC	NC	NC	

g. Technology Measures	This measure requires that manufacturers calibrate CO2 sensors at the factory before shipping and provide a certificate of calibration. Measure Availability: Multiple manufacturers already provide factory calibrated models for both wall and duct mounted applications. The type of calibration certification document provided by each manufacturer varies. Useful Life, Persistence, and Maintenance: Manufacturers claim that the factory calibration of CO2 sensors is valid for a period of five to eight years, depending on model and maker. Based on studies by Fisk (2008) and Shrestha (2010), however, these calibration intervals are likely to be significantly shorter than predicted by the manufacturers.

<table>
<tr><td>h. Performance Verification of the Proposed Measure</td><td>The party responsible for acceptance testing will have to verify that every CO2 sensor is accompanied by a certificate of calibration.</td></tr>
<tr><td colspan="2">Cost Effectiveness

Product specifications from major controls and HVAC manufacturers indicate that factory calibrated CO2 sensors are commonplace and readily available. Furthermore, product literature typically indicates that field calibrations are not recommended or necessary. As a result, installing factory calibrated sensors is cost neutral and does not affect the cost effectiveness of DCV systems found in the 2008 CASE Report “DDC to the Zone Level: Measure 4, Demand Control Ventilation (DCV) for Multiple Zone Systems”. The results of this CASE Report are summarized below.

“The results of our simulation indicate an average TDV cost savings of $1560 for a 400 ft2 zone. As established in the Title 24 2005 report for the single zone DCV measures (CEC April 2002), the installed costs for DCV are conservatively $575 per zone. This is only 37% of the calculated TDV savings.”</td></tr>
<tr><td>j. Analysis Tools</td><td>Not applicable.</td></tr>
<tr><td>k. Relationship to Other Measures</td><td>Required factory calibration is related to adding field verification of CO2 sensors to acceptance testing protocols.</td></tr>
</table>

<table>
<tr><td>a. Measure Title</td><td>Add field verification of CO2 sensors to acceptance testing of demand control ventilation systems.</td></tr>
<tr><td>b. Description</td><td>This measure requires that CO2 sensors be field verified as accurate to within +/-75 PPM during acceptance testing. Because calibrated hand-held CO2 analyzers and calibrated CO2/air mixtures are already designated in the Construction Inspection section of the MECH-6A form, no further instrumentation is necessary. Furthermore, studies show that many sensors are not calibrated directly from the factory. This additional verification would ensure that all CO2 sensors, at least at installation, are reading within acceptable levels.</td></tr>
<tr><td>c. Type of Change</td><td>This measure would change the acceptance testing for CO2 sensors and would require modifications to the NA7.5.5 Demand Control Ventilation Systems Acceptance Form (MECH-6A) as well as the Nonresidential Compliance Manual.</td></tr>
<tr><td>d. Energy Benefits</td><td>No benefits will be realized above energy savings already established for demand control ventilation (DCV) systems in prior CASE Initiatives. Improving sensor accuracy through acceptance testing verification, however, will help ensure that installed DCV systems are working properly and delivering these calculated energy savings.</td></tr>
<tr><td>e. Non-Energy Benefits</td><td>Accurate CO2 readings will enable proper control of demand control ventilation systems.</td></tr>
<tr><td colspan="2">f. Environmental Impact
The recommendation has no additional measureable impacts on water, water quality or environmental contaminants.</td></tr>
<tr><td>g. Technology Measures</td><td>Measure Availability:
Hand-held CO2 analyzers and calibrated CO2/air mixtures necessary to field verify CO2 sensors are widely available and already designated in the Construction Inspection section of the MECH-6A form.

Useful Life, Persistence, and Maintenance:
Manufacturers claim that the factory calibration of CO2 sensors is valid for a period of five to eight years, depending on model and maker. Based on studies by Fisk (2008) and Shrestha (2010), however, these calibration intervals are likely to be significantly shorter than predicted by the manufacturers.</td></tr>
<tr><td>h. Performance Verification of the Proposed Measure</td><td>The party responsible for acceptance testing will have to field verify the accuracy of every CO2 sensor used in each demand control ventilation system.</td></tr>
</table>

Cost Effectiveness Field verification will increase the installation cost of DCV systems by approximately $35 per CO2 sensor. As established in previous 2002 and 2008 DCV CASE studies, the installation cost for DCV controls are $575, and TDV cost savings are $1560 for a 400 square foot zone. Therefore, adding field verification to acceptance testing will increase installation costs to $610 per zone, but overall, DCV is still cost effective with a simple payback of 0.39 years.	
j. Analysis Tools	Not applicable.
k. Relationship to Other Measures	Field verification of CO2 sensors is related to Eliminating Field Calibration Option for CO2 sensors.

a. Measure Title	Explicitly require and confirm during acceptance testing that outdoor air rates are dynamically controlled for variable air volume systems.
b. Description	This measure would add language requiring dynamic control of outdoor air ventilation rates in the Standards and also add an explicit verification of these controls in acceptance testing. All mechanical ventilation and space-conditioning systems that are variable air volume would be affected. Specifically, the proposed acceptance testing changes would explicitly verify that variable air volume systems are using an acceptable dynamic control of outdoor air, not fixed damper position. As found in this study, the majority of VAV systems are not controlling outdoor air rates dynamically even though this is a requirement in the Nonresidential Compliance Manual.
c. Type of Change	This measure would add a mandatory requirement to Section 121 of the Standards that requires dynamic controls of outside air ventilation rates for VAV systems. Additionally, changes would be made to the NA7.5.1 Outdoor Air Acceptance Form and the Nonresidential Compliance Manual to require explicit verification of dynamic controls.
d. Energy Benefits	The energy benefit of dynamic control of outdoor air ventilation rates has been demonstrated in the 2005 codes enhancement. This measure will not result in additional energy savings, but through acceptance testing and explicit Standards language, it will ensure that energy savings from dynamic controls are being realized in the field.
e. Non-Energy Benefits	Additional indoor air quality benefits may be realized by proper control of outdoor air ventilation rates.
f. Environmental Impact The recommendation has no additional measureable impacts on water, water quality or environmental contaminants.	
g. Technology Measures	This measure encourages control strategies mentioned in Section 4.3.5 of the Nonresidential Compliance Manual. No new technologies are being proposed.
h. Performance Verification of the Proposed Measure	The party responsible for acceptance testing will have to verify the type of dynamic control implemented on all VAV systems. This step will require coordination with the controls, TAB or mechanical contractor.

Cost Effectiveness Explicit verification of dynamic controls will not impact the cost effectiveness of dynamic outside air control demonstrated in the 2005 codes enhancement. Specifically, Section 10.6.3 of the Nonresidential Compliance Manual currently states that the "Acceptance Agent should review the sequences of operation to ensure that the system has been designed for dynamic control of minimum outdoor air and review the installation to make sure that all of the devices that are part of that sequence are indeed installed." Any additional effort to document the review of sequences and installation in the acceptance test form will be negligible and not decrease the cost effectiveness of dynamic controls.	
j. Analysis Tools	Not applicable.
k. Relationship to Other Measures	No other measures are impacted by this recommendation.

a. Measure Title	Verify proper location of outdoor air ducts in plenum systems.
b. Description	This measure will verify proper location of outdoor air ducts in systems where a return air plenum is used to distribute outside air to a zonal heating or cooling unit. Although required by §121(e) of the Standards, proper location of outdoor air ducts in plenum systems is not currently verified in acceptance testing.
c. Type of Change	Changes would be made to the NA7.5.1 Outdoor Air Acceptance Form and the Nonresidential Compliance Manual to require that location of outdoor air ducts is verified.
d. Energy Benefits	This measure does not provide direct energy benefit.
e. Non-Energy Benefits	Proper location of outdoor air ducts may positively impact indoor air quality.
f. Environmental Impact The recommendation has no measureable impacts on water, water quality or environmental contaminants.	
g. Technology Measures	This measure will not require or encourage any new technologies.
h. Performance Verification of the Proposed Measure	The party responsible for acceptance testing will have to verify the location of the outside air supply and that the return air plenum is not used to distribute outside air to a zonal heating or cooling unit.
Cost Effectiveness The intent of this measure is to improve indoor air quality (not energy performance), and as a result, cost effectiveness analysis is not applicable.	
j. Analysis Tools	Not applicable.
k. Relationship to Other Measures	None.

a. Measure Title	Confirm pre-occupancy purge for all system types.
b. Description	Currently, pre-occupancy purge verification is only completed for single zone and unitary systems. This measure would extend verification to all system types as required in §121(c)2.
c. Type of Change	Changes would be made to the NA7.5.1 Outdoor Air Acceptance Form and the Nonresidential Compliance Manual to require that pre-occupancy purge is properly implemented.
d. Energy Benefits	This measure does not provide direct energy benefit.
e. Non-Energy Benefits	A programmed pre-occupancy purge will improve thermal comfort and air quality inside of the space.
f. Environmental Impact The recommendation has no measureable impacts on water, water quality or environmental contaminants.	
g. Technology Measures	This measure will not require or encourage any new technologies.
h. Performance Verification of the Proposed Measure	The party responsible for acceptance testing will have to verify that pre-occupancy purge has been programmed to meet the requirements of Standards Section 121(c)2. This step may require coordination with the controls or mechanical contractor.
Cost Effectiveness The intent of this measure is to improve indoor air quality (not energy performance), and as a result, cost effectiveness analysis is not applicable. Furthermore, the effort associated with verifying programming of the pre-occupancy purge is minimal.	
j. Analysis Tools	Not applicable.
k. Relationship to Other Measures	None.

a. Measure Title	Correct CO_2 sensor mounting height in Nonresidential Compliance Manual.
b. Description	This change will simply correct the one foot minimum CO_2 sensor mounting height mentioned in Nonresidential Compliance Manual to match the three foot minimum required in the NA7.5.5 Demand Control Ventilation Systems Acceptance Form (MECH-6A). This change will affect all demand control ventilation systems.
c. Type of Change	Changes would be made to the Nonresidential Compliance Manual to maintain consistency with the NA7.5.5 Demand Control Ventilation Systems Acceptance Form (MECH-6A).
d. Energy Benefits	No benefits will be realized above energy savings already established for demand control ventilation (DCV) systems in prior CASE Initiatives.
e. Non-Energy Benefits	Proper mounting height of CO_2 sensors will enable better control of demand control ventilation systems.
f. Environmental Impact The recommendation has no measureable impacts on water, water quality or environmental contaminants.	
g. Technology Measures	This measure will not require or encourage any new technologies.
h. Performance Verification of the Proposed Measure	None.
Cost Effectiveness This measure will not affect the cost effectiveness of DCV systems demonstrated in prior CASE Initiatives.	
j. Analysis Tools	Pending energy analysis methodology.
k. Relationship to Other Measures	None.

a. Measure Title	Add guidance for measuring outdoor air ventilation rates during acceptance testing.
b. Description	This measure will add guidance for how to measure outdoor air ventilation rates across all mechanical ventilation system types. Outdoor air flow measurements can be very inaccurate if not done properly, and this recommendation will clarify best practices for parties conducting acceptance testing. The guidance will cover choosing instrumentation, avoiding areas of turbulence, measuring free area and averaging multiple measurements.
c. Type of Change	Additional guidance would be added to the Nonresidential Compliance Manual regarding instrumentation and measurement location.
d. Energy Benefits	The proposed changes will not provide additional energy benefit but will help improve enforcement and testing of outside air rates.
e. Non-Energy Benefits	This guidance will educate acceptance testers, clarify testing protocol, and improve standardization of testing methods.
f. Environmental Impact The recommendation has no measureable impacts on water, water quality or environmental contaminants.	
g. Technology Measures	This measure will not require or encourage any new technologies.
h. Performance Verification of the Proposed Measure	This measure affects the methods used in performance verification but does not require additional verification itself.
Cost Effectiveness Not applicable.	
j. Analysis Tools	Not applicable.
k. Relationship to Other Measures	None.

a. Measure Title	Encourage reduction of outside air during partial occupancy.
b. Description	This measure will encourage reduction of outside air during partial occupancy by modifying text in the Nonresidential Compliance Manual.
c. Type of Change	A slight modification to the text in the Nonresidential Compliance Manual would be made regarding outside air during partial occupancy.
d. Energy Benefits	Because this guidance does not change requirements or mandatory measures, it does not result in direct energy benefits.
e. Non-Energy Benefits	None.
f. Environmental Impact The recommendation has no measureable impacts on water, water quality or environmental contaminants.	
g. Technology Measures	This measure will not require or encourage any new technologies.
h. Performance Verification of the Proposed Measure	Not applicable.
Cost Effectiveness Not applicable.	
j. Analysis Tools	Not applicable.
k. Relationship to Other Measures	None.

2. Methodology

As described in this section, the proposed measures related to outside air acceptance testing are based on three phases of study. First of all, a list of best practice methods for measuring outside air flow is developed by researching literature and speaking with industry stakeholders. Secondly, these methods are tested in the field to determine which are best suited for outside air acceptance testing. Finally, the methods determined to be most effective are used to measure outside air flow of 17 air handling units across California. The results of the test are analyzed against the outside air flow required by Title-24.

Field testing and detailed analysis of the remaining proposed measures is not necessary. In general, obtaining stakeholder feedback, researching industry and product literature, and ensuring consistency between the Standards and Compliance Manual were enough to propose the other measures in this report.

2.1 Methodology for Outdoor Air Acceptance Testing Recommendations

Recommendations for the acceptance testing and control of outdoor air ventilation rates are based on a two part study. This methodology is the basis for the following measures.

- Explicitly require and confirm during acceptance testing that outdoor air rates are dynamically controlled for variable air volume systems.
- Add guidance for measuring outdoor air ventilation rates during acceptance testing.

As described below, the first part determines the best practices for measuring outdoor air flows in the field while the second part consists of in-situ testing of air flows on existing ventilation systems.

2.1.1 Determining Best Practice Measurement Methodology

The purpose of this portion of the study is to define the best practice outside air flow measurement methodology for use in the field. Literature review and interviews with industry stakeholders indicate that the most viable options for field measurement include a hot wire anemometer, velocity matrix, flow hood or temperature balance. Below is a list of the stakeholders interviewed and literature reviewed.

Interviews

- James Fraley, P.E. – Indoor Air Professionals
- Chris Ruch – Airco Automation
- Mike Shell – Airtest Technologies Inc.
- James Farrah - Honeywell

Literature

- Kahoe Test & Balance Field Manual
- The Fundamentals of Testing, Adjusting & Balancing HVAC Systems - Associated Air Balance Council
- TAB Procedural Guide - Sheet Metal and Air Conditioning Contractors' National Association, Inc. (SMACNA), 2003.
- Indoor Air Quality Handbook
- National Standards for Total System Balance - Associated Air Balance Council

To determine which of these is most suitable and accurate, each method is applied to an air handler in both minimum flow condition (supply fans at 30% maximum flow) and at a high flow condition (supply fans at 65% maximum flow). During testing, the air handler is not economizing and intakes outside air only through a dedicated, minimum intake section. Each testing method is performed three times during steady state air handler operating conditions. Measurements are taken at both the interior and exterior side of the outside air intake dampers. For exterior measurements a temporary cardboard shroud is constructed to test whether the deflection of cross winds would affect measurements. The length of the shroud is equal to the width of the intake louver. A data collection form is used to record measurement data and field observations. A blank copy of this form has been provided as an Appendix.

Methodology	Measurement Location	Intake Shrouded?
Velocity Matrix	Interior	No
	Exterior	Yes
	Exterior	No
Hot Wire Anemometer	Interior	No
	Exterior	Yes
	Exterior	No
Flow Hood	Exterior	No
Temperature Split	N/A	No

Figure 1. Testing matrix for study of best practice measurement methodology

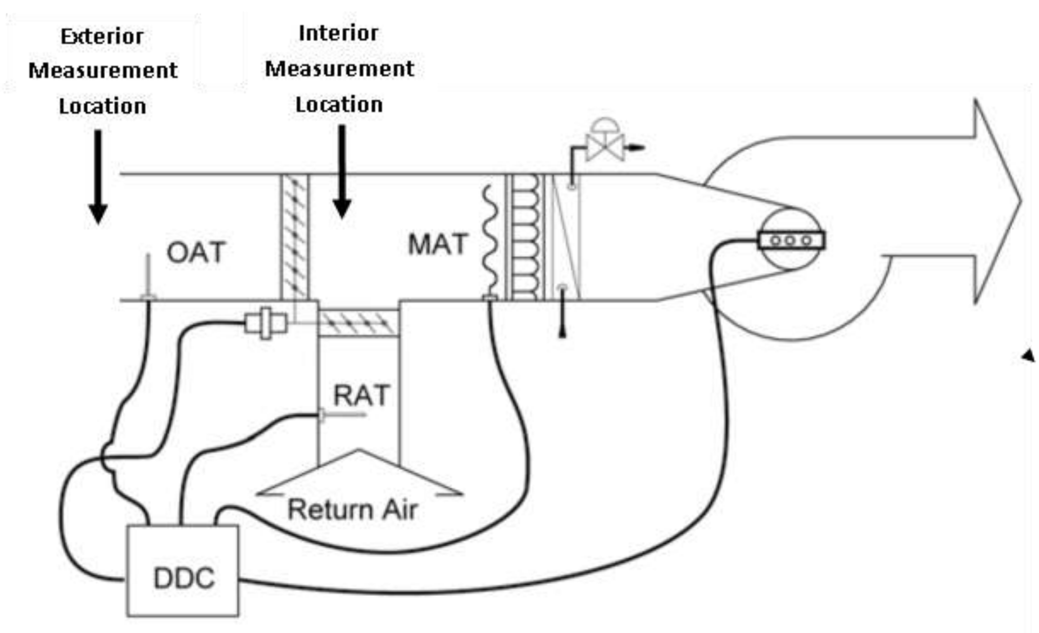


Figure 2. Diagram of exterior and interior measurement locations[1]

[1] Image adapted from: *Figure 4-3 – Energy Balance Method of Controlling Minimum Outdoor Air*. 2008 Building Efficiency Standards, Nonresidential Compliance Manual. California Energy Commission. CEC-400-2008-017-CMD. December 2008.

Installed Flow Sensor

The air handler's minimum intake louver is equipped with permanently installed flow sensing dampers. Because the latest calibration date (if any) of these sensors could not be confirmed, their measured values are used as a reference for the other methodologies, not as an absolute control against which accuracy can be assessed.

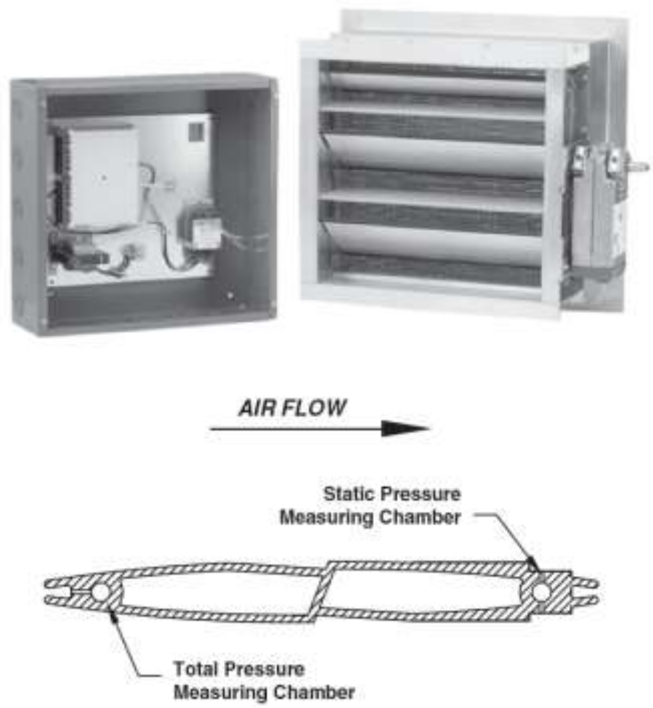


Figure 3. Flow sensing dampers.[2]

Velocity Matrix Traverse

A velocity matrix is essentially a 1'x1' grid of fixed pitot tubes that provides average measurements. To use this device, the damper opening is divided into approximately 1'x1' evenly distributed areas over the entire face. For example, if a louver face was 6'6" tall by 2' wide, the face was divided into 1'1"x1' squares rather than leaving a 6" strip untested at the edge of the louver. Measurements using the velocity matrix are then taken for each area and recorded. This test is performed on both the external face of the outside air louver as well as from the internal face of the damper in the mixed air plenum. The overall louver or damper dimensions from inside of frame to inside of frame are also recorded.

[2] *Flow Sensing Damper*. Specifications for AIR MEASURING STATION WITH INTEGRAL DAMPER AND CALIBRATED CONTROLS. Ruskin. Kansas City, 2008.

Figure 4. Velocity matrix.[3]

Flow Hood Traverse

A flow hood is used in a horizontal configuration to measure outside air intake from the exterior of the air handler. The intake end of the flow hood (e.g. the end closest to the ceiling diffuser during typical use) was placed against the louver, and multiple readings are taken such that the entire louver face is measured. The individual readings are summed in order to provide total flow.

[3] *Velocity Matrix*. Web Image. Professional Equipment. http://www.professionalequipment.com/velocity-matrix-probe-for-alnor-balometer-air-flow-capture-hood-801090/hvac-accessories/

→

Air Flow

→

To outside intake louver →

Figure 5. Flow hood traverse orientation.[4]

Hot Wire Anemometer Traverse

Hot wire anemometer measurements are taken across louver or damper blade openings at the face of the louver or damper opening. Measurements are averaged across each louver or damper blade opening. Dimensions of each louver or blade opening are recorded in order to find the exact free area of the louver or damper. These tests are performed both at the external louver face as well as within the mixed air chamber at the internal face of the damper.

Temperature Balance

Temperature measurements are recorded for outside air at the intake damper, return air at the return air damper, and mixed air at the middle of the filter bank face. Supply air flow is taken using a hot wire anemometer traverse measurement at the face of the cooling coil. Outdoor air flow is then calculated using the formula below.

[4] Image adapted from website image: *ABT703 Balometer® Capture Hood*. TSI Incorporated. Shoreview, MN. http://www.tsi.com/en-1033/models/20275/ABT703%20Balometer%20Capture%20Hood.aspx#

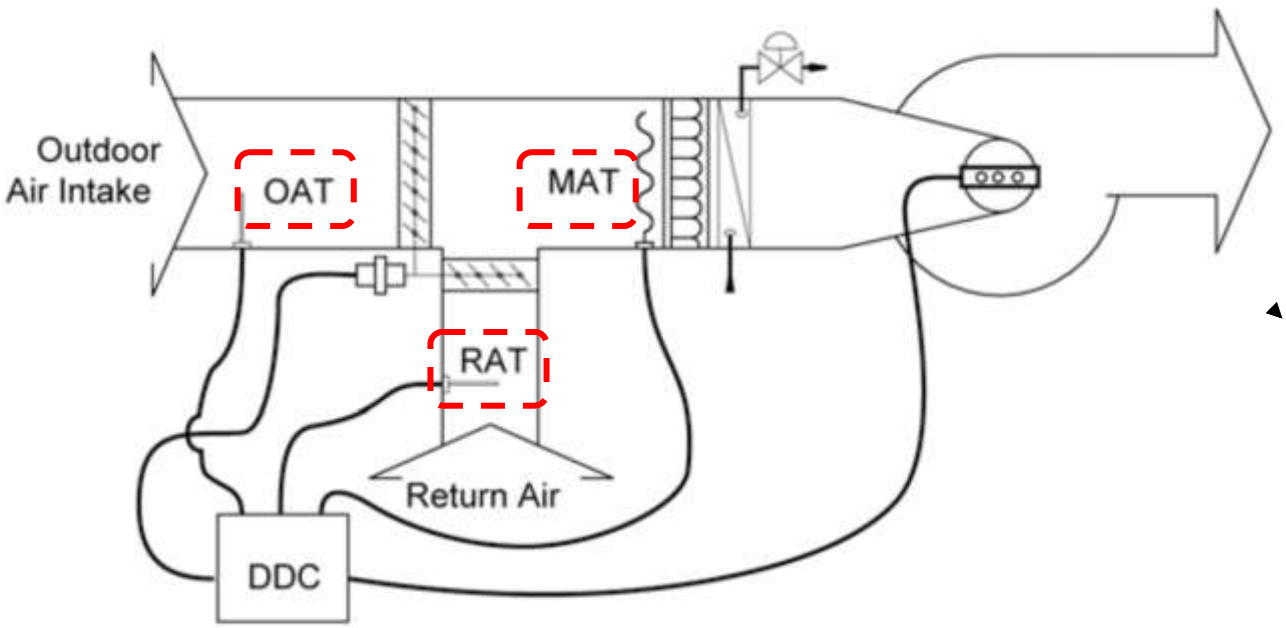


Figure 6. Temperature balance measurement locations.[5]

OA_flow = SA_flow x (RA_temp - MA_temp) / (RA_temp - OA_temp)

Where,

OA_flow = calculated flow rate of outside air, CFM
SA_flow = measured flow rate of supply air, CFM
RA_temp = measured temperature of return air, degrees Fahrenheit
MA_temp = measured temperature of mixed air, degrees Fahrenheit
OA_temp) = measured temperature of outside air, degrees Fahrenheit

2.1.2 In-situ testing of minimum outdoor ventilation rates

The purpose of this portion of the study is to measure outdoor air ventilation rates and compare actual performance to the Title 24 requirement. As shown in Figure 7, these tests cover multiple system types, and variable air volume (VAV) systems are tested at both minimum and maximum fan modes in order to assess performance of dynamic controls.

[5] Image adapted from: *Figure 4-3 – Energy Balance Method of Controlling Minimum Outdoor Air*. 2008 Building Efficiency Standards, Nonresidential Compliance Manual. California Energy Commission. CEC-400-2008-017-CMD. December 2008.

System Type	No. Systems Tested	No. Total Tests
Multi Zone	13	26
Built-Up Multi Zone	6	12
OA Control: Fixed Min Damper	5	10
OA Control: Dynamic	1	2
Packaged Multi Zone	7	14
OA Control: Fixed Min Damper	6	12
OA Control: Dynamic	1	2
Single Zone	4	7
OA Control: Fixed Min Damper	4	7
Total	**17**	**33**

Figure 7. Test matrix for in-situ testing of ventilation systems.

Based on results from the methodology testing, these measurements are taken using the hot wire anemometer and velocity matrix. Measurements are taken from the exterior of the air handling unit, unless system configurations require interior measurements. The velocity matrix is not used for flows below 250 feet per minute, and exterior testing does not include shrouding. Results and analysis regarding the outcome of methodology testing are summarized in section 3.4.2 Testing Results and Analysis.

2.2 Additional Measures

Testing methodologies are not necessary for certain measures due to their scope and simplicity. These recommendations are described below.

2.2.1 Correct CO2 sensor mounting height in Nonresidential Compliance Manual

Based on inspection, the Nonresidential Compliance Manual (CM) erroneously states that the mounting height of space CO2 sensors should be within one to six feet from the floor. No further study was conducted in order to recommend changing the Nonresidential Compliance Manual (CM) to match the three foot minimum required by §121(c)4B of the Standards and verified by NA7.5.5 Demand Control Ventilation Systems Acceptance Form (MECH-6A).

2.2.2 Verify proper location of outdoor air ducts in plenum systems

Although required by §121(e) of the Standards, proper location of outdoor air ducts in plenum systems is not verified in acceptance testing. No further study or analysis was conducted in order to recommend that acceptance testing protocol be made consistent with the Standards.

2.2.3 Confirm pre-occupancy purge for all system types in plenum systems

Although required by §121(c)2 of the Standards for all systems, pre-occupancy purge is currently verified only for single zone and unitary systems. No further study or analysis was conducted in order to recommend that acceptance testing protocol be made consistent with the Standards.

2.2.4 Encourage reduction of outside air during partial occupancy

Only a slight modification to the text in the Nonresidential Compliance Manual is necessary to implement this measure. The proposed modification originated from stakeholder feedback, and no further investigation was conducted.

2.3 Stakeholder Meeting Process

Response from stakeholders is an integral part of the development of measures. All of the main approaches, assumptions and methods of analysis used in this proposal have been presented for review at one of three public Nonresidential HVAC Stakeholder Meetings. Specifically, the CASE authors presented and discussed proposed measures with stakeholders and invited feedback on the proposed language and analysis.

A record of the Stakeholder Meeting presentations, summaries and other supporting documents can be found at www.calcodes.com. Stakeholder meetings were held on the following dates and locations:

- First Nonresidential HVAC Stakeholder Meeting: April 27, 2010, California Lighting Technology Center, Davis, CA.
- Second Nonresidential HVAC Stakeholder Meeting: December 7, 2010, San Ramon Valley Conference Center, San Ramon, CA
- Third Nonresidential HVAC Stakeholder Meeting: March 2011, via webinar.

In addition to the Stakeholder Meetings, informal outreach and working sessions were conducted to allow detailed review of specific technical issues.

Below is a summary of the key issues identified and discussion by stakeholders by topic.

2.3.1 CO2 Sensor Calibration

- The accuracy of CO2 sensors is highly variable.
- What are industry standards for testing/calibration of sensors?
- Requiring standardized regulations for CO2 sensor calibration will increase reliability and cost.

2.3.2 Dedicated Outside Air Intakes

- Requiring dedicated outside air intakes with dynamic controls/measurement and minimum flow velocities will improve control over ventilation rates.
- Dedicated intakes are more feasible for larger air handling units, but the cost for small units may be doubled if dedicated outside air intakes are required.
- Industry stakeholders expressed a desire for flexibility in finding alternative solutions to ventilation control other than required dedicated outside air intakes.
- If outside air flow measurement does not become prescriptive, credit should be given for systems with permanent airflow measurement.

2.3.3 Outside Air Measurements

- Best practice for measuring flow with an anemometer includes keeping the device normal to the direction of flow. In the field, this is sometimes difficult to do.
- Technicians often stand near the air intake which flaws results especially in low flow systems.
- Fan powered flow hoods may be a viable option for field testing of outside air measurements.

3. Analysis and Results

This section presents the findings from the literature review and field testing.

3.1 CO2 Sensor Performance - Literature Review

Although demand control ventilation has large energy savings potential, these savings are often not realized due to CO2 sensors that are not calibrated or non functional. Studies have shown that many CO2 sensors have large errors in the field and also that there are many sensors that are not calibrated directly from the factory (Fisk 2008, Shrestha 2010). Fisk has shown that within operating commercial office buildings, approximately 39% of the sensors would not provide accurate readings to appropriately control a DCV system in an office setting. Similarly, Shrestha has shown that of 45 sensors tested in laboratory conditions, only 15 were within the manufacturer's guidelines for accuracy. Seemingly a solution to these issues would be a field calibration of the sensor. However, Shrestha finds that many sensors do not easily allow for field calibration (if at all) and additional calibration equipment would be required by the commissioning agent.

3.2 CO2 Sensor - Availability of Factory Calibrated CO2 Sensors

Product specifications from major controls and HVAC manufacturers indicate that factory calibrated CO2 sensors are commonplace and readily available. Furthermore, product literature typically indicates that field calibrations are not recommended or necessary. A review of product literature from Honeywell, Johnson, Siemens, Trane and Airtest shows that all of these manufacturers/vendors offer both wall and duct mounted CO2 sensors that they claim are factory calibrated or require no recalibration in the field. These sensors are summarized in Figure 8.

Manufacturer/Vendor	Model Number	Type
Honeywell	C7232A	Wall
Honeywell	C7232B	Duct
Honeywell	C7632A	Wall
Honeywell	C7632B	Duct
Johnson	CD-Pxx-00-1	Duct
Johnson	CD-W00-00-1	Wall
Siemens	QPM21	Duct
Siemens	QPA20	Wall
Trane	X13790423010, VACO2DUCT010, SEN01092	Duct
Trane	X13790422010, VACO2ZONE010, SEN01087	Wall
Airtest	TR9290	Wall
Airtest	TR9294	Wall
Airtest	TR9291	Duct

Figure 8. List of factory calibrated CO2 sensors.

3.3 CO2 Sensors – Cost of Field Verification

In order to assess overall cost effectiveness, the incremental cost of field verifying CO2 sensors has been added to the installation cost. Specifically, the installed cost of DCV for a 400 square foot zone was calculated to be $575 in the Title 24 2005 report for single zone DCV measures (CEC April

2002). Assuming that a zone of this size would be served by a single CO2 sensor, the labor to verify the sensor is calculated in this study to be an additional $35 per zone. As demonstrated by the CASE Report for DCV for Multiple Zone Systems (2008), TDV cost saving for this zone is $1,560.

As summarized in Figure 9, the cost estimate for field verification includes one half hour of additional labor each for an HVAC installer and building inspector. Because a calibrated, handheld CO2 analyzer is already part of the acceptance test instrumentation, no additional materials cost are necessary. Hourly wages are conservatively based on 75th percentile hourly wages as reported by the California 2009 Occupational Employment Statistics (OES) survey.

	DCV Not Including CO2 Sensor Verification	**DCV Including Proposed CO2 Sensor Verification**
Cost savings per 400 sq.ft. zone	$1,560	$1,560
Hours to field verify one CO2 sensor	N/A	0.5
Building Inspector Hourly Wage	N/A	$40.37
HVAC Installer Hourly Wage	N/A	$30.05
Total CO2 sensor verification labor cost	N/A	$35
Total Installed Cost	$575	$610
Installed Cost as % of Cost Savings	37%	39%
Simple Payback (years)	0.37	0.39

Figure 9. Proposed labor cost of verifying CO2 sensor calibration.

Even after including field verification of sensors, demand control ventilation is cost effective with a 0.39 year simple payback period.

3.4 Outside Air Testing - Best Practice Measurement Methodology

3.4.1 Literature Review and Industry Interviews

Accurate measurement of outdoor air is difficult because of intake configurations, and as a result, guidance on how to directly measure outside air flows is scarce within the test and air balance industry (Ruch, 2010). In order to set minimum outdoor air levels, however, most industry guides recommend three methods: a duct traverse, subtracting return air flow from supply air flow, or using a temperature balance (SMACNA 2003, Steiskal 1993, AABC). Other options for measuring flow include tracer gas concentration tests and direct inlet measurements using flow hoods or anemometers (Spengler, 2002). In a residential setting, fan powered flow hoods have been shown in studies to be more than an order of magnitude more accurate than passive hoods (Wray 2002), but their application to measuring outside air is not well documented.

A number of these methods, however, are not practical for field measurements. The duct traverse method is not deployable because long, uninterrupted duct sections are necessary for accurate flow measurements. Outdoor air intakes rarely have a duct adequate to produce such steady, laminar flows (Spengler 2002). The subtraction method is not advantageous because under normal operating conditions, not only would exhaust air have to be accounted for, but measurement of supply and return air would introduce further error. Although accurate, the tracer gas method is impractical due to the need for highly specialized, expensive equipment and the significant time to set up and conduct the test.

As a result, the most viable options for field practitioners are indirect measurement using the temperature balance method as well as direct intake measurements using a hot wire anemometer, velocity matrix or flow hood. All of these direct measurement methods are easily conducted in the field and do not require special instrumentation or training. Although temperature balance tends to be inaccurate and is often listed as a last resort method in technical guides (Spengler 2002, AABC, SMACNA 2003, Steiskal 1993, Ruch 2010), this method is studied as a possible best practice due to its wide use in the industry.

3.4.2 Testing Results and Analysis

As seen in Figure 10, performance of each of the methodologies varies greatly when compared to the installed flow sensor. To clarify, these measurements are taken on a single air handler according to the methodology and test matrix summarized in Section 2.1.1 and Figure 7. The major takeaways from this testing are summarized below and discussed in detail in subsequent sections.

- The hot wire anemometer and velocity matrix provide relatively accurate and precise measurements. Because of their flexibility, these technologies are highly suitable for field measurements.
- The velocity matrix is not appropriate for flows slower than approximately 250 feet per minute.
- Measurements taken from the exterior of the air handler unit are slightly closer to reference values than measurements from the inside of the mixed air plenum.
- Shrouding of the intake for exterior readings does not have measureable benefit.
- The flow hood is not appropriate for field testing because of the increased pressure drop imposed by the hood.
- Although it performed well during this particular test, the temperature split method is very dependent on large temperature differences and highly accurate supply flow and temperature measurements. As a result, this method may not be widely applicable in the field.

At minimum and maximum flow, percent difference from the installed flow sensor is represented by blue and red bar graphs (corresponding values on the left hand vertical axis). The coefficient of variation for each methodology is represented by the triangular and circular points (corresponding values on the right hand vertical axis). Coefficient of variation is a non-dimensional measure of the variability in a data set. This value is equal to the standard deviation of the data set divided by the average of the data set (i.e. larger coefficient of variation indicates less precise data).

In general, methods to the left of the figure provide more accurate measurements as compared to the installed flow station. Relative precision of each method can be judged based on the height of the points denoting coefficient of variation, either circular or triangular.

For example, the temperature split method is the left most methodology yet has the highest coefficient of variation during maximum flow (red circle). This indicates that the average of these measurements is relatively accurate when compared to the flow station, but that the measurements themselves varied greatly and are not precise.

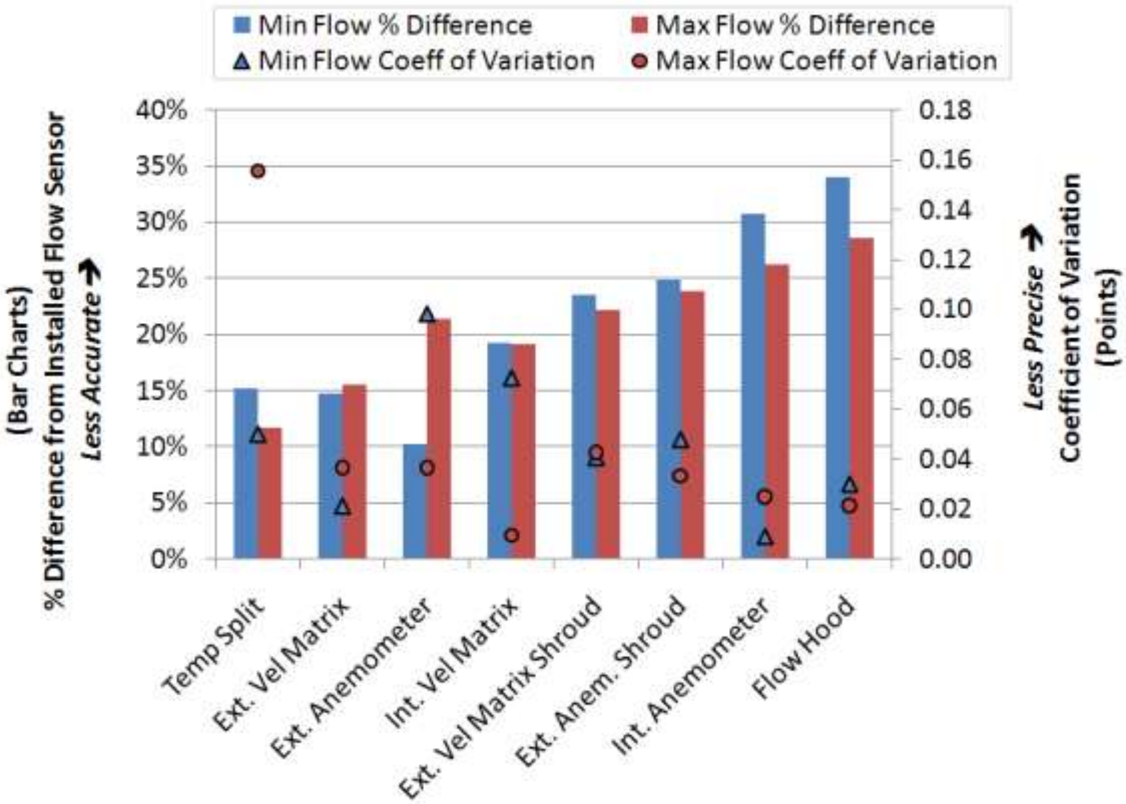


Figure 10. Relative accuracy and precision of OA measurement methodologies

Effect of Shrouding

As shown in Figure 11, the shroud does not have a significant impact on the precision of the exterior flow measurements. Measurements with the shroud are, on average, 8% further from flow station values than measurements without a shroud. Shrouded measurement, however, are also 15% less variable as indicated by coefficient of variation. Note that results using anemometer and velocity matrix are combined in Figure 11. In total, the inconclusive results do not prove that shrouding significantly improves measurement precision or accuracy. This conclusion is supported by the fact that discussion of intake measurements in literature does not mention shrouding as a technique to improve accuracy. As a result, presentation of data for each of the subsequent measurement methodologies do not include shrouded measurements.

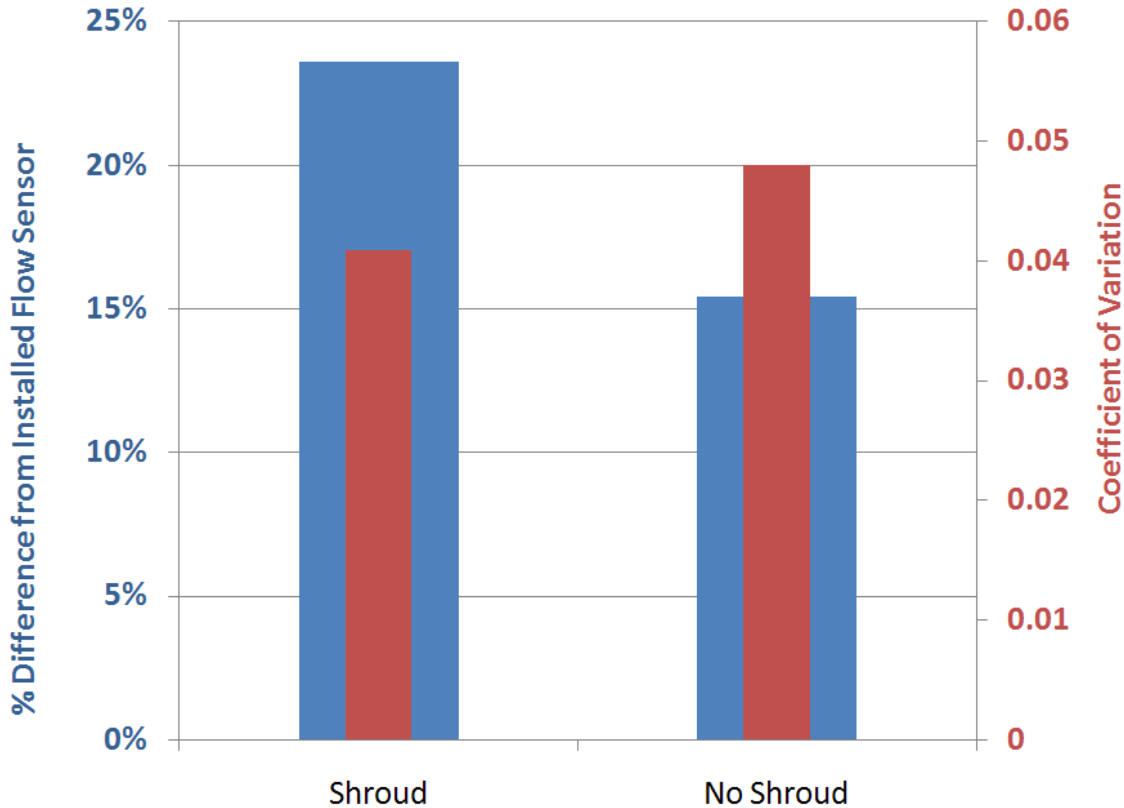


Figure 11. Effects of intake shrouding on OA flow measurement

Velocity Matrix Traverse

The velocity matrix provides measurements that are close to those of the flow sensor, especially when flow velocities are high. On average, external and internal measurements using the velocity matrix are within 15.1% and 19.2% of the flow sensor, respectively. From the maximum to minimum flow condition, however, the coefficient of variation for the internal velocity matrix increases by almost a factor of eight. This increase in variability confirms field observations that the velocity matrix does not perform well when flow velocities are low (i.e. less than 250 feet per minute).

Flow Hood Traverse

The flow hood measurements are on average 31.3% less than flow sensor readings. The flow hood is prone to large error due to the pressure drop created by the hood itself. The air speed across the louver is fairly slow, which leads to very low pressure drops across that louver. While the pressure drop from the hood testing equipment is fairly small, in comparison to the pressure drop across the louver, it is large enough to affect the flow dynamics and force more air to go around the hood and through the uncovered areas of the louver.

Hot Wire Anemometer Traverse

Internal and external hot wire measurements are within 28.5% and 15.8% of flow sensor values, respectively. Even during the minimum flow condition, internal anemometer measurements have the lowest coefficient of variation of all test methodologies. This outcome indicates that the anemometer is appropriate for use when velocities are low (i.e. less than 250 feet per minute). The low velocity flow applicability of hot wire anemometers, down to 10 ft/min, is supported by literature (Steiskal 1993, Spengler 2002).

Temperature Balance

Although the temperature split method yielded values within 13.4% of the flow sensor, variation of the measurements is relatively high. The temperature split is also error prone as it relies heavily on a large temperature difference between the outside air and the return air to give an accurate percentage of outside air. In many cases, the temperature difference may be sufficiently small that user error or temperature sensor resolution will dominate the measurement. Additionally, the uncertainty from each of the individual supply flow and three temperature measurements leads to severe error stacking (Spengler, 2002).

3.4.3 Testing Methodologies - Conclusions

The hot wire anemometer and velocity matrix are used in the remainder of the field tests in this study. Wherever possible, measurements are taken from the exterior of the air handling unit, but in practice, internal measurements may be the only option due to system configuration. The velocity matrix is not used for flows below 250 feet per minute, and exterior testing does not include shrouding.

3.5 Outside Air Testing - In-situ measurement of minimum outdoor ventilation rates

3.5.1 Over-ventilation

When considering all system types and modes of operation, the system types tested are over ventilating by an average of 62% (i.e. relative deviation) above the required Title 24 outdoor air flow requirement. As seen in Figure 12, the absolute deviation from Title 24 requirements averages 77% across all system types. Relative deviation includes both under and over performance values from individual tests. A relative deviation that is small in magnitude indicates high accuracy in delivering outside air rates. Absolute deviation considers only the magnitude of the deviation, regardless of whether it is over or under ventilation. An absolute deviation that is small in magnitude indicates high precision in delivering outside air rates. Note that a negative relative deviation represents under ventilation.

System Type	Average % Relative Deviation from Title 24 OA Requirement	Average % Absolute Deviation from Title 24 OA Requirement
Built-Up	84%	89%
Multi Zone	84%	89%
OA Control: Fixed Min Damper	98%	99%
OA Control: Dynamic	11%	40%
Packaged	50%	70%
Multi Zone	21%	36%
OA Control: Fixed Min Damper	25%	38%
OA Control: Dynamic	-1%	23%
Single Zone	108%	138%
OA Control: Fixed Min Damper	108%	138%
Total	**62%**	**77%**

Figure 12. Percent Deviation from Title 24 OA requirement by system type

As seen in Figure 13, the majority of tests result in over ventilation, and only 4% of tests yield flow rates that are compliant with Title 24 requirements. Per acceptance testing requirements of MECH-2A, systems are characterized as compliant if measured air flow is within 10% of the Title 24 requirement.

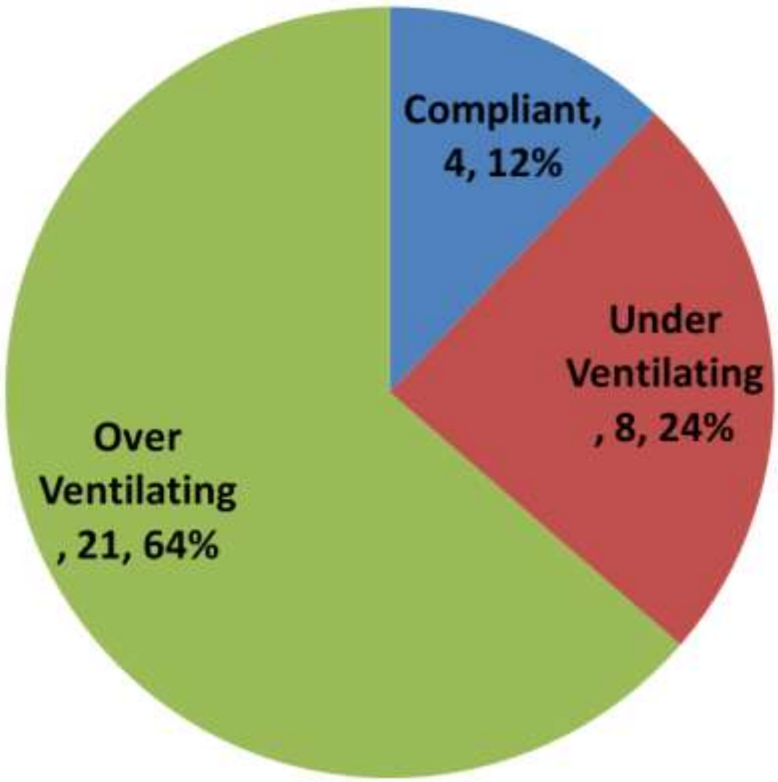


Figure 13. Outside air test results by type of deviation.

As seen in Figure 14, smaller ventilation units tend to deviate more from Title 24 requirements than larger systems. Outside air flow is used as proxy for system size, and percent deviation measured during minimum and maximum fan operating modes are averaged together.

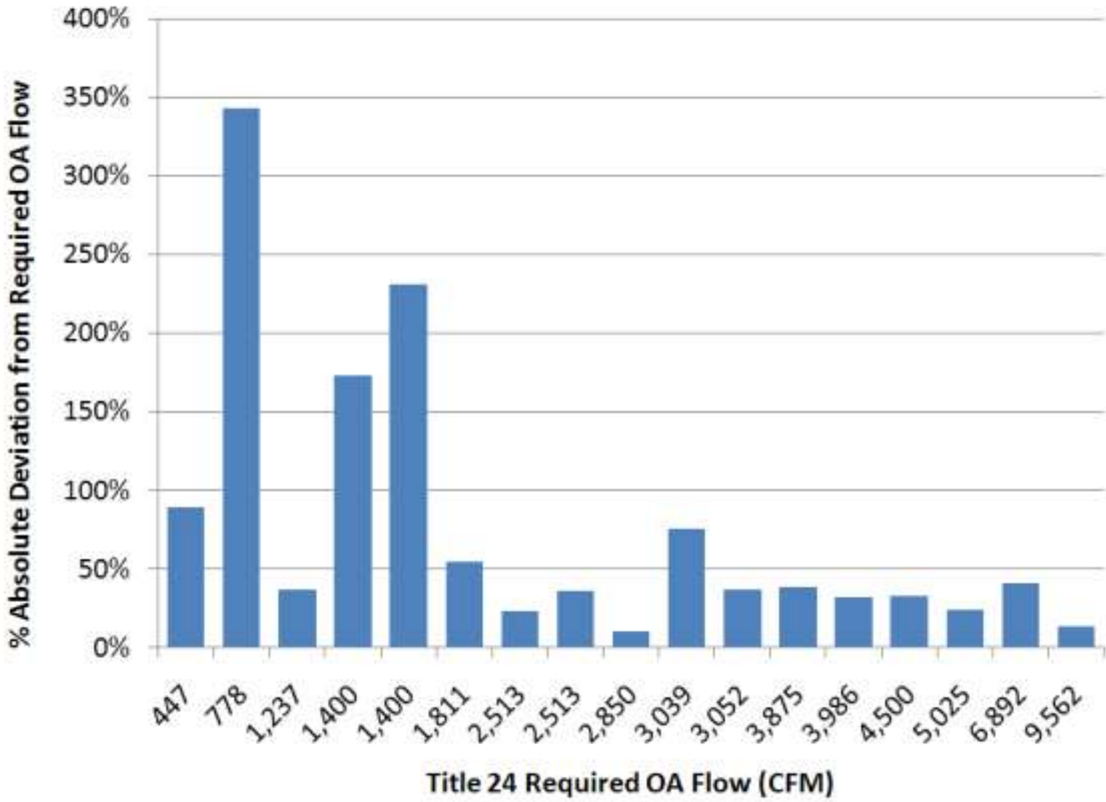


Figure 14. Percent relative deviation of OA flow arranged by amount of required OA flow.

3.5.2 Lack of Dynamic Controls

Although dynamic control of outside air is required for all 17 of the tested systems, 15 of the systems use a fixed minimum damper position. As seen in Figure 15, both the relative and absolute deviation of systems with fixed minimum dampers is significantly greater than that of dynamically controlled systems. In other words, dynamic systems are both more accurate (i.e. lower relative deviation) and more precise (i.e. lower absolute deviation) at delivering outside air ventilation.

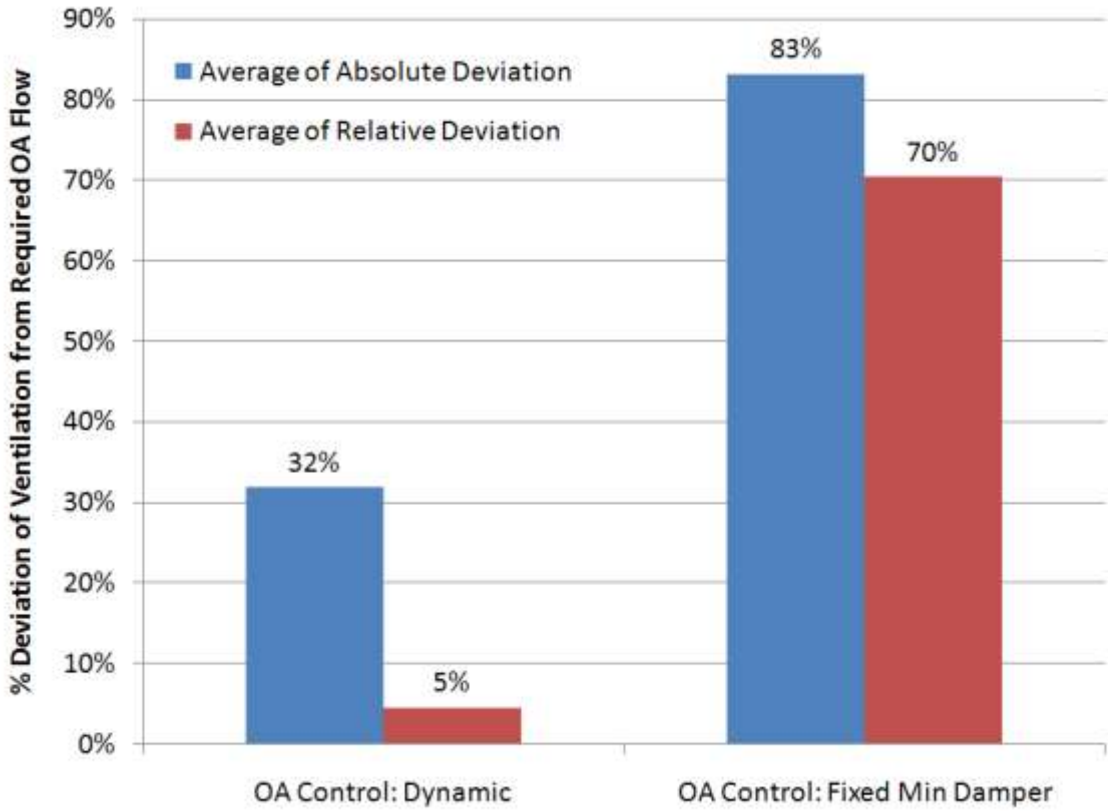


Figure 15. Percent deviation from Title 24 OA requirements using dynamic versus fixed minimum damper position control.

The two systems tested with dynamic control used active flow sensing dampers and a dedicated minimum ventilation damper with pressure control. Measurements show that the system with flow sensing dampers was both more precise and accurate than the pressure controlled system (relative & absolute deviation = -1.0% & 23% versus 11% and 40%, respectively). Because of the small sample, however, these results are anecdotal, and larger conclusions regarding the relative performance of different dynamic controls is beyond the scope of this study.

As seen in Figure 16, absolute deviation of measured OA rates is significantly lower for systems using dynamic controls. This deviation remains relatively consistent between ventilation modes (i.e. minimum to maximum), which indicates that the dynamic controls are effectively modulating to maintain a set OA rate. Deviation for systems with fixed minimum control, on the other hand, increases almost two fold from minimum to maximum ventilation mode. This result indicates that, in general, installers are setting the minimum damper position during minimum ventilation mode with no adjustment for higher supply air flows.

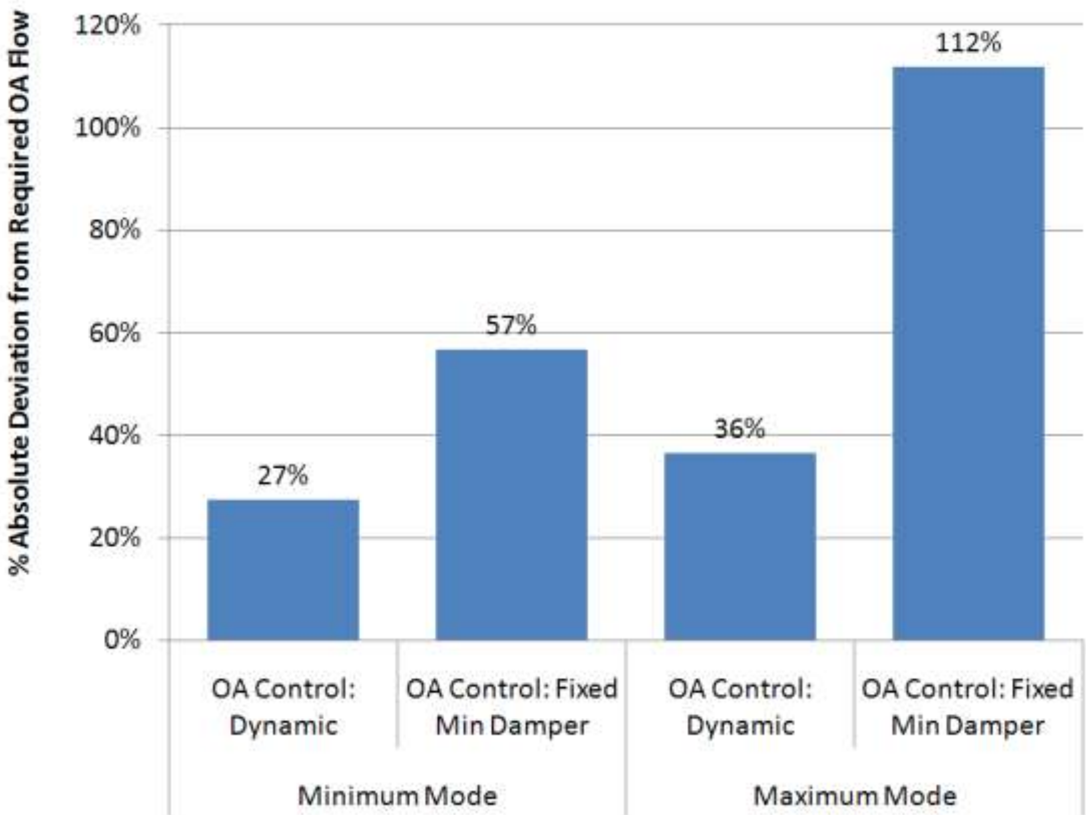


Figure 16. Absolute deviation by ventilation mode and OA control strategy.

3.5.3 In-Situ Testing - Conclusions

Systems are significantly over ventilating with outdoor air due to improper setting of the minimum condition and lack of dynamic controls. Changes to current acceptance testing protocols and guidance, however, can mitigate these common modes of installation failure. Specifically, explicit documentation in the acceptance testing form will help ensure that acceptance testers confirm dynamic controls are in place. Furthermore, adding guidance on how to measure outside air flow will lead to more accurate acceptance testing.

4. Recommended Language for the Standards Document, ACM Manuals, and the Reference Appendices

4.1 Require factory calibration of CO2 sensors and eliminate field calibration option

4.1.1 Proposed Language for the Standards Document, §121(c)4F

CO_2 sensors shall be certified by the manufacturer to be accurate within plus or minus 75 ppm at a 600 and 1000 ppm concentration when measured at sea level and 25°C, factory calibrated ~~*or calibrated at start-up*~~, and certified by the manufacturer to require calibration no more frequently than once every 5 years. Upon detection of sensor failure, the system shall provide a signal which resets to supply the minimum quantity of outside air to levels required by Section 121(b)2 to the zone serviced by the sensor at all times that the zone is occupied.

4.1.2 Proposed Language for the Reference Appendices, NA7.5.5 Demand Control Ventilation (DCV) Systems

NA7.5.5.1 Construction Inspection
Prior to Functional Testing, verify and document the following:

- Carbon dioxide control sensor is factory calibrated ~~*or field-calibrated*~~ per §121(c)4.
- The sensor is located in the high density space between 3ft and 6 ft above the floor or at the anticipated level of the occupants' heads.

DCV control setpoint is at or below the CO_2 concentration permitted by §121(c)4C.

4.1.3 Proposed Language for the Nonresidential Compliance Manual, Section 10.6.13

Second bullet point under the Construction Inspection section of Section 10.6.13 of the Compliance Manual:

~~*CO2 sensor is either factory calibrated or field calibrated. A calibration certificate from the manufacturer will satisfy this requirement. In order to perform a field calibration check, follow the calibration procedures provided by the manufacturer. Some sensor manufacturers may require using equipment-specific calibration kits (kits may include trace gas samples and other hand-held devices) whereas others may be calibrated simply by using a pre-calibrated hand-held CO2 measuring device and making proper adjustments through the sensor or ventilation controller.*~~ **CO2 sensor must be factory calibrated. A calibration certificate from the manufacturer will satisfy this requirement. Field calibration of CO2 sensors does not comply with Title 24.**

4.1.4 Proposed Language for MECH-6A - NA 7.5.5 Demand Control Ventilation Systems Acceptance Form

A full version of the acceptance testing form has been modified with all proposed changes from this CASE report and has been included as an Appendix. Excerpts from the existing form and proposed changes from this measure only are shown below.

Existing Construction Inspection Block

Construction Inspection

1 Instrumentation to perform test includes, but not limited to:

- a. Calibrated hand-held CO^2 analyzer
- b. Manufacturer's calibration kit
- c. Calibrated CO^2/air mixtures

2 Installation

- ☐ The sensor is located in the high density space between 3ft and 6 ft above the floor or at the anticipated level of the occupants' heads.

3 Documentation of all carbon dioxide control sensors includes (check one of the following):

- a. Calibration method
  - ☐ Factory-calibration certificate calibration cert must be attached
  - ☐ Field calibrated
- b. Sensor accuracy
  - ☐ Certified by manufacturer to be no more than +/- 75 ppm calibration cert must be attached

Proposed Construction Inspection Block

Construction Inspection

1 Instrumentation to perform test includes, but not limited to:

- a. Calibrated hand-held CO^2 analyzer
- b. Manufacturer's calibration kit
- c. Calibrated CO^2/air mixtures

2 Installation

- ☐ The sensor is located in the high density space between 3ft and 6 ft above the floor or at the anticipated level of the occupants' heads.

3 Documentation of all carbon dioxide control sensors includes (the following must be checked):

- ☐ Factory-calibration of sensor accuracy - Certified by manufacturer to be no more than +/- 75 ppm (factory calibration certificate must be attached)

4.2 Add field verification of CO2 sensors to acceptance testing of demand control ventilation systems

4.2.1 Proposed Language for the Nonresidential Compliance Manual

Section 10.6.12 – Estimated Time to Complete

~~*Functional testing: 1 to 2 hours (depending on how ambient CO2 concentration levels are manipulated, system response time to variations in CO2).*~~ **Functional testing: 1 to 3 hours (depending on number of CO2 sensors to be verified and how ambient CO2 concentration levels are manipulated, system response time to variations in CO2).**

Section 10.6.13 – Functional Testing

Add the following guidance above Step 1: Disable the economizer.

Before testing the system, verify that all CO2 sensors are accurate within +/- 75 PPM. In order to perform a field verification, follow the procedures provided by the manufacturer. Some sensor manufacturers may require using equipment-specific calibration kits (kits may include trace gas samples and other hand-held devices) whereas others may be verified simply by using a pre-calibrated hand-held CO2 measuring device. If a CO2 sensor is not accurate within +/- 75 PPM, the sensor must be replaced with another factory calibrated sensor and retested. Field calibration is not allowed.

4.2.2 Proposed Language for MECH-6A - NA 7.5.5 Demand Control Ventilation Systems Acceptance Form

Make the following changes to the "Functional Testing" and "Testing Results" Blocks of the MECH-6A Form. A full version of the acceptance testing form has been modified with all proposed changes from this CASE report and has been included as an Appendix. Excerpts from the existing form and proposed changes from this measure only are shown below.

Functional Testing Block

Existing Block

A.	Functional Testing	Results
a.	Disable economizer controls	
b.	Outside air CO^2 concentration (select one of the following)	
	☐ Measured dynamically using CO^2 sensor	________ ppm
c.	Interior CO^2 concentration setpoint (Outside CO^2 concentration + 600 ppm)	________ ppm

Proposed Block

A.	Functional Testing	Results
a.	Verify in the field that all CO2 sensors at both zone and system level are accurate to within +/- 75 PPM. ALL CO2 sensors must be verified, no sampling is allowed. Indicate PASS or FAIL in the Results field for ALL CO2 sensors.	
b.	Disable economizer controls	
c.	Outside air CO^2 concentration (select one of the following)	
	☐ Measured dynamically using CO^2 sensor	________ ppm
	☐ Interior CO^2 concentration setpoint (Outside CO^2 concentration + 600 ppm)	________ ppm

Testing Results Block

Existing Block

B. Testing Results	PASS	FAIL
Step 1: Simulate a high CO^2 load (check box complete)		
Step 2: Simulate a low CO^2 load (check box complete)		

Recommended Block

Step 3: System returned to initial operating conditions	Y / N	
B. Testing Results	**PASS**	**FAIL**
All CO2 sensors are verified to be accurate to within +/- 75 PPM		
Step 1: Simulate a high CO^2 load (check box complete)		
Step 2: Simulate a low CO^2 load (check box complete)		

4.3 Explicitly require and confirm during acceptance testing that outdoor air rates are dynamically controlled for variable air volume systems

4.3.1 Proposed Language for the Standards Document, §121(e)

Add the following language to the existing requirements under §121(e).

All variable air volume mechanical ventilation and space-conditioning systems shall include dynamic controls that maintain measured outside air rates within 10% of the required outside air rate at both full and reduced supply airflow conditions. Fixed minimum damper position is not dynamic and not an allowed control strategy.

Measured outdoor air rates of constant volume mechanical ventilation and space-conditioning systems must also be within 10% of the required outside air rate.

4.3.2 Proposed Language for the Nonresidential Compliance Manual

Section 10.6.2 – Purpose of the Test

This test ensures that adequate outdoor air ventilation is provided through the variable air volume air handling unit at two representative operating conditions. The test consists of **confirming dynamic control methods and** measuring outdoor air values at maximum flow and at or near minimum flow.

Section 10.6.2 – Acceptance Criteria

Add the following acceptance criteria to the end of the existing list.

Variable air volume systems use some form of active controls to modulate outdoor air rates. Fixed minimum damper setpoint CANNOT be used.

Section 10.6.3 – Construction Inspection

There are a number of means to dynamically control minimum OSA. A survey of common methods is presented in Chapter 4 of the Nonresidential Compliance Manual. **Note that fixed minimum damper setpoint, which is common industry practice, is not compliant with Title 24.** After validating that the sequence of control will dynamically control outdoor air check the ~~*"System is designed to dynamically control minimum OSA"*~~ **"Fixed minimum damper setpoint is NOT being utilized to control outside air"** box in the "Construction Inspection" section of MECH-2A. **Also, indicate in this section what type of dynamic control is being used.**

4.3.3 Proposed Language for MECH-2A - NA 7.5.1 Outdoor Air Acceptance Form

Per section 4.3.5 of the Nonresidential Compliance Manual, "[fixed minimum damper setpoint] does not comply with Title 24". Section 10.6.3 of the Compliance Manual indicates that confirmation of dynamic controls is intended to be part of acceptance testing, but this protocol has been omitted on MECH-2A. The following changes will add verification of the actual control strategy to acceptance testing documentation. A full version of the acceptance testing form has been modified with all proposed changes from this CASE report and has been included as an Appendix. Excerpts from the existing form and proposed changes from this measure only are shown below.

Existing Construction Inspection Block

Construction Inspection

1 Instrumentation to perform test includes, but not limited to:
 a. Watch
 b. Calibrated means to measure airflow
2 Check one of the following:
 ☐ Variable Air Volume (VAV) - Check as appropriate:
  a. Sensor used to control outdoor air flow must have calibration certificate or be field calibrated
   ☐ Calibration certificate (attach calibration certification)
   ☐ Field calibration (attach results)
 ☐ Constant Air Volume (CAV) - Check as appropriate:
  ☐ System is designed to provide a fixed minimum OSA when the unit is on

Recommended Construction Inspection Block

Construction Inspection

1 Instrumentation to perform test includes, but not limited to:
 a. Watch
 b. Calibrated means to measure airflow
2 Check one of the following:
 ☐ Variable Air Volume (VAV) - Check as appropriate:
  a. Sensor used to control outdoor air flow must have calibration certificate or be field calibrated
   ☐ Calibration certificate (attach calibration certification)
   ☐ Field calibration (attach results)
  b. Fixed Minimum Damper (the following must be checked)
   ☐ Fixed minimum damper setpoint is NOT being utilized to control outside air.
  c. One of the following dynamic controls is being utilized to control outside air (check as appropriate)
   ☐ Dual Minimum Setpoint Design
   ☐ Energy Balance Method
   ☐ Return Fan Tracking
   ☐ Airflow Measurement of the Entire Outdoor Air Inlet
   ☐ Injection Fan Method
   ☐ Dedicated Minimum Ventilation Damper with Pressure Control
   ☐ Other Active Control, Describe ______________________
 ☐ Constant Air Volume (CAV) - Check as appropriate:
  ☐ System is designed to provide a fixed minimum OSA when the unit is on

4.4 Verify proper location of outdoor air ducts in plenum systems

As part of acceptance testing, consider verifying Section 121(d) requirements for location of outdoor air supply for plenum systems (described in Section 4.3.4 of the Compliance Manual). The following modifications to the MECH-2A acceptance form and Nonresidential Compliance Manual are required to implement this recommendation.

4.4.1 Proposed Language for the Nonresidential Compliance Manual

Section 10.6.3 and Section 10.6.5

Add the following text to the end of the existing Construction Inspection text.

For systems where return air plenum is used to distribute outside air to a zonal heating or cooling unit, confirm that outside air supply is connected either:

Within five ft. of the unit
Within 15 ft. of the unit, with the air directed substantially toward the unit, and with a discharge velocity of at least 500 ft. per minute.

4.4.2 Proposed Language for MECH-2A - NA 7.5.1 Outdoor Air Acceptance Form

A full version of the acceptance testing form has been modified with all proposed changes from this CASE report and has been included as an Appendix. Excerpts from the existing form and proposed changes from this measure only are shown below.

Existing Construction Inspection Block

Construction Inspection

1 Instrumentation to perform test includes, but not limited to:
- a. Watch
- b. Calibrated means to measure airflow

2 Check one of the following:
- ☐ Variable Air Volume (VAV) - Check as appropriate:
  - a. Sensor used to control outdoor air flow must have calibration certificate or be field calibrated
    - ☐ Calibration certificate (attach calibration certification)
    - ☐ Field calibration (attach results)
- ☐ Constant Air Volume (CAV) - Check as appropriate:
  - ☐ System is designed to provide a fixed minimum OSA when the unit is on

Recommended Construction Inspection Block

Construction Inspection

1 Instrumentation to perform test includes, but not limited to:
- a. Watch
- b. Calibrated means to measure airflow

2 Check one of the following:
- ☐ Variable Air Volume (VAV) - Check as appropriate:
  - a. Sensor used to control outdoor air flow must have calibration certificate or be field calibrated
    - ☐ Calibration certificate (attach calibration certification)
    - ☐ Field calibration (attach results)
- ☐ Constant Air Volume (CAV) - Check as appropriate:
  - ☐ System is designed to provide a fixed minimum OSA when the unit is on

3 Check one of the following:
- ☐ Return air plenum is used to distribute outside air to a zonal heating or cooling unit.
  - a. Confirm that outside air supply is connected either (check one below)
    - ☐ Within five ft. of the unit.
    - ☐ Within 15 ft. of the unit, with the air directed substantially toward the unit, and with a discharge velocity of at least 500 ft. per minute.
- ☐ Return air plenum is NOT used to distribute outside air to a zonal heating or cooling unit.

4.5 Confirm pre-occupancy purge for all system types

4.5.1 Proposed Language for the Nonresidential Compliance Manual

Section 10.6.3 – Construction Inspection

Add the following text to the end of the existing Construction Inspection text.

Confirm that pre-occupancy purge has been programmed to meet the requirements of Standards Section §121(c)2. This is most easily accomplished by scheduling the unit to start one hour prior to actual occupancy.

Section 10.6.5 – Construction Inspection

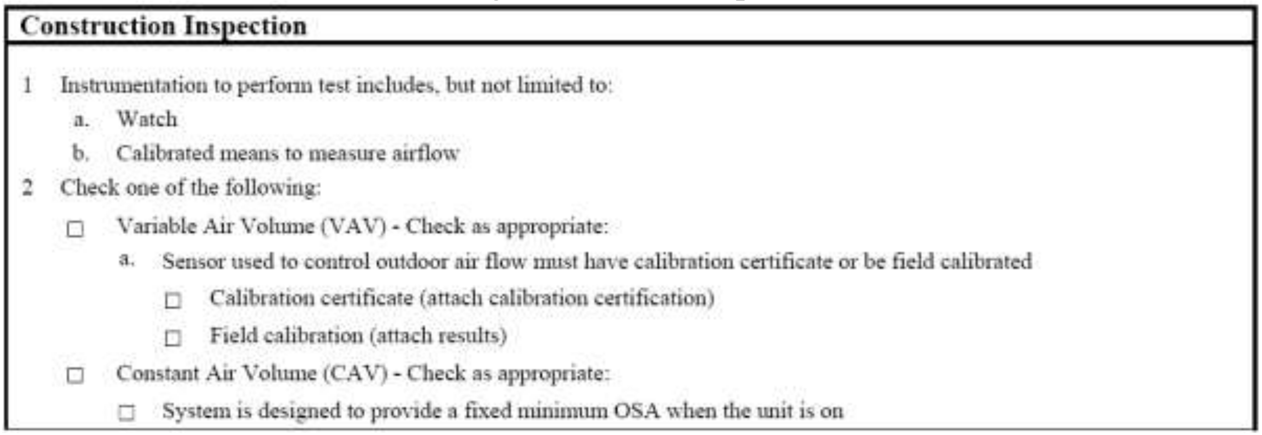
Add the following text to the end of the existing Construction Inspection text.

Confirm that pre-occupancy purge has been programmed to meet the requirements of Standards Section §121(c)2. This is most easily accomplished by scheduling the unit to start one hour prior to actual occupancy.

4.5.2 Proposed Language for the MECH-2A - NA 7.5.1 Outdoor Air Acceptance Form

A full version of the acceptance testing form has been modified with all proposed changes from this CASE report and has been included as an Appendix. Excerpts from the existing form and proposed changes from this measure only are shown below.

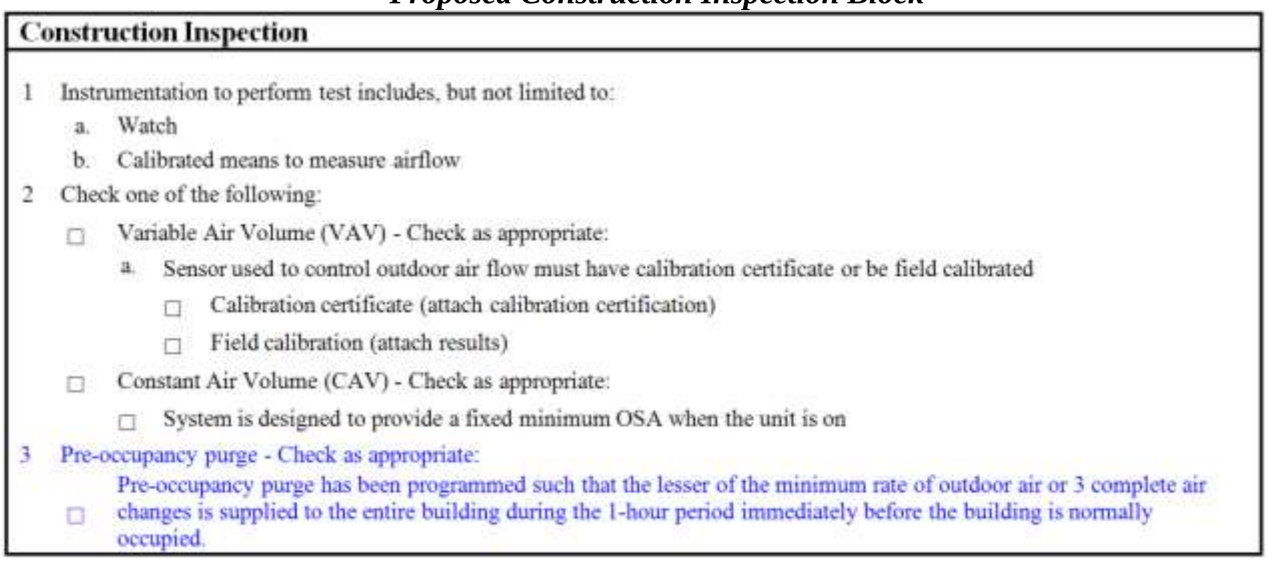
Existing Construction Inspection Block



Construction Inspection

1 Instrumentation to perform test includes, but not limited to:
  a. Watch
  b. Calibrated means to measure airflow
2 Check one of the following:
  ☐ Variable Air Volume (VAV) - Check as appropriate:
    a. Sensor used to control outdoor air flow must have calibration certificate or be field calibrated
      ☐ Calibration certificate (attach calibration certification)
      ☐ Field calibration (attach results)
  ☐ Constant Air Volume (CAV) - Check as appropriate:
    ☐ System is designed to provide a fixed minimum OSA when the unit is on

Proposed Construction Inspection Block



Construction Inspection

1 Instrumentation to perform test includes, but not limited to:
  a. Watch
  b. Calibrated means to measure airflow
2 Check one of the following:
  ☐ Variable Air Volume (VAV) - Check as appropriate:
    a. Sensor used to control outdoor air flow must have calibration certificate or be field calibrated
      ☐ Calibration certificate (attach calibration certification)
      ☐ Field calibration (attach results)
  ☐ Constant Air Volume (CAV) - Check as appropriate:
    ☐ System is designed to provide a fixed minimum OSA when the unit is on
3 Pre-occupancy purge - Check as appropriate:
  ☐ Pre-occupancy purge has been programmed such that the lesser of the minimum rate of outdoor air or 3 complete air changes is supplied to the entire building during the 1-hour period immediately before the building is normally occupied.

4.6 Correct CO2 sensor mounting height in Nonresidential Compliance Manual

4.6.1 Proposed Language for the Nonresidential Compliance Manual

Section 10.6.12 – Acceptance Criteria

Correct 1 foot to 3 foot text as shown in the excerpt below:

Each CO2 sensor is located correctly within the space ~~1~~ **3** to 6 feet above the floor.

4.7 Add guidance for measuring outdoor air ventilation rates during acceptance testing

4.7.1 Proposed Language for the Nonresidential Compliance Manual

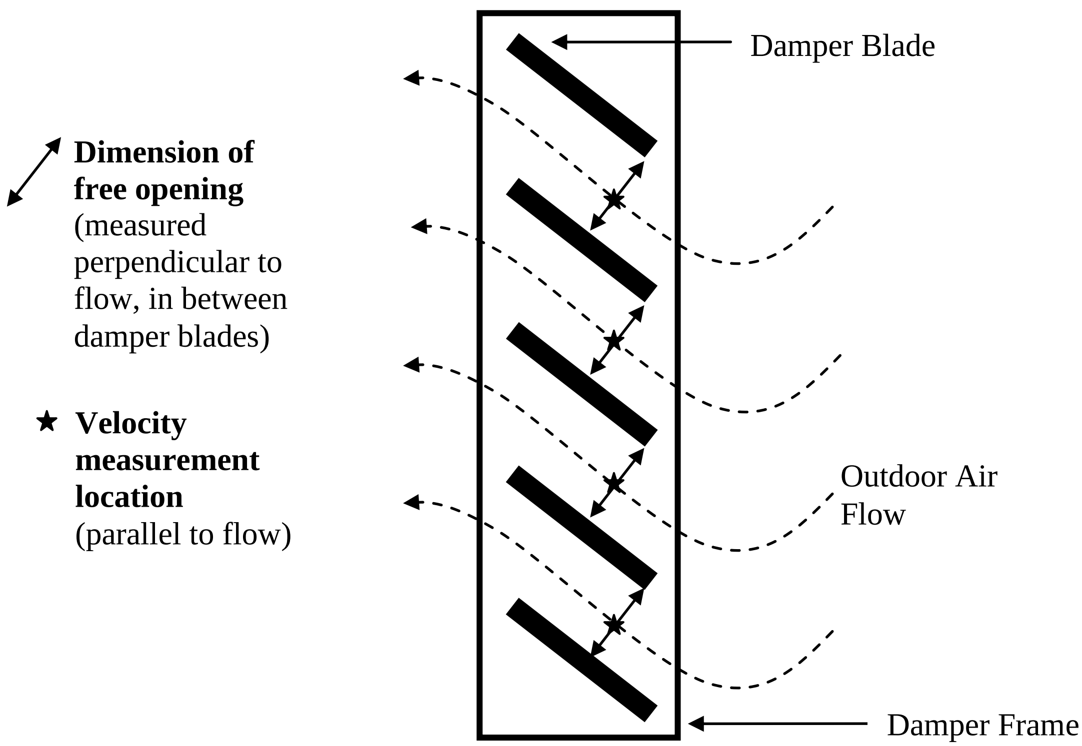
Add the following text to the end of the existing "Verify and Document" portion of Section 10.6.3 and Section 10.6.5.

Follow the best practice guidelines below in order to increase accuracy of outdoor air flow measurements:

- **Traverse measurements taken in supply, return or outdoor air ducts should be located in an area of steady, laminar flow. If possible, take measurements at least six to eight duct diameters away from turbulence, air intakes, bends, or restrictions.**

- **If using face velocity measurements to calculate outdoor air flow, care should be taken to accurately measure free area dimensions of intake.**

- **If velocity measurements are taken at the plane of the intake between damper blades where flow is restricted (i.e. to achieve faster flows), free area should be measured as the actual open space between dampers and should not include frames or damper blades. See diagram below for illustration of free opening measurements.**



Damper Section View

- **Hot wire anemometers are more appropriate than velocity pressure probes for measuring low speed flows (i.e. less than 250 feet per minute). When measuring flow with a hot wire anemometer, make sure to position the measurement device such that it is perpendicular to direction of flow.**

- **Take multiple measurements and average results in order to minimize affects of fluctuations in system operation and environmental conditions (i.e. wind).**

- **Your body can serve as an obstruction to air flow and affect measurements. To increase measurement accuracy, position your body away from the intake and flow of air.**

4.8 Encourage reduction of outside air during partial occupancy

4.8.1 Proposed Language for the Nonresidential Compliance Manual

Section 4.3.5 - Ventilation System Operation and Controls

~~*Regardless of how the minimum ventilation is controlled*~~, **While not required in the standards it is recommended that** care should be taken to reduce the amount of outdoor air provided when the system is operating during the weekend or after hours with only a fraction of the zones active. This can be provided by having the VAV boxes return to fully closed when their associated zone is in unoccupied mode. When a space or group of spaces is returned to occupied mode (e.g. through off-hour scheduling or a janitor's override) only the boxes serving those zones need to be active. During this partial occupancy the ventilation air can be reduced to the requirements of those zones that are active. If all zones are of the same occupancy type (e.g. private offices), simply assign a floor area to each isolation zone and prorate the minimum ventilation area by the ratio of the sum of the floor areas presently active divided by the sum of all the floor areas served by the HVAC system.

5. Considerations for Future CASE Initiatives

The following measures have been identified as potential measures to be considered for future CASE Initiatives.

5.1 Require dedicated minimum outdoor air intake for systems with economizers

5.1.1 Description

This measure would require all systems over a certain size with air side economizers to have a dedicated minimum outdoor air intake. These intakes would be required to have velocity flows between 300-750 feet per minute which would allow for more accurate measurement of outdoor air rates. As a result, dynamic control of outdoor air ventilation rates would improve and acceptance testing would become easier and simpler.

Aside from energy benefits, proper control of ventilation rates may positively impact indoor air quality. Also, having dedicated intakes would also make acceptance testing simpler, especially for VAV systems. A dedicated intake would provide better control of outdoor air for the life of the ventilation system. Assurance of minimum ventilation rates is all but guaranteed even if economizing dampers fail.

5.1.2 Future Study

Additional study must be conducted to determine the net energy benefit and cost effectiveness of dedicated intakes. On one hand, cooling and heating energy will be saved through better control of outdoor air ventilation rates. Fan energy, however, may increase due to increased velocities (i.e. resistance) across the intake louver.

Furthermore, although the technology already exists to implement dynamic controls on a dedicated minimum intake, in practice, many built-up and most packaged units do not include a minimum intake. Additional study is required to quantify the impacts of a dedicated intake to equipment cost and design.

Furthermore, this requirement would encourage the use of dynamic control methods that include injection fan systems, pressure control, or direct airflow measurement using a flow station or flow sensing louvers. A number of manufacturers (e.g. Ruskin) manufacture flow sensing louver sections that are designed to be installed as a dedicated minimum intake. These louvers are specifically designed to achieve high velocity flows.

5.1.3 Changes to Standards

To implement this measure, the following language can be added to §121(e) of the Standards.

All mechanical ventilation and space-conditioning systems that are 1) rated over XX,XXX CFM or XX tons and 2) required to have air side economizing by §144(e) are also required to have dedicated minimum outdoor air intakes. During non-economizing operation, air velocity across the face of this dedicated intake must be maintained between 300-750 feet per minute to allow for accurate measurement and dynamic control of air flow.

5.2 Require third party or standardized certification of CO2 sensors

5.2.1 Description

As demonstrated in literature and supported by stakeholders, the accuracy of CO2 sensors is highly variable. Because the accuracy of CO2 sensors is critical for the proper operation of demand control ventilation systems, third party or standardized certification of sensors would help ensure the energy savings associated with these systems.

Currently, most sensors are being factory calibrated, but industry wide calibration standards/protocols do not appear to exist. Each manufacturer appears to be using their own internal method to calibrate sensors, but these standards are usually proprietary and not published for review (She11 2011 and Farrah 2011). Requiring third party certification or manufacturer calibration according to an industry standard protocol could improve sensor performance.

5.2.2 Future Study

Additional study must be conducted to determine the cost impact of requiring third party or standardized sensor certification. This study should include the additional cost incurred by third party testing as well as identification of applicable CO2 calibration standards.

As standard calibration protocols are not in use, further work will have to be done to find or develop a suitable standard.

5.3 Remove the energy balance and return fan tracking methods from the allowed list of dynamic ventilation controls

5.3.1 Description

Currently, the Nonresidential Compliance Manual states that energy balance and return fan tracking are both approved methods of implementing dynamic outside air ventilation controls. The energy balance method, however, is prone to error due to the inaccuracies associated with temperature and air flow measurements, especially where temperature differences are small. Similarly, return fan tracking also relies on air flow measuring sensors that are both expensive and particularly inaccurate at low flows.

Consider removing both of these control methods from the approved list of dynamic controls.

5.3.2 Future Study

Additional study must be conducted to determine the field effectiveness and industry prevalence of these control methods. Furthermore, study should be conducted to assess the relative cost of alternative control methodologies.

6. Bibliography and Other Research

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7. Appendices

1. **Outside Air Field Test Form**
   Form used during in-situ measurement of outside air rates.

2. **MECH-6A - NA 7.5.5 Demand Control Ventilation Systems Acceptance Form with All NR13 Changes**
   Acceptance form updated with all changes proposed in this CASE Report. Changes are shown in blue font.

3. **MECH-2A - NA 7.5.1 Outdoor Air Acceptance Form with All NR13 Changes**
   Acceptance form updated with all changes proposed in this CASE Report. Changes are shown in blue font.

4. **MECH-2A - NA 7.5.1 Outdoor Air Acceptance Form with Combined Changes**
   Acceptance form updated with all changes proposed in this CASE Report (blue font) as well as changes recommended from the AT-1 CCC-PIER Acceptance Testing project (red font).

5. **Reduced Ventilation After Economizing Study**
   Reduced ventilation after economizing was originally included in NR13 as a measure but it was ultimately rejected due to its poor energy performance. The methodology, results and analysis of this study are provided for completeness and as a reference.