CODES AND STANDARDS ENHANCEMENT INITIATIVE (CASE)

Working Draft Measure Information Template

Reduce Reheat Measure

2013 California Building Energy Efficiency Standards

California Utilities Statewide Codes and Standards Team March 2011

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Reduce Reheat Measure

2013 California Building Energy Efficiency Standards

Proposer: Taylor Engineering
April 21, 2011

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1. Overview

1.1 Measure Title

Reduce Reheat

1.2 Description

This measure would require that in the heating portion of the dual maximum sequence for a VAV box, the zone supply air temperature goes up to the maximum setpoint before the zone airflow rate is increased. Dual maximum zone controls were added to the Standard in 2008. The intent was to require a temperature-first sequence (described below). A simultaneous flow/temperature sequence (described below) also meets the dual maximum requirement but is less efficient. This intent of this change, therefore, is to prescriptively prohibit the simultaneous flow/temperature sequence.

1.3 Type of Change

The proposed measure would be a prescriptive requirement.

1.4 Energy Benefits

This measure will reduce the amount of reheat done at the zone, and therefore not only save boiler energy, but will also save pump energy, cooling energy, and fan energy. The prototype building used for this analysis is a single-story, 10,000 square foot office building with 50% window to wall ratio and 5,100 square feet of perimeter space. A summary of the results is given in

	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (Therms/yr)	TDV Electricity Savings	TDV Gas Savings
CZ01 - Per Prototype Building	33.2	0.083	110.6	$54.06	$1,774
CZ01 - Savings per square foot	0.0065	1.64E-05	0.022	$0.01	$0.35
CZ02 - Per Prototype Building	24.2	0.098	78.5	$39.42	$1,280
CZ02 - Savings per square foot	0.0048	1.93E-05	0.015	$0.01	$0.25
CZ03 - Per Prototype Building	7.8	0.031	35.4	$12.67	$564
CZ03 - Savings per square foot	0.0015	6.13E-06	0.007	$0.00	$0.11
CZ04 - Per Prototype Building	16.4	0.097	54.1	$26.66	$891

CZ04 - Savings per square foot	0.0032	1.90E-05	0.011	$0.01	$0.17
CZ05 - Per Prototype Building	16.0	0.088	54.0	$25.61	$860
CZ05 - Savings per square foot	0.0031	1.73E-05	0.011	$0.01	$0.17
CZ06 - Per Prototype Building	7.4	0.080	26.5	$11.73	$442
CZ06 - Savings per square foot	0.0014	1.57E-05	0.005	$0.00	$0.09
CZ07 - Per Prototype Building	3.8	0.054	14.5	$6.07	$245
CZ07 - Savings per square foot	0.0007	1.06E-05	0.003	$0.00	$0.05
CZ08 - Per Prototype Building	6.4	0.080	22.7	$10.05	$384
CZ08 - Savings per square foot	0.0013	1.57E-05	0.004	$0.00	$0.08
CZ09 - Per Prototype Building	9.4	0.088	32.0	$15.27	$531
CZ09 - Savings per square foot	0.0018	1.73E-05	0.006	$0.00	$0.10
CZ10 - Per Prototype Building	9.2	0.095	30.5	$14.09	$512
CZ10 - Savings per square foot	0.0018	1.86E-05	0.006	$0.00	$0.10
CZ11 - Per Prototype Building	21.7	0.111	67.6	$34.85	$1,124
CZ11 - Savings per square foot	0.0042	2.18E-05	0.013	$0.01	$0.22
CZ12 - Per Prototype Building	25.1	0.103	79.0	$41.31	$1,319
CZ12 - Savings per square foot	0.0049	2.02E-05	0.015	$0.01	$0.26
CZ13 - Per Prototype Building	17.6	0.101	56.6	$28.53	$951
CZ13 - Savings per square foot	0.0035	1.99E-05	0.011	$0.01	$0.19
CZ14 - Per Prototype Building	17.7	0.119	53.8	$27.61	$906
CZ14 - Savings per square foot	0.0035	2.33E-05	0.011	$0.01	$0.18
CZ15 - Per Prototype Building	4.0	0.080	13.5	$6.35	$232
CZ15 - Savings per square foot	0.0008	1.56E-05	0.003	$0.00	$0.05

CZ16 - Per Prototype Building	61.2	0.120	174.6	$95.47	$2,890
CZ16 - Savings per square foot	0.0120	2.35E-05	0.034	$0.02	$0.57

Table 1 below. See Section 2 for details on the assumptions of the analysis and Section 3 for the detailed results.

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CZ01 - Per Prototype Building	33.2	0.083	110.6	$54.06	$1,774
CZ01 - Savings per square foot	0.0065	1.64E-05	0.022	$0.01	$0.35
CZ02 - Per Prototype Building	24.2	0.098	78.5	$39.42	$1,280
CZ02 - Savings per square foot	0.0048	1.93E-05	0.015	$0.01	$0.25
CZ03 - Per Prototype Building	7.8	0.031	35.4	$12.67	$564
CZ03 - Savings per square foot	0.0015	6.13E-06	0.007	$0.00	$0.11
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CZ16 - Per Prototype Building	61.2	0.120	174.6	$95.47	$2,890
CZ16 - Savings per square foot	0.0120	2.35E-05	0.034	$0.02	$0.57

Table 1. Summary of energy savings in each climate zone

1.5 Non-Energy Benefits

This measure requires the use of a discharge air temperature sensor on VAV boxes. The discharge air temperature sensor is beneficial for diagnosing problems during startup and while the building is running. This measure will also improve comfort and ventilation effectiveness by reducing thermal stratification. Stratification is discussed in Section 2.

1.6 Environmental Impact

This measure has negligible environmental impacts.

1.7 Technology Measures

This measure requires no particular technology.

1.8 Performance Verification of the Proposed Measure

This measure requires that during acceptance testing of zone terminal units, the box is driven from dead band to full heating in order to verify that the supply air temperature and airflow meet the requirements. See Section 5.3 for details.

1.9 Cost Effectiveness

The life-cycle cost of this measure is shown in

a	b	c		d		e		f	g	
Measure Name	Measure Life (Years)	Additional Costs– Current Measure Costs (Relative to Basecase) ($)		Additional Cost– Post-Adoption Measure Costs (Relative to Basecase) ($)		PV of Additional Maintenance Costs (Savings) (Relative to Basecase) (PV$)		PV of Energy Cost Savings – Per Proto Building (PV$)	LCC Per Prototype Building ($)	
		Per zone	Per Proto Building	Per zone	Per Proto Building	Per zone	Per Proto Building		(c+e)-f Based on Current Costs	(d+e)-f Based on Post-Adoption Costs
Reduce reheat	15	$75	$375	$75	$375	$0	$0	$1,334	-$959	-$959

Table 2 below for Climate Zone 12. The prototype building is a 10,000 square foot office building with 5,100 square feet of perimeter zone. The details of the assumptions are given in Section 3. Because discharge air temperature sensors are already common,, there is no post-adoption measure cost change.

a	b	c		d		e		f	g	
Measure Name	Measure Life (Years)	Additional Costs– Current Measure Costs (Relative to Basecase) ($)		Additional Cost– Post-Adoption Measure Costs (Relative to Basecase) ($)		PV of Additional Maintenance Costs (Savings) (Relative to Basecase) (PV$)		PV of Energy Cost Savings – Per Proto Building (PV$)	LCC Per Prototype Building ($)	
		Per zone	Per Proto Building	Per zone	Per Proto Building	Per zone	Per Proto Building		(c+e)-f Based on Current Costs	(d+e)-f Based on Post-Adoption Costs
Reduce reheat	15	$75	$375	$75	$375	$0	$0	$1,334	-$959	-$959

Table 2. Cost-effectiveness of measure in climate zone 12

1.10 Analysis Tools

eQuest already models the temperature-first dual-maximum sequence.

1.11 Relationship to Other Measures

This measure has no relation to other measures.

2 Methodology

Temperature-first and simultaneous flow/temperature sequences are both dual-maximum sequences for VAV boxes in which the airflow during dead band is at a minimum (the maximum of the ventilation rate, the box minimum, and 20% of the design cooling airflow). In both sequences, at maximum heating the airflow is at a heating maximum (limited by the standard to the larger of 50% of the design cooling airflow and the ventilation rate). The two sequences differ in how they get from dead band to maximum heating.

When a zone goes into heating with the temperature-first sequence (shown below in Figure 1), the hot water valve opens and the supply air temperature increases. To meet the heating load, the supply air temperature first increases to its maximum setpoint, then the supply airflow begins to increase, and continues to increase up to its heating maximum.

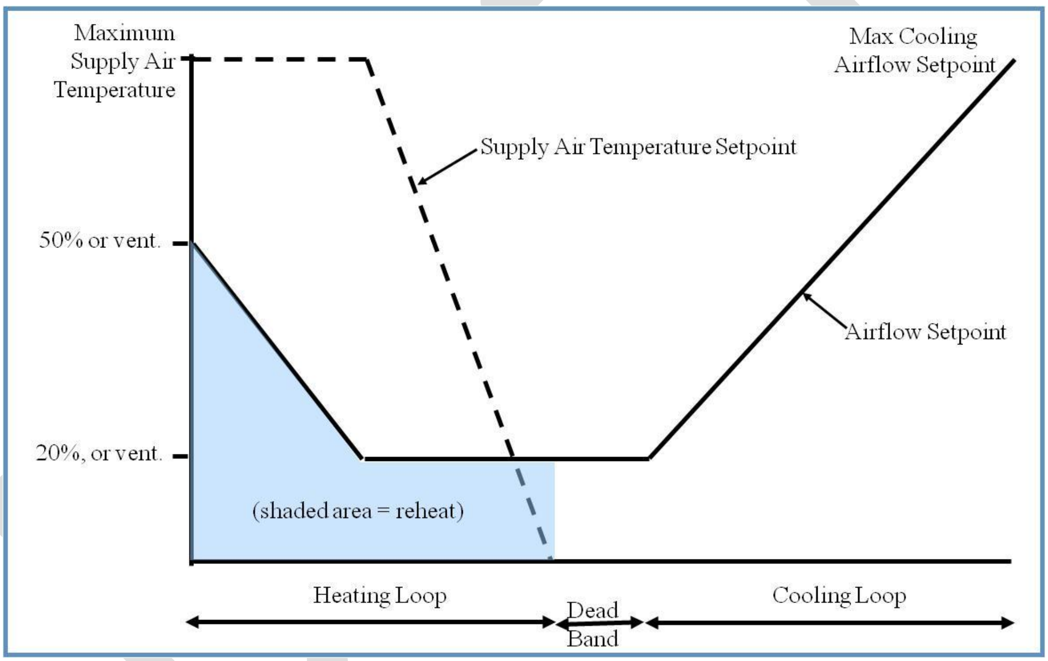

Figure 1. Temperature-first sequence

When a zone goes into heating with the simultaneous flow/temperature sequence (shown below in Figure 2), the hot water valve opens and the airflow increases at the same time. The supply air temperature and the airflow both increase in order to meet the heating load, and continue to increase up to their heating maximums.

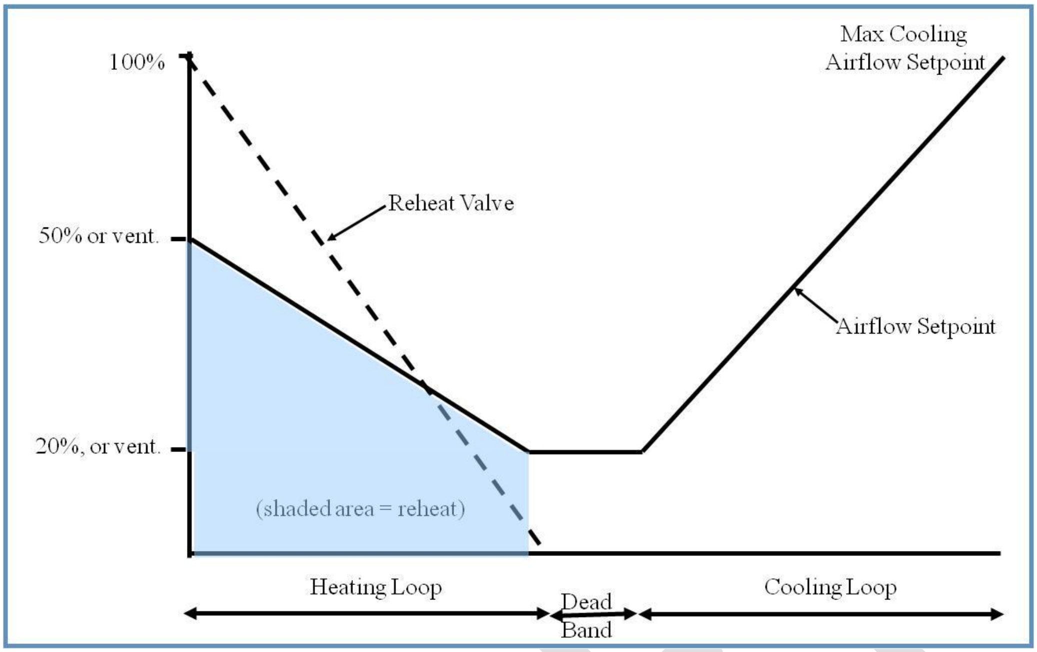

Figure 2. Simultaneous flow/temperature sequence

There is less reheat energy in the case of temperature-first than in simultaneous flow/temperature because the amount of primary air, which is typically 55^{0}F, is reduced. Less primary air means less reheating, which means less boiler energy and less fan energy. This can be clearly seen in Figure 3.

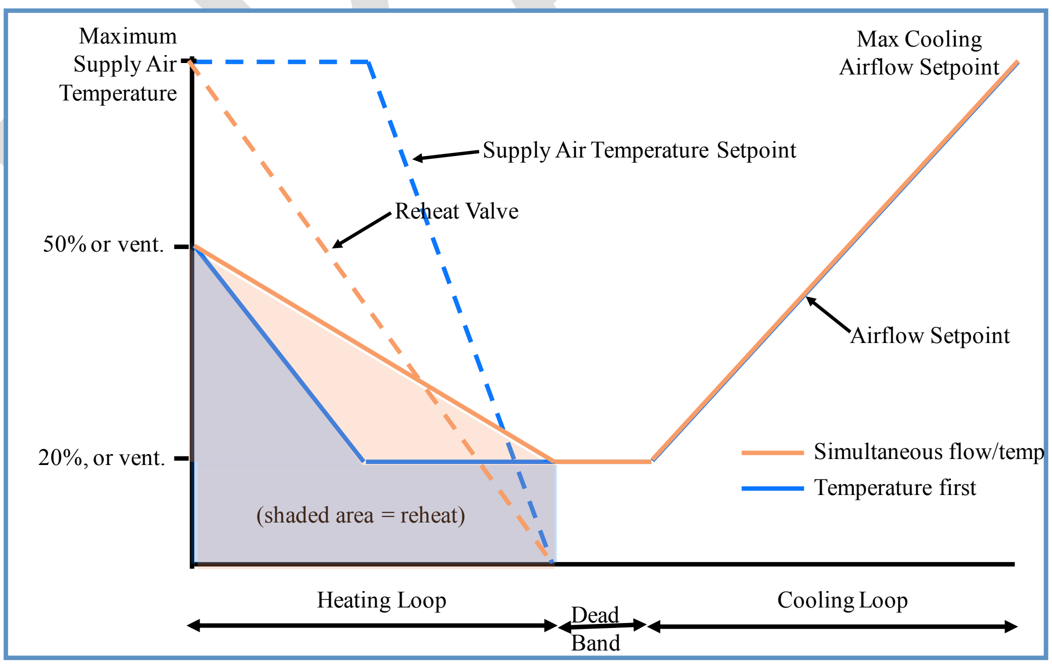

Figure 3. Both dual-max sequences

The energy savings for this measure were calculated using a combination of eQuest simulations and spreadsheets. A generic office building was modeled in eQuest in order to determine the space hourly heating load in each space. Then the actual fan and boiler energy for both temperature-first dual-max sequence and simultaneous flow/temperature dual-max sequence were calculated in spreadsheets.

The office building modeled is based on industry practice. It is a single-story, 10,000 square-foot square building with 15-foot deep perimeter zones totaling 5,100 square feet and one interior zone totaling 4,900 square feet. The floor-to-floor height is 12 feet and the plenum height is 3 feet. There is a continuous strip of glazing, double pane, low-e glass for a 50% window-to-wall ratio. There are no skylights and no daylighting controls. The undiversified internal loads include lighting power density of 0.9 watts per square-foot, equipment power density of 1.5 watts per square-foot, and an occupancy density of 100 square foot per person. The internal load schedules vary randomly, and average 53% of the peak during occupied hours. The average boiler efficiency is assumed to be 65%. This is based on trend data collected by Taylor Engineering from typical boiler plants.

For each climate zone the design zone airflows were determined based on zone peak cooling loads calculated in eQuest. The zone box minimum was assumed to be the maximum of 10% of the design cooling maximum and the minimum ventilation rate (the maximum of 0.15 cfm/sqft and 15 cfm/person). The analysis only considered perimeter zones since typically interior zones do not require heating.

The energy savings for each zone were calculated per square foot. For this analysis the average zone size was assumed to be 1,000 square feet. The boiler energy and primary fan energy were calculated. Savings would also be seen in hot water pumping energy and cooling energy, but these were not modeled for simplicity.

3 Analysis and Results

3.1 Costs

The total incremental cost of this measure is $75 per zone. This is a one-time total installed cost of a discharge air temperature sensor for a VAV box. This is because the simultaneous flow/temperature sequence does not require a discharge temperature sensor but the temperature-first sequence does. Cost data was provided by two Bay Area controls contractors.

Discharge air temperature sensors are already common and widely available from a number of manufacturers. VAV boxes from the major manufacturers have controllers that already come standard with an input for discharge air temperature. This measure does not have any incremental maintenance costs, i.e. the expected life of the temperature sensor exceeds the 15 year analysis period.

3.2 Energy model results

The energy savings of the temperature-first sequence over the simultaneous flow/temperature sequence were calculated using the methodology described above in Section 2. The savings were calculated separately for each zone in each climate zone, and are given below in terms of energy use and 15-year TDV energy in Table 3. The range of savings shown for each climate zone shows the differences in the savings depending upon orientation and internal load schedules.

Climate Zone	City	Annual gas savings (therms)	Annual electricity savings (kWh)	Range of savings ($/zone)
1	Arcata	21.1 - 33.	5.3 - 9.9	$270 - $427
2	Santa Rosa	17. - 24.9	4.3 - 8.1	$219 - $329
3	Oakland	6.1 - 11.4	1.2 - 2.6	$92 - $175
4	San Jose	11.4 - 17.5	3.1 - 5.7	$151 - $234
5	Santa Maria	10.9 - 17.9	3.2 - 5.5	$143 - $234
6	Torrance	4.5 - 8.8	1.4 - 2.5	$59 - $119
7	San Diego	1.8 - 5.	.5 - 1.3	$23 - $69
8	Fullerton	3.5 - 7.5	1.1 - 2.2	$47 - $102
9	Burbank Glendale	5.8 - 10.9	1.9 - 3.4	$76 - $146
10	Riverside	5.2 - 10.3	1.7 - 3.4	$69 - $140
11	Red Bluff	13.4 - 22.	4. - 7.6	$180 - $297
12	Sacramento	16.2 - 25.5	4.2 - 8.7	$215 - $344
13	Fresno	12. - 17.6	3.4 - 5.9	$163 - $239
14	Palmdale	9.9 - 19.2	3.4 - 6.8	$133 - $262
15	Palm Springs	1.4 - 5.	.5 - 1.5	$19 - $69
16	Blue Canyon	31.2 - 56.4	8.5 - 21.	$414 - $759

Table 3. Annual electricity and gas savings in each climate zone

The savings depend largely on the internal loads, window-to-wall ratio, zone orientation, zone size, and box size. The energy saving estimates given are based on conservative parameters, but can be considerably higher assuming lower internal load, higher window-to-wall ratios, larger zones, and oversized VAV boxes.

An energy savings that is not quantified is the savings from reduced stratification. With the simultaneous sequence it is common for the supply air temperature to exceed 95°F in heating mode. Ceiling supply of very hot air results in stratification—the hot air essentially pools on the ceiling, rather than diffusing through the space. The hot supply air short circuits back to the fan system. This has a number of consequences, including:

- Reduced ventilation effectiveness
- Reduced comfort due to temperature gradient
- Longer warm up times
- Higher energy use – the return air temperature is increased which can increase both the total heating load and total cooling load.

3.3 Life-cycle cost analysis

The life-cycle cost of the temperature-first sequence and the simultaneous flow/temperature sequence are given below in

Climate Zone	City	Temperature-first	Simultaneous	Life-cycle cost savings
1	Arcata	$1,799	$2,083	$283
2	Santa Rosa	$1,277	$1,461	$184
3	Oakland	$757	$870	$113
4	San Jose	$928	$1,033	$105
5	Santa Maria	$915	$1,013	$99
6	Torrance	$498	$512	$14
7	San Diego	$343	$318	-$26
8	Fullerton	$448	$451	$2
9	Burbank Glendale	$576	$608	$32
10	Riverside	$559	$588	$28
11	Red Bluff	$1,129	$1,281	$152
12	Sacramento	$1,279	$1,471	$192
13	Fresno	$957	$1,074	$117
14	Palmdale	$925	$1,033	$108
15	Palm Springs	$325	$297	-$28
16	Blue Canyon	$2,890	$3,400	$510

Table 4 for each climate zone. The cost is the 15-year cost per zone (averaged across all four zone orientations), including gas energy for reheat, fan energy during heating, and the incremental installed cost (cost of a discharge air temperature sensor). As noted above, there is no incremental annual maintenance.

Climate Zone	City	Temperature-first	Simultaneous	Life-cycle cost savings
1	Arcata	$1,799	$2,083	$283
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Table 4. 15-year life-cycle cost in each climate zone

4 Stakeholder Input

No stakeholder feedback was received on this measure.

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

5.1 Recommended language for standard

Below is the recommended language for the standard. Proposed new language is underlined, proposed deletions are crossed out.

EXCEPTION 1 to Section 144(d): Zones served by variable air-volume systems that are designed and controlled to reduce, to a minimum, the volume of reheated, re-cooled, or mixed air supply are allowed only if the controls meet the following requirements:

A. For each zone with direct digital controls (DDC):

1. The volume of primary air that is reheated, re-cooled, or mixed air supply shall not exceed the larger of:

a. 50 percent of the peak primary airflow, or

b. The design zone outdoor airflow rate per Section 121.

2. The primary airflow in the dead band shall not exceed the larger of:

a. 20 percent of the peak primary airflow; or

b. The design zone outdoor airflow rate per Section 121.

3. ~~Airflow between dead band and full heating or full cooling must be modulated~~

3. The first stage of heating consists of modulating the zone supply air temperature setpoint up to a maximum setpoint no larger than 95ºF while the airflow is maintained at the dead band flow rate.

4. The second stage of heating consists of modulating the airflow rate from the dead band flow rate up to the heating maximum flow rate.

5.2 ACM

5.3 Acceptance Testing

Below is the recommended language for the acceptance testing for zone terminal units. Proposed new language is underlined.

NA7.5.12.2 Functional Testing for Zone Terminal Units

Testing shall be performed on one of each type of terminal unit (VAV box) in the project. A minimum of 5 percent of the terminal boxes shall be tested.

1. Sensor drift/failure:

Step 1: Disconnect the tubing to the differential pressure sensor of the VAV box.

Step 2: Verify that control system detects and reports the fault.

Step 3: Reconnect the sensor and verify proper sensor operation.

Step 4: Verify that the control system does not report a fault.

2. Damper/actuator fault:

(a) Damper stuck open.

Step 1: Command the damper to be fully open (room temperature above setpoint).

Step 2: Disconnect the actuator to the damper.

Step 3: Adjust the cooling setpoint so that the room temperature is below the cooling setpoint to command the damper to the minimum position. Verify that the control system reports a fault.

Step 4: Reconnect the actuator and restore to normal operation.

(b) Damper stuck closed.

Step 1: Set the damper to the minimum position.

Step 2: Disconnect the actuator to the damper.

Step 3: Set the cooling setpoint below the room temperature to simulate a call for cooling. Verify that the control system reports a fault.

Step 4: Reconnect the actuator and restore to normal operation.

3. Valve/actuator fault (For systems with hydronic reheat):

Step 1: Command the reheat coil valve to (full) open.

Step 2: Disconnect power to the actuator. Set the heating setpoint temperature to be lower than the current space temperature, to command the valve closed. Verify that the fault is reported at the control workstation.

Step 3: Reconnect the actuator and restore normal operation.

4. Feedback loop tuning fault (unstable airflow):

Step 1: Set the integral coefficient of the box controller to a value 50 times the current value.

Step 2: The damper cycles continuously and airflow is unstable. Verify that the control system detects and reports the fault.

Step 3: Reset the integral coefficient of the controller to the original value to restore normal operation.

5. Disconnected inlet duct:

Step 1: From the control system workstation, commands the damper to full closed, then disconnect power to the actuator and verify that a fault is reported at the control workstation.

6. Discharge air temperature sensor

Step 1: Adjust zone setpoints to drive the box from dead band to full heating.

Step 2: Verify that in heating, the supply air temperature resets up to the maximum setpoint while the airflow is maintained at the dead band flow rate.

Step 3: Verify that after the supply air temperature is reset up to the maximum setpoint, the airflow rate then increases up to the heating maximum flow rate in order to meet the heating load.

6 Appendices