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Description:	By: Mark Alatorre, PE
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Economizer Fault Detection and Diagnostics for Built-Up Air Handlers

Mark Alatorre, PE
Building Standards Office
Efficiency Division

Pre-Rulemaking Workshop
Imbrecht Hearing Room
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Acknowledgements

California Statewide Codes and Standards Team

CASE Authors:

- Farhad Farahmand (TRC Energy Services
- Catherine Chappell (TRC Energy Services)
- Hillary Weitze (Integral Group)

Measure Background

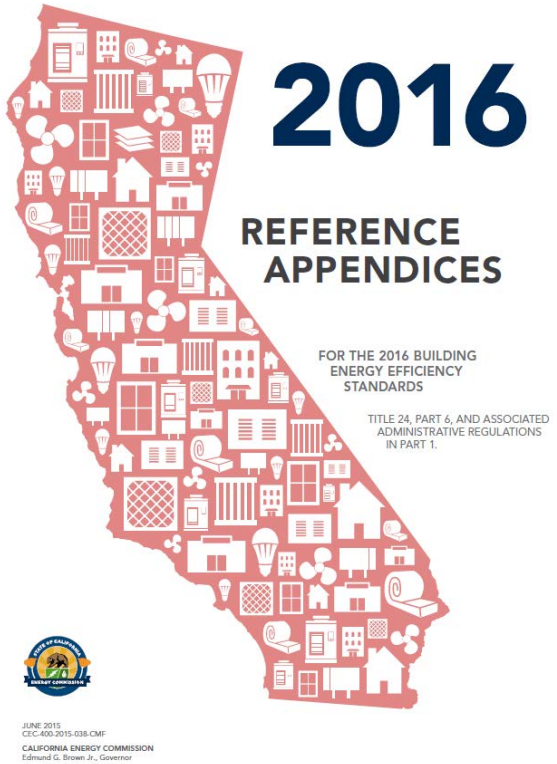
- Fault detection and diagnostic devices have been a mandatory requirement starting under the 2013 Building Energy Efficiency Standards.
  - Systems over 54 kBtu/hr
  - Air economizer
  - Limited to packaged systems
  - Manufacturer self certification
    - Guidance for FDD testing and certification

Measure Background

- Faults to be detected:
  - Air temperature sensor failure/fault
  - Not economizing when it should
  - Economizing when it should not
  - Damper not modulating
  - Excess outdoor air
- Provide system status:
  - Free Cooling Available
  - Economizer Enabled
  - Compressor Enabled
  - Heating Enabled (if system has heating)
  - Mixed Air Low Limit Cycle Active

Measure Background

- 2016 Building Energy Efficiency Standards
  - Certification according to JA6
    - Required testing according to 2013 Guidance



Proposed Change

- The CASE Team explored expanding FDD to built-up air handlers
  - This change would result in all HVAC systems over 54 kBtu/hr with an air economizer to have FDD
  - Moves from primarily standalone FDD Devices to Direct Digital Control (DDC) Systems

Proposed Code Change

- Under current regulations, FDD's have to be certified to the Energy Commission
  - Problematic for DDC Systems
    - Mechanical Designer
    - Controls Contractor
    - Third-Party FDD Vendor
    - DDC Manufacturer

Proposed Code Change

- Mechanical Designer
- Controls Contractor
- Third-Party FDD Vendor DDC Manufacturer
  - Each may be responsible for inputting the sequence of operation (SOO)
  - SOO is optimized per building, certifying pre-configured SOO is impractical

Proposed Code Change

- Recommendation is to not require certification for DDC based Energy Management System FDD
- Require that an Acceptance Test be conducted to ensure proper system setup

Acceptance Test

- CASE Team is proposing amending an existing Acceptance Test (NA7.5.12 – NRCA-MCH-13)
- The current Acceptance Test includes a functional test on heating and cooling coil valves and zone terminal units
- Not directly related to economizers or economizer FDD
- CASE Team recommendation is to split the NRCA-MCH-13 into an A and B
- NRCA-MCH-13-A will contain the new Acceptance Test for DDC FDD systems
- NRCA-MCH-13-B will retain the heating/cooling coil valves and zone terminal units

Acceptance Test

- NRCA-MCH-13-A will contain the new Acceptance Test for DDC FDD systems including:
  - Inspection test of the installed temperature sensor accuracy
  - Overriding the alarm delay
  - Direction to only disconnect local temperature sensors, not global sensors
  - Direction on which dampers are included in the test
  - Direction on how to override operating modes and clearing faults
  - Language to discourage disconnection of actuators

Energy Savings

- Prototype Building:
  - Large Office (498,000 ft^2 , 13 stories, central plant)
  - Modeled Faults:
    - Air Temperature Sensor Failure
      - Adjust sensors to mimic drift
    - Not Economizing when it should
      - High limit set point RAT – 10^oF
    - Economizing when it should not
      - High limit set point RAT + 10^oF
    - Damper not modulating
      - Stuck closed
    - Excess outdoor air
      - Stuck open

Energy Savings

Incidence Rates

Title 24, Part 6 Fault	Fault Incidence Over 15 years	Probability of Detecting Fault with FDD	Probability of Detecting Fault Without FDD	FDD Benefit (A x (B - C))
Air temperature sensor malfunction	19%	75%	25%	**10%**
Not economizing when it should	22%	75%	25%	**11%**
Economizing when it should not	8%	75%	25%	**4%**
Damper not modulating	13%	75%	25%	**6%**
Excess outdoor air	7%	75%	25%	**4%**

Energy Savings

- The FDD benefit for each fault was multiplied by the expected energy impact of the simulated faults
- The energy benefit for all faults were summed to yield energy and cost-effectiveness results

Energy Savings – First Year Impact

Climate Zone	Electricity Savings (kWh/yr/ft$_2$)	Peak Electricity Demand Reductions (W/ft$_2$)	Natural Gas Savings (therms/yr/ft$_2$)	TDV Energy Savings (TDV kBtu/yr/ft$_2$)
1	0.028	0.002	0.001	**1.1**
2	0.034	0.060	0.001	**1.4**
3	0.033	0.027	0.000	**0.9**
4	0.035	0.035	0.001	**1.1**
5	0.033	0.013	0.000	**0.9**
6	0.035	0.045	0.000	**1.0**
7	0.038	0.040	0.000	**1.0**
8	0.036	0.068	0.000	**1.2**
9	0.041	0.035	0.000	**1.6**
10	0.038	0.058	0.000	**1.3**
11	0.039	0.048	0.001	**1.8**
12	0.034	0.059	0.001	**1.4**
13	0.038	0.056	0.001	**1.7**
14	0.046	0.006	0.001	**2.0**
15	0.058	0.038	0.000	**2.2**
16	0.021	0.034	0.003	**1.1**

Energy Cost Savings – 15 years

Climate Zone	15-Year TDV Electricity Cost Savings (2020 NPV $/ft2)	15-Year TDV Natural Gas Cost Savings (2020 NPV $/ft2)	Total 15-Year TDV Energy Cost Savings (2020 NPV $/ft2)
1	0.08	0.01	**0.10**
2	0.11	0.01	**0.12**
3	0.07	0.01	**0.08**
4	0.09	0.01	**0.10**
5	0.07	0.01	**0.08**
6	0.09	0.00	**0.09**
7	0.09	0.00	**0.09**
8	0.11	0.00	**0.11**
9	0.14	0.00	**0.14**
10	0.11	0.01	**0.12**
11	0.14	0.01	**0.16**
12	0.12	0.01	**0.13**
13	0.14	0.01	**0.15**
14	0.16	0.01	**0.18**
15	0.20	0.00	**0.20**
16	0.06	0.04	**0.10**

Incremental Costs – First Cost

Component	Cost	Source
Contractor Implementation of RAT, MAT, and FDD SOO	$2,604	**3 Mechanical Designer and 2 Control Contractor Interviews (see Appendix)**
Acceptance Testing	$150	**2 Acceptance Test Technician Interviews**
Total Cost per Air Handler	$2,754	
Total Cost for 13 Air Handlers	$35,804	

The CASE Team is not assuming an increase in maintenance costs

Lifecycle Cost Effectiveness

Climate Zone	Benefits TDV Energy Cost Savings + Other PV Savings[1] (2020 PV $)	Costs Total Incremental Present Value (PV) Costs[2] (2020 PV $)	Benefit-to- Cost Ratio
1	$47,504	$35,804	**1.3**
2	$60,025	$35,804	**1.7**
3	$40,330	$35,804	**1.1**
4	$48,282	$35,804	**1.3**
5	$39,567	$35,804	**1.1**
6	$45,275	$35,804	**1.3**
7	$45,202	$35,804	**1.3**
8	$53,866	$35,804	**1.5**
9	$72,163	$35,804	**2.0**
10	$57,791	$35,804	**1.6**
11	$78,119	$35,804	**2.2**
12	$64,121	$35,804	**1.8**
13	$77,266	$35,804	**2.2**
14	$88,172	$35,804	**2.5**
15	$99,593	$35,804	**2.8**
16	$50,916	$35,804	**1.4**

Proposed Code Language

7. Proposed Revisions to Code Language

The proposed changes to the standards, Reference Appendices, and the ACM Reference Manuals are provided below. Changes to the 2016 documents are marked with underlining (new language) and ~~strikethroughs~~ (deletions).

7.1 Standards

SECTION 100.0 – SCOPE

TABLE 100.0-A APPLICATION OF STANDARDS

Occupancies	Application	Mandatory	Prescriptive	Performance	Additions/Alterations
[…]					
Covered Processes	Envelope, Ventilation, Space Conditioning, and Process Loads	110.2, 120.2(i), 120.6	140.9	140.1	120.6, 140.9

SECTION 120.2 – REQUIRED CONTROLS FOR SPACE-CONDITIONING SYSTEMS

Nonresidential, high-rise residential, and hotel/motel buildings shall comply with the applicable requirements of Sections 120.2(a) through 120.2(k).

(i) **Economizer Fault Detection and Diagnostics (FDD).** All newly installed ~~air-cooled packaged direct expansion units with an~~ air handlers with a mechanical cooling capacity greater than 54,000 Btu/hr ~~with~~ and an installed air economizer shall include a stand alone or integrated Fault Detection and Diagnostics (FDD) system in accordance with Subsections 120.2(i)1 through 120.2(i)8.

1. The following temperature sensors shall be permanently installed to monitor system operation: outside air, supply air, and when required for differential economizer operation, a return air sensor; and
2. Temperature sensors shall have an accuracy of ±2°F over the range of 40°F to 80°F; and
3. The controller shall have the capability of displaying the value of each sensor; and
4. The controller shall provide system status by indicating the following conditions:
   A. Free cooling available;
   B. Economizer enabled
   C. ~~Compressor~~ Mechanical cooling enabled;
   D. Heating enabled, if the system is capable of heating; and
   E. Mixed air low limit cycle active.

Questions?

Mark Alatorre
mark.alatorre@energy.ca.gov
(916) 654-4642

Comments Due by July 7th
Docket Number 2017-BSTD-01
docket@energy.ca.gov

6.4 Other Non-Energy Impacts

Occupants are expected to be more comfortable with improved economizer performance.

7. PROPOSED REVISIONS TO CODE LANGUAGE

The proposed changes to the standards, Reference Appendices, and the ACM Reference Manuals are provided below. Changes to the 2016 documents are marked with underlining (new language) and ~~strikethroughs~~ (deletions).

7.1 Standards

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3. The controller shall have the capability of displaying the value of each sensor; and
4. The controller shall provide system status by indicating the following conditions:
   A. Free cooling available;
   B. Economizer enabled
   C. ~~Compressor~~ Mechanical cooling enabled;
   D. Heating enabled, if the system is capable of heating; and
   E. Mixed air low limit cycle active.

5. The unit controller shall allow manual~~ly initiate~~ initiation of each operating mode so that the operation of ~~compressors~~ cooling systems, economizers, fans, and heating systems can be independently tested and verified; and
6. Faults shall be reported in one of the following ways:
   A. Reported to an Energy Management Control System regularly monitored by facility personnel.
   B. Annunciated locally on one or more zone thermostats, or a device within five (5) feet of zone thermostat(s), clearly visible, at eye level, and meeting the following requirements:
      i. On the thermostat, device, or an adjacent written sign, display instructions to contact
      ii. In buildings with multiple tenants, the annunciation shall either be within property management offices or in a common space accessible by the property or building manager.
   C. Reported to a fault management application which automatically provides notification of the fault to remote HVAC service provider.
7. The FDD system shall detect the following faults:
   A. Air temperature sensor failure/fault;
   B. Not economizing when it should;
   C. Economizing when it should not;
   D. Damper not modulating; and
   E. Excess outdoor air.
8. The FDD System shall be certified by the Energy Commission as meeting requirements of Sections 120.2(i)1 through 120.2(i)7 in accordance with Section 110.0 and JA6.3.
   EXCEPTION to 120.2(i)8: FDD algorithms based in Direct Digital Control systems are not required to be Certified to the Energy Commission.

7.2 Reference Appendices

7.2.1 Joint Appendices

JA6.3 Economizer Fault Detection and Diagnostics Certification Submittal Requirements.

Title 24, Part 6, Section 120.2(i) requires that economizer FDD functions be installed on all ~~air-cooled unitary air-conditioning systems with an~~ air handlers with a mechanical cooling capacity over 54,000 Btu/hr cooling capacity and an economizer, with the ability to detect the faults specified in Section 120.2(i). Each air conditioning system manufacturer, controls supplier, or FDD supplier wishing to certify that their FDD analytics conform to the FDD requirements of Title 24, Part 6, may do so in a written declaration. This requires that a letter be sent to the California Energy Commission declaring that the FDD conforms to Title 24, Part 6, Section 120.2(i). The declaration at the end of this section shall be used to submit to the California Energy Commission. FDD algorithms based in Direct Digital Control sytems are not required to be certified to the California Energy Commission, but manufacturers, controls suppliers, or other market actors can choose to apply for certification.

7.2.2 Nonresidential Appendices

NA7.5.12 is currently split into two functional test sections, NA7.5.12.1 (for air handling units) and NA7.5.12.2 (for zone terminal units). The Statewide CASE Team recommends that these two sections remain, with the exception that the valve actuator tests be removed from NA7.5.12.1 (and possibly onto NA7.5.12.2). Because NA7.5.12.2 is not directly related to economizers, it is out of the scope of this proposal.

NA7.5.12 Automatic Fault Detection and Diagnostics (AFDD) for Air Handling Units and Zone Terminal Units.

NA7.5.12.1 Functional Testing for Air Handling Units

Prior to Functional Testing, verify and document the following:

(a) Verify on the submittal documents or sensor specifications that locally installed supply air, outside air, and return air (if applicable) temperature sensors have an accuracy of +/2°F over the range of 40°F to 80°F.

NA7.5.12.~~1~~2 Functional Testing for Air Handling Units

Testing of each AHU with FDD controls shall include the following tests.

(a) Bypass alarm delays

Step 1: If applicable, bypass alarm delays to ensure that faults generate alarms immediately

(~~a~~b) Sensor ~~drift/~~failure:

Step 1: Disconnect ~~outside air~~ local supply air temperature sensor from unit controller.
Step 2: Verify that the FDD system reports a fault.
Step 3: Connect S~~O~~AT sensor to the unit controller.
Step 4: Verify that FDD indicates normal system operation and clear all faults and alarms.
Step 5: If the outside air temperature sensor is local, disconnect the local OAT from the unit controller.
Step 6: Verify that the FDD system reports a fault.
Step 7: Connect the local OAT sensor to the unit controller.
Step 8: Verify that FDD indicates normal system operation and clear all faults and alarms.

(~~b~~c) ~~Damper/actuator fault~~ Inappropriate economizing:

Step 1: Override the operating state to occupied heating mode by overriding zone thermostat(s) to create a heating demand and overriding the OAT sensor below the low limit lockout.
Step ~~1~~2: From the control system workstation, ~~command~~ override the ~~mixing box~~ economizer dampers to ~~full open (~~100% outdoor air mode~~)~~.
Step ~~2~~3: ~~Disconnect power to the actuator and~~ Verify that a fault is reported at the control workstation.
Step ~~3~~4: ~~Reconnect power to the actuator and command the mixing box dampers to full open~~ Remove the economizer damper override and verify that the control system indicates normal system operation..
Step ~~4~~5: ~~Verify that the control system does not report a fault~~ Remove all overrides and clear all faults and alarms.
Step 6: Override the operating state to economizer-only cooling mode by overriding zone thermostat(s) to create a cooling demand and overriding the OAT sensor so that free cooling is available.
Step ~~5~~7: From the control system workstation, ~~command~~ override the ~~mixing box~~ economizer dampers to ~~a full closed position (~~0% outdoor air mode~~)~~.
Step ~~6~~8: ~~Disconnect power to the actuator and~~ Verify that a fault is reported at the control workstation.
Step ~~7~~9: ~~Reconnect power to the actuator and command the dampers closed~~ Remove the economizer damper override and verify that the control system indicates normal system operation.
Step ~~8~~10: ~~Verify that the control system does not report a fault during normal operation~~ Remove all overrides and clear all faults and alarms~~.~~

~~(c) Valve/actuator fault:~~

~~Step 1: From the control system workstation, command the heating and cooling coil valves to full open or closed, then disconnect power to the actuator and verify that a fault is reported at the control workstation.~~

Note that the Statewide CASE Team recommends item (c) Valve/actuator fault be removed from this test and into Section NA 7.5.12.2. Furthermore, the Statewide CASE recommends that the Valve/actuator test be modified in a similar way as the newly proposed item (c) Inappropriate Economizing above. Because the Valve/actuators section is not directly related to economizers, it is out of the scope of this proposal.

~~(d) Inappropriate simultaneous heating, mechanical cooling, and/or economizing:~~

~~Step 1: From the control system workstation, override the heating coil valve and verify that a fault is reported at the control workstation.~~
~~Step 2: From the control system workstation, override the cooling coil valve and verify that a fault is reported at the control workstation.~~
~~Step 3: From the control system workstation, override the mixing box dampers and verify that a fault is reported at the control workstation.~~

The Statewide CASE Team also recommends that item (d) Inappropriate simultaneous heating, mechanical cooling, and/or economizing Steps 1 and 2 be eliminated due to redundancy with item (c) Valves/Actuators, if item (c) Valves/actuators is revised in the same way as item (b) Inappropriate Economizing above. Because item (c), (d)1, and (d)2 are about valves, they are out of the scope of this proposal.

(d) Reinstate alarm delay

Step 1: Reinstate alarm delays to ensure that faults generate alarms as before Step (a), if applicable

7.3 ACM Reference Manual

The Statewide CASE Team proposes that compliance software outputs always show, on the NRCC-MCH-01-E form, that the NRCA-MCH-13a-A form must be used for acceptance testing in built-up systems with air handlers larger than 54 kBtu/h in size with an economizer.

The valve/actuator portion of the air handling unit functional test, and the zone terminal unit functional test, should remain optional compliance credits in NRCA-MCH-13b-A. The compliance credits for these portions of the test must be recalculated.

7.4 Compliance Manuals

Chapter 4, Section 4.5.1.8, of the Nonresidential Compliance Manual will need to be revised according to the changes to the standard. Example 4-38 and Table 4-23 will also need to be revised accordingly. In addition to changes reflecting the standards, the Statewide CASE Team proposes adding the following language at the end of Section 4.5.1.8:

For air handlers controlled by Direct Digital Controls (DDC), including packaged systems, FDD sequences of operations (SOO) must be developed to adhere with the requirements of 120.2(i)1 through 7.

ASHRAE Guideline 36-2017 is one good reference for developing SOO specifically for the faults listed in 120.2(7). The purpose of Guideline 36 is to provide uniform sequences of operation for heating, ventilating, and air-conditioning (HVAC) systems that are intended to maximize HVAC system energy efficiency and performance, provide control stability, and allow for real-time fault detection and diagnostics. To properly adhere to Guideline 36, all SOO design elements in sections 5.N.14 and/or sections 5.P.11 must be implemented, including defining operating states, the use an alarm delay, and the installation of an averaging mixed air temperature (MAT) sensor. If a designer wishes to use Guideline 36 to detect the required economizer faults in Title 24 Section 120.2(i)7, SOO should include Guideline 36 Fault Conditions #2, 3, and 5 through 13 at a minimum. Other Title 24 FDD requirements in Section 120.2(i) and acceptance tests are not met by including these fault conditions into SOO.

FDD systems controlled by Direct Digital Controls are not required to be certified to the California Energy Commission, but manufacturers, controls suppliers, or other market actors can choose to apply for certification.

Due to the proposed changes to the Automatic Fault Detection and Diagnostics (AFDD) for Air Handling Units and Zone Terminal Units acceptance test, Chapter 13 Acceptance Tests will also need to be revised according to proposals in Section 7.5 below.

7.5 Compliance Forms

The existing acceptance form for NRCA-MCH-13-A, Automatic Fault Detection and Diagnostics (AFDD) for Air Handling Units and Zone Terminal Units, is revised and renamed to NRCA-MCH-13a-A, Automatic Fault Detection and Diagnostics (AFDD) for Air Handling Units, according to proposed changes in 7.2. Several parts of this test are recommended to be moved to NRCA-MCH-13b-A.

A. Construction Inspection	**Results**
1. Instrumentation to perform test includes, but not limited to:	
a. No instrumentation is required – changes are implemented at the building automation system control station	n/a
2. Installation	
b. Verify on the submittal documents or sensor specifications that locally installed supply air, outside air, and return air (if applicable) temperature sensors have an accuracy of +/2°F over the range of 40°F to 80°F. ~~The functional testing verifies proper installation of the controls for FDD for air handling units and zone terminal units. No additional installation checks are required.~~	Yes/No

B. Functional Testing for Air Handling Units	**Results**
Testing of each AHU with FDD controls shall include the following tests:	
Step 1: Bypass alarm delays	
a. If applicable, bypass alarm delays to ensure that faults generate alarms immediately	Yes/No

Step ~~1~~2: Sensor ~~drift/~~failure	
a. Disconnect ~~outside air~~ local supply air temperature sensor from unit controller.	Yes/No
b. Verify that the FDD system reports a fault.	Yes/No
c. Connect S~~O~~AT sensor to the unit controller.	Yes/No
d. Verify that FDD indicates normal system operation and clear all faults and alarms.	Yes/No
e. If local, disconnect local outside air temperature sensor from unit controller.	Yes/No
f. Verify that the FDD system reports a fault.	Yes/No
g. Connect OAT sensor to the unit controller.	Yes/No
h. Verify that FDD indicates normal system operation and clear all faults and alarms.	Yes/No
Step ~~2~~3: ~~Damper/actuator fault~~ Inappropriate economizing	
a. Override the operating state to occupied heating mode by overriding zone thermostat(s) to create a heating demand and overriding the OAT sensor below the low limit lockout.	Yes/No
~~a~~b. From the control system workstation, ~~command~~ override the ~~mixing box~~ economizer dampers to ~~full open (~~100% outdoor air mode~~)~~.	Yes/No
~~b~~c. ~~Disconnect power to the actuator and~~ Verify that a fault is reported at the control workstation.	Yes/No
~~c~~d. ~~Reconnect power to the actuator and command the mixing box dampers to full open~~ Remove the economizer damper override and verify that the control system indicates normal system operation.	Yes/No
~~d~~e. ~~Verify that the control system does not report a fault.~~ Remove all overrides and clear all faults and alarms	Yes/No
f. Override the operating state to economizer-only cooling mode by overriding zone thermostat(s) to create a cooling demand and overriding the OAT sensor so that free cooling is available.	Yes/No
~~e~~g. From the control system workstation, ~~command~~ override the ~~mixing box~~ economizer dampers to ~~a full-closed position (~~0% outdoor air mode~~)~~.	Yes/No
~~f~~h. ~~Disconnect power to the actuator and~~ Verify that a fault is reported at the control workstation.	Yes/No
~~g~~i. ~~Reconnect power to the actuator and command the dampers closed.~~ Remove the economizer damper override and verify that the control system indicates normal system operation.	Yes/No
~~h~~j. ~~Verify that the control system does not report a fault during normal operation~~. Remove all overrides and clear all faults and alarms.	Yes/No

~~Step 3: Valve/actuator fault~~	

Note that the Statewide CASE Team recommends Step 3 (valve/actuator faults) be removed from this test and onto a new NRCA-MCH-13b-A compliance form. Furthermore, the Statewide CASE recommends that this step be modified in the same way as Step 2 above. Because Step 3 is not directly related to economizers, it is out of the scope of this proposal.

~~**Step 4: Inappropriate simultaneous heating, mechanical cooling, and/or economizing**~~	
~~a. From the control system workstation, override the heating coil valve and verify that a fault is reported at the control workstation.~~	~~Yes/No~~
~~b. From the control system workstation, override the cooling coil valve and verify that a fault is reported at the control workstation.~~	~~Yes/No~~
~~c. From the control system workstation, override the mixing box dampers and verify that a fault is reported at the control workstation.~~	~~Yes/No~~

Note that the Statewide CASE Team recommends that Steps 4a and 4b also be eliminated due to redundancy with Step 3, if Step 3 is revised in the same way as Step 2. Because Steps 3, 4a, and 4b are about valves, they are out of the scope of this proposal.

Step 4: Reinstate alarm delay	
a. Reinstate alarm delays to ensure that faults generate alarms as before Step 1, if applicable	Yes/No

~~**C. Functional Testing for Zone Terminal Units**~~	~~**Results**~~
~~Testing of each AHU with FDD controls shall include the following tests:~~	

Note that the Statewide CASE Team recommends Part C (functional test for zone terminal units) be removed from this test and onto a new NRCA-MCH-13b-A compliance form. Because Part C is not directly related to economizers, it is out of the scope of this proposal.

8. REFERENCES

CA DOF (California Department of Finance). "Economic and Fiscal Impact Statement." 2009. http://www.documents.dgs.ca.gov/bsc/proc_rsltn/2009/STD-399-EconomicandFiscalImpactStatement.pdf.

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