CALIFORNIA ENERGY CODES & STANDARDS
A STATEWIDE UTILITY PROGRAM

Second Stakeholder Meeting for Nonresidential HVAC

Economizer Fault Detection & Diagnostics (FDD) for Built-Up Air Handlers

March 15, 2017

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CALIFORNIA ENERGY CODES & STANDARDS
A STATEWIDE UTILITY PROGRAM

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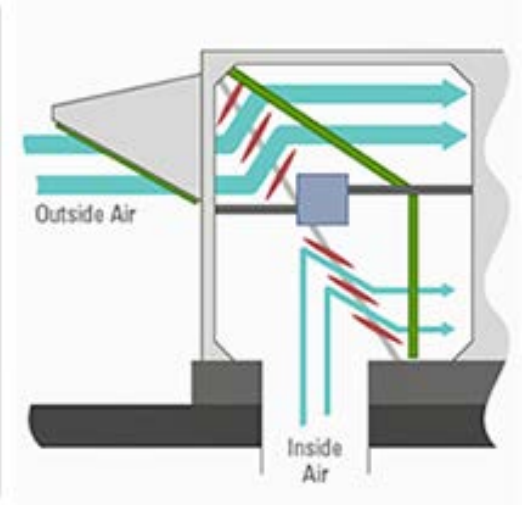
Agenda

1. Background
2. Proposed Code Changes
3. Technical and Market Barriers
4. Compliance and Enforcement
5. Cost-Effectiveness and Energy Impacts
6. Next Steps

1. Background

What Is Economizer Fault Detection & Diagnostics (FDD)?

- Economizers increase fresh air intake to condition indoors
  - Sensors, dampers, controls, actuators, seals, linkages, etc..
- Economizer FDD helps save energy by reporting faults at economizer
- Economizer FDD can be integrated or standalone



Economizer diagram courtesy of HVAC-Optimization.com

Integrated FDD Examples: Belimo ZIP and Honeywell Jade

Existing requirements in Title 24, Part 6 Section 120.2(i)

- Economizer FDD is mandatory for packaged units > 4.5 tons with air economizer (added 2013 cycle)
  - Standalone or integrated, permanently installed
  - Provide status (free cooling, compressor enabled, etc…)
  - Report to a thermostat, EMCS, or fault management application
- Faults detected
  - Air temperature sensor failure/fault
  - Not economizing when it should
  - Economizing when it should not
  - Damper not modulating
  - Excess outdoor air
- Certify to California Energy Commission (CEC) per Joint Appendix 6.3
- No diagnostics

Other Relevant Codes

- 2015 IECC: Same requirements as 2013 Title 24, Part 6
- ASHRAE Guideline 36: Sequences of operation (in development)

FC#2	**Equation**	$MAT_{AVG} + \varepsilon_{MAT} < \min[(RAT_{AVG} - \varepsilon_{RAT}), (OAT_{AVG} - \varepsilon_{OAT})]$	**Applies to OS #1 – #5**
	Description	MAT too low; should be between OAT and RAT	
	Possible Diagnosis	RAT sensor error MAT sensor error OAT sensor error	

Operating States, Defined by Commanded Position of Valves and Dampers																				
1 - Heating only																				
2 - Economizer cooling only																				
3 - Economizer and mechanical cooling																				
4 - Mechanical cooling only																				
Title 24, Part 6 Fault to be Detected (120.2(i)7)	**A. Air Temp Sensor**				**B. Not Economizing When it Should**				**C. Economizing When it Should Not**				**D. Damper Not Modulating**				**E. Excess Outdoor Air**			
Guideline 36 Operating State #	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Guideline 36 Fault Condition Description																				
1 - Duct static pressure too low																				
2 - MAT too low; should be between OAT and RAT	X	X	X	X																
3 - MAT too high; should be between OAT and RAT	X	X	X	X																
4 - Too many changes in operating state																				
5 - SAT too low; should be higher than MAT	X																			
6 - OA fraction not equal to %OAmin	X			X					X			X	X			X	X			X
7 - SAT too low in full heating	X								X				X				X			
8 - SAT and MAT should be approximately equal		X																		
9 - OAT too high for economizer cooling only		X																		
10 - OAT and MAT should be approximately equal			X				X													
11 - OAT too low for 100% cooling			X				X								X					
12 - SAT too high; should be less than MAT			X	X																
13 - SAT too high in full cooling			X	X								X				X				X
14 - Temperature drop across inactive cooling coil																				
15 - Temperature rise across inactive heating coil																				

2. Proposed Code Changes

Proposed Code Change

- Expand current economizer FDD requirements in Section 120.2(i) from packaged systems to include built-up (BU) air handling units (AHUs)
  - Mandatory
  - Nonresidential buildings
  - BU AHUs > 4.5 tons with an air economizer
  - Applies to new construction and additions, not alterations
- Compliance
  - CEC certification
  - Acceptance test (about 1 hour per AHU)
  - Compliance Manual to point to Guideline 36 (should be available)

Draft language is provided in the “Downloads” area of this meeting room and on Title24Stakeholders.com.

Why Are We Proposing this Code Change?

- Built-up AHUs have no economizer FDD requirements
  - Historically, economizer malfunctions are prevalent
    - Technicians have lack of time and/or training
    - Customers unaware or unwilling to prioritize appropriate repair
  - Energy savings opportunity if fault is appropriately detected and corrected
- BU AHUs typically controlled by DDC, some with FDD
- Multiple market actors that can support compliance
  - Mechanical designers develop sequence of operations (SOO)
  - Control contractor SOO
  - DDC manufacturers develop pre-configured FDD modules
  - 3rd party FDD vendor

Does this make sense to you?

3. Technical and Market Barriers

Market Overview

- 118 Packaged FDD products on the market, 73 certified to CEC
  - A handful of 3rd party FDD products intended to be integrated with DDC
- Market impacts if proposal is implemented
  - Expand FDD to all air handlers controlled by DDC
    - Including packaged systems!
  - All market actors will need to update their sequences
- Market barriers
  - Uncertainty of how to design FDD algorithms
  - Lack of impetus for building occupants, owners, and operators to understand and fix economizer faults

Primary Technical and Market Barrier: Initial Design of Algorithms

- DDC-based FDD can be integrated by many actors
  - Mechanical designer SOO
  - Controls contractor SOO
  - DDC manufacturer pre-configured FDD modules (none existing)
  - 3rd party FDD vendor
- Designing algorithms may require several days for each actor
- Compliance process may require a lab setting (discussed later)

Primary Technical and Market Barrier: Initial Design of Algorithms

- **Variety of algorithms can meet requirements**
  - Air sensors (supply, return, outside, mixed)
    - Mixed must be an averaging sensor
  - Feedback actuators
  - Comparison of mechanical cooling power or valve position(s) vs. outdoor air conditions
- **Resources**
  - Manufacturers' packaged product algorithms can be transferred
  - Guideline 36
- **SOO or modules can be replicated and improved across projects**

What about compliance issues?

4. Compliance and Enforcement

Compliance and Enforcement Barriers – CEC Certification

- Joint Appendix JA6.3 requires submittal of evidence for CEC Certification
  - "Manufacturer instructions"
  - Sensor specifications
  - Test procedure and alarm responses
- Market actors that could submit for CEC Certification
  - ~~Mechanical designer SOO~~
  - Controls contractor SOO
    - L&H AirCo certified an Alerton product
  - DDC manufacturer pre-configured FDD modules
    - Many have expressed interest and capability to develop
    - Flexible to allow integration with a variety of systems
    - But not too flexible to avoid improper setup
  - 3rd party FDD vendors perhaps using in-field setup

Compliance and Enforcement Barriers – Acceptance Test

- NRCA-MCH-13-A: Automatic Fault Detection and Diagnostics for Air Handling Units and Zone Terminal Units
  - Currently a compliance credit
  - Includes functional test for economizer FDD, coil valves, and zone terminal unit FDD
- Functional test for economizer FDD on NRCA-MCH-13-A would become mandatory (with revisions)
  - Anticipated about 1 hour per AHU
- Other functional tests would remain compliance credit under new form NRCA-MCH-13-B

Compliance Process

Design Phase

- Mechanical designers develop SOOs
- Note in AHU schedule and controls diagrams that economizer FDD is required per 120.2(i)
- Ensure on NRCC-MCH-01-E form that NRCA-MCH-13-A test is required to be completed

Permit Application Phase

- Plan reviewer will verify on NRCC-MCH-01-E form that NRCA-MCH-13-A test is required to be completed

Compliance Process

Construction Phase

- Mechanical designer and controls contractor coordinate to select and install appropriate equipment (e.g., sensors and actuators).
- Controls contractors will implement economizer FDD SOOs
- Controls contractors will test system and refine SOO from project-to-project

Inspection Phase

- Mechanical Acceptance Test Technicians (MATTs) need to become acquainted with NRCA-MCH-13-A form
- MATTs perform test when applicable

What about compliance and enforcement?

5. Cost-Effectiveness and Energy Impacts

Definition of Baseline and Proposed Conditions

- Prototype: Large office, 498,000 ft2, 13-stories, with a central plant
- Modeled Faults:
  - **Air temperature sensor failure:**
    Adjust SAT +/- 1˚ F and adjust economizer upper limit by +/- 1˚ F (to mimic OAT sensor drift).
  - **Not economizing when it should:**
    High limit set point = RAT - 10˚ F
  - **Economizing when it should not:**
    High limit set point = RAT + 10˚ F
  - **Damper not modulating:**
    No economizer (stuck closed)
  - **Excess outdoor air:**
    80% outside air system (stuck open)
- Applied fault incidence rates

Fault Incidence Rates

2013 Incidence Rates from AirCare Plus program data

	Prob. of detecting the fault w/FDD	Prob. of detecting the fault w/o FDD	Fault incidence over 15 years	FDD benefit x Fault incidence
Air temperature sensor malfunction	75%	25%	2%	1%
Not economizing when it should	75%	25%	30%	15%
Economizing when it should not	75%	25%	0% (no data)	0%
Damper not modulating	75%	25%	24%	12%
Excess outdoor air	75%	25%	24%	12%

Incremental Costs

- Incremental First Cost
  - Current standards require SAT and OAT
  - Contractor implementation of RAT, averaging MATs, and FDD SOO ($2,604 per AHU)
  - Acceptance Test ($150 per AHU)
  - Total cost per AHU ($2,754)
  - **Total Incremental First Cost for 13 AHUs ($35,804)**
- Incremental Maintenance Costs over 15-year period of analysis
  - On-site facilities engineers paid annual salary, economizer maintenance is within normal job description ($0)
  - Service technicians typically on “all-embracing” or “full parts and labor” contracts for large facilities. Economizer faults are likely to be addressed during regularly scheduled visits. ($0)
  - **Total Incremental Maintenance Cost ($0)**
- **Total Incremental Cost over 15-year period of analysis = $35,804**

Benefit-to-Cost Ratio

Climate Zone	Benefit to Cost
1	2.6
2	3.9
3	1.9
4	2.5
5	1.9
6	2.0
7	1.9
8	2.8
9	5.1
10	4.0
11	5.9
12	4.4
13	5.9
14	6.7
15	8.0
16	3.2

- Total Energy Cost Savings = range of **$66,482 to $287,585** depending on climate zone
- Total Incremental Cost over 15-year period of analysis = **$35,804**

Cost Effective in All Climate Zones

If Benefit-to-Cost Ratio is over 1, measure is cost effective.

Annual Energy Savings per Square Foot

Climate Zone	TDV Energy Savings (TDV kBtu/yr-ft^2)	15 Year TDV Energy Cost Savings (2020 $/ft^2)
1	2.1	$0.18
2	3.1	$0.28
3	1.5	$0.14
4	2.0	$0.18
5	1.5	$0.13
6	1.6	$0.14
7	1.5	$0.13
8	2.3	$0.20
9	4.1	$0.37
10	3.2	$0.28
11	4.8	$0.42
12	3.6	$0.32
13	4.7	$0.42
14	5.4	$0.48
15	6.5	$0.58
16	2.6	$0.23

Annual Energy Savings Per Square Foot

Climate Zone	Annual Electricity Savings (kWh/yr-ft^2)	Annual Natural Gas Savings (therms/yr-ft^2)	Peak Electric Demand Reduction (W/ft^2)
1	0.05	0.00	0.00
2	0.06	0.00	0.09
3	0.06	0.00	0.03
4	0.06	0.00	0.06
5	0.06	0.00	0.01
6	0.05	0.00	0.05
7	0.06	0.00	0.04
8	0.06	0.00	0.11
9	0.07	0.00	0.09
10	0.07	0.00	0.14
11	0.08	0.00	0.08
12	0.06	0.00	0.09
13	0.08	0.00	0.09
14	0.10	0.00	0.01
15	0.14	0.00	0.12
16	0.04	0.01	0.04

What about the incremental costs & savings?

6. Next Steps

Next Steps

- Please send any additional feedback within 2 weeks to:
  - CASE Author (see contact info at end of this presentation)
  - Info@title24stakeholders.com
- Keep an eye on Title24Stakeholders.com for:
  - Presentations from today's meeting
  - Draft Code Change Language
  - Notes from today's meeting
  - Draft CASE Report (will be posted in April)

Let's move on to…

Wrap-up

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Appendix:

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Economizer Fault Detection & Diagnostics (FDD) for Built-Up Air Handlers

March 15

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Cost Details

The Statewide CASE Team collected costs for adding RAT and MAT sensors to the air handler primarily from two sources: mechanical designers and controls contractors. Mechanical designers provided a rule-of-thumb meant to represent the cost of an additional control point, summarized below in Table 15. Designers also noted that MATs and RATs are more often installed in built-up air handlers, if not for control then for monitoring and trending. Nonetheless, the CASE Team conservatively assumed that RATs and MATs represented entirely additional control points.

Table 15: Mechanical Designer Costs Per Additional Control Point

Designer	Minimum of Range	Maximum of Range	Average
#1	$1,000	$2,000	$1,500
#2	$500	$2,000	$1,250
#3	$1,000	$1,500	$1,250
Average Cost			$1,333

Based on Table 15, the average cost for adding two control points (the RAT and MAT) would be $2,666 per air handler, or $34,658 for the thirteen air handlers in the large office prototype. The Statewide CASE Team also spoke with two controls contractors to attain itemized costs for adding the two control points, summarized in Table 16. Costs include all markups.

Table 16: Current Incremental Construction Cost for Economizer FDD in Built-Up Systems

		Control Contractor #1			Control Contractor #2		
Row	Cost Component	Number of Units Per Air Handler	Cost Per Unit	Cost Per Air Handler	Number of Units Per Air Handler	Cost Per Unit	Cost Per Air Handler
A	Averaging MAT Sensor	4	$238	$952	4	$170	$680
B	RAT Sensor	1	$78	$78	1	$50	$50
C	Upsized Controller	1	$700	$700	1	$350	$350
D	Control and Electrical Contractor Installation and Wiring (Hours and Materials)	5	$105	$525	-	-	$1,150
E	Control Contractor Implementation, Startup, and Testing (Hours)	1	$75	$75	4	$125	$500
F	**Total Cost Per Air Handler (A+B+C+D+E)**			$2,355			$2,730
G	**Total Cost for 13 Air Handlers (F x 13)**			**$30,610**			**$35,490**
H	**Average Cost for RAT, MAT, and FDD SOO**			**$33,050**			

Based on Table 16, the average cost for adding the RAT and MAT and programming the FDD SOO would be $33,050. The overall average of the mechanical design estimate and the control contractor cost estimates for implementing the necessary sensors and controls to complete economizer FDD is $33,854, or $2,604 per air handler.

JA6.3.1

JA6.3.1 Information that shall be included with the Declaration

The air conditioning system manufacturer, controls supplier, or FDD supplier provides evidence as shown below:

(a) The following temperature sensors are permanently installed to monitor system operation:
   i. Outside air.
   ii. Supply air.
   iii. Return air, when required for differential economizer operation.

   Evidence: Photograph or schematic of all required sensors indicating their recommended mounting instructions.

(b) Temperature sensors have an accuracy of ±2°F over the range of 40°F to 80°F
   Evidence: Photocopy of sensor specification.

(c) The controller is capable of providing system status by indicating the following:
   i. Free cooling available.
   ii. Economizer enabled.
   iii. Compressor enabled.
   iv. Heating enabled, if applicable.
   v. Mixed air low limit cycle active.
   vi. The current value of each sensor.

   Evidence: Laboratory test: describe how the mode is simulated and the wording used to indicate the status.

(d) The unit controller is capable of manually initiating each operating mode so that the operation of compressors, economizers, fans, and heating system, if applicable, can be independently tested and verified.
   Evidence: Photocopy of controller manual showing instructions for manually initiating each operating mode.

JA6.3.1 continued

(e) The unit controller is capable of reporting faults one of the following ways:

A. To an Energy Management Control System regularly monitored by facility personnel, or;

B. Annunciated locally on one or more zone thermostats, or on 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 appropriate building personnel or an HVAC technician.

ii. In buildings with multiple tenants, the annunciation shall either be within property management offices, or in common space accessible by the property or building manager.

C. To a fault management application which automatically provides notification of the fault to a remote HVAC service provider.

Evidence: Supplier's description of how they comply, and supporting documentation such as a photocopy of controller manual or photograph of fault management application, zone thermostat, or other device showing indication of a fault.

(f) The unit control is capable of detecting the following faults:

i. Air temperature sensor failure/fault.
ii. Not economizing when it should.
iii. Economizing when it should not.
iv. Damper not modulating.
v. Excess outdoor air.

JA6.3.2

JA6.3.2 Fault Detection Test Specifications

To provide evidence that the required faults are detected by the FDD functionality, the FDD Provider shall perform a No-Fault and Fault test for each of the tests in Table 1. A pre-defined Test Procedure such as the one provided in the example shown in Table 2 could be used to fill out Table 1.

Table 1 – Sample of a completed fault test

Tests	Faults: Air temperature sensor failure/fault	Not Economizing when it should	Economizing when it Should not	Damper not modulating	Excess outdoor air
1. Damper is Stuck Open			X	X	X
2. Damper Stuck at Minimum		X		X	
3. Bad or Unplugged Actuator		X	X	X	
4. Sensor Hard Failure	X	X	X		X
5. Actuator Mechanically Disconnected		X	X	X	X

JA6.3.3

JA6.3.3 Reporting of Test Results

The results of each test shall be provided in a report using a standard test results reporting format that provides the following information for each test:

a. Organization and individual conducting the test.

b. Time, Date, and Location of test.

c. Make and model of unit/control tested.

d. Range of models represented by test.

e. Test procedure used, including description of the method for imposing fault with repeatability.

f. Test driving Conditions (outdoor air temperature, return air temperature or enthalpy as required by the type of high limit control being used).

g. Results of the test: Alarms generated.

h. Provide a bill of materials for the configuration that is being certified.

i. The FDD supplier shall describe any special field or data verifications that are required for the particular FDD analytics (beyond those included in Acceptance Test requirements).

j. Sample of documentation that would accompany each qualifying set of FDD analytics.

k. Name and contact information of company personnel in charge of certification.

l. A mapping from the manufacturer's alarm description to what is required by Title 24 similar to Table 1.

JA6.3.3 continued

Table 2 - Sample Test Procedure

Step	Description	Purpose
1	Close the economizer damper fresh air blades, then secure the blades in a manner that prevents opening.	Test alarm response when "Damper Stuck at Minimum"
2	Simulate conditions such that the damper actuator attempts to open the fresh air blades. Verify the damper blades remains secured and that the fault(s) specified in Table 1 are detected. Record the annunciated fault(s) and fault text.	
3	Release the blades and allow the economizer damper to modulate open. Verify the annunciated fault(s) have cleared.	
4	Open fully the economizer damper fresh air blades, then secure the blades in a manner that prevents closing.	Test alarm response when "Damper is Stuck Open"
5	Simulate conditions such that the damper actuator attempts to modulate the fresh air blade closed. Verify the damper remains secured and that the fault(s) specified in Table 2 are detected. Record the annunciated fault(s) and fault text.	
6	Release the blades and allow the economizer damper to modulate. Verify the annunciated fault(s) have cleared.	
7	Disconnect 1 sensor and verify the fault(s) specified in Table 1 are detected. Record the annunciated fault(s) and fault text.	Test alarm response when "Sensor Hard Failure"
8	Reconnect the sensor and verify that the annunciated fault(s) have cleared.	
9	Repeat steps 7 – 8 for each available sensor.	
10	Electrically disconnect the damper actuator and verify the fault(s) specified in Table 1 are detected. Record annunciated fault(s) and fault text.	Test alarm response when "Bad or Unplugged Actuator"
11	Reconnect the damper actuator. Verify the fault(s) have cleared and normal economizer operation has resumed.	
12	Mechanically disconnect the damper actuator from the damper blade assembly	Test alarm response when "Actuator

JA6.3.4

JA 6.3.4 Declaration

Consistent with the requirements of Title 24, Part 6, Sections 100.0(h) and 120.2(i), companies wishing to certify to the California Energy Commission shall execute a declaration under penalty of perjury attesting that all information provided is true, complete, accurate, and in compliance with the applicable provisions of Part 6. Companies may fulfill this requirement by providing the information, signing the declaration below and submitting to the California Energy Commission as as specified by the instructions in JA6.3.5.

Manufacturer, Model Name and Number of all devices being certified

Manufacturer	Model Name	Model Number

When providing the information below, be sure to enter complete mailing addresses, including postal/zip codes.

Certifying Company

Contact Person Name *	Phone 1
Certifying Company Name **	Phone 2
Address	Fax
(Address)	E-mail
(Address)	Company Website (URL)

* If the contact person named above is NOT the person whose signature is on the Declaration, then the full contact information for the person whose signature is on the Declaration must also be provided on a separate page.

** If the company named above is: A) a parent entity filing on behalf of a subsidiary entity; B) a subsidiary entity filing on behalf of a parent entity; or C) an affiliate entity filing on behalf of an affiliate entity, the above contact information must be provided for any additional entities on a separate page.

JA6.3.4 continued

Manufacturer (if different from Certifying Company)

Contact Person Name	Phone 1
Manufacturing Company Name	Phone 2
Address	Fax
(Address)	E-mail
(Address)	Company Website (URL)

Declaration

I declare under penalty of perjury under the laws of the State of California that:

(1) All the information in this statement is true, complete, accurate, and in compliance with all applicable provisions of Section 120.2(i) of Title 24, Part 6 of the California Code of Regulations.

(2) Each Fault Detection and Diagnostic (FDD) system has been tested in accordance with all applicable requirements of Section 120.2(i)1-120.2(i)7 of Title 24, Part 6 of the California Code of Regulations.

(3) [If the party submitting this statement is a corporation, partnership, or other business entity] I am authorized to make this declaration, and to file this statement, on behalf of the company named below.

Certifying Company Name _____ Date _____

Name/Title (please print) _____ Signature _____

JA6.3.5 Certification

Send declarations and evidence of functionality or test reports to the addresses below. Electronic submittals are preferred.

(1) Electronic submittal:

CertifiedtoCEC@energy.ca.gov