Measure Information Template –

Fault Detection and Diagnostics for Rooftop Air Conditioners

2008 California Building Energy Efficiency Standards

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CONTENTS

Overview

Description	Packaged air conditioners are the most poorly maintained type of HVAC system. In California, they use about 54% of the HVAC energy in the commercial sector. The Purdue research team developed thermo-fluids based fault detection methods that can pinpoint five common maintenance problems. The FDD technology is designed to automatically detect faults in rooftop (packaged) air conditioning systems, and to provide diagnostic information to an outside source. The basic principal here is that by maintaining optimal operation of the system, energy efficiency will be achieved over the life of the system.
Type of Change	It is proposed that the FDD technology be incorporated into the Standards as both a Compliance Option in the Nonresidential Performance Method, and also as a feature related to the Acceptance Requirements. Two documents will require changes to incorporate this feature. Section 3 of the Nonresidential ACM Manual will require an additional section describing this feature, and Chapter 8 of the Nonresidential Manual where the Acceptance Requirements are described. In addition, software vendors will need to modify their ACM products to incorporate this feature, and to incorporate the appropriate messages on the PERF-1 form identifying both the feature, as well as the requirement for field verification via the Certificate of Acceptance.
Energy Benefits	The most obvious benefit of this feature will be long term energy savings on packaged systems due to optimum operation. This feature parallels the TXV feature implemented on split systems many years ago as an energy conservation measure in the Standards. Since air conditioner operation is one of the bigger energy use components during peak demand periods, the primary savings from this measure will occur during the peak demand periods. The potential for savings will be mainly in compressor energy consumption; since we typically assume that fans are operational during occupied hours, there would be a small energy savings potential on fan consumption related to filter maintenance. When we apply the TDV numbers to this feature, we will see a more significant benefit, since the air conditioning use typically occurs during high TDV periods. Just as in the case of the TXV, the FDD technology will result in a higher Coefficient Of Performance on the cooling compressor related to better maintenance practices.

Non-Energy Benefits	Three primary non-energy benefits result from the use of the FDD technology. The first will be lower operational and maintenance costs. Clearly, by maintaining optimal performance of the system, energy cost savings will occur over the life of the system. In addition, this product can actually decrease maintenance costs for a building owner by eliminating unnecessary maintenance costs. This same type of approach is now being incorporated into high-end automobiles and trucking fleets; these vehicles will actually monitor driving habits and engine performance, and extend maintenance periods in response to actual operation. The second area of impact will be equipment life. By maintaining operational peak efficiency, the life of the system, and in particular the compressor will be extended. The third area of benefit would be in property management. Organizations that manage multiple properties would perceive a huge benefit by having this portion of building maintenance automated. Just as in the example of operators of trucking fleets, having a system that will automate HVAC maintenance would have a huge market potential.
Environmental Impact	No perceived negative environmental impacts will result from this technology.
Technology Measures	Measure Availability and Cost FDD builds on technology used in the HVAC Service Assistant system that's now available from Honeywell (visit http://acrx.com/serviceassistant.cfm). Enhancements include an online user interface and exclusive use of temperature sensors for diagnostics, which makes installation easier. Honeywell is considering integrating the FDD technology into its more-advanced product offerings. The initial cost of this feature is about $300. Note that this does not involve any interaction with an Energy Management System, but functions as a standalone diagnostic feature. Annual energy savings from this feature ranged from $400 - $1,000 in the field test performed. Field sites schools in Woodland and Oakland (Zones 12 and 3) four restaurant sites in Sacramento and San Francisco (Zones 12 & 3) as well as retail stores in Anaheim and Rialto (Zones 8 & 10). Based upon the demonstrated savings, this technology has the potential for a payback period of less than one year. Clearly with this type of energy savings, other manufacturers will be entering this arena. In fact, once adequate market penetration exists, which should occur by 2011, it would be recommended to implement this as a mandatory measure, similar to Demand Control Ventilation. Useful Life, Persistence and Maintenance The FDD technology is designed to last the life of the equipment. The one unknown area related to persistence of this measure is not related to reliability of the product, but rather the reliability of the service operator who is notified of the fault. Since service operators are in the business of making money based upon service calls, there is no reason not to believe that maintenance would not be performed.

Performance Verification	Clearly the only way to assure installation of this measure is via the Acceptance Requirements. The most obvious parallel would be DCV controls in the 2005 Standards. While building departments are responsible for verifying the correct specification of this feature, final verification and commissioning occurs via the MECH-6-A Acceptance Certificate. One of the benefits of the FDD, however, is the ability to verify proper equipment performance, including such features as the economizers. Therefore, it would be recommended that the MECH-3-A and MECH-4-A be modified to simplify functional testing when this measure is included. Installer verification would then be simplified to the task of proper calibration and operation of the FDD feature, as opposed to the system itself.
Cost Effectiveness	The FDD technology has a payback period of less than one year. Clearly, with such a cost effective measure, this should really be a mandatory measure for packaged units. However, just as DCV controls were in their initial stages 10 years ago, this same technology does not enjoy widespread use yet. Therefore, this measure change has been proposed as a compliance option.
Analysis Tools	The current reference method, DOE-2.1E is proposed to be used as the basis of determining savings for this measure, although the procedures developed in this measure template could be applied to any certified Alternative Calculation Method. One of the problems that we have with our analysis tools is that they assume a perfectly functioning building. This technology demonstrates that, in reality, we are being way too generous with this assumption as regards the HVAC system. However, the current nonresidential reference method can be used to model a reasonable representation of this "broken" HVAC system. In fact, procedures are already in the Standards for modeling of TXV valves using the same concept. The system without the TXV valve is modeled as using more energy than the system with the TXV valve. It is recommended that we apply the same concept to the FDD feature.
Relationship to Other Measures	No other measures are impacted by this feature in the modeling.

Methodology

Since current practice in the industry is not to utilize FDD technology, and field data has shown that a high percentage of packaged systems have one or more faults, the baseline building assumption will include HVAC systems that do not include FDD. When the Standard building includes Packaged DX systems, they will be assumed to be "broken" in the same fashion as we do with TXVs. In fact, it is the recommendation of this measure template that we apply an identical approach to FDD technology as we do for TXVs. Hence, the Standard building under the performance method will have a 6% degradation factor applied to the cooling EIR. In addition, to account for the FDD impact on economizer operation, the economizer in the Standard building would be assumed to have a 10% degradation factor, only allowing 90% of outside air into the building.

If the proposed building includes the FDD, the cooling EIR would be restored to normal, and the economizer, if present, assumed to provide 100% outside air to the building.

In regards to the 10% degradation factor related to economizers, a conservative value was chosen. A field study on 503 rooftop units done by the New Buildings Institute (NBI) (see reference material at the end of this report) showed that 64% of the economizers to be faulty. This study includes 215 units surveyed by the California Energy Commission. Estimates in this report of energy savings by repairing the economizers were a 25% savings.

Note that this measure is not being proposed as a mandatory measure, nor as a prescriptive requirement. It is being proposed as a compliance option for building owners who choose to incorporate this feature. Given the large failure rate shown in the NBI report, and the fact that all sites that incorporated the FDD in the PIER study benefited, this measure offers excellent savings potential to building owners.

Analysis and Results

An FDD system uses sensors embedded in the RTU controller to monitor conditions at various points in the cooling cycle. The system's logic uses data such as ambient dry bulb temperature and the dry- and wet bulb temperatures of return, mixed, and supply air to predict normal operating temperatures—including evaporator temperature, suction superheat, condenser temperature, condenser subcooling, and compressor hot gas temperature—as well as differences in condenser and evaporator air temperatures. The FDD system then calculates the difference between monitored and expected temperatures and analyzes the data to determine what problems may be imminent and what actions should be taken. The device communicates this diagnostic information to the facilities Manager.

The new FDD system can detect a variety of problems in compressors, heat exchangers, expansion valves, and economizers, and other components. Field tests have shown not only how common these problems are but also how successful an FDD can be at detecting them. Roughly 71 percent—15 of the 21 systems studied—had some kind of problem that affected performance. Filter/drier restrictions plagued 11 of the systems, 10 had a low refrigerant charge and 8 suffered from both low charge and filter/drier restrictions.

Recommendations

The following is recommended language for the Nonresidential ACM Manual.

Equation N2-20 should be modified to include the term F_{fdd}

F_{fdd} Cooling system performance adjustment factor, default = 0.90. For packaged systems with FDD controls, F_{fdd} shall be 0.96.

Equation N2-1

$$EERnf_{EWB,ODB} = 1.0452 \times EER_{EWB,ODB} + 0.0115 \times EER_{EWB,ODB}^{2} + 0.000251 \times EER_{EWB,ODB}^{3} \times F_{TXV} \times F_{AIR} \times F_{FDD}$$

In section 2.5.2.6, the entire equation for calculating the COOLING-EIR has been omitted, so it would be suggested that the following language be added, which is based upon the previous ACM Manual:

Description: ACMs shall require the user to input the EER for all packaged cooling equipment that are not covered by DOE appliance standards.

ACMs shall also require the user to input the net cooling capacity, CAPa, at ARI conditions for all cooling equipment.

ACMs shall calculate the electrical input ratio, EIR, according to Equation N2-19

DOE Keyword: COOLING-EIR

Input Type: Default

Tradeoffs: Yes

Modeling Rules for Proposed Design: The ACM shall require the user to input efficiency descriptors at ARI conditions for all equipment documented in the plans and specifications for the building.

Default: Minimum EER as specified in the Appliance Efficiency Regulations.

Modeling Rules for Standard Design (New): For the reference method, the standard design shall assign the EER and EIR of each unit according to the applicable requirements of the Appliance Efficiency Standards or the Standards. The EIR of the equipment will be based on the proposed system with an EER that meets the applicable requirements of the Standards but has the same cooling capacity and ARI fan power as the unit selected for the proposed design.

Modeling Rules for Standard Design the (Existing Unchanged & Altered Existing): ACMs shall use the EER, EIR, and the ARI fan power of the existing system. The EIR of the existing equipment must be based on the EER and the ARI fan power of existing system. ACMs shall model the existing system as it occurs in the existing building. If the permit involves alterations, ACMs shall model the system before alterations.

2.5.3.7 Air Economizers

Description: The reference method is capable of simulating an economizer that: (1) modulates outside air and return rates to supply up to 100% of design supply air quantity as outside air; and, (2) modulates to a fixed position at which the minimum ventilation air is supplied when the economizer is not in operation. The reference method will simulate at least two types of economizers and all ACMs shall receive input for these two types of economizers:

1. Integrated. The economizer is capable of providing partial cooling, even when additional mechanical cooling is required to meet the remainder of the cooling load. The economizer is shut off when outside air temperature or enthalpy is greater than a fixed setpoint.

2. Nonintegrated/fixed set point. This strategy allows only the economizer to

	operate below a fixed outside air temperature set point. Above that set point, only the compressor can provide cooling. The default for MAX-OA-FRACTION shall be 0.9 to represent imperfect operation of the economizer.
DOE Keyword:	ECONO-LIMIT ECONO-LOCKOUT ECONO-LOW-LIMIT MAX-OA-FRACTION

Chapter 3 should be modified with the following language:

3.3.18 Packaged System Fault Detection & Diagnosis

Description:	A nonresidential ACM may be approved with the optional capability of controls that allow for self detection and diagnostic of faults in packaged systems. This optional capability is only available for Packaged DX cooling systems.
DOE Keyword:	COOLING-EIR MAX-OA-FRACTION
Input Type:	Required
Tradeoffs:	Yes
Modeling Rules for Proposed Design:	ACMs shall model the optional feature of proposed design FDD controls as input by the user according to plans and specifications for the building. For systems with FDD controls the cooling system performance adjustment factor F_{fdd} in equationN2-20 shall be 0.96. The economizer MAX-OA-FRACTION keyword shall be 1.0.
Modeling Rules for Standard Design (New):	ACMs shall determine the standard design according to Table N2-10.
Modeling Rules for Standard Design (Existing Unchanged & Altered Existing):	ACMs shall model the existing system as it occurs in the existing building. If the permit involves alterations, ACMs shall model the system before alterations.

Material for Compliance Manuals

It is recommended that only Chapter 8 of the Nonresidential Compliance Manual be changed to accommodate this measure since it will be dealt with as an Acceptance Requirement item. Additional information pertaining to the use of the FDD should be incorporated into the MECH-3-A form and simplifications made to the MECH-4-A.

Bibliography and Other Research

Information for this measure template has been taken from the PIER research project number 500-03-096-A1 report. This PIER report is available from the California Energy Commission's PIER website as an Adobe Acrobat file, and includes the detailed background and research related to this measure template proposal.

The hyperlink for this project is as follows:

http://www.energy.ca.gov/reports/2003-11-18_500-03-096-A1.PDF

The field study by the New Buildings Institute on rooftop unit performance can be found at:

http://www.newbuildings.org/downloads/NWPCC_SmallHVAC_Report_R3_.pdf