529 14th Street, N. W., Suite 600 Washington, D.C. 20045 202.507.4000 202.429.2248 www.aceee.org

Emerging Technologies Report

Automated Fault Detection and Diagnostics for Rooftop Units

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Definition	RTUs with automated fault detection and diagnostics capability					
Base Case	5-ton RTU					
New Measure:	Incorporation of advanced features	Percent savings	2025 Savings TBtu (Source)	Cost of Saved Energy	Success Rating (1-5)
		10%	131	negative	4

Summary

Smart equipment that recognizes when it is failing or has failed, or when environmental conditions have drifted outside its optimum capability range, could save substantial amounts of energy if the equipment sent useful information to the owner's representative. The necessary capabilities are referred to as automated Fault Detection and Diagnostics (FDD). Implemented on commercial roof-top units (RTUs), these capabilities should save at least 10%.

Background and Description

Even the most efficient HVAC equipment will waste energy if it is operated incorrectly. In addition, the performance of HVAC equipment often degrades over time, so periodic maintenance is required to maintain equipment efficiency. Some of the problems that can affect the energy efficiency of RTUs include:

- Insufficient evaporator airflow
- Condenser coil fouling
- Incorrect refrigerant charge
- Compressor valve leakage
- Liquid line restrictions
- Economizer damper failure
- Sensor failure/degradation

Fault detection and diagnostics for roof-top air-conditioners refers to technologies that monitor components, sense problems as "faults," and can optimize operation and/or notify personnel, ensuring timely identification and correction of operating and service issues.

In recent years, advances in electronics have meant that sensor capability has improved and costs of sensors and controllers have declined significantly. Automated FDDs have been introduced for applications as diverse as nuclear power plants, aircrafts, chemical process plants, and automobiles.[1]

Manufacturers are producing "smarter" equipment that can self-diagnose faults, and some that can detect and adjust operations based on real-time conditions and performance data.[2] This is at least in part due to growing awareness by building operators for the need to monitor building performance, which has resulted in the growth of building operation and maintenance services, and demand for relevant data reporting. This, coupled with the increasing use of information technology in buildings and building

[1] "Automated Fault Detection and Diagnostics for Vapor Compression Cooling Equipment", Braun
[2] http://www.achrnews.com/Articles/Feature_Article/BNP_GUID_9-5-2006_A_10000000000000125170

equipment, has helped to create basic infrastructure to enable widespread adoption of automated FDDs in RTUs.

Data Summary

Market Sector	Market Application		End Use	Fuel Type
Commercial	New/Replace on Burnout; Long Life		Cooling	Electricity
Current Status	**Date of Com**		**Product Life (years)**	**Source**
Commercialized			15	DOE TSD[3]
Base Case Energy Use		**Units**	**Notes, Explanation**	**Source**
Efficiency	10.0	EER	Federal mandated energy efficiency, 2010	
Electricity Use	9,621	kWh/year	Using FEMP energy cost calculator and adding electricity consumption due to faults in refrigerant charge and airflow, assuming that the fault occurs midway through the year (since the fault can occur at anytime)	FEMP
Summer Peak Demand	3.24	kW	0.9 coincidence factor assumed	ACEEE estimate
Winter Peak Demand	0.0	kW		
Fuel Use	0.0	MMBtu/year		
New Measure Energy Use				
Efficiency	10.0	EER	Federal mandated energy efficiency, 2010	
Electricity Use	8,659	kWh/year	Using FEMP energy cost calculator	FEMP
Summer Peak Demand	3.24	kW	0.9 coincidence factor assumed	ACEEE estimate
Winter Peak Demand	0.0	kW		
Fuel Use	0.0	MMBtu/year		
Savings				
Electricity Savings	962	kWh/year		
Summer Peak Demand Svgs	0.0	kW		
Winter Peak Demand Svgs	0.0	kW		
Fuel Savings	0.0	MMBtu/year		
Percent Savings	10%			
Percent Feasible	70%		Assume in market 2010, replacement only (18.4 yrs lifespan), 50% takeup (due to upfront cost)	PIER
Industrial Savings > 25%?	No			
Costs				
Incremental Cost	$ 500	$	.5* PIER uper bound estimate	PIER
Other Costs (Savings)	-100	$/ year	From PIER analysis, annual non-energy benefit for diag. & monitoring	PIER

[3] Technical support document: "Energy Efficiency Program for Commercial and Industrial Equipment: Commercial Unitary Air Conditioners and Heat Pumps**. "** Chapter 8. *Life-Cycle Cost and Payback Period Analysis*, p. 8-45. http://www1.eere.energy.gov/buildings/appliance_standards/comm.

Ranking Metrics		
2025 Savings Potential	12,500	GWh
2025 Savings Potential	131	TBtu
Cost of Saved Energy	$ (0.026)	$/kWh
Cost of Saved Energy	$ (2.46)	$/MMBtu

Unusual Market Barriers	Non-Energy Benefits	Current Activity	Next Steps
	Improved maintenance and serviceability Increased reliability and robustness		Incentives Standards & Codes

Likelihood of Success	4	(1-5)
Priority	Medium	Low, Med, High
Data Quality Assessment	C	(A-D)

Principal Contacts
By Wilson Lin, with Harvey Sachs

Besides the energy efficiency benefits arising from ensuring the proper operation of RTUs, automated FDD on RTUs can also help:

- Provide greater comfort to occupants by providing information for building management and control systems (BAS, EMS);
- Minimize interruptions to building operations due to system failures;
- Reduce time (and costs) needed for maintenance and troubleshooting; and
- Avoid damage to RTU components (and replacement costs) by predicting component failure (prognostics) and implementing preventive maintenance.

Automated FDD with prognostics analyses diagnostic data from sensors and generates trend lines to predict possible failures. It can also help promote other emerging technologies in HVAC: A common market barrier to emerging technologies is that consumers are concerned about the availability of the technology, such as whether spare parts would be quickly available if there is a need to replace them. Prognostics can help address this by allowing the HVAC supplier ample time to ship the necessary parts and replace them even before the failures occur. In an extreme case, the implications of the lack of FDD can be huge: It is estimated that a faulty VAV can waste 25–35% with a fully-closed damper fault, ~30% with a fully open damper for a unit on the interior side, and 20–50% if the minimum value of the demand airflow rate or set point of the supply air temperature is stuck at an abnormal value.[4]

Current Status of Measure

There is an existing program for the commercialization of advanced automated HVAC fault detection and diagnostics under the California Energy Commission's PIER initiative. A project under this program aims to embed FDD methods in selected controller components for use with RTUs.[5] Known as the ACRx Sentinel, the system is currently undergoing field tests.

Savings Potential and Cost-Effectiveness

Automated FDD can help reduce utility and maintenance costs. It allows building operators to take early action to correct faults in the RTUs, helping to reduce the amount of time the RTUs are operating in an inefficient manner due to these faults.

[4] http://www.ibpsa.org/proceedings/BS2005/BS05_0777_784.pdf
[5] http://www.archenergy.com/pier-fdd/rtu_diagnostics/rtu_diagnostics.htm

Diagnostic data can help building operators better understand energy consumption patterns and may highlight ways in which to reduce energy consumption. The data allow building operators to take a more active approach towards building management, shifting towards a more "reliability-centered" approach from the current "reactive" one.[6] It can also reduce the cost for the building to undergo continuous commissioning, since the data needed for commissioning is already collected.

A meta-analysis of building commissioning reviewed the cost-effectiveness of commissioning in improving energy efficiency.[7] The analysis found that most of the reported building performance problems were due to the HVAC systems. A report by the International Energy Agency reported that typically 20–30% energy savings can be achieved in commercial buildings by correcting faulty operation in the HVAC system.[8] It is likely that the potential energy savings from intelligent HVAC systems will exceed this estimate, since intelligent HVAC systems provide opportunities for energy savings that go beyond just the correction of faults (such as dynamic matching of capacity to load when installed with variable output components).

In a 2005 paper for DOE,[9] TIAX estimated that FDDs could reduce national primary energy consumption by 0.025 to 0.14 quads for RTUs, assuming that they only address three key faults: insufficient evaporator airflow, condenser coil fouling, and incorrect refrigerant charge. This compares to the relevant energy consumption of 0.74 quads (3–18% savings).

A California PIER project on advanced automated HVAC fault detection and diagnostics commercialization estimates that at least 10% of the energy used in CA commercial buildings is wasted due to excessive run time and problems in the HVAC equipment and controls — problems that could be addressed by diagnostics/prognostics.

Based on a review of field studies on commercial rooftop units in the Pacific Northwest and California,[10] it was found that:

- An average of 46% of the units tested had refrigerant charge that deviated by more than 5% from the specifications. Correcting the refrigerant charge is estimated to result in 5–11% savings in the cooling energy;
- An average of 64% of the units tested had economizers that failed or required readjustment. Repairing a failed economizer is estimated to result in 15–40% savings in the cooling energy, depending on the climate zone and other factors; and
- An average of 42% of the units tested had airflow that was out of range. The correction of airflow is estimated to result in about 10% savings in the cooling energy.

Our study assumes 10% savings, a conservative estimate.

Market Barriers

The commercial roof-top air-conditioner market is fiercely competitive, and dominated by lower-efficiency commoditized products sold as least purchase price solutions. Utility incentives, such as those coordinated by the Consortium for Energy Efficiency (CEE), are considered essential for moving the market to higher performance.[11] It will be important for CEE to consider the results of field research and begin to require automated FDD measures for program eligibility.

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[6] http://www.peci.org/ncbc/proceedings/2006/17_Cherniack_NCBC2006.pdf
[7] Mills, et al. ""The Cost-Effectiveness of Commercial-Building Commissioning," 2004.
[8] "Technical Synthesis Report Annex 34," IEA Annex 34, 2006.
[9] "Energy Impact of Commercial Building Controls and Performance Diagnostics: Market Characterization, Energy Impact of Building Faults and Energy Savings Potential," TIAX LLC, 2005.
[10] Cowan A., "Review of Recent Commercial Roof Top Unit Field Studies in the Pacific Northwest and California," Oct. 8, 2005,
[11] http://www.cee1.org/com/hecac/hecac-main.php3.

Key Assumptions Used in Analysis

While automated FDDs can help to identify faults in the system, corrective action must still be taken by the building operator to fix these faults. It is conceivable that some operators would chose not to fix identified faults under certain circumstances. The analysis does not take these situations into consideration.

Average Price of Electricity	$0.1032/kWh[12]
Average Price of Natural Gas	$10.97/MMBtu[13]
Real Discount Rate	4.53%
Projected 2025 End Use Gas Consumption[14]	1.25 quads
Heat Rate	10.48 kBtu/kWh

Recommended Next Steps

The fastest way to increase market penetration of FDD could be through building energy code provisions in progressive states like California. However, it is not clear whether a state can adopt an efficiency-related equipment requirement without violating the preemption requirements of NAECA and EPACT.

In the absence of state action, voluntary programs such as utility and public benefit incentives are likely to work well for increasing penetration and understanding of the potential gains.

[12] EIA, "Electric Power Monthly – Feb 2009," (YTD-Nov08, Commercial Price).
[13] http://tonto.eia.doe.gov/dnav/ng/ng_sum_lsum_dcu_nus_m.htm.
[14] EIA 2009. "Annual Energy Outlook 2009 with Projections to 2030". Tables 4 and 5.