



PIER Advanced Automated HVAC Fault Detection and Diagnostics Program

**California Energy Commission
Contract # 500-03-030**

Final Report Describing Economizer, DCV, and Controls Diagnostic Algorithms

Project 5: Rooftop Unit Diagnostics

Deliverable D5.4d

September 23, 2005

Submitted To:
Accounting Office, MS-2
California Energy Commission
1516 Ninth Street, 1st Floor
Sacramento, CA 95814

Submitted by:
Prime Contractor:
Architectural Energy Corporation
2540 Frontier Avenue, Suite 201
Boulder, Colorado 80301

Responsible Subcontractor:
Field Diagnostic Services, Inc.
446 Old Lincoln Highway
Fairless Hills, PA 19030

Table of Contents

Executive Summary	4
Introduction	4
Diagnostic Approach.....	6
Performance Information	17
Development Status.....	19
References	21
Bibliography	21

THIS REPORT WAS PREPARED AS A RESULT OF WORK SPONSORED BY THE CALIFORNIA ENERGY COMMISSION (COMMISSION). IT DOES NOT NECESSARILY REPRESENT THE VIEWS OF THE COMMISSION, ITS EMPLOYEES, OR THE STATE OF CALIFORNIA. THE COMMISSION, THE STATE OF CALIFORNIA, ITS EMPLOYEES, CONTRACTORS, AND SUBCONTRACTORS MAKE NO WARRANTY, EXPRESS OR IMPLIED, AND ASSUME NO LEGAL LIABILITY FOR THE INFORMATION IN THIS REPORT; NOR DOES ANY PARTY REPRESENT THAT THE USE OF THIS INFORMATION WILL NOT INFRINGE UPON PRIVATELY OWNED RIGHTS. THIS REPORT HAS NOT BEEN APPROVED OR DISAPPROVED BY THE COMMISSION NOR HAS THE COMMISSION PASSED UPON THE ACCURACY OR ADEQUACY OF THE INFORMATION IN THIS REPORT.

©2005, FIELD DIAGNOSTIC SERVICES, INC.
ALL RIGHTS RESERVED.

List of Figures

Figure 1. Differential Dry-bulb Economizer Operation Plot	9
Figure 2. OAF Plot for Differential Dry-bulb Economizer Operation	9
Figure 3. Economizer and Control Diagnostic Algorithm Flowchart.....	16
Figure 4. Cycle Definition	17
Figure 5. Outdoor Air Fraction (OAF) Occurrence Plot.....	18
Figure 6. Acceptable Range of Temperature and Humidity (ASHRAE, 2004)	19

List of Tables

Table 1. Summary of Target Faults	5
Table 2. Setup Data.....	6
Table 3. Monitored Parameters.....	7
Table 4. Economizer Fault Diagnostics	11
Table 5. Control Fault Diagnostics	14
Table 6. Field Test Sites.....	20

Executive Summary

This report summarizes the status of the development and software implementation of economizer, demand controlled ventilation (DCV), and controls diagnostic algorithms (Tasks 5.4.1 and 5.4.3). The report includes a description of target faults, the diagnostic approach, performance information, and the development status. This report includes revisions and updates to the draft report (D5.4c).

Introduction

This report describes the development and software implementation of economizer, demand controlled ventilation (DCV), and controls diagnostic algorithms as defined by Tasks 5.4.1 and 5.4.3. These tasks are summarized below:

Task 5.4.1, Performance Monitoring Indices.

Simple indices for evaluating/displaying the performance of the packaged systems have been developed. These indices will measure impact on comfort, efficiency, reliability, control performance, indoor air quality, etc. and will be determined from low-cost measurements. The accuracy of simplified approaches for estimating these performance indices will be evaluated.

Task 5.4.3, Economizer, DCV, and Control System Diagnostics Development.

Diagnostic algorithms for 1) economizers, 2) demand control ventilation controllers, 3) internal unit operational controls, and 4) building controls have been developed.

Standard faults were identified for the economizer, DCV, and control systems of small and medium-sized packaged HVAC units (nominal cooling capacity up to approximately 50 tons) and are summarized in Table 1. Faults associated with economizer and controls often go undetected because they do not always have a direct impact on occupant comfort. The potential impacts of these faults include increased energy use, reduced ventilation air and indoor air quality, and reduced equipment life. The potential system impact of the system faults is also identified in Table 1. The diagnostic algorithms were developed to provide the capability of detecting and diagnosing the faults listed in Table 1.

Table 1. Summary of Target Faults

Fault Category	Fault Description	Potential System Impact
Economizer and DCV	No economizer cooling at low outdoor air temperature/enthalpy	Energy use
Economizer and DCV	High outdoor air fraction when high outdoor air temperature/enthalpy	Energy use, comfort
Economizer and DCV	Low outdoor air fraction during occupied period	Ventilation
Economizer and DCV	DCV signal and low outdoor air fraction	Ventilation
Economizer and DCV	Low mixed air temperature	Equipment life, comfort
Economizer and DCV	Low airside temperature difference during heating or cooling	Comfort, energy use
Economizer and DCV	High airside temperature difference during heating or cooling	Comfort, energy use
Economizer and DCV	Outdoor air during unoccupied period	Energy use
Economizer and DCV	Sensor problem	Limited system diagnostics available because of invalid sensor input(s)
Controls	Continuous call for cooling or heating	Energy use, comfort
Controls	Simultaneous heating and cooling	Energy use, comfort
Controls	Fan cycling during occupied period when should be continuous	Ventilation
Controls	Fan running continuously during unoccupied period	Energy use
Controls	Mechanical cooling at low outdoor air temperature when should be only economizer	Energy use
Controls	Thermostat cooling demand but no cooling	Comfort
Controls	Thermostat heating demand but no heating	Comfort
Controls	Unit short cycling; short off-time or runtime for compressor	Equipment life
Controls	Extended runtime (long cycles)	Equipment life, comfort, energy use
Controls	Sensor problem	Limited system diagnostics available because of invalid sensor input(s)

Diagnostic Approach

The diagnostic approach is based on a comparison of the observed system performance to expected performance for a properly operating system. The expected performance is established based on selected inputs describing the HVAC system configuration and associated measured driving conditions (e.g., outdoor air temperature). The diagnostic approach is similar to the diagnostic approach developed by Pacific Northwest National Laboratory (PNNL) and described by Brambley et al. (1998) and PECI (2003) in that it is rule-based. Detailed discussion of the diagnostic approach is presented in the following sections.

Input Data

The input data for the system includes static setup information, measured input parameters, and computed parameters. Basic static input information required to define the HVAC system configuration is summarized in Table 2 and includes the occupancy schedule, economizer control strategy, ventilation control strategy, and heating type. Measured input parameters and computed parameters are summarized in Table 3 and include airside temperatures and thermostat control signals. Calculated performance indices are defined in the following sections.

Table 2. Setup Data

Parameter	Code	Building or Unit Level	Detailed description and options
Zone description			
Zone occupancy schedule		Unit	Occupied/unoccupied period defined for each day of the week
Economizer control strategy	ECON	Unit	0 None, 1 Dry-bulb changeover, 2 Enthalpy changeover, 3 Differential dry-bulb, 4 Differential enthalpy
Integrated economizer	INT	Unit	0 Not integrated (mechanical cooling not available when economizer active) 1 Integrated
Ventilation control strategy	VENT	Unit	Fixed minimum ventilation, Demand controlled ventilation (DCV)
Ventilation setpoint for DCV	VS	Unit	
Minimum ventilation outdoor air fraction	mOAF	Unit	Fixed minimum ventilation rate as outdoor air fraction of total system airflow
Heating type	Htype	Unit	0 No heating, 1 Gas-fired, 2 Heat pump (HP), 3 Electric resistance, 4 HP with electric resistance

Table 3. Monitored Parameters

Parameter	Code	Data Type	Units	Notes
Thermostat stage 1 call for cooling status (Y1)	Y1	Digital Input	off/on	
Thermostat Stage 2 call for cooling status (Y2)	Y2	Digital Input	off/on	
Thermostat Stage 1 call for heating status (W1)	W1	Digital Input	off/on	
Thermostat Stage 2 call for heating status (W2)	W2	Digital Input	off/on	
Thermostat Fan status	G	Digital Input	off/on	
Indoor Airflow status	FAN	Digital Input	off/on	
Outdoor air temperature	OAT	Analog Input	°F	
Return air temperature	RAT	Analog Input	°F	
Mixed air temperature	MAT	Analog Input	°F	
Supply air temperature	SAT	Analog Input	°F	Located downstream of any heat sources
Outdoor air humidity	OAH	Analog Input	% RH	
Return air humidity	RAH	Analog Input	% RH	
DCV input	VI	Analog Input		
DCV status	DCV	Calculated	off/on	DCV=on when VI>VS setpoint; otherwise, DCV=off
Return air enthalpy	Rh	Calculated	Btu/lb	Calculated from RAT and RAH
Outdoor air enthalpy	Oh	Calculated	Btu/lb	Calculated from OAT and OAH
Mixed air enthalpy	Mh	Calculated	Btu/lb	Refer to Equation 2
Mechanical cooling status	MCOOL	Calculated	off/on	Determined from refrigeration system pressures
Economizer cooling status	ECOOL	Calculated	off/on	On status indicated by Equations 3 and 4 or Equations 5 and 6
Heating status	HEAT	Calculated	off/on	HEAT=on when (SAT-MAT)>10°F; otherwise, HEAT=off
Outdoor Air Fraction	OAF	Calculated	-	Refer to Equation 1

Performance Indices

One performance index has been identified for economizer and control systems diagnostics and is discussed below. Additional indices will be identified as appropriate.

A common performance index (e.g., Friedman and Piette, 2001) used for economizer operation and outdoor airflow is the outdoor air fraction, OAF, defined as

$$OAF = \frac{MAT - RAT}{OAT - RAT} \quad (1)$$

OAF is considered to be valid when (a) airflow is verified, (b) the associated temperature inputs are valid and (c) $|OAT-RAT| > 5^\circ\text{F}$. The third limit filters out data that will have a high error associated with the calculated OAF. Example performance of an economizer with a fixed minimum ventilation rate is illustrated in Figure 1. The datasets labeled “OA Damper Closed” and “OA Damper Fully Open” define the range of valid operating points. The dataset labeled “Minimum 20% OA” represents a fixed minimum ventilation rate of 20% of the total system airflow. The dataset labeled “Economizer” represents operation of an economizer with a differential dry-bulb control strategy and a target cooling temperature difference of 20°F . Whenever (OAT-RAT) is greater than zero, the system should operate at the minimum outdoor air position as indicated by the line with slope of 0.2. When (OAT-RAT) is less than zero, the economizer will be active and (MAT-RAT) should follow the economizer line. The outdoor air damper will be modulated to maintain the minimum mixed air (or supply air) temperature setting until it reaches the minimum position based on the minimum ventilation rate. As (OAT-RAT) decreases, the outdoor air damper will modulate until it reaches the minimum position setting. The corresponding OAF plot is presented in Figure 2 for the economizer operation. Operation for an economizer with a dry-bulb changeover strategy would be similar except the operation of the economizer would not occur until (OAT-RAT) is less than (Changeover Setpoint-RAT). For evaluation of enthalpy economizer control strategies the return air and outdoor air enthalpy values are computed from the measurements and mixed air enthalpy is calculated using the OAF as follows:

$$Mh = OAF(Oh - Rh) + Rh \quad (2)$$

The enthalpy values are then compared to determine the appropriate status of the outdoor air damper. OAF is discussed further in the section Performance Information.

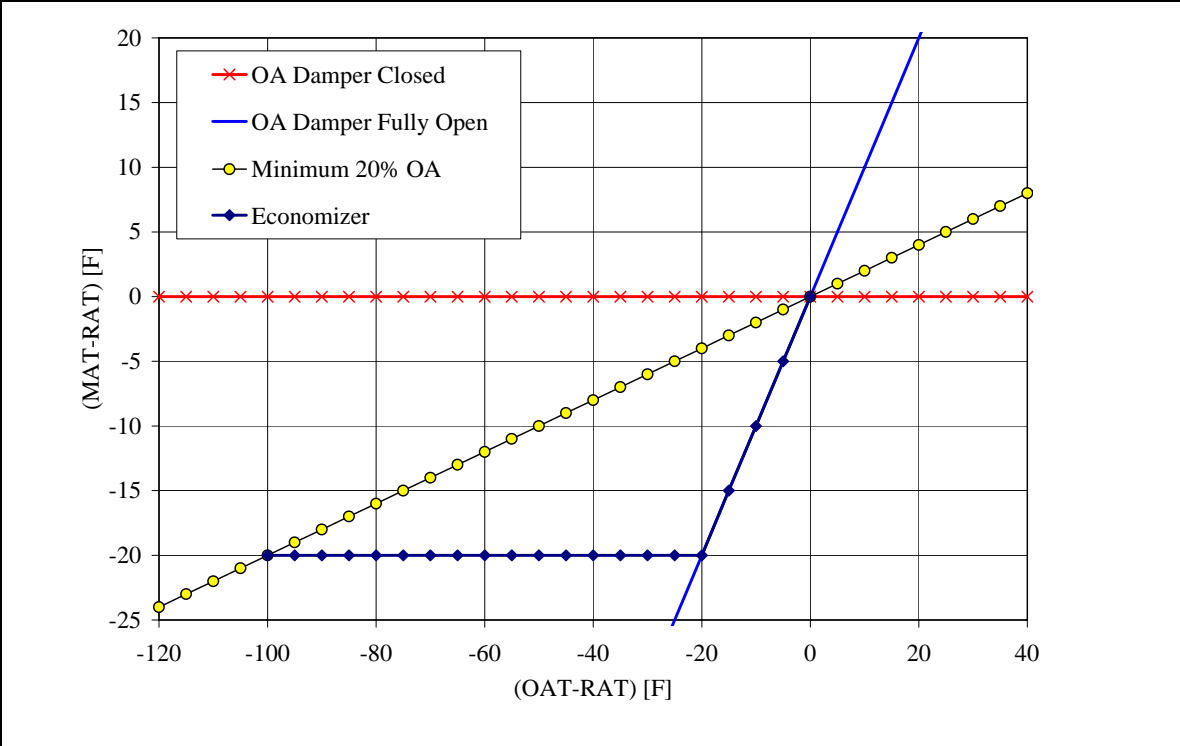


Figure 1. Differential Dry-bulb Economizer Operation Plot

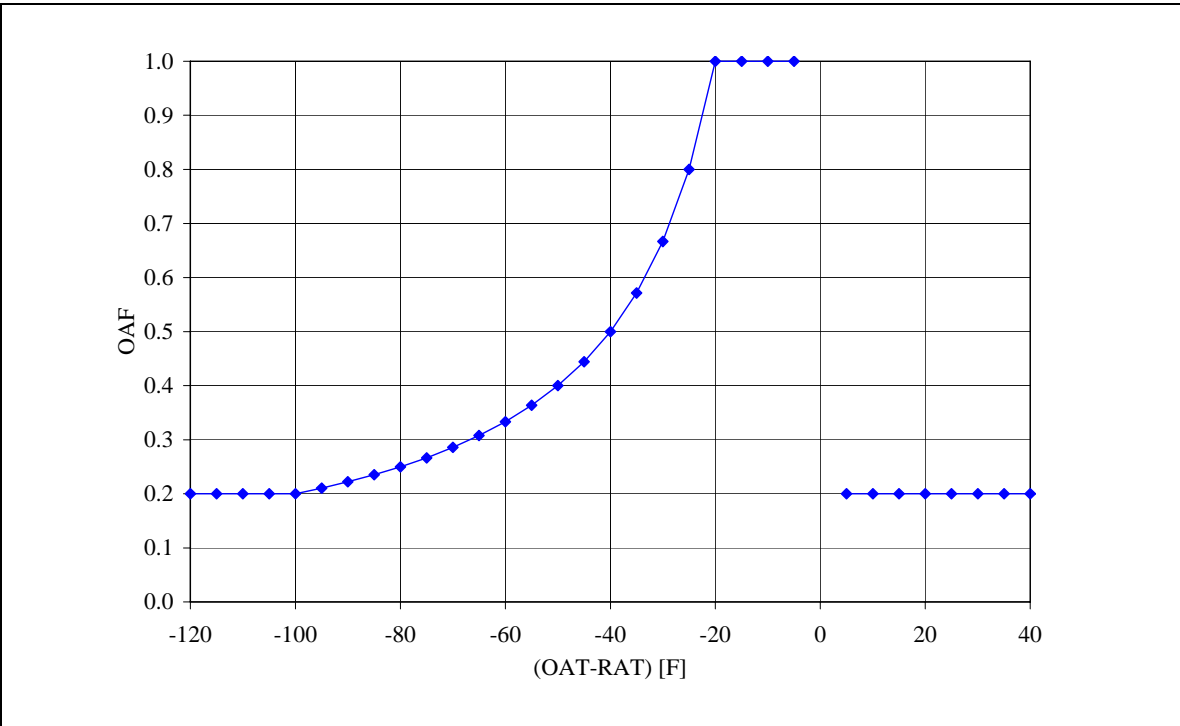


Figure 2. OAF Plot for Differential Dry-bulb Economizer Operation

Diagnostic Algorithms

The diagnostic algorithms are based on an approach that compares the observed system performance to expected performance for a properly operating system. The expected performance is established based on selected inputs describing the HVAC system configuration and associated measured driving conditions (e.g., outdoor air temperature). In general the diagnostic algorithms have the form of a system of rules defining fault conditions. The diagnosis is based on the particular rule or rules that are violated.

The current diagnostic approach is similar to previous work by others in that it is rule-based, but differs in the specific rules and their implementation. The diagnostic approach developed by Pacific Northwest National Laboratory (PNNL) and covered by United States Patent 6,778,945 (Chassin, et al. 2004) covers a method for determining unit status based at least on 1) the occupancy, 2) the operational status of the fan, 3) the validity of the outdoor air fraction, 4) the outdoor air fraction status, and 5) the current mode status. The current diagnostic approach being developed uses a number of measured inputs and calculated parameters; however, it is not, in general, based on outdoor air fraction (OAF). OAF is used only for identifying selected economizer faults.

In addition to the basic measurements and calculated performance indices, the diagnostic algorithms use several other system status parameters. The indoor airflow status (on/off) is determined from a sensor input to the diagnostic system as indicated in Table 3. The mechanical cooling status (on/off) is determined from refrigeration system pressure measurements. The economizer cooling status with dry-bulb control is determined from airside measurements and is considered to be on when

$$(OAT - RAT) < -5^{\circ}F \quad (3)$$

and

$$OAF > mOAF \quad (4)$$

The economizer cooling status with enthalpy control is determined from airside measurements and is considered to be on when

$$(Oh - Rh) < -5Btu/lb \quad (5)$$

and

$$OAF > mOAF \quad (6)$$

Heating status (off/on) is determined based on the temperature difference between SAT and MAT as indicated in Table 3.

The rules for identifying faults and the corresponding diagnosis (specific fault and possible causes) are summarized in Table 4 (economizer and DCV) and Table 5 (controls). The diagnostic rules were developed based primarily on dry-bulb economizer control and have been extended to address enthalpy based economizer control strategies. Most economizer and control operations

occur in real-time, as the system responds to varying outdoor air conditions and cooling or heating loads. Therefore, the majority of the diagnostics rules are applied to real-time data to assess the system performance. Selected diagnostic rules are based on cycle data and, therefore, are applied to calculated cycle data (e.g., cycle off-time). These cases are noted in Table 5. In addition to the basic criteria, many of the faults have criteria for a minimum number of occurrences or minimum fault duration as indicated in Table 4 and Table 5.

The diagnostic algorithm implementation for real-time fault detection and diagnosis is outlined in Figure 3. The flowchart presents the main elements of the diagnostic approach, including the sequence of evaluation. All fault identification based on air temperature measurements requires verification of indoor airflow (shape 2) to ensure reasonable air temperature measurements. Limited control diagnostics are available for data corresponding to times when there is no system airflow (shape 20 branch). Airflow verification is followed by sensor verification (shapes 3, 5, and 8) and then calculation of the OAF (shape 12) if sensor values are valid. The economizer (shape 14) and control (shape 17) diagnostic rules are then checked. The detailed rules are summarized in Table 4 (economizer and DCV) and Table 5 (controls) as previously indicated.

Additional cycle related diagnostic rules are also applied to identify control system faults. A cycle is defined based on a call for cooling or heating as indicated in Figure 4. The diagnostic rules are summarized in Table 5 as previously indicated.

Table 4. Economizer Fault Diagnostics

General Fault	Specific Fault	Basic Fault Criteria	Occurrence Criteria	Possible Causes
Sensor problem	RAT out of range	RAT < 65°F or RAT > 85°F	10 minutes in 24h period	Bad or misplaced sensor
Sensor problem	OAT out of range	OAT > 125°F or OAT < (-15°F)	10 minutes in 24h period	Bad or misplaced sensor
Sensor problem	MAT out of range	MAT>OAT>RAT or MAT<OAT<RAT	10 minutes in 24h period	Bad or misplaced sensor
Sensor problem	SAT out of range	SAT > 130°F or SAT < 45°F	10 minutes in 24h period	Bad or misplaced sensor
Sensor problem	OAH out of range	OAH > 100% or OAH < 5%	10 minutes in 24h period	Bad or misplaced sensor
Sensor problem	RAH out of range	OAH > 70% or OAH < 15%	10 minutes in 24h period	Bad or misplaced sensor
No economizer cooling at low outdoor air	Fault with dry-bulb control	Y1=on and (OAT-RAT) < (-10°F) and ECOOL=off and	25 minutes in 24h period	Faulty economizer control,

General Fault	Specific Fault	Basic Fault Criteria	Occurrence Criteria	Possible Causes
temperature		(ECON=1 or ECON=3)		damper problem
No economizer cooling at low outdoor air enthalpy	Fault with enthalpy control	Y1=on and (Oh-Rh) < (-7 Btu/lb) and ECOOL=off and (ECON=2 or ECON=4)	25 minutes in 24h period	Faulty economizer control, damper problem
High outdoor air fraction when high outdoor air temperature		(OAT-RAT) > 0°F and OAF > mOAF and DCV=off and (ECON=1 or ECON=3)	10 minutes in 24h period	Faulty economizer control, damper problem
High outdoor air fraction when high outdoor air enthalpy		(Oh-Rh) > (0 Btu/lb) and OAF > mOAF and DCV=off and (ECON=2 or ECON=4)	10 minutes in 24h period	Faulty economizer control, damper problem
Low outdoor air fraction during occupied period		Occupied period and OAF < mOAF	10 minutes in 24h period	Faulty economizer control, damper problem
DCV signal and low outdoor air fraction		DCV=on and OAF < (2*mOAF)	10 minutes in 24h period	Faulty economizer or DCV control, damper problem
Low mixed air temperature		MAT < 40°F	10 minutes in 24h period	Low SAT setpoint, damper or operator problem
Low airside temperature difference during heating or cooling	Low cooling temperature difference	(Y1=on or Y2=on) and (RAT-SAT) < 12°F	25 minutes in 24h period	Low cooling capacity, high airflow rate
Low airside temperature difference during heating or cooling	Low heating temperature difference	(W1=on or W2=on) and (SAT-RAT) < 10°F	25 minutes in 24h period	Low heating capacity, high airflow rate
High airside temperature difference during heating or cooling	High cooling temperature difference	(Y1=on or Y2=on) and (RAT-SAT) > 30°F	10 minutes in 24h period	Low airflow, economizer control problem
High airside temperature difference during	High heating temperature difference	(W1=on or W2=on) and (SAT-RAT) > 50°F	10 minutes in 24h period	Low airflow, heating control problem

General Fault	Specific Fault	Basic Fault Criteria	Occurrence Criteria	Possible Causes
heating or cooling				
Outdoor air during unoccupied period		MAT-RAT >5°F and Y1=off and DCV=off and unoccupied period	25 minutes or 20% of unoccupied period for day	Faulty economizer control, damper problem

Table 5. Control Fault Diagnostics

General Fault	Specific Fault	Basic Fault Criteria	Occurrence Criteria	Possible Causes
Sensor problem		Y2=on and Y1=off	10 minutes in 24h period	Thermostat or wiring problem
Sensor problem		W2=on and W1=off	10 minutes in 24h period	Thermostat or wiring problem
Sensor Problem		Y1=on and G=off	10 minutes in 24h period	Thermostat or wiring problem
Continuous call for cooling or heating	Continuous call for heating	W1=on for 24 hour period	1 occurrence	Thermostat or other controls problem; capacity problem
Continuous call for cooling or heating	Continuous call for cooling	Y1=on for 24 hour period	1 occurrence	Thermostat or other controls problem; capacity problem
Simultaneous heating and cooling	Controls signal	(W1=on or W2=on) and (Y1=on or Y2=on)	10 minutes in 24h period	Thermostat or other controls problem
Simultaneous heating and cooling	Economizer cooling and heating	ECOOOL=on and DCV=off and HEAT=on	10 minutes in 24h period	Controls problem
Simultaneous heating and cooling	Mechanical cooling and heating	MCOOL=on and HEAT=on	10 minutes in 24h period	Controls problem
Fan cycling during occupied period when should be continuous		FAN=off and occupied period	25 minutes or 20% of occupied period for day	Controls setup problem
Fan running continuously during unoccupied period		FAN=on and W1=off and W2=off and Y1=off and Y2=off and unoccupied period	25 minutes or 20% of unoccupied period for day	Controls setup problem
Mechanical cooling at low outdoor air temperature when should be only economizer		MCOOL=on and OAT<50°F	10 minutes in 24h period	Controls setup or economizer problem
Thermostat cooling demand but no cooling		(Y1=on or Y2=on) and MCOOL=off and ECOOL=off	2h in 24h period	Controls or cooling system problem
Thermostat heating demand but no heating		(W1=on or W2=on) and HEAT=off	2h in 24h period	Controls or heating system problem

General Fault	Specific Fault	Basic Fault Criteria	Occurrence Criteria	Possible Causes
Unit short cycling; short off-time or runtime for compressor	Short off-time for compressor (cycle data) Reference: Copeland, 1981	Off-time < 5 minutes and (mechanical cooling or HP heating)	10 occurrences or 10% of occurrences in 24h period	Controls problem
Unit short cycling; short off-time or runtime for compressor	Short runtime for compressor (cycle data)	Runtime < 5 minutes and (mechanical cooling or HP heating)	10 occurrences or 10% of occurrences in 24h period	Thermostat or other controls problem
Extended runtime (long cycles)	Extended mechanical cooling or heating (cycle data)	Runtime > 4 hours and (mechanical cooling or heating)	1 occurrence	Thermostat or other controls problem
Heating without call for heating		W1=off and HEAT=on	10 minutes in 24h period	Controls problem or sensor problem
Cooling without call for cooling	Mechanical cooling with call	Y1=off and MCOOL=on	10 minutes in 24h period	Controls problem or sensor problem
Cooling without call for cooling	Economizer cooling without call	Y1=off and ECOOL=on and DCV=off	10 minutes in 24h period	Controls problem or sensor problem
No indoor fan operation when should be on		(G=on or W1=on or Y1=on) and FAN=off	10 minutes in 24h period	Controls or sensor problem, fan problem

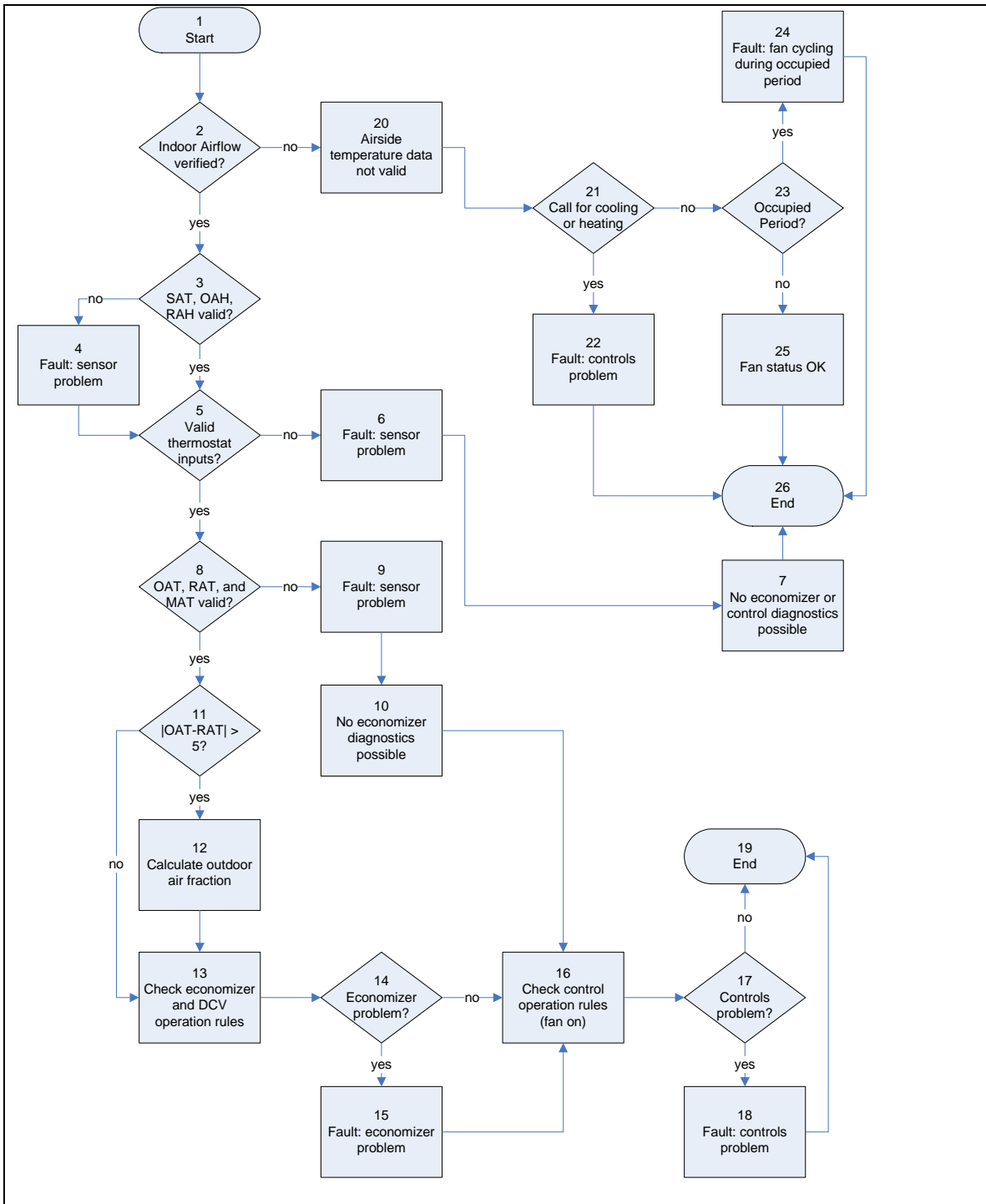
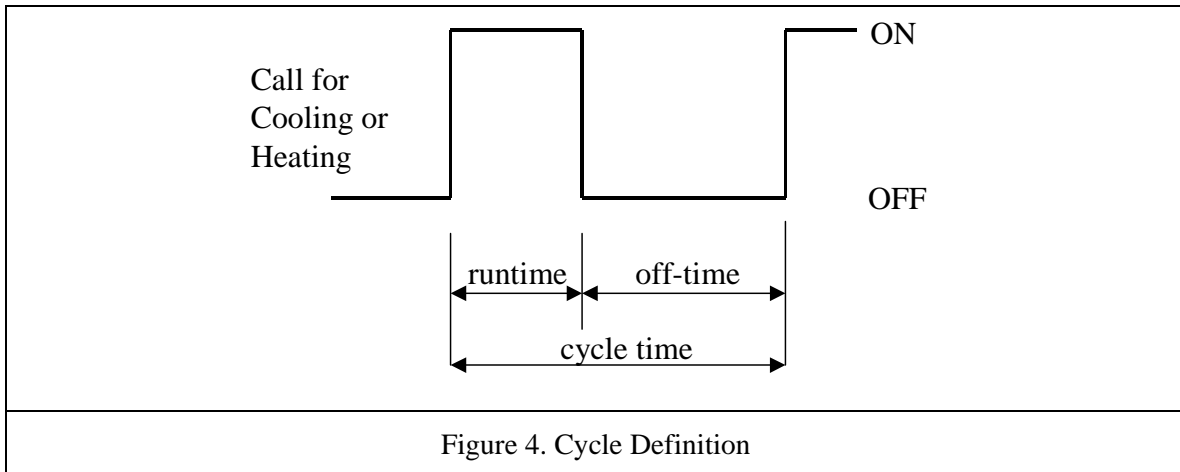


Figure 3. Economizer and Control Diagnostic Algorithm Flowchart



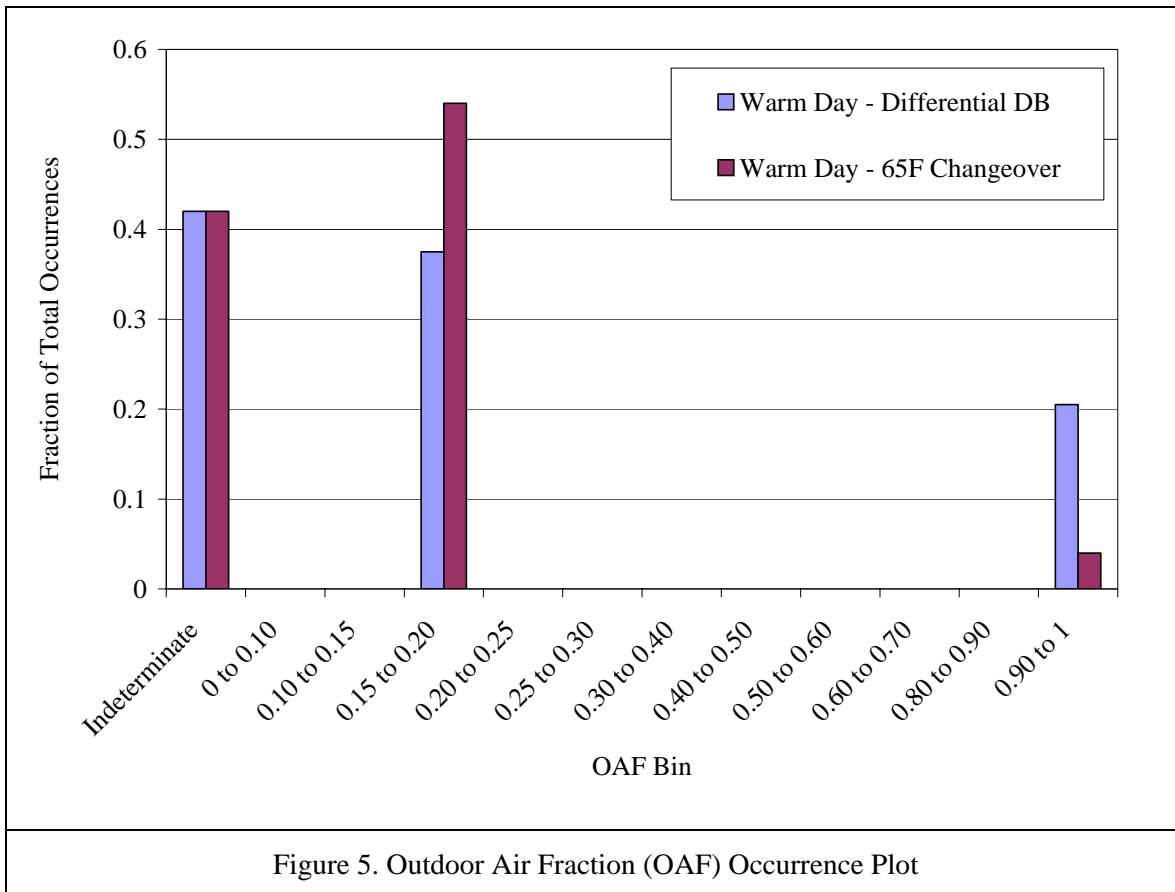
Economic Analysis of Faults

An economic analysis approach is being developed to quantify the impact of economizer and control faults on the system operating costs. Potential cost impacts include energy costs, maintenance costs, and equipment replacement costs. Energy costs will include the cost of additional electric energy use associated with the fault. Maintenance costs will include labor and material costs associated with correcting the fault (repair) and any offset of future periodic maintenance costs. Equipment replacement costs will address the impact of reduced equipment life on operating costs. The detailed economic analysis approach will be presented in a future report.

Performance Information

Economizer and Outdoor Air

In addition to the outdoor damper performance plot of Figure 2, economizer and outdoor air performance can also be evaluated by considering the distribution of outdoor air fraction (OAF) values. One approach is to bin the time spent at different OAF values. It is often appropriate to consider occupied and unoccupied periods separately since the occupied period should have continuous ventilation at a minimum OAF compared to the unoccupied period that will typically have outdoor air only for economizer cooling. Two example cases are presented in Figure 5 for a system operating over a day with an OAT varying from 64 to 84°F and a constant RAT of 75°. The minimum outdoor air fraction is 0.2 and two different economizer control strategies were considered: differential dry-bulb and changeover dry-bulb at 65°F. The figure represents ideal performance with no measurement errors. The “indeterminate” occurrences correspond to $|\text{OAT} - \text{RAT}| < 5^\circ\text{F}$. The operation of the economizer is represented by the “0.90 to 1” bin and the “0.15 to 0.20” bin is operation at minimum OAF when economizer operation is not favorable. The changeover control strategy results in less economizer operation as expected based on the 65°F changeover compared to the 75°F RAT. This type of plot can be used to identify economizer operation, low outdoor airflow (ventilation air), and operation at minimum OAF.



Thermal Comfort

Approaches are being considered for evaluating and reporting the ability of the HVAC to maintain thermal comfort in the conditioned space. One method of evaluating the space thermal comfort conditions is based on the return air temperature and relative humidity conditions during the occupied period. These conditions can be compared to the criteria of ASHRAE Standard 55-2004, Thermal Environmental Conditions for Human Occupancy, as presented in Figure 6, to determine if minimum requirements are satisfied. This approach is only an approximation of the actual space thermal comfort conditions for two main reasons: 1) return air conditions can be influenced by return duct leakage and heat gain/loss, and 2) dry-bulb temperature and humidity do not fully describe the conditions necessary to maintain thermal comfort. An alternate approach is to consider the thermostat being satisfied (call for cooling or heating ends) and the system runtime as indicators of the space thermal comfort conditions. These approaches are being evaluated and the implementation will be discussed in a future report.

System Operation

Approaches are also being considered for providing an indication of the overall operation of the HVAC system. This evaluation is focusing on system operation characteristics that include

number of cooling or heating cycles, runtime, cycle length, and other cycle statistics. These approaches are being evaluated and the implementation will be discussed in a future report.

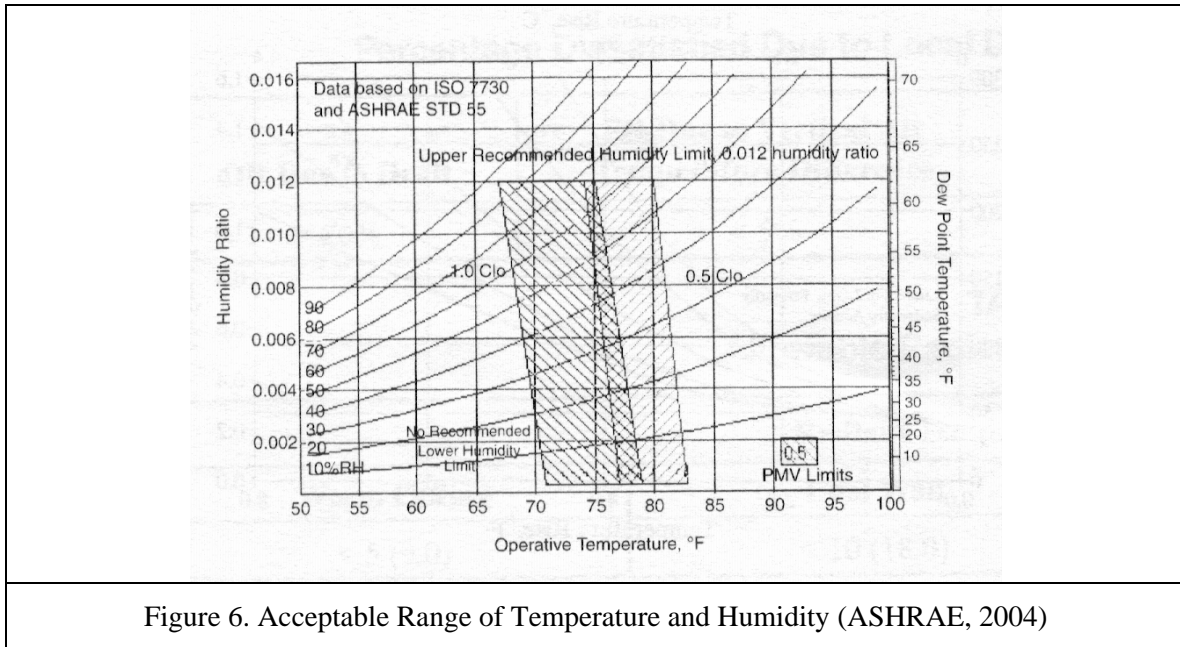


Figure 6. Acceptable Range of Temperature and Humidity (ASHRAE, 2004)

Development Status

Diagnostic Algorithm Development

The diagnostic algorithm development is relatively complete as outlined in Figure 3, Table 4, and Table 5. The existing rules are being refined and new rules are being added as a result of the testing process.

Software Implementation

The majority of the diagnostic algorithms have been implemented in software that currently runs on a central server. The software is used to process test data and data received from a number of field test sites and to report on the status of the monitored units. Additional information is presented in the section Field Testing. Observation of faults for the monitored units have included sensor problems, mechanical cooling at low outdoor air temperature, and short compressor off-times.

Laboratory Testing

Testing of the diagnostic algorithms is being completed using simulated test data and laboratory data from Herrick Laboratories (Purdue University). Specific laboratory testing at Herrick Laboratories is focusing on economizer performance and mixed air temperature measurement. The results of the testing will be reported under Task 5.5, Controlled Testing.

Field Testing

Testing of the diagnostic algorithms is also being completed using field data from several demonstration sites as summarized in Table 6. The field test data are being used to test the diagnostic algorithms that have implemented and the results are used to refine the diagnostic rules. The results are also being reported with the web-reporting tool that is being developed. Results of the field testing are reported on an ongoing basis through progress reports and conference calls. A summary of the field test results will be reported under Task 5.6, Initial Prototype Development and Implementation, and Task 5.8, Final Product Implementation.

Table 6. Field Test Sites

Site Description	Location	No. of Units	Operational Date	General Unit Description
Walgreens - Anaheim	Anaheim, CA	5	2002	Packaged HP with economizer
Walgreens - Rialto	Rialto, CA	5	2002	Packaged HP with economizer
Honeywell GSRC	Atlanta, GA	5	December 2004	Packaged AC with economizer
UCLA	Los Angeles, CA	8	Planned for October 2005	Packaged AC or HP (1 or 2-stage) no economizer
UCSD	San Diego, CA	7	Planned for October 2005	Packaged AC (1-stage) with gas heat and economizer
CSU Hayward	Hayward, CA	7	Planned for September 2005	Packaged AC (1 or 2-stage) with economizer

References

- ASHRAE, 2004. ASHRAE Standard 55-2004, Thermal Environmental Conditions for Human Occupancy. Atlanta, GA: ASHRAE.
- Brambley, Pratt, Chassin, Katipamula, and Hatley, 1998. Diagnostics for Outdoor Air Ventilation and Economizers. ASHRAE Journal, Vol. 40, No. 10, October 1998.
- Copeland, 1981. Compressor Short Cycling, An Unrecognized Problem. Application Engineering Bulletin AE-1262. Copeland Corporation.
- Friedman and Piette, 2001. Comparative Guide to Emerging Diagnostic Tools for Large Commercial HVAC Systems. LBNL Report 48629, Lawrence Berkeley National Laboratory, Berkeley, CA. May 2001.
- PECI, 2003. Methods for Automated and Continuous Commissioning of Building Systems. ARTI-21CR/610-30040-01. Portland, Oregon: Portland Energy Conservation, Inc.

Bibliography

- AEC, 2003a. Small HVAC System Design Guide. California Energy Commission Report 500-03-082-A12.
- AEC, 2003b. Integrated Energy Systems: Productivity & Building Science Program, Element Four—Integrated Design of Small Commercial HVAC Systems, Summary of Problems Observed in Field Studies of Small HVAC Units. Submitted to the California Energy Commission. Boulder, CO: Architectural Energy Corporation. (P500-03-082-A-25)
- CEE, 2001. Guidelines for Energy-Efficient Commercial Unitary HVAC Systems. Boston, MA: Consortium for Energy Efficiency.
- Chassin, David P., Pratt, Robert G., and Reid, Larry Dean, 2004. Rooftop Package Unit Diagnostician. United States Patent Number 6,778,945. August 17, 2004.
- Cowan, Alan, 2004. Review of Recent Commercial Rooftop Unit Field Studies in the Pacific Northwest and California. New Buildings Institute Report to Northwest Power and Conservation Council and Regional Technical Forum.
- NEMA, 2003. Standard Publication DC 3-2003, Residential Controls – Electrical Wall-Mounted Room Thermostats. Rosslyn, Virginia: NEMA.
- Seem, John, 2001. Integrated Control and Fault Detection of HVAC Equipment. United States Patent Number 6,223,544. May 1, 2001.