

**Advanced Automated HVAC Fault
Detection and Diagnostics
Commercialization Program**

**Final Report Describing VM
Implementation, Emulation / Bench Testing
and Laboratory Testing, and Field
Installation**

CONSULTANT REPORT

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Implementation of FDSI Embedded FDD System

The FDSI embedded FDD system consists of the following components as shown in Figure 1: data acquisition hardware component, data processing component, fault diagnostics component, and Web component (database and user interface). The hardware component samples sensor data and feeds into data processing component. The data processing component extracts feature values from raw sensor data. The fault diagnostics component takes the extracted feature values and runs diagnostic algorithms to generate alarm data and performance data. The alarm and performance information of the unit is presented through the Web user interface. A detailed description of each component is presented in the following sections.

1.1 Embedded FDD Hardware Component

The following hardware platforms were assembled, tested and installed in the field: FDSI first generation of Virtual Mechanic (VM) hardware and PointSix hardware.

1.1.1 VM hardware

FDSI VM hardware integrates all channels (digital/analog) into one hardware module. Figure 2 shows the data communication of VM hardware module. In a field installation, for a site with multiple air conditioner (AC) units, each AC unit has a VM and one is set as a master VM and all the others as slave VMs. Slave VMs are connected to the master VM. The master VM is hooked up to the phone system through a modem. The data server computer can communicate with the master VM and slave VMs by means of calling the phone hooked up to the master VM. The phone system at a site can be either land-based or cellular telephone lines. FDSI VM hardware was installed at two Walgreen sites (Anaheim and Rialto). Table 1 shows the description of sensor inputs of VM hardware.

1.1.2 PointSix hardware

The PointSix hardware platform consists of the data acquisition unit, point manager, and Web server. The data acquisition unit transfers sensor data to the point manager via RF communication. The point manager posts the data to the Web server via http protocol. The PointSix hardware platform requires a wired connection to the outside world. Figure 3 shows the data communication of the PointSix hardware platform. Two versions of PointSix hardware platforms were installed in the field as described below:

1). PointSix hardware installed at the Honeywell GSRC Atlanta site

For PointSix hardware installed at the Honeywell GSRC Atlanta site, the airside measurements and refrigeration side measurements are collected in one module. Table 2 and Table 3 list the sensor inputs of the data acquisition units.

2). PointSix hardware installed at California university sites

For the PointSix hardware installed at California university sites, the airside measurement and refrigeration side measurement are separated into two modules: evaporator module and compressor module. Table 4 and Table 5 list the sensor inputs of the compressor module. Table 6 and Table 7 list the sensor inputs of the evaporator module.

1.2 Embedded FDD Data Processing Component

Two data processing strategies were described in the draft report describing the strategy for processing data and the design of the user interface [FDSI August 2005]: centralized versus distributed data processing. For the current field implementation, the centralized data processing approach is applied. The field sensor data is transferred to a central server continuously or once per day. The data processing algorithm runs on the central server and analyzes the sensor data and

extracts and stores feature values. Figure 4 shows the central server's data processing sequence [FDSI August 2005].

1.3 Embedded FDD Diagnostics Component

The embedded FDD diagnostics component has the capability to detect control faults, airside faults, and refrigeration cycle faults. The identified faults and diagnostics rules are available in the FDSI report describing economizer, DCV, and controls diagnostic algorithms [FDSI June 2005]. Table 8 shows the identified control faults and their diagnostics rules. Table 9 shows the identified airside faults and their diagnostics rules. Table 10 shows the current identified refrigeration cycle faults and their diagnostics rules. The complete set of refrigeration fault diagnostic rules has not been implemented to date. The embedded FDD diagnostics module also includes the calculation of the following performance parameters:

- 1) Efficiency index
- 2) Mechanical cooling runtime fraction
- 3) Outdoor air damper operation
- 4) Outdoor air fraction
- 5) Compressor cycle statistics

1.4 Embedded FDD Web User Interface Component

The embedded FDD user interface module is a Web-based tool that allows the user to access information and data for the monitored units. The user can view the current status of each monitored unit, alarms/faults that have been identified, performance data, economic data for alarms/faults, and static unit data. Figure 5 shows the navigation of the Web user interface [FDSI August 2005].

Emulation/Bench Testing and Laboratory Testing

2.1 Hardware testing

2.1.1 Scope of hardware testing

The goals of the bench testing of the hardware platform were: 1) identify whether there is any faulty sensors or mis-calibrated sensors. 2) Identify whether there is any problem with data collection and communication.

2.1.2 Approach for hardware testing

The point manager in PointSix hardware provides an html page to display the current value of sensor. The following items are tested: digital inputs, pressure sensors, temperature sensors, and humidity sensors. To test digital inputs, 24-volt power is applied and a person can visually check whether there is a digital reading in the html page. To test the pressure sensor, it is connected to a cylinder and a person can visually check whether there is reading in the html page. The temperature sensor and humidity sensor are tested under room conditions. To test the data communication, on the server, an ASP program was made that can insert the sensor data accepted from the point manager via an HTTP-protocol connection into a central database.

2.1.3 Results of hardware testing

Based on the testing, the following issues were found and fixed:

- 1) The offset of the pressure sensor was not set correctly.
- 2) Found some failed humidity sensors.
- 3) Found some failed pressure sensors.

2.2 Testing of data processing

2.2.1 Scope of data processing testing

The goal of the data processing testing was to test and verify the implementation of individual functionalities of the data processing algorithm.

2.2.2 Approach for data processing testing

The data processing algorithm was tested based on field data from the Walgreen sites, the GSRC site, and the California university sites. All the sensor inputs from these sites are stored in a central database. The following major functionalities were tested:

- 1) Refrigerant property calculation
- 2) Mixed air humidity calculation
- 3) Cycle state machine calculation
- 4) Compressor on/off detection
- 5) Bin data calculation

For each functionality testing, we ran the data processing algorithm with a given set of sensor inputs and output the intermediate calculated result and compared it with the expected result.

2.2.3 Results of data processing testing

The test results indicate that the data processing algorithm performs the calculations as expected. For example, the evaporating temperature and condensing temperature are calculated based on a polynomial fit using the refrigerant property table. The error associated with the calculation is within 1° F.

2.3 Testing of diagnostics algorithm

2.3.1 Scope of the diagnostics algorithm testing

The goal of the diagnostics algorithm testing was to 1) verify that the diagnostics algorithm was implemented as specified in the design and 2) test the sensitivity of the diagnostics rule set to the field data.

2.3.2 Approach for diagnostics algorithm testing

The diagnostics algorithm was tested with the field data from the Walgreen sites, the GSRC site, and the California university sites. The following functionalities were tested:

- 1) The calculation of performance parameters from bin data.
- 2) Application of the diagnostics rule set.
- 3) The sensitivity of the rule set to the field data.

In addition to that, a simulation tool has been under development to generate representative data for the thermostat module, airside module and refrigeration cycle module. The development of lab test data for economizer operation is complete and ready for testing the economizer diagnostic algorithm.

2.3.3 Results of the diagnostics algorithm testing

The functionality of the diagnostics algorithm was verified by the testing, although some of the diagnostics rules were adjusted based on the testing. For example, the original rule set for the

“SAT out of range” fault was found to be problematic based on the testing, and the rule set was improved.

Field Installation

3.1 Procedure for field installation

3.1.1 Sensor locations

The sensor locations on the AC unit are shown in Figure 6. In particular:

- 1) Evaporating temperature (ICT) sensor should be installed at the inlet of the middle evaporator coil. If it is really difficult to do this, place the sensor as close to the inlet of the middle coil as possible.
- 2) Condensing temperature (OCT) should be installed at the 4th or 5th return bend of the middle condenser coil.
- 3) Suction line temperature (ST) should be measured at the compressor suction.
- 4) Discharge line temperature (DT) sensor should be placed as close to the compressor as possible.
- 5) Liquid line temperature (LT) should be measured at the condenser outlet.
- 6) For ambient temperature (OAT) and humidity (OAH), make sure there is no direct solar radiation to the sensor and the sensor should be in the airflow stream.
- 7) Condenser outlet air temperature (AOC) should be placed in the middle of the condenser fan grid.
- 8) Filter temperature (FT) sensor should be placed after the liquid-line filter/dryer.
- 9) Return air temperature (RAT) and humidity (RAH) should be in the return air duct close to the mixing box.
- 10) Mixing air temperature (MAT) and humidity (MAH) should be placed where air is mixed.
- 11) For refrigerant line sensors, extreme care should be taken with the temperature sensor insulation and contact. The sensor should have good thermal contact with the target tube, and insulation should prevent air from passing around the sensor.

3.2 Site Installation

The FDSI embedded diagnostics system was installed at six sites. Table 11 describes the field site information. The functionalities of data processing, diagnostics and the Web user interface are included for all units at these sites. (The Web user interface was enabled in March 2005.)

3.2.1 Walgreen site installation

The installations at the Walgreen sites were completed in 2003. FDSI VM hardware was installed. Table 12 and Table 13 show the unit information at the Walgreen Anaheim site and the Rialto site respectively.

3.2.2 GSRC site installation

The installation at the Honeywell GSRC site was completed in 2004. The PointSix hardware was installed. Table 14 shows the unit information at GSRC Atlanta site. Table 19 shows the field installation issues and observations at the GSRC Atlanta site.

3.2.3 California university site installation

The installations at the California university sites were completed in 2005 and 2006. The PointSix hardware was installed. Table 15, Table 16 and Table 17 show the unit information at the

California State University Hayward site, UCLA site, and UCSD site respectively. Table 18 shows the field installation issues and observations at the California university sites.

References

FDSI, August 2005. Report Describing Strategy for Processing Data and Design of the User Interface. Deliverable D5.4e to California Energy Commission under Contract 500-03-030

FDSI, June 2005. Report Describing Economizer, DCV, and Controls Diagnostic Algorithms. Deliverable D5.4c to California Energy Commission under Contract 500-03-030

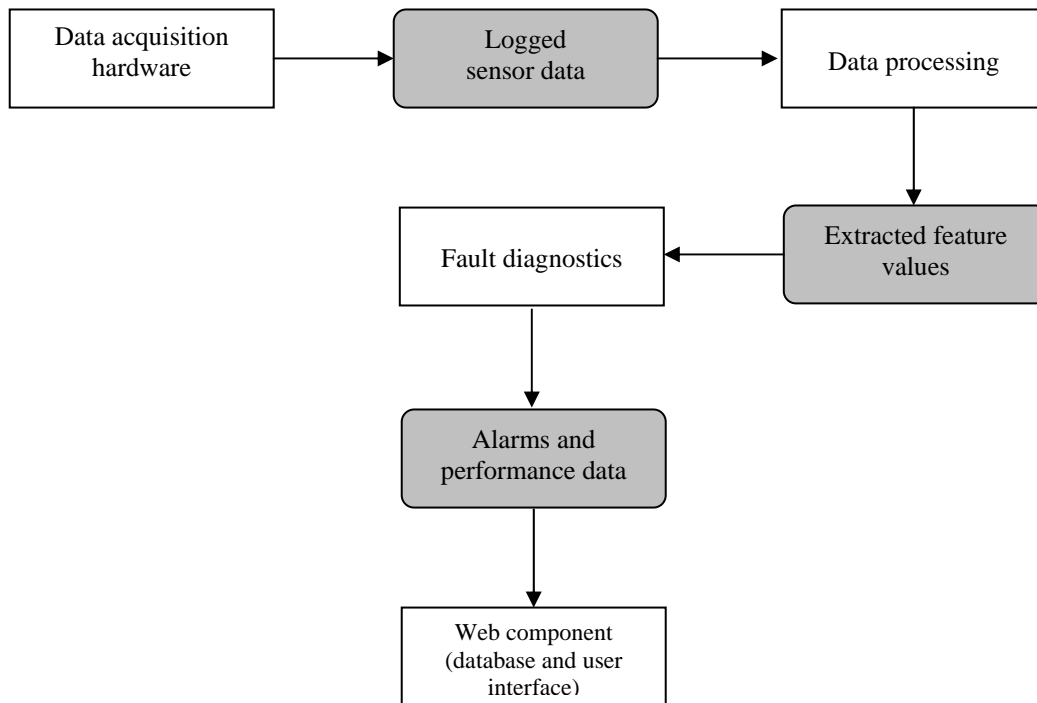


Figure 1. Component View of FDSI Embedded FDD System

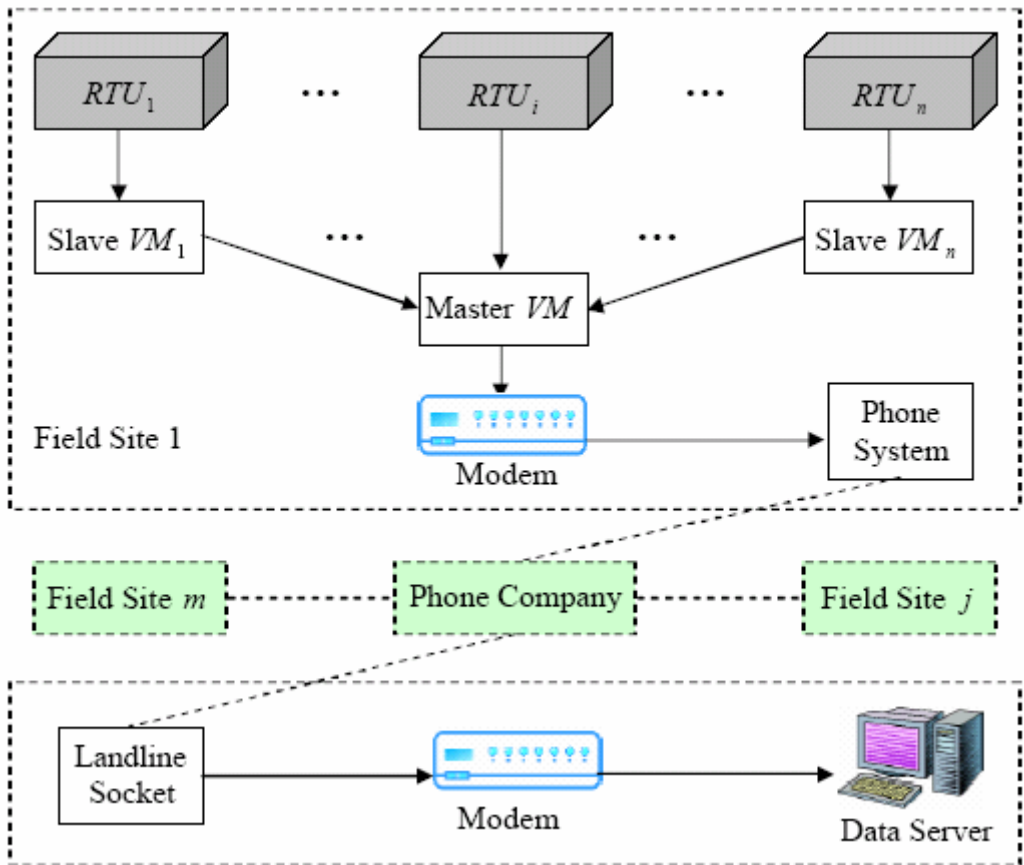


Figure 2. Data Communication of FDSI VM Hardware Platform

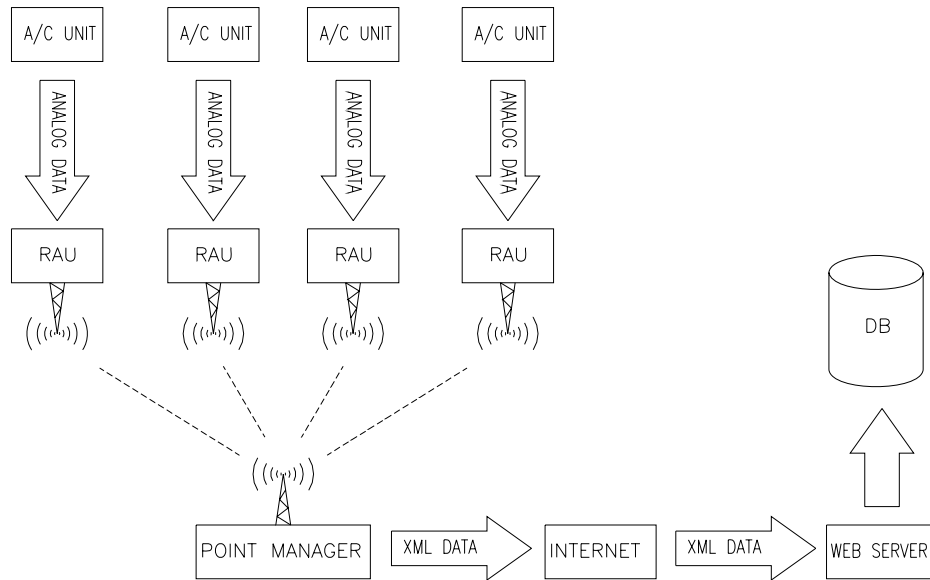


Figure 3. Data Communication of PointSix Hardware Platform

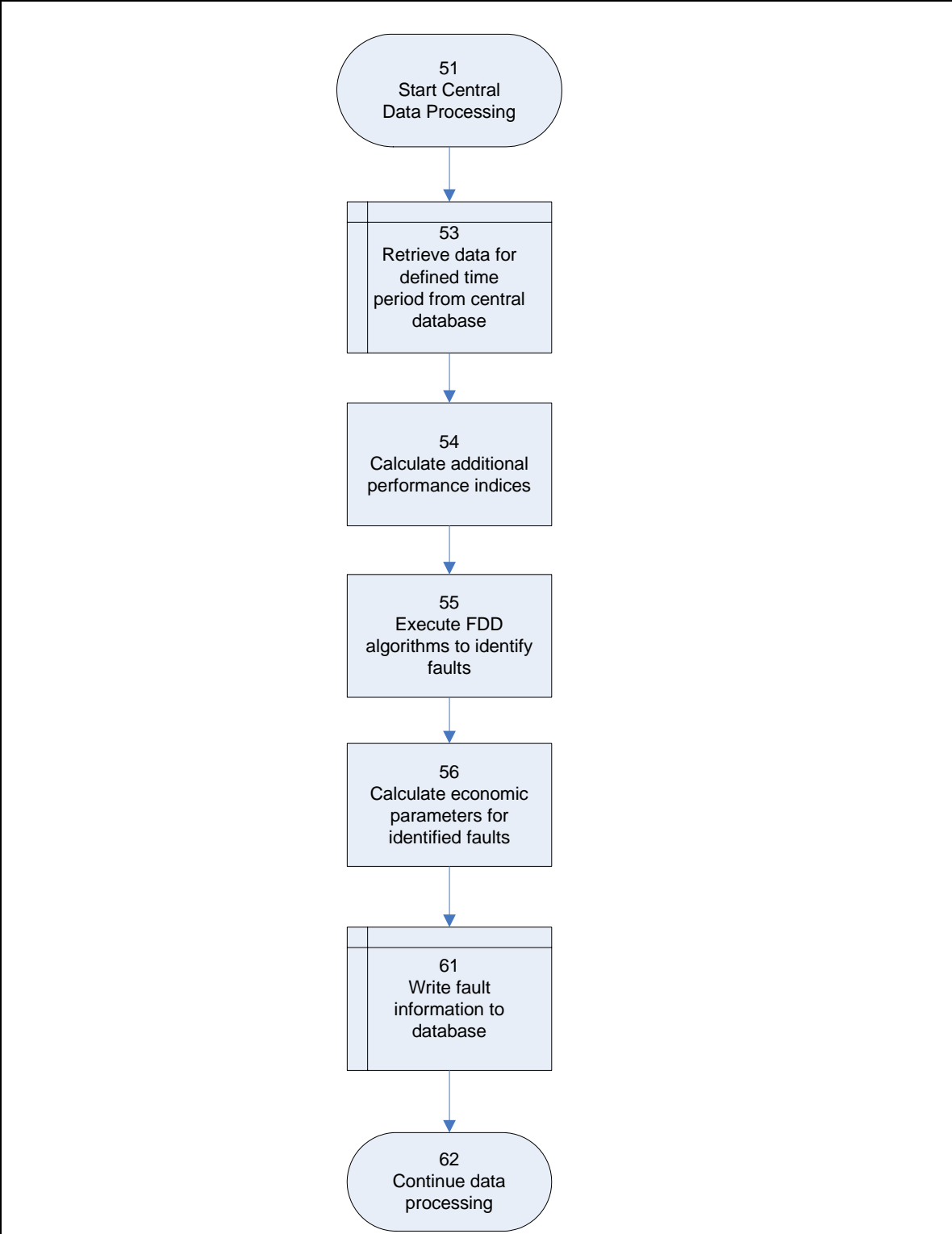


Figure 4. Central Data Processing Flowchart [FDSI August 2005]

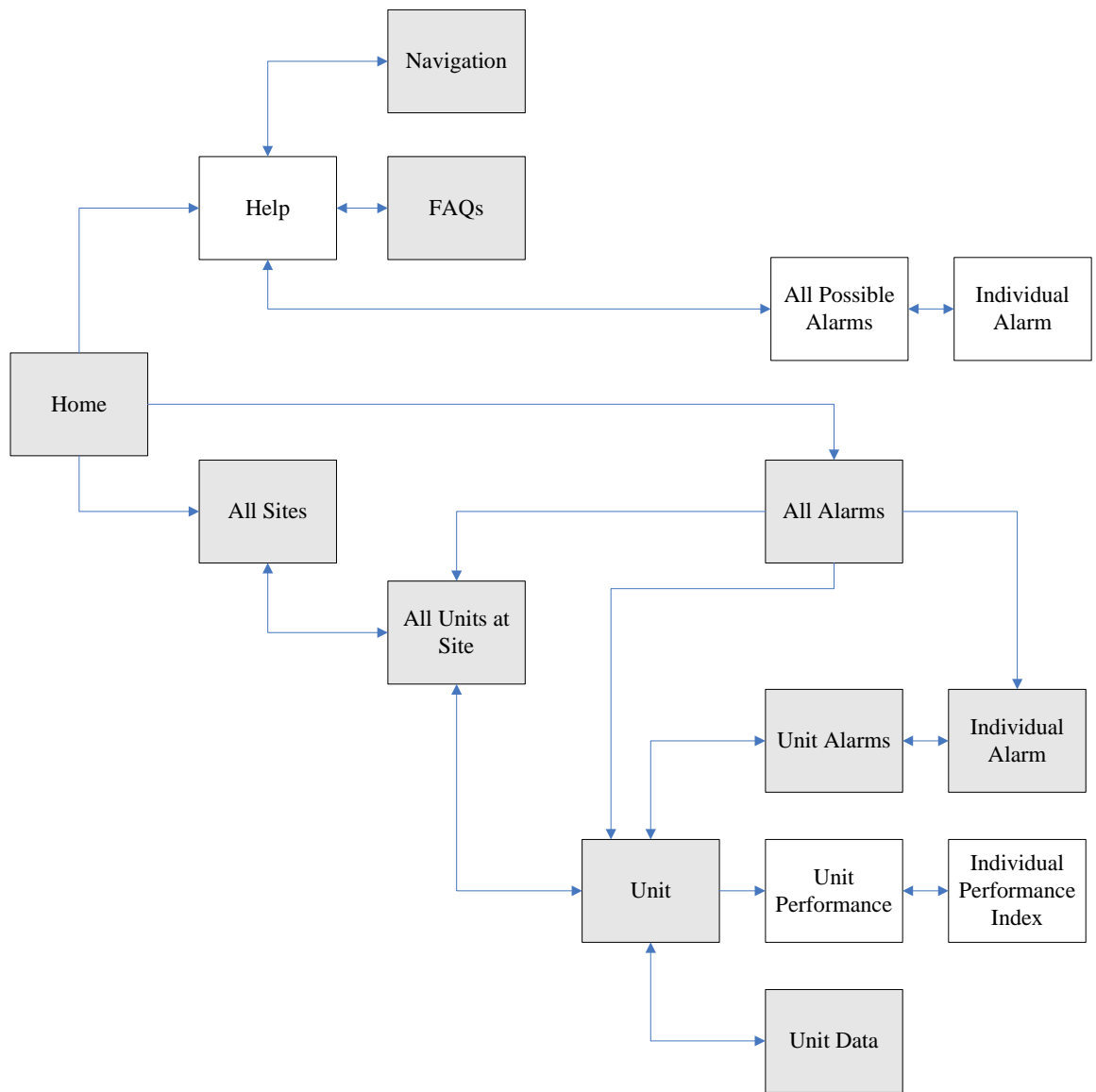


Figure 5. Central User Interface Navigation [FDSI August 2005]

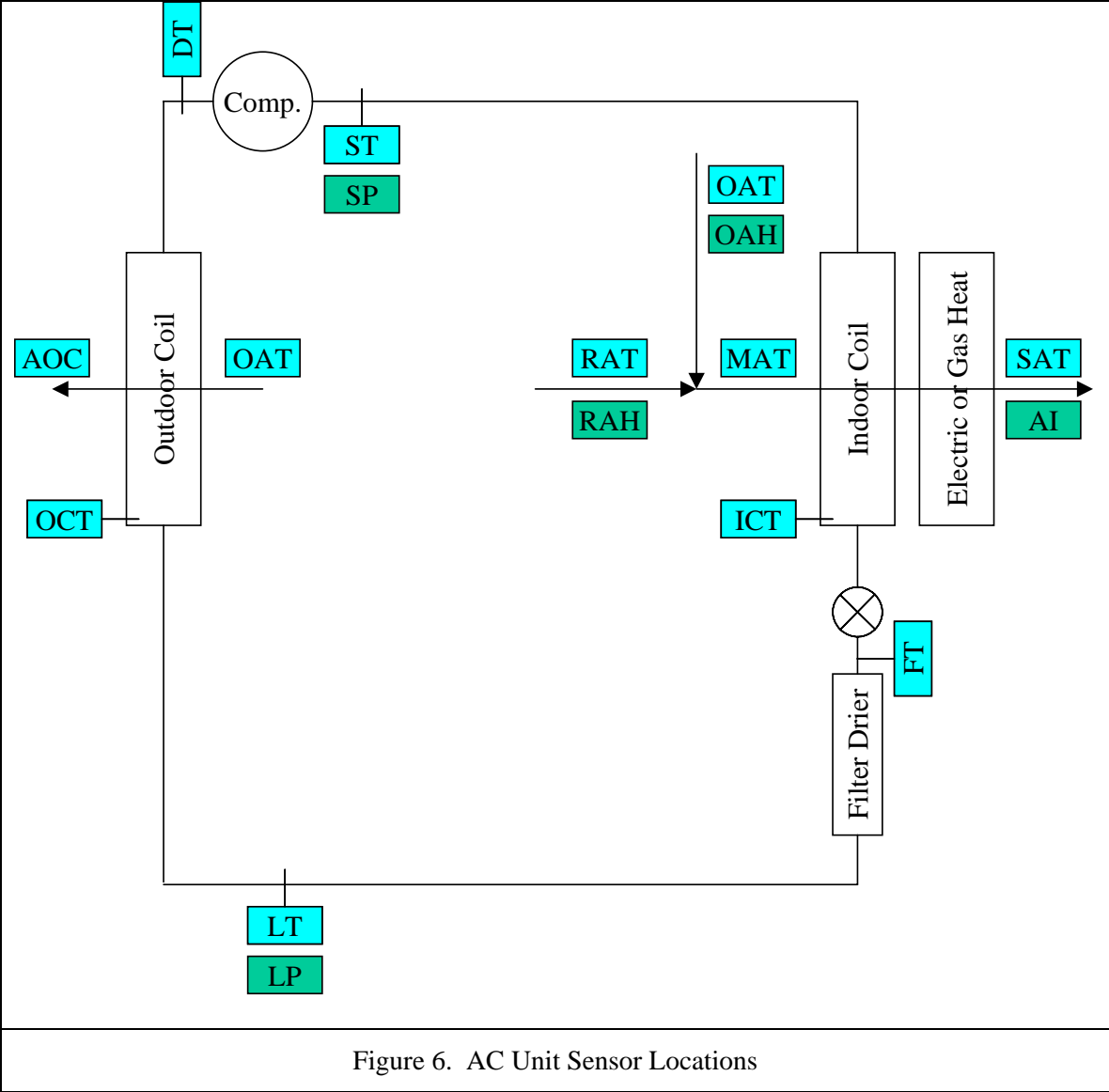


Figure 6. AC Unit Sensor Locations

Table 1 FDSI VM hardware sensor inputs

Item	Description
1	unit voltage 1 (V)
2	unit voltage 2 (V)
3	unit voltage 3 (V)
4	unit current 1 (A)
5	unit current 2 (A)
6	suction pressure, stage 1 (PSIG)
7	discharge pressure, stage 1(PSIG)
8	mixed air temp. (°F)
9	return air temp (°F)
10	Ambient temperature (°F)
11	supply air temperature (°F)
12	air in condenser (°F)
13	air off condenser (°F)
14	suction temperature, stage 1(°F)
15	discharge temperature, stage 1 (°F)
16	liquid temperature, stage 1(°F)
17	liquid temperature (after dryer), stage 1 (°F)
18	evaporating temperature, stage 1 (°F)
19	condensing temperature, stage 1(°F)
20	HW slave type
21	HW run indicator(0 =off, 255=on)
22	HW firmware version
23	HW firmware revision
24	HW boot-up flag
25	HW EEPROM checksum fault
26	HW ROM checksum fault
27	HW RAM write/read fault
28	HW mixed air temp sensor fault
29	HW outdoor air temp sensor fault
30	HW outdoor humidity sensor fault
31	HW outdoor air quality sensor fault
32	HW return air temp sensor fault
33	HW return air humidity sensor fault
34	HW indoor air quality sensor fault
35	HW actuator fault
36	HW damper pos. control (0=norm, 1=MDP,, 2=closed, 3=open)
37	HW sensor config. (0=temp/RH, 1 =enthalpy)
38	HW IAQ control (0=disabled, 1=enabled)
39	HW shutdown (0=normal, 1 = shutdown)
40	HW enthalpy mode(0=normal, 1=override)
41	HW enthalpy control(0=disabled, 1=enabled)
42	HW occupancy state(0=unoccupied, 1=occupied)
43	HW fan state(0=inactive, 1=active)
44	HW call for cooling(0=no cooling, 1= cooling demand)
45	HW enthalpy arrangement (0=dry bulb, 1=ref., 2=compare)

Item	Description
46	HW power exhaust status (0=inactive, 1=active)
47	HW enthalpy status (0= not OK to economize, 1=OK to economize)
48	HW max allowed value for min. damper position(%)
49	HW power exhaust activation point. Referenced to damper position(%)
50	HW remote minimum damper position(%)
51	HW enthalpy setpoint corresponding to value on psychometric chart
52	HW indoor air quality setpoint(ppm)
53	HW indoor air quality (carbon dioxide) level (ppm)
54	HW mixed air temp (°F)
55	HW return air temp (°F)
56	HW return air humidity (%RH)
57	HW outdoor air humidity (%RH)
58	HW outdoor air temp (°F)
59	HW current damper position (%)
60	HW current minimum damper position (%)
61	HW local minimum damper position (%)
62	superheat, stage 1 (°F)
63	subcooling, stage 1 (°F)
64	evaporating temperature, stage 1 (°F)
65	condensing temperature, stage 1(°F)
66	condensing temperature over ambient (CT-AIC), stage 1 (°F)
67	unit power (kW)
68	unit (KWh)
69	digital input 1, supply fan, run time (hours)
70	digital input 2, cooling 1, run time (hours)
71	digital input 3, cooling 2, run time (hours)
72	digital input 4, heat 1, run time (hours)
73	digital input 5, heat 2, run time (hours)
74	digital input 6 run time (hours)
75	time since reset accumulators (hours)
76	up time (hours)
77	board battery voltage (V)
78	dсен1:supply fan
79	dсен2:cooling 1
80	dсен3:cooling 2
81	dсен4:heat 1
82	dсен5:heat 2
83	dсен6: other

Table 2 Sensor Inputs of PointSix Data Acquisition Module Installed at GSRC Atlanta Site
(first stage)

Channel	P/N	Description	Symbol	Location
Status – 1		Fan – Green / Black (common)	F	Wire to T-Stat
Status – 2		Cool 1 – Yellow / Black Y1	C1	Wire to T-Stat
Status – 3		Cool 2 – Blue / Black Y2	C2	Wire to T-Stat
Status – 4		Heat 1 – White / Black W1	H1	Wire to T-Stat
Status – 5		Heat 2 – Brown / Black W2	H2	Wire to T-Stat
Status – 6		N/A		
CH 0	ML500PS1PC	0-500 PSI Honeywell Pressure Sensor (Stage 1)	LP1	Liquid pressure port (Stage 1)
CH 1	ML200PS1PC	0-200 PSI Honeywell Pressure Sensor (Stage 1)	SP1	Suction pressure port (Stage 1)
CH 2	HIH-3610	FDSI Humidity/ Temperature Sensor (Humidity)	MAH	Mixed air before filter
CH 3	thermometrics	FDSI Humidity/ Temperature Sensor (Temperature)	MAT	Mixed air before filter
CH 4	TS665 TKY40B	Minco Temperature Sensor (Stage 1)	LT1	Mounted to liquid line
CH 5	TS665 TKY40B	Minco Temperature Sensor (Stage 1)	ST1	Mounted to suction line
CH 6	590-59AD12-103	Honeywell Temperature Probe	AMB	Under economizer hood
CH 7	590-59AD12-103	Honeywell Temperature Probe	RA	Return Air Duct
CH 8		N/A		
CH 9		N/A		

Table 3 Sensor Inputs of PointSix Data Acquisition Module Installed at GSRC Atlanta Site
(second stage)

Channel	P/N	Description	Symbol	Location
Status – 1		N/A		
Status – 2		N/A		
Status – 3		N/A		
Status – 4		N/A		
Status – 5		N/A		
Status – 6		N/A		
CH 0	ML500PS1PC	0-500 PSI Honeywell Pressure Sensor (Stage 1)	LP2	Liquid pressure port (Stage 2)
CH 1	ML200PS1PC	0-200 PSI Honeywell Pressure Sensor (Stage 1)	SP2	Suction pressure port (Stage 2)
CH 2		N/A		
CH 3		N/A		
CH 4	TS665 TKY40B	Minco Temperature Sensor (Stage 2)	LT2	Mounted to liquid line
CH 5	TS665 TKY40B	Minco Temperature Sensor (Stage 2)	ST2	Mounted to suction line
CH 6		N/A		
CH 7		N/A		
CH 8		N/A		
CH 9		N/A		

Table 4 Sensor Inputs of PointSix Data Acquisition Module Installed at CA University Sites –

Compressor Module (first stage)

Channel	P/N	Description	Symbol	Location
CH 0	TS665 TKY40B	Minco Temperature Sensor (Stage 1)	LT1	Mounted to liquid line
CH 1	TS665 TKY40B	Minco Temperature Sensor (Stage 1)	ST1	Mounted to suction line
CH 2	D1004MC22PO	ATP Sensors	CT1	Return Bend Condenser Coil
CH 4	TS665 TKY40B	Minco Temperature Sensor (Stage 1)	DT1	Discharge Temperature (stage 1)
CH 5	TS665 TKY40B	Minco Temperature Sensor (Stage 1)	FD1	Filter-Dryer Temperature (stage 1)
CH 6	ML500PS1PC	0-500 PSI Honeywell Pressure Sensor (Stage 1)	LP1	Liquid pressure port (Stage 1)
CH 7	ML200PS1PC	0-200 PSI Honeywell Pressure Sensor (Stage 1)	SP1	Suction pressure port (Stage 1)
CH 8				
CH 9				
Status – 1		Fan – Green / Black (common)	F	Wire to T-Stat
Status – 2		Cool 1 – Yellow / Black Y1	C1	Wire to T-Stat
Status – 3				
Status – 4		Heat 1 – White / Black W1	H1	Wire to T-Stat
Status – 5				
Status – 6				

Table 5 Sensor Inputs of PointSix Data Acquisition Module Installed at CA University Sites –

Compressor Module (second stage)

Channel	P/N	Description	Symbol	
CH 0	TS665 TKY40B	Minco Temperature Sensor (Stage 2)	LT2	Mounted to liquid line (Stage 2)
CH 1	TS665 TKY40B	Minco Temperature Sensor (Stage 2)	ST2	Mounted to suction line (Stage 2)
CH 2	D1004MC22PO	ATP Sensors	CT2	Return Bend Condenser Coil
CH 3				
CH 4	TS665 TKY40B	Minco Temperature Sensor (Stage 2)	DT2	Discharge Temperature (stage 2)
CH 5	TS665 TKY40B	Minco Temperature Sensor (Stage 2)	FD2	Filter-Dryer Temperature (stage 2)
CH 6	ML500PS1PC	0-500 PSI Honeywell Pressure Sensor (Stage 2)	LP2	Liquid pressure port (Stage 2)
CH 7	ML200PS1PC	0-200 PSI Honeywell Pressure Sensor (Stage 2)	SP2	Suction pressure port (Stage 2)
CH 8				
CH 9				
Status – 1				
Status – 2				
Status – 3		Cool 2 – Blue / Black Y2	C2	Wire to T-Stat
Status – 4				
Status – 5		Heat 2 – Brown / Black W2	H2	Wire to T-Stat
Status – 6				

Table 6 Sensor Inputs of PointSix Data Acquisition Module Installed at CA University Sites –
Evaporator Module (1 stage unit)

Channel	P/N	Description	Symbol	
CH 0	590-59AD12-103	Honeywell Temperature Probe	MAT	Mixed air before filter
CH 1	D1004MC22PO	ATP Sensors	ET1	Return Bend Evaporator Coil
CH 2				
CH 3				
CH 4	thermometrics	Honeywell Temperature Probe	RA	Return Air Duct
CH 5	thermometrics	Honeywell Temperature Probe	SA	Supply Air Duct
CH 6	HHH-3610	Honeywell Humidity Sensor	RAH	Return Air Duct
CH 7	HHH-3610			
CH 8	MA100GG232C	Air Flow (overheated thermetrics 2K thermistor)	SAF	Supply Air Duct
CH 9				
Status – 1				
Status – 2				
Status – 3				
Status – 4				
Status – 5				
Status – 6				
Digital Input		Air Flow (micro switch)	SAF	Supply Air Duct

Table 7 Sensor Inputs of PointSix Data Acquisition Module Installed at CA University Sites –
Evaporator Module (2 stage unit)

Channel	P/N	Description	Symbol	Location
CH 0	590-59AD12-103	Honeywell Temperature Probe	MAT	Mixed air before filter
CH 1	D1004MC22PO	ATP Sensors	ET1	Return Bend Evaporator Coil
CH 2	D1004MC22PO	ATP Sensors	ET2	Return Bend Evaporator Coil
CH 3				
CH 4	thermometrics	Honeywell Temperature Probe	RA	Return Air Duct
CH 5	thermometrics	Honeywell Temperature Probe	SA	Supply Air Duct
CH 6	HHH-3610	Honeywell Humidity Sensor	RAH	Return Air Duct
CH 7				
CH 8	MA100GG232C	Air Flow (overheated thermetrics 2K thermistor)	SAF	Supply Air Duct
CH 9				
Status – 1				
Status – 2				
Status – 3				
Status – 4				

Channel	P/N	Description	Symbol	Location
Status – 5				
Status – 6				
Digital Input		Air Flow (micro switch)	SAF	Supply Air Duct

Table 8 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	ECOOL=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

General Fault	Specific Fault	Basic Fault Criteria	Occurrence Criteria	Possible Causes
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
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

Table 9 Airside Fault Diagnostics

General Fault	Specific Fault	Basic Fault Criteria	Occurrence Criteria	Possible Causes
Sensor error	RAT invalid	Fault detection at analog input circuit		Open or short sensor or circuit
Sensor error	OAT invalid	Fault detection at analog input circuit		Open or short sensor or circuit
Sensor error	MAT invalid	Fault detection at analog input circuit		Open or short sensor or circuit
Sensor error	SAT invalid	Fault detection at analog input circuit		Open or short sensor or circuit
Sensor error	OAH invalid	Fault detection at analog input circuit		Open or short sensor or circuit
Sensor error	RAH invalid	Fault detection at analog input circuit		Open or short sensor or circuit
Sensor problem	RAT out of valid range	RAT < 65°F or RAT > 85°F	10 minutes in 24h period	Bad or misplaced sensor
Sensor problem	OAT out of valid range	OAT > 125°F or OAT < (-15°F)	10 minutes in 24h period	Bad or misplaced sensor
Sensor problem	MAT out of valid range	MAT>OAT>RAT or MAT<OAT<RAT	10 minutes in 24h period	Bad or misplaced sensor
Sensor problem	SAT out of valid range	SAT > 130°F or SAT < 40°F	10 minutes in 24h period	Bad or misplaced sensor
Sensor problem	OAH out of valid range	OAH > 100% or OAH < 5%	10 minutes in 24h period	Bad or misplaced sensor
Sensor problem	RAH out of valid range	RAH > 70% or RAH < 15%	10 minutes in 24h period	Bad or misplaced sensor
No economizer cooling at low outdoor air temperature	Fault with dry-bulb control	Y1=on and (OAT-RAT) < (-10°F) and ECOOL=off and (ECON=1 or ECON=3)	25 minutes in 24h period	Faulty economizer control, 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	10 minutes in 24h period	Faulty economizer control, damper

General Fault	Specific Fault	Basic Fault Criteria	Occurrence Criteria	Possible Causes
		or ECON=4)		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 heating or cooling	High heating temperature difference	(W1=on or W2=on) and (SAT-RAT) > 50°F	10 minutes in 24h period	Low airflow, heating control problem
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 10 Refrigeration Cycle Fault Diagnostics

General Fault	Specific Fault	Basic Fault Criteria	Occurrence Criteria	Possible Causes
Low Evaporating Temperature	Low Evaporating Temperature	Steady-state cooling operation and evaporating temperature less than 28 F	10 minutes accumulated during a day	Low indoor airflow, refrigerant flow restriction
High Evaporating Temperature	High Evaporating Temperature	Steady-state cooling operation and evaporating temperature greater than 55 F	10 minutes accumulated during a day	Faulty compressor
Low Superheat	Low Superheat	Steady-state cooling operation and superheat residual (actual – goal) less than -15 F	10 minutes accumulated during a day	High refrigerant charge
High Superheat	High Superheat	Steady-state cooling operation and superheat residual (actual – goal) greater than 20 F	10 minutes accumulated during a day	Low refrigerant charge
High Condenser Over Outdoor Air Temperature	High Condenser Over Outdoor Air Temperature	Steady-state cooling operation and the residual (actual – goal) of condensing temperature over outdoor air temperature greater than 15 F.	10 minutes accumulated during a day	Low condenser airflow

Table 11 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	January 2006	Packaged AC or HP (1 or 2-stage) no economizer
UCSD	San Diego, CA	7	February 2006	Packaged AC (1-stage) with gas heat and economizer
CSU Hayward	Hayward, CA	7	December 2005	Packaged HP (1-stage) with economizer

Table 12 Walgreens – Anaheim Unit Information

Unit	Stages	Indoor Exp Dev	Outdoor Exp Dev	Equip Type	Nominal (total) cooling capacity (tons)	Economizer control
RTU1	1	Fixed	TxV	Package HP	5	Yes
RTU2	1	Fixed	TxV	Package HP	6.25	Yes
RTU3	1	Fixed	TxV	Package HP	6.25	Yes
RTU4	1	Fixed	TxV	Package HP	7.5	Yes
RTU5	1	Fixed	TxV	Package HP	7.5	Yes

Table 13 Walgreens – Rialto Unit Information

Unit	Stages	Indoor Exp Dev	Outdoor Exp Dev	Equip Type	Nominal (total) cooling capacity (tons)	Economizer control
RTU1	1	Fixed	TxV	Package HP	6.25	Yes
RTU2	1	Fixed	TxV	Package HP	7.5	Yes
RTU3	1	Fixed	TxV	Package HP	7.5	Yes
RTU4	1	Fixed	TxV	Package HP	7.5	Yes
RTU5	1	Fixed	TxV	Package HP	7.5	Yes

Table 14 Honeywell GSRC Unit Information

Unit	Stages	Indoor Exp Dev	Outdoor Exp Dev	Equip Type	Nominal (total) cooling capacity (tons)	Economizer control
RTU1	1	TxV		Package Cool	30	Yes
RTU2	1	TxV		Package Cool	30	Yes
RTU3	2	Fixed		Package Cool	10	Yes
RTU5	1	Fixed		Package Cool	7.5	Yes

Table 15 CSU Hayward Unit Information

Unit	Stages	Indoor Exp Dev	Outdoor Exp Dev	Equip Type	Nominal (total) cooling capacity (tons)	Economizer control
RTU1	1	Fixed		Package Cool	5	Yes
RTU2	1	Fixed		Package Cool	5	Yes
RTU3	1	Fixed		Package Cool	5	Yes
RTU4	1	Fixed		Package Cool	5	Yes
RTU5	1	Fixed		Package Cool	5	Yes
RTU6	2	Fixed	TxV	Package HP	12.5	Yes
RTU7	1	Fixed		Package Cool	5	Yes

Table 16 UCLA Unit Information

Unit	Stages	Indoor Exp Dev	Outdoor Exp Dev	Equip Type	Nominal (total) cooling capacity (tons)	Economizer control
RTU1	2	--	--	--	10	--
RTU2	1	Fixed	TxV	Package HP	3	No econ
RTU3	2	Fixed		Package Cool	15	No econ
RTU4	2	Fixed		Package Cool	10	No econ
RTU5	2	Fixed		Package Cool	15	No econ
RTU6	2	Fixed	TxV	Package HP	15	No econ
RTU7	2	Fixed	TxV	Package HP	10	No econ
RTU8	1	Fixed		Package Cool	3	No econ

Table 17 UCSD Unit Information

Unit	Stages	Indoor Exp Dev	Outdoor Exp Dev	Equip Type	Nominal (total) cooling capacity (tons)	Economizer control
RTU1	1	Fixed		Package Cool	3	Honeywell DVC
RTU2	1	Fixed		Package Cool	6	Honeywell DVC
RTU3	1	Fixed		Package Cool	3	Honeywell DVC
RTU4	1	Fixed		Package Cool	4	Honeywell DVC
RTU5	1	Fixed		Package Cool	6	Honeywell DVC
RTU6	1	Fixed		Package Cool	5	Honeywell DVC
RTU7	1	Fixed		Package Cool	4	Honeywell DVC

Table 18 Field Installation Issues and Observations at CA University Sites

Site	Installation issues	Observations
UCLA		These units are Trane and do not have a conventional thermostat input
UCSD	Had to take the evaporator boxes apart to route the wires through the rooftop unit. This added considerable time to the installation.	
	Return bend sensors had to be insulated. This also took considerable time since the return bends were behind the compressor and out of reach.	
	Had three pressure sensors fail on installation. One sensor leaked and two others were shorted out.	
	The return air probe had to be mounted parallel to the airflow instead of perpendicular, as it was physically impossible to mount it any other way.	

Site	Installation issues	Observations
	The supply air probe was mounted before the gas heat, as this was the only place to mount it.	
	Need to design clip to mount the mixed air temperature sensor to the filter. Due to the design of the unit there was no place to mount the sensor other than directly onto the filter.	
	We could not mount the compressor or evaporator box in their respective compartment. We mounted both boxes in the same compartment behind the condenser coil, as this was the only place that we could mount them.	
	Product needs to be smaller. Some of the areas to mount the boxes are not very big and usually have other wires and stuff running through them.	
	Probes need to be a smaller diameter to be able to pass them through the rooftop unit without having to either drill bigger holes or taking them apart while routing the wire.	

Table 19 Field Installation Issues and Observations at Honeywell GSRC Site

Site	Installation issues	Observations
Honeywell GSRC	For RTU1 and RTU2, it's hard to get MAT and MAH because of two air streams coming from different directions with only 1 foot in large chamber to mix. Sensor is placed in middle to do the best we can.	RTU1 and RTU2 have two compressors sharing a common circuit
		For RTU1 and RTU2, compressors alternate first each time they cycle
		For RTU1 and RTU2, F, C1, and C2 current switches are installed on both units.
		For RTU1 and RTU2, no H1 and H2 on either of the two big units. Heaters are after the SA sensors in the ducts
		RTU 4 is down for repairs. Do not expect pressures to match call for cooling.