Fault Detection & Diagnostics (FDD)
Rooftop HVAC Units: Technology, Code Requirements, Commissioning

California Commissioning Collaborative
August 9, 2012

Working toward a more energy efficient future.
Material Covered

• Why RTUs?

• 2013 CA T24 Mandatory Economizer FDD
  – on the path toward progress

• Continuous Performance Monitoring-based Commissioning/Controls
Why RTUs?
NW Profile

Primary HVAC System Type
1.3 billion sq.ft. (nearly half the stock)
RTU Size Demographics
NW Profile

CBSA Data: Building Average Cooling Tons per Package HVAC Unit
(Only systems <50 tons, sample size = 1041 buildings)

64% of buildings with ≤ 6 ton units
RTU Size Demographics
California Profile

Figure 45 Unitary System Market Share by Cooling Capacity, California

Economizers required @ 6.25 tons

T24 CASE Report > slide 14)
AHRI Data Provided for Title 24 Proceeding

California Commercial Packaged Rooftop 2010 Unit Volume

- 2013 T24 ≥ 4.5 ton economizer requirement
- 4.5-5.4 tons
- 2.75 -3.24 tons
- [2.75 ton economizer proposal 90.1-2013]

~85% of units ≤ 6 tons
RTU Diagnostic Tune Up > RTU DTU

1. CONTROLLER OFF LINE
2. SENSOR FAILURE
3. SENSOR STUCK
4. SENSOR OUT OF CALIBRATION
5. IMPROPER SENSOR LOCATION
6. COOLING/HEATING STAGE FAILURE
7. COOLING/HEATING/FAN CYCLING
8. DAMPER HUNTING
9. STUCK DAMPER
10. DAMPER LEAKAGE
11. OVERSIZING
12. IMPROPER TEST, ADJUST, BALANCE
13. EXCESS OUTDOOR AIR INTAKE
14. OVER CIRCULATION
15. EXTREMELY UNEVEN RUNTIME RATIO
16. LOW AIR FLOW RATE
   - Faulty fan
   - Slipping belt
   - Fouling
   - Improper or no TAB
17. EXCESS AIR FLOW RATE
18. SETPOINTS NOT MET
19. FAULTY ECONOMIZER CONTROL
20. LOW COOLING CAPACITY
   - Low air flow rate
   - Low charge
   - Low compressor efficiency
21. OVERCHARGE
22. CONDENSER FOULING
23. LIQUID-LINE RESTRICTION
24. NON-CONDENSIBLE GAS
25. MALFUNCTIONING EXPANSION DEVICE
PIER 2003 - 215 RTUs

PIER - Frequency of Problems

- Refrigerant Charge: 46%
- Economizers: 64%
- Low Airflow: 39%
- Cycling fans during occupied period: 38%
- Fans run during unoccupied period: 30%
- Simultaneous heating and cooling: 8%
- No outside air intake at unit: 8%
NBI Summary of RTU Studies

Weighted Average for All Programs - Frequency of Problems

- Refrigerant circuit: 46%
- Economizer: 64%
- Air flow: 42%
- Thermostat: 58%
- Sensors: 27%
Potential Energy Savings

Estimated Cooling Energy Savings

<table>
<thead>
<tr>
<th>Component</th>
<th>High</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refrigerant circuit</td>
<td>5%</td>
<td>5%</td>
</tr>
<tr>
<td>Economizer</td>
<td>14%</td>
<td>5%</td>
</tr>
<tr>
<td>Air flow</td>
<td>40%</td>
<td>5%</td>
</tr>
<tr>
<td>Thermostat</td>
<td>10%</td>
<td>5%</td>
</tr>
<tr>
<td>Sensors</td>
<td>40%</td>
<td>5%</td>
</tr>
</tbody>
</table>
Fault Typology

Categories
- Description
- Monitoring
- Detection
- Diagnostics
- Annunciation

Faults
- Hard fault
  - Loss of a function/whole unit
  - Sensors and Simple Alarms
  - Comfort not maintained
  - Fault is easy, cause may be more difficult
  - Technician during Service Call, or Remote to Service Center with Data Mining
- Degradation fault
  - No loss of function, but not performing as expected
  - Performance Monitoring
  - Models for symptoms or performance metrics
  - Need for specific procedure/tools
  - Remote to Service Center
- Fault Prediction
  - Identify a unit that is near the end of its useful life
  - Characteristic performance metrics and inspection
  - Models for symptoms and Inspection
  - Fault is easy, cause may be more difficult
  - Technician during Service Call, or Remote to service center
## 2013 CA T24 RTU FDD—We Got A Good Start

<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensor Failure (not incl drift)</td>
<td>Sensor failure/fault (incl drift)</td>
</tr>
<tr>
<td>Low refrigerant Charge</td>
<td>Low refrigerant charge</td>
</tr>
<tr>
<td>-</td>
<td>High refrigerant charge</td>
</tr>
<tr>
<td>Compressor short cycling</td>
<td>Compressor short cycling</td>
</tr>
<tr>
<td>Refrigerant line restrictions/TXV problem</td>
<td>-</td>
</tr>
<tr>
<td>Refrigerant line non-condensables</td>
<td>-</td>
</tr>
<tr>
<td>Low side HX problem</td>
<td>Low evaporator air flow</td>
</tr>
<tr>
<td>High side HX problem</td>
<td>Dirty filter</td>
</tr>
<tr>
<td>Efficiency metric for tracking or comparison with no-fault model</td>
<td>Capacity degradation</td>
</tr>
<tr>
<td>Efficiency degradation</td>
<td>Efficiency degradation</td>
</tr>
<tr>
<td>Not economizing when it should</td>
<td>Not economizing when it should</td>
</tr>
<tr>
<td>Economizing when it shouldn’t</td>
<td>Economizing when it shouldn’t</td>
</tr>
<tr>
<td>Damper not modulating</td>
<td>Damper not modulating</td>
</tr>
<tr>
<td>Excess Outdoor Air</td>
<td>Excess outdoor air</td>
</tr>
<tr>
<td></td>
<td>Low ventilation</td>
</tr>
</tbody>
</table>

*Note: economizing when it should NOT be economizing when it shouldn’t.*
T24 Mandatory Measure

• CEC PIER + IOU CASE joint effort: built on 2008 T24 RTU FDD

• Western HVAC Performance Alliance Subcommittee on Onboard/In-Field FDD

• Collaboration with HVAC OEM representatives and related public and private industry stakeholders

• RTU FDD methods of test for being developed in CA for Title 24 and through ASHRAE SPC 207 -Laboratory Method of Test of Fault Detection and Diagnostics Applied Commercial Air-Cooled Packaged Systems
2013 CA T24 RTU FDD Reference  
(15-day language)

CEC REQUIRED CONTROLS FOR SPACE-CONDITIONING SYSTEMS  
(pg. 137)  
( pgs. 139-140)

CEC REFERENCE APPENDICES  
( pgs. NA7-17 through top of NA7-19)

Codes and Standards Enhancement (CASE) Initiative Light Commercial Unitary HVAC Working Draft Information Template – Statewide IOU CASE Team  
2013 CA T24 RTU FDD

• **Mandatory Measure** Jan 2014 for **all** air cooled unitary (package, split, heat pump, VRF/VCHP) with economizers $\geq 4.5$ tons/54,000 Btu/hr

• Detect the following fault conditions:
  ✓ Air temperature sensor failure/fault
  ✓ Not economizing when it should
  ✓ Economizing when it should not
  ✓ Damper not modulating
  ✓ Excess outdoor air
“Faults shall be reported to a fault management application accessible by day-to-day operating or service personnel, or annunciuated locally on zone thermostats.” – T24

• 1st step: Get the information off the roof!
• 2nd step: Pray hard that someone notices and does something with the information!

CxP: In your building:
- Who is responsible for RTU performance?
- How is RTU performance monitored?
T24 RTU FDD Construction Inspection

• Verify FDD hardware is installed on HVAC unit
• Verify the FDD system matches the make and model reported on the design drawings
• Verify the following air temperature sensors are permanently installed:
  – outside air  [placement & housing issue]
  – supply air
  – return air
T24 RTU FDD Construction Inspection

• **Verify** the controller has the **capability of displaying** the value of the following parameters:
  – Air temperatures: outside air, supply air, return air.
  – Refrigerant pressure and temperature sensors (if present, their output shall be made available)

• **Verify** the **controller provides system status** by indicating the following conditions:
  – Free cooling available
  – Economizer enabled
  – Compressor enabled
  – Heating enabled
  – Mixed air low limit cycle active
T 24 FDD Functional Testing

- Functional Testing for Air Temperature Sensor Failure/Fault
- Functional Testing for Excess Outside Air
- Functional Testing for Economizer Operation
- Functional Testing for Refrigerant Diagnostic Sensors
Electrical power distribution systems shall be designed to permit the disaggregated measurement of electrical load energy uses downstream from the service meter.

<table>
<thead>
<tr>
<th>TABLE 130.5-A MINIMUM REQUIREMENTS FOR METERING OF ELECTRICAL LOAD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Meter Type</strong></td>
</tr>
<tr>
<td>Instantaneous (at the time) kW demand</td>
</tr>
<tr>
<td>Historical peak demand (kW)</td>
</tr>
<tr>
<td>Resettable kWh</td>
</tr>
<tr>
<td>kWh per rate period</td>
</tr>
</tbody>
</table>
# Title 24 Metering-Detail

<table>
<thead>
<tr>
<th>Load Type</th>
<th>Services rated 50 kVA or less</th>
<th>Services rated more than 50kVA and less than or equal to 250 kVA</th>
<th>Services rated more than 250 kVA and less than or equal to 1000kVA</th>
<th>Services rated more than 1000kVA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lighting including exit and emergency lighting</td>
<td>Not required</td>
<td>All lighting in aggregate</td>
<td>All lighting disaggregated by floor, type or area</td>
<td>All lighting disaggregated by floor, type or area</td>
</tr>
<tr>
<td>HVAC systems and components including chillers, fans, heat recovery, package units, cooling towers, and circulation pumps associated with HVAC</td>
<td>Not required</td>
<td>All HVAC in aggregate</td>
<td>All HVAC in aggregate and each HVAC load rated at least 50kVA</td>
<td>All HVAC in aggregate and each HVAC load rated at least 50kVA</td>
</tr>
<tr>
<td>Domestic and service water system pumps and related systems and components</td>
<td>Not required</td>
<td>All loads in aggregate</td>
<td>All loads in aggregate</td>
<td>All loads in aggregate</td>
</tr>
<tr>
<td>Plug load including appliances rated less than 25 kVA</td>
<td>Not required</td>
<td>All plug load in aggregate</td>
<td>All plug load separated by floor, type or area</td>
<td>All plug load separated by floor, type or area</td>
</tr>
<tr>
<td>Elevators, escalators, moving walks, and transit systems</td>
<td>Not required</td>
<td>All loads in aggregate</td>
<td>All loads in aggregate</td>
<td>All loads in aggregate</td>
</tr>
<tr>
<td>Other individual non-HVAC loads or appliances rated 25kVA or greater</td>
<td>Not required</td>
<td>All</td>
<td>Each</td>
<td>Each</td>
</tr>
<tr>
<td>Industrial and commercial load center 25 kVA or greater including hazmat lighting installations and commercial kitchens</td>
<td>Not required</td>
<td>All</td>
<td>Each</td>
<td>Each</td>
</tr>
<tr>
<td>Renewable power source (not of total)</td>
<td>Each group</td>
<td>Each group</td>
<td>Each group</td>
<td>Each group</td>
</tr>
<tr>
<td>Loads associated with renewable power source</td>
<td>Not required</td>
<td>All loads in aggregate</td>
<td>All loads in aggregate</td>
<td>All loads in aggregate</td>
</tr>
<tr>
<td>Charging stations for electric vehicles</td>
<td>All loads in aggregate</td>
<td>All loads in aggregate</td>
<td>All loads in aggregate</td>
<td>All loads in aggregate</td>
</tr>
</tbody>
</table>
T24 Metering Load Types

≤50kVA  [+ all]  ≤250kVA  ≤1000kVA

- Lighting: exit/egress/exterior
- HVAC systems and components including chillers, fans, heaters, furnace units, package units, cooling towers, circulation pumps associated with HVAC
- Domestic/service water system pumps and related systems and components
- Plug load including appliances rated less than 25kVA
- Elevators, escalators, moving walks and transit systems
- Other individual non-HVAC loads or appliances 25kVA or greater
- Industrial/commercial load centers 25kVA or greater: theatrical lighting, commercial kitchens
- Renewable power source (net or total)
- Loads associate with renewable power source
- Charging stations for electric vehicles

**PLUG LOADS:** “At least one controlled receptacle installed within 6 feet from each uncontrolled receptacle or a split-wired duplex receptacle with one controlled and one uncontrolled receptacle be installed; Controlled receptacles shall have a permanent marking to differentiate them from uncontrolled receptacles.”
Under the Hood

*Data quality from operating RTUs is worse than assumed*

- Sensor data is one of the major sources of faults rather than the solution for optimizing control

  - Temperature sensors: poor reliability/out of calibration/stuck readings/in poor location/failure
    - Sensor errors up to 20°F in heating mode in operating units
  
  - Humidity sensor calibration problems

-Dr. Haorong Li, Univ. of Nebraska
How Could You Know What Is Wrong?

Ubiquitous economizer controller: Honeywell W7459 with C7650 dry bulb sensor

Does snap disc current [ >20mA] burn out protective motor circuit prematurely?
Way Under the Hood

- Honeywell W7459 controller w/C7650 dry bulb sensor: 6-10°F deadband in changeover point
- Limiting economizing since the 1990’s
- $20 drybulb vs $40 enthalpy
- C7660 +$4 at wholesale; C7650 obsoleted

**CxP: Change out all C7650 to C7660 Right Now!**
## Analog vs Digital Sensor

<table>
<thead>
<tr>
<th></th>
<th>C7650</th>
<th>C7660</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 models</td>
<td>2 models</td>
<td></td>
</tr>
<tr>
<td>Dry bulb changeover based on A, B C and D setting on economizer module</td>
<td>8 Selectable changeover temperatures</td>
<td></td>
</tr>
<tr>
<td>10 degree dead band</td>
<td>2 degree dead band</td>
<td></td>
</tr>
<tr>
<td>35°F to +100°F (+4°C to +38°C) ambient temp The device remains operational after exposure to extremes of –40° to 125°F (-40°C to 52°C)</td>
<td>-40 to 149°F (-40° to 65° C) ambient temp</td>
<td></td>
</tr>
<tr>
<td>-40°F to +150°F (-40°to 66°C) shipping temp</td>
<td>-40 to 149°F (-40° to 65° C) shipping temp</td>
<td></td>
</tr>
<tr>
<td>Underwriters Laboratories Inc. Flammability Rating: UL94-5V</td>
<td>Underwriters Laboratories Inc. Flammability Rating: UL94-5V</td>
<td></td>
</tr>
</tbody>
</table>
# Analog vs Digital Sensor

<table>
<thead>
<tr>
<th>C7650</th>
<th>C7660</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analog circuit based on C7400 circuit</td>
<td>Microprocessor based control with +/- 1 degree F hysteresis</td>
</tr>
<tr>
<td>10 to 20 mA output signal to economizer logic module</td>
<td>4 OR 20 mA output signal to economizer control; At 4 mA not OK to economize, 20 mA OK to economize</td>
</tr>
</tbody>
</table>
## Dip Switchable Control-Wide Range

<table>
<thead>
<tr>
<th>DIP SWITCH POSITION</th>
<th>CHANGEOVER TEMPERATURE</th>
</tr>
</thead>
<tbody>
<tr>
<td>ON OFF 1 2 3</td>
<td>48°F</td>
</tr>
<tr>
<td>ON OFF 1 2 3</td>
<td>53°F</td>
</tr>
<tr>
<td>ON OFF 1 2 3</td>
<td>55°F</td>
</tr>
<tr>
<td>ON OFF 1 2 3</td>
<td>58°F</td>
</tr>
<tr>
<td>ON OFF 1 2 3</td>
<td>63°F</td>
</tr>
<tr>
<td>ON OFF 1 2 3</td>
<td>68°F</td>
</tr>
<tr>
<td>ON OFF 1 2 3</td>
<td>73°F</td>
</tr>
<tr>
<td>ON OFF 1 2 3</td>
<td>78°F</td>
</tr>
</tbody>
</table>

Honeywell C7660 Sensor
JADE W7220 with PCMOD Comm
Honeywell

Polarity insensitive wire

~$250 retail

Remote data logging with PC in place

~$150 to contractors

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### JADE Economizer / DCV Screen

![JADE Configuration Wizard](image)

#### Ventilation / Demand Control Ventilation
- Automatic damper calibration: **MAN**
- Ventilation min (low speed): 2.50 [Vdc]
- Ventilation max/min pos (low speed): 2.25 [Vdc]
- Ventilation max/min pos: 2.80 [Vdc]
- Ventilation min (automatic mode): 500 [CF/m]
- Ventilation max (automatic mode): 1000 [CF/m]
- Indoor DCV setpoint: 1100 [CF/m]
- Exhaust fan1 (low speed) setpoint: 85 [%]
- Exhaust fan2 (low speed) setpoint: 80 [%]
- Exhaust fan1 setpoint: 50 [%]
- Exhaust fan2 setpoint: 75 [%]
- Carbon Dioxide zero position: 0 [ppm]
- Carbon Dioxide span: 2000 [ppm]
- Shutdown damper position: **Closed**
- Unit single (H1 Speed) capacity ctrl: 5000 [CF/m]
- 2 Speed Fan Delay: 5 [min]

#### Temperature
- Freeze protection setpoint: 45 [°C]
- Freeze protection damper position: **Close**
- Lockout temperature setpoint: 32 [°C]
- Mixed air temperature: 53 [°C]
- Stage 3 ON delay: 2 h

#### Enthalpy
- Dry bulb temperature setpoint: 63 [°C]
- ES curve selection: 3
- Energy Recovery Ventilation setpoint: 32 [°C]
JADE Calibration Screen
JADE Checkout Screen

JADE™ Economizer

Version 1.0.0.15

JADE Economizer Serial Number: 00
Roof Top Unit Model: RTU1

Connected sensors
- Mixed Air: 74
- Outdoor Air (Dry Bulb): N/A
- Outdoor Air (Enthalpy): 74
- Return Air: 77
- Discharge Air: 77

JADE Economizer Checkout Report

RTU model: RTU1
JADE Economizer SN 00
JADE Economizer firmware version: 1.5

Operator ID:

- Damper Minimum Position: Passed
  - Economizer damper moves to its minimum position
- Damper Maximum Position: Passed
  - Economizer damper moves to its maximum position
- Damper Open Position: Passed
  - Economizer damper moves to its full open position
- Damper Closed Position: Passed
  - Economizer damper moves to its full close position
- Compressor Stage 1 ON: Passed
  - Compressor Stage 1 (Y1) is on

Save report  Close
# Carrier Centurian FDD

<table>
<thead>
<tr>
<th>Alarm</th>
<th>Description</th>
<th>Probable Cause</th>
</tr>
</thead>
<tbody>
<tr>
<td>T110</td>
<td>Circuit A Loss of Charge</td>
<td>Low refrigerant or faulty suction pressure transducer</td>
</tr>
<tr>
<td>T126</td>
<td>Circuit A High Refrigerant Pressure</td>
<td>An overcharged system, high outdoor ambient temperature coupled with dirty outdoor coil, plugged filter drier, or a faulty high-pressure switch.</td>
</tr>
<tr>
<td>T133</td>
<td>Circuit A Low Refrigerant Pressure</td>
<td>Low refrigerant charge, dirty filters, evaporator fan turning backwards, loose or broken fan belt, plugged filter drier, faulty transducer, excessively cold return air, or stuck open economizer when the ambient temperature is low.</td>
</tr>
<tr>
<td>T408</td>
<td>Dirty Filter</td>
<td>Dirty Filter</td>
</tr>
<tr>
<td>T414</td>
<td>Economizer Damper Actuator Out of Calibration</td>
<td>Calibrate economizer (E.CAL). If problem still exist then determine what is limiting economizer rotation.</td>
</tr>
<tr>
<td></td>
<td>Economizer Damper Actuator Torque Above Load Limit Alert</td>
<td>Actuator load too high. Check damper load.</td>
</tr>
<tr>
<td></td>
<td>Economizer Damper Actuator Hunting Excessively</td>
<td>Damper position changing too quickly.</td>
</tr>
<tr>
<td></td>
<td>Economizer Damper Stuck or Jammed</td>
<td>No economizer motion. Check damper blades, gears, and actuator.</td>
</tr>
<tr>
<td></td>
<td>Economizer Damper Actuator Mechanical Failure</td>
<td>Check actuator and replace if necessary.</td>
</tr>
<tr>
<td></td>
<td>Economizer Damper Actuator Direction Switch Wrong</td>
<td>Actuator direction control switch (CCW, CW) wrong.</td>
</tr>
</tbody>
</table>
• Sensors not detected or out of range
• Economizer damper stuck
• Compressor contactor failure
• Exhaust fan relay failure
• Mis-wired thermostat
• Supply air temperature drop is insufficient
Field Diagnostic Services
fielddiagnostics.com
FDSI Analytics

Executive Summary

Proposed Generator Demo aims to reduce your energy consumption, decrease operating costs and maximize your asset knowledge to allow you to more effectively plan for both capital and operational spend.

Inspection Results

The Principal Generator Demo has inspected 6 package HVAC units at Pets On The Box. These were located on January 10, 2004. Advanced fault detection and diagnostic algorithms were used to assess the performance of your mechanical systems. As a result of this testing, 6 of those units were found to be running optimally*. The remaining 6 units, or 100%, were found to be running inefficiently.

Key Findings

- 0 units running optimally
- 6 units running inefficiently
- 2 units are at operational risk
- 4 units require upgradings
- 3 units require replacement

In order to a unit be considered running optimally, all units must be running in acceptable conditions and the monitoring information must be healthy.

Impact

Cost Savings found are detailed in this report. The financial implications of these recommendations are as follows:

<table>
<thead>
<tr>
<th>Cost</th>
<th>Savings</th>
<th>Payback Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upgrade</td>
<td>$16,939</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>$760</td>
<td></td>
</tr>
<tr>
<td>Repair</td>
<td>$16,644</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>$54,520</td>
<td></td>
</tr>
<tr>
<td>Replacement</td>
<td>$16,451</td>
<td>3 yrs</td>
</tr>
<tr>
<td>Cost</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Savings</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Payback Period</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Based on the findings described in this report, addressing sub-optimal operational conditions would result in the following:

- **Reduced Spending**
  - Upgrades $17,225
  - Repairs $33,156
- **Reduced CO2 Emissions**
  - Upgrades 130,441 lbs
  - Repairs 139,145 lbs
- **Total Equivalency**
  - Upgrades 1,484 tons
  - Repairs 1,592 tons
- **Reduced Operational Risk**
  - $300

1. Includes service cost for replacements.
2. Upgrades, replacements and/or repairs of existing premises or replacement of equipment. Other risks may exist.
3. Total CO2 upgrade savings are taken into account when commissioning new opportunities are also present.

nbi new buildings institute

California Commissioning Collaborative
Environmental Impact

Proposal Generator Demo is dedicated to protecting the environment with a comprehensive and contemporary commitment. This is one of the central tenets of how we do business throughout the world.

Environmental stewardship means acting in a way that is both productive and sustainable. In fact, our solutions and technologies expand sustainable capacity and improve the efficiency of products and processes, fostering ‘Sustainable Opportunity.’

Our products and services help conserve energy, reduce waste, and protect our offices. We help other companies become more efficient and productive with our products and solutions. Our processes identify and address risks and promote a culture of safety excellence.

Environmental Impact

This amounts to improvements in energy efficiency that have a real impact on the earth. The impact is as follows:

<table>
<thead>
<tr>
<th></th>
<th>Reduction in CO2</th>
<th>Trees Equivalency</th>
<th>Barrels of Oil Equivalency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upgrades</td>
<td>118,918 lbs/yr</td>
<td>1,399 trees</td>
<td>125</td>
</tr>
<tr>
<td>Repairs</td>
<td>25,218 lbs/yr</td>
<td>297 trees</td>
<td>27</td>
</tr>
<tr>
<td>Replacements</td>
<td>18,866 lbs/yr</td>
<td>222 trees</td>
<td>20</td>
</tr>
</tbody>
</table>

1. This much of a savings in carbon dioxide (CO2) emitted into the atmosphere.
2. The amount of CO2 sequestered by this many ten-year-old medium growth coniferous trees.
3. Equivalent to avoiding the CO2 emissions from consuming this number of barrels of crude oil.
# FDSI RTU

## Comparison of Unit Condition

**Date of Inspection:** January 19, 2006

As a result of this testing, 6 were found to be running optimally. The remaining 6 units, or 100%, were found to be running inefficiently.

### Alarms Legend

- **Operation Fail**: Caution (green)
- **Energy Savings Opportunity**: Caution (red)
- **Proper Operation**: Acceptable (no repair required)

1. Pass at least one of the correct refrigeration diagnostics parameters.
2. Requires no service and is operating within acceptable range of efficiency and capacity.

### Service Legend

<table>
<thead>
<tr>
<th>Unit</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RTU Alerts</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zone</td>
<td>General</td>
<td>General</td>
<td>General</td>
</tr>
<tr>
<td>Make</td>
<td>Carrier</td>
<td>Carrier</td>
<td>Carrier</td>
</tr>
<tr>
<td>Model</td>
<td>40JGE010-020</td>
<td>40JGE010-020</td>
<td>40JGE010-020</td>
</tr>
<tr>
<td>Serial #</td>
<td>0501036889</td>
<td>0501036890</td>
<td>0501036811</td>
</tr>
<tr>
<td>Test Date</td>
<td>January 19, 2006</td>
<td>January 19, 2006</td>
<td>January 19, 2006</td>
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</table>

### Upgrade

<table>
<thead>
<tr>
<th>UPG</th>
<th>REST</th>
<th>REST</th>
<th>REST</th>
</tr>
</thead>
<tbody>
<tr>
<td>For</td>
<td>E2</td>
<td>D2</td>
<td>D2</td>
</tr>
<tr>
<td>Vast</td>
<td>PV</td>
<td>PV</td>
<td>PV</td>
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</table>

### Repair

<table>
<thead>
<tr>
<th>REPAIR</th>
<th>YES</th>
<th>NO</th>
<th>YES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Even Repair Req</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Even Fault</td>
<td>2</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Salt</td>
<td>10</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>Age</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>REPLACED?</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Expansion Device</td>
<td>TiV</td>
<td>TiV</td>
<td>TiV</td>
</tr>
<tr>
<td>High Service Port</td>
<td>Liquid Line</td>
<td>Liquid Line</td>
<td>Liquid Line</td>
</tr>
<tr>
<td>Total Capacities</td>
<td>20.0</td>
<td>16.0</td>
<td>16.0</td>
</tr>
<tr>
<td>Stage</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Stage Capacities ( tons)</td>
<td>13</td>
<td>10</td>
<td>5</td>
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</table>

### Performance Index

<table>
<thead>
<tr>
<th>PERFORMANCE INDEX</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
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</thead>
<tbody>
<tr>
<td>R11 %</td>
<td>95</td>
<td>96</td>
<td>96</td>
<td>96</td>
</tr>
<tr>
<td>R134a %</td>
<td>93</td>
<td>94</td>
<td>94</td>
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### Risk

<table>
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<tr>
<th>RISK</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
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<tbody>
<tr>
<td>Refrigeration Fail</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Equipment Splitting</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Cond.3,3 Parts Leakage</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Inefficient Operation</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Insufficient Capacity</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

### Recommendations

- **nbi new buildings institute**
• Formerly *Sensus Machine Intelligence* – Italy
• Working with Dr. Haorong Li (Univ. of Nebraska) on CEC PIER Virtual Sensor Project:
  - Virtual OA fraction
  - Virtual mixed air temperature
  - Virtual heating capacity
  - Virtual air flow rates
  - Virtual cooling capacity
  - Virtual building load
  - Virtual compressor power consumption
  - Virtual fan power consumption
  - Virtual EER and SHR
  - Virtual refrigerant charge

Using existing 4 RTU temp sensors + embedded OEM alarms + weather data
Ezenics Operations Level
Ezenics Portfolio Level
Ezenics Building Level
Ezenics Floor Level

Operations Dashboard

Floor Summary

Issues & Impact

<table>
<thead>
<tr>
<th>Total Faults</th>
<th>Total Fault Occurrences</th>
<th>Average Fault Severity</th>
<th>Total Fault $ Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>64</td>
<td>2.58</td>
<td>$23.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total Exceptions</th>
<th>Total Exception Occurrences</th>
<th>Average Exception Severity</th>
<th>Total Exception $ Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>7</td>
<td>2.60</td>
<td>$40.00</td>
</tr>
</tbody>
</table>

Current Total $ Impact: $63.00

Energy

Electricity

- Total: 309 kW
- Labs: 243 kW
- ALL/All: 1.29 kW
- ALL/H/H: 0.23 kW

Carbon Footprint

- 0.664 Tonnes
- 0.00022 Tonnes/h/c

Operations Dashboard
FLOOR LEVEL - STABILITY VIEW

nbi new buildings institute

California Commissioning Collaborative
Ezenics Energy Trending
Mitsubishi VRF Monitoring/FDD TG-2000A

- Free System Design Tool
- Detailed ‘abnormality’ alerts on all subsystems with automated testing protocols
  
  Ex: # 2507 “Water system not operate due to dew condensation prevention control activated”

- Real time energy use + $ cost reporting per AHU
- Parts position tool for locating and replacing parts for all models
Ductless Mini-Split Alarms

- High Pressure
- High discharge Temp
- Pipe Temperature
- Low Capacity
- Filter
### Performance Monitoring/Control

<table>
<thead>
<tr>
<th>Product Name</th>
<th>Product Features</th>
<th>Web Location</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Catalyst/Transformative Wave Technologies</strong>&lt;br&gt;<strong>NW-based Snohomish PUD + BPA-PECI tested</strong></td>
<td>Integrate with existing EMS/t-stats; eIQ wireless platform, VSD evapor fan; energy cost display, DCV, FDD including economizer alarm</td>
<td><a href="http://www.catalysteecc.com/">http://www.catalysteecc.com/</a></td>
</tr>
<tr>
<td><strong>Digi-RTU</strong></td>
<td>VSD supply fan + compressor, optimization, some FDD</td>
<td><a href="http://www.dtlcontrols.com/poptimizer.html">http://www.dtlcontrols.com/poptimizer.html</a></td>
</tr>
<tr>
<td><strong>Drive Pak</strong></td>
<td>VSD supply fan, expert installer</td>
<td><a href="http://www.drivepak.com/works.html">http://www.drivepak.com/works.html</a></td>
</tr>
<tr>
<td><strong>Enerfit</strong></td>
<td>VSD supply fan, DCV, optimization, FDD</td>
<td><a href="http://www.enerfitllc.com/index.html">http://www.enerfitllc.com/index.html</a></td>
</tr>
<tr>
<td><strong>Optimum Energy</strong>&lt;br&gt;<strong>NW-based NEEA-NBI tested</strong></td>
<td>Proof-of concept: VSD on supply/condenser fans + compressor, continuous optimization</td>
<td><a href="http://www.optimumenergyco.com/">http://www.optimumenergyco.com/</a></td>
</tr>
<tr>
<td><strong>REGEN</strong></td>
<td>Swarm logic, demand response; online access, ongoing commissioning</td>
<td><a href="http://www.regenenergy.com/default.htm">http://www.regenenergy.com/default.htm</a></td>
</tr>
<tr>
<td><strong>Unity</strong>&lt;br&gt;<strong>NW-based</strong></td>
<td>Integrated controller/monitoring-lighting, HVAC, refrigeration, supply fan VSD, wireless t-stat, use with energy displays</td>
<td><a href="http://kiteandlightning.com/">http://kiteandlightning.com/</a></td>
</tr>
<tr>
<td><strong>Virtjoule</strong></td>
<td>Mechanical vibration sensors, FDD</td>
<td><a href="http://virtjoule.com/">http://virtjoule.com/</a></td>
</tr>
</tbody>
</table>
Current State:
- Fixed control strategies and equipment set-points
- Fixed equipment and zones set-points based on predetermined schedules
- Decoupled systems operation
- Manual commissioning
- Rule-based diagnostics & corrective maintenance

Desired State:
- Automatic determination of optimum controls and set-points
- Occupancy-based schedules and set-points
- Integrated operation of building systems
- Initial automatic commissioning
- Continuous Commissioning Energy/Fault Diagnostics & Prognostics
Rethinking Inside the Box

Typical construction

- Fiberglass Insulation
- Sheet Metal Thermal Bridge
- Conductive Pathway
- Only External Wall

AAON standard

- Polyurethane Injected Foam
- Thermal Break
- Galvanized Steel Internal and External Walls
- Insulating Gasket

Graph:
- R-13
- AAON
- (~2.5” P-foam)
- (~0.5” fiberglass)

nbi new buildings institute

California Commissioning Collaborative
## AAON Envelope $ Savings

<table>
<thead>
<tr>
<th>City</th>
<th>5</th>
<th>10</th>
<th>20</th>
<th>35</th>
<th>75</th>
<th>125</th>
<th>175</th>
<th>210</th>
<th>Annual Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atlanta</td>
<td>$242</td>
<td>$465</td>
<td>$884</td>
<td>$1,562</td>
<td>$3,281</td>
<td>$5,218</td>
<td>$7,214</td>
<td>$8,612</td>
<td>19%</td>
</tr>
<tr>
<td>Chicago</td>
<td>$228</td>
<td>$431</td>
<td>$801</td>
<td>$1,422</td>
<td>$2,964</td>
<td>$4,678</td>
<td>$6,429</td>
<td>$7,655</td>
<td>19%</td>
</tr>
<tr>
<td>Houston</td>
<td>$278</td>
<td>$544</td>
<td>$1,058</td>
<td>$1,861</td>
<td>$3,946</td>
<td>$6,442</td>
<td>$8,958</td>
<td>$10,719</td>
<td>17%</td>
</tr>
<tr>
<td>Los Angeles</td>
<td>$46</td>
<td>$91</td>
<td>$177</td>
<td>$311</td>
<td>$662</td>
<td>$1,088</td>
<td>$1,516</td>
<td>$1,816</td>
<td>5%</td>
</tr>
<tr>
<td>Miami</td>
<td>$394</td>
<td>$769</td>
<td>$1,493</td>
<td>$2,628</td>
<td>$5,569</td>
<td>$9,089</td>
<td>$12,635</td>
<td>$15,117</td>
<td>21%</td>
</tr>
<tr>
<td>Minneapolis</td>
<td>$244</td>
<td>$461</td>
<td>$856</td>
<td>$1,518</td>
<td>$3,162</td>
<td>$4,980</td>
<td>$6,840</td>
<td>$8,142</td>
<td>18%</td>
</tr>
<tr>
<td>New York</td>
<td>$212</td>
<td>$401</td>
<td>$748</td>
<td>$1,326</td>
<td>$2,769</td>
<td>$4,383</td>
<td>$6,030</td>
<td>$7,182</td>
<td>19%</td>
</tr>
<tr>
<td>Sacramento</td>
<td>$163</td>
<td>$306</td>
<td>$562</td>
<td>$999</td>
<td>$2,073</td>
<td>$3,242</td>
<td>$4,439</td>
<td>$5,278</td>
<td>12%</td>
</tr>
<tr>
<td>Seattle</td>
<td>$160</td>
<td>$300</td>
<td>$548</td>
<td>$975</td>
<td>$2,020</td>
<td>$3,146</td>
<td>$4,303</td>
<td>$5,113</td>
<td>20%</td>
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<tr>
<td>Tulsa</td>
<td>$271</td>
<td>$520</td>
<td>$981</td>
<td>$1,735</td>
<td>$3,640</td>
<td>$5,818</td>
<td>$8,032</td>
<td>$9,582</td>
<td>16%</td>
</tr>
</tbody>
</table>

Estimated Savings From AAON Rigid Polyurethane Foam Cabinet

AAON Claim
Which Way Do We Go To Get There?

...Or Will We   Or...
Mark Cherniack
New Buildings Institute
markc@newbuildings.org