Rooftop HVAC
Strategic Considerations

“…Up on the roof… I've found a paradise that's trouble proof… up on the roof.” -- C.King/G.Goffin 1962

Mark Cherniack
November 30, 2011
Air conditioning and other technologies have made it so there’s no place on the planet where we couldn’t live. We can condition the air; we can make it right.”


…the climate change that takes place due to increases in carbon dioxide concentration is largely irreversible for 1,000 years after emissions stop.”

–Proceedings of the National Academy of Sciences, December, 2008

“On Thursday, September 8, Ft. Belvoir (VA) received an astounding 7.03” of rain in three hours. According to the National Weather Service that amount of rain in that amount of time was an “off the charts above a 1000-year rainfall...”

– Think Progress website, September 13, 2011
NBI HVAC–related activities …

- PNW Region Technical Forum- Rooftop Unit Working Group management; RTU annualized savings M&V protocol with calculator
- NW Energy Efficiency Alliance (NEEA) , City of Seattle, BC Hydro, Preservation. Green Lab, PNNL--specify HVAC and controls performance in outcome-based codes
- NEEA ‘Deep Renewal’ Initiative project case studies: www.newbuildings.org
- NEEA Indirect/direct/Dx evaporative hybrid project management: 2 projects
- NEEA Optimum Energy POC: all VSD fans/compressor
- Western Cooling Efficiency Center: Steering Comm member; RTU FDD in CA T24
- UC/Davis, Ecology Action--delivering deep retrofits to the small/medium commercial market sector – includes HVAC review + controls upgrades
- Rocky Mountain Institute-- case studies including HVAC, controls and monitoring technologies in low/zero energy use buildings
- Western HVAC Performance Alliance AFDD Subcommittee Chair; Climate Optimized Stds/Tech Subcommittee support staff
- Invited participant US DOE HVAC Roadmap; member of Education and Training Work Group
“Renewal means more than retrofit, it is really giving an existing building new life.”

-- NEEA

- 40-60% reduction in energy use on the way to net zero energy use in commercial buildings

- Integrated approach is required for deeper existing building savings
Walmart anticipated whole store savings roadmap 2005 actual to 2009 prototype

**2005 Baseline**

- **Lighting** 24.2%
  - General Lighting
  - Outdoor Lighting
- **Refrigeration** 21.7%
  - Showcase
  - Compressor
- **HVAC** 37.8%
  - Heating & Cooling
- **Others** 16.3%
  - Kitchen Equipment
  - Process Equipment
  - Hot Water System

**Sustainable Initiatives**

- Perimeter Reduction + Night Dim LPD
- No Change – LED Potential Forward
- LED in LT Cases
- LE Door Heaters
- ECM Fan Motors
- HE Coils
- VFD to refrigeration compressor
- Floating Head & Suction Strategies
- Vestibule Air Curtains & Temperature
- DOAS AHUs with Heat Recovery
- CO2 Demand Ventilation
- HE RTUs & WSHPs
- VAV Fan Application
- Refrigeration Waste Heat Recovery
- Perimeter Reduction + Night Dim LPD
- No Change – LED Potential Forward

**Reduction %**

- **Lighting** 21.7%
- **Refrigeration** 24.8%
- **HVAC** 27.3%
- **Others** 26.2%

**2009 Prototype**

- **Lighting** 21.7%
- **Refrigeration** 24.8%
- **HVAC** 27.3%
- **Others** 26.2%

**Total 25 % Reduction**

**Energy Consumption**

- 2005 Baseline Store
  - Electricity Consumption 4,767,886 Kwh/year/store
  - Natural Gas Consumption 1,203,983 Kwh/year/store
  - = Saving 1,970,649 Kwh/year/store vs. 2005 Baseline
Deep renewal challenges…

“Need to draw a predictable roadmap for opportunistic, whole-system efficiency measure integration that bundles technologies, investment strategies and building types with strategic energy management principles and practices.”
Existing RTU needs for deeper savings…

- WE&T INCLUDING USERS
- QI/QM REQUIREMENTS
- PERFORMANCE MONITORING/CONTROLS/FDD
- SENSOR QUALITY
- ABOVE NEMA PREMIUM MOTORS
- INTEGRATED DESIGN PRACTICE
PNW Regional Technical Forum
Rooftop Unit Working Group – RTUG

- Active 2006-present
- Participants from: PNW public/private utilities, ETO, CA/NE utilities, technical consultants, manufacturers, HVAC program managers

- Identified Honeywell dry bulb sensor issue: C7650 > C7660

- Recommended features for the Honeywell JADE W7220 controller

- Supported BPA RTU field research project

- Supported creation of publicly accessible RTU research results database: 125 RTUs with 4 weeks to 12 months metered data

- Finalizing RTU field M&V protocol + annualized savings calculator

- Developing savings calculator for RTU heat pumps
What's Wrong & Right with this Picture?

Ubiquitous controller W7459

New C7660 Sensor

Economizer Damper Actuator

Does snap disc input current [ >20mA] burn out motor protective circuit prematurely?

CEC PIER ARTU Spec with RTUG input

Whiz Bang Honeywell Controller – JADE W7220
PCMOD software for JADE W7220...

W7220 Economizer Controller

Polarity insensitive wire

PC Interface Module

PC

USB
RTUs in PNW Regional Power Plan…

Primary HVAC System Type - n= 1.3 billion SF (nearly half the stock)
PNW % buildings, tons per RTU...

 CBSA Data: Building Average Cooling Tons per Pack HVAC Unit (Systems <50 Tons Cooling per HVAC unit) n=1041

64% of buildings <6 tons
79% of buildings <10 tons
PNW RTUs— an aging fleet…

<table>
<thead>
<tr>
<th>Age category</th>
<th>Under 5 tons</th>
<th>5 to 10 tons</th>
<th>Over 10 tons</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 to 4</td>
<td>44%</td>
<td>36%</td>
<td>20%</td>
</tr>
<tr>
<td></td>
<td>17%</td>
<td>30,000</td>
<td>24,000</td>
</tr>
<tr>
<td>5 to 10</td>
<td>32%</td>
<td>56,000</td>
<td>46,000</td>
</tr>
<tr>
<td>10 to 19</td>
<td>35%</td>
<td>62,000</td>
<td>50,000</td>
</tr>
<tr>
<td>20+ years</td>
<td>16%</td>
<td>28,000</td>
<td>23,000</td>
</tr>
</tbody>
</table>

51% of the units have been on the roof for over a decade!
RTU repair or replace…

- **Repair:** short fix time (hours/day), little downtime, contractor service quality established

- **Replace:** might take a week – downtime
  - Good old days: repair up to 25-30% before consider replacement
  - Bad new days: 50% repair threshold with new compressor & HX
RTU HVAC repair/replace criteria…

- Unit age/end of life
- Repair history
- Cost to repair
- Expense vs. capital
- Refrigerant type – R-410a replacing R-22
- Depreciation schedule
- Corporate energy/environment/sustainability policy
- Prep for building sale
- Prep for lease
- Availability of state or federal tax incentives
- Utility incentives
- Building energy code requirements
- Customer and/or employee comfort
- Owner willingness to try something new
Repair/replace issues…

- DEEP SAVINGS OR BAU?
- Stop thinking about RTUs as the solution - just one element of whole building context
- Lack of measured energy/cost savings results for ‘deeper’ RTU and whole building retrofit
- Lack of RTU screening method for utility program design
- If repair on older unit [10+ yrs.], what is the impact on replacement cost-effectiveness decision for owner/EE program?
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 AND 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

16. LOW AIR FLOW RATE
   • Faulty fan
   • Slipping belt
   • Fouling
   • Improper or no TAB
Workforce (and User) Education & Training (WE&T)

"An incomplete, and highly uninformative guide" HVACR News

Rooftop HVAC FOR DUMMIES

Be able to answer questions about subcooling at parties!

A Useless Reference for the Rest of Us!

nbi new buildings institute
Bonneville Power Administration
2009 t-stat measure results...

Based on Operating Schedules

- Average annual savings for 30 RTUs: 3,307 kWh
- Average annual savings 7 tons and greater: 5,198 kWh
- **83% of the units realized savings**
- Maximum savings: 15,408 kWh
Bonneville Power Administration

RTU run time metered results…

Compressor and Fan Energy Savings Per Ton

Savings Per Ton (kWh/ton)

RTUs

Compressor Savings (kWh)  Fan Savings (kWh)
The purpose of this standard is to establish minimum HVAC inspection and maintenance requirements that preserve a system’s ability to achieve acceptable thermal comfort, energy efficiency, and indoor air quality in commercial buildings.
Content of the 180 Standard...

- Definitions
- Dialogue with the owner
  - Philosophy of the operation
  - Understanding (inventory)
    - Performance – Appendix A
    - Failure Points – Appendix B
  - Implementation (inside/outside)
  - Timing (ongoing or at failure)
- Task listings
- Adjustment of inspection frequencies
- Documentation
WE&T related realities…

- US DOE Commercial Buildings Workforce Training - standards for 6 commercial building energy professions:
  - energy auditor, comm/retrocomm agent, energy modeler, facility manager, operating engineer/technician, energy/sustainability manager

- RTU training curriculum: gaps [economizer/air flow], digital controls; higher ed. engineering disconnect with the field

- Cultural realities: retirement of old hands, more advanced equipment, HVAC still seen as ‘downward’ vocational track

HVAC WE&T Initiative recommendations...

- State/Regional WE&T conferences: HVAC educators (community college, trades, higher ed), contractors, energy efficiency organizations, code officials, utilities

- Conduct comprehensive skill gap analysis of current training curricula from all sources

- Determine priorities and next steps

- ‘Big Bold’ Economizer Initiatives

- Technician credentialing + QI/QM requirements for ratepayer incentives
## RTU technology buckets...

<table>
<thead>
<tr>
<th>Package Dx</th>
<th>Variable Refrigerant Flow</th>
<th>Evaporative Technologies</th>
<th>Ground Source Heat Pumps</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOE/CBEA High Performance RTU Challenge 40-60% savings</td>
<td>30% higher equivalent capacity over single package ducted system; up to 50% cost adder</td>
<td>Condenser pre-cooling</td>
<td>Cost 30-60% more than conventional systems</td>
</tr>
<tr>
<td>Min IEER 18 advanced controls/performance monitoring VSD/ECM/FDD evap pre-cooling ready</td>
<td>New product introduction curve</td>
<td>Full cooling: 1 Indirect/Dx hybrid 1 IDEC add on</td>
<td>Water/ground source Radiant or air distribution</td>
</tr>
<tr>
<td>40-60% kWh savings</td>
<td>10-60% kWh savings</td>
<td>Hybrids promise: 80% kWh /60% kW savings</td>
<td>30-40% kWh savings</td>
</tr>
</tbody>
</table>
By 2015, develop portfolio of vapor compression (VC) technology to meet 2030 goal of space cooling/heating energy use and carbon emissions reduced by 50% + ventilation energy use by 5% versus 2005 levels.

By 2025, develop a portfolio of advanced technology options based primarily on non-VC technology to meet 2050 goal of space cooling/heating energy use and carbon emissions reduced by 70% and carbon emissions and ventilation energy use by 15% versus 2005 levels.

ORNIL leading Roadmap activities including Refrigerant Roadmap
HVAC refrigerant loads

Refrigerant: 410A = very low ozone impact
= higher GWP than R-22

<table>
<thead>
<tr>
<th></th>
<th>Standard RTU</th>
<th>VRF</th>
<th>GSHP</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 Ton</td>
<td>6 lbs</td>
<td>19 lbs</td>
<td>4 lbs</td>
</tr>
<tr>
<td>10 Ton</td>
<td>Circuit 1 – 8 lbs</td>
<td>27 lbs</td>
<td>9 lbs</td>
</tr>
<tr>
<td></td>
<td>Circuit 2 – 6 lbs</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
120,000-240,000 Btu/h (10-20 tons) capacity

Supply fan test @ 0.7 IWC external static [nat’l test standard = 0.2” IWC]

Fan shall be variable volume or multi-stage operation

DDC controller shall support full bi-directional communication read for all sensor data, all signal and status information including fault diagnostic codes and messages


RTU shall output remotely performance metrics at least once every 15 minutes:

- Overall efficiency of the unit (e.g. as COP or EER) averaged over time interval between measurements
- Electricity use in kWh over the time interval between measurements
- Measured cooling (in Btu) delivered to the supply air over the time interval between measurements
AAON rethinking the box...

Standard industry

Standard AAON

AAON est. annual savings for Seattle, WA
20% overall
5 ton = $160/yr
10 ton = $300/yr
20 Ton = $548/yr
Variable Refrigerant Flow systems...
Variable Refrigerant Flow systems...

1. Maintain clean filters and coils

2. Large refrigerant runs pose a potential risk

3. Oil return requires auto flush where it has accumulated

4. Indoor AHU require condensate drain

5. Separate OA supply for ventilation if ductless
Minimum IEER requirements for VRF systems have been set at 10% higher than minimum unitary equipment requirements with approval from the VRF industry.

On July 1, 2012, the VRF minimum IEER will be increased to 15% above unitary requirement, further emphasizing the higher efficiency part-load performance of VRF equipment.
Mitsubishi no cost tools...TG–2000

- Free tool supports detailed system design
- Detailed ‘anomaly’ diagnostics/reporting on ~200 points with trending, condensate check + test protocols
- Real time energy use + $ cost reporting/zone
- Parts position tool for locating and replacing parts for all models

Parts position tool
Variable Capacity Heat Pump (VCHP) roadmap…
Bonneville Power Administration

**Barriers**
- Contractor Unfamiliarity with VCHP (p.2)
- Designer Unfamiliarity with VCHP (p.3)
- Owner Unfamiliarity with VCHP (p.4)
- Lack of Information to prioritize measures (p.5)
- Uncertain Savings, Costs and Cost effectiveness (p.6-7)
- Difficult to Develop Measures and Incentive Programs (p.8-9)
- Codes and Standards (p.10)
- Others Barriers (p.11)

**Action Items**
- Develop contractor qualifications and training
- Develop commissioning requirements
- Develop best practices to ensure energy saving
- Develop screening tool for cost effective opportunities
- Develop owner training on utility incentives and VCHP benefits
- Document operation and energy use
- Develop designer training and outreach
- Select and define highest priority measures
- Develop high consensus M&V protocols
- Quantify savings and costs over a specific baseline
- Develop measures
- Develop program
- Deliver program
- Follow developing codes and standards
- Define value proposition for utilities, building owners and contractors

**Resources**
- Manufacturer training
- Lessons learned from previous projects
- Lab and field testing resources
- Existing owner training channels
- VCHP research and resources
- Industry, professional and utility research and resources
- Codes and standards research and resources
Non-energy benefits are adoption drivers
Bonneville VCHP roadmap…

Design and Installation

- Uses less space, smaller shafts, mechanical rooms etc. possibly resulting in lower first cost
- Integrated controls may lower Cx and O&M costs
- Flexibility - large array of applications and models - can fit many different needs
- Easier installation in retrofit applications
- Smaller footprint
- Multi splits can prevent zones from fighting
- Allows for the application of a heat pump to larger buildings where traditional HP systems aren't feasible
- Modular components may help simplify design and flexibility for tenant changes
- Requires less space in ceilings and walls
- Easier to add A/C to older buildings
- System flexibility
- Less ductwork or no ductwork
- Good for "older building" renovations
- Straight forward retrofit for many existing systems

Aesthetics

Aesthetically more pleasing than a PTAC or PTHP

Interface

Energy use monitoring and tenant billing

- Central control and monitoring of zones

FDD capabilities and remote displays

- Packaged controls

Improved Comfort

Zonal control can be more precise, minimizing reheating requirements

DOAS with heat recovery can be more efficient and comfortable

- Low noise

Improved comfort with smaller zones and temperature control
Evaporative
“Feral camels ate my air conditioner!”
Peak demand management—What peak demand?

DX and Evaporative Demand for Comparable Load during Peak Day. Based on monitoring data from Davis Energy Group (1998), peak temperature of 108°F
Western Cooling Efficiency Center (WCEC)
UC/Davis – Western Cooling Challenge (WCC)

- Climate-appropriate packaged RTU to reduce electrical demand/energy use in western US climates by at least 40% compared to ASHRAE 2010 standards
- **Push beyond prototype demonstration** by advancing the market introduction of commercialized equipment
- WCEC conducts demonstrations and field evaluation of certified equipment
- NREL is WCC lab testing partner
RTU evaporative options...

<table>
<thead>
<tr>
<th></th>
<th>Options</th>
<th>URL</th>
</tr>
</thead>
<tbody>
<tr>
<td>DualCool</td>
<td>with return water sump</td>
<td><a href="http://icidualcool.com/about-us">http://icidualcool.com/about-us</a></td>
</tr>
<tr>
<td>Thermal Flow</td>
<td>condenser &amp; chiller pre-cooling</td>
<td><a href="http://www.thermalflow.net/commercial.htm">http://www.thermalflow.net/commercial.htm</a></td>
</tr>
<tr>
<td>Speakman Quattro*</td>
<td>IDEC/HP RTU hybrid</td>
<td><a href="http://speakmancooling.com">http://speakmancooling.com</a></td>
</tr>
<tr>
<td>CRS 2500</td>
<td>IDEC add-on</td>
<td><a href="http://www.airmax-solutions.com">www.airmax-solutions.com</a> (under construction)</td>
</tr>
<tr>
<td>b. M-Cycle Concept</td>
<td>b. Desiccant-based</td>
<td>a. TBD</td>
</tr>
</tbody>
</table>

*Note: *The CRS 2500 option is under construction as of the date of this document. The URL is provided for reference but may not be accessible in the future.
Gen 2 *DualCool*: 24-ton Lennox *Strategos* – Davis/CA Target Store
**DualCool economics…**

- 10, 20-ton Walmart RTUs at 105°F peak
- Demand reduction 8.8 kW each unit
- Turnkey installed ~$60,000 including 2-year full replacement warranty/service plan
- < $800/kW
- Annual demand savings ~$20,000
- Simple payback ~3 years
- Does not include water costs or service costs after first two years that extend the payback by almost a year
- 100,000 kWh/yr savings bonus to owner
**Coolerado H80**, 5-ton RTU, NREL tested

WCC sensible EER spec @ 90°F ≥17  \[\text{MEASURED} = 51.8 \text{ EER}\]

WCC sensible EER spec @ 105°F ≥14  \[\text{MEASURED} = 21.7 \text{ EER}\]

**MEASURED REDUCTIONS** = 80% kWh/58% kW

WCC water use spec ≤ 4.0 gal/ton•h  \[\text{MEASURED} = 1.85\]
Controls/Performance Monitoring/FDD
Control strategies differ...

And you reckon it's cheaper to leave it running all the time?
Lessons learned from RTU FDD projects
Dr. Haorong Li, Univ. Nebraska…

Data quality from operating RTUs is worse than assumed
– Measurement (sensor data) is one of the major sources of faults rather than the solution for optimizing control
  o Temp sensors: poor reliability/out of calibration/stuck readings/in poor location/failure
  o Errors up to 12°F in heating mode
  o Zone temperature/humidity sensor problems

>> NATIONAL SENSOR QUALITY INITIATIVE <<
CEC PIER Virtual Sensors

Developing Virtual Sensors using 4 existing RTU sensors + equipment technical data + manufacturers’ embedded alarms + weather station data - Dr. H. Li

- 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
Outside air sensor placement poorly implemented...

Honeywell listens again!
New OA sensor housing is light gray, channel aspirated
Smart (in some cases ‘brilliant’) t-stats short list…

<table>
<thead>
<tr>
<th>Tool</th>
<th>Features</th>
<th>URL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eco-Factor</td>
<td>smart T-stat, online access, demand response, FDD, smart algorithms, comm/res</td>
<td><a href="http://ecofactor.com/">http://ecofactor.com/</a></td>
</tr>
<tr>
<td>Emme</td>
<td>smart T-stat, online access, comm/res, data logging, real time kWh/kW monitoring</td>
<td><a href="http://www.getemme.com">http://www.getemme.com</a></td>
</tr>
<tr>
<td>Telkonet</td>
<td>smart T-stat, online access, ‘smart recovery’ from setback</td>
<td><a href="http://www.telkonet.com/">http://www.telkonet.com/</a></td>
</tr>
</tbody>
</table>
Dreamwatts system...
Dreamwatts t-stat history...
Dreamwatts – RTU1...
Emme...
Emme capabilities...

HVAC Equipment: Heat Pump
Change-Over: Cool
Heat Pump: 1 Stage
Aux Heat: Electric Strip
Compressor Lockout: No Lockout
### Advanced RTU controls short list...

<table>
<thead>
<tr>
<th>Transformer Wave/Catalyst</th>
<th>Integrate with existing BMS/t-stats; eIQ wireless platform, VFD; energy display</th>
<th><a href="http://www.catalystecc.com/">http://www.catalystecc.com/</a></th>
</tr>
</thead>
<tbody>
<tr>
<td>Digi-RTU</td>
<td>VFD supply fan, optimization, some FDD</td>
<td><a href="http://www.dtlcontrols.com/poptimizer.html">http://www.dtlcontrols.com/poptimizer.html</a></td>
</tr>
<tr>
<td>Drive Pak</td>
<td>VFD + controller; expert installer</td>
<td><a href="http://www.drivepak.com/works.html">http://www.drivepak.com/works.html</a></td>
</tr>
<tr>
<td>REGEN</td>
<td>Swarm logic, demand response</td>
<td><a href="http://www.regenenergy.com/default.htm">http://www.regenenergy.com/default.htm</a></td>
</tr>
<tr>
<td>Unity</td>
<td>Integrated controller for lights, RTUs, VFD, wireless t-stat, energy displays</td>
<td><a href="http://kiteandlightning.com/">http://kiteandlightning.com/</a></td>
</tr>
</tbody>
</table>
New crop...

- **Catalyst**: “Managed Solutions,” PNW, SCE/CA, VSD, DCV, integ econo, Premium Ventilation functionality, some FDD. Savings: 25-48%

- **Enerfit**: VSD evap fan only, indexed to 3 speeds: 40%-75%-90% DDC. Savings: 50-78%, FDD

- **Digi-RTU**: full VSD on evap fan & compressor, FDD/DCV/econo. Measured savings: avg 41% kW, 52% kWh, Omaha Public Power, Minnesota Center for Energy Environment

- **Optimum Energy**: VSD both fans + compressor; proportional control-Tom Hartman. Savings: 50-60%? NEEA POC > NBI office

- **Premium Ventilation Package**: estimated 25-45% savings; optimum start, strip heat lockout, morning warm up (heating savings), VSD fan control for supply air, DCV where appropriate

- **NREL Applications Guide**: SZ CAV to SZ VAV: Kohl’s 168 stores/1500 RTUs Measured: 40-60% of fan energy [50-70% of a/c kWh] savings, est. 3 year payback
Sequence of operation, control configuration, and hardware requirements to retrofit with VFD to ramp down supply fan during part load operation

A 10-ton, 2-stage Dx RTU with a peak 4,000 cfm flow rate would operate at 3,000 cfm (75% of full flow) under first-stage Dx cooling at a 45%–55% reduction in fan power

40%–50% savings in hot dry climates; 50–60% in temperate to cold climates; **Seattle estimate: 61% fan energy savings = 1.2kWh/sf**

Enables greater humidity control from lower flow rates and lower face velocities across the DX coil under first-stage cooling

**Implemented in Kohl’s: 168 stores/1500 RTUs, 40-60% fan savings [50-70% of a/c kWh], est. 3 year payback w/o incentives**
<table>
<thead>
<tr>
<th>CA T24 Proposal</th>
<th>NBI/WCEC PIER + IOU CASE</th>
<th>DOE/CBEA High Performance FDD Spec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensor failure</td>
<td>Sensor failure/fault (incl drift)</td>
<td>High refrigerant charge</td>
</tr>
<tr>
<td>Low refrigerant charge</td>
<td>High refrigerant charge</td>
<td>Low refrigerant charge</td>
</tr>
<tr>
<td>Compressor short cycling</td>
<td>Compressor short cycling</td>
<td></td>
</tr>
<tr>
<td>Refrigerant line restrictions/TXV problem</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Refrigerant line non-condensables</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Low side HX problem</td>
<td>Low evaporator air flow</td>
<td>Low ventilation</td>
</tr>
<tr>
<td>High side HX problem</td>
<td>Dirty filter</td>
<td></td>
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<tr>
<td>Efficiency metric tracking or comparison with no-fault model</td>
<td>Capacity degradation</td>
<td>Efficiency degradation</td>
</tr>
<tr>
<td>Not economizing when it should</td>
<td>Not economizing when it should</td>
<td></td>
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<tr>
<td>Economizing when it shouldn’t</td>
<td>Economizing when it shouldn’t</td>
<td></td>
</tr>
<tr>
<td>Damper not modulating</td>
<td>Damper not modulating</td>
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</tr>
<tr>
<td>Excess outdoor air</td>
<td>Excess outdoor air</td>
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</tr>
</tbody>
</table>

RTU FDD in CA T24 and DOE/CBEA
Controls roadmap on-ramps…

- How do facility owners/occupants/mechanical contractors take advantage of the active monitoring capabilities, embedded or added-on, of any particular product?
- Assess cost-benefit of a range of control products: functional testing, verification, accuracy, persistence
- Expanded controls demonstration programs
- Identify target markets for the variety of simple/advanced control products
- Assess need for a commercial ‘Controls Guide’ for a range of control products
- Identify linkages from advanced controls assessment to WE&T activities
## RTU Controls & Monitoring

### E3T EM #338: Advanced Rooftop Unit Controls
with Remote Access and Energy Monitoring

<table>
<thead>
<tr>
<th>Target Systems:</th>
<th>Unitary single-zone rooftop unit (RTU) systems with both single stage and multi-stage direct expansion (dX) cooling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum Control Requirements</td>
<td>Minimum Monitoring Requirements</td>
</tr>
<tr>
<td>Supply Fan Control (VSD or Cycling)</td>
<td>Web based setpoints &amp; scheduling</td>
</tr>
<tr>
<td>Demand Controlled Ventilation</td>
<td>Time series Point monitoring (Trending)</td>
</tr>
<tr>
<td>Digital Integrated Economizer Control</td>
<td>Monitored point threshold alerts</td>
</tr>
<tr>
<td>Differential Economizer High Limit</td>
<td></td>
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<tr>
<td>Desirable Control Options</td>
<td>Desirable Monitoring Options</td>
</tr>
<tr>
<td>Occupancy Vent &amp; Temp Standby</td>
<td>Fault Detection &amp; Diagnostics</td>
</tr>
<tr>
<td>Night Flush Cooling</td>
<td>Time-series energy monitoring</td>
</tr>
<tr>
<td>Demand Management or Response</td>
<td>Mode Runtime</td>
</tr>
<tr>
<td>Split dX coil flow control</td>
<td>RTU Energy benchmarking (single unit)</td>
</tr>
<tr>
<td>Compressor variable control</td>
<td>RTU Energy benchmarking (multiple units)</td>
</tr>
<tr>
<td>Condenser fan variable control</td>
<td>Demand Response M&amp;V</td>
</tr>
<tr>
<td>Optimum Start w/ OAT input</td>
<td>Dashboard presentation</td>
</tr>
</tbody>
</table>
Staged, measured RTU retrofits…

- Advanced controls with remote monitoring/FDD
- Variable speed fans & compressors
- Demand control ventilation
- Super efficient motors – beyond NEMA Premium
- Advanced fan blade design
Motors
National motor movement…

- ASHRAE 90.1-2010 (6.4.3.10)
- New RTUs, single zone, 9.2 tons and up
- Supply fan @ 2 speed or variable speed
- At less than 50% cooling demand, fan at no greater than 2/3 of full load
Concept 3: ½ horsepower brushless permanent magnet motor

In drier climates, the evaporator fan runs at very low speed for a time after the compressor turns off to evaporate remaining condensate and capture additional sensible capacity

[retrofit control only $100: avg. ↓16% on 10 house demo]

Concept 3 motor savings:

- 50% reduction in fan electrical energy use during heating
- 11% reduction in cooling energy use
- 10% reduction in peak demand
- 80% savings for continuous ventilation applications
SMUD Customer Advanced Technology—NovaTorque (.com) axial flux…

Figure 1 The Premium Plus+™ Brushless Permanent Magnet Motor and Exploded View
Comparing the Operating Efficiencies of (3) Variable Speed Motors
Product comparison – 3hp with **green** attributes…

<table>
<thead>
<tr>
<th></th>
<th>NovaTorque motor</th>
<th>General Purpose Induction motor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor diameter</td>
<td>167 mm 179 mm w/ external fins</td>
<td>200 mm</td>
</tr>
<tr>
<td>Frame Size</td>
<td>143T</td>
<td>182T</td>
</tr>
<tr>
<td>Maximum Speed</td>
<td>2700 rpm</td>
<td>2700 rpm</td>
</tr>
<tr>
<td>Motor Weight</td>
<td>52 pounds</td>
<td>69 pounds</td>
</tr>
<tr>
<td>Motor Length</td>
<td>301 mm</td>
<td>420 mm</td>
</tr>
<tr>
<td>Operating Efficiency Range</td>
<td>70-94%</td>
<td>70-87.5%</td>
</tr>
</tbody>
</table>

No rare earth metals used

Available from Hunt Air, Tualatin, OR

Aluminum or copper windings
Market Transformation
CA Energy Efficiency Strategic Plan HVAC goals...

- HVAC-related permits are obtained for 50% of installations by 2015
- By 2020, 100% of systems are installed to quality standards and optimally maintained
- Integrated design and construction practices are standard practice by 2020
- At least 15% of equipment shipments are optimized for California’s climate by 2015
An HVAC Advisory Group should be chartered to involve high-level HVAC industry stakeholders—such as manufacturers, distributors, contractors, educators—to coordinate industry sponsorship of and participation in HVAC strategies. Membership should also include other key players, such as the utilities, regulators, building owners/managers, consumers, efficiency advocates/organizations, state/local/federal governments.
CA HVAC Action Plan
4 Goal areas....

Goal 1: Code/Permit Compliance

Goal 2: Res/Comm QI/QM

Goal 3: Whole Building Design/Integration

Goal 4: Advanced Technologies
Western HVAC Performance Alliance–WHPA

www.performancealliance.org
Existing RTU needs for deeper savings…

- WE&T INCLUDING USERS
- QI/QM REQUIREMENTS
- PERFORMANCE MONITORING/CONTROLS/FDD
- SENSOR QUALITY
- ABOVE NEMA PREMIUM MOTORS
- INTEGRATED DESIGN PRACTICE
Total US Cooling Solution

CTU – COUNTRY TOP UNIT
50 MILLION TONS @ SEER 1726 @ 2,064.4” IWC
Thanks!

markc@newbuildings.org