Agenda and Objectives

Trane Engineers Newsletter Live Series

High-Performance VAV Systems

Variable-air-volume (VAV) systems have been used to provide comfort in a wide range of building types and climates. This course will discuss design and control strategies that can significantly reduce energy use and ensure proper ventilation in VAV systems. Topics will likely include: ventilation system design and control, optimized VAV system controls, cold air distribution, and other energy-saving strategies.

By attending this ENL you will be able to:

1. Summarize ASHRAE Standard 189.1 requirements for a VAV system
2. Explain how to implement optimized VAV system control strategies
3. Summarize how to design and control cold-air VAV systems
4. Apply air-to-air energy recovery in a VAV system

Agenda

1) Opening (welcome, agenda, introductions)

2) What does ASHRAE 189.1 (or the IGCC) require for a VAV system?

3) Optimized VAV system controls
   - a) Optimal start/Optimal stop
   - b) Fan-pressure optimization
   - c) Supply-air-temperature reset
   - d) Ventilation optimization

3) Cold-air Distribution
   - a) Benefits
   - b) Tips to maximize energy savings
   - c) Minimizing comfort problems due to cold air “dumping”
   - d) Avoiding condensation on air distribution system components

4) Air-to-air energy recovery

5) List of other energy-saving strategies (RTVAV and CHWVAV)

6) Share results of example TRACE analyses

4) Summary

Presenters

Trane Engineers Newsletter Live Series

High-Performance VAV Systems

(2011)

Dennis Stanke | staff application engineer | Trane

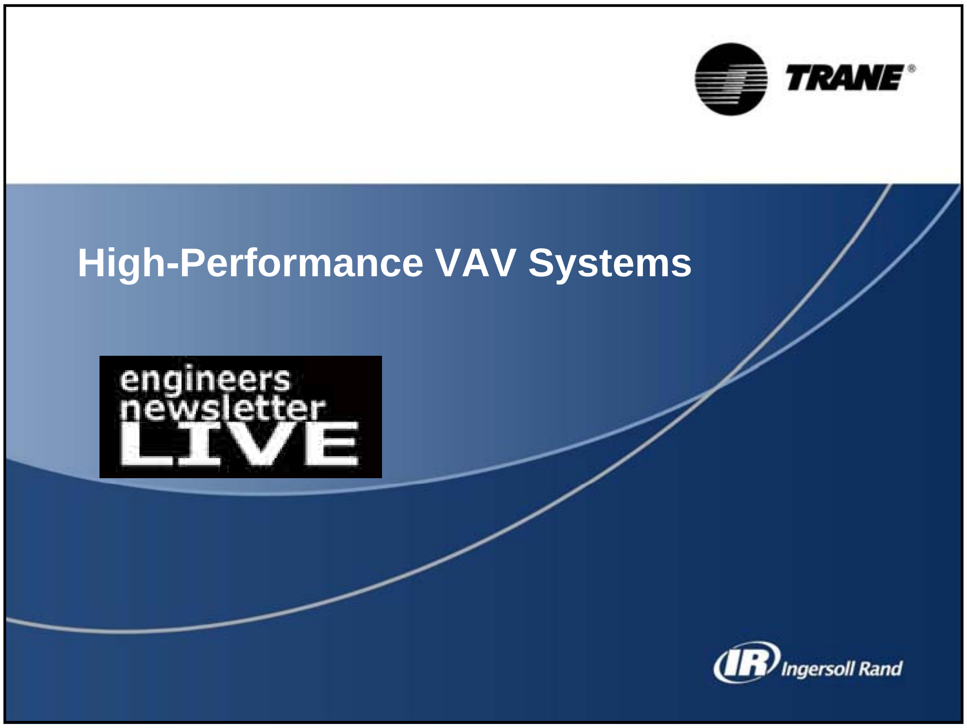
With a BSME from the University of Wisconsin, Dennis joined Trane in 1973, as a controls development engineer. He is now a Staff Applications Engineer specializing in airside systems including controls, ventilation, indoor air quality, and dehumidification. He has written numerous applications manuals and newsletters, has published many technical articles and columns, and has appeared in many Trane Engineers Newsletter Live broadcasts.

An ASHRAE Fellow, he currently serves as Chairman for ASHRAE Standard 189.1, Standard for the Design of High-Performance Green Buildings Except Low-Rise Residential Buildings. He recently served as Chairman for ASHRAE Standard 62.1, Ventilation for Acceptable Indoor Air Quality, and he served on the USGBC LEED Technical Advisory Group for Indoor Environmental Quality (the LEED EQ TAG).

John Murphy | applications engineer | Trane

John has been with Trane since 1993. His primary responsibility as an applications engineer is to aid design engineers and Trane sales personnel in the proper design and application of HVAC systems. As a LEED Accredited Professional, he has helped our customers and local offices on a wide range of LEED projects. His main areas of expertise include energy efficiency, dehumidification, dedicated outdoor-air systems, air-to-air energy recovery, psychrometry, and ventilation.

John is the author of numerous Trane application manuals and Engineers Newsletters, and is a frequent presenter on Trane's Engineers Newsletter Live series of broadcasts. He also is a member of ASHRAE, has authored several articles for the ASHRAE Journal, and is a member of ASHRAE's "Moisture Management in Buildings" and "Mechanical Dehumidifiers" technical committees. He was a contributing author of the Advanced Energy Design Guide for K-12 Schools and the Advanced Energy Design Guide for Small Hospitals and Health Care Facilities, and technical reviewer for The ASHRAE Guide for Buildings in Hot and Humid Climates.


TRANE
High-Performance VAV Systems
engineers newsletter LIVE
Ingersoll Rand


Ingersoll Rand
is a USGBC Education Provider committed to enhancing the professional development of the building industry and LEED Professionals through high-quality continuing education programs.
As a USGBC Education Provider, we have agreed to abide by USGBC-established operational and educational criteria, and are subject to course reviews and audits for quality assurance.
EDUCATION PROVIDER
GBCI CMP
High-Performance VAV Systems Course ID: 0090005954
Approved for 1.5 GBCI CE Hours for LEED Professionals.

"Trane" is a Registered Provider with The American Institute of Architects Continuing Education Systems. Credit earned on completion of this program will be reported to CES Records for AIA members. Certificates of Completion for non-AIA members are available on request.

This program is registered with the AIA/CES for continuing professional education. As such, it does not include content that may be deemed or construed to be an approval or endorsement by the AIA of any material of construction or any method or manner of handling, using, distributing, or dealing in any material or product.

3 © 2011 Trane, a business of Ingersoll-Rand

Copyrighted Materials

This presentation is protected by U.S. and international copyright laws. Reproduction, distribution, display, and use of the presentation without written permission of Trane is prohibited.

© 2011 Trane, a business of Ingersoll-Rand. All rights reserved.

4 © 2011 Trane, a business of Ingersoll-Rand

High-Performance VAV Systems

Today's Topics

- ASHRAE 189.1 requirements
- Optimized VAV system controls
- Cold-air distribution
- Air-to-air energy recovery
- Other energy-saving strategies
- Energy modeling results
- Summary

5 © 2011 Trane, a business of Ingersoll-Rand

Today's Presenters

Dennis Stanke
Staff Applications Engineer

John Murphy
Applications Engineer

6 © 2011 Trane, a business of Ingersoll-Rand

ASHRAE Standard 189.1-2009

- What does the “high performance green building” standard require in a “high performance VAV system?
- For commercial, institutional, and hi-rise residential buildings, the standard covers …

 © 2011 Trane, a business of Ingersoll-Rand

Std 189.1-2009
HPGB Provisions

- Site sustainability: e.g., site location, heat island, rainwater
- Water use efficiency: e.g., turf, fixtures, once-through, condensate recovery
- Energy efficiency: Std 90.1 compliance **plus…**
- Indoor environmental quality (IEQ): e.g., Std 62.1 all sections, **plus** OA sensing and no smoking, Std 55 compliance, acoustics, daylighting
- Atmosphere, materials and resources: e.g., recycle, reuse, no CFC’s allowed
- Construction and plans for operation

 © 2011 Trane, a business of Ingersoll-Rand

©2011 Trane a business of Ingersoll Rand

Std 189.1-2009 and high performance VAV
HPGB VAV-Specific Provisions

- Optimized VAV controls
- Cold air distribution
  - Energy performance modeling shows value of HP VAV cold air distribution
- Air-to-air energy recovery

 © 2011 Trane, a business of Ingersoll-Rand

	Energy Requirements		
	Std 189.1-2009 Provisions		***90.1-2010***
Topic	***90.1-2007***	***Plus 189.1-2009***	
Optimal start/stop controls	6.4.3.3.3 Controls must automatically adjust start time for 10,000 cfm air handlers, based on space temperature, occupied setpoint and time prior to occupancy	No additional requirements (i.e., same as 90.1-2007)	Same as 189.1-2009
Fan pressure optimization	6.5.3.2 Prescriptive option must reset supply static pressure lower to keep one zone damper nearly wide open	No additional requirements (i.e., same as 90.1-2007)	Same as 189.1-2009
Supply air temperature reset	No mandatory or prescriptive requirements	No mandatory or prescriptive requirements	6.5.3.4 Prescriptive option must reset supply air temperature by approximately 5°F
Demand controlled ventilation	6.4.3.9 Must use DCV in zones >500ft^2 with >40 people/1000 ft^2	7.4.3.2 Prescriptive option must include DCV in zones >500 ft2 with ≥25 people/1000 ft^2	6.4.3.9 Must use DCV in zones >500ft^2 with >40 people/1000 ft^2

 © 2011 Trane, a business of Ingersoll-Rand

©2011 Trane a business of Ingersoll Rand

	Energy Requirements		
	Std 189.1-2009 Provisions		***90.1-2010***
Topic	***90.1-2007***	***Plus 189.1-2009***	
Ventilation reset control	No mandatory or prescriptive requirements	No mandatory or prescriptive requirements	6.5.3.3 Prescriptive option must reset VAV system OA intake based on system ventilation efficiency
Cold-air distribution	No mandatory or prescriptive requirements	No mandatory or prescriptive requirements	Same as 189.1-2009
Air-to-air energy recovery	6.5.6.1 Prescriptive option must recover enthalpy with ≥50% effectiveness in systems with ≥5000 cfm and OA ≥70% of design supply air	7.4.3.8 Prescriptive option must recover enthalpy with ≥60% effectiveness in systems ranging from 1000 to 30,000 cfm and OA ranging from 10% to 80% of design supply air	6.5.3.4 Prescriptive option must recover enthalpy with ≥50% effectiveness in systems ranging from 1000 to 26,000 cfm and OA ranging from 30% to 80% of design supply air

11

© 2011 Trane, a business of Ingersoll-Rand

TRANE®

High-Performance VAV Systems

engineers newsletter LIVE

Optimized System Controls

Ingersoll Rand

High-Performance VAV Systems

Today's Topics

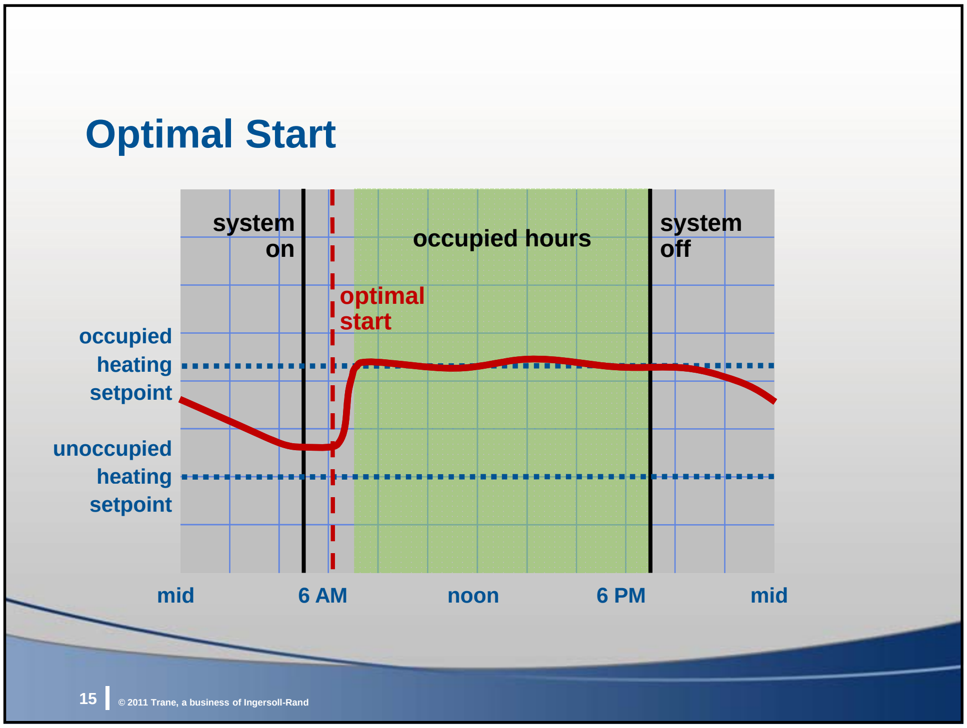
- ASHRAE 189.1 requirements
- Optimized VAV system controls
- Cold-air distribution
- Air-to-air energy recovery
- Other energy-saving strategies
- Energy modeling results
- Summary

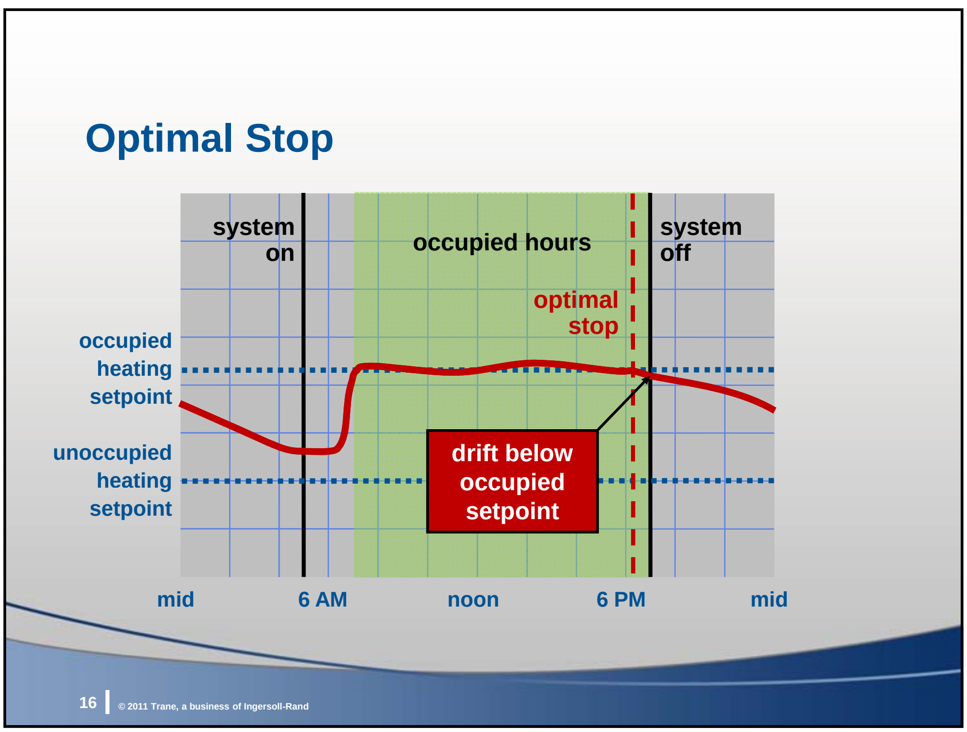
13 © 2011 Trane, a business of Ingersoll-Rand

Optimized VAV System Controls

- Optimal start/stop
  - Time-of-day scheduling
- Fan-pressure optimization
- Supply-air-temperature reset
- Ventilation optimization
  - Demand-controlled ventilation (DCV) at the zone level
  - Ventilation reset control at the system level (TRAQ dampers)

14 © 2011 Trane, a business of Ingersoll-Rand


Optimal Start
system
on
occupied hours
system
off
optimal
start
occupied
heating
setpoint
unoccupied
heating
setpoint
mid
6 AM
noon
6 PM
mid
15
© 2011 Trane, a business of Ingersoll-Rand

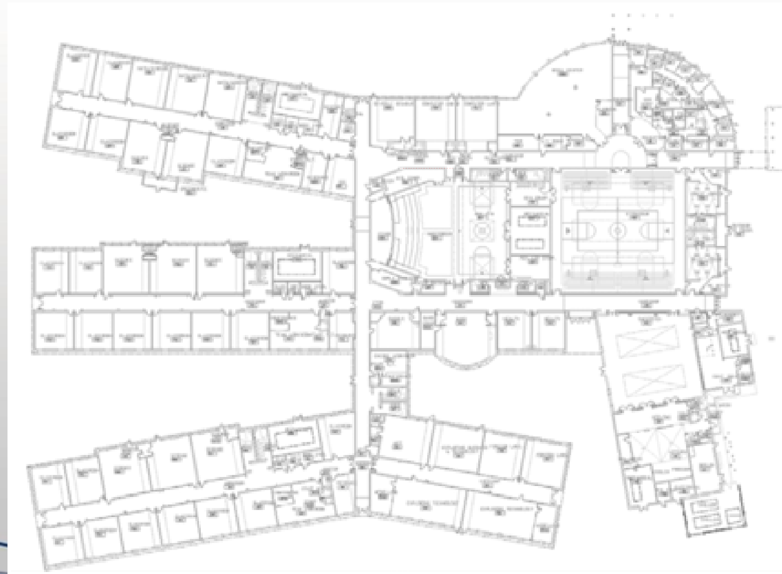

Optimal Stop
system
on
occupied hours
system
off
optimal
stop
occupied
heating
setpoint
unoccupied
heating
setpoint
drift below
occupied
setpoint
mid
6 AM
noon
6 PM
mid
16
© 2011 Trane, a business of Ingersoll-Rand

Time-of-Day Scheduling

- Avoid overly-conservative scheduling by including a timed override button on zone sensors
- Use separate schedules for areas with differing usage patterns

17 © 2011 Trane, a business of Ingersoll-Rand

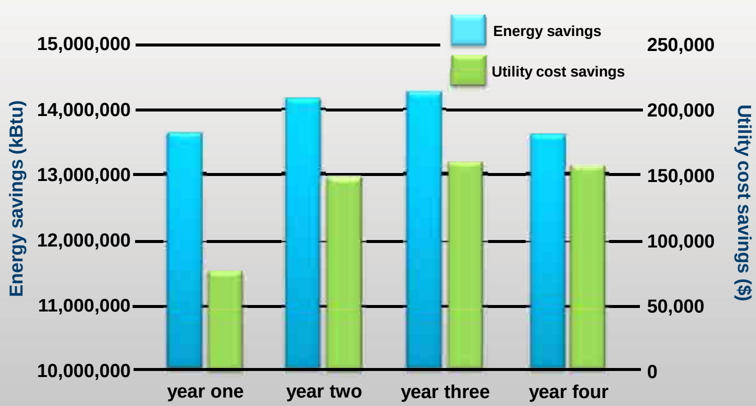
18 © 2011 Trane, a business of Ingersoll-Rand



© 2011 Trane, a business of Ingersoll-Rand

measured energy savings for a small school district

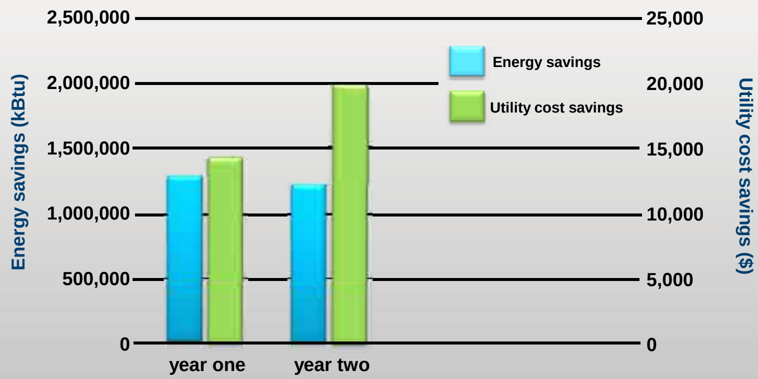
Proper Scheduling, Night Setback



© 2011 Trane, a business of Ingersoll-Rand

©2011 Trane a business of Ingersoll Rand

measured energy savings for a government office building
Proper Scheduling, Night Setback

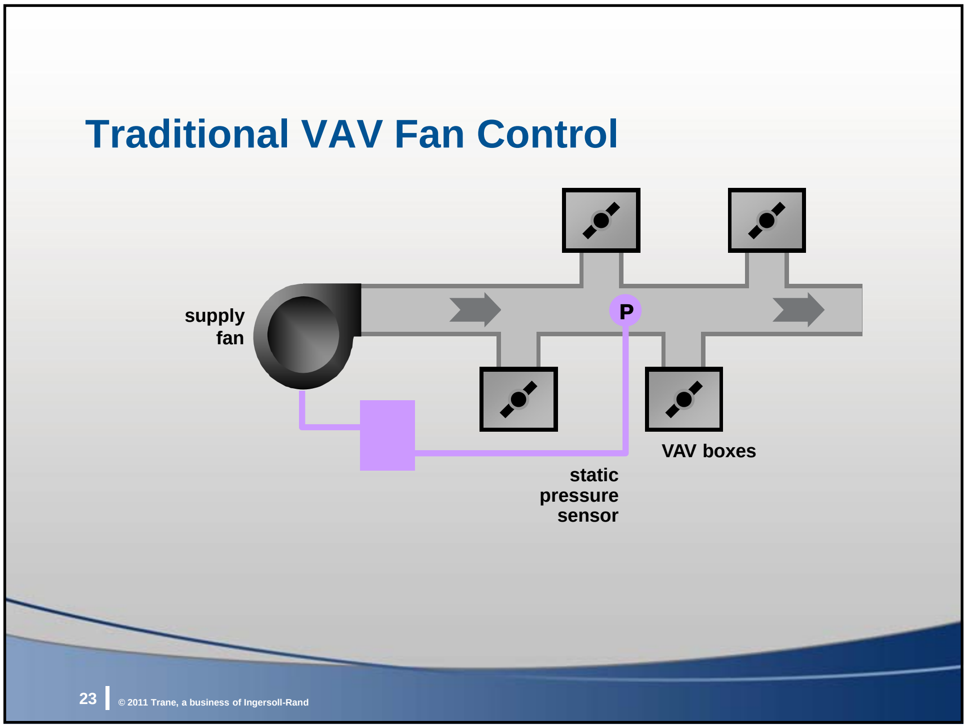


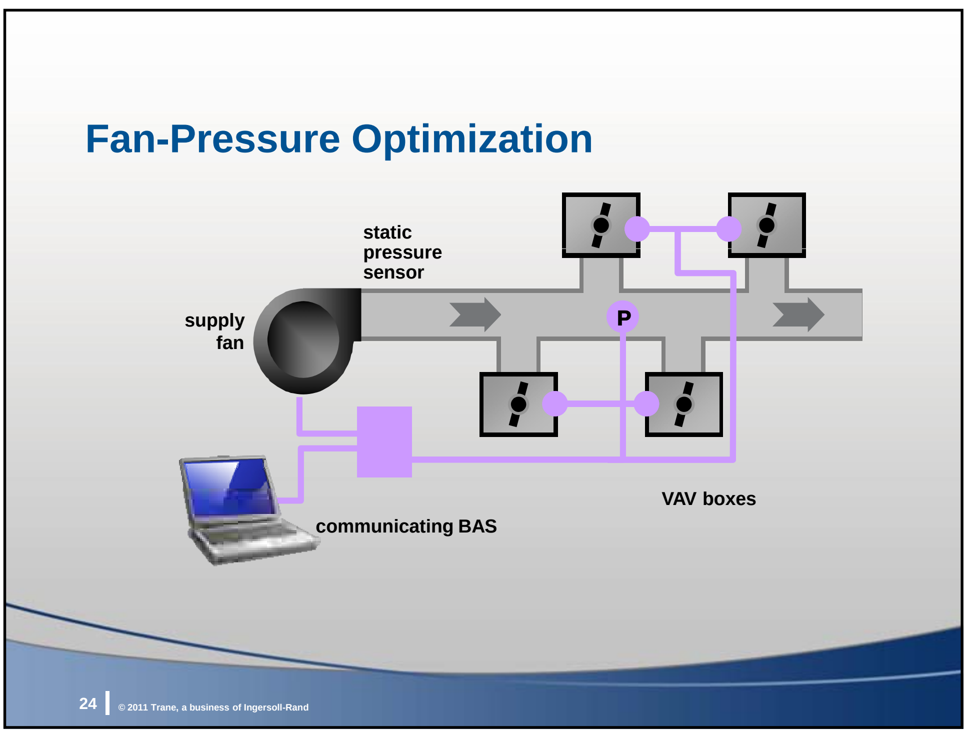
21 © 2011 Trane, a business of Ingersoll-Rand

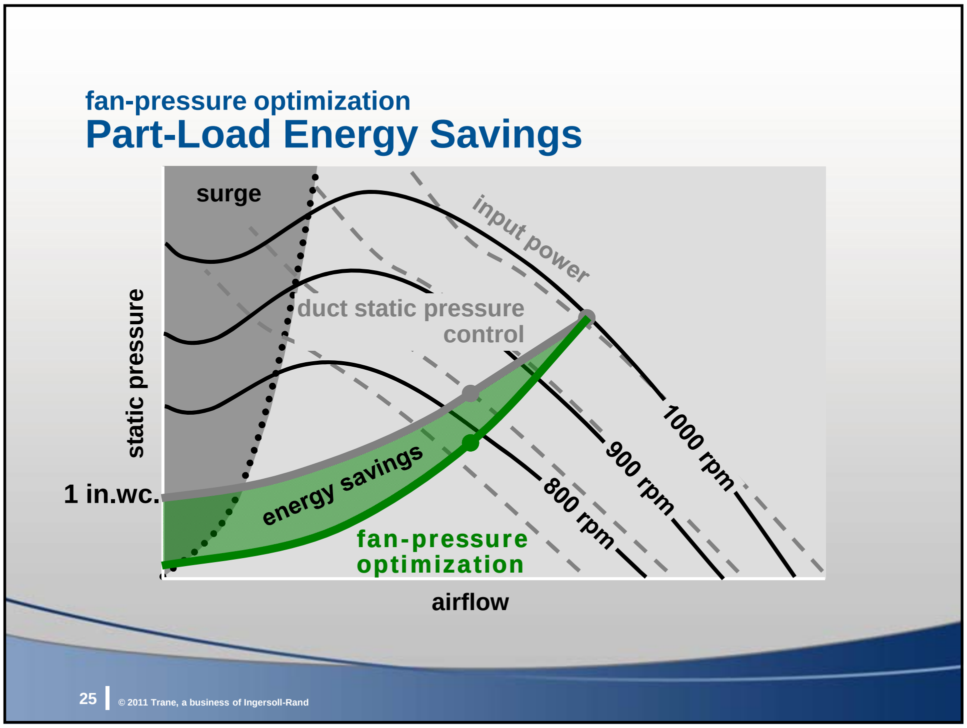
Optimized VAV System Controls

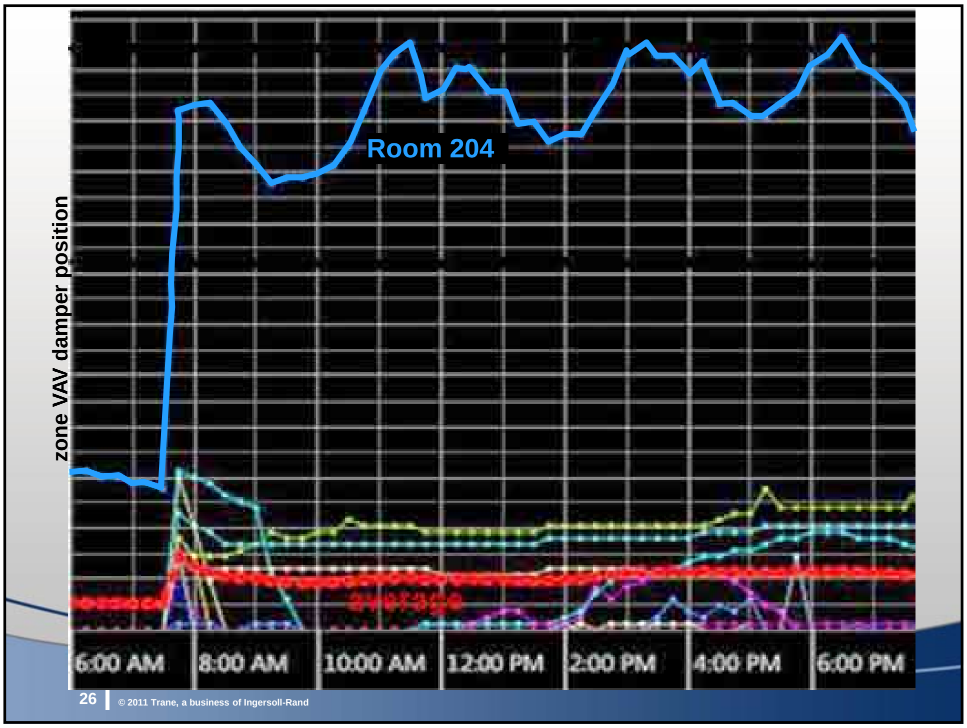
- Optimal start/stop
  - Time-of-day scheduling
- Fan-pressure optimization
- Supply-air-temperature reset
- Ventilation optimization
  - Demand-controlled ventilation at zone level
  - Ventilation reset at system level (and TRAQ dampers)

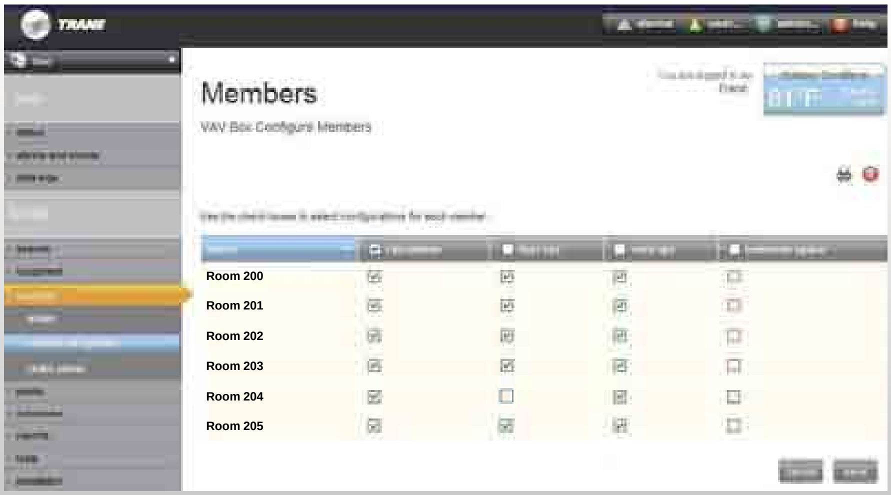
22 © 2011 Trane, a business of Ingersoll-Rand


Traditional VAV Fan Control
supply fan
P
VAV boxes
static pressure sensor
23
© 2011 Trane, a business of Ingersoll-Rand


Fan-Pressure Optimization
static pressure sensor
supply fan
P
VAV boxes
communicating BAS
24
© 2011 Trane, a business of Ingersoll-Rand

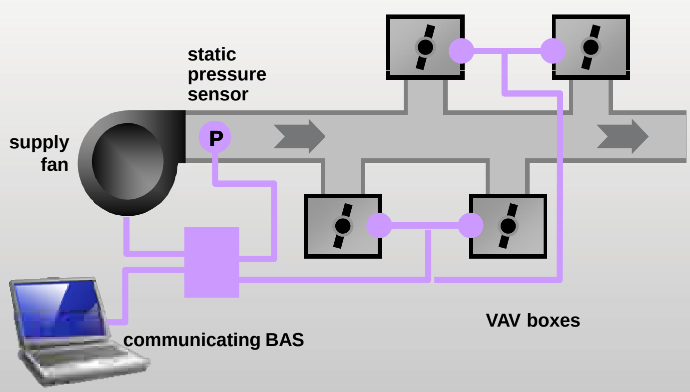

fan-pressure optimization
Part-Load Energy Savings
surge
input power
duct static pressure
control
static pressure
1 in.wc.
energy savings
fan-pressure
optimization
1000 rpm
900 rpm
800 rpm
airflow
25
© 2011 Trane, a business of Ingersoll-Rand


Room 204
zone VAV damper position
average
6:00 AM
8:00 AM
10:00 AM
12:00 PM
2:00 PM
4:00 PM
6:00 PM
26
© 2011 Trane, a business of Ingersoll-Rand



27 © 2011 Trane, a business of Ingersoll-Rand

Fan-Pressure Optimization



28 © 2011 Trane, a business of Ingersoll-Rand

fan-pressure optimization
Benefits

- Part-load energy savings
- Lower sound levels
- Better zone control
- Less duct leakage
- Reduced risk of fan surge
- Factory-installation and -commissioning of duct pressure sensor
- Operator feedback to "tune the system"

29 © 2011 Trane, a business of Ingersoll-Rand

Optimized VAV System Controls

- Optimal start/stop
  - Time-of-day scheduling
- Fan-pressure optimization
- Supply-air-temperature reset
- Ventilation optimization
  - Demand-controlled ventilation (DCV) at the zone level
  - Ventilation reset control at the system level (TRAQ dampers)

30 © 2011 Trane, a business of Ingersoll-Rand

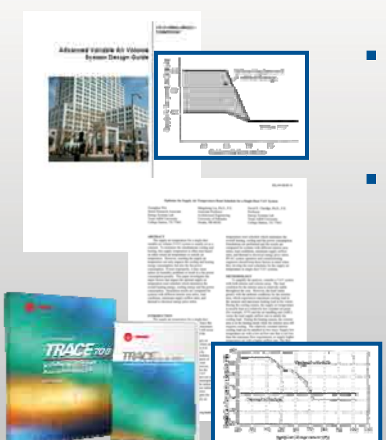
Supply-Air-Temperature (SAT) Reset

- Benefits
  - Decreases compressor energy
  - More hours when economizer provides all necessary cooling (compressors/chiller shut off)
  - Decreases reheat energy
- Drawbacks
  - Increases fan energy
  - May raise humidity level in zones

31 | © 2011 Trane, a business of Ingersoll-Rand

SAT reset

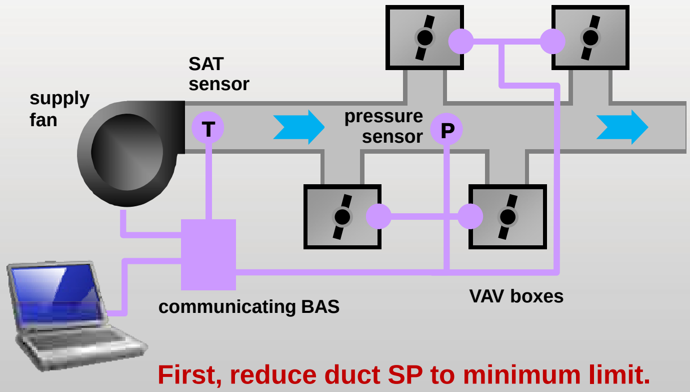
General Principles



- First reduce supply airflow
  - Significant energy savings from unloading the fan
- Raise SAT setpoint when it can enhance airside economizing and/or reduce reheat energy

32 | © 2011 Trane, a business of Ingersoll-Rand

SAT reset based on VAV damper positions
Example #1



First, reduce duct SP to minimum limit.

Then, raise SAT setpoint.

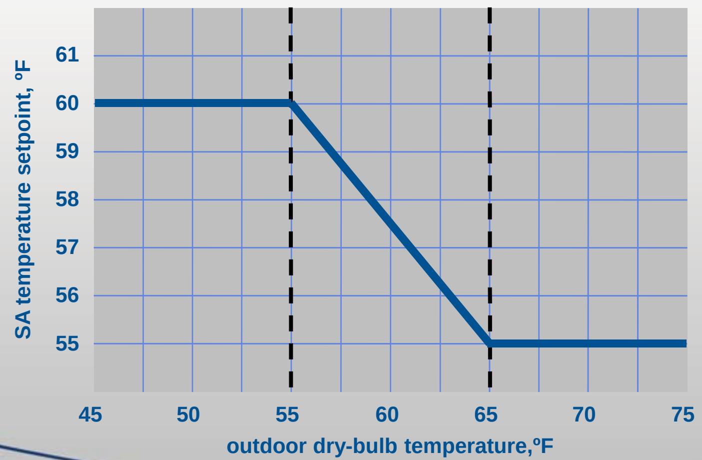
33 | © 2011 Trane, a business of Ingersoll-Rand

SAT reset based on VAV damper positions
Example #1

- Benefits of this approach
  - Maximizes fan energy savings by waiting until you have reset the duct SP as low as possible before you raise the SAT setpoint
  - Ensures that no zone is over-heated (starved for air)
- Drawbacks of this approach
  - SAT setpoint may not get reset upward very often, so might not have much impact on reheat energy use
    - Cooling load in *every* zone needs to be low enough that all VAV dampers are partially closed, even when duct SP setpoint is at minimum

34 | © 2011 Trane, a business of Ingersoll-Rand

SAT reset based on OA temperature
Example #2



35 © 2011 Trane, a business of Ingersoll-Rand

SAT reset based on OA temperature
Example #2

- When OA temperature > 65°F, no SAT reset
  - When it is this warm outside, the economizer has not likely been activated yet and the cooling load in most zones is likely high enough that reheat is not yet required to prevent overcooling
  - Takes advantage of significant energy savings from unloading supply fan
  - The colder (and drier) supply air allows the system to provide sufficiently dry air to the zones, keeping indoor humidity levels lower
- When OA temperature < 65°F, reset SAT upward (max SAT limit of 60°F)
  - Supply fan is likely significantly unloaded by this point
  - Increases benefit of airside economizer, allows compressors to shut off sooner
  - Reduces any reheat required to prevent overcooling the zones
  - Outdoor air is less humid so the risk of elevating indoor humidity by providing warmer (and wetter) supply air is lessened
- Limiting SAT reset to 60°F allows the system to satisfy cooling loads in interior zones without needing to substantially oversize VAV terminals and ductwork
- Disable SAT reset when outdoor dew point is too high (e.g. above 60ºF or 65ºF) or when indoor humidity is too high (e.g. above 60% or 65% RH)

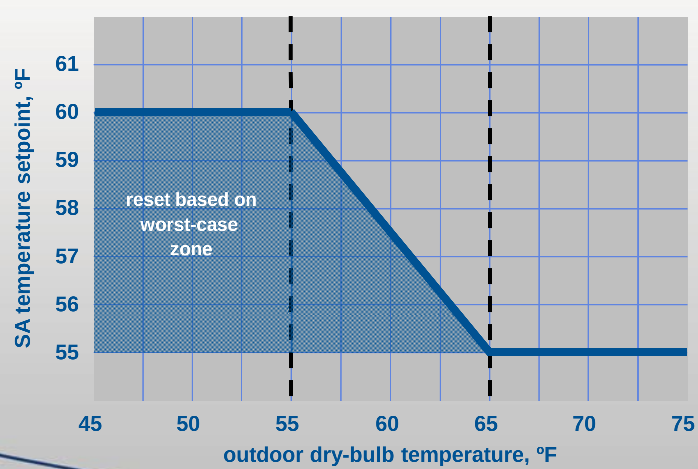
36 © 2011 Trane, a business of Ingersoll-Rand

SAT reset based on OA temperature
Example #2

- Benefits of this approach
  - Achieves fan energy savings by waiting until it is cool outside before raising the SAT setpoint
  - May achieve more reduction reheat energy by not waiting for duct SP to be reset to minimum
- Drawbacks of this approach
  - "Open loop" control does not ensure that a zone is not over-heated (starved for air)

37 © 2011 Trane, a business of Ingersoll-Rand

SAT reset based on OA temperature and VAV damper positions
Example #3



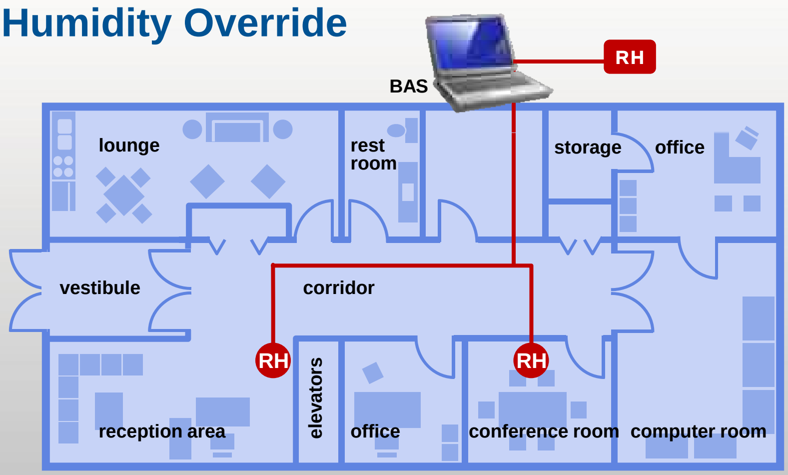
38 © 2011 Trane, a business of Ingersoll-Rand

SAT reset based on OA temperature and VAV damper positions
Example #3

- Benefits of this approach
  - Achieves fan energy savings by waiting until it is cool outside before raising the SAT setpoint
  - May achieve more reduction reheat energy by not waiting for duct SP to be reset to minimum
  - Ensures that no zone is over-heated (starved for air)
- Drawbacks of this approach
  - Both sequences use the same input signal (position of the furthest-open VAV damper), so they require careful coordination

39 © 2011 Trane, a business of Ingersoll-Rand

SAT reset
Humidity Override



40 © 2011 Trane, a business of Ingersoll-Rand

SAT reset
Application Considerations

- Will compressor and reheat energy savings outweigh additional fan energy?
- Consider impact on zone humidity
- Design zones with nearly-constant cooling loads for warmer (reset) SAT
  - May require larger VAV terminals and ductwork
  - Allows SAT reset while still providing needed cooling to these zones
- Design an efficient air distribution system
  - Employ fan-pressure optimization

41 © 2011 Trane, a business of Ingersoll-Rand

Optimized VAV System Controls

- Optimal start/stop
  - Time-of-day scheduling
- Fan-pressure optimization
- Supply-air-temperature reset
- Ventilation optimization (dynamic reset)
  - Demand-controlled ventilation at zone level
  - Ventilation reset at system level (and TRAQ™ dampers)

42 © 2011 Trane, a business of Ingersoll-Rand

dynamic reset approaches – zone level

Demand Controlled Ventilation (DCV)

- Estimate current population (*Pz*) based on:
  1. Time-of-day schedule (e.g., when a class is in session)
  2. Occupancy sensors (e.g., motion detectors)
  3. Actual sense population (e.g., using turnstiles, ticket sales, and so on, or changes in CO_2 levels)
- Find required breathing zone OA flow (*Vbz*) using estimated population
- Alternatively:
  4. CO_2-based: Estimate required breathing zone OA flow (*Vbz*) directly based on CO_2 levels

43 © 2011 Trane, a business of Ingersoll-Rand

dynamic reset approaches – zone level

Demand Controlled Ventilation (DCV)

- Estimate the current OA flow required using CO_2 levels
  - Steady state concentration equation

    $$(Cr - Co) = k*m/(Vbz/Pz)$$

  - Typical straight-line proportional controller

    $$Vbz = slope*\Delta CO_2 + offset$$

44 © 2011 Trane, a business of Ingersoll-Rand

©2011 Trane a business of Ingersoll Rand

dynamic reset approaches – system level
Outdoor Air Intake Flow w/DCV

- For single zone systems:

  $Vot = Vbz/Ez$

- For 100% zone systems:

  $Vot = \Sigma_{all\ zones}(Vbz/Ez)$

- For multiple-zone systems:

  $Vou = \Sigma(Rp*Pz) + \Sigma(Ra*Az)$

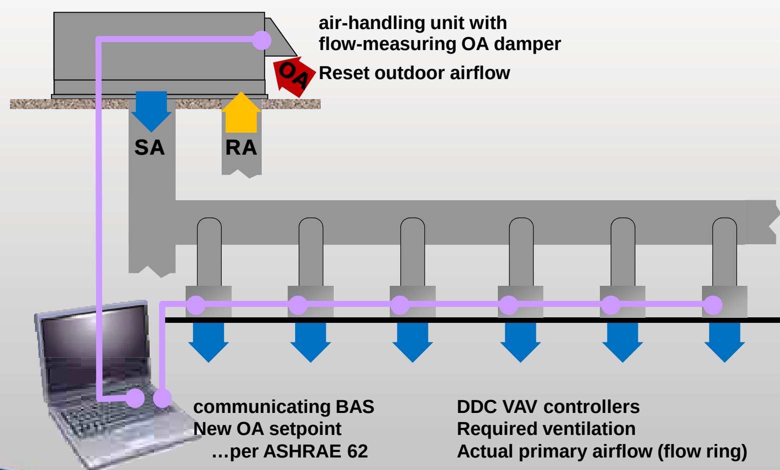
  $Zdz_{critical\ zone} = Vbz/Vdz$

  $Ev = 1 + Vou/Vps – Zdz_{critical\ zone}$

  $Vot = Vou/Ev$

45 | © 2011 Trane, a business of Ingersoll-Rand

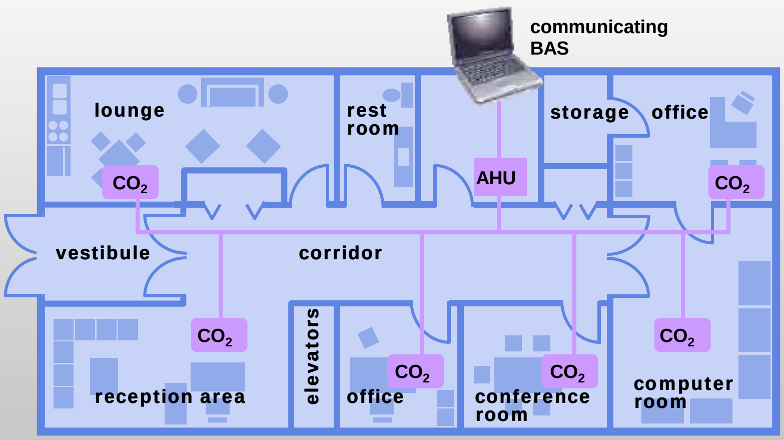
dynamic reset approaches – zone/system level
Ventilation Reset Control



46 | © 2011 Trane, a business of Ingersoll-Rand

dynamic reset approaches – zone/system level

CO_2 Sensor in Every Zone?



 © 2011 Trane, a business of Ingersoll-Rand

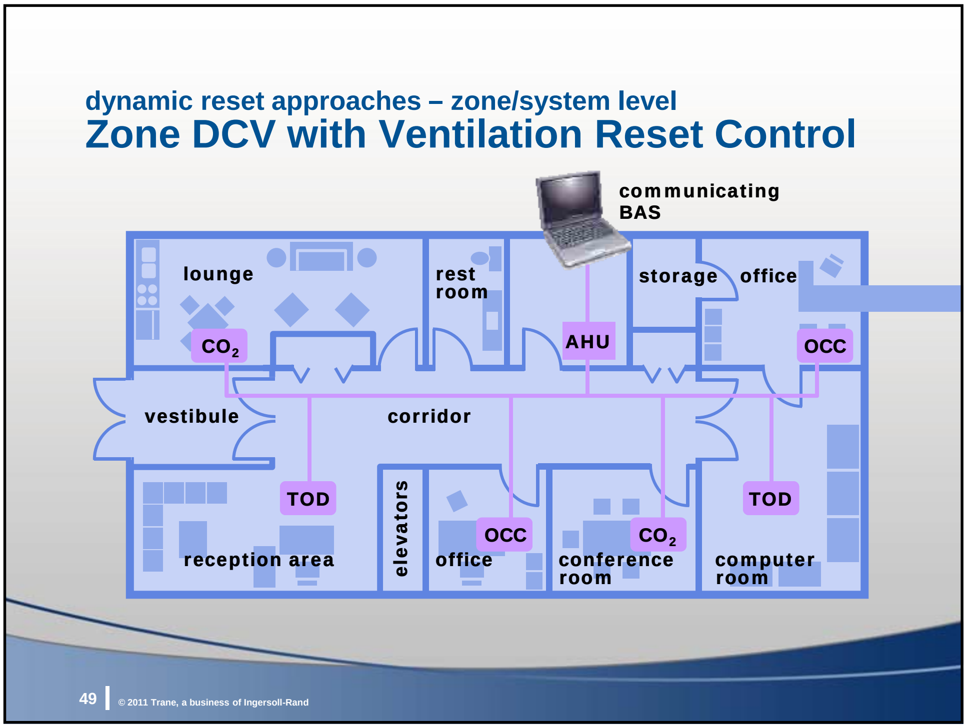
CO_2 sensor in every zone

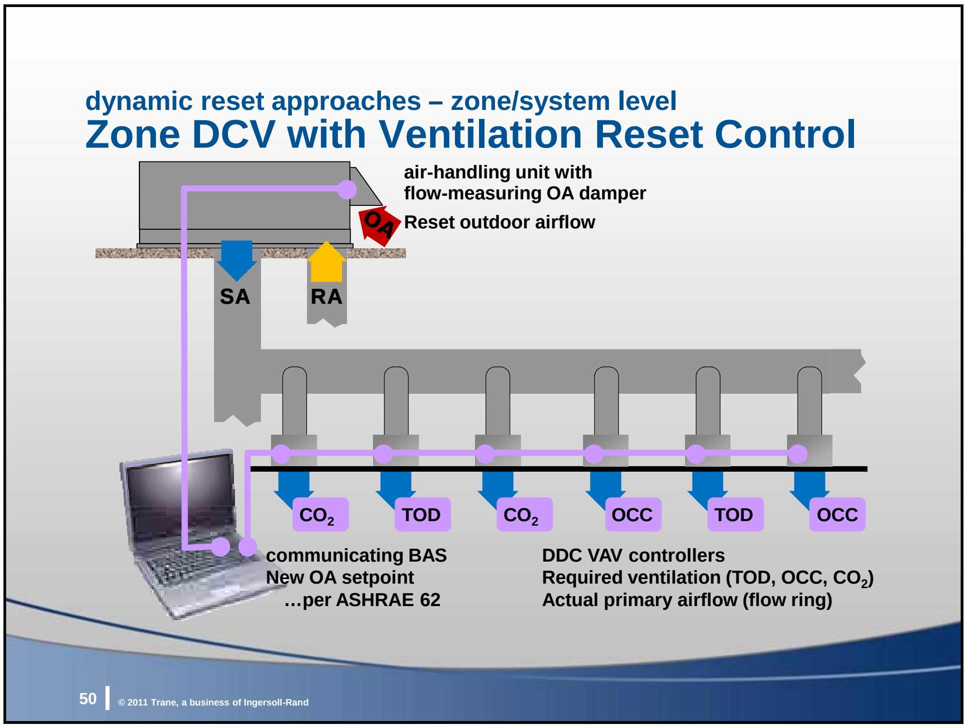
Drawbacks

- Requires a CO_2 sensor in every zone
  - Increases installed cost and maintenance
  - Unnecessary use of sensors (CO_2 level doesn't change much in many of the zones, non-critical zones will always be over-ventilated)
  - Increases risk of over-ventilating or under-ventilating
- Requires BAS to poll all sensors to determine OA damper position
- Requires some method to ensure minimum outdoor airflow

 © 2011 Trane, a business of Ingersoll-Rand

©2011 Trane a business of Ingersoll Rand


dynamic reset approaches – zone/system level
Zone DCV with Ventilation Reset Control
communicating BAS
lounge
rest room
storage
office
CO_2
AHU
OCC
vestibule
corridor
TOD
elevators
OCC
CO_2
TOD
reception area
office
conference room
computer room
49
© 2011 Trane, a business of Ingersoll-Rand


dynamic reset approaches – zone/system level
Zone DCV with Ventilation Reset Control
air-handling unit with
flow-measuring OA damper
Reset outdoor airflow
OA
SA
RA
CO_2
TOD
CO_2
OCC
TOD
OCC
communicating BAS
New OA setpoint
…per ASHRAE 62
DDC VAV controllers
Required ventilation (TOD, OCC, CO_2)
Actual primary airflow (flow ring)
50
© 2011 Trane, a business of Ingersoll-Rand

ventilation optimization
Benefits

- Saves energy during partial occupancy
- Lower installed cost, less maintenance, and more reliable than installing a CO_2 sensor in every zone
  - Use zone-level DCV approaches where they best fit (CO_2 sensor, occupancy sensor, time-of-day schedule)
  - Combine with ventilation reset at the system level

© 2011 Trane, a business of Ingersoll-Rand

"Occupied Standby" Mode

- Use an occupancy sensor to:
  - Shut off lights
  - Raise/lower zone temperature setpoint by 1ºF or 2ºF
  - Reduce outdoor airflow requirement
  - Lower minimum airflow setting to reduce or avoid reheat

© 2011 Trane, a business of Ingersoll-Rand

©2011 Trane a business of Ingersoll Rand

occupied standby mode
Example

1000-ft^2 conference room
(design occupancy = 50)

	occupied mode	occupied standby mode
Lights	on	off
Zone cooling setpoint	75ºF	77ºF
Outdoor airflow required	310 cfm ($R_p \times P_z + R_a \times A_z$)	60 cfm ($R_a \times A_z$)
Minimum primary airflow setting	450 cfm	225 cfm

53 © 2011 Trane, a business of Ingersoll-Rand

outdoor airflow sensing
Traq™ Damper/Sensor Assembly

- A damper assembly that …
  - Controls airflow by modulating a set of round dampers
  - Measures airflow at all conditions (as required indirectly by Std 62.1 and Std 90.1, and as required explicitly by Std 189.1 and for a LEED credit)

54 © 2011 Trane, a business of Ingersoll-Rand

outdoor airflow sensing
Damper Assembly

- Uses proven flow-sensing technology
  - Flow ring senses differential (total inlet to “wake” outlet) pressure), which can be very low
  - Air doesn’t enter sensing ports, so filtration isn’t needed
  - Transducer auto-calibrates once each minute, to correct for drift due to temperature changes
  - Bell mouth inlet directs air across flow ring to reduce turbulence and pressure drop

55 © 2011 Trane, a business of Ingersoll-Rand

outdoor airflow sensing
Damper Assembly

- Accuracy
  - Tested in accordance with AMCA 610 “Airflow Measurement Station Performance”
  - ± 5% of actual airflow
  - Precision maintained from 100% down to 15% of nominal (design) flow (or down to 5% in some configurations)
- Damper leakage
  - “Low leak” class
  - Meets Std 90.1 requirements

56 © 2011 Trane, a business of Ingersoll-Rand

outdoor airflow sensing

Damper Assembly

For a #25 air-handling unit, 12,500 cfm

Device	ΔP in. wc.	Inlet Velocity
Traq™	**0.30**	1,900 fpm
Blade assembly:		
Filter	0.39	
Sensor	0.00	
Damper	0.25	
Total Assembly	**0.64**	1,200 fpm

57 | © 2011 Trane, a business of Ingersoll-Rand

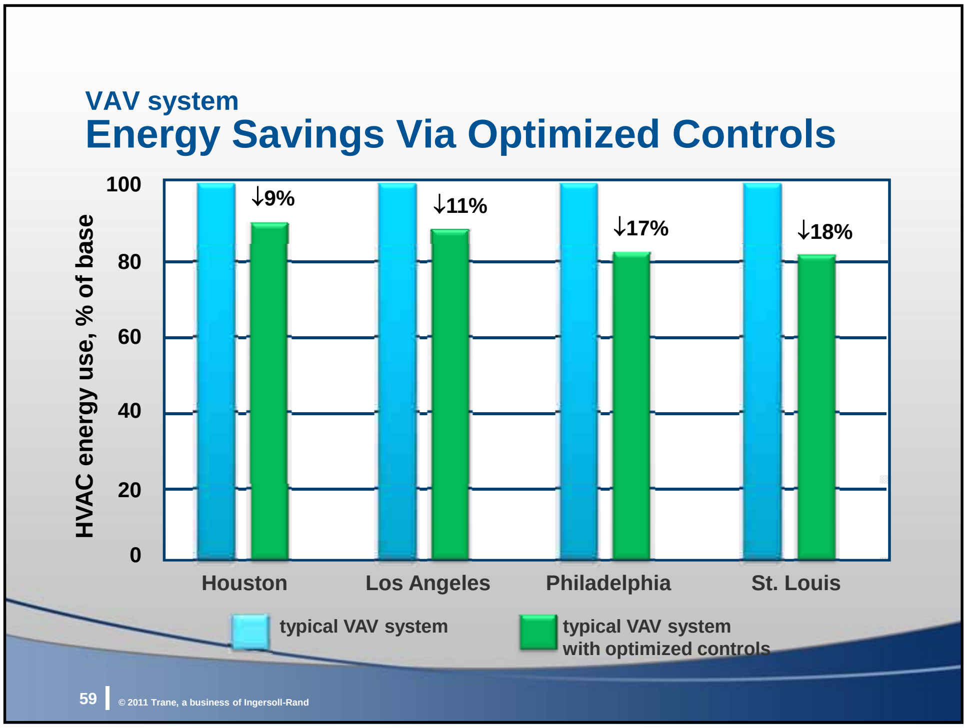
Example TRACE® 700 Analysis

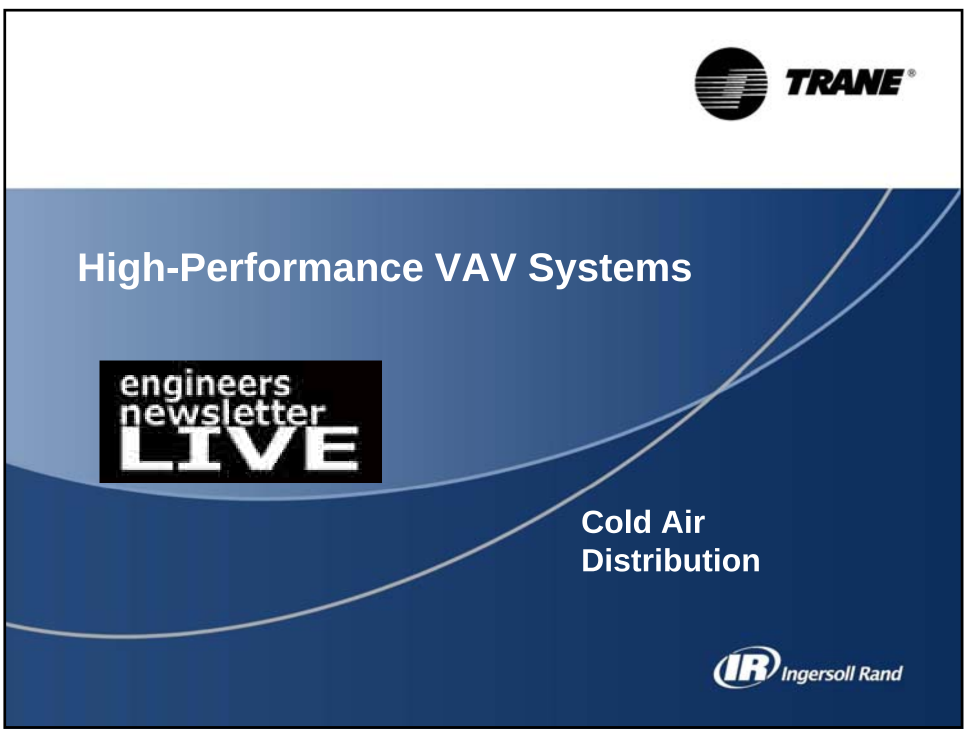
Optimized VAV system controls

- Optimal start
- Fan-pressure optimization
- Supply-air temperature reset
- Ventilation optimization
  - DCV at zone level
  - Ventilation reset at system level

58 | © 2011 Trane, a business of Ingersoll-Rand

©2011 Trane a business of Ingersoll Rand


VAV system
Energy Savings Via Optimized Controls
HVAC energy use, % of base
100
80
60
40
20
0
↓9%
↓11%
↓17%
↓18%
Houston
Los Angeles
Philadelphia
St. Louis
typical VAV system
typical VAV system with optimized controls
59
© 2011 Trane, a business of Ingersoll-Rand


TRANE
High-Performance VAV Systems
engineers newsletter LIVE
Cold Air Distribution
Ingersoll Rand

High-Performance VAV Systems
Today's Topics

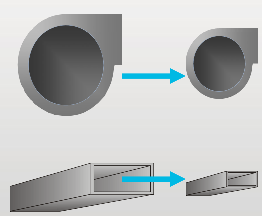
- ASHRAE 189.1 requirements
- Optimized VAV system controls
- Cold-air distribution
- Air-to-air energy recovery
- Other energy-saving strategies
- Energy modeling results
- Summary

61 | © 2011 Trane, a business of Ingersoll-Rand

Lower Supply-Air Temperature

Benefits

- Reduces supply airflow
  - Less supply fan energy and less fan heat gain
  - Smaller fans, air handlers, VAV terminals, and ductwork
- Lowers indoor humidity levels



Drawbacks

- Fewer economizer hours
- Increased reheat energy

62 | © 2011 Trane, a business of Ingersoll-Rand

lower supply-air temperature
Maximize Energy Savings

- Use supply-air temperature reset during mild weather
  - Maximizes benefit of airside economizer
  - Reduces reheat energy use

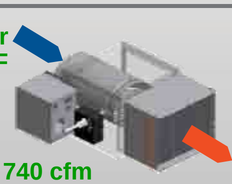
 © 2011 Trane, a business of Ingersoll-Rand

Impact of SAT on Reheat Energy

primary air
55ºF

design primary airflow = 1000 cfm
minimum primary airflow = 300 cfm
(30%) → reheat activated when space cooling load drops below 30% of design

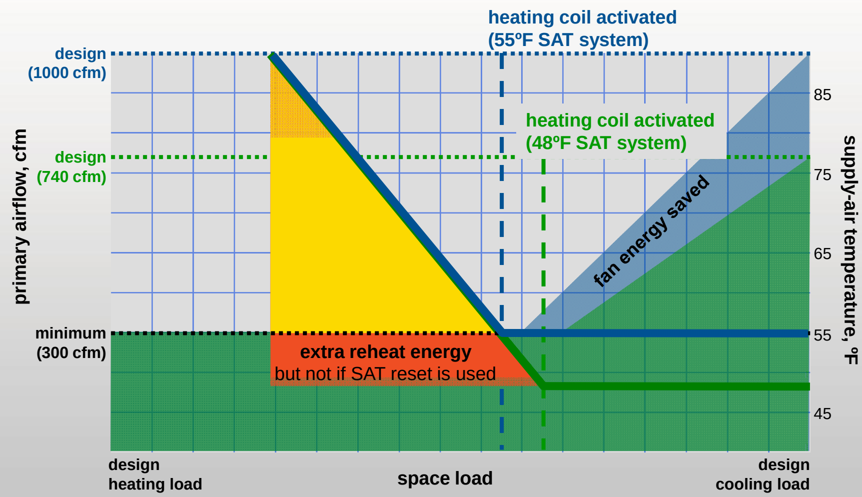
primary air
48ºF



design primary airflow = 740 cfm
minimum primary airflow = 300 cfm
(40%) → reheat activated when space cooling load drops below 40% of design

 © 2011 Trane, a business of Ingersoll-Rand

©2011 Trane a business of Ingersoll Rand



65 © 2011 Trane, a business of Ingersoll-Rand

lower supply-air temperature

Maximize Energy Savings

- Use supply-air temperature reset during mild weather
- Raise space setpoint by 1ºF or 2ºF
  - Lower indoor humidity often allows zone dry-bulb temperature to be slightly warmer
  - Further reduces airflow and fan energy use

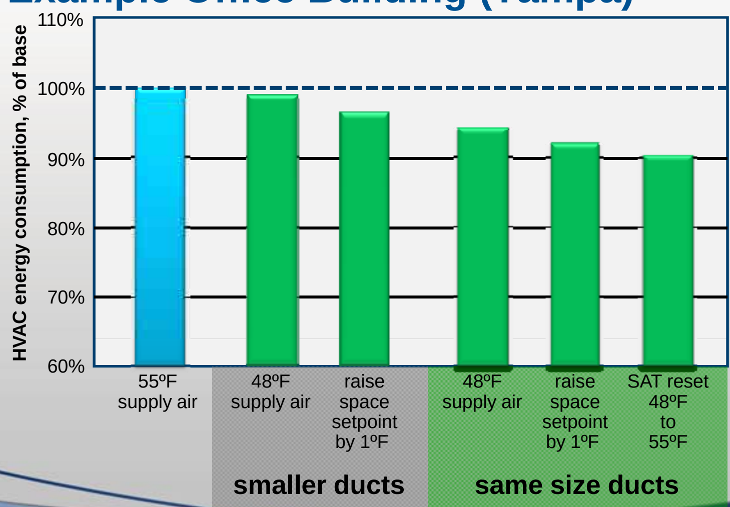
66 © 2011 Trane, a business of Ingersoll-Rand

lower supply-air temperature
Maximize Energy Savings

- Use supply-air temperature reset during mild weather
- Raise space setpoint by 1ºF or 2ºF
- Keep same size ductwork
  - Further reduces fan energy use
  - Allows SAT reset in systems that serve zones with near-constant cooling loads
  - Capable of delivering more airflow if loads increase in the future

67 © 2011 Trane, a business of Ingersoll-Rand

chilled-water VAV system
Example Office Building (Tampa)



68 © 2011 Trane, a business of Ingersoll-Rand

High-Velocity Round Ductwork

69 © 2011 Trane, a business of Ingersoll-Rand

lower supply-air temperature

Maximize Energy Savings

- Use supply-air temperature reset during mild weather
- Raise space setpoint by 1ºF or 2ºF
- Keep same size ductwork
- Use parallel fan-powered VAV terminals
  - Reduces reheat energy use by recovering heat from warm air in ceiling plenum

70 © 2011 Trane, a business of Ingersoll-Rand

lower supply-air temperature

Challenges

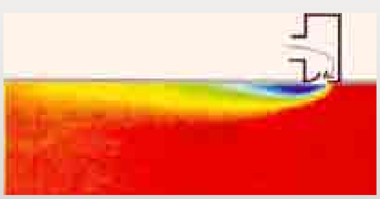
- Minimize comfort problems due to “dumping”
- Avoid condensation on air distribution system components

71 © 2011 Trane, a business of Ingersoll-Rand

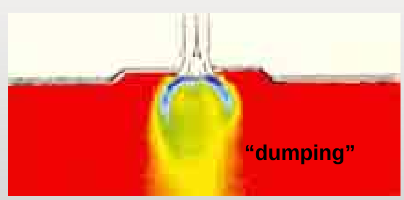
lower supply-air temperature

Minimizing Comfort Problems (Dumping)

- Use linear slot diffusers



linear slot diffuser



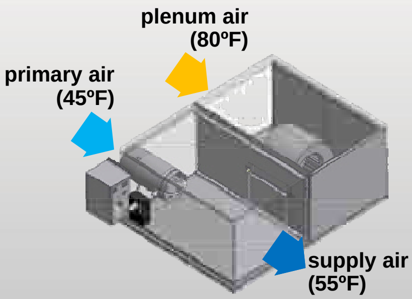
conventional concentric diffuser

- Implement supply-air-temperature reset

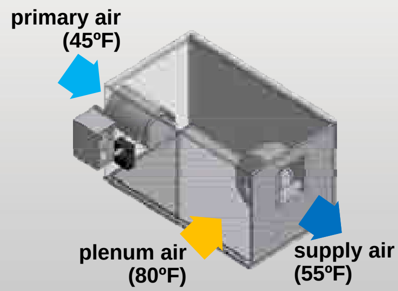
72 © 2011 Trane, a business of Ingersoll-Rand

lower supply-air temperature
Minimizing Comfort Problems (Dumping)

…or use fan-powered VAV terminals as “air blenders”



parallel fan-powered
VAV terminal



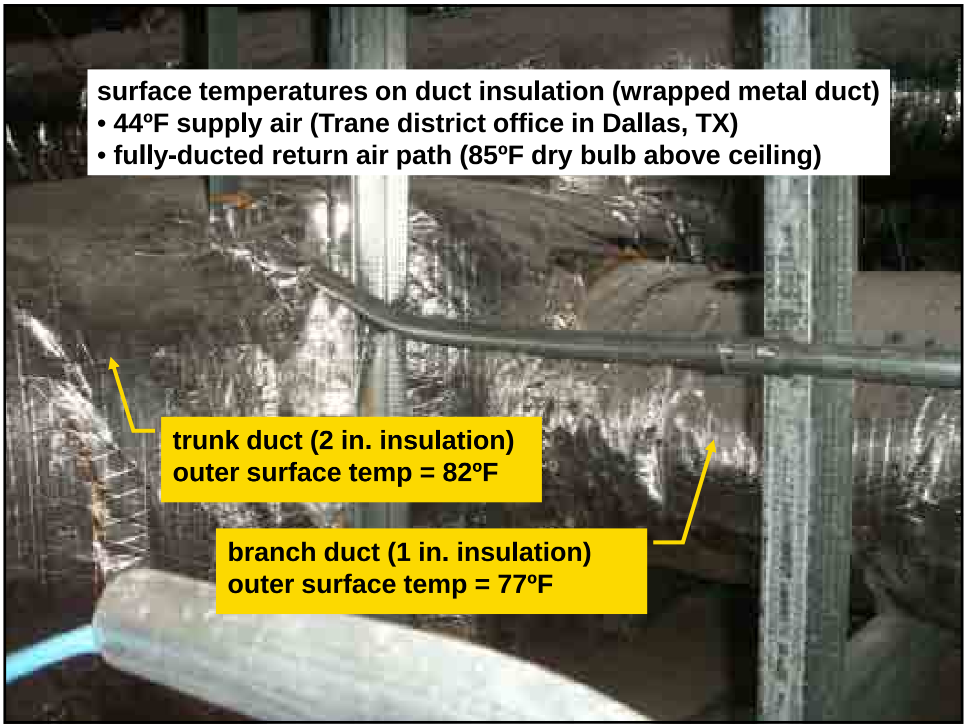
series fan-powered
VAV terminal

73 © 2011 Trane, a business of Ingersoll-Rand

lower supply-air temperature
Avoiding Condensation

- Properly insulate and vapor-seal ductwork, VAV terminals, and supply-air diffusers

74 © 2011 Trane, a business of Ingersoll-Rand



lower supply-air temperature

Avoiding Condensation

- Properly insulate and vapor-seal ductwork, VAV terminals, and supply-air diffusers
- Use an open ceiling plenum return, if possible
- Maintain positive building pressure to reduce infiltration of humid outdoor air
- Use linear slot diffusers to increase air motion
- Monitor indoor humidity during unoccupied periods and prevent it from rising too high
- During startup, slowly ramp down the supply-air temperature to pull down indoor dew point

76 © 2011 Trane, a business of Ingersoll-Rand

©2011 Trane a business of Ingersoll Rand

examples

Humidity Pull-Down Sequence

- SAT ramp-down schedule

	supply airflow limit	supply-air temperature
2 hours before occupancy	40% of design	55ºF
1 hour before occupancy	65% of design	51ºF
Scheduled occupancy	no limit	48ºF

Source: ASHRAE *Cold Air Distribution System Design Guide* (pp 138-140)

- SAT ramp-down based on indoor dew point
  ex: SAT = current indoor dew point – 3ºF

77 © 2011 Trane, a business of Ingersoll-Rand

TRANE

High-Performance VAV Systems

engineers newsletter LIVE

Air-to-Air
Energy Recovery

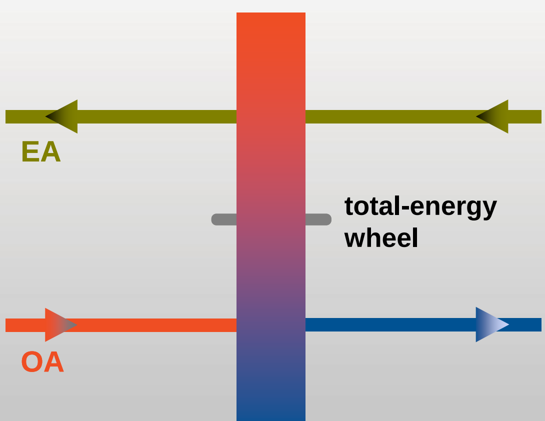
Ingersoll Rand

High-Performance VAV Systems
Today's Topics

- ASHRAE 189.1 requirements
- Optimized VAV system controls
- Cold-air distribution
- Air-to-air energy recovery
- Other energy-saving strategies
- Energy modeling results
- Summary

79 © 2011 Trane, a business of Ingersoll-Rand

Air-to-Air Energy Recovery



80 © 2011 Trane, a business of Ingersoll-Rand

©2011 Trane a business of Ingersoll Rand

Air-to-Air Energy Recovery

Benefits

- Reduces cooling, dehumidification, heating, and humidification energy
- Allows equipment downsizing

Drawbacks

- Increases fan energy
- Requires exhaust air be routed back to the device

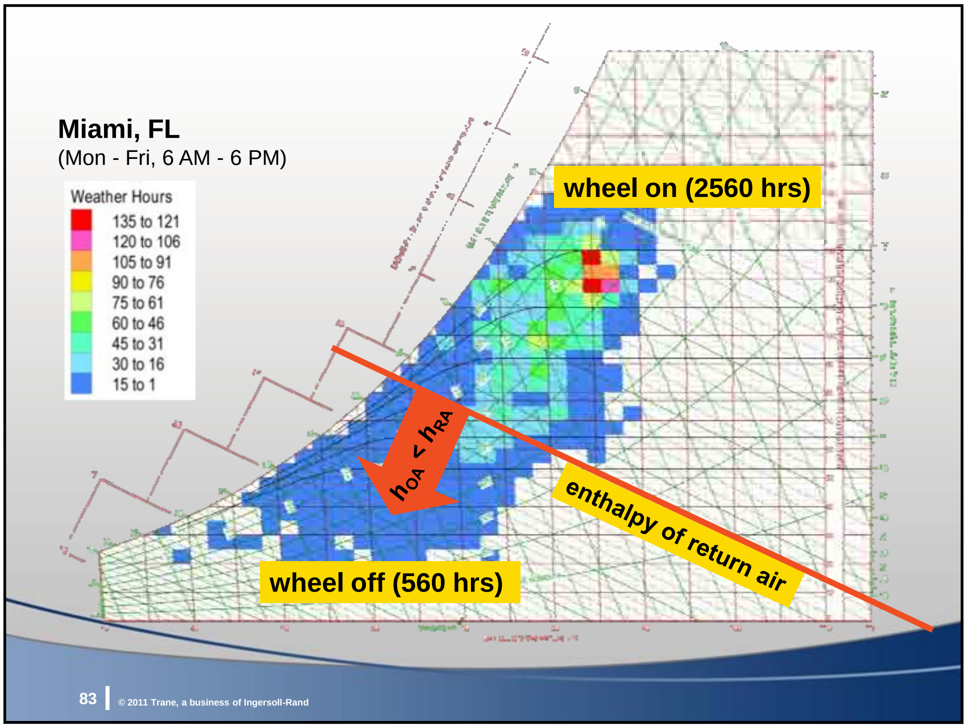
81 © 2011 Trane, a business of Ingersoll-Rand

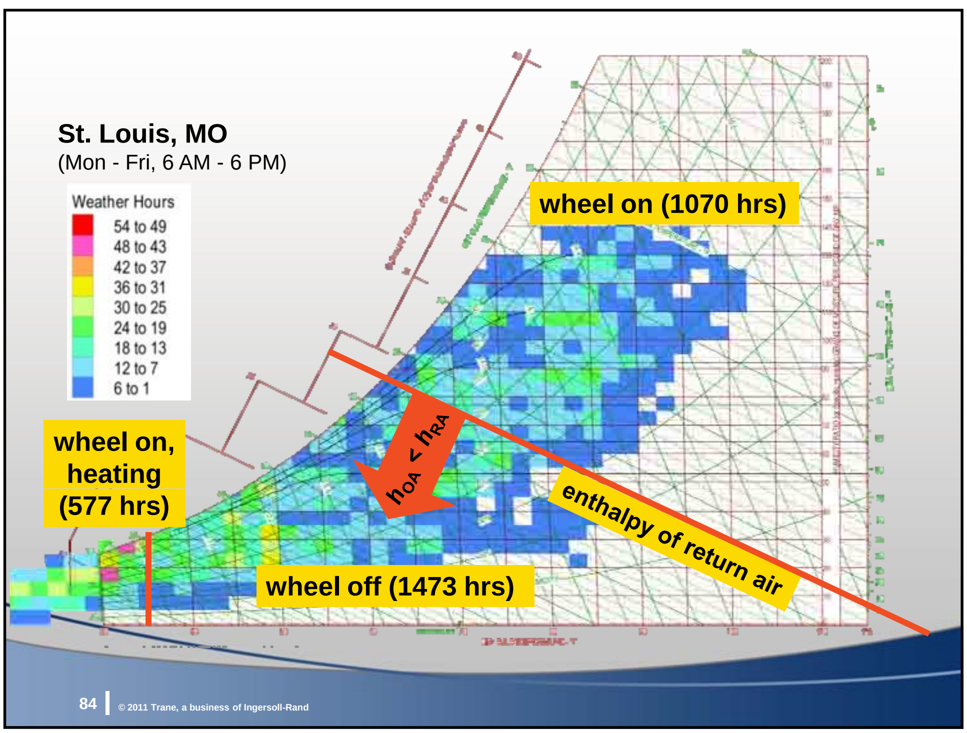
air-to-air energy recovery

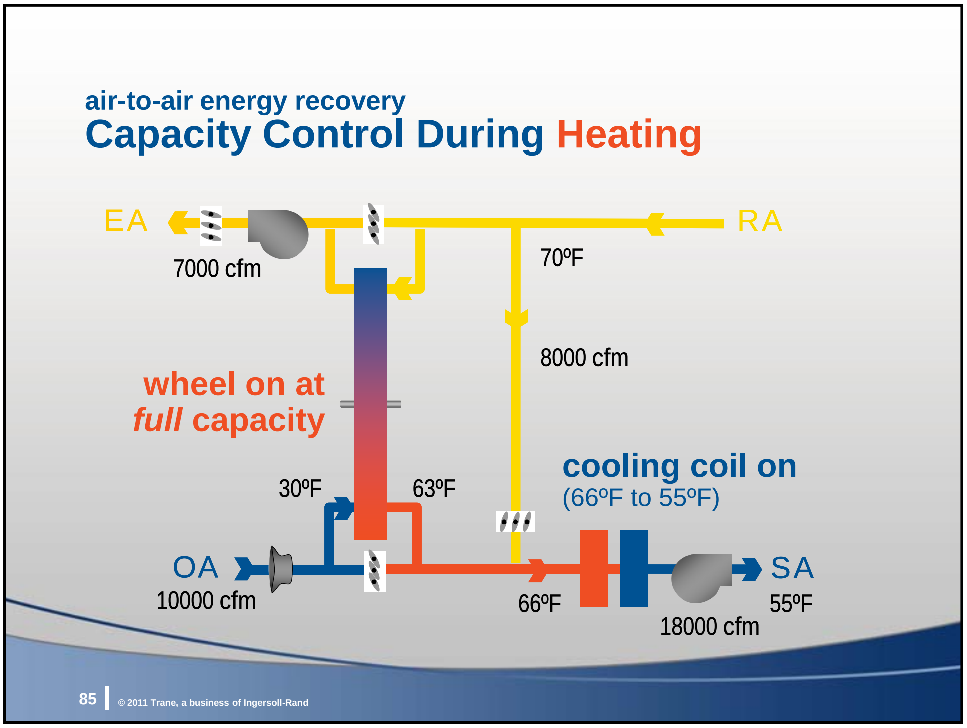
Considerations for VAV Systems

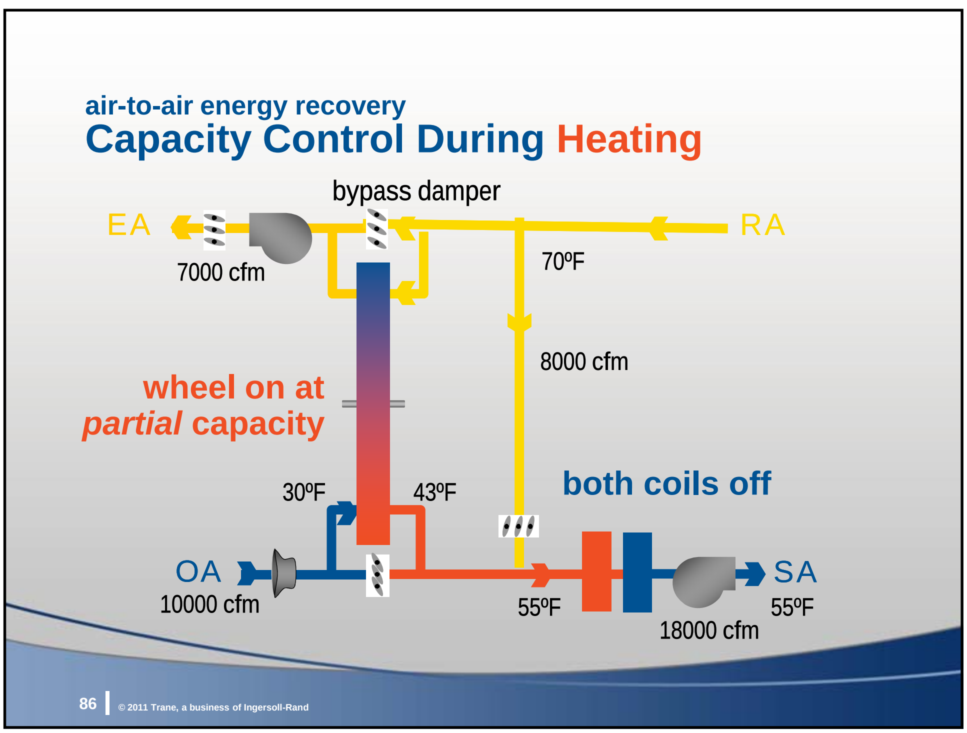
- Size energy-recovery device for minimum outdoor airflow required, not economizing airflow
- Strive for balanced airflows
- Ensure that the device is controlled properly
  - Turn off during mild weather to avoid wasting energy
  - Provide a means of capacity control during heating
  - Include bypass dampers for airside economizing

82 © 2011 Trane, a business of Ingersoll-Rand


Miami, FL
(Mon - Fri, 6 AM - 6 PM)
Weather Hours
135 to 121
120 to 106
105 to 91
90 to 76
75 to 61
60 to 46
45 to 31
30 to 16
15 to 1
wheel on (2560 hrs)
hOA < hRA
enthalpy of return air
wheel off (560 hrs)
83
© 2011 Trane, a business of Ingersoll-Rand


St. Louis, MO
(Mon - Fri, 6 AM - 6 PM)
Weather Hours
54 to 49
48 to 43
42 to 37
36 to 31
30 to 25
24 to 19
18 to 13
12 to 7
6 to 1
wheel on (1070 hrs)
hOA < hRA
wheel on, heating (577 hrs)
enthalpy of return air
wheel off (1473 hrs)
84
© 2011 Trane, a business of Ingersoll-Rand


air-to-air energy recovery
Capacity Control During Heating
EA
RA
7000 cfm
70ºF
8000 cfm
wheel on at
full capacity
cooling coil on
(66ºF to 55ºF)
30ºF
63ºF
OA
10000 cfm
66ºF
SA
55ºF
18000 cfm
85
© 2011 Trane, a business of Ingersoll-Rand


air-to-air energy recovery
Capacity Control During Heating
bypass damper
EA
RA
7000 cfm
70ºF
8000 cfm
wheel on at
partial capacity
both coils off
30ºF
43ºF
OA
10000 cfm
55ºF
SA
55ºF
18000 cfm
86
© 2011 Trane, a business of Ingersoll-Rand

air-to-air energy recovery

Considerations for VAV Systems

- Size energy-recovery device for minimum outdoor airflow required, not economizing airflow
- Strive for balanced airflows
- Ensure that the device is controlled properly
  - Turn off during mild weather to avoid wasting energy
  - Provide a means of capacity control during heating
  - Include bypass dampers for airside economizing
- Provide a method for frost prevention in cold climates

87 © 2011 Trane, a business of Ingersoll-Rand

TRANE

High-Performance VAV Systems

engineers newsletter LIVE

Other Energy-Saving Strategies

Ingersoll Rand

©2011 Trane a business of Ingersoll Rand

High-Performance VAV Systems
Today's Topics

- ASHRAE 189.1 requirements
- Optimized VAV system controls
- Cold-air distribution
- Air-to-air energy recovery
- Other energy-saving strategies
- Energy modeling results
- Summary

89 © 2011 Trane, a business of Ingersoll-Rand

"High-Performance" Rooftop VAV System

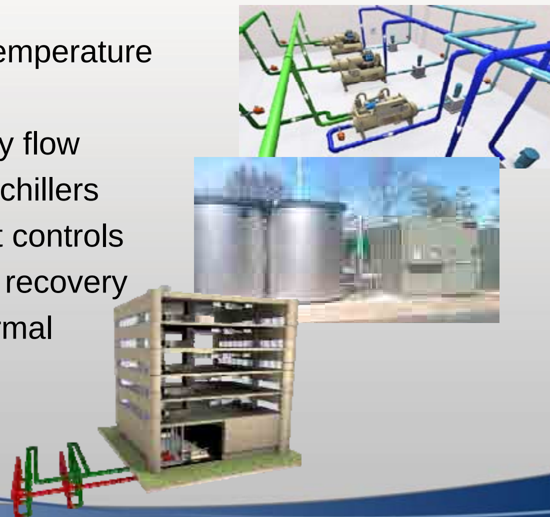
- High-efficiency rooftop
- Evaporative condensing
- Central relief/exhaust fan, rather than a return fan
- Solar hot-water system for reheat

rooftop unit with evaporative condenser

90 © 2011 Trane, a business of Ingersoll-Rand

“High-Performance” Chilled-Water System

- Low flow, low temperature
- Ice storage
- Variable primary flow
- High-efficiency chillers
- Optimized plant controls
- Waterside heat recovery
- Central geothermal



91 © 2011 Trane, a business of Ingersoll-Rand

TRANE

High-Performance VAV Systems

engineers newsletter LIVE

Example Energy Analyses

Ingersoll Rand

©2011 Trane a business of Ingersoll Rand

High-Performance VAV Systems
Today's Topics

- ASHRAE 189.1 requirements
- Optimized VAV system controls
- Cold-air distribution
- Air-to-air energy recovery
- Other energy-saving strategies
- Energy modeling results
- Summary

93 | © 2011 Trane, a business of Ingersoll-Rand

large office building
Example Energy Analysis

"Baseline" chilled-water VAV system

- Per ASHRAE 90.1-2007, Appendix G
- 55ºF supply air

"High-performance" chilled-water VAV system

- 48ºF supply air (no downsizing of ductwork)
- Optimized VAV system controls (ventilation optimization, SAT reset)
- Parallel fan-powered VAV terminals
- Low-flow, water-cooled chiller plant

94 | © 2011 Trane, a business of Ingersoll-Rand

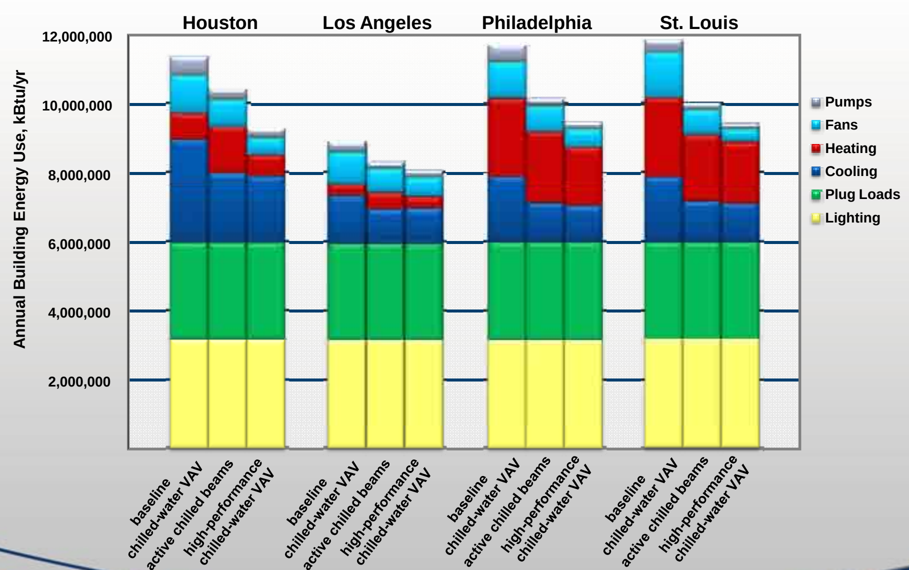
large office building

Example Energy Analysis (continued)

Active chilled beam (ACB) system

- Four-pipe active chilled beams
- Separate primary AHUs for perimeter and interior areas (with airside economizers)
- Water-cooled chiller plant supplying the chilled beams
- Separate low-flow, water-cooled chiller plant supplying the primary AHUs

95 © 2011 Trane, a business of Ingersoll-Rand



96 © 2011 Trane, a business of Ingersoll-Rand

small office building
Example Energy Analysis

“Baseline” rooftop VAV system

- Per ASHRAE 90.1-2007, Appendix G
- 55ºF supply air

“High-performance” rooftop VAV system

- High-efficiency, air-cooled packaged rooftop unit
- 52ºF supply air (no downsizing of ductwork)
- Optimized VAV system controls (ventilation optimization, SAT reset)
- Parallel fan-powered VAV terminals

© 2011 Trane, a business of Ingersoll-Rand

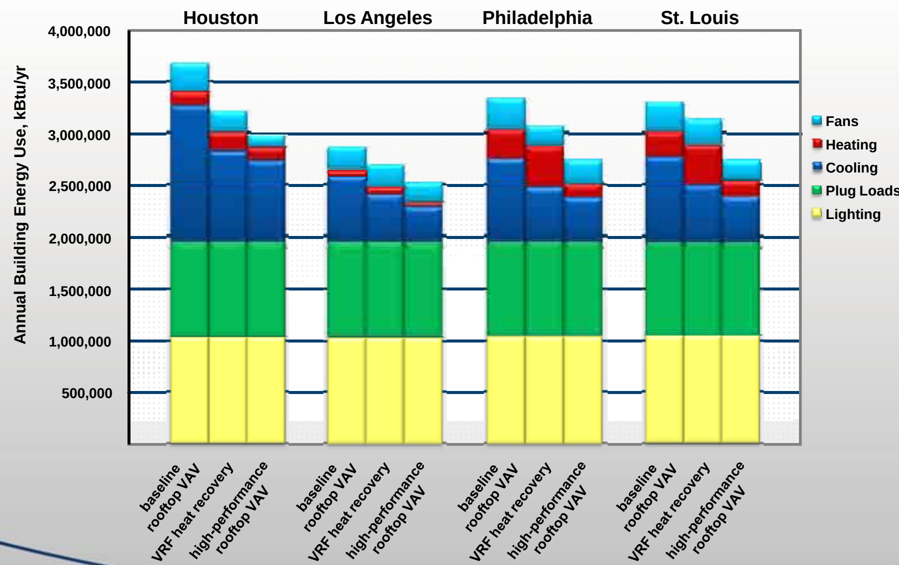
small office building
Example Energy Analysis (continued)

Variable refrigerant flow (VRF) system

- Heat recovery, air-cooled outdoor units
- Packaged DX dedicated outdoor-air unit with hot gas reheat

© 2011 Trane, a business of Ingersoll-Rand

©2011 Trane a business of Ingersoll Rand



99 | © 2011 Trane, a business of Ingersoll-Rand

Advanced Energy Design Guides

www.ashrae.org/freeaedg

- Funded by U.S. Dept of Energy
- Climate-specific recommendations for achieving 30% or 50% energy savings (envelope, lighting, HVAC, water heating)
- Based on building energy simulations

Item	Component	Recommendation	How-To Tip	
Packaged Rooftop VAV System	Rooftop air conditioner (≥240 kBtu/h)	10.0 EER and 10.4 IPLV	HV5, HV7–8, HV10	
	Gas furnace (≥225 kBtu/h)	80% E_t		
	Gas boiler	85% E_c	HV5, HV7, HV10, HV26	
	Economizer	>54 kBtu/h	HV13	
	Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
	Fans	1.3 hp/1000 cfm	HV19	
Item	**Component**	**Recommendation**	**How-To Tip**	
VAV and Chiller System	Air-cooled chiller efficiency	9.6 EER and 11.5 IPLV	HV6–8, HV10, HV25	
	Water-cooled chiller efficiency	Comply with Standard 90.1*	HV6–8, HV10, HV25	
	Gas boiler	85% E_c	HV6–7, HV10, HV26	
	Economizer	>54 kBtu/h	HV13	
	Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
	Fans	1.3 hp/1000 cfm	HV19	

100 | © 2011 Trane, a business of Ingersoll-Rand

Advanced Energy Design Guides

AEDG for Small or Medium Office Buildings

- "High-performance" rooftop VAV systems are included as an option to achieve **50%** energy savings

AEDG for K-12 Schools

- Both rooftop VAV and chilled-water VAV systems are included as options to achieve **30%** energy savings

AEDG for Small Hospitals and Healthcare Facilities

- Both rooftop VAV and chilled-water VAV systems are included as options to achieve **30%** energy savings

 © 2011 Trane, a business of Ingersoll-Rand

summary
High-Performance VAV Systems

- Optimized VAV system controls
- Cold-air distribution
- Air-to-air energy recovery
- Other energy-saving strategies

 © 2011 Trane, a business of Ingersoll-Rand

©2011 Trane a business of Ingersoll Rand

References for This Broadcast
Where to Learn More

www.trane.com/EN

103 | © 2011 Trane, a business of Ingersoll-Rand

Watch Past Broadcasts
ENL Archives

Insightful topics on HVAC system design:

- Chilled-water plants
- Air distribution
- Refrigerant-to-air systems
- Control strategies
- Industry standards and LEED
- Energy and the environment
- Acoustics
- Ventilation
- Dehumidification

www.trane.com/ENL

104 | © 2011 Trane, a business of Ingersoll-Rand

©2011 Trane a business of Ingersoll Rand

LEED Continuing Education Courses

on-demand, no charge, 1.5 CE credits

- ASHRAE Standards 62.1 and 90.1 and VAV Systems
- ASHRAE standard 62.1: Ventilation Rate Procedure
- ASHRAE 90.1-2010
- Energy Saving Strategies for Rooftop VAV Systems
- Air-Handing Systems, Energy and IAQ
- Central Geothermal System Design and Control
- Ice Storage Design and Control

www.trane.com/ContinuingEducation

105 © 2011 Trane, a business of Ingersoll-Rand

2011 ENL Programs

- **March**
  Upgrading Existing Chilled-Water Systems
- **June**
  High-Performance VAV Systems
- **October**
  Dedicated Outdoor-Air Units

106 © 2011 Trane, a business of Ingersoll-Rand

Trane *Engineers Newsletter Live* program

Bibliography

8 June 2011

High-Performance VAV Systems

Industry Standards

American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE). *ANSI/ASHRAE Standard 62.1-2010: Ventilation for Acceptable Indoor Air Quality*. Available at www.ashrae.org/bookstore

American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE). *ANSI/ASHRAE IESNA Standard 90.1-2010: Energy Standard for Buildings Except Low-Rise Residential Buildings*. Available at www.ashrae.org/bookstore

American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE). *ANSI/ASHRAE/USGBC/IES Standard 189.1-2009: Standard for the Design of High-Performance Green Buildings Except Low-Rise Residential Buildings*. Available at www.ashrae.org/bookstore

Industry Articles, Papers, and Publications

Advanced Energy Design Guides <www.ashrae.org/aedg>

American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc. (ASHRAE). 1996. Cold Air Distribution System Design Guide. Atlanta, GA: ASHRAE.

California Energy Commission (CEC). 2003. Advanced Variable Air Volume System Design Guide. Sacramento, CA: CEC.

Murphy, J. and N. Maldeis, "Using Time-of-Day Scheduling to Save Energy," *ASHRAE Journal* 51(5), May 2009, pp. 42-48.

Stanke, D., "System Operation: Dynamic Reset Options," *ASHRAE Journal* 48(12), December 2006, pp 18–32.

Stanke, D., "Single-Path Multiple-Zone System Design," *ASHRAE Journal* 47(1) January 2005, pp 28-35.

Wei, G., Liu, M., and D. Claridge, "Optimize the Supply Air Temperature Reset Schedule for a Single-Duct VAV System," *Proceedings of the Twelfth Symposium on Improving Building Systems in Hot and Humid Climates,* San Antonio, TX, May 2000.

Trane Application Manuals

available to purchase from <www.trane.com/bookstore>

Murphy, J. and J. Harshaw. *Rooftop VAV Systems,* application manual SYS-APM007-EN, November 2009.

Murphy, J. and B. Bakkum. *Chilled-Water VAV Systems,* application manual SYS-APM008-EN, September 2009.

Murphy, J. and B. Bradley. *Air-to-Air Energy Recovery,* application manual SYS-APM003-EN, September 2008.

Trane *Engineers Newsletter Live* program

Bibliography

June 2011

High-Performance VAV Systems

Trane *Engineers Newsletters*

available to download from <www.trane.com/engineersnewsletter>

Eppelheimer, D. "Cold Air Makes Good $ense." *Engineers Newsletter* 29-2 (2000).

Murphy, J. "CO_2-Based Demand-Controlled Ventilation with ASHRAE Standard 62.1." *Engineers Newsletter* 34-5 (2005).

Murphy, J. "Energy-Saving Control Strategies for Rooftop VAV Systems." *Engineers Newsletter* 35-4 (2006).

Stanke, D. "Potential ASHRAE Standard Conflicts: Indoor Air Quality and Energy Standards." *Engineers Newsletter* 37-4 (2008).

Stanke, D. "VAV System Optimization: Critical Zone Reset." *Engineers Newsletter* 20-2 (1991).

Trane *Engineers Newsletter Live* Broadcasts

available to view online at <www.trane.com/ENL>

Stanke, D., Schwedler, M., Taylor, S., and J. Harshaw, "ASHRAE Standards 62.1 and 90.1, and VAV Systems," *Engineers Newsletter Live* broadcast (November 2008).

Murphy, J., Stanke, D., Lee, T., and M. Schwedler, "CO2-Based Demand-Controlled Ventilation," *Engineers Newsletter Live* broadcast (November 2005).