Agenda and Objectives

Trane Engineers Newsletter Live Series

Energy-Saving Strategies for Rooftop VAV Systems

Rooftop variable-air-volume (VAV) systems are used to provide comfort in a wide range of building types and climates. This ENL discusses HVAC system design and operating strategies that can save energy in these systems.

By attending this event you will be able to:

1. Identify cost-effective strategies to reduce the energy used by rooftop VAV systems
2. Summarize how to analyze the economic benefit of various energy-savings strategies
3. Identify system-level control strategies that improve the performance and flexibility of rooftop VAV systems.

Agenda

1) Overview of a rooftop VAV system (components, benefits, challenges, code requirements)
2) Equipment configuration strategies
    a) high-efficiency versus standard efficiency (EER, IPLV)
    b) air-to-air energy recovery
    c) relief fan versus return fan
    d) air-cooled evaporative condensing
    e) hot gas bypass
    f) fan-powered VAV
    g) ECMs on fan-powered VAV boxes
3) System design strategies
    a) Single-zone VAV (arenas, auditoriums, gymnasiums, sanctuaries)
    b) Hot gas reheat for unoccupied humidity control
    c) Duct design
    d) "Twinning" units into a shared supply duct system?
    e) DOA unit delivering cold OA direct to spaces or dual-duct boxes
    f) Maintenance program
4) Optimized system control strategies
    a) Airside economizing
    b) Optimum start/stop
    c) Fan-pressure optimization
    d) Supply-air temperature reset
    e) Ventilation optimization: DCV (TOD schedule, occupancy sensor, CO2 sensor) combined with ventilation reset
4) Example TRACE analysis
5) Summary

Presenters

Trane Engineers Newsletter Live Series

Energy-Saving Strategies for Rooftop VAV Systems

(2006)

Phil Baggett | marketing engineer – large rooftops | Trane
Since starting with Trane in 1968 Phil has served in several roles of increasing responsibility in manufacturing engineering, product marketing, training, product planning, and product management organizations. Phil's primary responsibility as marketing engineer for large rooftop products is to identify and implement product change opportunities, and new product-platform development initiatives. He is also responsible for identifying and assisting in the development of sales and application tools to support those initiatives.

John Murphy | senior applications engineer | Trane
John has been with Trane since 1993. His primary responsibility as an applications engineer is to aid system design engineers and Trane sales personnel in the proper design and application of HVAC systems. His main areas of expertise include dehumidification, air-to-air energy recovery, psychrometry, ventilation, and ASHRAE Standards 15, 62.1, and 90.1.

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 satellite broadcasts. He is also the primary author of the Trane Air Conditioning Clinics, a series of training manuals on HVAC fundamentals. John is a member of ASHRAE, has authored several articles for the ASHRAE Journal, and is a member of that society's "Moisture Management in Buildings" and "Mechanical Dehumidifiers" technical committees.

Paul Solberg | senior principal applications engineer | Trane
A mechanical engineer from the University of Wisconsin at Platteville, Paul is a 26-year veteran of Trane. He specializes in compressor and refrigeration systems, and has authored numerous Trane publications on these subjects, including application manuals, engineering bulletins, and Engineers Newsletters. Paul served in the technical service and applications engineering areas at various manufacturing locations, where he developed particular expertise supporting split systems, small packaged chillers, rooftop air conditioners, and other unitary products.

Justin Wieman| C.D.S. marketing engineer | Trane
After finishing the Trane Graduate Training Program in 2001, Justin joined the Customer Direct Service (C.D.S.) group as a marketing engineer. Since then he has provided support for various Trane software applications. Presently he is team leader for Trane's Analysis Software group, and project manager for the Trane Air-Conditioning Economics (TRACE™ 700) product family.

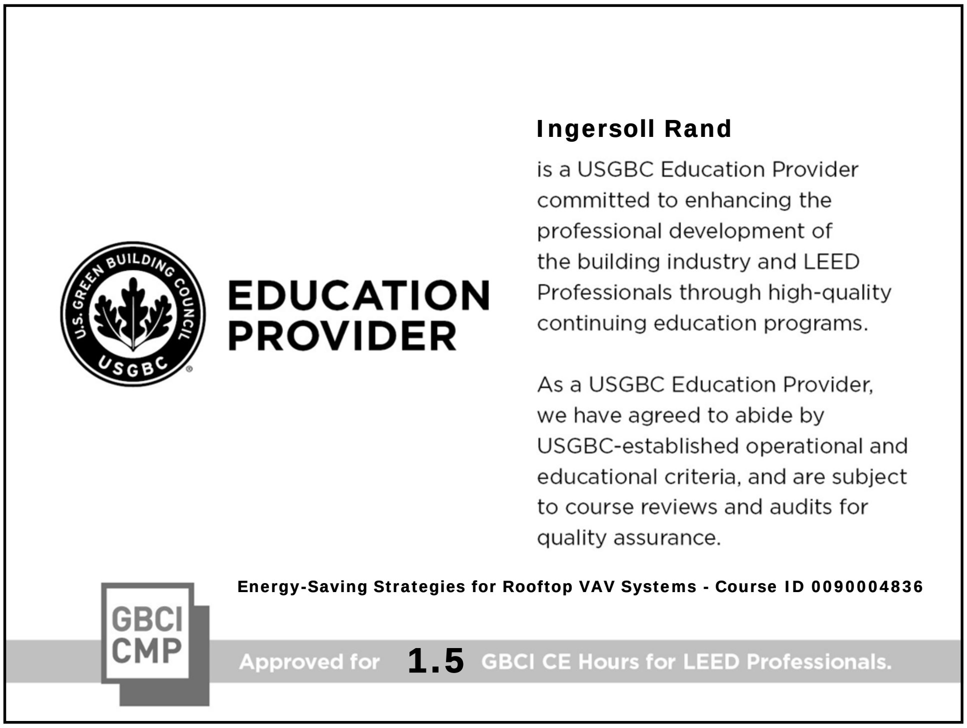
Energy-Saving Strategies for Rooftop VAV Systems

TRANE

an
Engineers Newsletter Live
telecast

rooftop VAV systems
Energy-Saving Strategies

- **Equipment configurations**
- **Alternative system designs**
- **Optimized system controls**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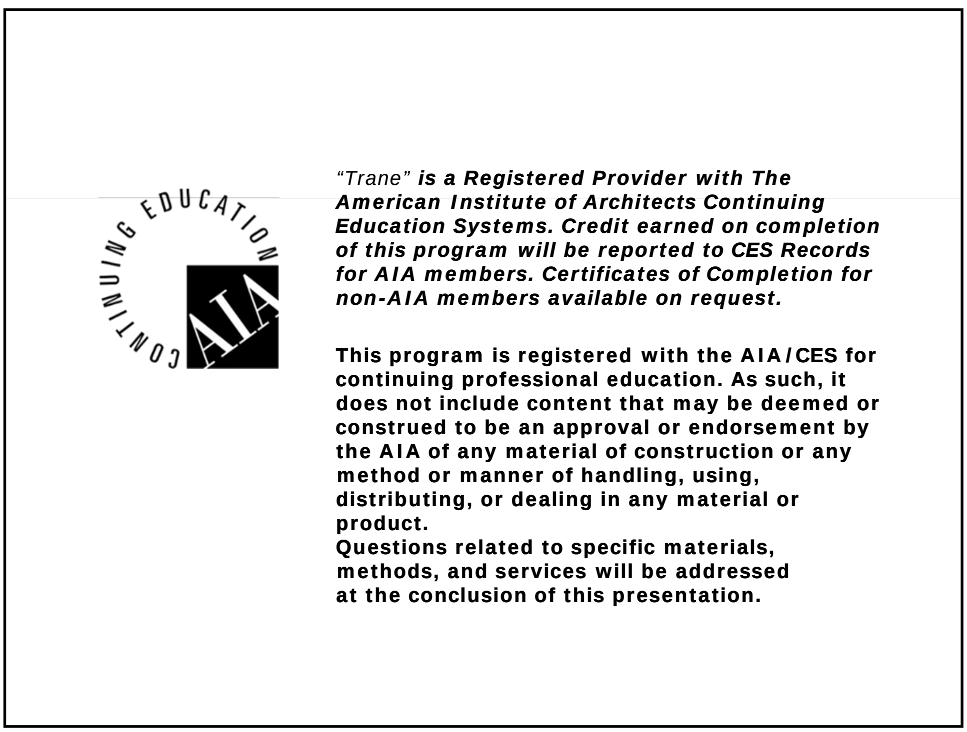
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AIA continuing education

Learning Objectives

Participants will learn the following about rooftop VAV systems:

- **Cost-effective strategies to reduce energy use**
- **How to analyze economic impact of various energy-saving strategies**

Today's Presenters

Justin Wieman
marketing engineer

Phil Baggett
marketing engineer

John Murphy
applications engineer

Paul Solberg
applications engineer

ASHRAE Standard 90.1 and 62.1 Requirements

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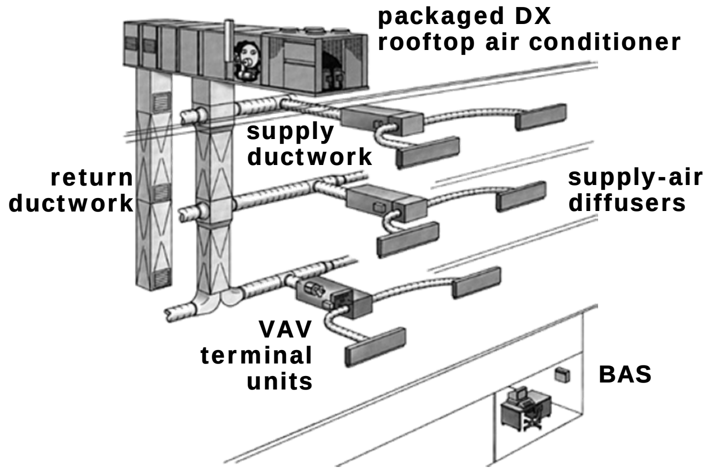
Energy-saving strategies for rooftop VAV systems

Rooftop VAV System



Satisfy

- **Occupant comfort**
- **Code (or standard) minimum requirements**
  - ASHRAE 90.1-2004
  - ASHRAE 62.1-2004

ASHRAE 90.1-2004
Rooftop VAV Systems

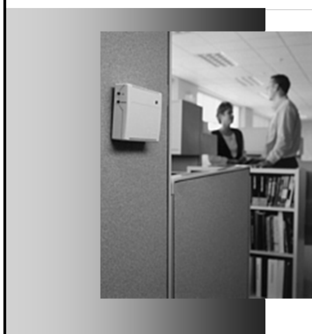
- **Mandatory**
  - Equipment efficiency
  - Controls
- **Prescriptive**
  - Economizers
  - Limitation on reheat
  - Design fan power
  - Fan control
  - Energy recovery
  - Hot gas bypass

packaged rooftop (air-cooled)
Equipment Efficiencies

Size Category	Heating Section Type	Minimum Efficiency
<65,000 Btu/h	All	12.0 SEER*
≥65,000 Btu/h and <135,000 Btu/h	Electric Resistance Other	10.3 EER 10.1 EER
≥135,000 Btu/h and <240,000 Btu/h	Electric Resistance Other	9.7 EER 9.5 EER
≥240,000 Btu/h and <760,000 Btu/h	Electric Resistance Other	9.5 EER, 9.7 IPLV 9.3 EER, 9.5 IPLV
≥760,000 Btu/h	Electric Resistance Other	9.2 EER, 9.4 IPLV 9.0 EER, 9.2 IPLV

*NAECA requires 13.0 SEER

Zone Thermostatic Controls



- **Required for each zone**
  Perimeter can be treated differently
- **≥5° F deadband**
  Dual setpoint or deadband (can be software for DDC)

systems ≥ 15,000 Btu/h

Automatic Shutdown

- **Automatic 7-day/week time clock with 10-hour battery backup**
  - Exception: 2-day/week thermostat for residential applications
- **Occupancy sensor**
- **Manually operated timer (maximum duration: 2 hours)**
- **Security system interlock**

systems ≥ 15,000 Btu/h

Setback Controls

- **Climate zones 2-8: Lower heating setpoint to 55°F or less**
- **Climate zones 1b, 2b, 3b (hot/dry): Automatically restart, temporarily operate**
  - Raise cooling setpoint to 90°F or higher, or
  - Prevent high space humidity levels

mandatory HVAC provisions

Other Off-Hour Controls

- **Provide optimum start if system supply-air capacity > 10,000 cfm**
- **Zone isolation:**
  - 25,000 ft² maximum zone size on one floor
  - Isolation devices to shut off outdoor and exhaust airflow
  - Central systems capable of stable operation

ventilation
High Occupancy

If outdoor airflow > 3,000 cfm and design occupancy > 100 p/1000 ft²…

Automatically reduce outdoor air intake below design requirements when spaces are partially occupied

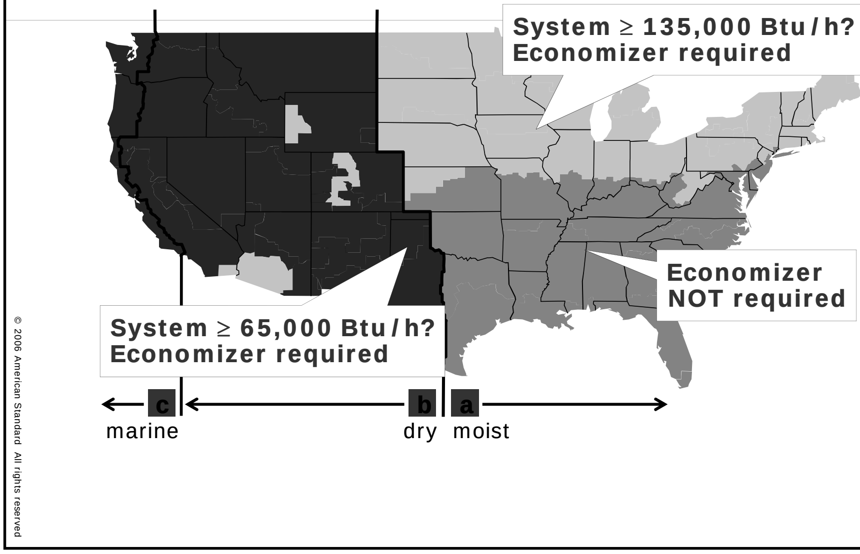
Exception:
Systems with exhaust-air energy recovery complying with Section 6.5.6.1

ASHRAE 90.1-2004
Rooftop VAV systems

- **Mandatory**
  - Equipment efficiency
  - Controls
- **Prescriptive**
  - Economizers
  - Limitation on reheat
  - Design fan power
  - Fan control
  - Energy recovery
  - Hot gas bypass

Std 90.1 economizer requirements

Exception (a)



airside economizer use

Exceptions

- (a) Individual fan-cooling units with less-than-minimum capacities installed in specific climate zones
- (b) Systems with gas-phase outdoor air cleaning to meet ASHRAE Standard 62
- (c) Systems with > 25% of supply air serving spaces humidified above 35°F DP for process needs
- (d) Systems with condenser heat recovery

airside economizer use
Exceptions

(e) **Residential space systems with capacities < 5× limit in Exception (a)**

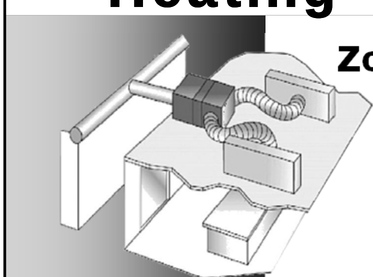
(f) **Space sensible cooling load ≤ transmission + infiltration load at 60°F**

(g) **Systems that operate < 20 hr / wk**

(h) **Supermarket applications, where outdoor air for cooling affects open refrigerated cases**

(i) **Systems with high mechanical cooling efficiency (≥ Table 6.3.2 requirements)**

Simultaneous Heating–Cooling



Zone controls

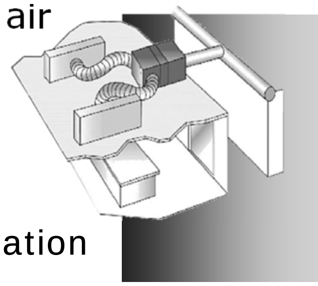
- No reheating
- No recooling
- No mixing or simultaneously supplying mechanically-cooled and mechanically-heated air
- Exceptions based on zone airflow

simultaneous heating–cooling

Exceptions

Zone airflow does not exceed whichever is largest:

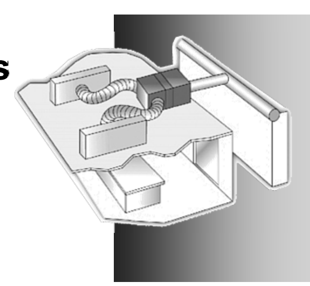
- ASHRAE Standard 62 zone requirements for outdoor air
- 0.4 cfm/ft²
- 30% of supply air
- 300 cfm
- ASHRAE Standard 62 equation



simultaneous heating–cooling

Exceptions

- **Zones with special pressurization requirements**
- **Zones with code-required minimum circulation rates**
- **Site-recovered or site-solar energy provides ≥ 75% of reheat energy**



dehumidification
Exceptions

- Reducing supply airflow to 50%, or minimum ventilation rate
- Systems < 6.67 tons that can unload at least 50%
- Systems smaller than 3.3 tons

dehumidification
Exceptions

- Systems with specific humidity requirements (museums, surgical suites)
- 75% of reheat/recool energy is site-recovered or site-solar

Fan Power Limitation

	Allowable nameplate motor power	
Supply air volume	Constant volume	Variable volume
< 20,000 cfm	**1.2 hp**/1,000 cfm	**1.7 hp**/1,000 cfm
≥ 20,000 cfm	**1.1 hp**/1,000 cfm	**1.5 hp**/1,000 cfm

Air System Control

VAV fan control

- Motors ≥ 15 hp require
  - Variable-speed drive or
  - Vaneaxial fan with variable-pitch blades or
  - Design wattage ≤ 30% at 50% air volume
- DDC systems must include setpoint reset (fan-pressure optimization)

Airside Energy Recovery

- **Required if:**
  - Supply air capacity ≥ 5,000 cfm
  - Minimum outdoor air ≥ 70%
- **Recovery system effectiveness ≥ 50%**

Hot Gas Bypass

Rated capacity of system	Maximum HGBP capacity, % of total capacity
≤ 240,000 Btu/h	**50%**
> 240,000 Btu/h	**25%**

- **Applied in systems with stepped or continuous unloading**
- **Exception: Packaged unitary systems ≤ 90,000 Btu/h (7.5 tons)**

ASHRAE 62.1 Ventilation Requirements

- **Design**
  - Calculate zone ventilation airflow
  - Determine air distribution effectiveness
  - Calculate system design ventilation intake airflow
- **Operation:**
  - Dynamically calculate system ventilation airflow
  - In VAV system, fixed damper position does not meet requirements

Base Rooftop VAV System

- **Equipment efficiency**
- **Zone controls**
- **Economizer**
- **Simultaneous heating and cooling**
- **Design fan power**
- **Fan control**
- **Airside energy recovery**
- **Hot gas bypass**
- **Ventilation**

Equipment Configuration Strategies

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Energy-saving strategies for rooftop VAV systems

High-Efficiency Equipment

Benefits

- Reduced operating cost
- Potential energy rebates
- Meet mandated energy codes
- Environmentally intelligent, reduces greenhouse gas emissions

Drawbacks

- Higher first cost
- Extended return on investment in some areas

High-Efficiency Equipment

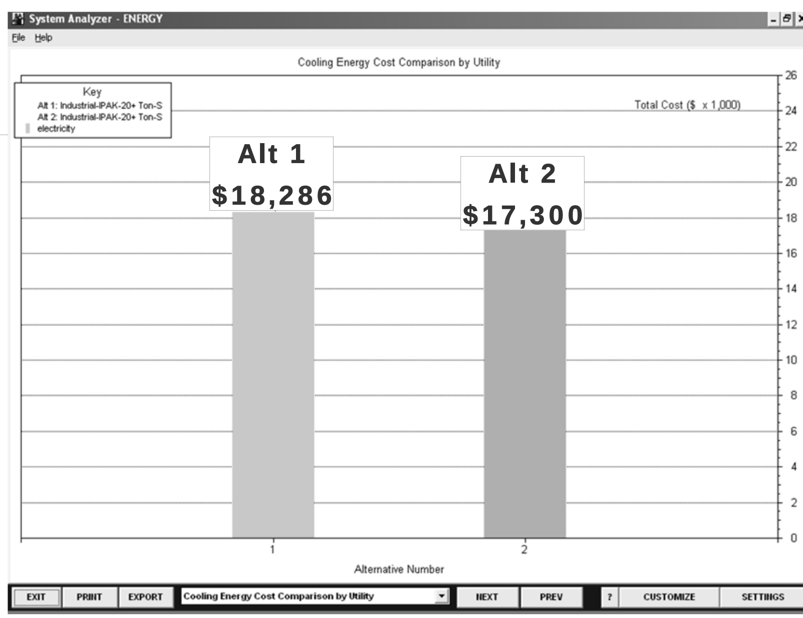
- **High-efficiency supply and exhaust fan motors**
  - Insist on NEMA Premium rated
- **Additional evaporator coil rows**
- **Additional condenser coil capacity**

High-Efficiency Equipment

- **Standard efficiency rooftop (Alt 1)**
  - 9.6 EER
    - 604 gross MBH
- **High-efficiency rooftop (Alt 2)**
  - 10.4 EER
    - 644 gross MBH

High-Efficiency Equipment

- **Example energy savings**
  - Three story 60,000 sq. ft office building
  - VAV with reheat system
  - Default settings for building type and exposures
  - Alameda, CA weather data and PG&E utility rate

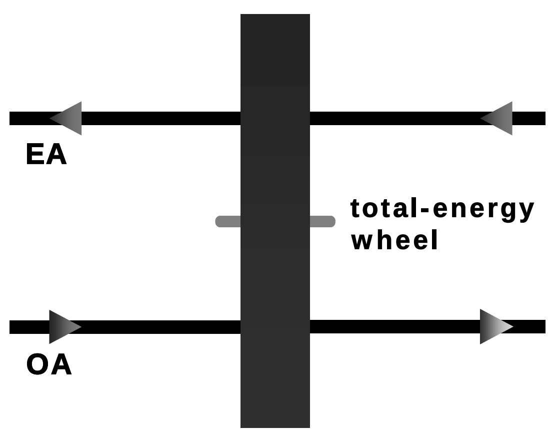


High-Efficiency Equipment

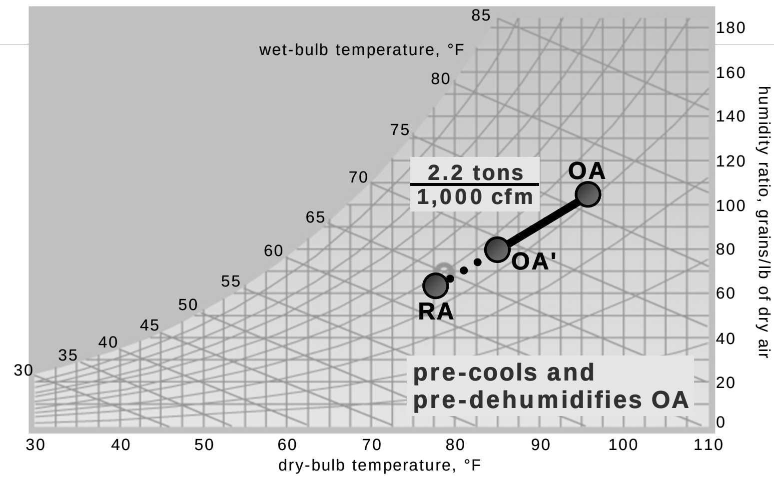
- **Reduced fossil fuel emissions**
  - CO_2 -5,415 lbm/yr
  - SO_2 -5,956 gm/yr
  - NO_x -8,122 gm/yr

ENVIRONMENTAL IMPACT ANALYSIS	Alt 2 - 1
CO2 Impact (- denotes Reduction)	-5,415 lbm/year
SO2 Impact (- denotes Reduction)	-5,956 gm/year
NOX Impact (- denotes reduction)	-8,122 gm/year

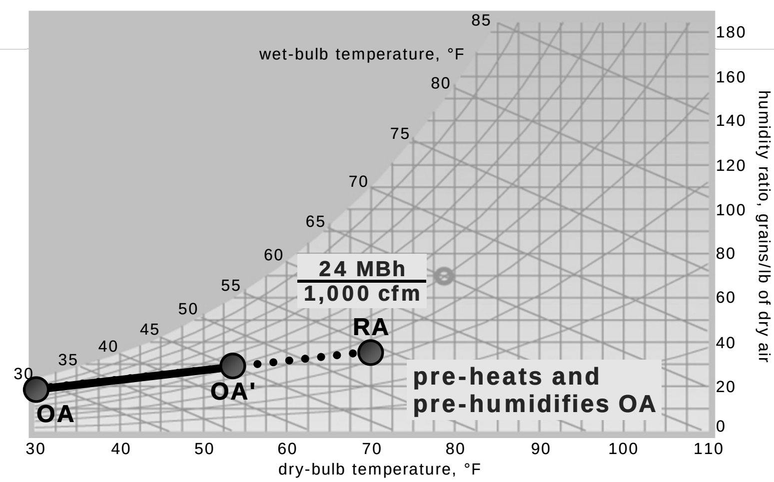
Air-to-Air Energy Recovery



total-energy recovery:
Example in Cooling Mode



total-energy recovery:
Example in Heating Mode



Air-to-Air Energy Recovery

Benefits

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

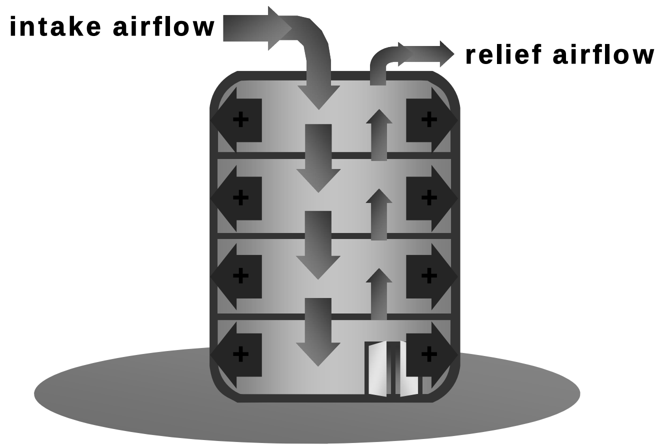
Drawbacks

- Increases fan energy
- Requires exhaust air be routed back to rooftop unit

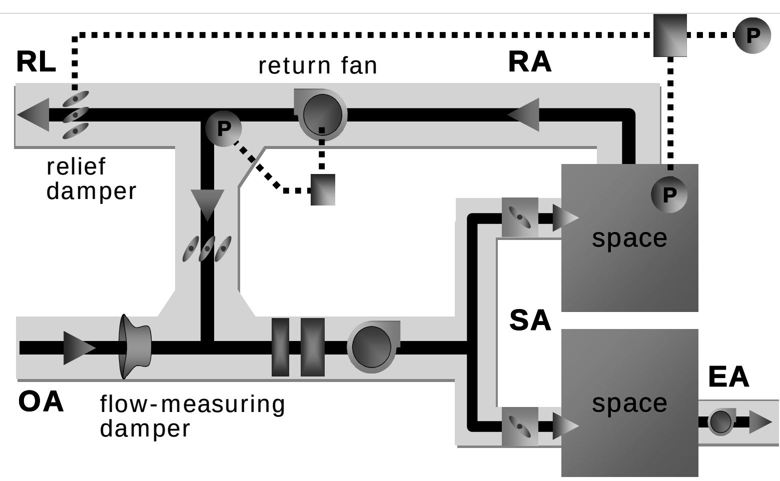
Air-to-Air Energy Recovery

- Size energy-recovery device for minimum outdoor airflow
- Strive for balanced airflows
- Integrate control with airside economizer operation
- How much cross-leakage is acceptable?
- Provide a means of capacity control

Building Pressure Control

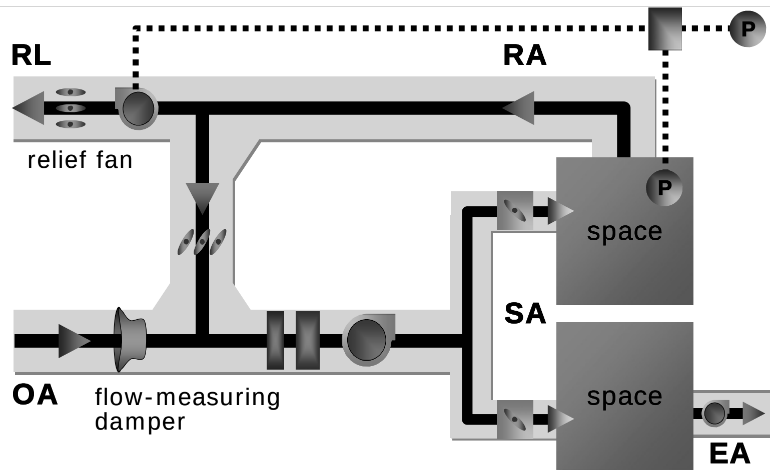


control based on RA plenum pressure
Central Return Fan



modulated control

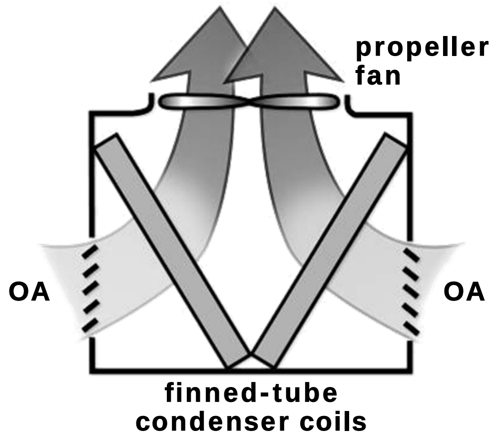
Central Relief Fan



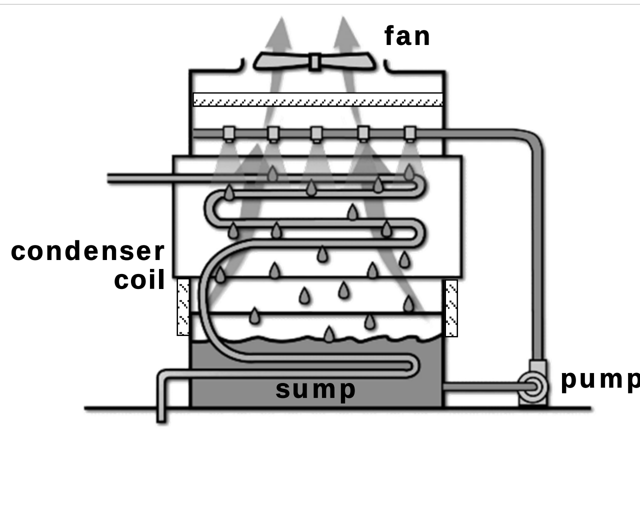
Return vs. Relief Fan?

Return Fan	Relief Fan
■ **Partial static placed on return fan** Use in systems with high RA pressure drop	■ **Supply fan must be sized for entire static**
■ **Two continuous motors to provide ventilation air**	■ **Intermittent relief fan operation** Reduced operating cost
■ **(+) Pressurized diverting plenum** RA leakage out relief dampers	■ **(-) Pressurized diverting plenum** OA leakage in relief dampers

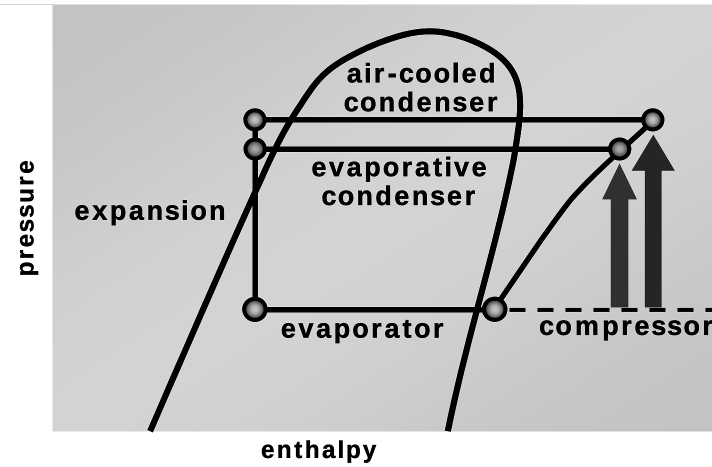
Air-Cooled Condenser



Evaporative Condenser



condensing
Air-Cooled vs. Evaporative



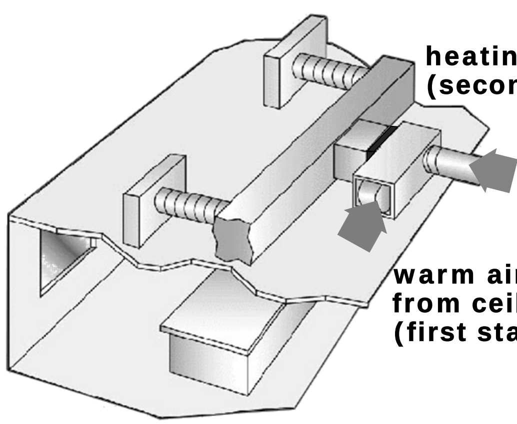
Avoid Hot Gas Bypass

- **Purpose**
  - Frost prevention
  - Stabilize discharge temperature
- **HGBP**
  - One step greater capacity
  - poor energy efficiency

Avoid Hot Gas Bypass

- Choose units that maximize the stages of compression
- Use intertwined coils
- Don't oversize rooftop tonnage… maximizes suction temperature
- Use frost control
- Remember that the average air condition is what is important

parallel
Fan-Powered VAV



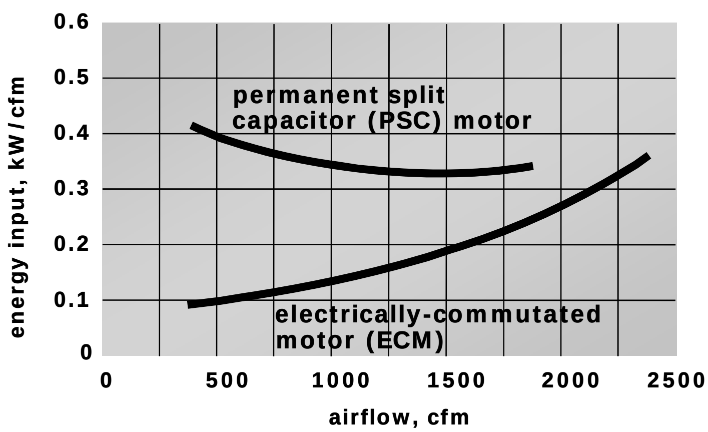
ECM Fan-Powered Boxes

Benefits

- **Reduces VAV terminal fan energy**

Drawbacks

ECM Efficiency



ECM Fan-Powered Boxes

Benefits

- Reduces VAV terminal fan energy
- Greater airflow range
- Capability for self-balancing
- Less-annoying sound levels

Drawbacks

- Higher first cost
- Potential for disruptive harmonic currents

Equipment Configuration Strategies

- High efficiency
- Energy recovery
- Exhaust fan
- Evaporative condenser
- Avoid hot gas bypass
- Fan-powered boxes
- Electronically commutated motors

Alternative System Designs

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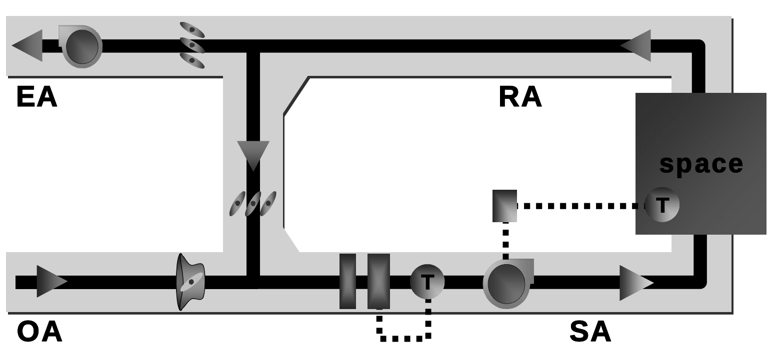
Energy-saving strategies for rooftop VAV systems

Single-Zone VAV



single-zone VAV
Benefits

- **Lower operating cost…**
  Reduces fan speed at part load
- **Reduced sound levels…**
  Reduces fan-generated noise at part load
- **Improved dehumidification…**
  Continues to supply cool, dry air at part load
- **Simple controls and standard equipment**

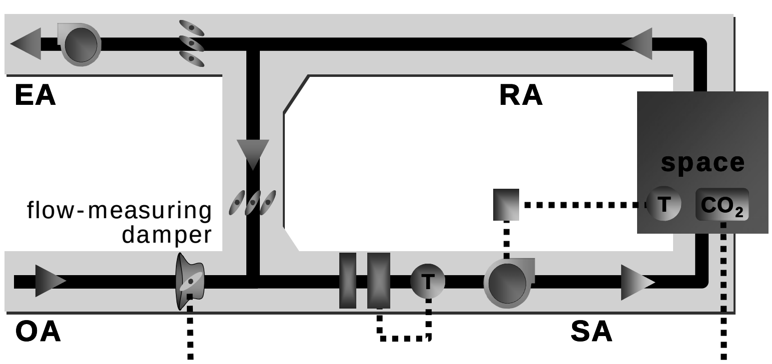
single-zone VAV
Application Considerations

- **Large zones should have uniform loads**
- **Design air distribution system for variable airflow**
  - Short, symmetrical ducts
  - Size for low-to-medium duct velocities
  - Diffusers that prevent "dumping"
- **Consider need for zone heating**

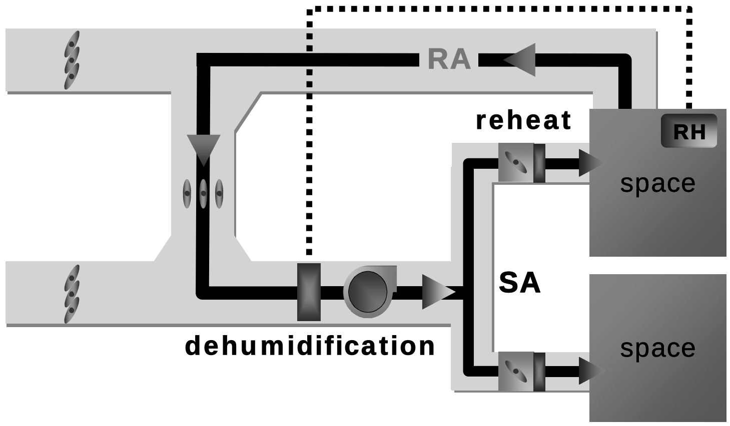
single-zone VAV
Application Considerations

- Prevent overcooling the zone… SA temperature reset
- Employ CO_2-based DCV

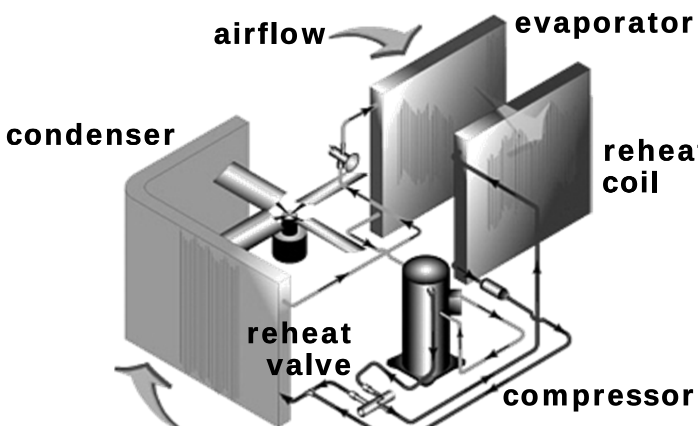
single-zone VAV
CO_2-Based DCV



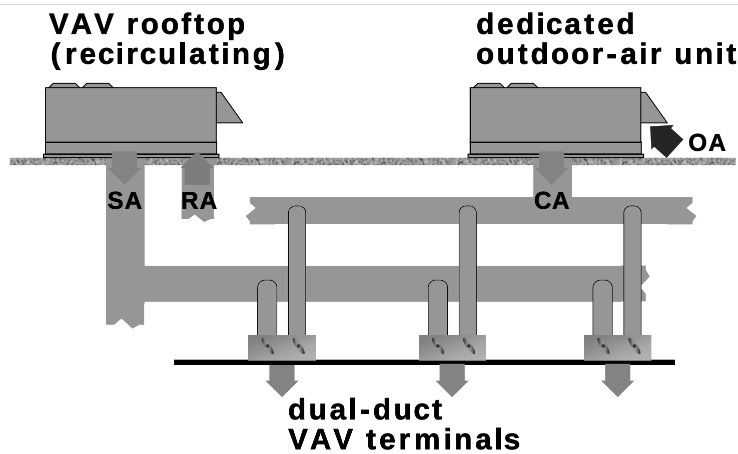
humidity control
Unoccupied Mode



unoccupied humidity control
Hot Gas Reheat



Dedicated OA System



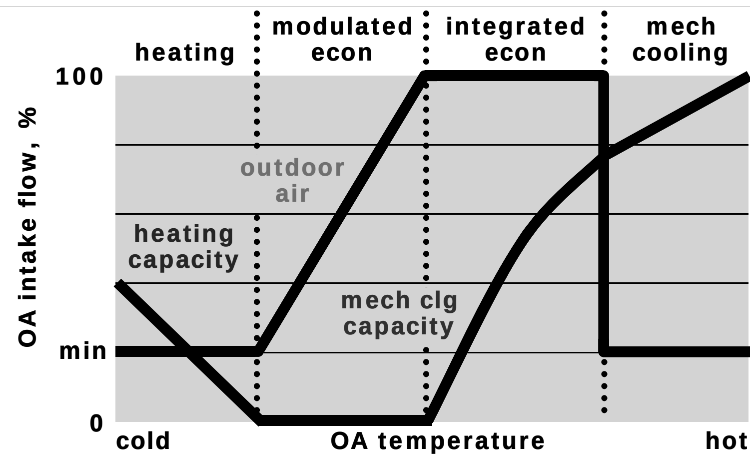
Alternative System Designs

- Single-zone VAV
- Demand-controlled ventilation
- Humidity control
- Dedicated outdoor-air unit in conjunction with rooftop

Optimized System Controls

Energy-saving strategies for rooftop VAV systems

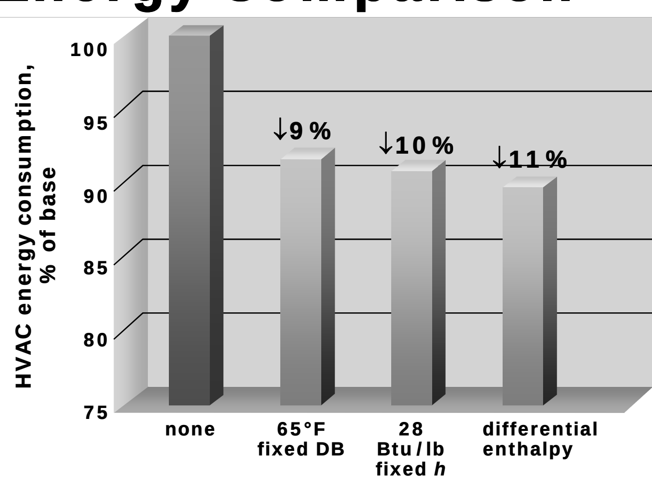
Airside Economizer



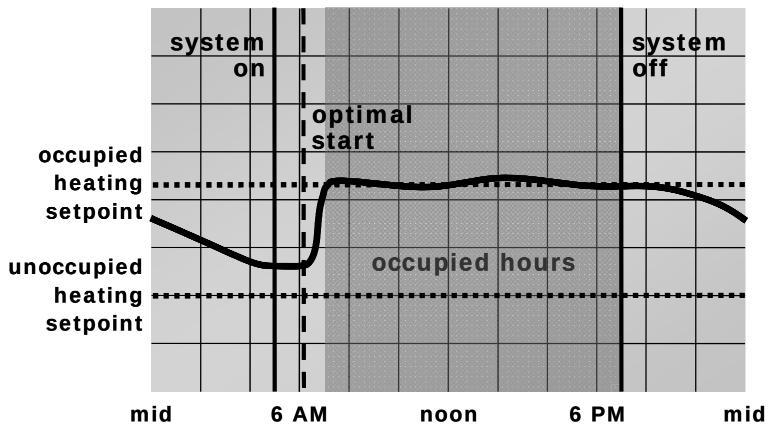
High-Limit Shutoff

Control type	Disable econ (minimum OA) when OA is:	Enable econ (up to 100% OA) when OA is:
Fixed dry bulb	Warmer than fixed setting	Cooler than fixed setting
Fixed enthalpy	Higher enthalpy than fixed setting	Lower enthalpy than fixed setting
Differential enthalpy	Higher enthalpy than RA	Lower enthalpy than RA

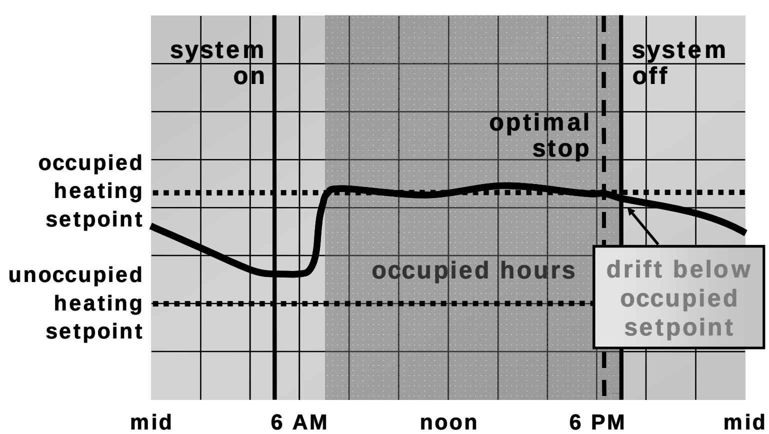
VAV system (Cincinnati, Ohio)
Energy Comparison



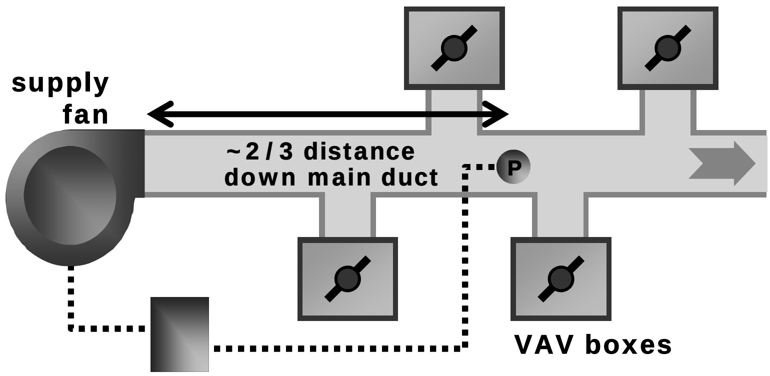
Optimal Start



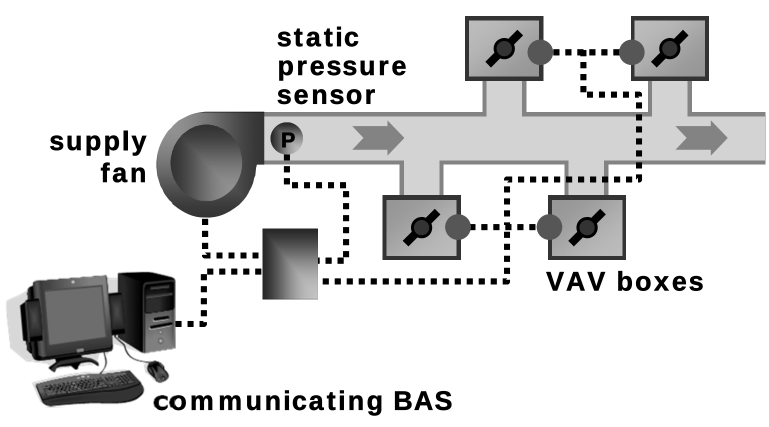
Optimal Stop



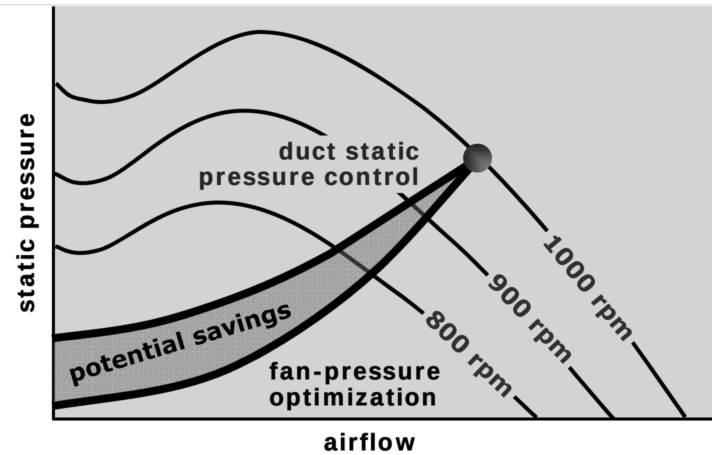
Supply Fan Control



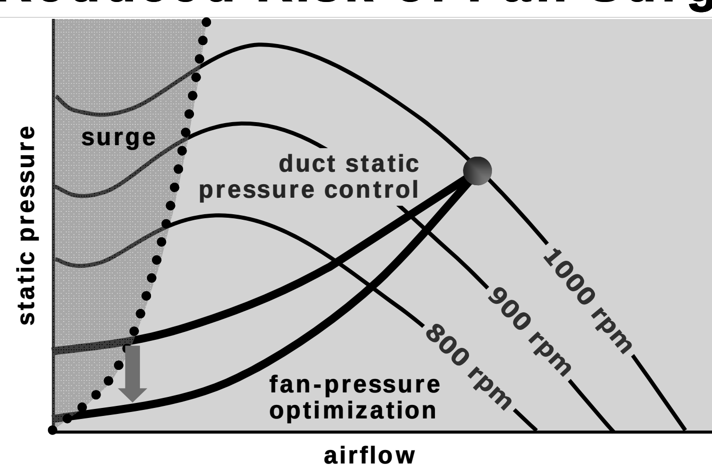
Fan Pressure Optimization



Part-Load Energy Savings



Reduced Risk of Fan Surge



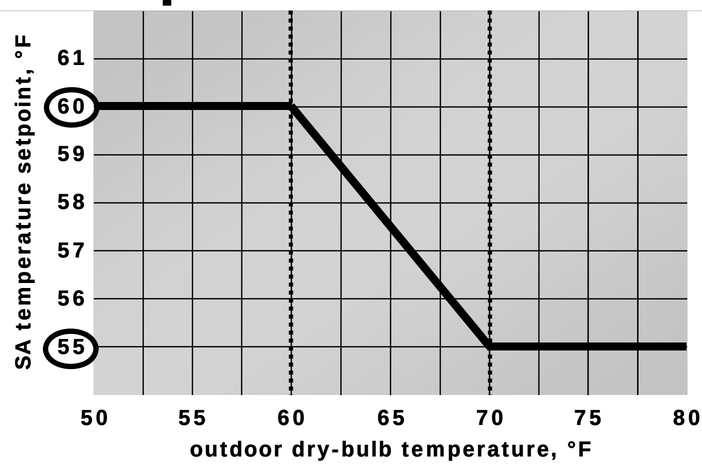
SA Temperature Reset

- **Decreases compressor energy**
  - Higher suction pressure
  - More hours of modulated economizing
- **Decreases reheat energy**
- **Increases fan energy**
- **Raises humidity level in the zones**

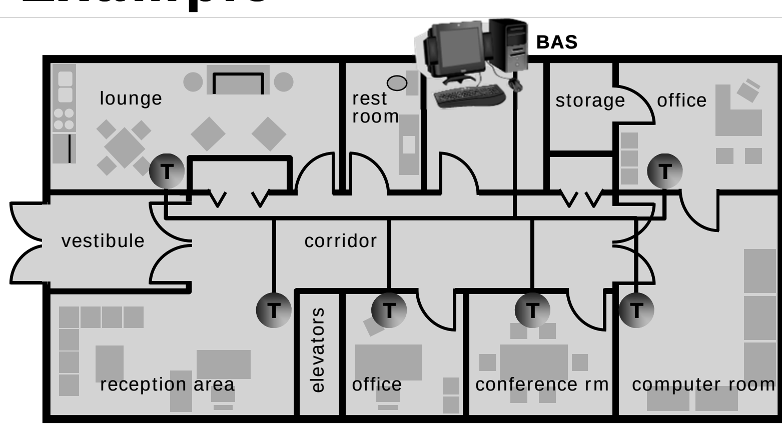
To Reset or Not to Reset

To Reset	Not to Reset
Mild climates (many hours when OADB < 60°F)	**Hot climates or humid climates (few hours when OADB < 60°F)**
Minimum VAV airflow settings > 30%	**Efficient part-load fan modulation**
Efficient air distribution system	**Inefficient air distribution system**
Interior zones with varying cooling loads	**Zones with near-constant cooling loads**

SAT reset based on OA temperature
Example



SAT reset based on “critical” zone
Example



Trane, in proposing these system design and application concepts, assumes no responsibility for the performance or desirability of any resulting system design. Design of the HVAC system is the prerogative and responsibility of the engineering professional.

SAT reset
Application Considerations

- **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

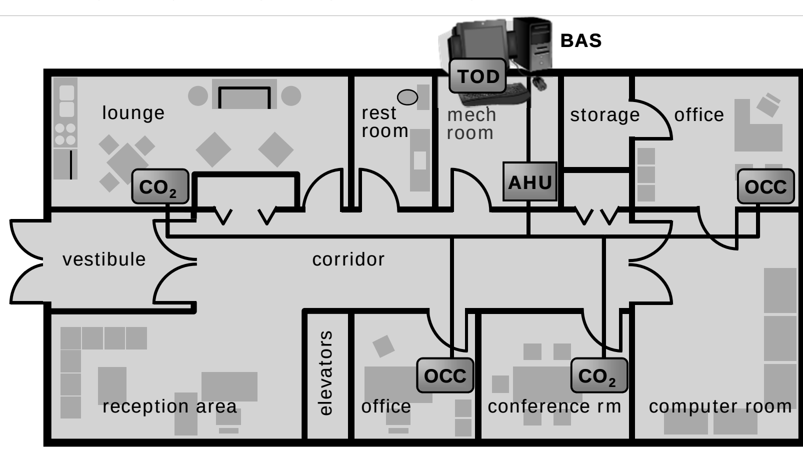
SAT reset
Application Considerations

- **Analyze the system**
  - Will compressor and reheat energy savings outweigh additional fan energy?
- **Consider impact on zone humidity**
  - Disable reset when humid outside
  - Use a humidity sensor to disable reset when zone humidity gets too high

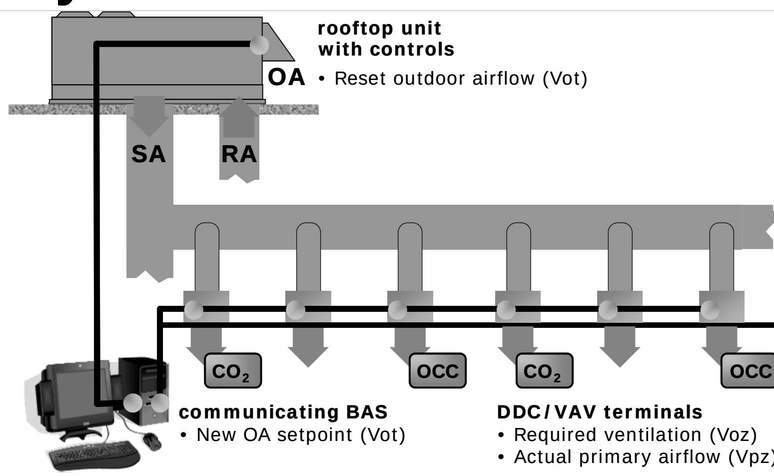
ASHRAE 62.1-2004
Dynamic Reset of OA

- **May reset OA intake flow or zone OA flow in response to:**
  - Variations in zone population (DCV)
  - Variations in ventilation efficiency due to changes in airflow (ventilation reset)

ventilation optimization
Zone Level: DCV



ventilation optimization
System Level: Vent Reset



ventilation optimization
DCV and Vent Reset

- Assures each zone receives proper ventilation without requiring a CO_2 sensor in every zone
- Enables documentation of actual ventilation system performance
- System-level ventilation reset equations are defined by ASHRAE 62

Optimized System Controls

- Economizer
- Optimal stop and start
- Fan pressure optimization
- Supply air temperature reset
- Demand controlled ventilation and ventilation reset

Analysis

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Energy-saving strategies for rooftop VAV systems

Building Analysis Tools

TRACE™ 700
HVAC load design and analysis software

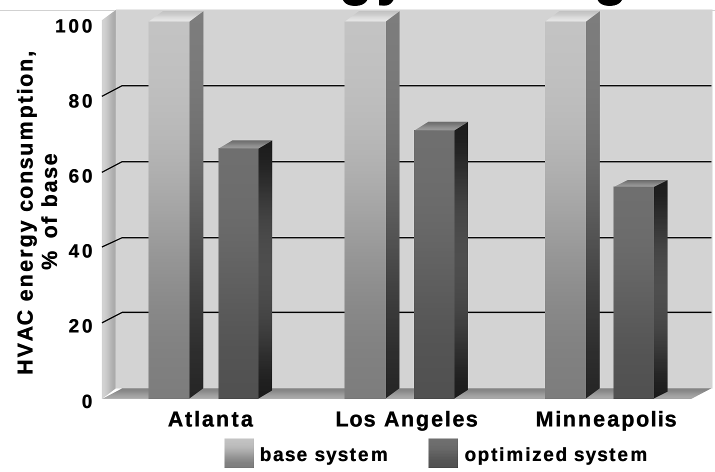
- Comprehensive energy and economic analysis for virtually any building

rooftop VAV system
Example Analysis

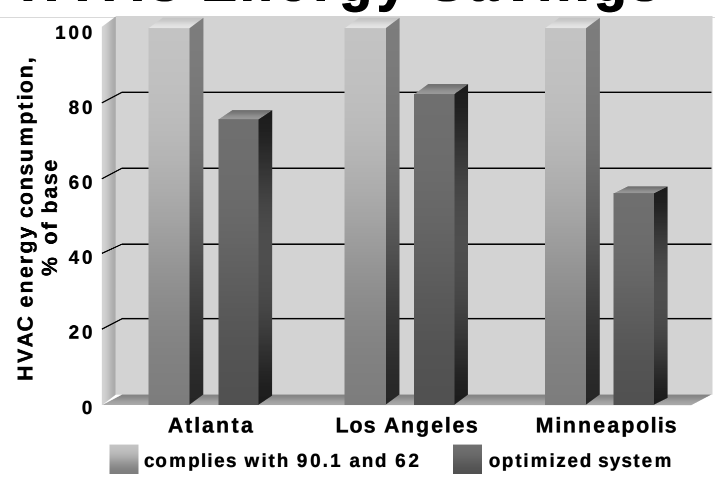
“Optimized” System

- **Optimal start**
- **SA temperature reset**
- **Ventilation optimization**
- **Fan-pressure optimization**
- **Total-energy wheel**
- **Comparative enthalpy economizer**
- **Parallel FPVAV (perimeter zones)**

rooftop VAV system
HVAC Energy Savings



rooftop VAV system
HVAC Energy Savings



Keep the system working properly

engineers newsletter LIVE

Energy-saving strategies for rooftop VAV systems

Proper Maintenance

- **Periodic maintenance enhances unit performance**
  - Always perform airside maintenance first
  - Inspect air filters regularly, clean or replace as necessary
    - 0.1 inch of additional static pressure increases supply motor kW by 7%
  - Inspect condensate drains and traps whenever filters are inspected, clean as needed

Proper Maintenance

- **Periodic maintenance enhances unit performance**
  - Inspect fresh- and return-air damper mechanisms
    - Clean blades as necessary
    - Verify all damper linkages move freely
  - Check supply/relief fan motor and shaft bearings, lubricate, repair, or replace as necessary

Proper Maintenance

- **Periodic maintenance enhances unit performance**
  - Inspect evaporator and condenser coils for dirt buildup, clean as needed
  - Make sure that condenser fans rotate freely, check bearings for wear
  - Verify all condenser fan mountings are secure

Proper Maintenance

- **Periodic maintenance enhances unit performance**
  - #1: Improper refrigerant charge
    - Overcharging decreases superheat and increases subcooling
    - 10% overcharge can increase compressor kW by approximately 3.5% at design conditions

Proper Maintenance

- **Periodic maintenance enhances unit performance**
  - #1: Improper refrigerant charge
    - Undercharging increases superheat and decreases subcooling… resulting in capacity loss
    - Always charge according to manufacturers recommendations, and instructions

Answers to Your Questions

engineers newsletter LIVE

Energy-saving strategies for rooftop VAV systems

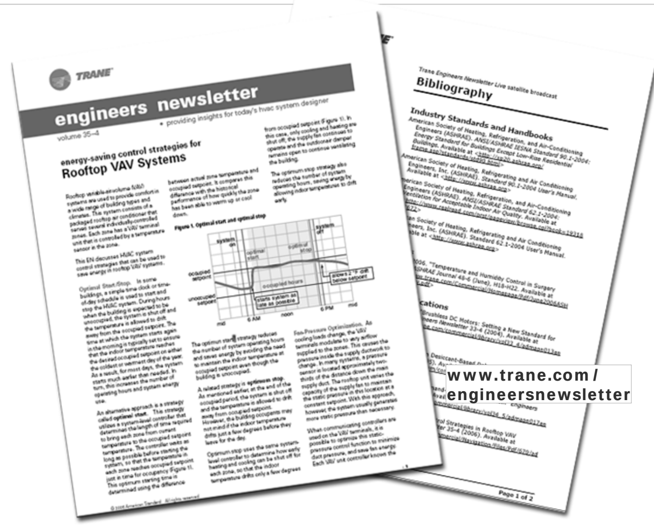
This concludes the American Institute of Architects Continuing Education System Program

Energy-efficient rooftop VAV systems

- Equipment configuration strategies
- Alternative system designs
- Optimized system controls
- Analysis
- Maintenance

references for this broadcast

Where to Learn More



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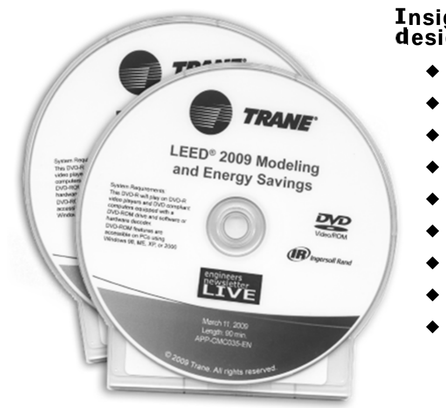

Insightful topics on HVAC system design:

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

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