Latest in High-Performance Dedicated Outdoor Air Systems (DOAS)

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Latest in High-Performance Dedicated Outdoor Air Systems (DOAS)

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LEED AP O+M ☐

Learning Objectives

- Know the different types of DOAS systems and unit types.
- Understand why DOAS can have low energy use, particularly in high-performance buildings
- Be able to describe the differences between DOAS and mixed air (HVAC) systems and when to use one or the other.
- Know where to get additional DOAS information

Let’s get your input:

Survey Question #1

What is your role?

A. Design
B. Installation
C. Operation
D. Manufacturer
E. Academic/Code Enforcement/Other

Survey Question #2

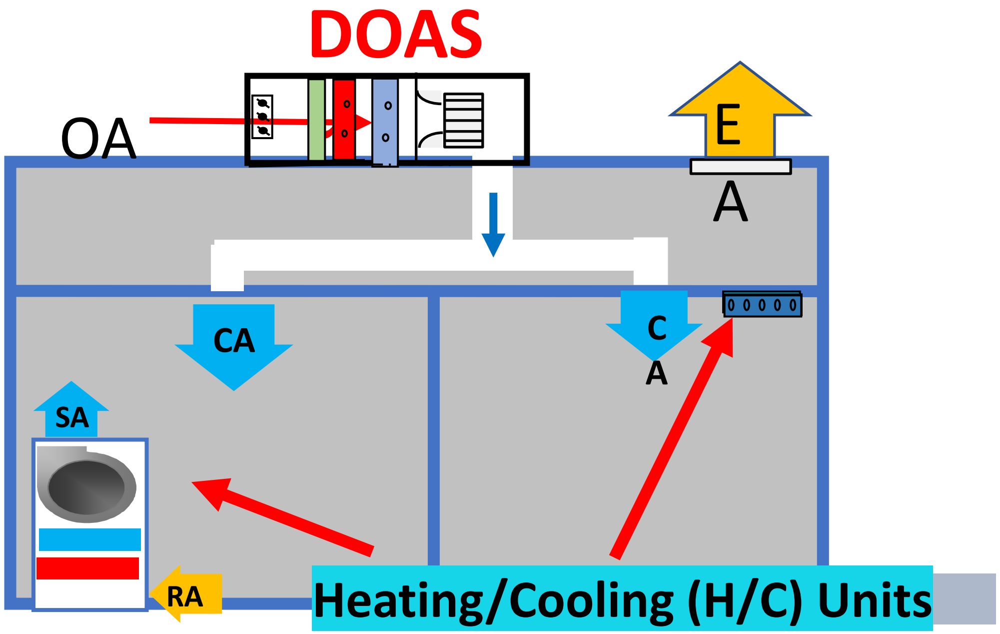
What is your DOAS experience?

A. In depth knowledge/use
B. Have done some
C. Fairly new to the subject.
D. Fine tuning my knowledge. We are being required by code officials and/or our owner to use it.
E. Need PDH credit, other

Let’s start here: Terminology: Dedicated Outdoor Air System (DOAS)

Uses a DOAS unit (DOASu) to condition all of the outdoor air brought into a building for ventilation and delivers it to each zone, either directly or through heating/cooling (H/C) units

First Generation DOAS – Make up air systems



HVAC or V+H/C

Make up air unit providing ventilation air direct to the space is DOAS.

Ventilation direct space is considered the <u>primary of a two system design.</u>

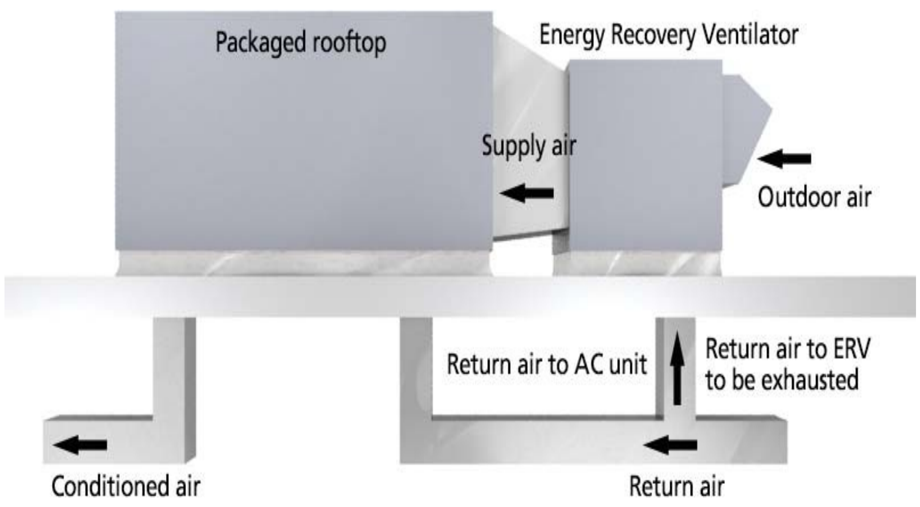
Heating/Cooling units provides zone* conditioning. This is the <u>secondary system.</u>

*zone is also called a local space or room.

Second Generation DOAS used Cost-Effective ATA Energy Recovery Devices

Unitized System:

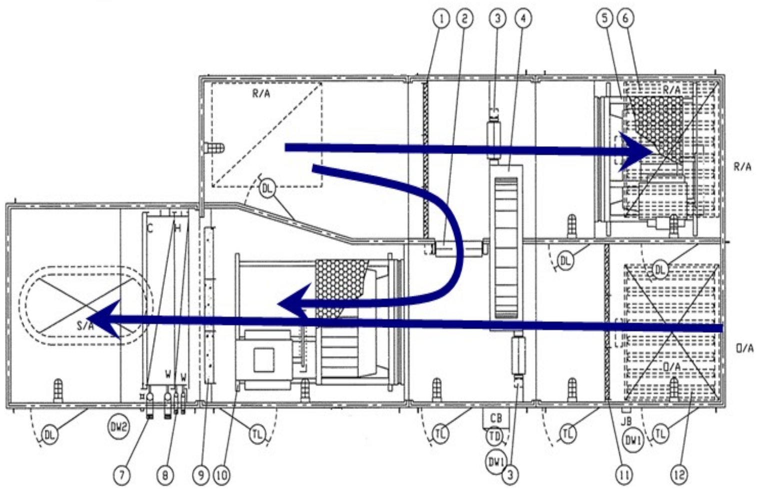
An air-to-air energy recovery ventilation (AAERV) accessory attached directly to a unit air conditioner, typically in the field. Lowers operating costs and reduces primary tonnage. Popular in the 1980-90's.

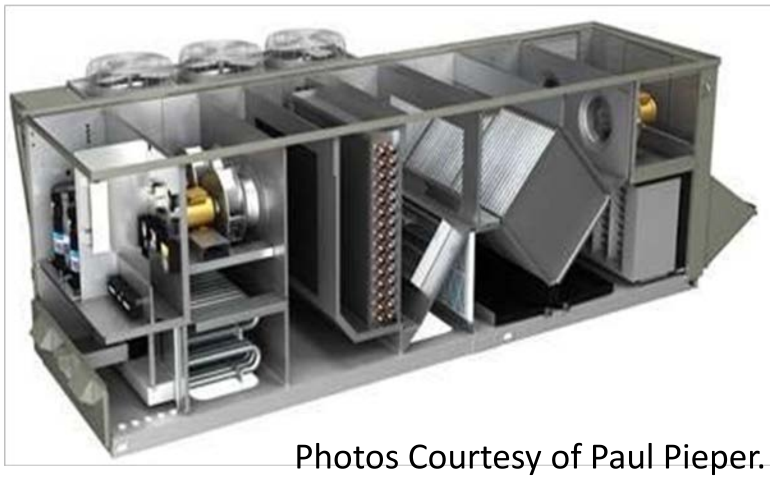


Often field provided controls and room neutral

Photos Courtesy of Paul Pieper.

Third Generation DOAS - Packaged DOAS Units (DOASu)

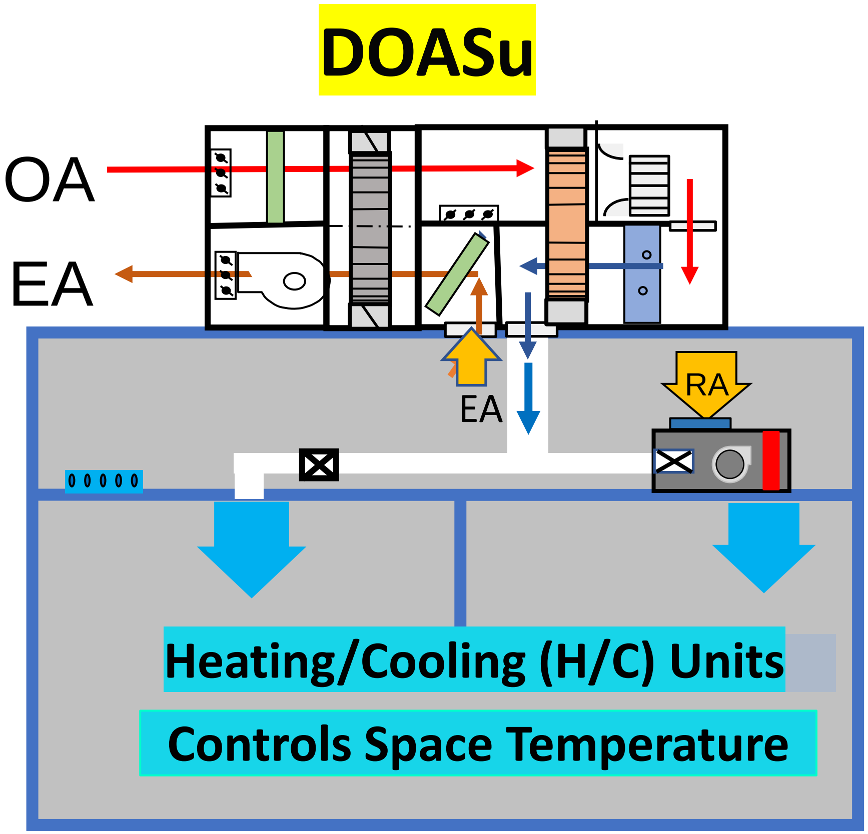




Photos Courtesy of Paul Pieper.
ALI ATA Course

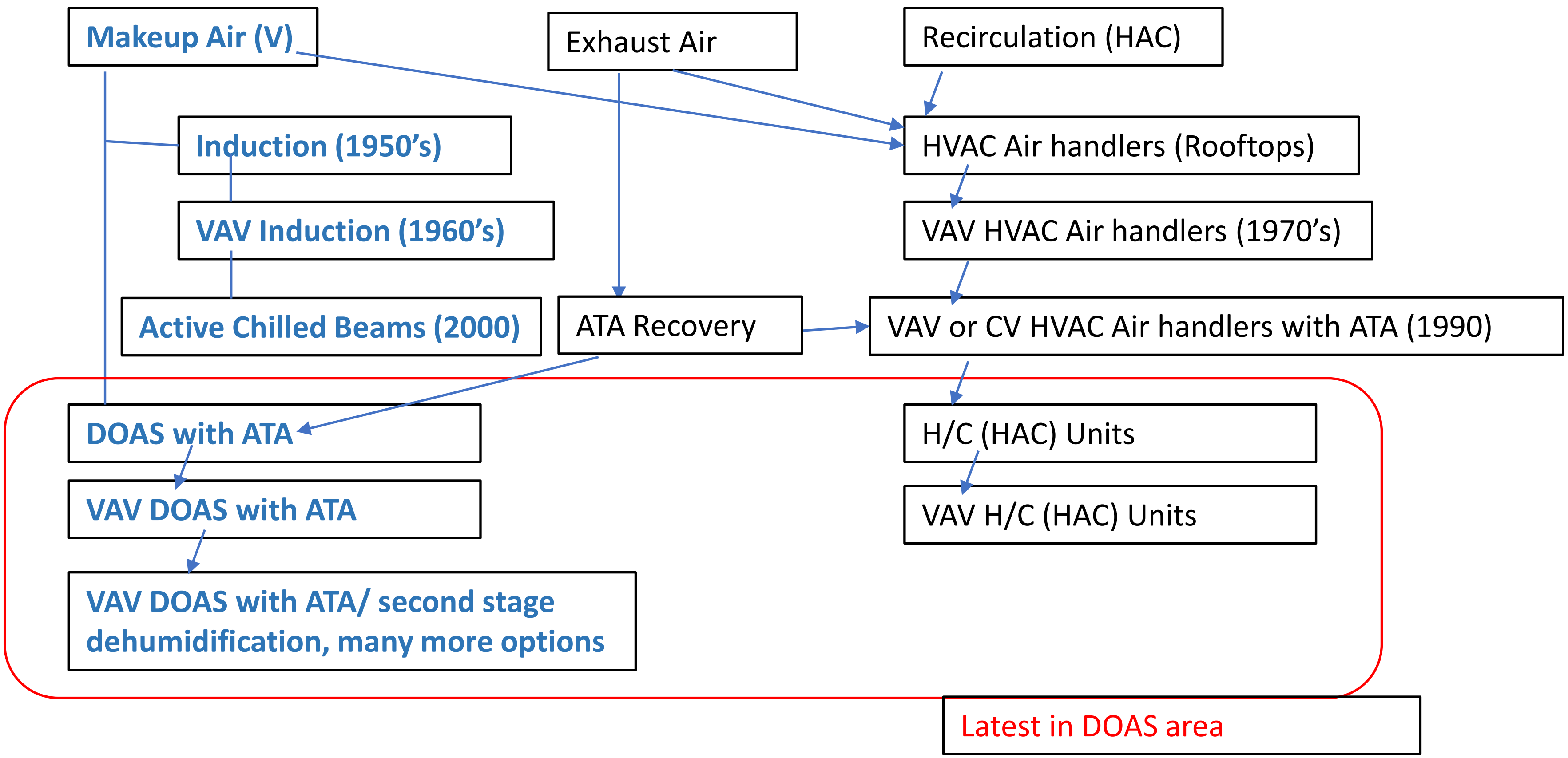
Integrated units. Indoor/outdoor casings with options like VAV, packaged DDC controls, first stage energy recovery, second stage dehumidification, enhanced OA filters, more. Focus of ASHRAE “Latest in DOAS” ALI Course.

Third Generation DOAS (Latest in DOAS)

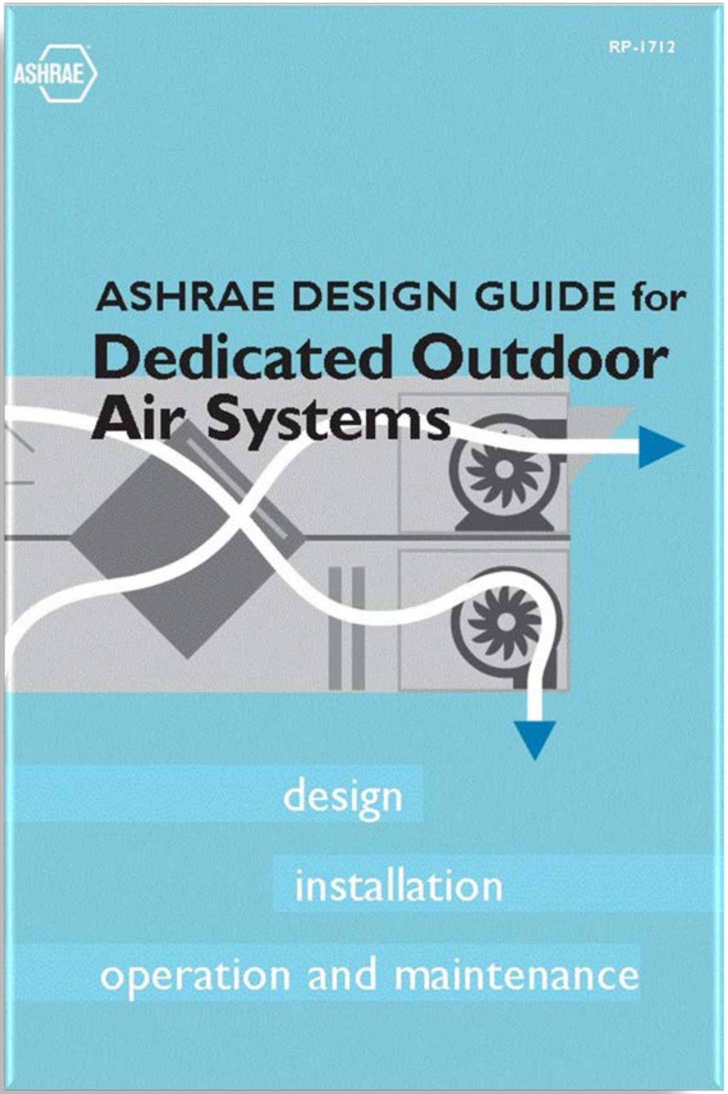


- Delivers prescribed amount of clean OA
- Controls building humidity
- Controls building pressurization
- Helps cool the space (60°F) – Reduces system fighting

DOAS Evolution (my version)



Unit Progression: Custom first, Cataloged next, then Unitary



Interested in more depth?
Get the ASHRAE Design Guide for Dedicated Outdoor Air Systems (2017)

Supported by ASHRAE TC 8.12, 8.10, 5.5, and 1.12

And a brand new 2020 ASHRAE Handbook Chapter

CHAPTER 51

DEDICATED OUTDOOR AIR SYSTEMS

Dedicated outdoor air systems (DOASs) use separate equipment to condition all of the outdoor air brought into a building for ventilation, and deliver it to each occupied space, either directly or in conjunction with local or central HVAC units serving those same spaces. The local or central HVAC units are used to maintain space temperature. Figure 1 shows a typical DOAS configuration for a large retail store. A DOAS unit can be simple, with just a few components (e.g., a fan and a cooling coil), or more complex, with several energy recovery devices, cooling coils, heating coils and one or more fans. Generally, the objective of a DOAS is to condition incoming outdoor air before it mixes (and is diluted) with the remainder of the building air so that it is easier to dehumidify and clean, and so that energy in outgoing air can be recovered to precondition incoming outdoor air.

1. APPLICATIONS

A DOAS can be effectively incorporated into nearly any commercial, institutional, industrial, or multifamily building. Although all building types can benefit from DOAS, those with strict requirements for indoor air quality, ventilation, humidity, or energy efficiency make particularly good candidates. As the amount of outdoor air rises in proportion to recirculated return air, DOAS benefits rise accordingly (Kosar 1989). Examples of particularly good candidates include

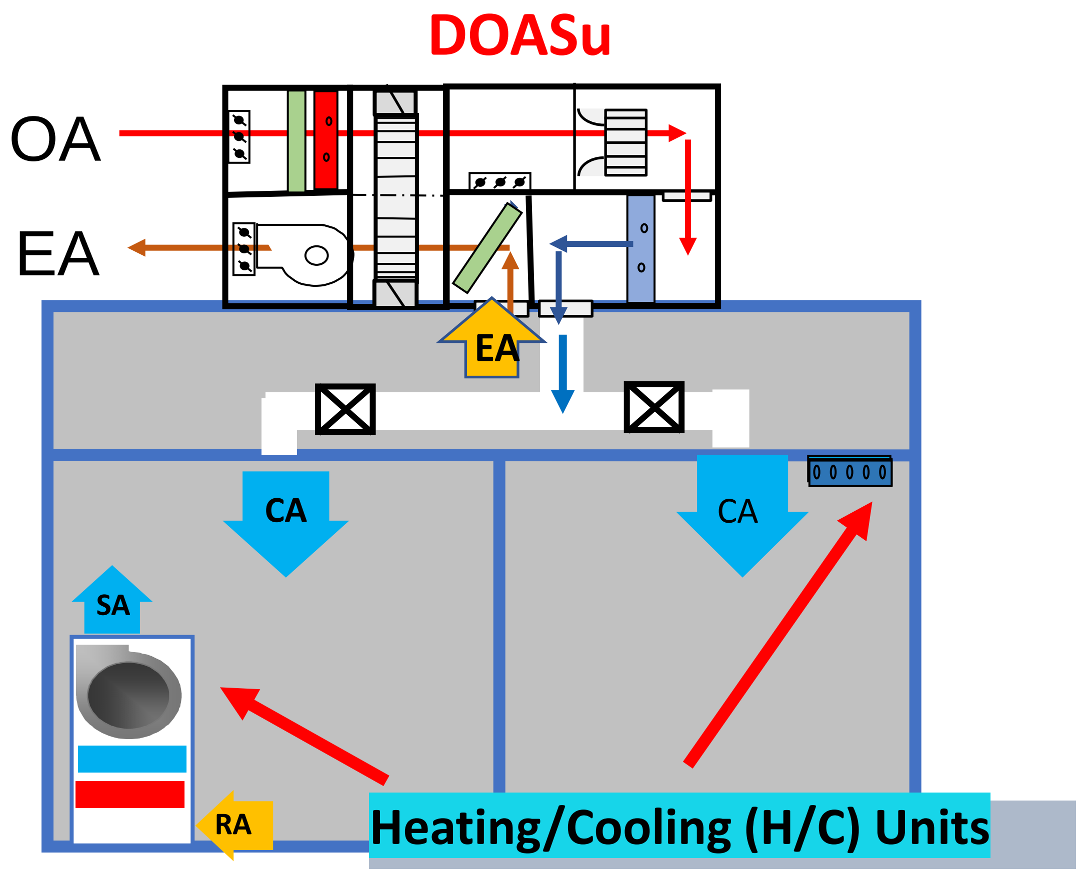
- Buildings in very humid climates
- Facilities that require more than minimum code-required ventilation rates (e.g., hospitals, laboratories, others that handle pollutants that should not be recirculated to other spaces)

Facilities using DOAS also typically benefit from the use of energy recovery. Other common drivers are (1) improving indoor humidity control, (2) reducing energy use, (3) simplifying ventilation system design and control, (4) the desire to use heating and cooling equipment that does not provide ventilation and/or dehumidification (e.g., radiant panels, passive chilled beams), and (5) reducing installation cost.

1.1 HUMIDITY CONTROL

In many locations, for both residential and commercial buildings, mechanical ventilation is either a code requirement or an industry standard practice. Introducing outdoor air often increases dehumidification loads: incoming outdoor or makeup air typically carries more than 80% of a building's annual dehumidification load (see the section on HVAC Systems in Chapter 64 of the 2019 *ASHRAE Handbook—HVAC Applications*).

Latest Option 1: VAV DOAS Direct to space



DOASu and ductwork provides the right amount of conditioned OA direct to each VAV zone

H/C units provide (zone, space, local) temp control

Direct to Space H/C Unit Option

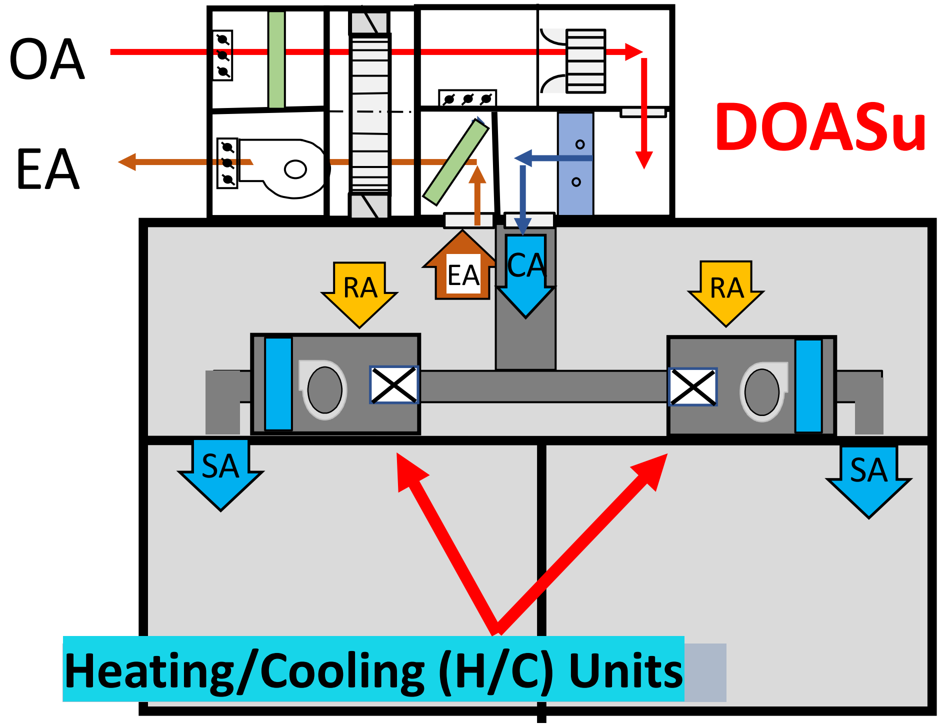
Radiant Heating
and/or
Cooling Panels

Note: Direct to space H/C can use any sensible heat transfer product

Photo Credit: Messana

Advantages: Many. True separate systems. Offers some redundancy. Fluid-based system. Small or no plenums. Simple controls. Low power. Very quiet. Low to no maintenance.

Latest Option 2: DOAS through H/C Units



Conditioned outdoor air (CA) goes to (VAV) H/C unit, becomes supply air (SA)

DOAS Chilled-Water H/C Unit

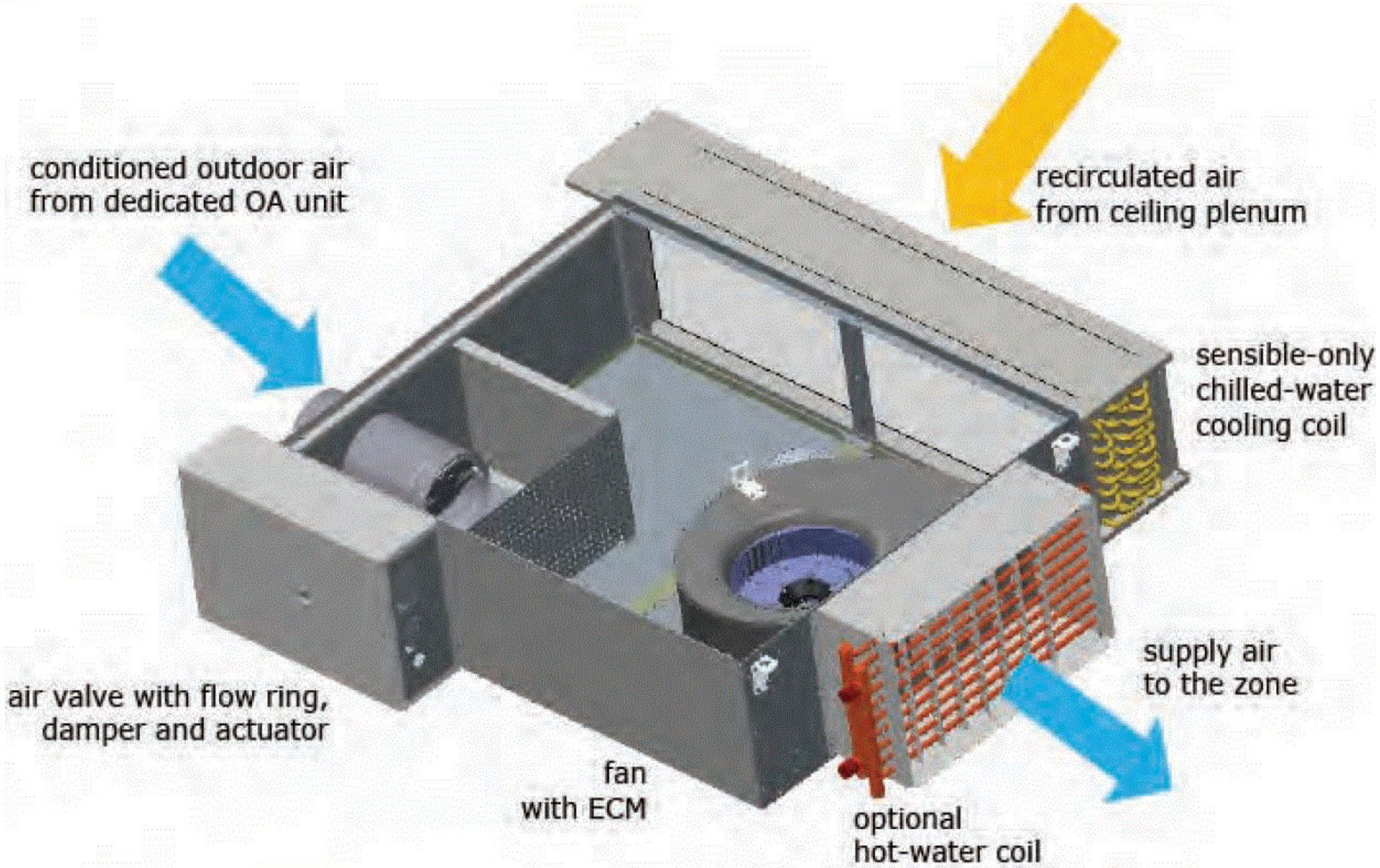


Photo Courtesy of Trane Technologies

Advantages of these two "Latest in VAV DOAS" Systems

- Required ventilation airflow reaches each zone. No over or under ventilated zones.
- Air valves allows variable-controlled ventilation based on any control—people, space, contaminants
- Space ventilation amount can be easily reset.
- Room incoming OA is measured. Easier to commission, recommission if ventilation rates change. (BIG DEAL)
- Building is easy to control with DDC if properly setup
- Trend- DOAS/DOASu have factory packaged controls for faster installation and commissioning.

Benefits of DOAS have been known for some time

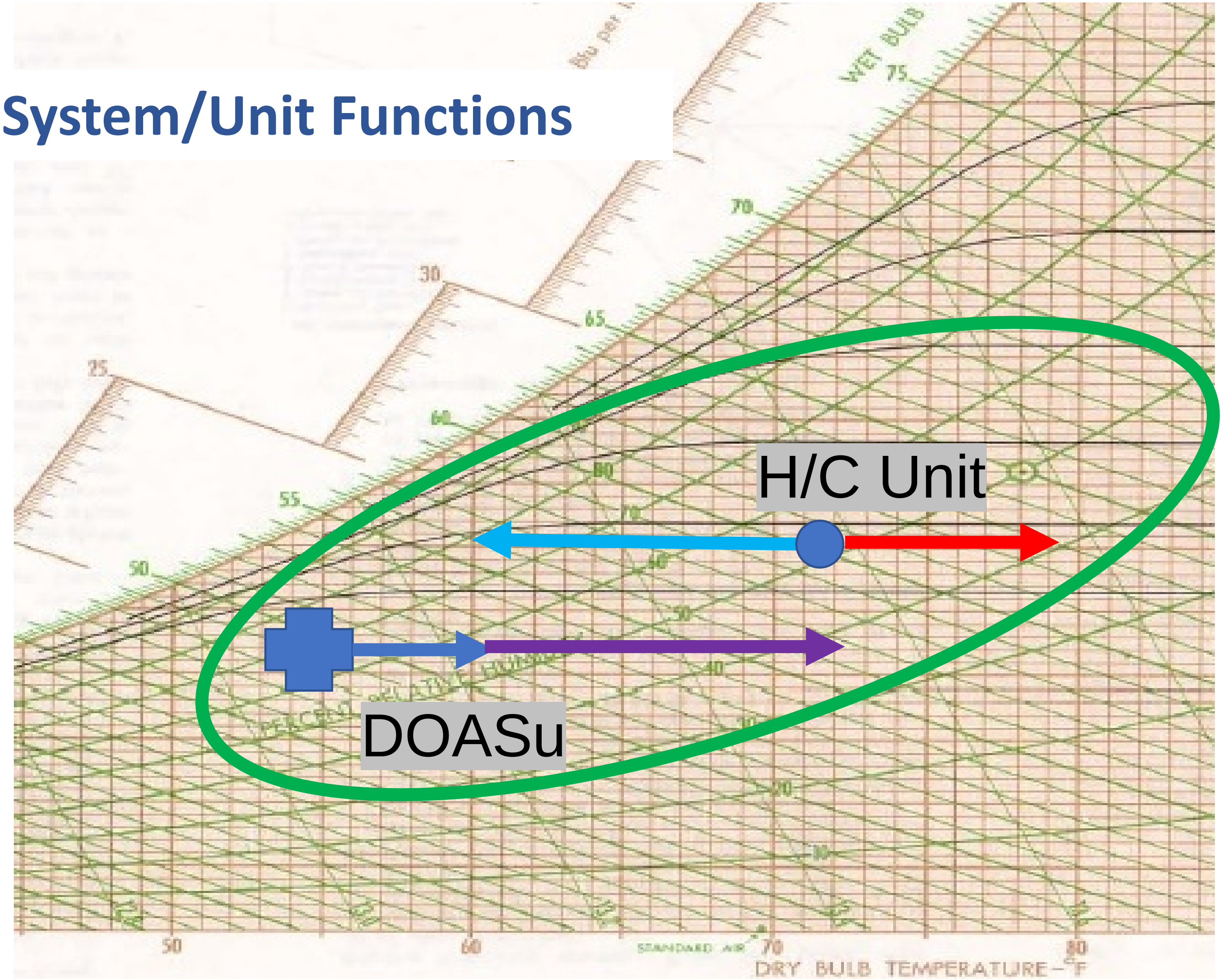
“Not only can the DOAS approach save energy—perhaps 8 to 20 percent—it also provides assurance, verifiable in a court of law, that a conditioned space is receiving the mandatory minimum ventilation air.”

ENERGY STAR. 2006. *Building Upgrade Manual*, Chapter 10. Facility Type: K–12 Schools. https://www.energystar.gov/sites/default/files/buildings/tools/EPA_BUM_CH10_Schools.pdf.

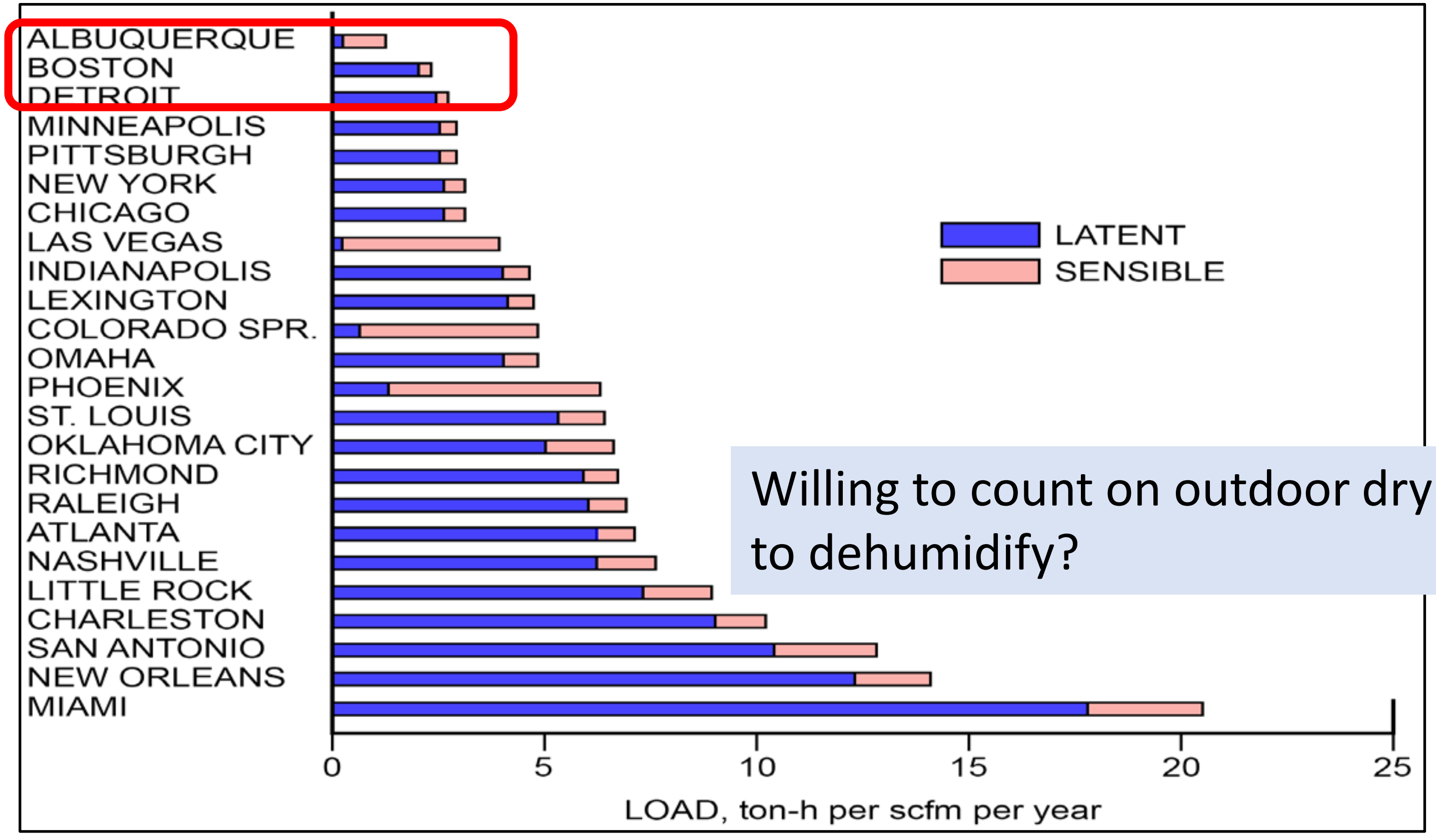
DOAS Humidity Management
Designing for Success

A major DOAS advantage

System/Unit Functions



Outdoor Humidity Impacts HVAC and DOAS System Selection



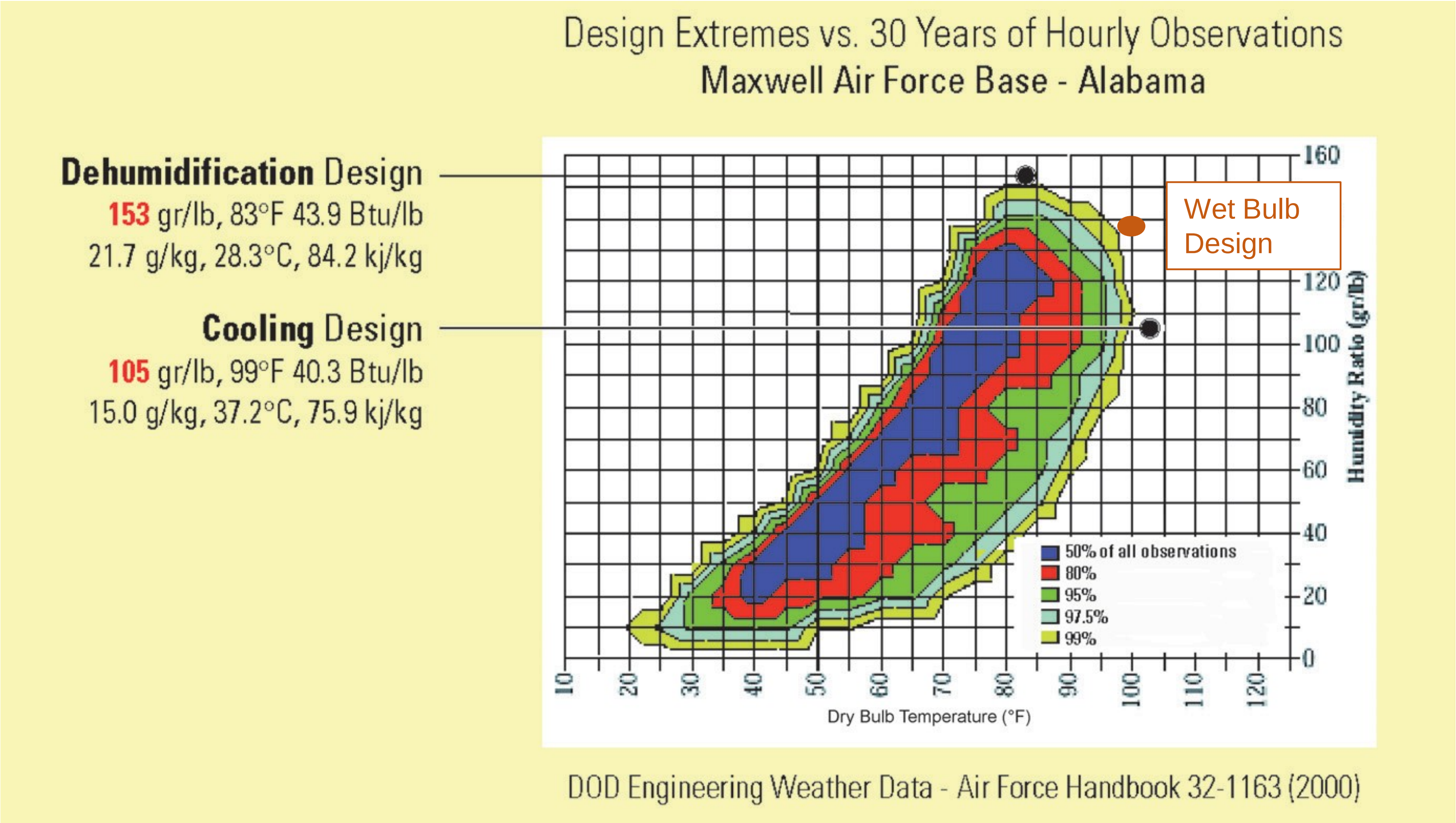
Willing to count on outdoor dry air to dehumidify?

Source: Harriman et al. 1997.

First Step: The Envelope

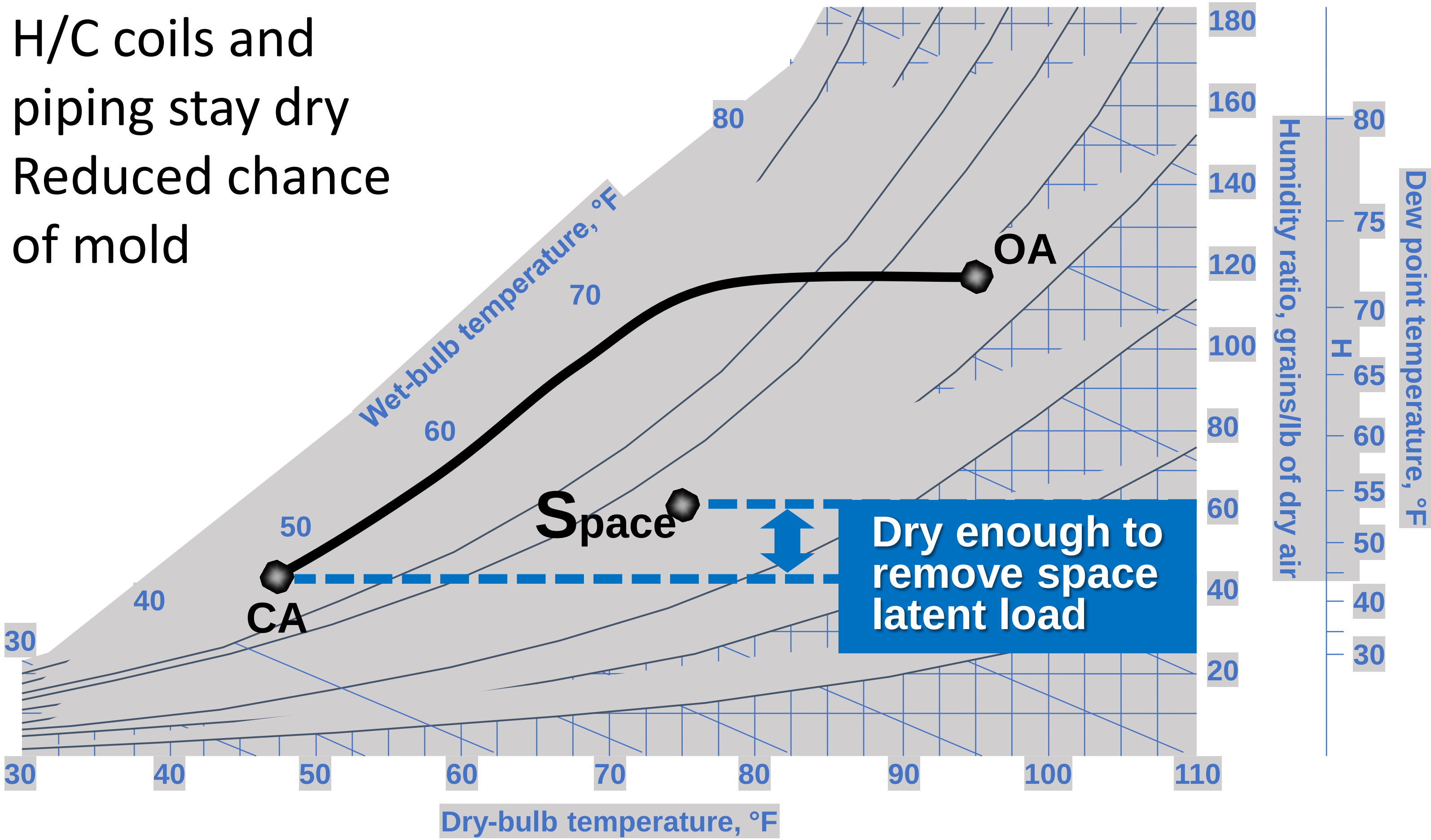
- **Temperate, Humid, Tropical Climates**
- “Weather is great” sometimes. Temperature is “good” but humidity can vary to the oppressive level
- Envelopes are “light,” natural ventilation often encouraged
- Consider ceiling fans to “cool” people

DOAS Design – use Peak Dew-Point, Wet Bulb or Sensible (Cooling) Design?

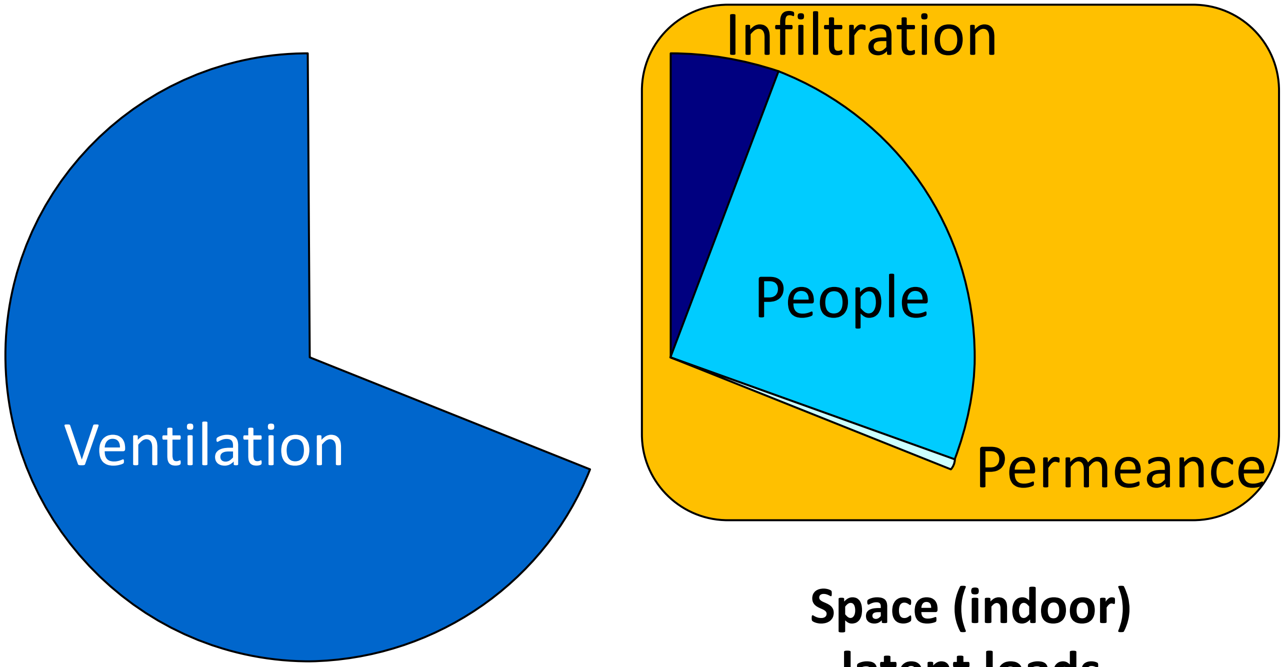


Use DOASu to handle indoor humidity

- H/C coils and piping stay dry
- Reduced chance of mold



Total Dehumidification Duty

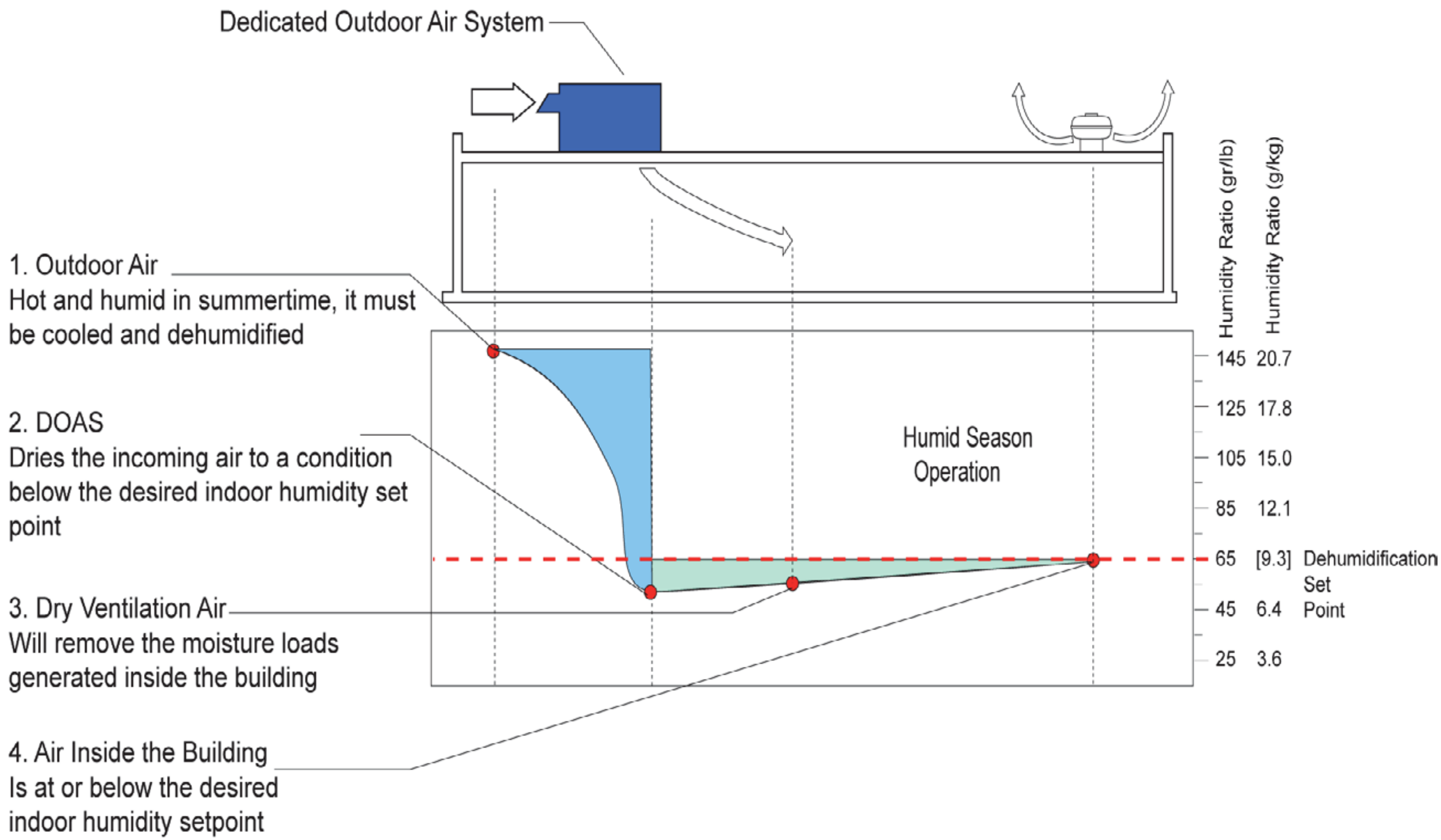


Typical latent loads for a school classroom

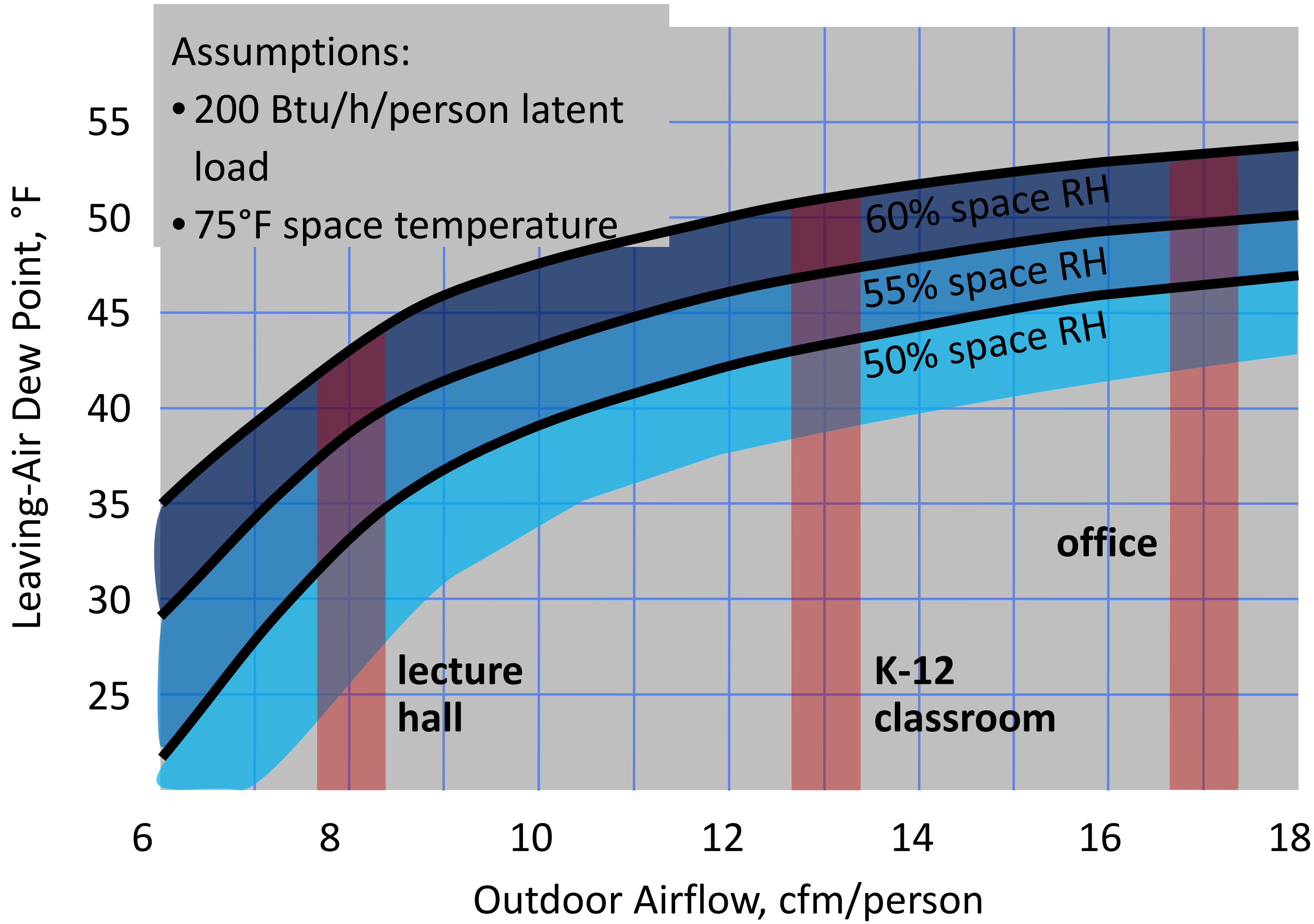
Space (indoor) latent loads

Source: *Humidity Control Design Guide*, ASHRAE 2001, p. 278

Best Practice—Let DOASu Handle the Internal Latent Loads



What is the Right Supply Air Dew Point?



Credit: Stan Mumma

DOAS Dew-Point Design Calculation

1. Calculate W_{ca} for each space

2. Most demanding zone sets the DOAS dewpoint design

3. Using DOASu design humidity and temperature, determine cfm need by zone to meet dehumidification needs.

4. If constant volume, DOASu cfm will be the sum of the peaks. If VAV DOAS, calculate the block cfm load to size “coil”.

Classroom Example – 60% rh

$Q_{space,latent} = 0.68 \times V_{ot} \times (W_{space} - W_{ca})$

(0.68 = 1060 Btu/h * 0.075 lb/cu ft * 60 min/h / 7000 grains per lbs water)

$Q_{space,latent}$	= 5465 Btu/h (25 students, low activity level)
V_{ot}	= 450 cfm (18 cfm/student)
W_{space}	= 77.8 gr/lb (75°F DBT, **60% rh**, 60°F DPT in space)
5,465	$= 0.68 \times 450 \times (77.8 - W_{ca})$
W_{ca}	= 60.2 gr/lb **(53°F DPT)** (off DOASu)

In this example, at 7.5 cfm/person design, a supply dewpoint of 53°F will be 60% rh in the space

Classroom Example–50% rh

$$Q_{space,latent} = 0.68 \times V_{ot} \times (W_{space} - W_{ca})$$

$Q_{space,latent}$	= 5465 Btu/h
V_{ot}	= 450 cfm
W_{space}	= 64.7 gr/lb (75°F DBT, **50% rh**, 55°F DPT)
5,465	$= 0.68 \times 450 \times (64.7 - W_{ca})$
W_{ca}	= 47.1 gr/lb **(47°F DPT)**

In this example, at the 7.5 cfm/person design, a supply dewpoint of 47°F will be 50% rh in the space. A significant change is performance and cost.

Humidity Related Observations

1. Building startup can be a critical time. Control the DOAS dewpoint setpoint to avoid duct sweating and once building is dry, keep it dry.
2. H/C cooling unit coils and piping needs to stay above space dewpoint if they do not have drain pans. 3-5 degrees separation is typical with active space humidity control.
3. Remember: Any cold surfaces below space dew point can condense—potentially creating indoor rain.

Humidity capacitance of structures is a factor in performance

- Buildings store water vapor in carpets, drywall, and ceilings. Keeping dew point under control 100% of the time:
  - Enhances occupant comfort
  - Permits faster recovery from night or summer setback
  - Helps with off-hours comfort
- Some energy modeling programs can model this subject. Makes sizing, energy predictions more accurate.

H/C System Optimization Observations

- System level controls should minimize DOAS - H/C system unit fighting in controlling space temperature
- All units should be monitored and controlled by BAS
- Energy transfer (heat pump units) often have a big impact on reducing primary energy use
- Energy storage options may lower some utility bills, allow for equipment downsizing and provide some redundancy.
- One cooling system or two?

Survey Question #3

How important is positive humidity control in your buildings?

A. Very important
B. Important
C. Not important
D. Other

DOAS—Ideal for High-Performance Buildings

- ❑ Why?

- ❑ Max tech and zero energy buildings have lower sensible loads. Roughly the same latent loads.

- ❑ Result: Latent (humidity) space control is a significant issue.

- ❑ DOAS is a good system choice because it independently controls humidity along with the building pressure and air quality.

System Comparison Example

Mixed-air system at room level (8.3 tons)

Cooling Loads	Sensible Load	Latent Load
	Btu/h (W)	Btu/h (W)
Conduction through roof	12,312 (3563)	
Conduction through exterior wall	502 (144)	
Conduction through windows	1210 (359)	
Solar radiation through windows	22,733 (6477)	
People	4500 (1350)	3600 (990)
Lights	22,097 [6480)	
Equipment	8184 (2404)	1540 (450)
Infiltration	2988 (876)	3969 (1159)
Total space cooling load	74,626 (21,623)	9109 (2599)
Ventilation	6540 (2047)	8820 (2709)
Total coil cooling load	**81,266 (23,670)**	**17,929 (5308)**
	SHR =	0.82

System Comparison

DOAS (OA Dehumidification Only) + H/C System

Cooling Loads	Sensible Load	Latent Load		
	Btu/h (W)	Btu/h (W)		
Conduction through roof	12,312 (3563)			
Conduction through exterior wall	502 (144)			
Conduction through windows	1210 (359)			
Solar radiation through windows	22,733 (6477)			
People	4500 (1350)	3,600 (990)		
Lights	22,097 (6480)			
Equipment	8184 (2404)	1540 (450)		
Infiltration	2988 (876)	3969 (1159)	Btu/h	tons
Total space cooling load	**74,626 (21,623)**	**9109 (2599)**	**83735**	**7.0**
Ventilation	**6540 (2047)**	**8820 (2709)**	**15360**	**1.3**
SHR =	0.89	0.43		

System Comparison

DOAS (Handles total latent) + H/C System

Cooling Loads	sensible load	latent load		
	Btu/hr [W]	Btu/hr [W]		
conduction through roof	12,312 [3563]			
conduction through exterior wall	502 [144]			
conduction through windows	1210 [359]			
solar radiation through windows	22,733 [6477]			
people	4500 [1350]	3600[990]		
lights	22,097 [6480]			
equipment	8184 [2404]	1540 [450]		
infiltration	2988 [876]	3969 [1159]	Btu/h	tons
total space cooling load	**74,626 [21,623]**	**9109 [2599]**	**74626**	**6.2**
ventilation	**6540 [2047]**	**8820 [2709]**	**24469**	**2.0**
SHR =	1	0.27		

Note: Load is shifting to DOASu

System Comparison High-Performance Building

DOAS (handles all latent) + H/C system (8.3 - 4.9 tons)

	Btu/hr	Btu/hr		
conduction through roof	6000			
conduction through exterior wall	300			
conduction through windows	800			
solar radiation through windows	7000			
people	4500	3600		
lights	8000			
equipment	6500	1540		
infiltration	2000	2657	Btu/h	tons
total space cooling load	**35,100**	**7797**	**35,100**	**2.9**
ventilation	**6540**	**8820**	**23,157**	**2**
SHR =	1.00	0.28		
Decrease	53%	5%		

more insulation, light-color roof, and better glass

better glass

LED lighting

laptops and flat monitors

tighter construction

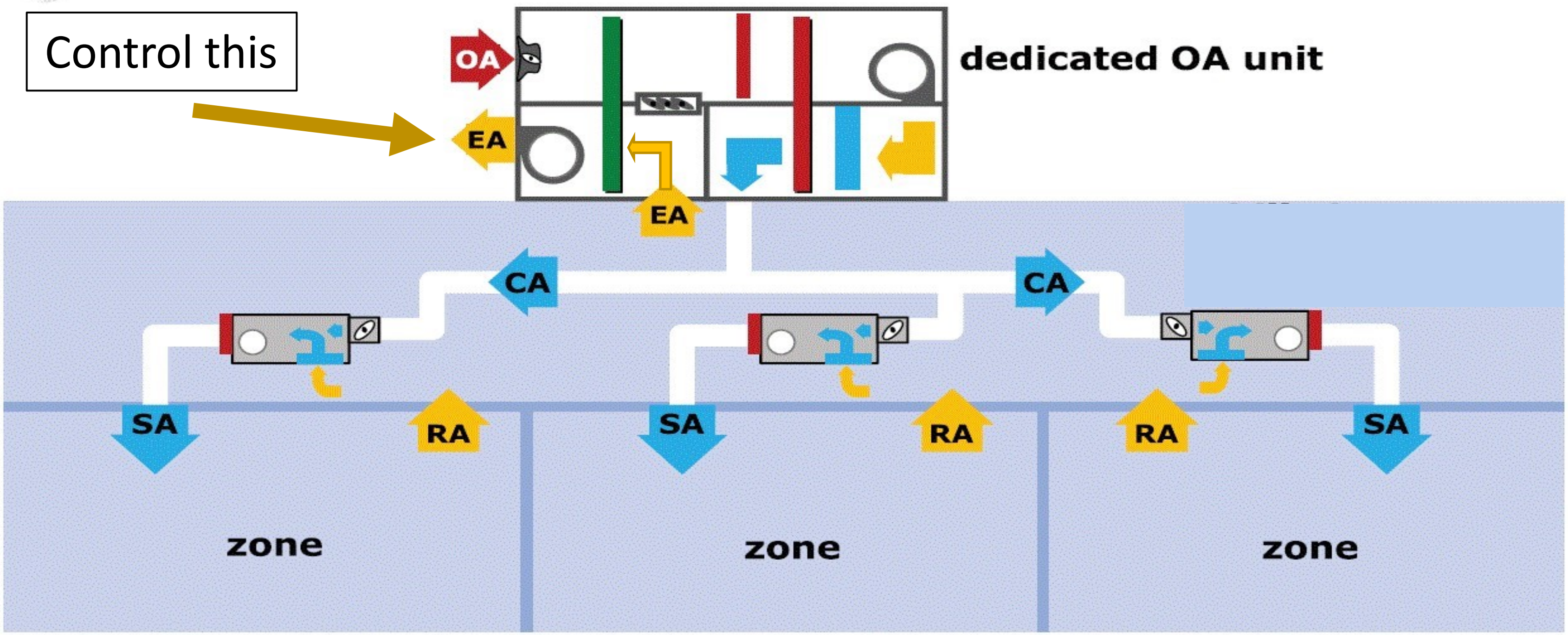
DOAU is now 40% of load
H/C units are 50% smaller

High-Performance Building

Critical Issues

- DOAS unit needs to dehumidify at low loads and airflows. Very important in high-performance buildings
- **If using DX compressors, avoid short cycling DX DOASu cooling coil for better space humidity control**
  - DX coils take time to start dehumidifying and they re-evaporate a lot of water on the coil when turned off
  - Ask unit and controls manufacturer for this performance.

DOAS Building Pressure Control



Incoming OA quantity is set by space ventilation.
Building pressure controlled by changing exhaust fan airflow (e.g., direct space pressure control).

Building Pressurization is Important

From Lew Harriman ASHRAE ALI Humidity course:

- ❑ Two biggest problems in buildings
  1. Lack of a good vapor barrier
  2. Negative building pressure
- ❑ Solution with DOAS
  - Maintain positive building pressure by varying DOASu exhaust air amount
  - Exfiltration and remote exhaust defines the minimum OA needed
  - Remember the ATA device needs exhaust air to work

DOAS can isolate a Building

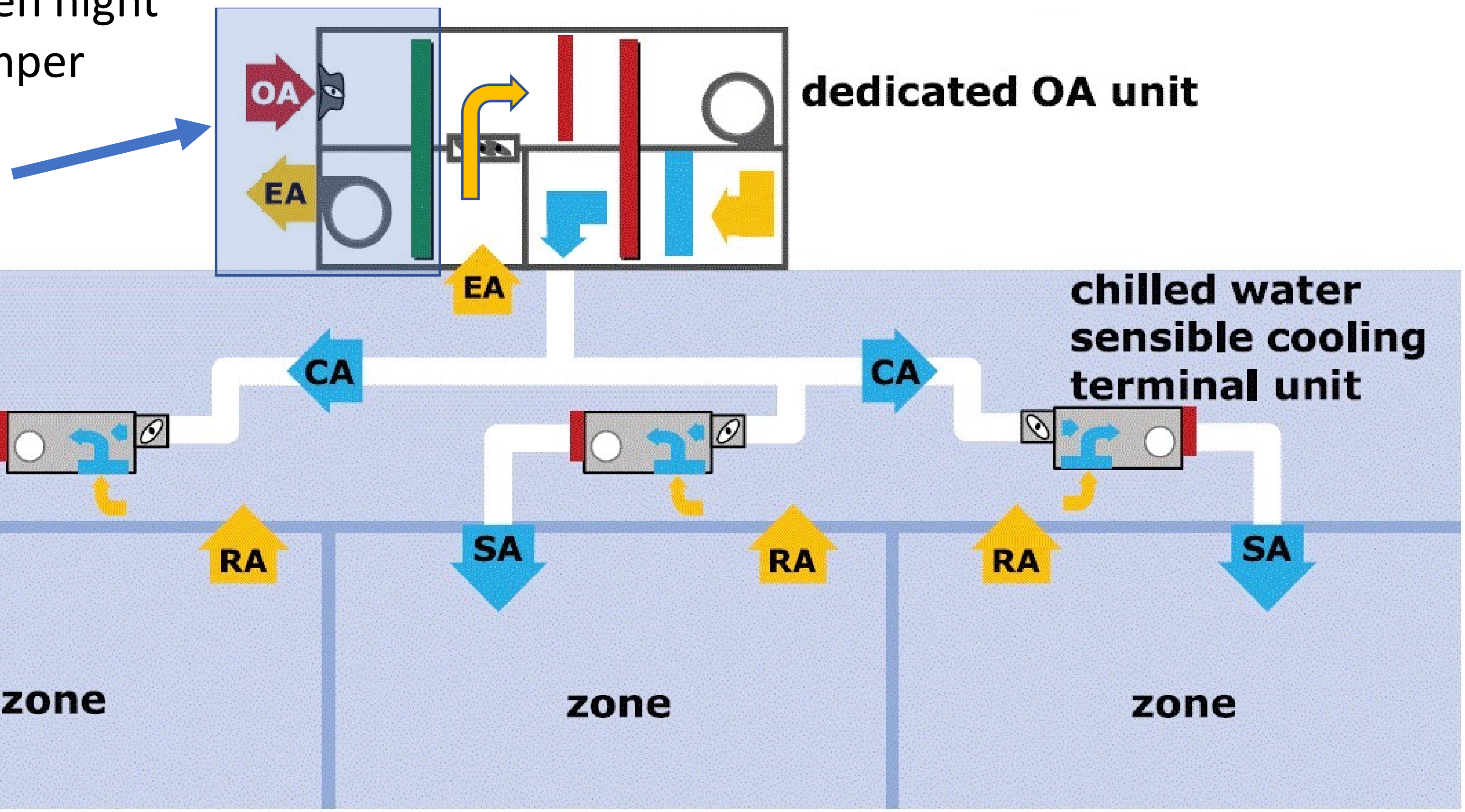
- In the event of unacceptable outside air (chemical or terrorist type attack) the DOAS units can control building pressure by controlling OA/EA quantities.
- DOAS generally supplies air to many zones, so building has fewer OA/EA openings.
- OA and exhaust air flows out through DOASu. Under DOAS control.
- DOASu can be enhanced with custom air cleaning options for reducing outside contaminates.
- Note: ASHRAE 62.1 is now setting OA contaminant limits for Ozone.

DOAS Morning “Warm-Up”

- Strategy depends on factors like climate and energy costs. Generally simpler to use H/C units. Space is dry, so recovery is fast.
- Other option is to use DOASu heat.

DOAS Night Setback

Stop this part of unit and open night setback damper



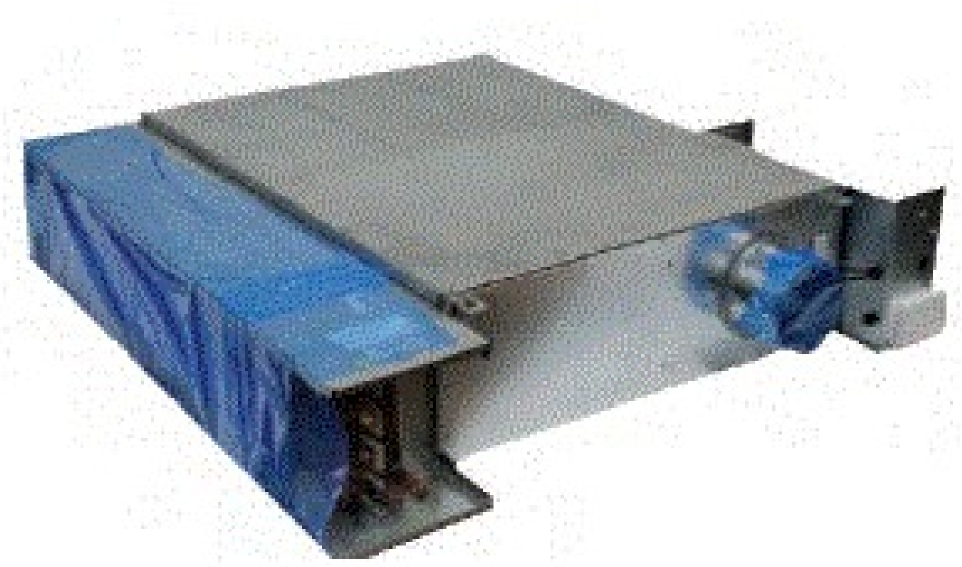
DOAS Control Suggestion:

DOAS controls space dewpoint

Use temperature and relative humidity sensors to calculate dew point

More stable, less expensive than chilled mirror

Next topic – DOAS H/C Units



Plenum-Mounted
Chilled -Water DOAS
H/C Units

Basically, it is a low height, packaged, mini vav air handler

DOAS Chilled-Water H/C Unit

Works like a single zone VAV HVAC unit.

Fan Operation

- Continuous operation during occupied modes
- Intermittent operation during unoccupied modes
- Fan speed modulates slowly up to maximum in conjunction with heating or cooling capacity, as needed to maintain desired zone temperature and ventilation delivery. ECM motor.
- Fan size needs to meet the greater of the design cooling or heating airflow to the zone

Air Valve— pressure independent flow measuring, size to meet the design outdoor airflow requirement for the zone.

Acoustics—select for design background sound pressure levels in the occupied space

DOAS H/C Units Observations

- Typical one unit per control zone. If two or more units in one control zone, avoid stat fighting
- Size determined by maximum OA cfm, cooling/heating requirements, desired noise level, plenum space
- Typical control options
  - Unit-optimized temperature/occupancy/CO_2 sensors
  - Wireless communicating, allows system optimization
  - Condensate pan (not drain pan) indicator

Next - the DOASu Options

Overview

Cooling/Dehumidification

- Coil
- First stage—parallel air-to-air recovery device
- Second stage—enhanced humidity transfer device

Air Cleaning, Filters

Supply and Exhaust Fans, Variable-Speed Motors, Drives

Motorized Control, Bypass and Shutoff Dampers

Unit Controls

Today, DOASu options can be selected for the specific climate, altitude, and application—“customized”

Accurate equipment performance prediction selection and energy modeling programs are critical to success and first-cost decisions

Dedicated Outdoor Air Unit

- Humidity (vapor pressure) equalize in a building. Stopped by vapor barriers. Can impact which DOAS units serve a space.
- One DOASu unit can serve a building, floor, or space. Fewer units reduces system cost. (DOAS unit versus ductwork).
- Oversizing DOASu for lower pressure drops saves energy but requires a cost/energy savings evaluation
- DOASu has the coldest temperatures in the building. Therefore, DOAS unit leakage and thermal insulation—in the DOASu exterior walls, interior walls and around components is important detail to "specify." Thermal cameras can show performance.

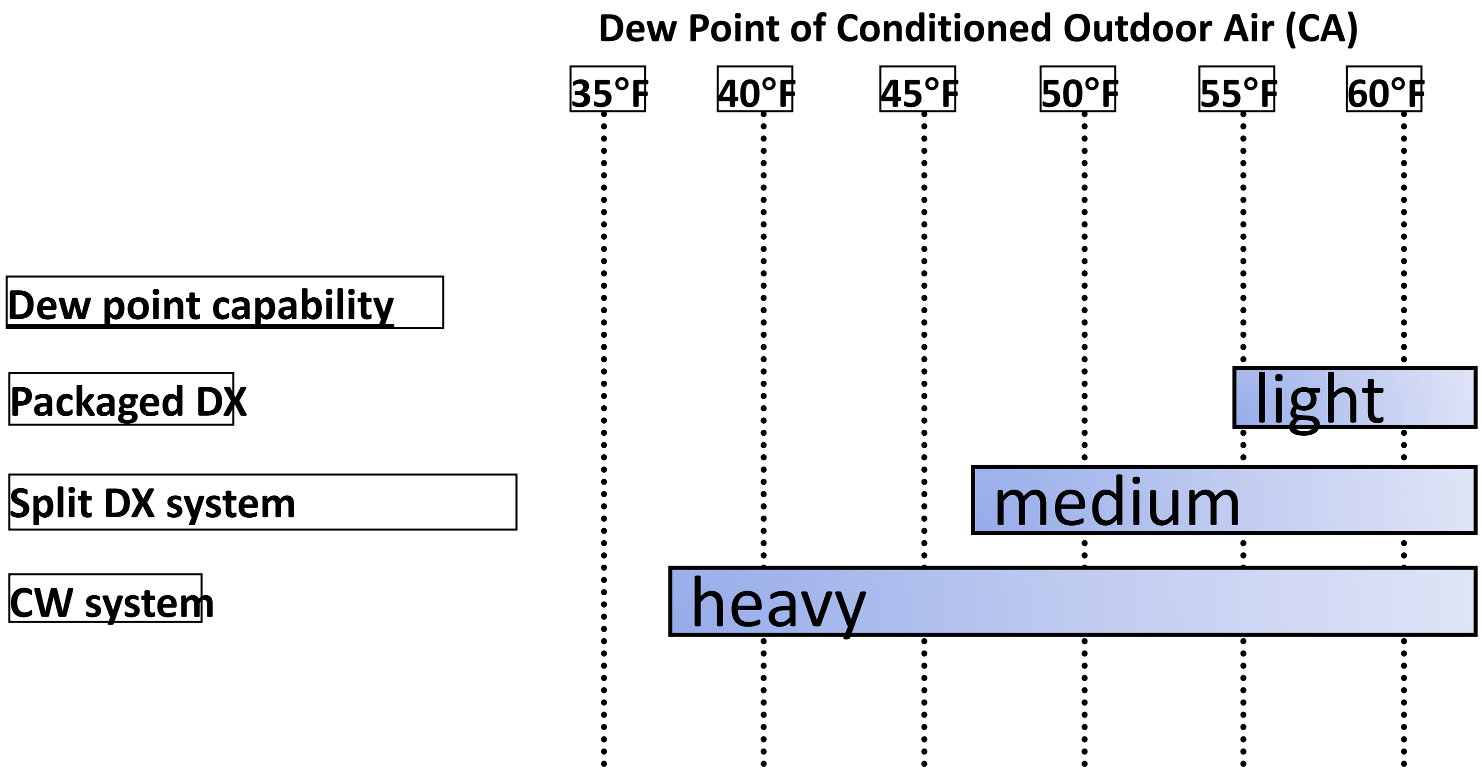
DOASU Design

Cold Coil

- Design supply dew-point design drives the coil-compressor-chiller selection.
- DOAS design dew points are typically between 44°F–55°F.
- Requires cooling coil that can seriously dehumidify (e.g., 6/8 row, 100–250 fpm)
- Coils need to dehumidify from peak dew-point design at almost “any” OA flow condition

DOASu Unit Design

System delivery dewpoint impacts system selection



DOAS

Condensing Options

1. Ground storage (lowest energy use— generally most expensive)
2. Water (towers, etc.) cooled: allows use of ice or water storage
3. Air cooled (generally lowest cost, highest energy use)

Key DOAS Design Question: Should the Building be CW, DX, or Both?

Depends on:

- DOASu and H/C loads and when they occur
- DOASu and H/C system efficiencies
- Modulation capability of H/C equipment
- Amount of duct and piping insulation
- What can building operating staff maintain?
- What are electric utility costs now and in future?
  - kW, kWh, time of day—impacts thermal storage decisions (e.g., ice storage)
- System cost

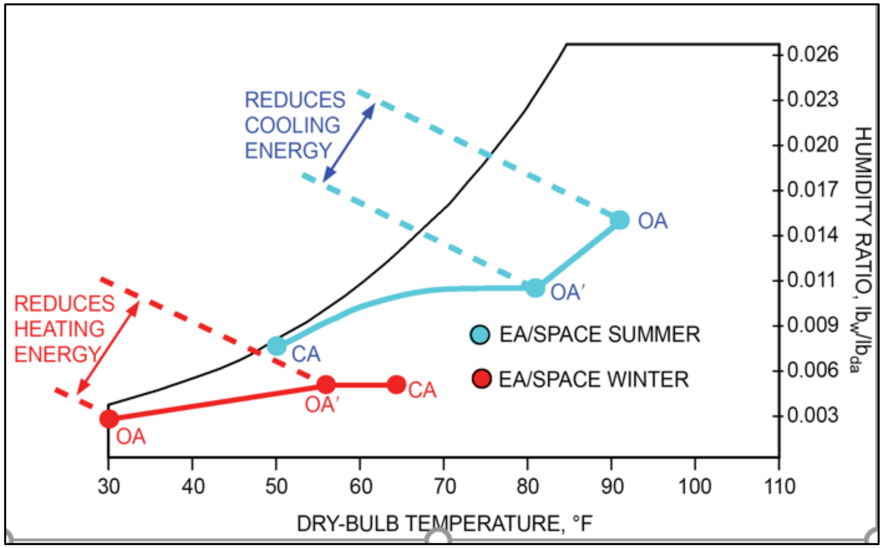
Air to Air Recovery Technologies

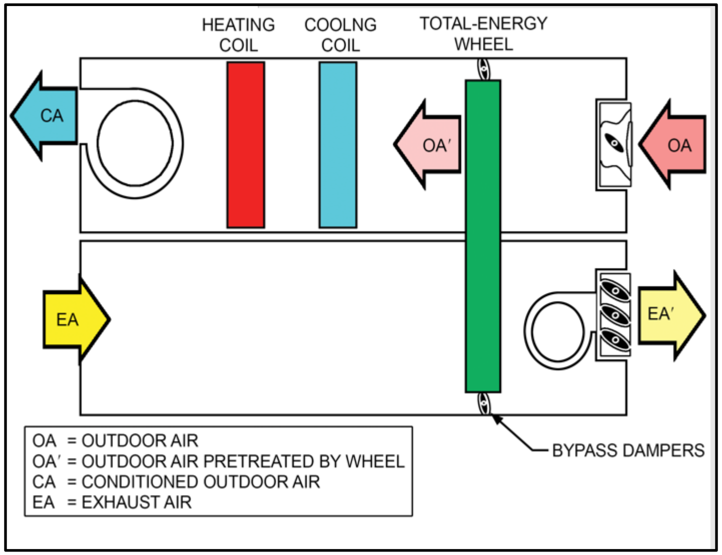
Paper-Based and Polymeric Latent Plates

Enthalpy Energy Recovery Wheels

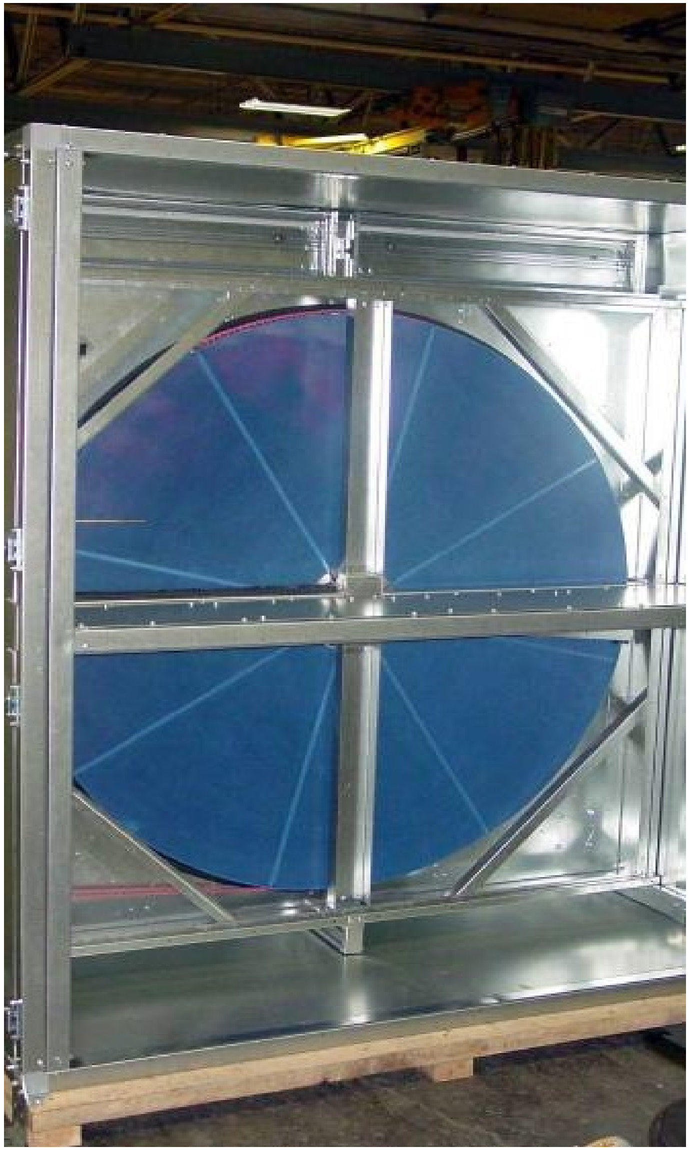
Photos Courtesy of Paul Pieper, ASHRAE ALI

Stage 1 DOASu Enthalpy Transfer





Credit: 2020 ASHRAE Handbook DOAS Chapter S51_f07



Energy Recovery Wheel

- In United States, two substrates available: silica and molecular sieve
- AHRI 1060 certification
- 70%–85% total effectiveness
- Wheel rotation speed can tell you wheel type—color does not. Typically rotates around 20 rpm
- Use bypass dampers for economizer, fan energy savings, frost protection
- Filter air into both sides of wheel

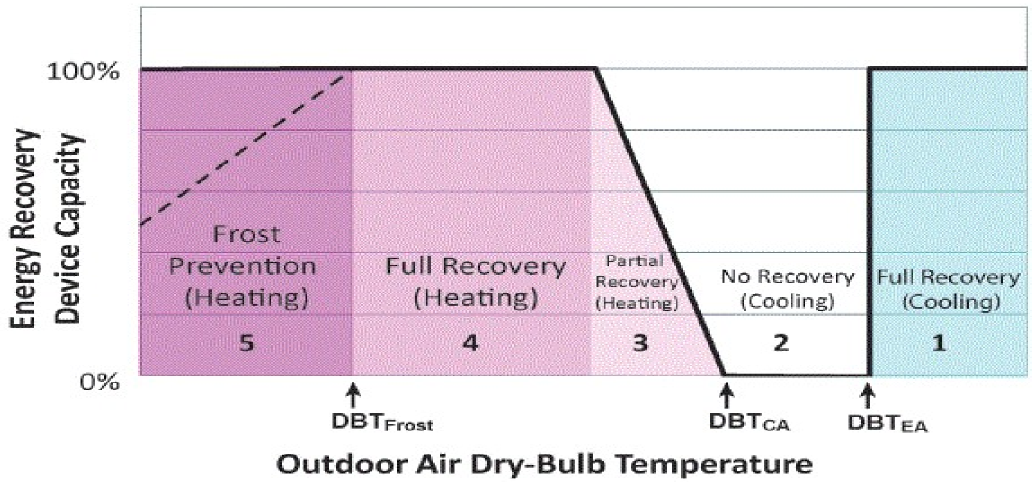
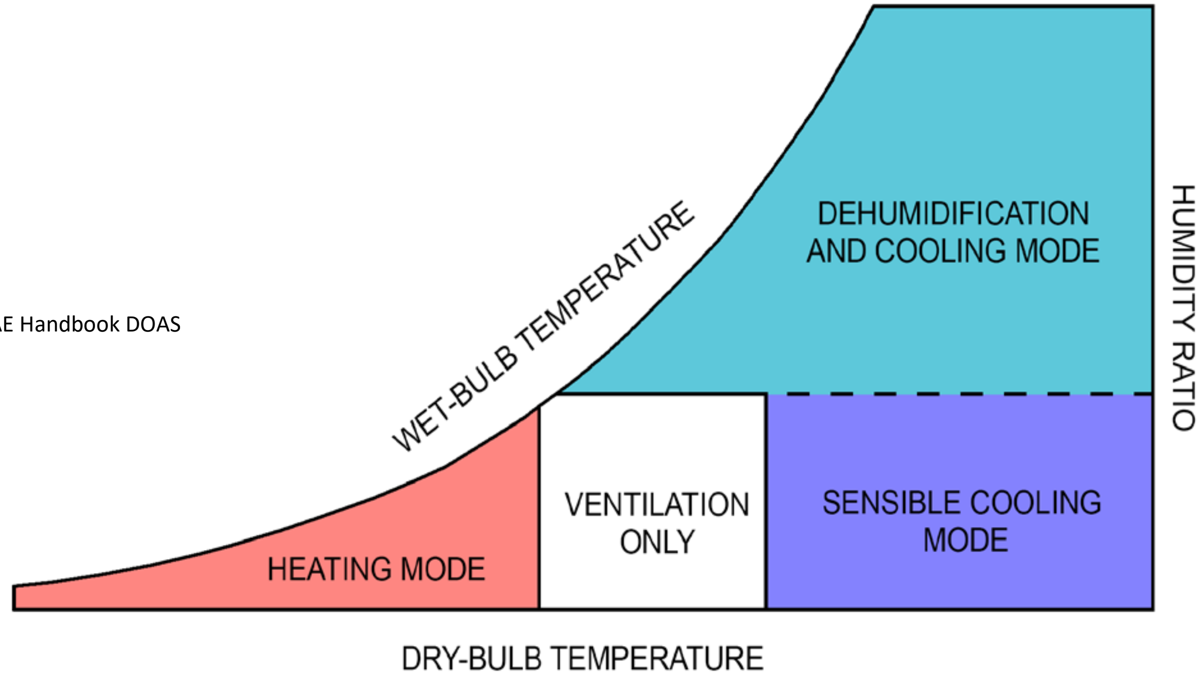


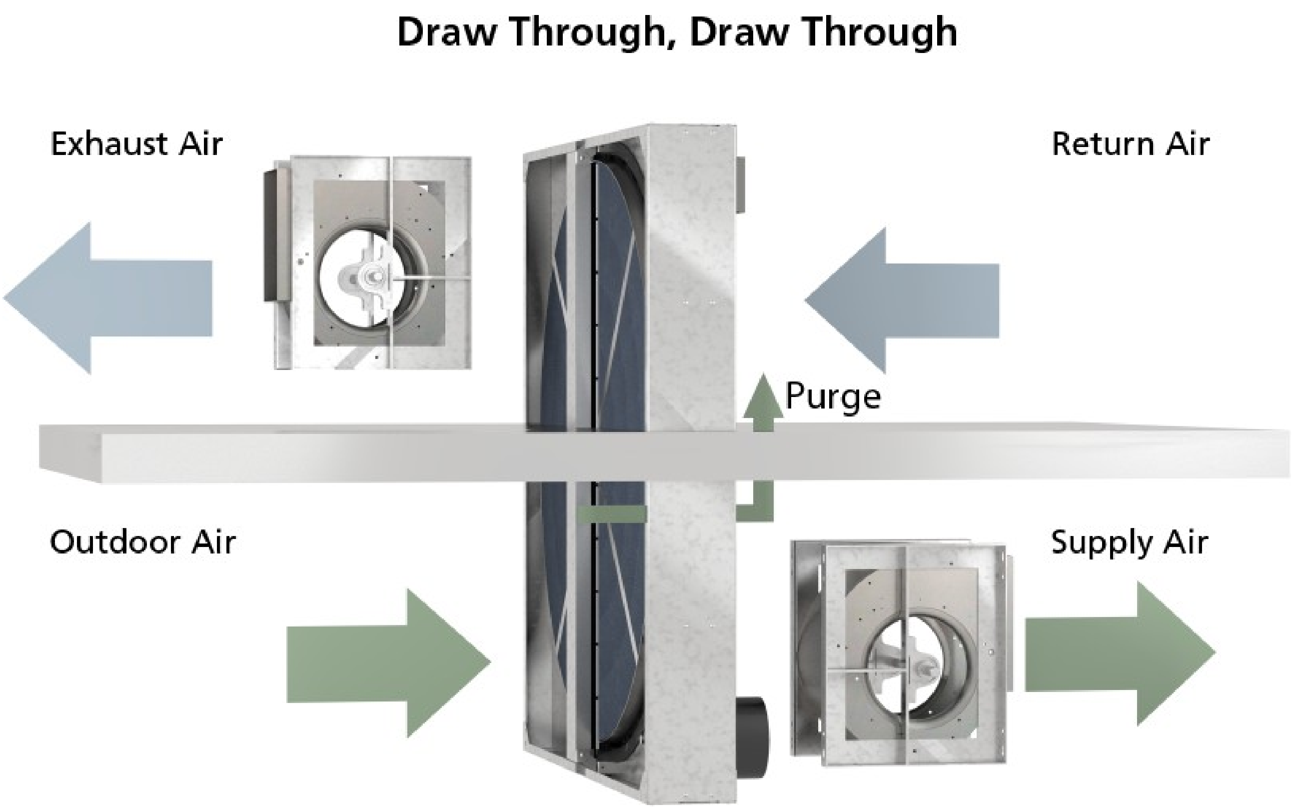
Figure 5-10 Total-energy wheel control modes.
Adapted from Quinnell (2016)

Credit: 2020 ASHRAE Handbook DOAS
Chapter S51_f09



Valuable Takeaway

Effect of Fan Placement



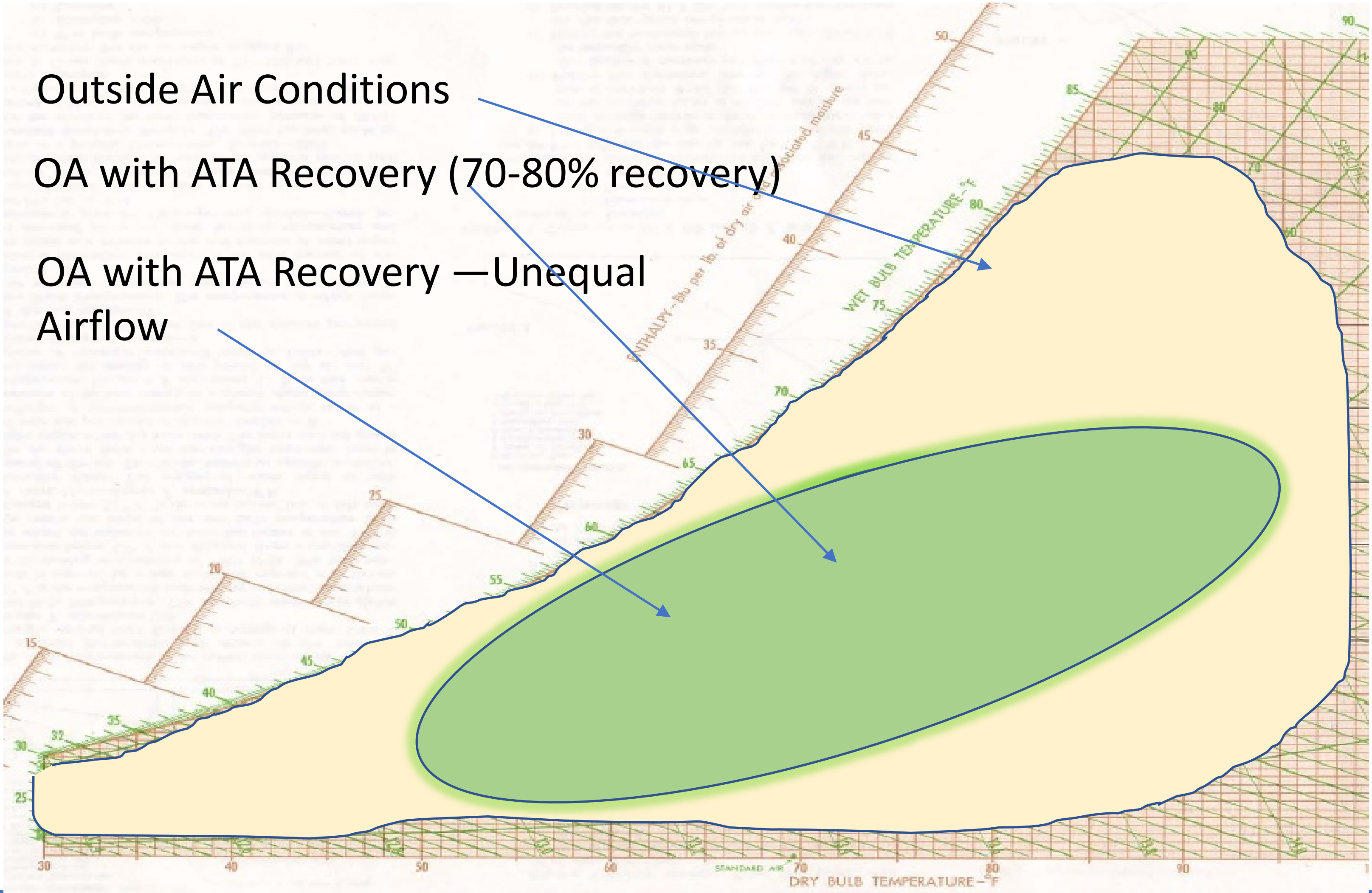
Provides a reasonable amount of exhaust air transfer (EATR)

Photos Courtesy of Paul Pieper.

"As-Applied" Versus "Rated" Effectiveness

- Be careful not to confuse "as-applied" *enthalpy recovery ratio (ERR)* (required by ASHRAE Standard 90.1) with "rated" effectiveness (AHRI 1060)
- Strive for balanced airflows
  - Bring back as much exhaust air to DOAS unit as possible

DOASU First Stage ATA Recovery



ASHRAE/IES Standard 90.1-2016

Changed the language to use the term *enthalpy recovery ratio (ERR),* rather than the term *effectiveness*. This enthalpy recovery ratio is defined as

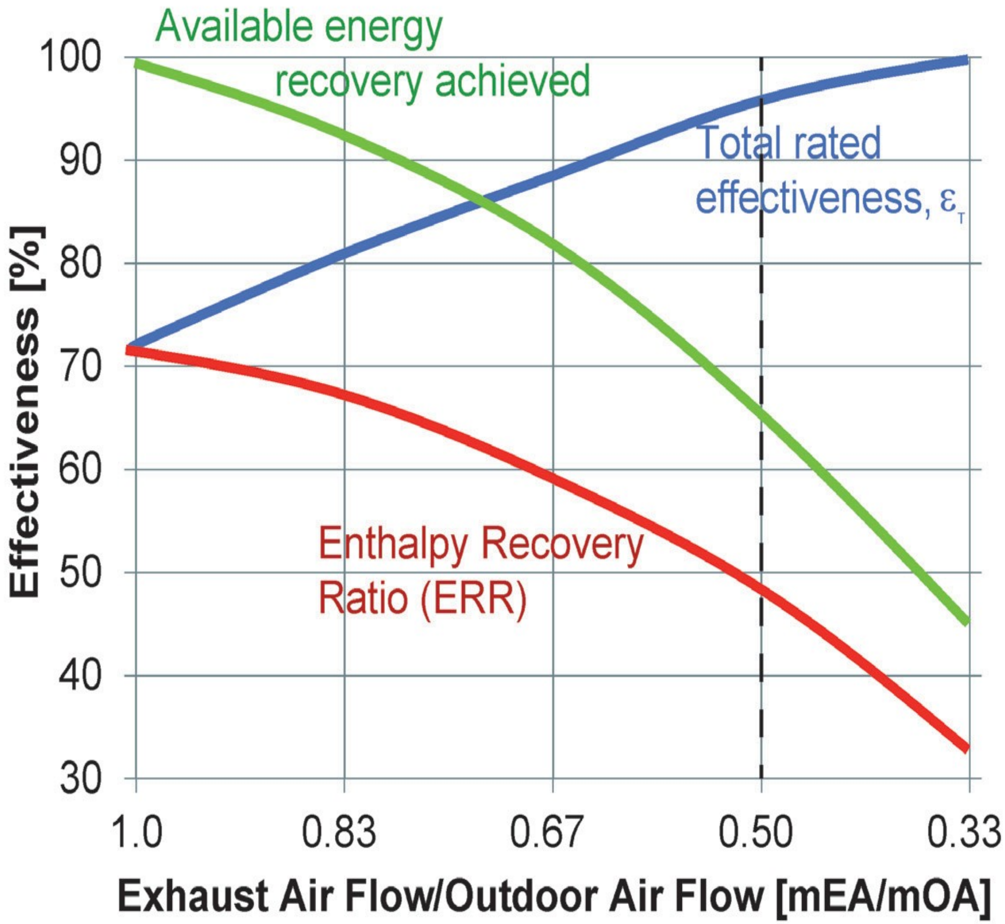
$$ERR = (h1 - h2)/(h1 - h3)$$

where *hx* corresponds to the enthalpy of the respective airstreams.

ERR—fraction of total available energy transferred to (or from) the outdoor airstream. Accounts for air imbalance between the outdoor and exhaust airstreams as well as the effects of purge air.

Using this measure, ASHRAE/IES Standard 90.1-2016 requires that the exhaust air energy recovery device has an ERR of 50% or greater.

At a minimum, use the DOASu manufacturer provided performance program that calculates ERR for based on AHRI certified data

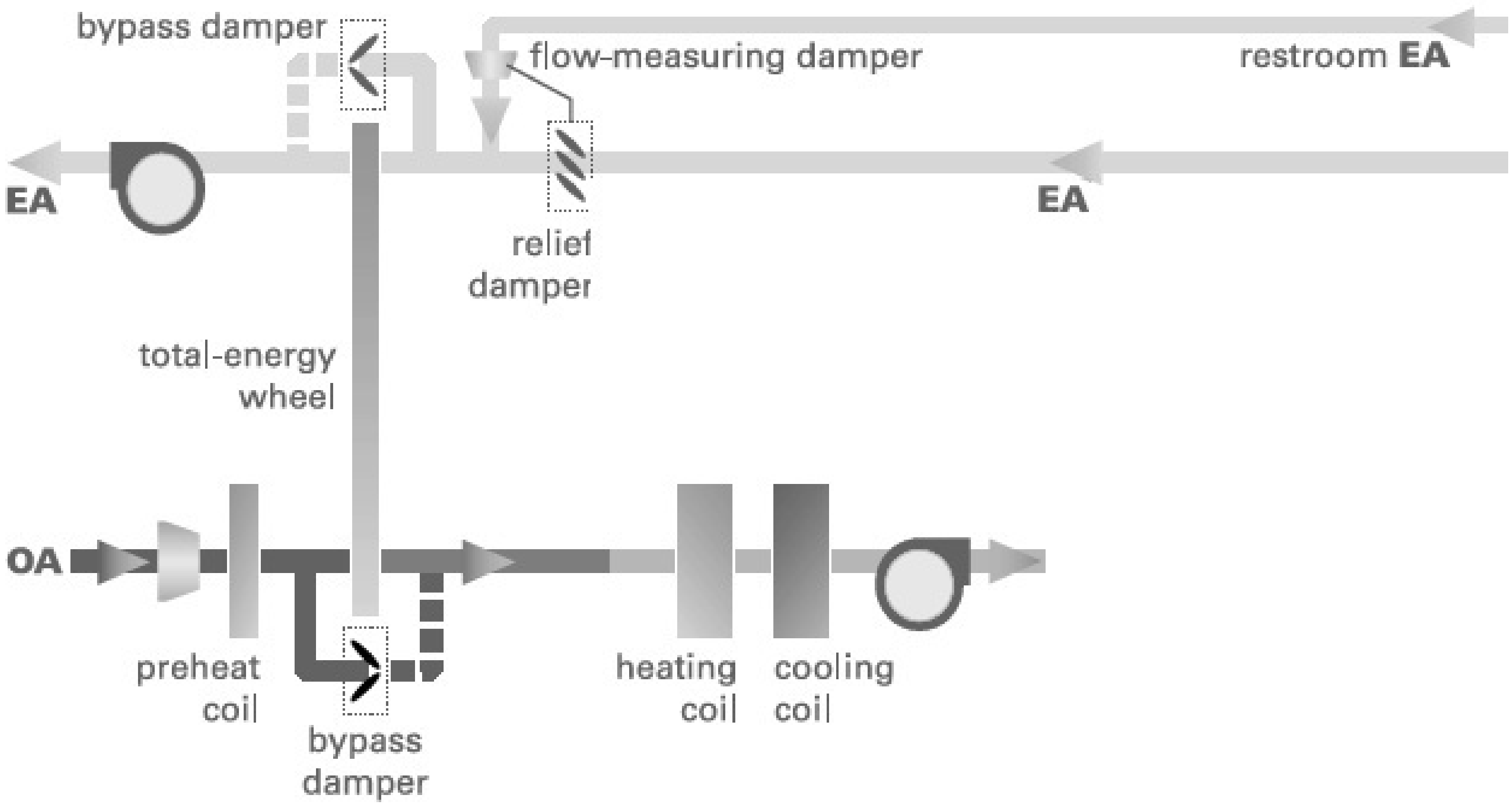


- Impact of unbalanced flow on energy recovery effectiveness and ERR
- Adapted from Mumma (2014)

Mumma, Stan. 2014. *Understanding & Designing Dedicated Outdoor Air Systems*. Atlanta: ASHRAE.

Exhaust-Air Energy Recovery

Good Idea—Recover Restroom Exhaust Air Energy



DOASu Recovery of Restroom Exhaust

Energy recovery air is often drawn from restrooms and similar low-contaminant areas.

ASHRAE Standard 62.1-2016 states Class 2 air (which includes restrooms) “shall not be recirculated or transferred to Class 1 spaces. Exception: When using an energy recovery device, recirculation from leakage, carryover, or transfer from the exhaust side of the energy recovery device is permitted. Recirculated Class 2 air shall not exceed 10% of the outdoor air design intake airflow.”

Air Classification and Recirculation

5.17.1 Classification

Class 1: Air with low contaminant concentration; inoffensive odor and sensory irritation intensity

Examples: Office spaces, classrooms, assembly rooms.

Class 2: Air with moderate contaminant concentration; mildly offensive odors or sensory irritation intensity

Examples: Restrooms, swimming pools, dining rooms, locker rooms

Source: ASHRAE Standard 62.1-2016.

Wheel or Plate Freeze Protection

In cold climates

- A preheat coil before the energy recovery device can prevent water freezing on the wheel,
  or
- A modulating bypass damper in the recovery section can help prevent ice from forming on ATA device. This limits recovery so preheat may be needed or amount of OA may need to be reduced with really cold weather.

What if the Recovery Wheel Stops rotating?

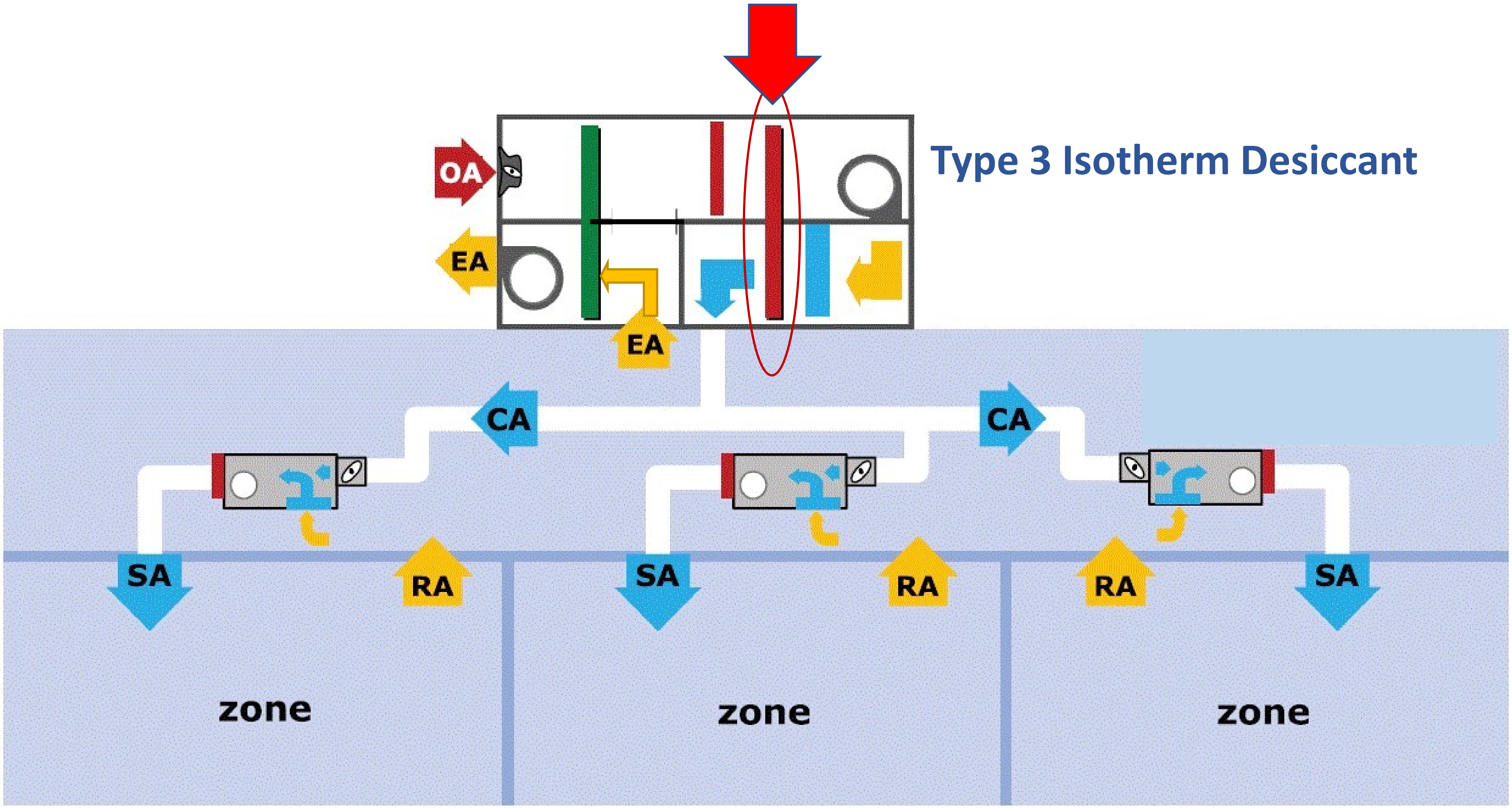
- It can happen. The drive motor or belt fails. It is recommended that the wheel get a temperature sensor in the two airstreams—both up and downstream of the wheel. Four total. A simple fault analysis can be set up. Wheel on and no transfer; time to check it out.

Energy Wheel or ATA Plate Flow Measurement

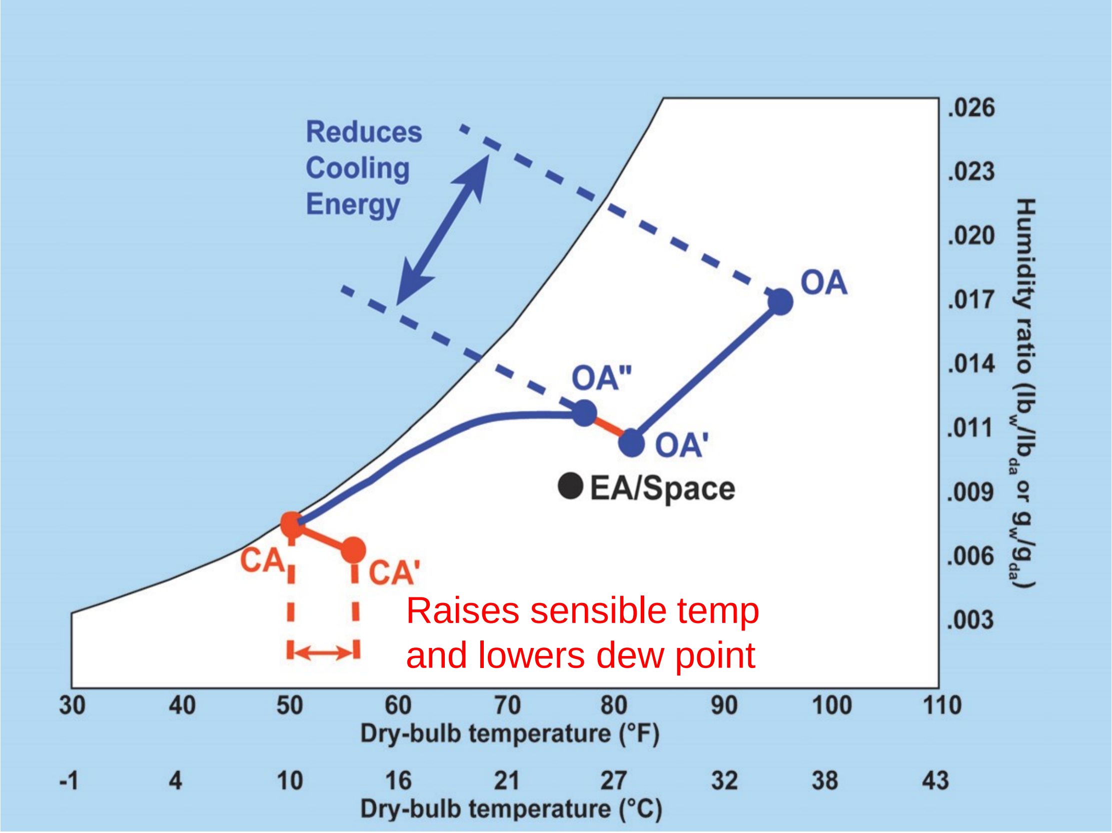
Flow measurement through the device can tell if adequate outdoor and exhaust air is getting through the device.

One easy way to do this is by measuring pressure drop across both sides of the device.

Second Stage Humidity Transfer Option



Humidity Transfer with a Type 3 Isotherm Desiccant

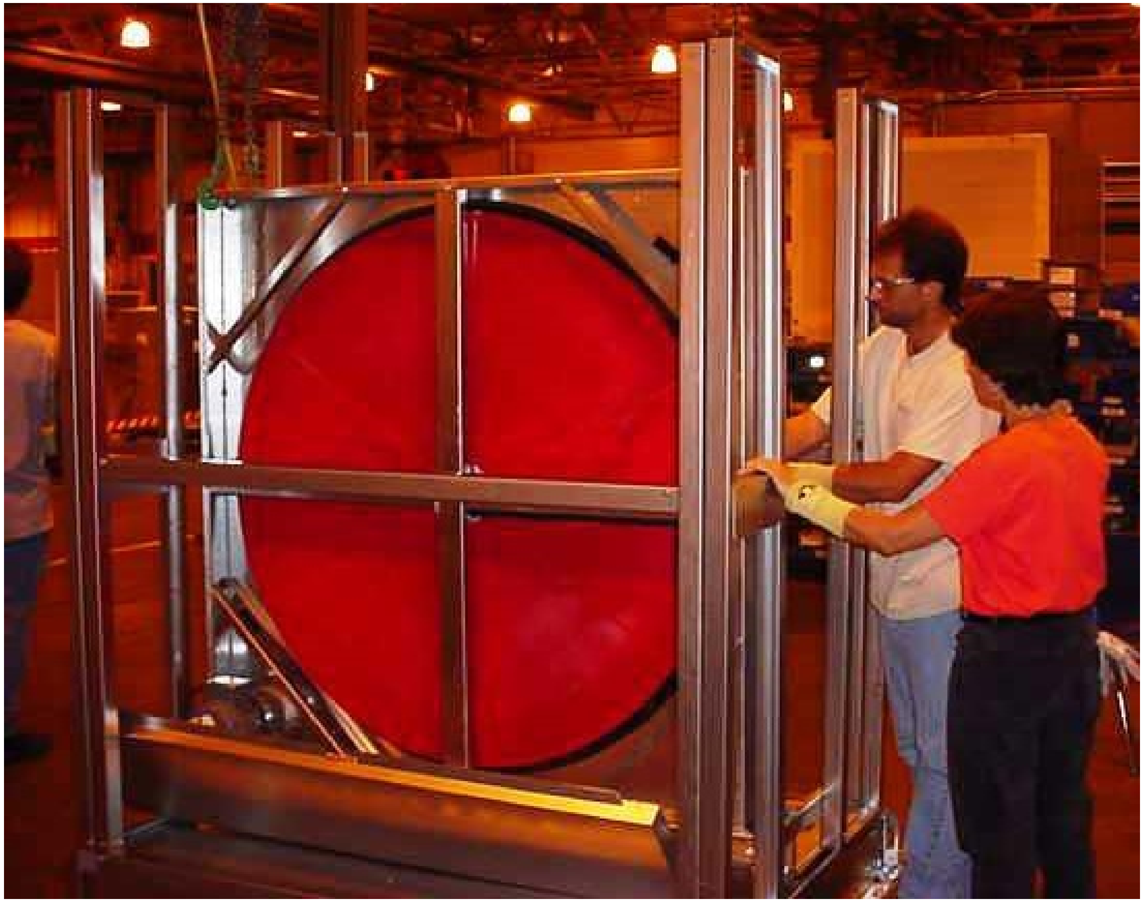


Transfer follows close to enthalpy line. Makes the air drier, warmer. Transfer happens by RH change, no energy except fan to handle wheel air pressure drop and the wheel motor.

Source: Mumma et al. 2013. (Decades old technology still catching on)

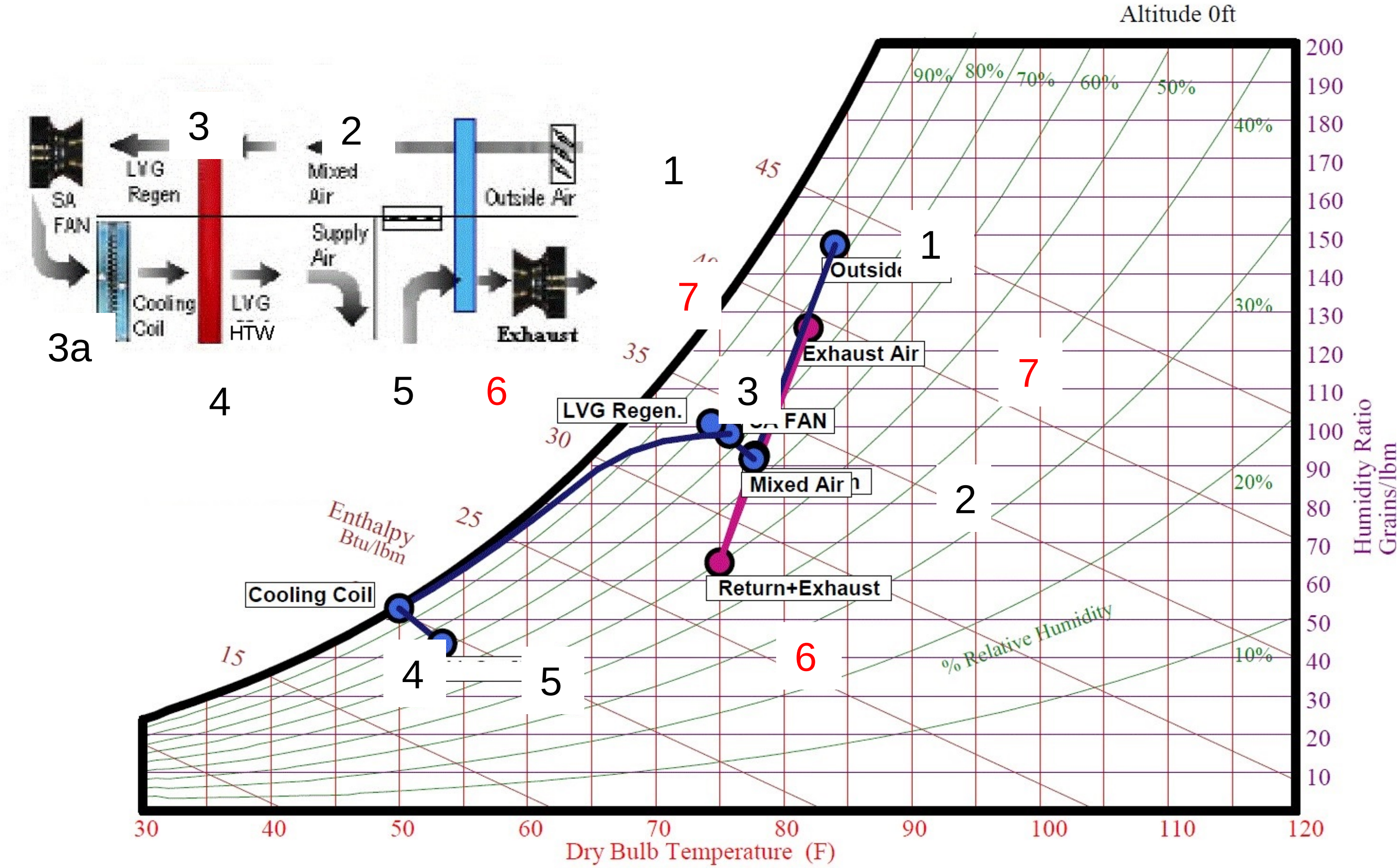
Rotates ***slowly***
8 RPH

Note bypass dampers to reduce PD if not operating

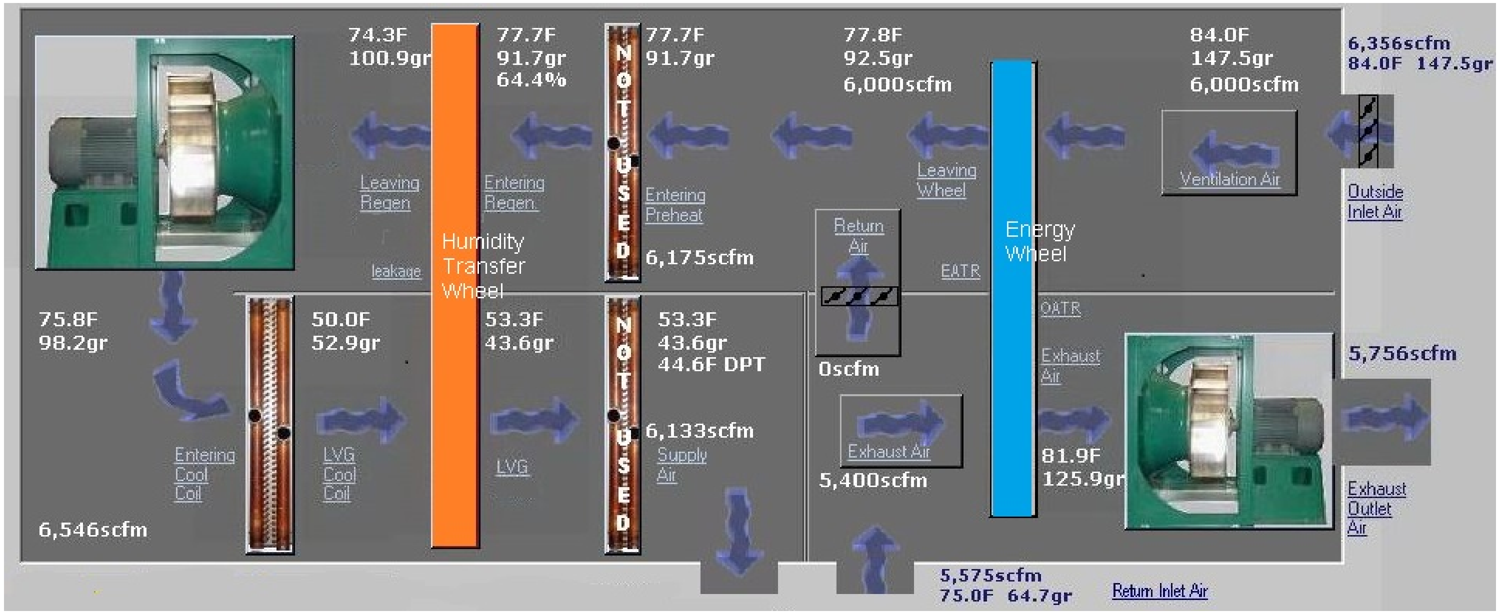


Isotherm Type 3 Desiccant Wheel

Isoterm Type 3 Wheel Saves Cooling and Reheat Energy



Two-Stage DOASu with Type 3 Desiccant Humidity Transfer Wheel



ASHRAE Tullie HQ DOAS Unit—Peak Dew-Point Design Condition

Survey Question #4

Have you heard of the type 3 desiccant prior to this introduction?

A. Yes
B. No
C. No response (Stepped away for a minute)

DOAS Operation

What Supply Air Temperature
- Room Neutral or Cool?

Cool is generally better

Latest ASHRAE/IES Standard 90.1 Requirement

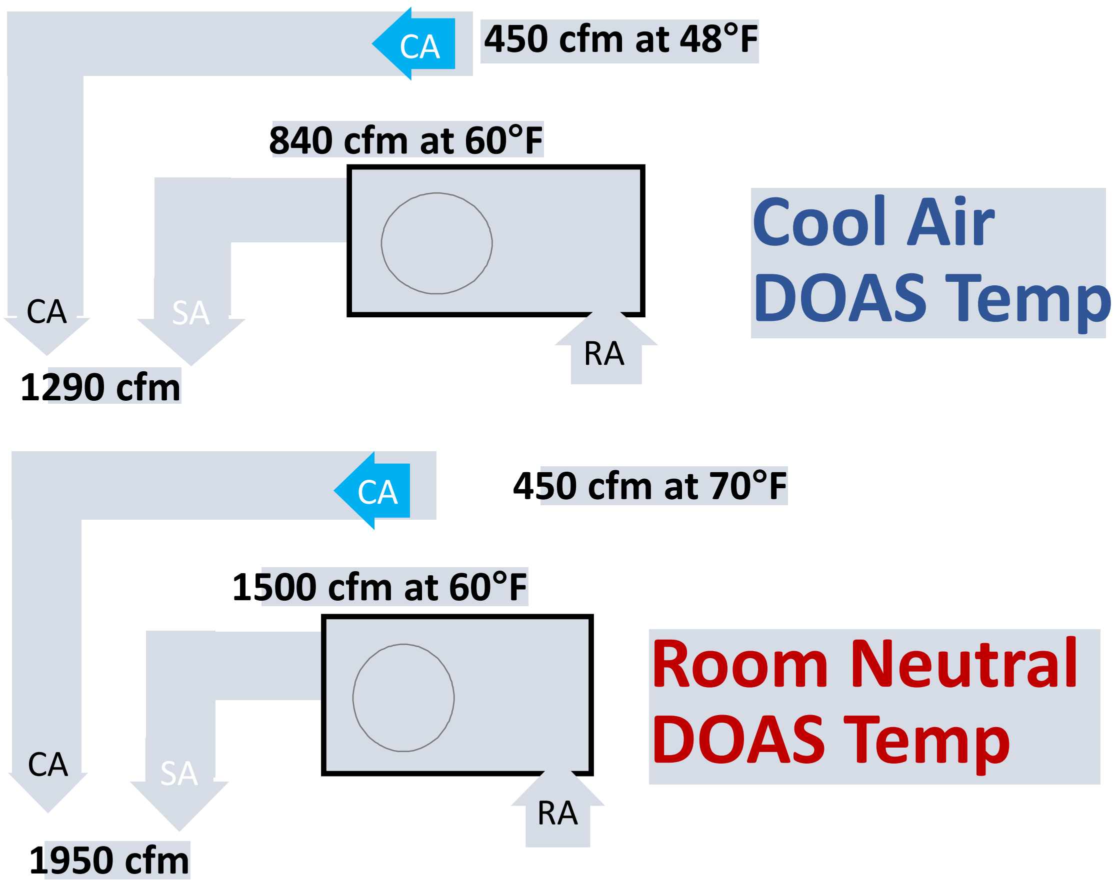
Due to the inefficiency of room neutral air in a DOAS application, Section 6.5.2.6 in the 2016 ASHRAE/IES Standard 90.1 now states the DOAS outdoor air shall be no warmer than 60°F (15.6°C) during the cooling season.

A few exceptions.

Cool Air is Better than Neutral Air

- Makes sense:
  - If majority of zones are in cooling mode, cool DOAS air will reduce H/C cooling energy.
  - Reason ASHRAE added it to the 90.1 Standard
- Cool air might reduce H/C unit size.
- Cool air will might **increase** the DOAS energy use but will reduce H/C system energy use.
- Does not have to be always “cool.” DOAS supply air needs to be dry first, then adjust sensible temperature to reduce H/C energy use.

DOAS does not have to be 60F. That is a maximum. How about 48F. What is the impact?



This is a 75°F space with the same sensible cooling requirement.

Room neutral DOAS needs 51% more air.

Impacts H/C unit size, ducts, diffusers, operating cost.

Can Cool VAV DOAS Air Overcool Space?

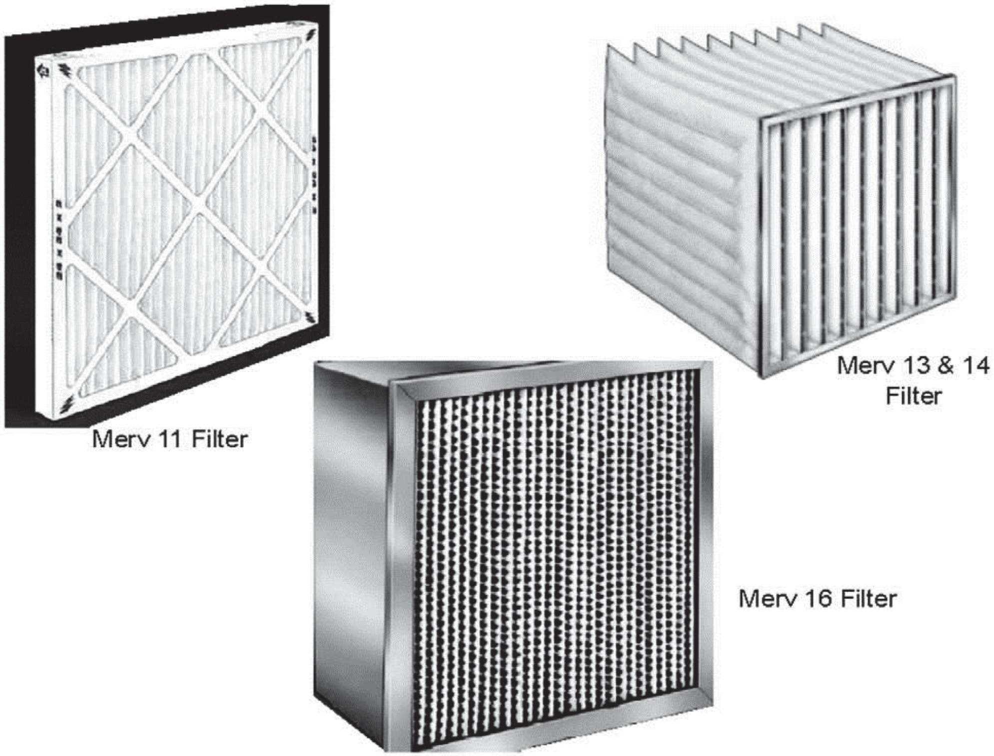
Yes, at conditions well below design cooling.

How to avoid this issue?

1. If a VAV DOAS system, the OA is tied to the people load. When load is less then design, modulate the DOAS cfm and H/C temperature to not overcool the space and avoid system fighting
2. If building space humidity is satisfied, the DOAU supply air temperature could be raised, reducing any H/C fighting and overcooling potential.
3. If needed, the H/C unit would need to heat, perhaps with recovered energy.

Air Cleaning

- Particulate filters protects coils, wheels, people. MERV 8 is popular with a trend to MERV 13-14. Some electric enhancement increases MERV without added pressure drop. Be careful.



Advanced Air Cleaning to meet ASHRAE 62.1

Additional OA air cleaning options can meet IAQ standards like ASHRAE 62. 1.

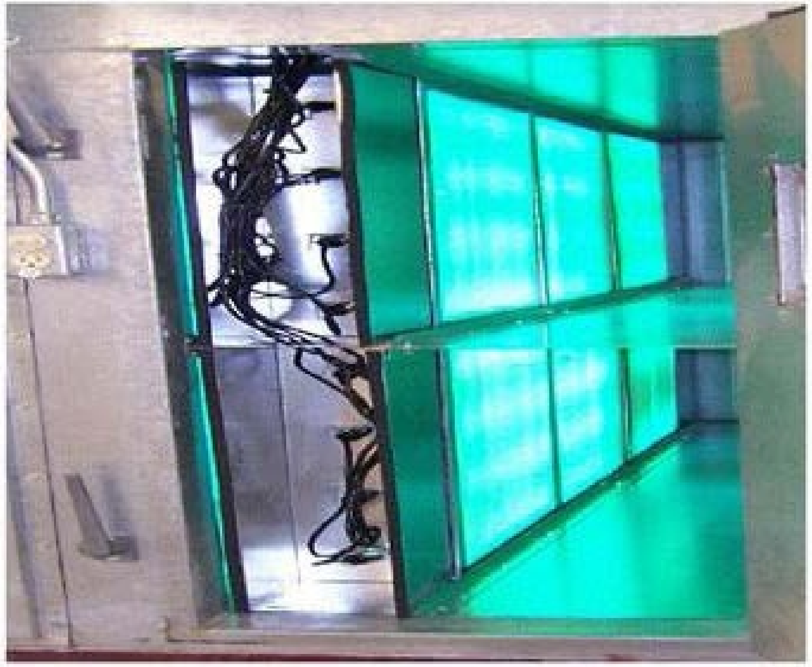
This is a new area of ASHRAE interest.

- Odors
- VOC
- Pathogens
  - Viruses
  - Spores
- Fumes
- Ozone

What is in OA that Needs to be Removed?

Chemical

Photocatalytic Oxidation (PCO)



Survey Question #5

Have you recommended/used any of the following ideas or technologies? Maybe to help control COVID. Multi-choice question. Select any that apply.

A. UVc
B. PCO
C. Ozone
D. Ionization or Dry Hydrogen Peroxide
E. More outdoor air, MERV13+ filters, etc.

DOASU Fans

Direct Drive Plenum AF fan with variable speed motor

- Select on
    - o Efficiency
    - o Unloading
    - o Noise
    - o Maintenance

No belt or modulation option energy losses. AF wheel optimized for peak efficiency. Low maintenance. Low blade tone (noise).

Multiple Fan Array for Large CFM DOASu

Photo Credit: Trane

Many manufacturers now offer this option.

Advantages

- F-Energy efficiency
- F-Reliability
- F-Serviceability
- U-Unit acoustics
- U-Unit footprint
- U-Installed cost
- U-Redundancy

- F=Fan, U=Unit

Fan Piezometer Flow Control

- Inlet cone flow measurement is low cost, effective

DOASu Pressure Drop Savings Ideas

- Internal component bypass dampers
  - In parallel with ATA - ~0.3 in. versus ~1.0 in. wheel pressure drop
  - Can be used with any high pressure drop component
  - When used – saves fan static or low energy mini airside economizer, gets to the +30% air goal.
  - Can be used for frost protection and flow control through a component
  - Negatives - will increase DOAS unit size and cost

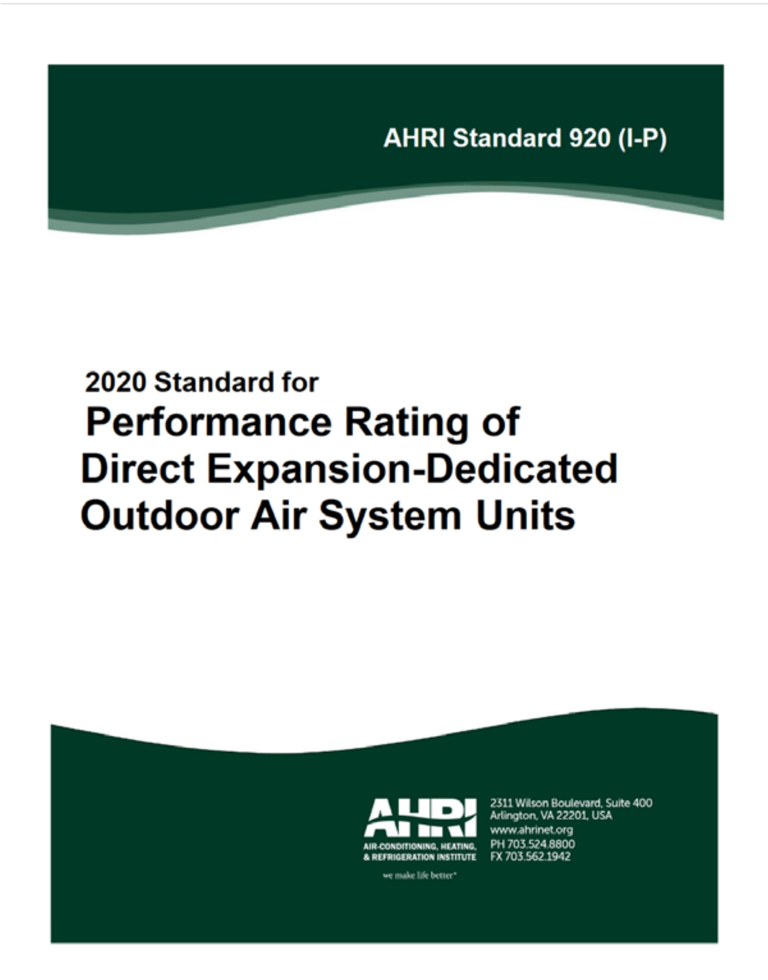
DOAS Control

- Growing acceptance - Factory packaged DDC controls with communicating controls for data logging, fault detection, and performance sensors
- Some key DOASu measurements:
  - Leaving dewpoint and supply air temperature
  - Supply and exhaust fan volume and lift, energy use
  - Component performance, status
- DOAS units can have upwards of 50 points sensor and control points. Some have more then 100. Needed because the DOASu can be 50% of building tonnage and operationally is the largest HVAC energy user. Proper control points have operational value.

DOAS Energy Modeling

- DOAS is modeled first and performance is assigned to each H/C thermal zone
- Energy Modeling Program needs to model all the types of DOAS units under consideration
- Program should model structure thermal and humidity capacitance
- Part of the Digital Twin Idea

AHRI Standard 920


AHRI Standard 920 (I-P)

2020 Standard for
Performance Rating of
Direct Expansion-Dedicated
Outdoor Air System Units

AHRI
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Rating Standard for DX compressor units with air or water cooled condensers.

Evolving. Part of growing acceptance of DOAS industry wide.

Table 4. Conditions for Standard Rating and Maximum Operating Tests for Classifications A, B, and W DX-DOAS Units[1]

	Rating Condition	Outdoor Air (OA) Temperature, °F		Condenser Water Entering Temperature, Cooling Tower Water, °F[2]	Condenser Water Entering Temperature, Chilled Water, °F[2,3]	Ambient Air Temperature[4], °F
		Dry bulb	Wet bulb			
DEHUMIDIFICATION	Standard Rating A Conditions[5]	95.0	78.0	86.0	45.0	95.0
DEHUMIDIFICATION	Standard Rating B Conditions[5]	80.0	73.0	81.0	45.0	80.0
DEHUMIDIFICATION	Standard Rating C Conditions[5]	70.0	66.0	74.0	45.0	70.0
DEHUMIDIFICATION	Standard Rating D Conditions[5]	63.0	59.0	67.0	45.0	63.0
DEHUMIDIFICATION	Maximum Operating Conditions	115.0	75.0	90.0	N/A	115.0
HEATING	Part Load Standard Rating E Conditions[6,7]	47.0	43.0	N/A	N/A	47.0
HEATING	Standard Rating F Conditions[6,7,8]	17.0	15.0	N/A	N/A	17.0
HEATING	Maximum Operating Conditions	70.0	N/A	N/A	N/A	70.0

Notes:
1. Supplementary Heat is not tested under this standard.
2. See Section 6.1.6.5 for test liquid requirements.
3. Informative note: While many configurations of a chilled water-cooled condenser may exist, typically this system would apply when a water-cooled DX-DOAS unit is connected to a chilled water loop to provide lower dew point air than would be possible with that chilled water and a water coil, the "Condenser Water Entering Temperature, Chilled Water" temperature condition may be used to provide the heat rejection capability for a DX-DOAS unit.
4. Conditions surrounding the unit and entering the condenser (outdoor) coil are the same as the Outdoor Air entering conditions, except as described in Section C2.1.2 of Appendix C.
5. Return Air for Standard Rating Conditions A, B, C and D shall be 75.0 °F dry bulb temperature and 62.5 °F wet bulb temperature, except as described in Section C4 of Appendix C.
6. Return Air for Standard Rating Conditions E and F shall be 70.0 °F dry bulb temperature, except as described in Section C4 of Appendix C.
7. For Standard Rating Conditions E and F, Return Air wet bulb conditions of 58.5 °F is required for Relief Air-Cooled DX-DOAS. Otherwise, control of Return Air water vapor content is not required for Standard Rating Conditions E and F.
8. Standard Rating F Condition test is optional. If Standard Rating F Condition test is not conducted, a default value of 1 shall be assigned for $COP_{DOAS,F}$.

DOASu full and part load measurement points. From AHRI 920-2020

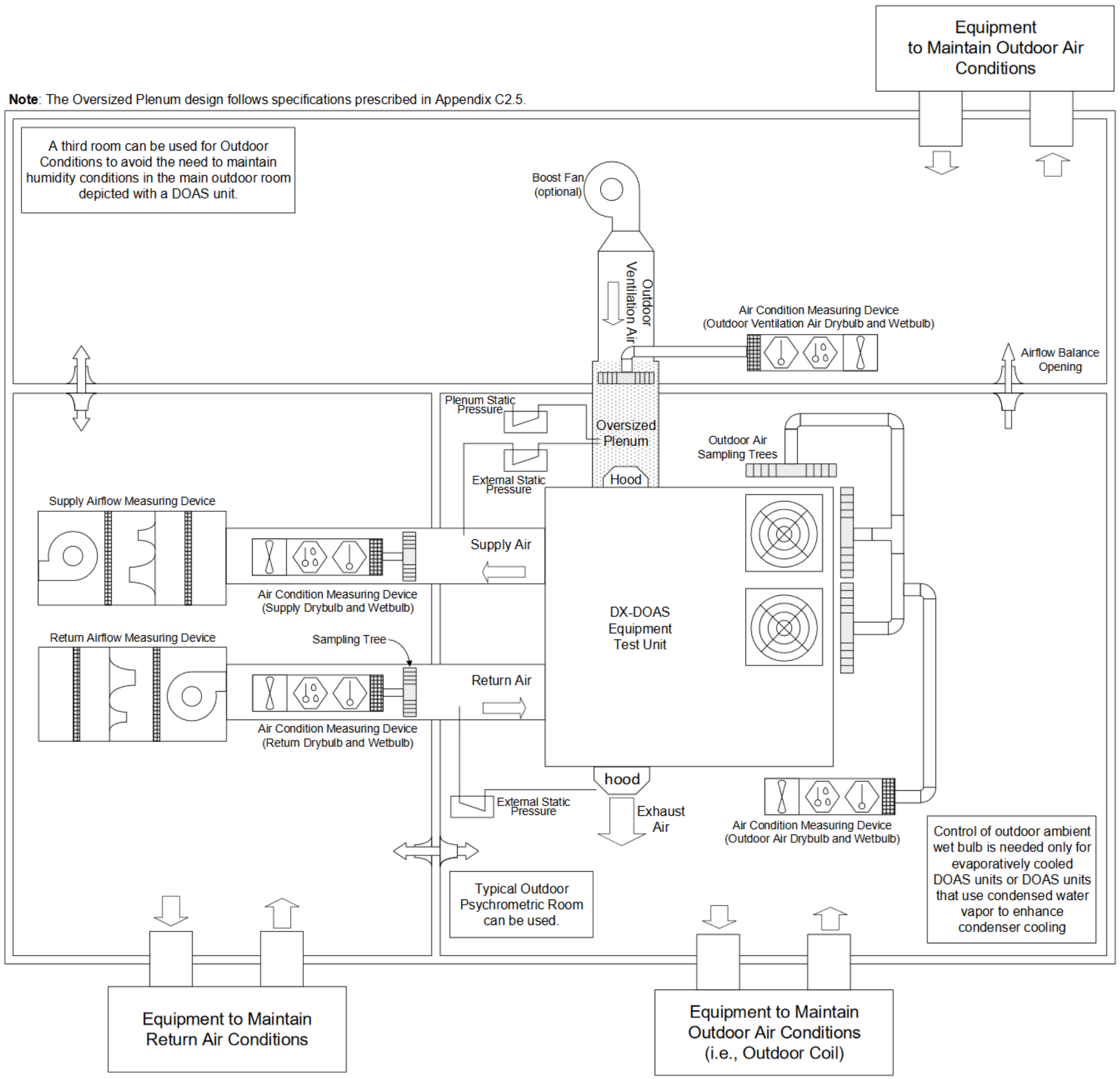


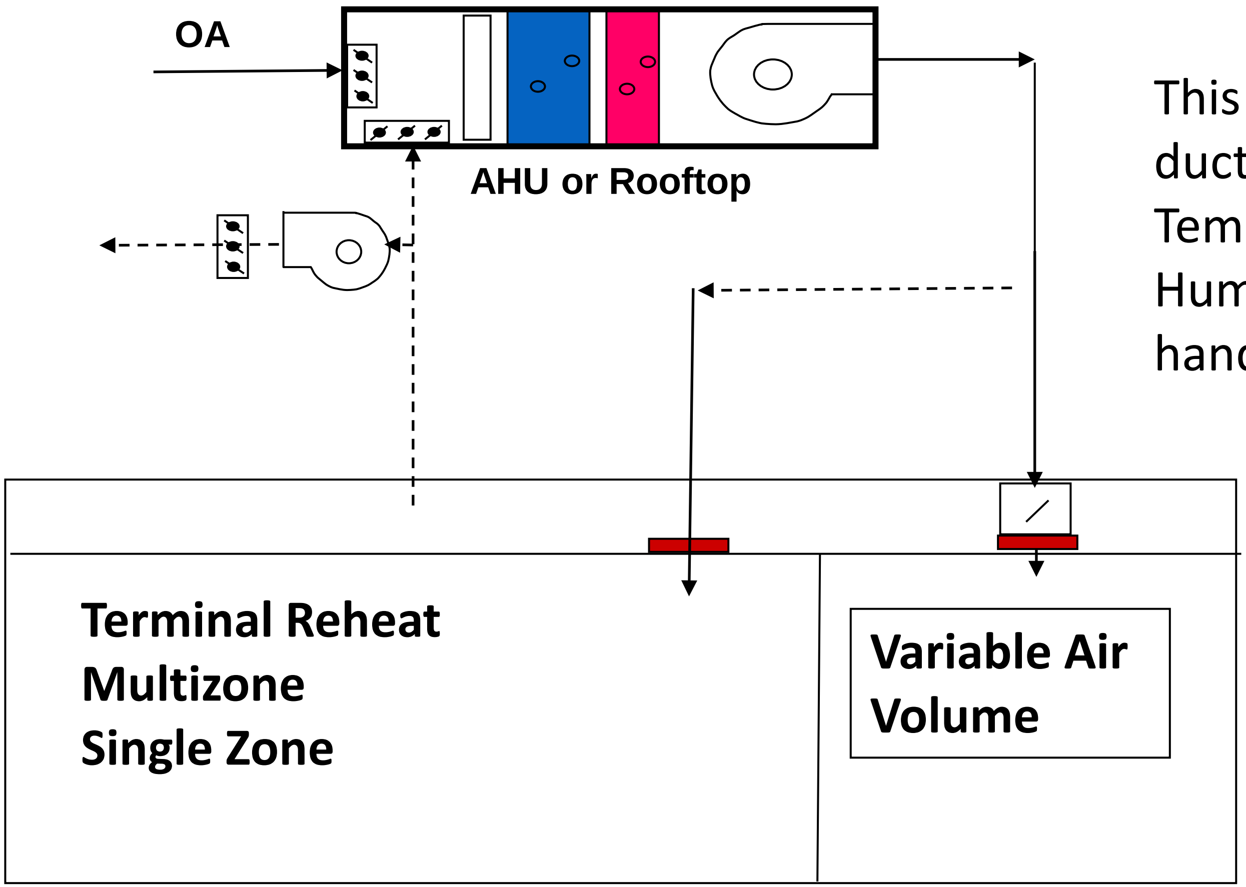
Figure E4. Single Package DX-DOAS unit with VERS (Option 1 – 3 Rooms)

One of several DOASu test setups.
This is a challenging test.
From AHRI 920-2020

Unit Energy Use

- For any equipment item
- Know the equipment power use
  - 100%, 75%, 50%, and 25%
  - 0%.
  - 0% is not off. 0% is not a AHRI rating point. Measure it!

Let’s compare DOAS with Mixed-Air Systems



This is a single path duct system. Temperature and Humidity are handled in series.

Mixed-Air System

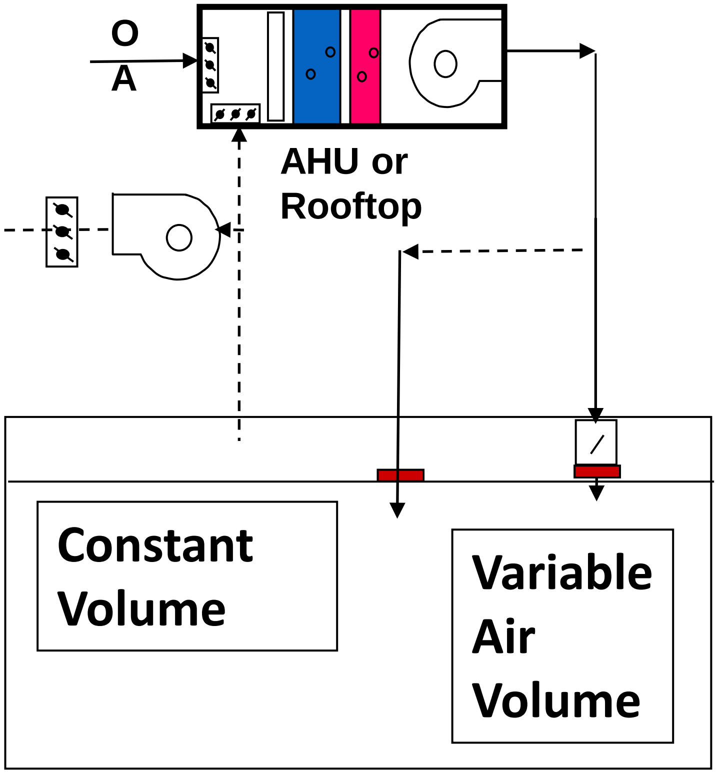
Return air and outdoor air is mixed before cooling/heating coil (e.g., HVAC). Typical rooftop or unit vent. Series airflow system

DOAS System

Outdoor air goes directly to zone; parallel units handle space temperature control. Parallel airflow system

Mixed-Air Systems

- OA mixes with return air
- Requires full amount of supply air to be dehumidified
- Air stratification in "mixing box" can be a problem, especially in CW air handlers
- Control complexity if highly efficient, meeting latest codes
- Can have air economizer
- If VAV, some zones need higher the minimum OA amounts to properly ventilate other zones. Uses more OA than DOAS.



Code-Defined High-Performance VAV System in Lieu of DOAS

- 16 criteria—sample of key requirements from 2015 Washington State Energy Code
  - Must have air-side economizer and DDC controls
  - If zone is >2500 cfm must have
    - System OA flow measurement with VAV terminal feedback reset
    - VAV terminal supply airflow measurement
  - Primary supply air reset based on zone feedback
  - Spaces larger than 150 ft^2 and >25 people/1000 ft^2 must have VAV terminal with CO_2 demand reset and occupancy sensor
  - Computer, server rooms must have separate system
  - Hydronic: staged chillers or storage, >90% efficiency gas boilers
  - Fan powered motors—ECM with 66% minimum turndown
  - Fault management, monthly VAV terminal diagnostic checks
  - Designed and configured to ASHRAE Guideline 36

DOAS does not use an 100% air economizer, it can use a partial economizer

- ASHRAE/IES Standard 90.1-2016 requires each cooling system with a fan to include an air or water economizer. There are 11 exceptions. Best ones are as follows:
  - State code mandates DOAS as the system of choice.
  - Number 1—individual fan-cooling units with a supply capacity less than the minimum listed in Table 6.5.1-12. (Allocate DOAU fan energy to the local H/C units to meet Table 6.5.1.)
  - Number 10—For comfort cooling where the cooling *efficiency* meets or exceeds the *efficiency* improvement requirements in Table 6.5.1-2.

100% OA Economizers

- A significant fraction of the expected benefits of airside economizers are not borne out in practice because of improper installation, poor relief or operation, stratification/frozen coil, and equipment failure over time.
- Economizers controlled by dry-bulb temperature (particularly those using temperature reset) can introduce excess humidity, which can lead to added energy consumption, uncomfortable spaces, and IAQ problems (Mumma 2005a, 2006).
- Active building pressure control is needed to make100% OA economizers work—adds first cost. Hallstrom 2020

Survey Question #6

Can a conventional VAV system be converted to DOAS?

A. Yes
B. Yes – I have done it
C. No
D. Not sure

Conclusion

- Latest in DOAS, third generation, offer the following benefits:
  - Assured ventilation performance
  - Excellent humidity and building pressure control
  - Good IAQ with low energy use
  - In general, easy to understand system controls
  - Can handle future space use ventilation changes.
  - Fairly competitive life cycle based first cost

Congratulations to those of you already designing/building/using DOAS!

Acknowledgements:

Would like to recognize

Dr. Stan Mumma, Ph.D. P.E., ASHRAE Fellow, Professor Emeritus of Architectural Engineering at Pennsylvania State University

Donald P. Gatley, P.E., ASHRAE Fellow
Bill Coad, P.E, ASHRAE Fellow
John Murphy, ASHRAE Fellow, Leed AP

for their interest, involvement, and contributions with DOAS.

Useful References

ASHRAE Learning Institute:

- *Latest in High-Performance Dedicated Outdoor Air Systems (DOAS)*—presented by Arthur Hallstrom, P.E., Fellow/Life Member ASHRAE, BEMP
- *Air-to-Air Energy Recovery Fundamentals*—presented by Paul Pieper, P.Eng., Member ASHRAE

- **Standards:**
- ANSI/ASHRAE Standard 62.1-2019
- ANSI/ASHRAE/IESNA Standard 90.1-2019
- ANSI/ASHRAE Standard 84-2020
- ANSI/ASHRAE Standard 198-2013
- AHRI Standard 1060-2018
- ANSI/AHRI Standard 920-2020

- **Books:**
- *ASHRAE Design Guide for Dedicated Outdoor Air Systems* (DOAS) (2017)—developed with the support of ASHRAE TC 8.12, 8.10, 5.5, and 1.12
- *ASHRAE Guide for Building in Hot and Humid Climates*—developed with the support of ASHRAE TC 9.12, 8.12, 4.4, and 1.12

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A copy of the presentation is available at:
https://www.ashrae.org/doas2021SpringOnline2march

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