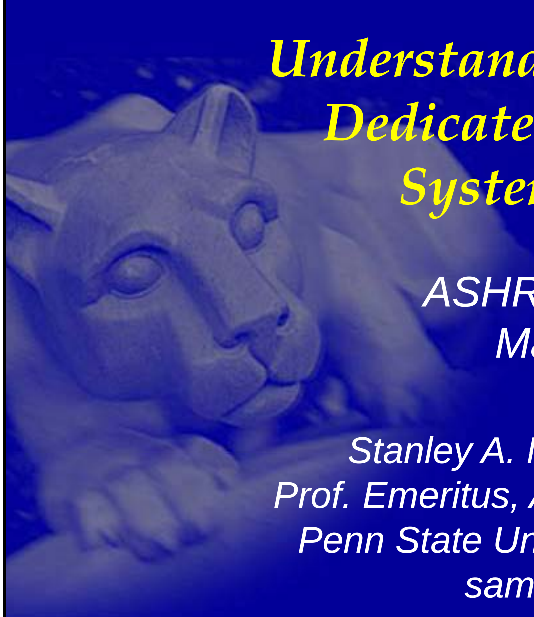

Understanding & Designing Dedicated Outdoor Air Systems (DOAS)

ASHRAE Short Course
March 23, 2010

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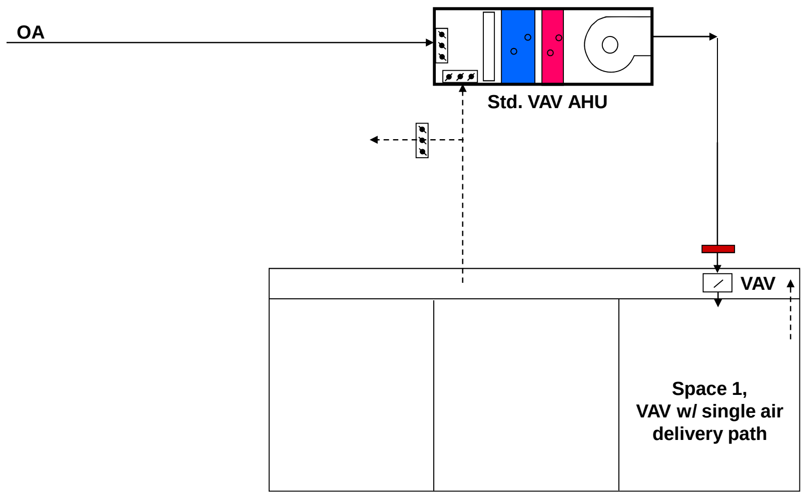
Presentation Outline & Learning Objectives

- Quick review of current leading building HVAC system issues.
- Define DOAS.
- Explain terminal equipment choices and issues.
- Describe Air Side Economizer lost—implications. Break #39
- Describe DOAS equipment choices and Psychrometrics.
- Explain design steps for DOAS and provide example
- 30% surplus OA, why and does it use more energy? Break #75
- Explain relevance of DOE and ASHRAE Research findings.
- Describe field applications.
- Conclusions.

Current HVAC system of choice: VAV



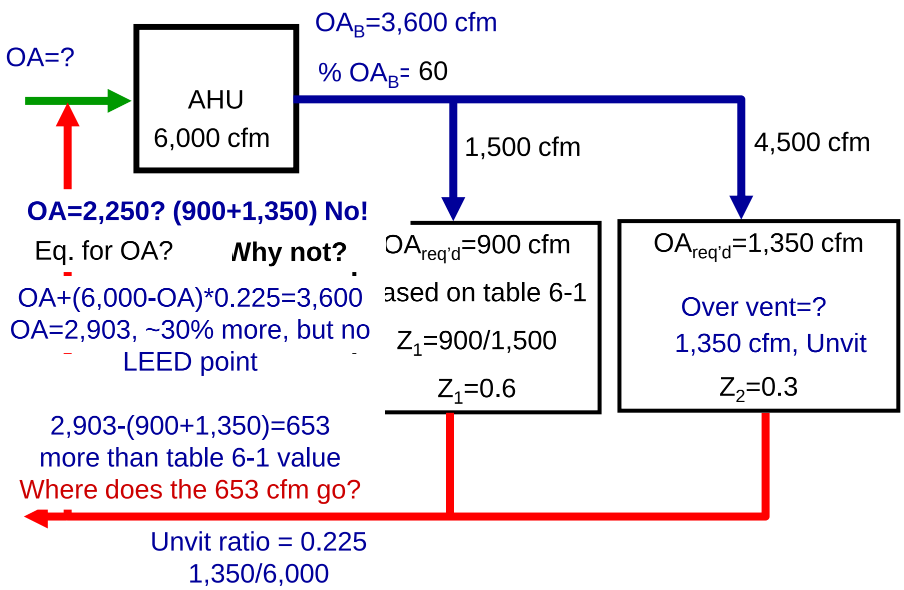
Why VAV is system of choice.

- Eliminates bucking: a characteristic of predecessor systems such as dual duct, multi-zone, and terminal RH.
- At off design conditions, the majority of the time, fan power is reduced, i.e. at 50% flow, fan power is 0.5^3 – or 12.5%. Huge improvement over previous systems.
- Single duct, and easy to design for tenant fit out.
- Often thought to be simple to control – but that is not a fact – especially with ventilation needs, SAT reset, economizer, and building pressurization.

Inherent Problems with VAV Systems

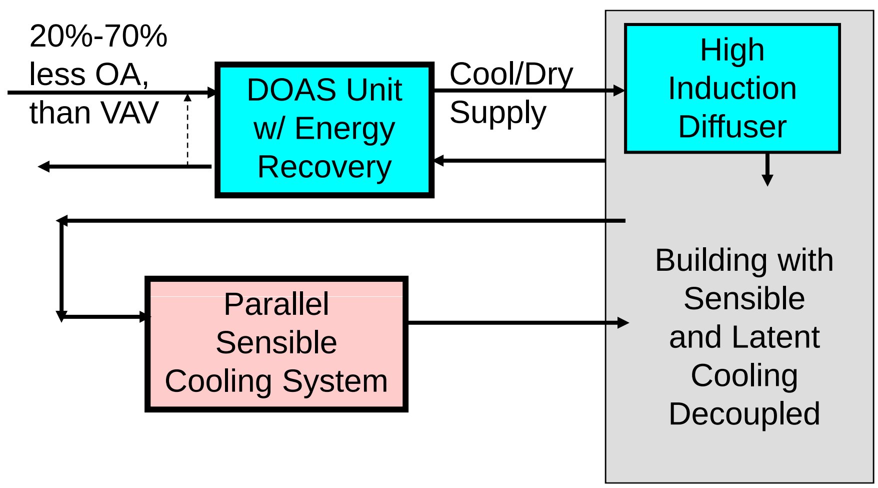
- Poor air distribution
- Poor humidity control
- Poor acoustical properties
- Poor use of plenum and mechanical shaft space
- Serious control problems, particularly with tracking return fan systems
- Poor energy transport medium: air
- Poor resistance to the threat of biological and chemical terrorism
- Poor and unpredictable ventilation performance

Poor & unpredictable vent'n performance.



Can VAV limitations be ove e?

DOAS Defined for This Presentation

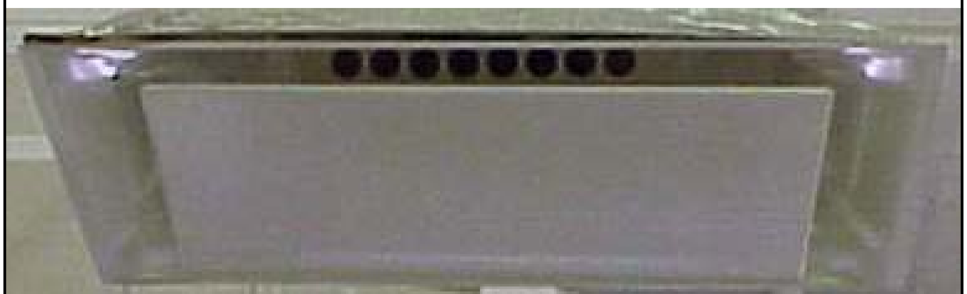


Key DOAS Points

1. 100% OA delivered to each zone via its own ductwork
2. Flow rate generally as spec. by Std. 62.1-2007 or greater (LEED, Latent. Ctl)
3. Employ TER, per Std. 90.1-2007
4. Generally CV
5. Use to decouple space S/L loads—Dry
6. Rarely supply at a neutral temperature
7. Use HID, particularly where parallel system does not use air

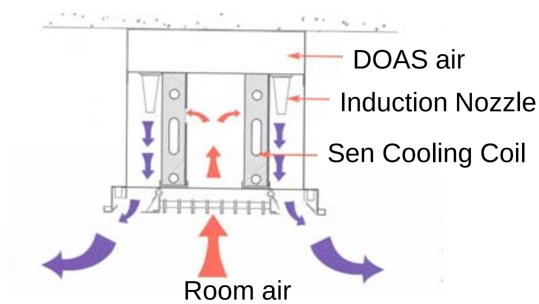
Total Energy Recovery (TER) Wheel

High Induction Diffuser



- Provides complete air mixing
- Evens temperature gradients in the space
- Eliminates short-circuiting between supply & return
- Increases ventilation effectiveness

Parallel Terminal Systems



Chilled Beams

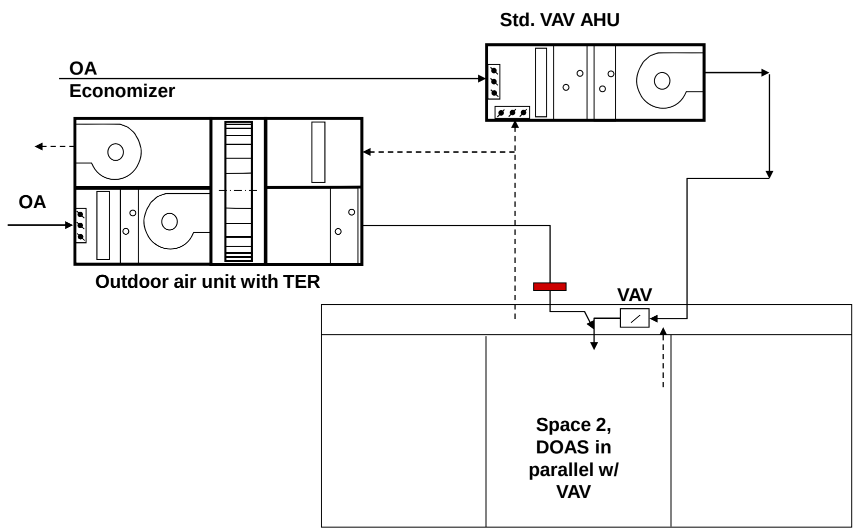
Fan Coil Units

Air Handling Units
CV or VAV

VRV
Multi-Splits

Unitary ACs
i.e., WSHPs

DOAS with Parallel VAV

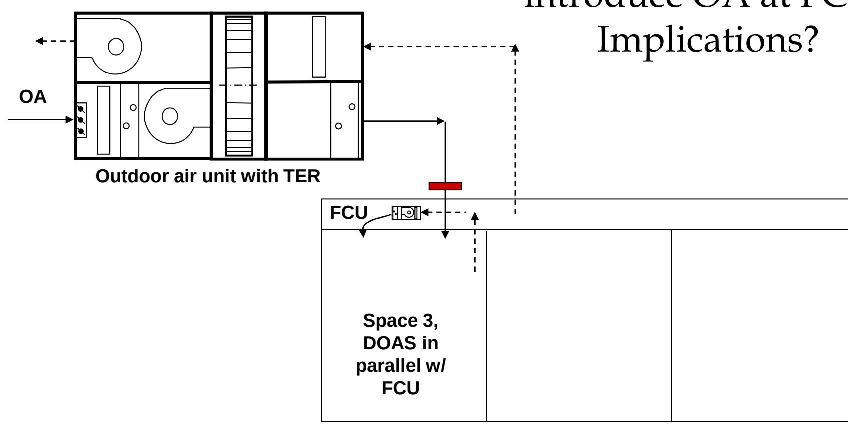


VAV Problems Solved with DOAS/Parallel VAV

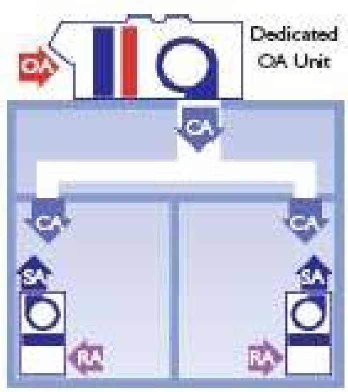
- **Poor air distribution**
- **Poor humidity control**
- Poor acoustical properties
- Poor use of plenum and mechanical shaft space
- Serious control problems, particularly with tracking return fan systems
- Poor energy transport medium: air
- Poor resistance to the threat of biological and chemical terrorism
- **Poor and unpredictable ventilation performance**

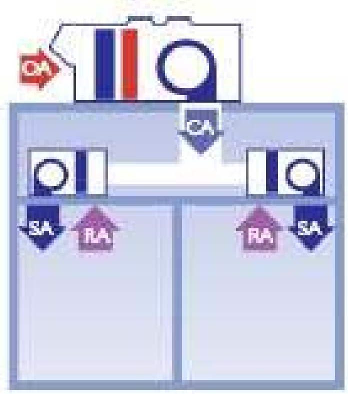
DOAS with Parallel FCU

Other ways to introduce OA at FCU? Implications?



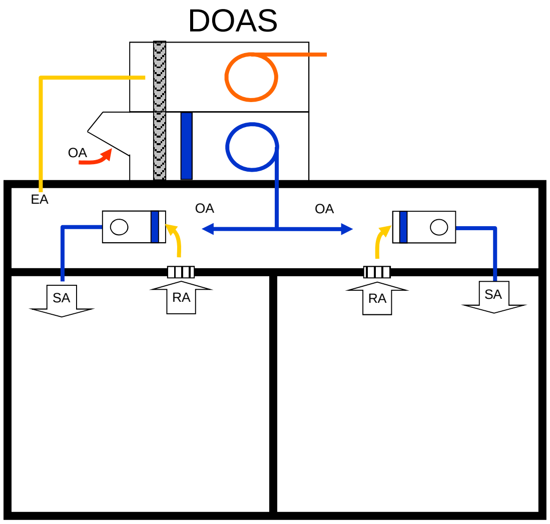
Parallel vs. Series OA introduced for DOAS-FCU applications?



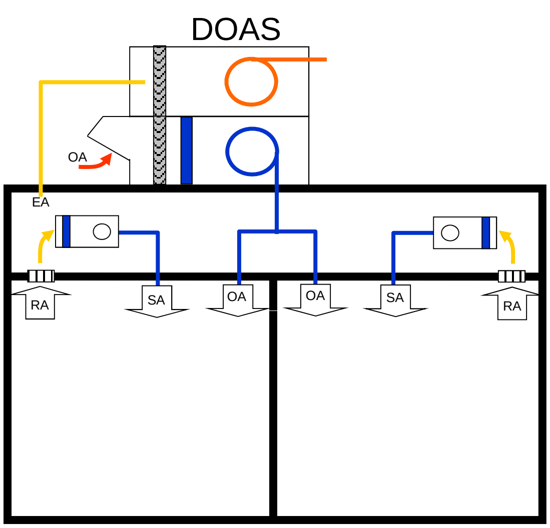


Parallel, Good *Series, Bad*

Common arrangement of FCU in series with DOAS--BAD



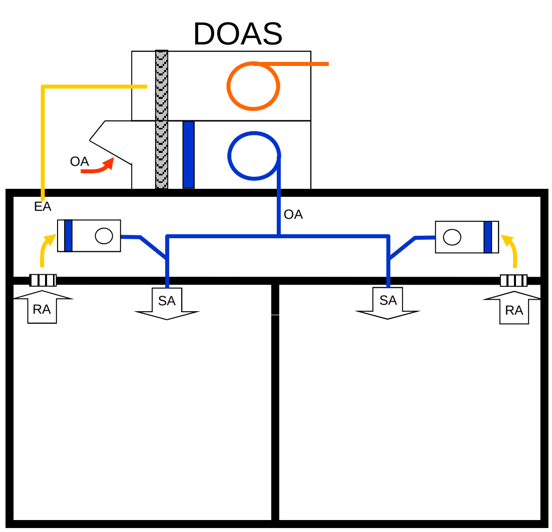
Usual concept of ceiling FCU in parallel with DOAS—a false paradigm



Reasons given by series camp for using series arrangement of FCU with DOAS over the false paradigm parallel arrangement

- Superior thermal comfort
- Superior IAQ
- Superior energy efficiency and performance
- Simpler arrangement
- Reduced 1st $, labor and materials
- Ideal for constant volume systems
- Best for low occupancy density spaces
- Simpler controls
- Eliminates the need for DOAS terminal reheat
- Simplifies the selection, performance and placement of diffusers
- Eliminates the distribution of cold DOAS air to perimeter spaces in the winter.

The correct paradigm of ceiling FCU in parallel with DOAS



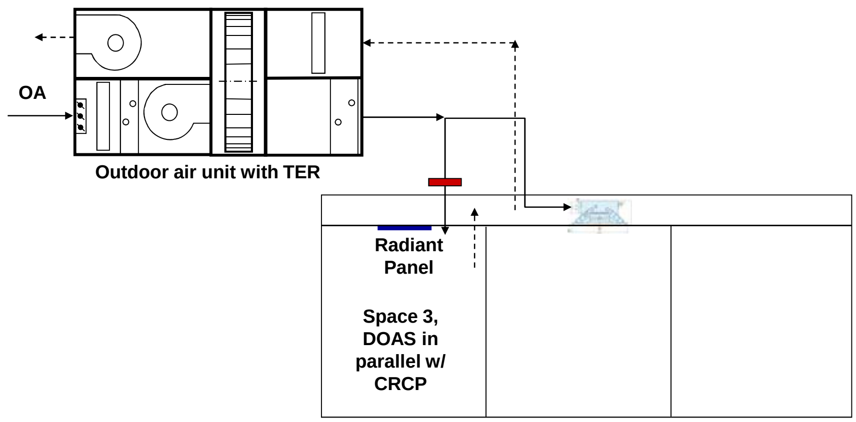
Advantages of the correct paradigm parallel FCU-DOAS arrangement

- At low sensible cooling load conditions, the terminal equipment may be shut off—saving fan energy
- The terminal device fans may be down sized since they are not handling any of the ventilation air, reducing first cost
- The smaller terminal fans result in fan energy savings
- The cooling coils in the terminal FCU's are not derated since they are handling only warm return air, resulting in smaller coils and further reducing first cost.
- Opportunity for plenum condensation is reduced since the ventilation air is not introduced into the plenum near the terminal equipment, for better IAQ
- Is not inferior to the *series* arrangement in any of the 11 categories sited above as advantages by the *series* camp, when configured with the correct *parallel* paradigm

VAV Problems Solved with DOAS/Parallel FCU

- **Poor air distribution**
- **Poor humidity control**
- Poor acoustical properties
- **Poor use of plenum and mechanical shaft space**
- **Serious control problems, particularly with tracking return fan systems**
- Poor energy transport medium: air
- **Poor resistance to the threat of biological and chemical terrorism**
- **Poor and unpredictable ventilation performance**

DOAS with Parallel Radiant, or Chilled Beam



VAV Problems Solved with DOAS/Radiant-Chilled Beam

- Poor air distribution
- Poor humidity control
- Poor acoustical properties
- Poor use of plenum and mechanical shaft space
- Serious control problems, particularly with tracking return fan systems
- Poor energy transport medium: air
- Poor resistance to the threat of biological and chemical terrorism
- Poor and unpredictable ventilation performance

Additional Benefits of DOAS/Radiant-Chilled Beam

Beside solving problems that have gone unsolved for nearly 35 years with conventional VAV systems, note the following benefits:

- Greater than 50% reduction in mechanical system operating cost compared to VAV
- Equal or lower first cost
- Simpler controls
- Generates up to 80% of points needed for basic LEED certification

Role of Total Energy Recovery

DOAS & Energy Recovery

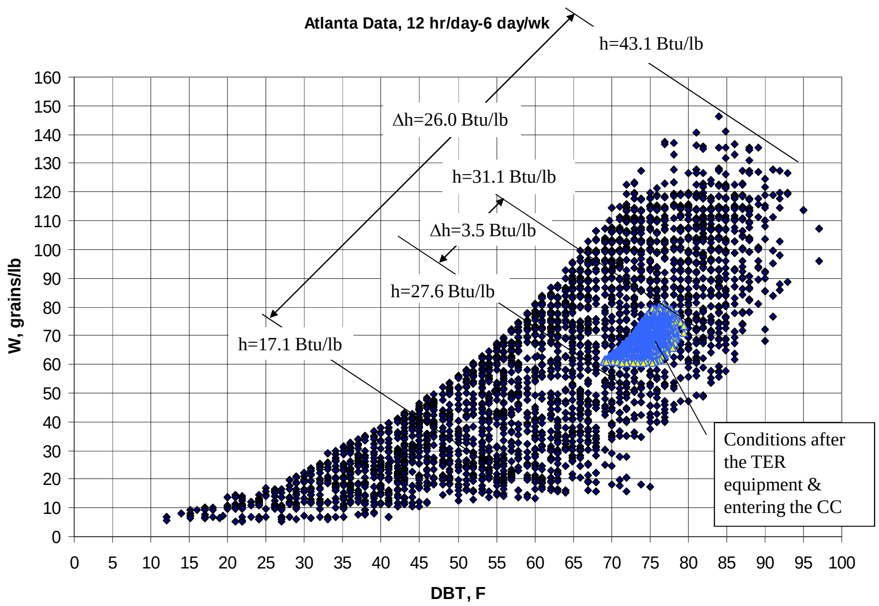
ASHRAE Standard 90.1-2007 in section 6.5.6.1 Exhaust Air Energy Recovery requires the following:

"Individual fan systems that have both a ***design supply air capacity of 5000 cfm*** or greater and have a ***minimum outside air supply of 70%*** or greater of the design supply air quantity shall have an energy recovery system ***with at least 50% total energy recovery effectiveness."***

Std 62.1-2007 allows its use with class 1-3 air.

Merits of Using a TER (Enthalpy Wheel) with DOAS

- A significant reduction in the design OA cooling load, reducing both the chiller size & the peak demand
- A reduction in the annual OA cooling and dehumidify energy consumption
- A significant reduction in the OA heating and humidification energy consumption (in the N)
- Conforms to ASHRAE Standard 90.1-2007
- A major reduction in the variability of the OA conditions entering the CC (critical w/ pkg. equip.)



Implications of the Small Area on the Psychrometric Chart Entering the CC

- Variation in the OA load on the CC ranges by only 25% (from a low of 75% to a max of 100%)
- At peak design load conditions, the enthalpy wheel reduces the OA load on the chiller by 70-80%. Often 40-50% of the total design load on the chiller.

Air side economizer lost: implications!

- This a frequent question, coupled with the realization that without full air side economizer, the chiller may run many more hours in the winter than owners and operators would expect based on their prior experiences.
- The following slides will address this issue.
- For more details, please check the link: http://doas-radiant.psu.edu/IAQ_Econ_Pt1_Pt2.pdf

100% Air Side Economizer Lost!

ANSI/ASHRAE/IESNA Standard 90.1
Energy Standard for Buildings Except Low-Rise Residential Buildings

6.5.1 Air (100% OA) or Water (via a cooling tower) Economizers: a prescriptive requirement

11.1.1 Energy Cost Budget Method, *an alternative to the prescriptive provisions.* It may be employed for evaluating the compliance of all proposed designs. Requires an energy analysis.

Air Side VAV Econ. Performance Vs. DOAS

An example, assuming:

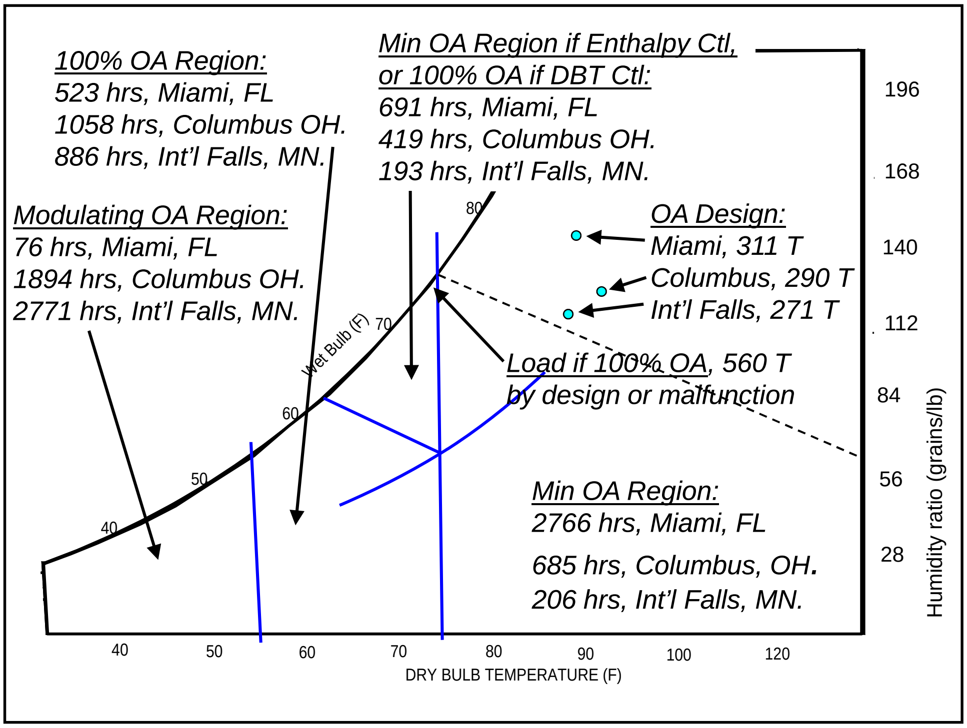
- Internally dominated cooling load building. Fully occupied 6 days per week, from 6 am to 7 pm (13 hours per day, 4,056 hours per year).
- 100,000 cfm design supply air flow rate at 55°F
- Minimum ventilation air requirement: 20,000 cfm
- In the economizer mode, the OA flow can modulate between 20,000 cfm and 100,000 cfm.
- Therefore, the only variability in chiller energy consumption/demand is the economizer control and the geographic location.

Objective

Show that DOAS w/o economizer uses less energy than VAV with economizer

Assumes:

- 0.7 kW/ton cooling
- Fan eff. 70%: Motor eff. 90%
- Electricity: $0.08/kWh
- AHU internal ΔP=3″, External ΔP=4″



Economizers frequently experience malfunctioning problems, including stuck or improperly operating dampers. Malfunctions can be minimized as follows:

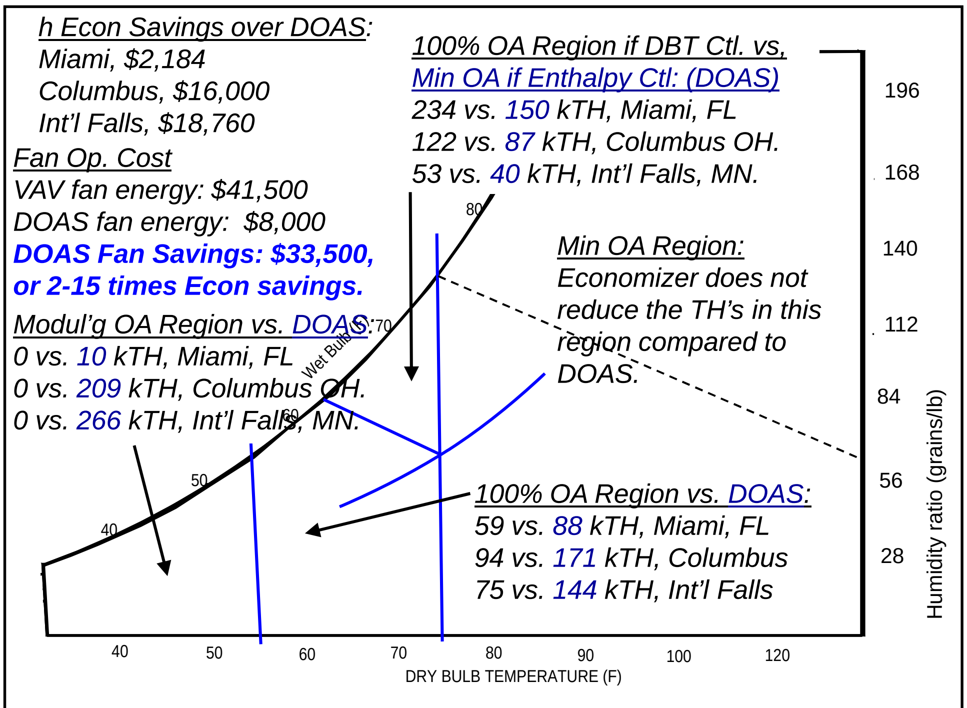
1. ***quality components must be selected and properly maintained.***
2. ***economizer dampers need to be tested twice annually before entering each cooling and heating season.***

Item 2 is rarely done because of operational priorities and the frequent inaccessibility of the hardware.

Industry advice when Economizers experience repeated problems.

Ref: http://www.uppco.com/business/eba_8.aspx

- *The electric utilities recommend, in order to place a lid on high demand, "locking the economizer in the __minimum__ outside air position if an economizer repeatedly fails, and it is prohibitively expensive to repair it.*
- *Although the potential benefits of the economizer's energy savings are lost, it is a certain hedge against it becoming a significant energy/demand waster."*



Economizer Summary

Using water economizer with DOAS-hydronic systems is a good idea, and can save mechanical cooling energy.

It is recommended for applications employing water cooled chillers.

However the DOAS-hydronic systems should not need WSFC to comply with the Energy Cost Budget Method of Std. 90.1.

That’s good, because many projects are too small for cooling towers, but are excellent candidates for DOAS-hydronic.

DOAS Equipment on the Market Today

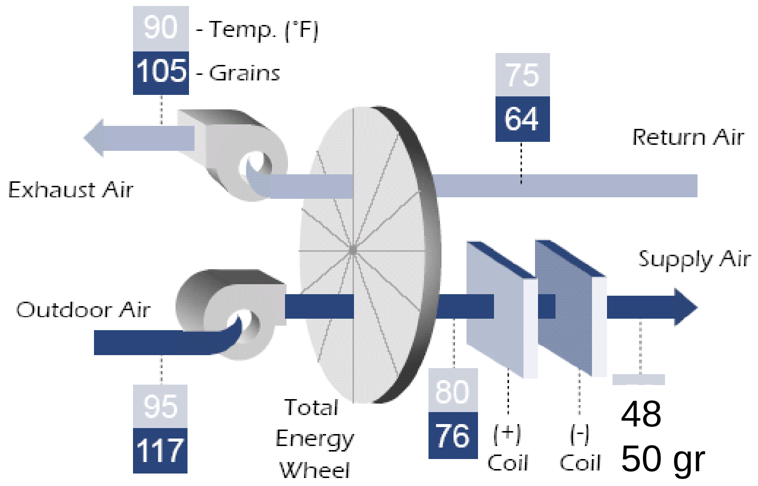
I: Equipment that adds sensible energy recovery or hot gas for central reheat

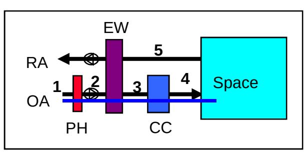
II: Equipment that uses total energy recovery

III: Equipment that uses total energy recovery and passive dehumidification wheels

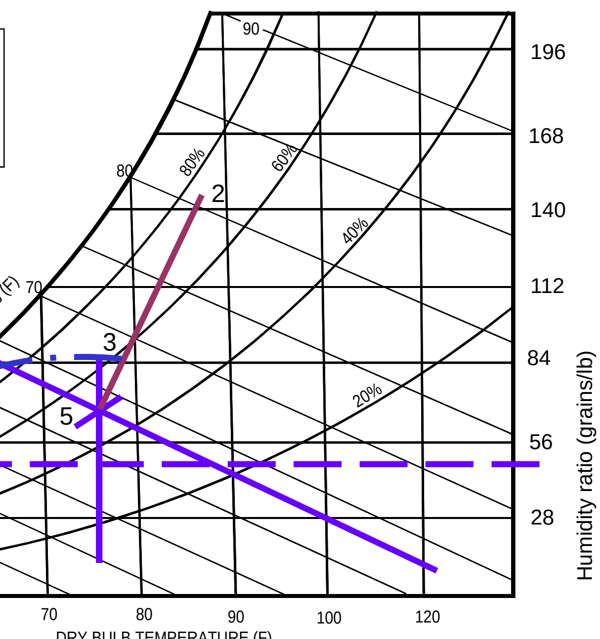
IV: Equipment that uses active dehumidification wheels, generally without energy recovery

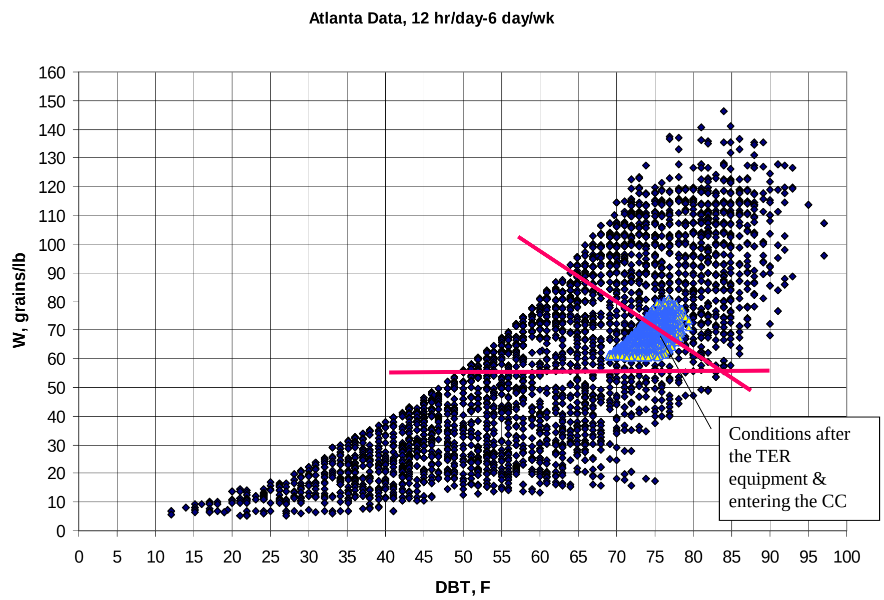
DOAS Equipment on the Market Today



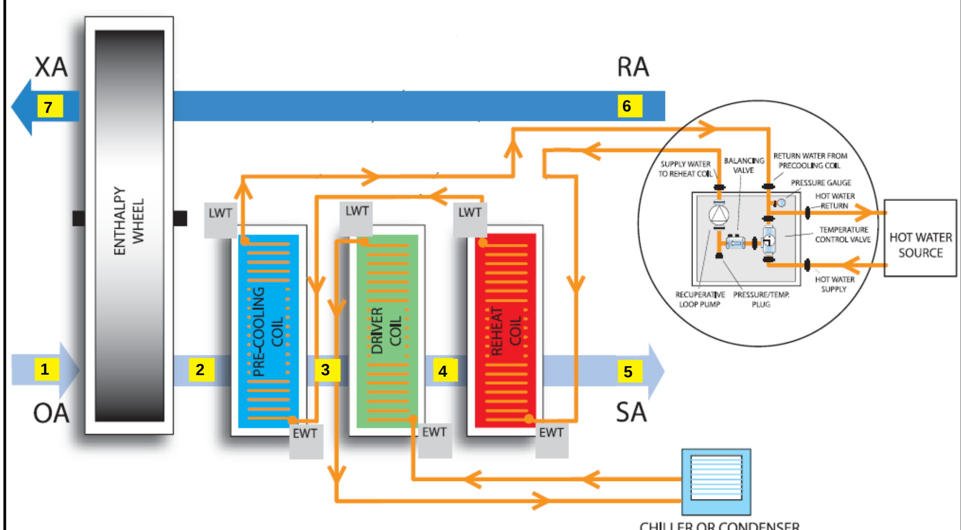


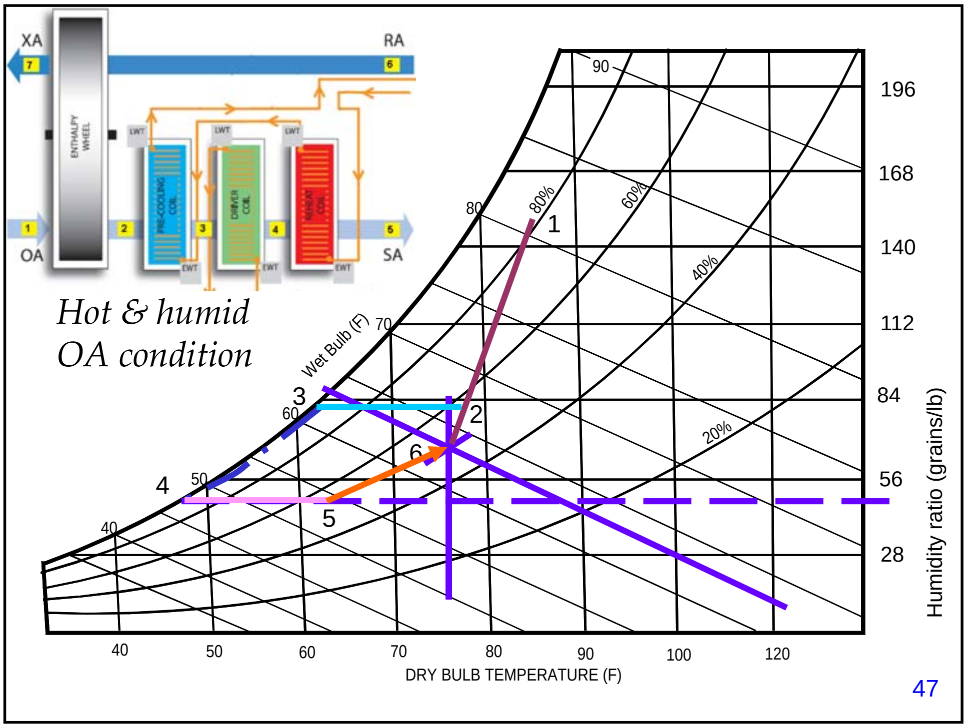
Hot & humid OA condition





DOAS Equipment on the Market Today



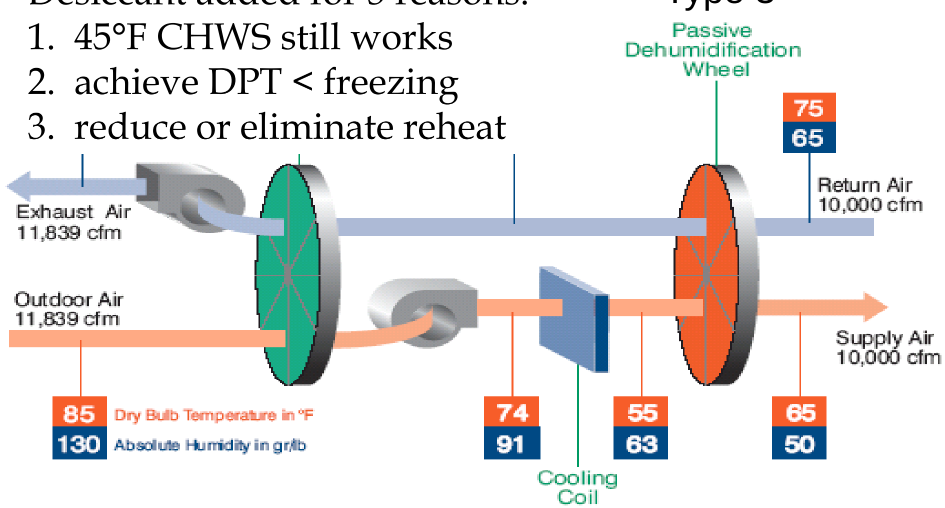


DOAS Equipment on the Market Today

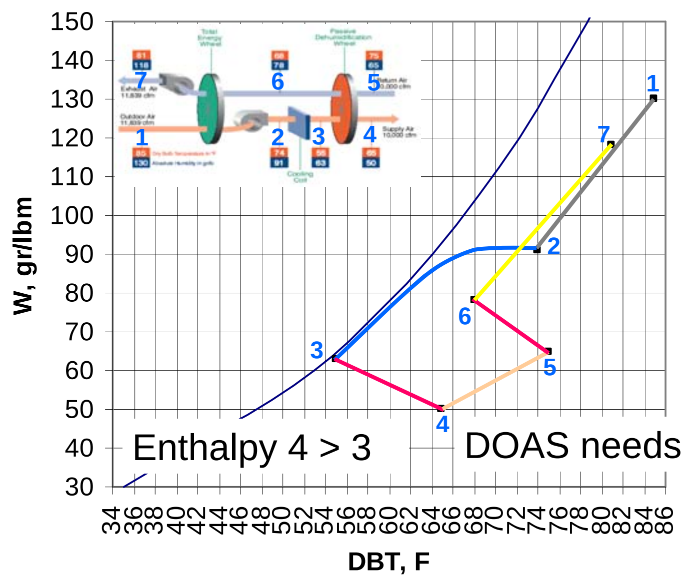
Desiccant added for 3 reasons:

1. 45°F CHWS still works
2. achieve DPT < freezing
3. reduce or eliminate reheat

Type 3

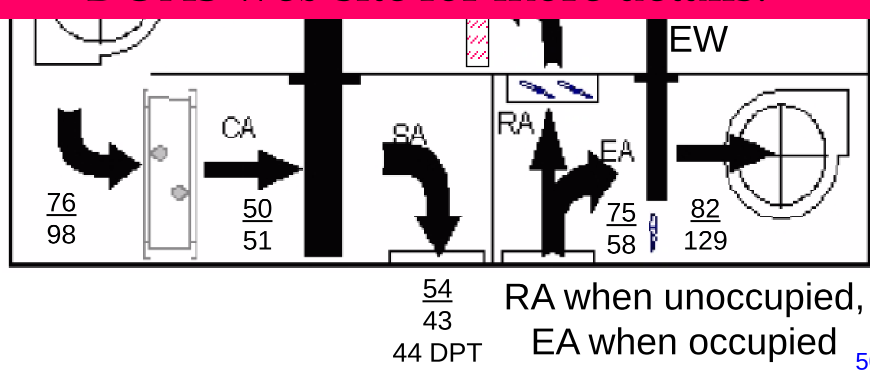


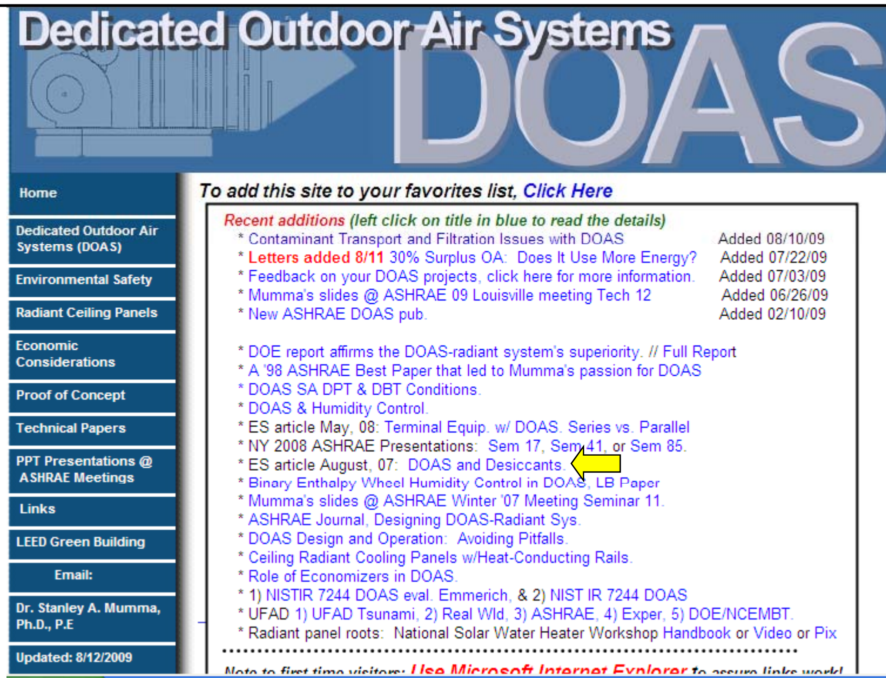
Process on the Psych Chart



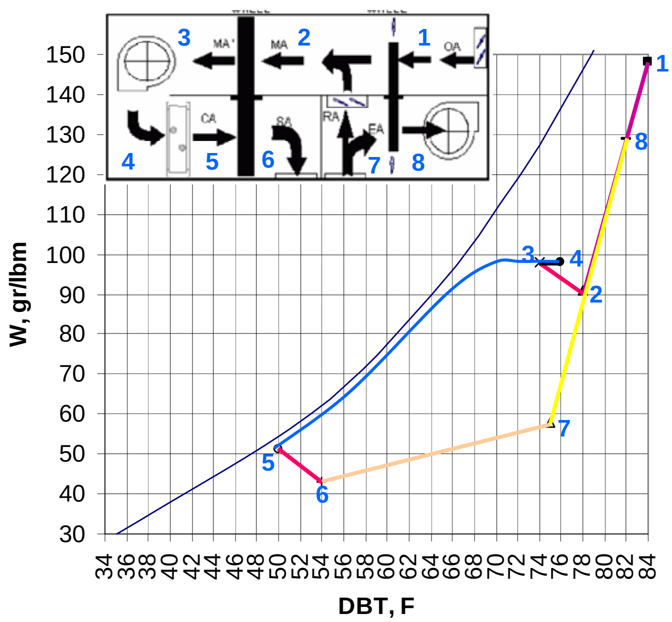
DOAS Equipment on the Market Today

This is often marketed without the EW. I strongly recommend only using with the EW. See DOAS & Desiccants article on the DOAS web site for more details.

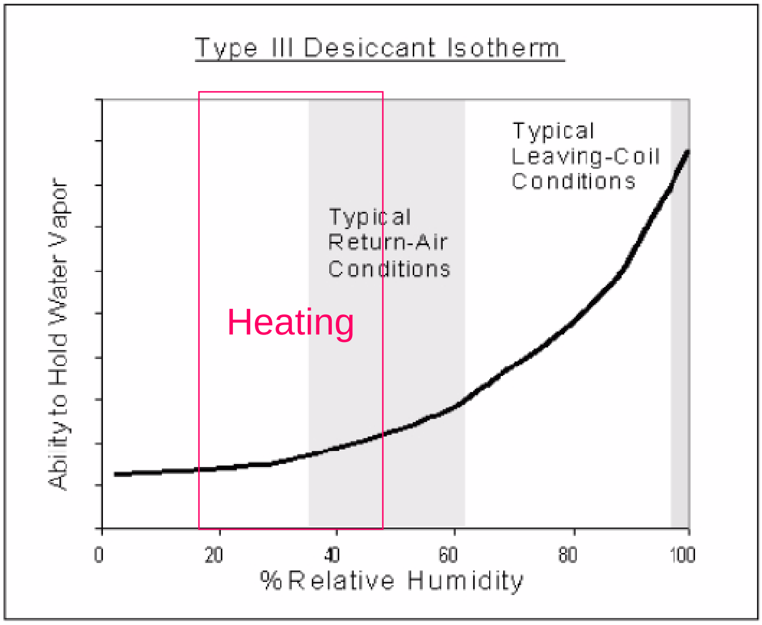




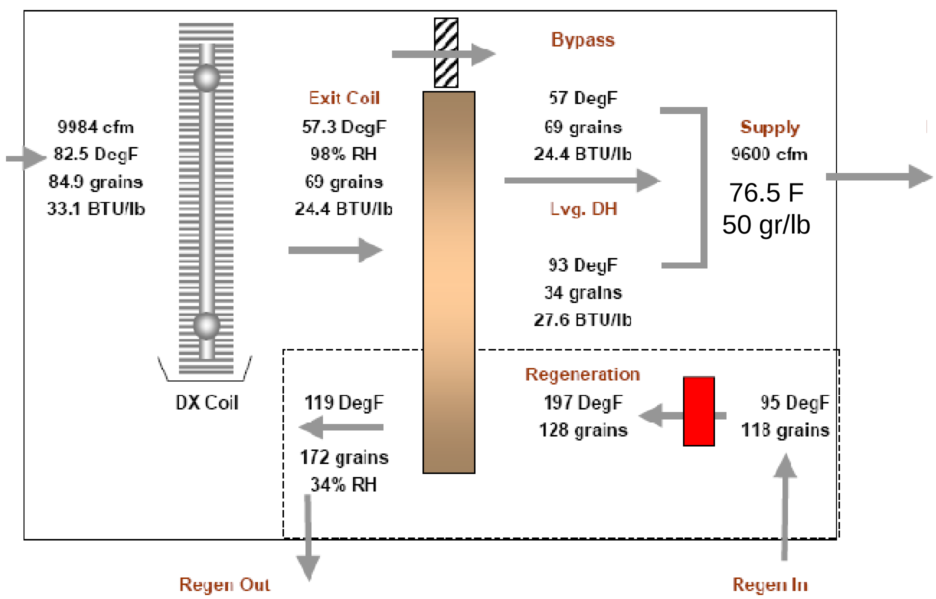
Process on the psych chart



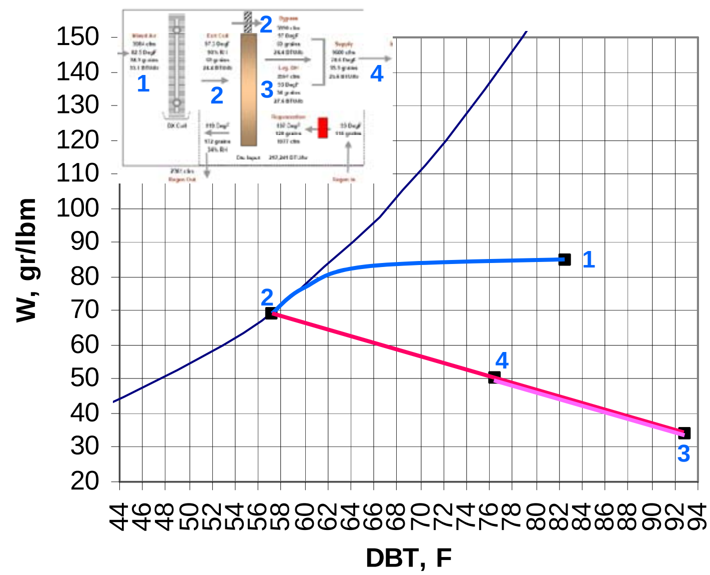
Type III Desiccant Wheel



DOAS Equipment on the Market Today



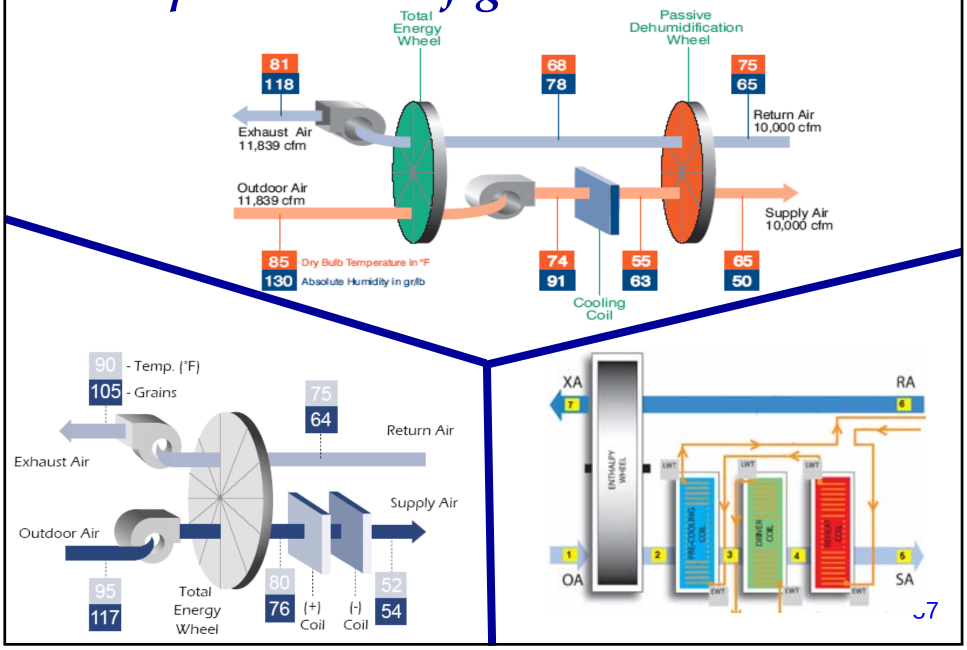
Psychrometric Process



DOAS Equipment Summary: Conditioning 1,000 scfm of 85°F 148 Gr OA

Description	CC Load, T	SA DBT, F	Lost Sen. Cooling ref CC alone, T	Total Cooling input, T	Ranking
CC alone	9.7	44	0.0	9.7	6
CC w/ HGRH	9.7	70	2.3	12.0	8
EW + CC	5.2	44	0.0	5.2	1
EW+ PCC+CC+RHC	3.7	61.4	1.6	5.3	1
EW+CC+SW	4	68	2.2	6.2	5
PDHC+CC	9.0	53.1	0.8	9.8	7
EW+CC+PDHC	4	63.3	1.7	5.7	1
EW+PDHC+CC	5.2	53	0.8	6.0	4
CC+ADesW	6.8	88.5	4	10.8	9

Top DOAS Configuration Choices



A few additional comments regarding DOAS equipment.

- TER Effectiveness is an important factor.
- TER desiccant an important choice.
- TER purge, pro and con.
- Fan energy use management.
- Reserve capacity must be considered: many benefits .
- Importance of building pressurization, and the impact on TER effectiveness when unbalanced flow exists.
- Smaller DOAS with a pressurization unit.

DOAS Design Steps

Step 1: Determine the design space condition (i.e., 75°F/50% RH) and compute the design sensible & latent cooling loads for each space.

Step 2: Determine the minimum ASHRAE Std. 62.1-2007 ventilation flow rate that DOAS must deliver to each space. In some cases, flow must be increased above minimum to dehumidify the space.

Step 3: Determine the SA humidity ratio (W_{SA} grains/lb) for each space using the following equation:

$W_{SA} = W_{space} - Q_{lat}/(0.68*scfm)$

Note: lowest W_{SA} dictates.

Step 4: In most cases, the design SA DBT will equal the required SA DPT (required to achieve the W_{SA})

Step 5: Take advantage of total energy recovery, and make sure the exhaust can be brought back to the DOAS unit.

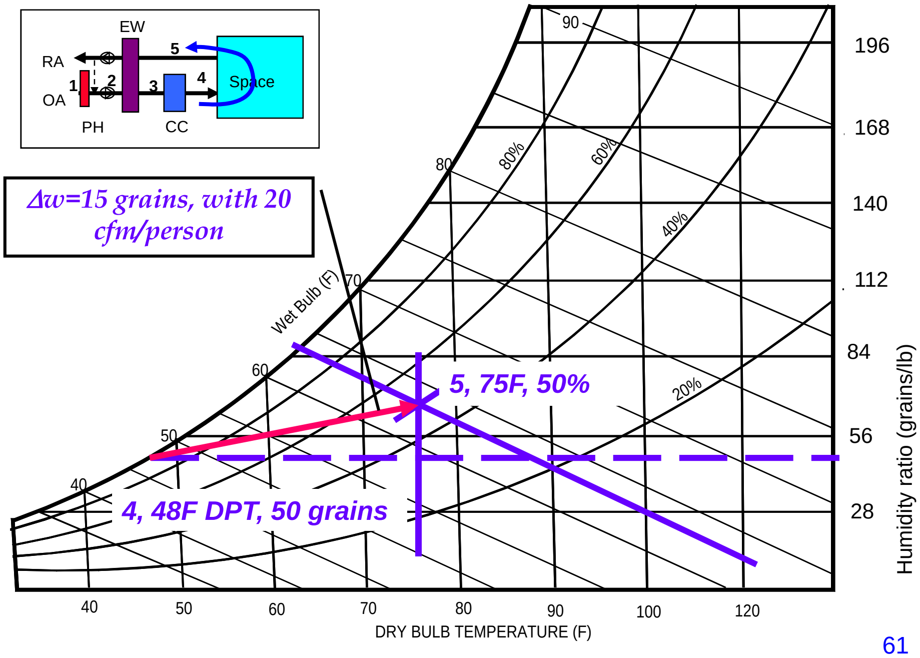
Selecting the Supply Air DPT

$Q_{latent}=0.68*scfm*\Delta w$ *(grains)*

If all latent load from people @ 205 Btu/person, then,

Δw=15 gr/lb with 20 scfm/person, requires 48°F DPT if space 75°F 50% RH

or Δw=10 gr/lb with 30 scfm/person, requires 51°F DPT if space 75°F 50% RH



Parallel Device Design Steps for Air-Based Systems

Step 1: Calculate the sensible cooling load met by the DOAS SA in each space ($Q_{sen,DOAS\ SA}$).

Step 2: Calculate sensible load remaining on the parallel system for each space.

Step 3: Select the SA DBT for parallel systems (e.g., 55°F—hold above the space DPT to avoid condensation).

Step 4: Determine SA flow rate in each parallel sensible cooling device

$$scfm_{parallel} = \frac{Q_{sen,parallel}}{1.08*(DBT_{space} - DBT_{SA,parallel})}$$

Parallel Device Design Steps for CRCP System

Step 1: Calculate the sensible cooling load met by the DOAS SA in each space ($Q_{sen,SA}$)

Step 2: Calculate sensible load remaining on the parallel system for each space: $Q_{sen,panel}$.

Step 3: Select the design panel cooling capacity (q_{panel}) from manufacturer's catalog or other sources. This is a function of panel inlet water temperature (>space DPT), panel flow rate, enclosure design, etc.

Step 4: Determine required cooling panel area

$$A_{panel} = Q_{sen,panel} / q_{panel}$$

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Example Design Calculation for DOAS w/ VAV Comparison

Building Data:

70,000 ft^2 3-story office building
350 occupants, 245 Btu/hr sen, 205 Btu/hr lat.
Uncorrected Ventilation: 350*5+70,000*.06=5,950 scfm
Other lat load: 20 Btu/hr-person
Internal generation, lights & equip: 4W/ft^2 or 80 tons
Design Envelope load: 15 tons sens.
Design Space: 75°F for VAV, 78°F DBT, 40% RH DOAS
SA, VAV, 55°F and Sat, DOAS 44°F and Sat.
OA conditions, St. Petersburg, 94°F DBT, 80°F WBT
Max Zp=0.55
DOAS energy recovery, single EW eff=0.85
Radiant Panel avg heat flux, 34 Btu/hr-ft^2

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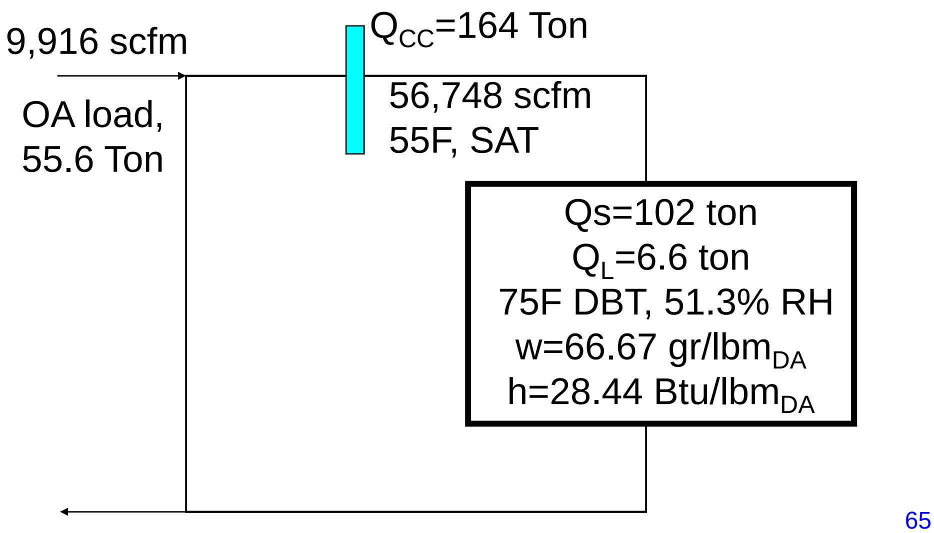
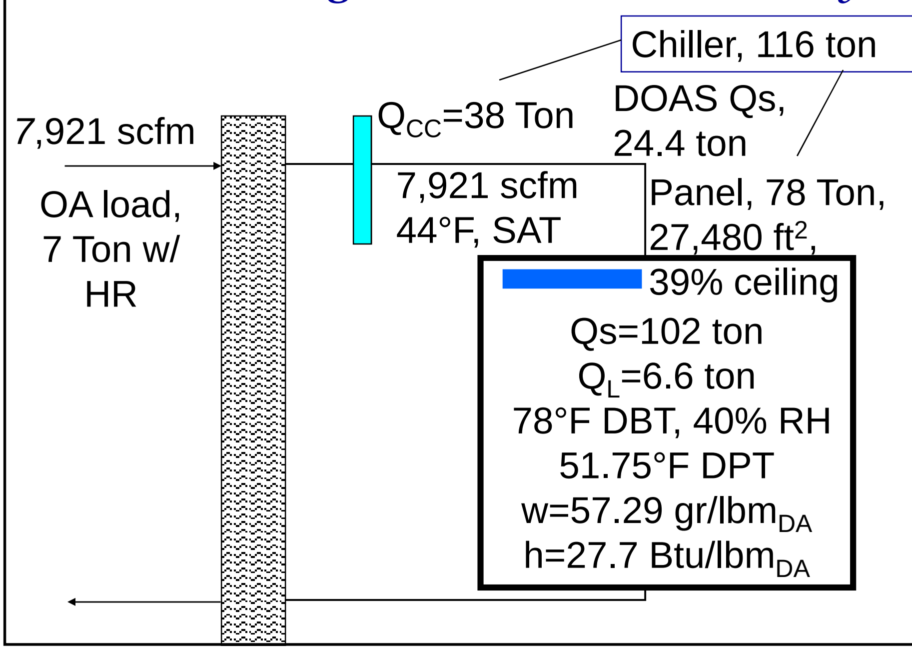
VAV Design Calculation Summary



DOAS Design Calculation Summary



VAV vs. DOAS/radiant comparison

	VAV	DOAS/Radiant
OA, scfm	9,916	7,921
OA_{load}, Tons	55.6	7
CC_{load}, Tons	164	38, (7 OA, 31 Internal)
Terminal load, Tons	0	78, rad. panels
Total Chiller load, tons	164	116 (70%)

Leadership in Energy and Environmental Design

LEED 2009 for New Construction and Major Renovations

IE Q Prerequisite 1: Minimum Indoor Air Quality Performance Required

Intent

To establish minimum indoor air quality (IAQ) performance to enhance indoor air quality in buildings, thus contributing to the comfort and well-being of the occupants.

Requirements

CASE 1. Mechanically Ventilated Spaces

Meet the minimum requirements of Sections 4 through 7 of ASHRAE Standard 62.1-2007, Ventilation for Acceptable Indoor Air Quality (with errata but without addenda1). Mechanical ventilation systems must be designed using the ventilation rate procedure or the applicable local code, whichever is more stringent.

IE Q Credit 2: I

Intent

To provide additic

improve indoor ai

comfort, well-bein

Requirer

CAS

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quired by A

ata but without

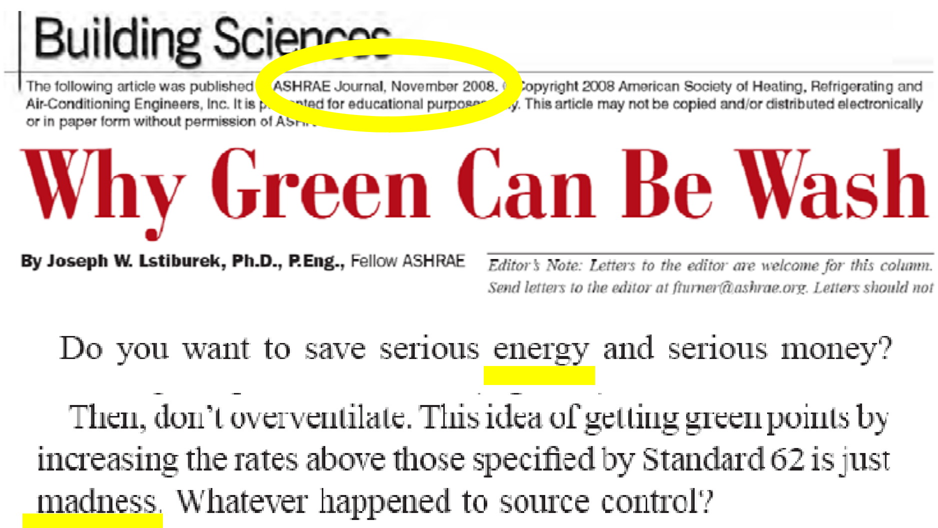
Prerequisite 1: Mi

Performance.

Sustainable site	26	24%
H_2O η	10	9%
Energy & Atmos	[illegible]	?%
Mat'ls &	[illegible]	13%
[illegible]	15	14%
...on	6	5%
Regional Priority	4	4
Max points	110	
Gold: 60-79 points		

Is this a good reason for 30% surplus ventilation air?

30% surplus air questioned!


Building Sciences

The following article was published ASHRAE Journal, November 2008. Copyright 2008 American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. It is p... for educational purpose... This article may not be copied and/or distributed electronically or in paper form without permission of ASH...

Why Green Can Be Wash

By Joseph W. Lstiburek, Ph.D., P.Eng., Fellow ASHRAE

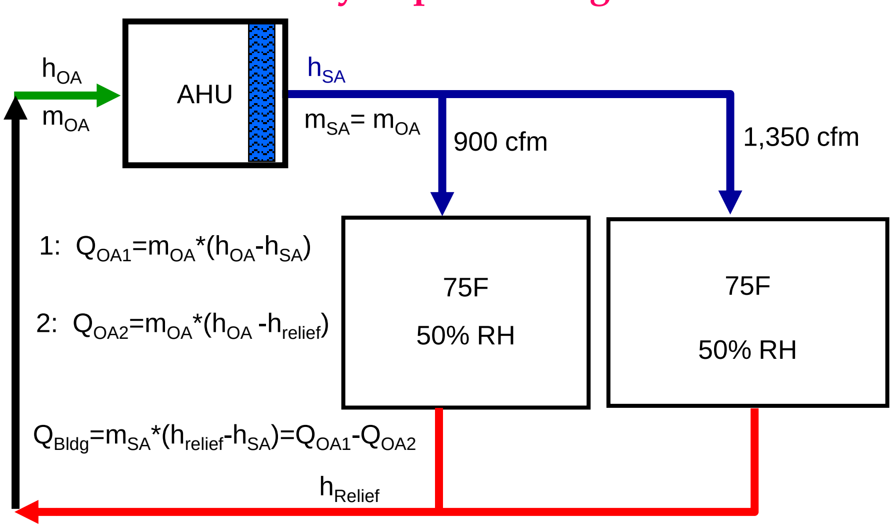
Editor's Note: Letters to the editor are welcome for this column. Send letters to the editor at fturner@ashrae.org. Letters should not

Do you want to save serious energy and serious money?

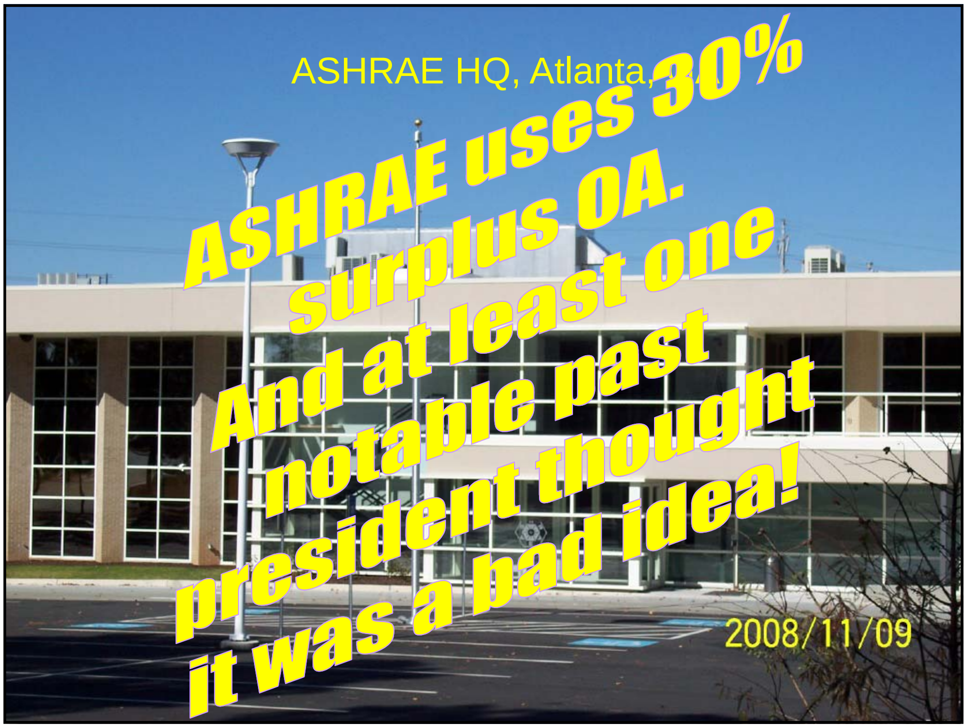
Then, don't overventilate. This idea of getting green points by increasing the rates above those specified by Standard 62 is just madness. Whatever happened to source control?

Calculating the OA load:

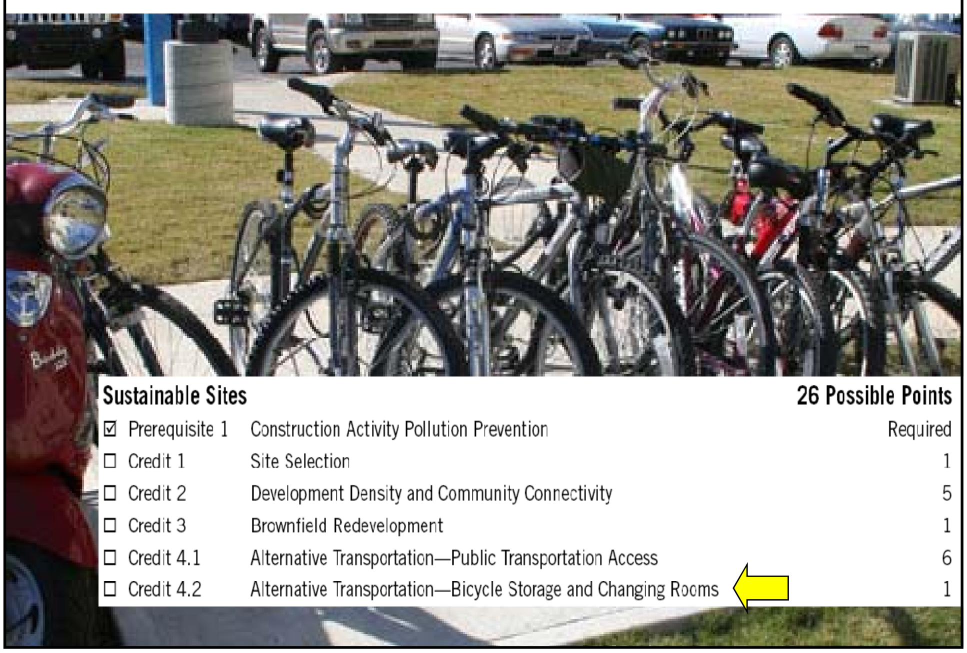
Very important to get correct!



So, Q_{OA2} is correct: $Q_{OA1}=Q_{OAcorrect}+Q_{Bldg}$= coil load



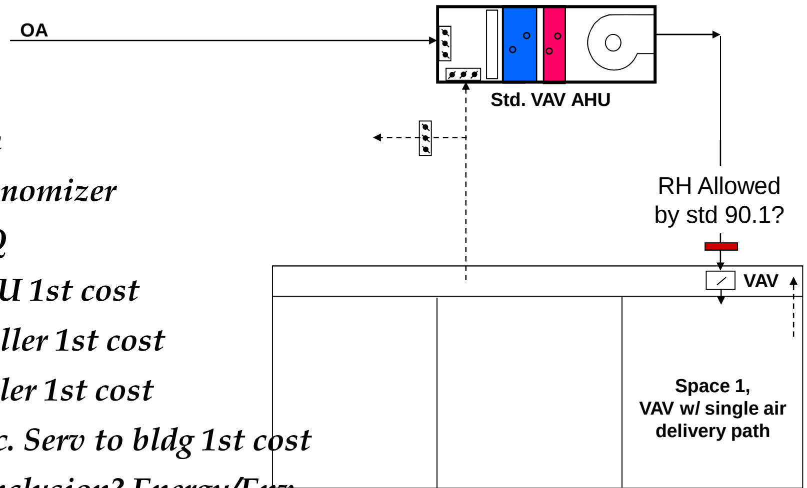
Limits of LEED authority



Sustainable Sites			26 Possible Points
☑	Prerequisite 1	Construction Activity Pollution Prevention	Required
☐	Credit 1	Site Selection	1
☐	Credit 2	Development Density and Community Connectivity	5
☐	Credit 3	Brownfield Redevelopment	1
☐	Credit 4.1	Alternative Transportation—Public Transportation Access	6
☐	Credit 4.2	Alternative Transportation—Bicycle Storage and Changing Rooms	1

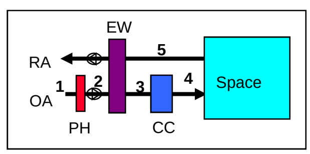
Why question 30% surplus OA? 1st consider a Standard VAV System

- CC
- HC
- Fan
- Economizer
- IEQ
- AHU 1st cost
- Chiller 1st cost
- Boiler 1st cost
- Elec. Serv to bldg 1st cost
- Conclusion? Energy/Env



Why question 30% surplus OA? Consider DOAS.

- CC
- HC
- Fan
- Economizer
- IEQ
- AHU 1st cost
- Chiller 1st cost
- Boiler 1st cost
- Elec. Serv to bldg 1st cost
- Conclusion? (1st, op, LCC, env)



How does the 62.1 flow impact DOAS design—w/ space latent load decoupled

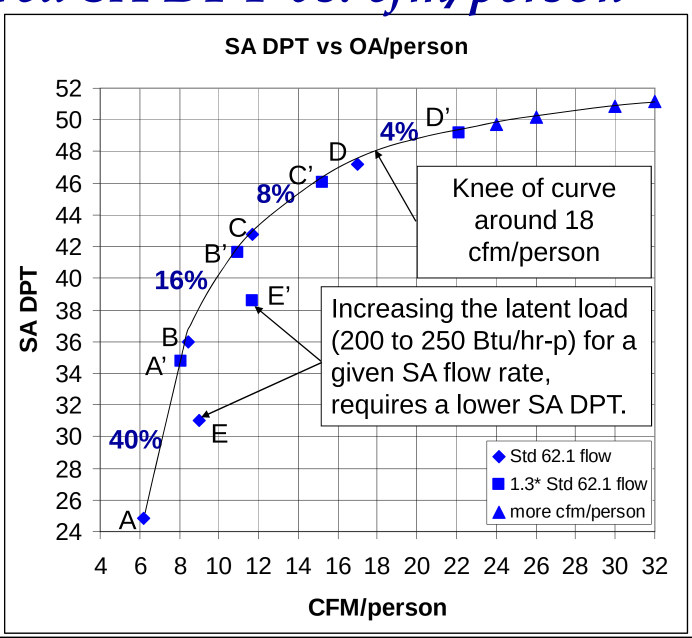
	Occ. Category	cfm/p	SA DPT ^{0}F
A	Conf. rm	6.2	24.84
B	Lec. cl	8.42	35.9
C	Elem. cl	11.71	42.75
D	Office	[illegible]	47.18
E	Museum	9	31.05

?

Key reason to overventilate!
Elevate SA DPT.

Required SA DPT vs. cfm/person

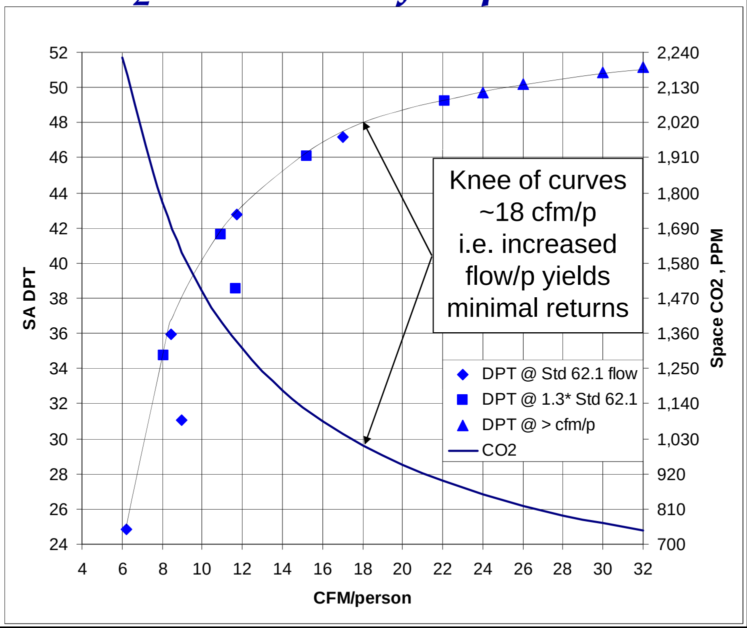
	Occ. Category
A	Conf. rm
B	Lec. cl
C	Elem. cl
D	Office
E	Museum



S.S. CO_2 PPM vs. cfm/person

Assumes an OA CO_2 conc. of 400 PPM & an occupant CO_2 gen. rate of 0.31 L/min.

Note: CO_2 conc. Is a measure of dilution, i.e. IEQ



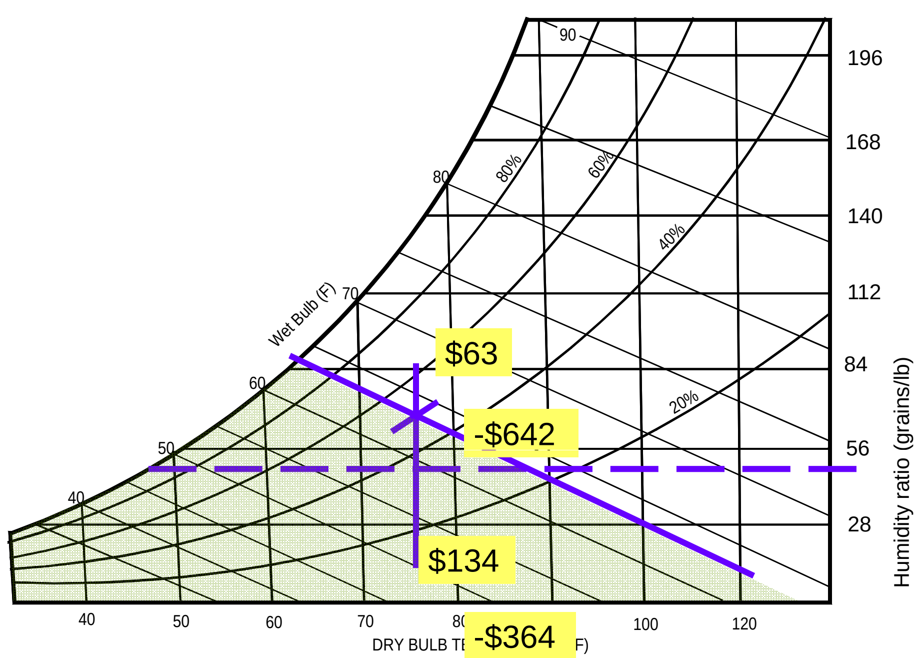
30% surplus OA Hypotheses: in context of DOAS

- Increasing the ventilation air flow rate will increase the energy required to cool and dehumidify, as well as temper the outdoor air (OA), but **only about 20-25%** as much as would occur if TER equipment were not used.
- Increasing the DOAS ventilation air flow rate will result in a **reduction in the winter cooling plant operation**, saving operating cost.
- The **extra free winter cooling will more than offset the increased cooling energy use during the summer** months, i.e. **refuting the "madness"** statement in the ASHRAE Journal article.

*Test of the hypotheses based upon a 4,600 cfm & 6,000 cfm (i.e. 1.3*4,600 cfm) DOAS*

- After many assumptions, including operating with and without an EW, energy use and costs were evaluated for a few diverse geographical locations:
  - Atlanta, GA
  - New Orleans, LA
  - Columbus, OH
  - International Falls, MN

Ref: http://doas-radiant.psu.edu/mumma_Journal_30_PC_OA_6_09.pdf



Operating cost

1	2	3	4	5	6	7	8
Flow CFM	**TH w/o EW**	**TH w/ 80% Eff EW**	**OP COST w/o EW $**	**OP COST w/ 80% Eff EW-$**	**Hours No Free clg**	**Hrs Some Free clg**	**Lowest Temp Exit EW Cold'st day**
Columbus, OH simulation data							
4,600	7,506	1,500	$525	**$105**	1,092		
6,000	9,786	1,957	$685	**$137**	1,092		
4,600	-47,084	-11,814	**-$3,296**	[illegible]		2,964	
6,000	-61,387	-15,402	**-$4,297**	[illegible]		2,964	**61**
International Falls, MN simulation data							
4,600	1,934	387	$135	**$27**	308		
6,000	2,521	504	$176	**$35**	308		
4,600	-75,795	-19,210	**-$5,303**	[illegible]		3,748	
6,000	-98,774	-25,045	**-$6,914**	[illegible]		3,748	**59**

$32

-$1,001

$8

-$1,611

1st and Op Cost summary.

III) Columbus, OH, Economic comparison of 6,000 and 4,600 cfm flow ***without*** EW			
Flow	1st cost	Op. Cost OA	Fan op cost
6,000	$43,900	$685-$4,297=-$3,612	$1,230
4,600	$39,450 to $43,750	$525-$3,296=-$2,771	$950
Extra $ for surplus air	**$4,450 to $150**	**-$841**	**$280**
Payback years with surplus air	**8 to 0.3 years**		
IV) Columbus, OH, Economic comparison of 6,000 and 4,600 cfm flow ***with*** EW			
Flow	1st cost	Op. Cost OA	Fan op cost
6,000	$48,200	$137-$4,297=-$4,160	$1,562
4,600	$43,770 to $48,070	$105-$3,296=-$3,191	$1,204
Extra $ for surplus air	**$4,430 to $130**	**-$969**	**$358**
Payback years with surplus air	**7 to 0.2 years**		

30% surplus Conclusion #1:

- The veracity of the Journal article claim concerning the cooling energy waste ***"madness"*** of garnering a LEED point in the IEQ category has been ***disproved*** w/ DOAS.
- Even Atlanta and New Orleans, locations not required by Standard 90.1 to have economizers, used less cooling energy with 30% surplus OA.
- Significantly more energy savings were demonstrated for Columbus and International Falls, where economizers are required.

30% surplus Conclusion #2:

The 3 hypotheses set forth above were confirmed:

- A TER device substantially reduces the summer cooling energy used to treat OA.
- 30% surplus air is quite beneficial in the winter at reducing the cooling plant energy use.
- The winter savings offsets the added cooling energy use during the warm months ***for*** the locations explored.

30% surplus Conclusion #3

Increasing the ventilation air to spaces with low OA cfm/person ***yields big dividends*** in terms of allowing the SA DPT to be elevated while still accommodating all of the occupant latent loads. ***This strongly suggests a non-uniform ventilation increase strategy!!!!***

In other words, if a space combined minimum OA/person is ~ 18 cfm/person, do not increase those values at all. But for spaces with the 6 to 18 cfm/person range, increase those values upward close to 18 cfm/person. Then step back and assess how close the entire building ventilation has approached a total 30% increase.

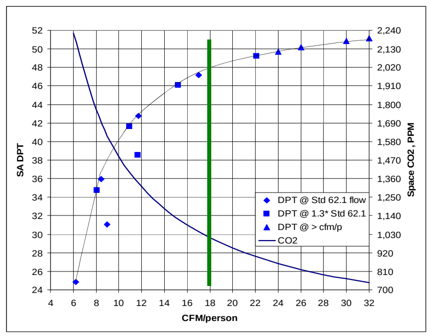
30% surplus Conclusion #3, cont'd

If, after ***equalizing the flow rate per person*** to about 18 cfm, the 30% surplus ventilation has been achieved, ***take the LEED point***. ***Note***, the point is simply ***a by-product*** of elevating the SA DPT.
Otherwise abandoning the goal of gaining a LEED point by this method (time to consider the bike rack?!:)—**but don't reduce the cfm/person!!!!**

Such an approach should make gaining the LEED point possible while ***significantly simplifying the equipment choices*** and ***avoiding elevated first cost by eliminating the need for below freezing DPTs to some spaces.***

30% surplus Conclusion #3, cont'd

Increasing the OA flow rate beyond 18 cfm/person yields diminishing returns in terms of increasing the required SA DPT or enhanced IEQ achievement.



DOE Report: Ranking of DOAS and Parallel Radiant Cooling

Energy Consumption Characteristics of Commercial Building HVAC Systems: Volume III, Energy Savings Potential

Available at:
http://doas-radiant.psu.edu/DOE_report.pdf

Table 4-1: Energy Savings Potential Summary for 15 Options

Technology Option	Technology Status	Technical Energy Savings Potential (quads)	
Adaptive/Fuzzy Logic Controls	New	0.23	
Dedicated Outdoor Air Systems	Current	0.45	#3
Displacement Ventilation	Current	0.20	
Electronically Commutated Permanent Magnet Motors	Current	0.15	
Enthalpy/Energy Recovery Heat Exchangers for Ventilation	Current	0.55	#2
Heat Pumps for Cold Climates (Zero-Degree Heat Pump)	Advanced	0.1	
Improved Duct Sealing	Current/New	0.23	
Liquid Desiccant Air Conditioners	Advanced	0.2 / 0.06[12]	
Microenvironments / Occupancy-Based Control	Current	0.07	
Microchannel Heat Exchanger	New	0.11	
Novel Cool Storage	Current	0.2 / 0.03[13]	
Radiant Ceiling Cooling / Chilled Beam	Current	0.6	#1
Smaller Centrifugal Compressors	Advanced	0.15	
System/Component Diagnostics	New	0.45	#3
Variable Refrigerant Volume/Flow	Current	0.3	

91

Both DOAS and Radiant Have Instant Paybacks

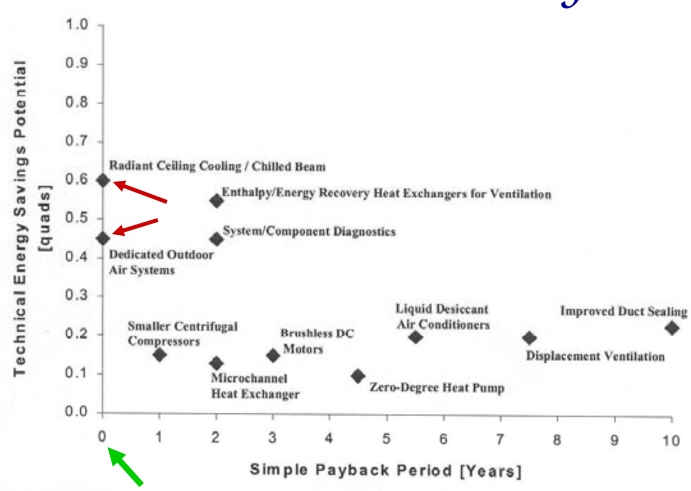


Figure 5-2: Estimated Technical Energy Savings Potential and Simple Payback Periods for the 15 Options

What has ASHRAE sponsored research found?

ASHRAE 1254-RP EVALUATING THE ABILITY OF UNITARY EQUIPMENT TO MAINTAIN ADEQUATE SPACE HUMIDITY LEVELS, PHASE II

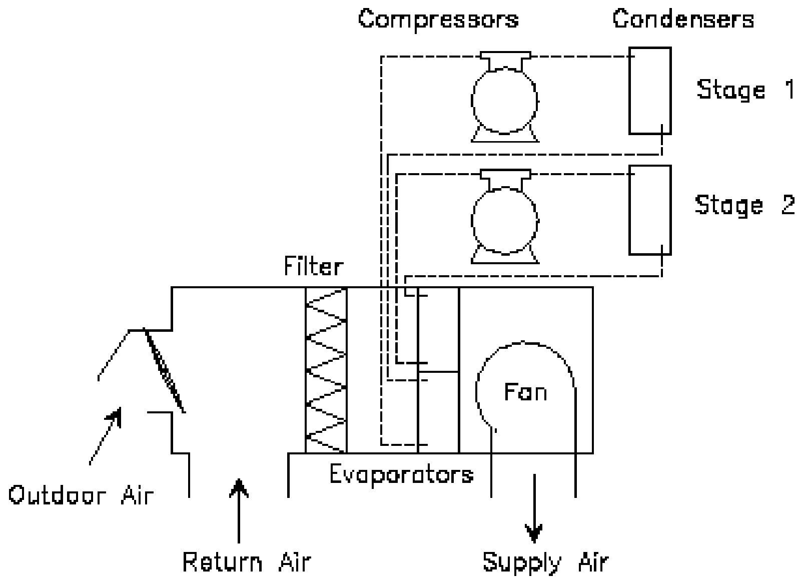
FINAL REPORT

Results of Cooperative Research between the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., and ***censored***

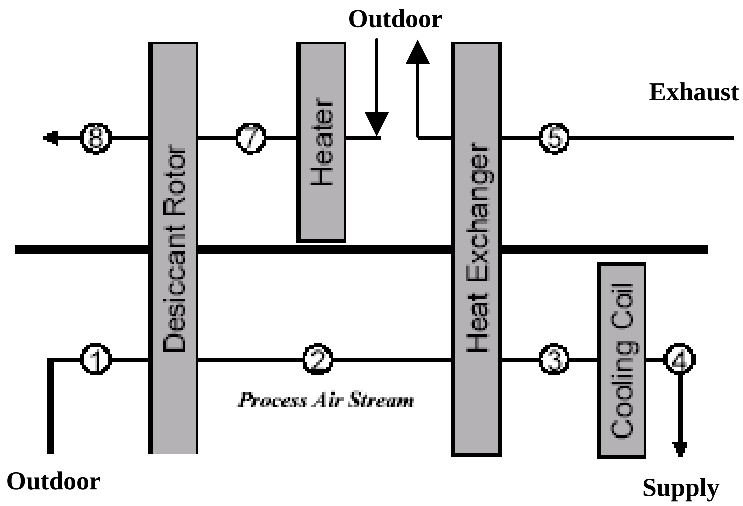
Office: 1 story 6,600 ft^2

Retail: 1 story 79,000 ft^2

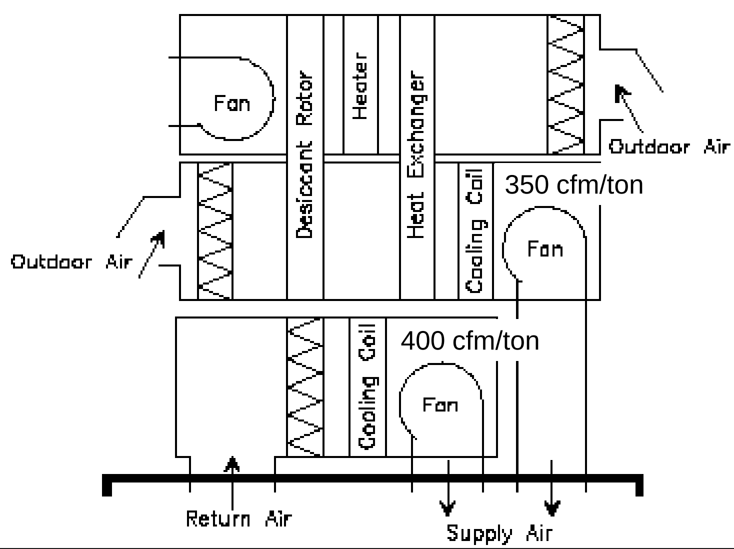
Base Case: DX, 350 cfm/ton



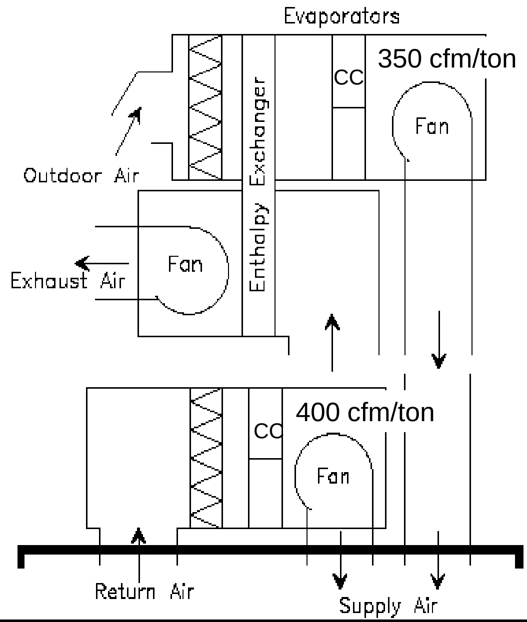
DX (400 cfm/ton) with Desiccant



DOAS w/ Desiccant +DX



DOAS w/ EW +DX



Performance for office, based upon 62.1-2007 ventilation req'd

Humidity Control (Occ. Hours >65% RH)

Location	Miami	Hous	Shrev	Ft. Wor	Atlant	DC	St. Lo	NY	Chic	Port
DX w/ Desiccant	0	0	0	0	0	0	0	0	0	0
DOAS w/ Des. +DX	0	0	0	0	0	0	0	0	0	0
DOAS w/ EW +DX	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

Annual Op Cost vs. Base DX

DX w/ Desiccant	52%	23	18	12	9	1	-2	1	-8	-1
DOAS w/ Des. +DX	48%	18	14	8	8	-3	-5	-6	-14	-8
DOAS w/ EW +DX	**-18%**	**-21**	**-20**	**-19**	**-19**	**-23**	**-26**	**-19**	**-26**	**-14**

LCC: Equipment 1st + 15 yr Gas and Electric $, 1,000's 2004 dollars

DX w/ Desiccant	51	45	43	45	40	44	41	59	41	38
DOAS w/ Des. +DX	54	48	46	48	44	47	45	63	45	42
DOAS w/ EW +DX	**35**	**35**	**33**	**37**	**33**	**37**	**35**	**52**	**37**	**36**

Performance for retail, based upon 62.1-2007 ventilation req'd

Humidity Control (Occ. Hours >65% RH)

Location	Miami	Hous	Shrev	Ft. Wor	Atlant	DC	St. Lo	NY	Chic	Port
DX w/ Desiccant	0	0	0	0	0	0	0	0	0	0
DOAS w/ Des. +DX	0	0	0	0	0	0	0	0	0	0
DOAS w/ EW +DX	**0**	**1**	**6**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

Annual Op Cost vs. Base DX (%)

DX w/ Desiccant	169	79	75	47	61	18	14	6	-11	-2
DOAS w/ Des. +DX	137	53	44	20	20	-9	-11	-14	-30	-15
DOAS w/ EW +DX	**-39**	**-42**	**-41**	**-42**	**-41**	**-51**	**-54**	**-44**	**-55**	**-28**

LCC: Equipment 1st + 15 yr Gas and Electric $, 1,000's 2004 dollars

DX w/ Desiccant	322	250	235	226	210	209	189	247	174	148
DOAS w/ Des. +DX	313	245	228	220	203	205	189	242	174	153
DOAS w/ EW +DX	**88**	**91**	**90**	**104**	**92**	**100**	**90**	**138**	**100**	**106**

Do Other DOAS-Radiant Systems Currently Exist—in the US?

Let's look briefly at one

Max points, 272: VAV 53%, DOAS-Rad 90%

Sys. Alts	IAQ (5) (wtg)	1st $ (5)	Op. $ (4)	DBT Ctl. (3)	Plenum depth (5)	AHU (1)	Future Flex (4)	Maint (3)	Ductwork (2)	Noise (2)	Total Score
FCU w/ DOAS	5/25	7/35	1/4	1/3	6/30	8/8	1/4	1/3	6/12	1/2	126
VAV, HW RH	4/20	5/25	3/12	5/15	2/12	4/4	5/20	7/21	2/4	7/14	145
LT VAV, HW RH	4/20	6/30	4/16	6/18	3/30	4/4	6/24	7/21	3/6	7/14	183
FPVAV, HW RH	2/10	4/20	5/20	4/12	4/20	8/8	3/12	3/9	4/8	2/4	123
FPVAV, Chw recool	1/5	3/15	6/24	3/9	5/25	8/8	4/16	2/6	7/14	3/6	128
LT DDVAV	3/15	2/10	2/8	2/6	1/5	4/4	2/8	4/12	1/2	5/10	80
UFAD	6/30	1/5	7/28	8/24	8/40	4/4	8/32	5/15	8/16	4/8	202
CRCP-DOAS	8/40	8/40	8/32	7/21	7/35	8/8	7/28	8/24	5/10	8/16	254

- Category Feature rating/score
- System performance in a category (i.e. 1st cost) rating 1-8 (8 Best): i.e. FCUw/ DOAS meeting 1st cost earns a 7
- Importance weighting of a category 1-5 (5 most important)
- Score: in a cell: product of importance weighting and system performance. i.e. for CRCP-DOAS in the category of Op $, the score is 4*8=32

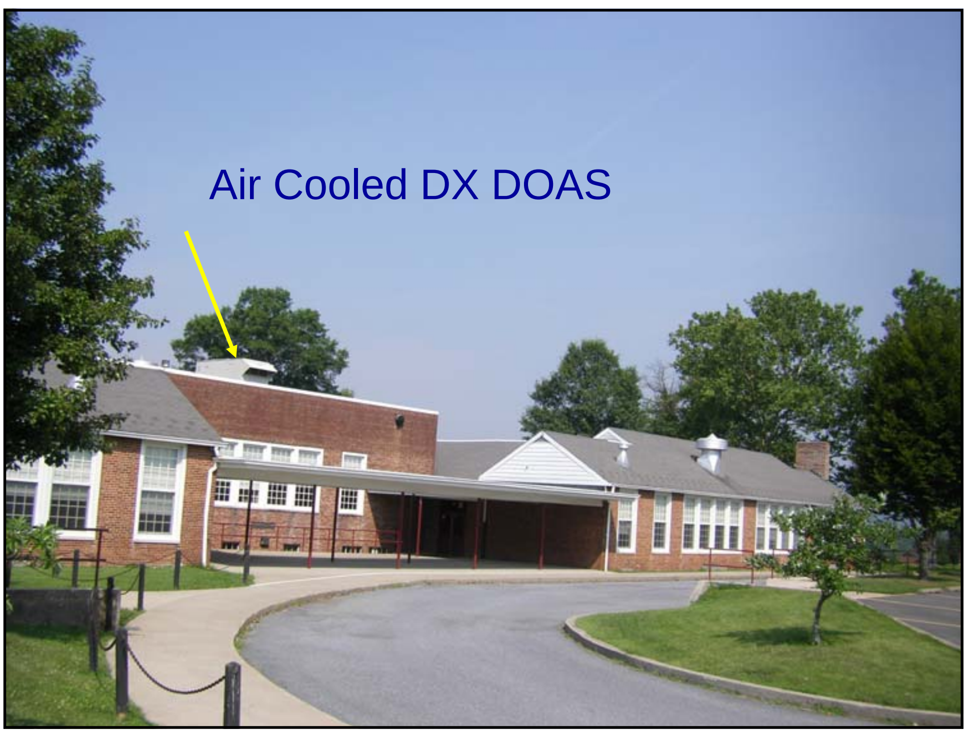
Conventional VAV 145 pts: DOAS-Rad 254 pts

A few other DOAS Applications


ASHRAE HDQ DOAS
VRV Outdoor Units


Bldg
DOAS
oat 71.1
72.3 °F
oah 57.5
95.0 %rh
oae 27.9
29.4 enthalpy
oaCo2 360 ppm
Fire Alarm Trouble
HVAC Shutdown
efs/s On
stat On
speed 79 %
CDQ 1st pass
S-1
100
%open
72.6 °F
45.1 %rh
0.060 "wc
49.8 °F dewpoint
50.3 °F dewpoint
42.4
75.0 °F
efs/s On
stat On
speed 5 %
alarm Off
vfd Auto
Open
backdraft damper
106


Middle School w/ DOAS
TUSCARORA JUNIOR HIGH SCHOOL
HAVE A SAFE
ENJOYABLE SUMMER


Air Cooled DX DOAS


Chiller serving
2-pipe FCU’s

Mumma Preferred Equipment Choices

- Always consider dual path DOAS to the spaces, and use where it makes sense.
- I have yet to find a DOAS application where EW's should not be used, when controlled properly.
- In most situations, use mechanical refrigeration to dehumidify, even if it means increasing the ventilation rate above the Std. 62.1 minimums. Choice is supported by the ASHRAE research.
- To achieve the low temperature chilled water economically, use OPAC where cost effective.

Conclusion

- It is time to select systems that solve the inherent problems of VAV,
- While retaining the advantages of VAV,
- At equal or lower first cost,
- With lower operating cost,
- And achieves superior humidity control, thermal comfort, sense of wellbeing and productivity.

Questions

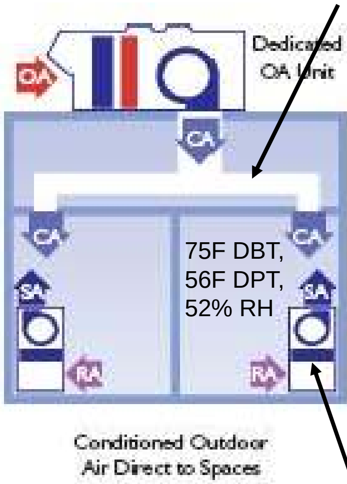
Illustration of the performance difference: series vs. parallel FCU-DOAS

Assume a 1000 ft^2 classroom:

- Default values from Std. 62.1-2007
  35 students, 13 cfm of OA/student, or 455 cfm
- OA Occupant latent load, 7,175 Btu/hr
- DOAS supply air (455 cfm) at 45°F
- FCU used to support DOAS: *series* or *parallel*
- Room DBT maintained at 75°F each case
- Sensible load assumed for each case, *20k Btu/hr*
- Resulting room condition each case:
  75°F DBT, 56°F DPT, 52% RH

Fan Coil Performance in the Parallel DOAS-FCU Arrangement

455 cfm from DOAS, at 45F and saturated, Providing 14, 742 Btu/hr sensible cooling and all the latent cooling (7,175 Btu/hr)



Sensible load for FCU, 5,260 Btu/hr

Coil 12 X 12, 3 rows deep, 10 fpi

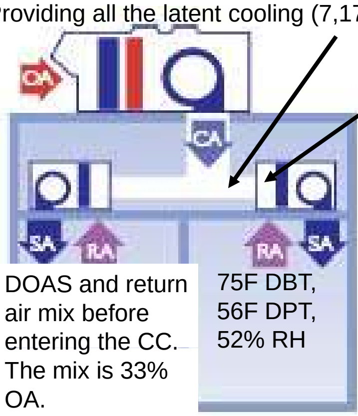
Table 1. Coil Performance for the *Parallel* FCU

Finned height	12 in
Finned length	12 in
Rows deep	3
Fins per inch	10
Tube OD and thickness	5/8 OD, 0.020 wall
Fin material and thickness	Corrugated Al, 0.0060" thick
Face Area	1 ft^2
Air flow	***420 scfm***
Face Vel.	***420 fpm***
Air side pressure drop	***0.17 in WG***
Entering air DBT	***75F***
Entering air WBT	63F
Leaving air DBT	***63.2F***
Leaving air WBT	58.7F
Entering chilled water temperature	***56F***
Leaving chilled water temperature	58F
Circuits	4
GPM	5
Water side pressure drop	1.5 ft H_2O
Liquid velocity	1.4 fps
Total capacity	5,260 Btu/hr
Sensible capacity	5,260 Btu/hr—Dry coil!

Fan Coil Performance in the Series DOAS-FCU Arrangement

455 cfm from DOAS, at 45F and saturated, Providing all the latent cooling (7,175 Btu/hr)

The mix condition entering the coil is 65F DBT, 57.24F WBT, and 52.9F DPT. Same coil as for *Parallel* arrangement!



DOAS and return air mix before entering the CC. The mix is 33% OA.

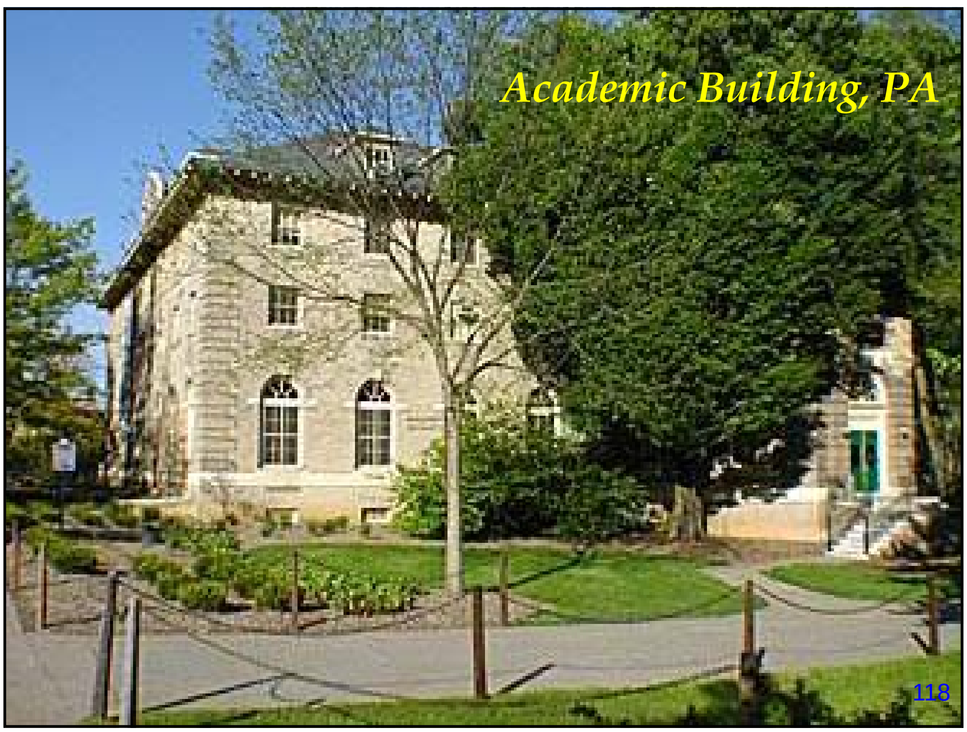
The FCU supplies 61.3F air to the space. Or 20,000 Btu/hr sen. cooling.

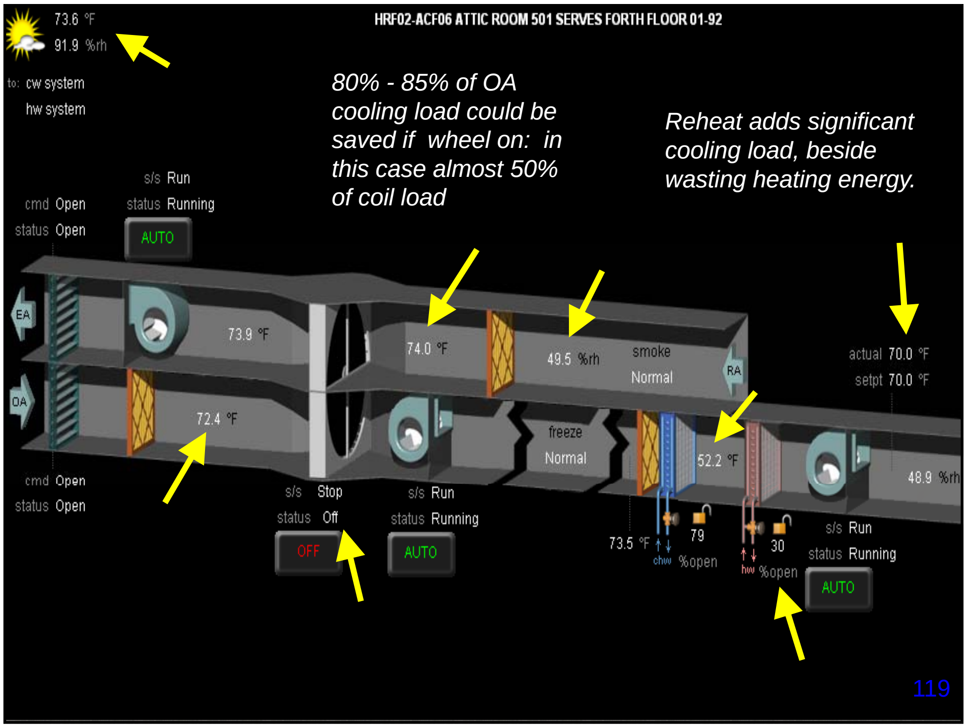
Coil 12 X 12, 3 rows deep, 10 fpi

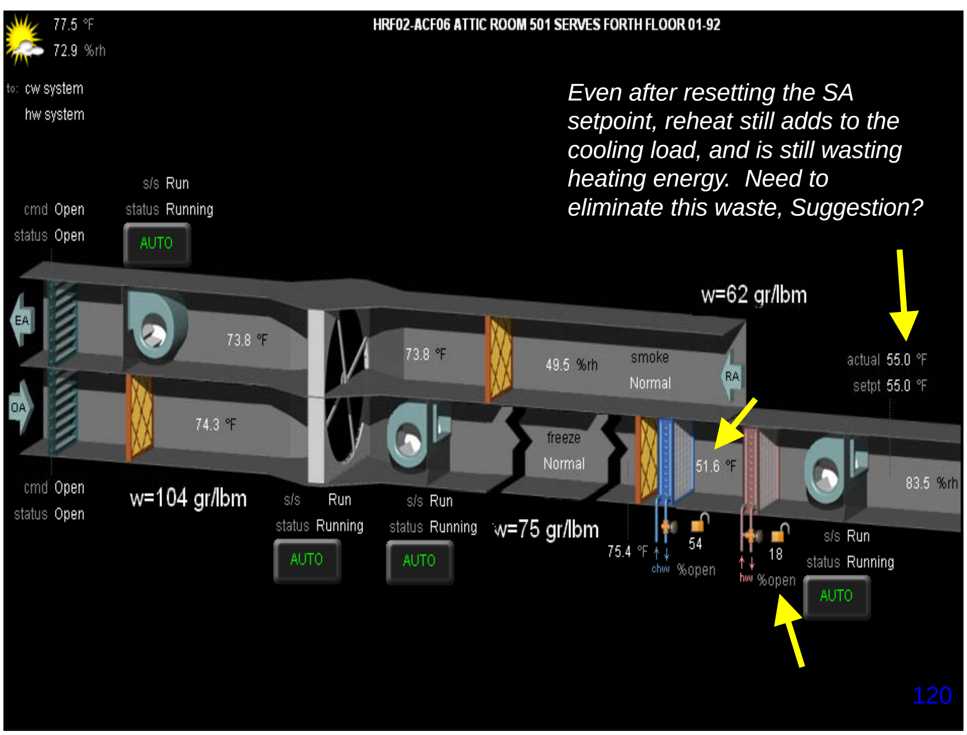
Table 3. Coil Performance for the *Series* FCU

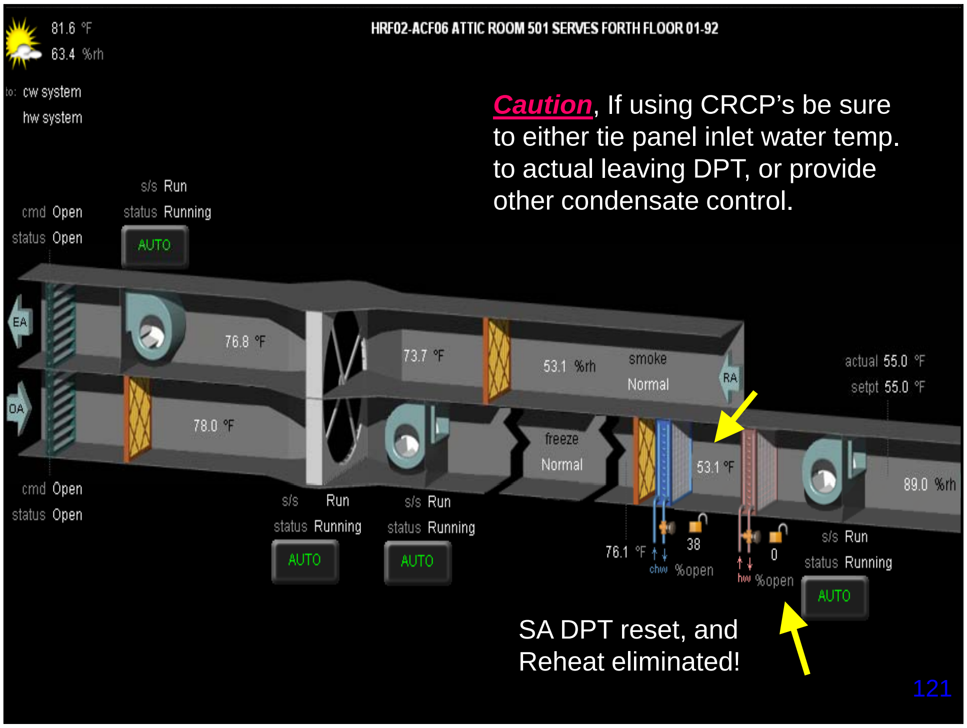
Finned height	12 in
Finned length	12 in
Rows deep	3
Fins per inch	10
Tube OD and thickness	5/8 OD, 0.020 wall
Fin material and thickness	Corrugated Al, 0.0060" thick
Face Area	1 ft^2
Air flow	***1,380 scfm***
Face Vel.	***1,380 fpm***
Air side pressure drop	***1.4 in WG***
Entering air DBT	***65.1F***
Entering air WBT	57.8F
Leaving air DBT	***61.4F***
Leaving air WBT	58.5F
Entering chilled water temperature	***53F***
Leaving chilled water temperature	55.2F
Circuits	4
GPM	5
Water side pressure drop	1.5 ft H_2O
Liquid velocity	1.4 fps
Total coil capacity	5,260 Btu/hr
Sensible coil capacity	5,260 Btu/hr—Dry coil!

Some ATC Design Issues and DOAS in a Campus Building with FCUs and CRCPs




HRF02-ACF06 ATTIC ROOM 501 SERVES FORTH FLOOR 01-92
73.6 °F
91.9 %rh
to: cw system
hw system
80% - 85% of OA cooling load could be saved if wheel on: in this case almost 50% of coil load
Reheat adds significant cooling load, beside wasting heating energy.
s/s Run
status Running
AUTO
cmd Open
status Open
EA
OA
73.9 °F
72.4 °F
74.0 °F
49.5 %rh
smoke
Normal
RA
actual 70.0 °F
setpt 70.0 °F
freeze
Normal
52.2 °F
48.9 %rh
cmd Open
status Open
s/s Stop
status Off
OFF
s/s Run
status Running
AUTO
73.5 °F
chw
79
%open
hw
30
%open
s/s Run
status Running
AUTO
119

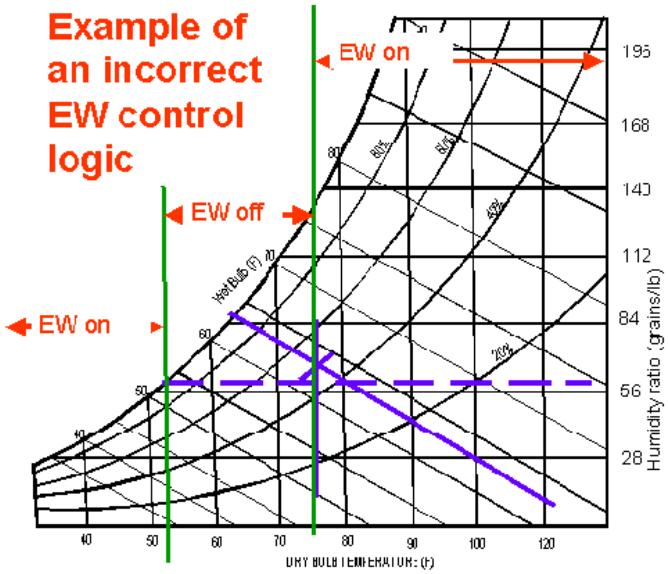

HRF02-ACF06 ATTIC ROOM 501 SERVES FORTH FLOOR 01-92
77.5 °F
72.9 %rh
to: cw system
hw system
Even after resetting the SA setpoint, reheat still adds to the cooling load, and is still wasting heating energy. Need to eliminate this waste, Suggestion?
s/s Run
status Running
AUTO
cmd Open
status Open
w=62 gr/lbm
EA
OA
73.8 °F
74.3 °F
73.8 °F
49.5 %rh
smoke
Normal
RA
actual 55.0 °F
setpt 55.0 °F
freeze
Normal
51.6 °F
83.5 %rh
cmd Open
status Open
w=104 gr/lbm
s/s Run
status Running
AUTO
s/s Run
status Running
AUTO
w=75 gr/lbm
75.4 °F
chw
54
%open
hw
18
%open
s/s Run
status Running
AUTO
120



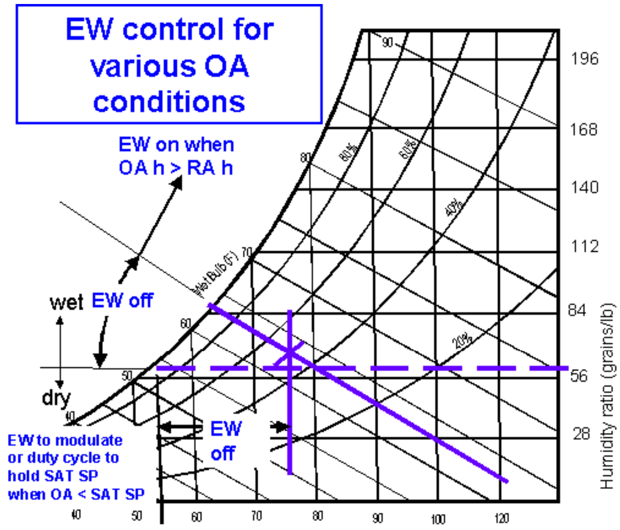
Common pitfalls to be avoided when applying DOAS?

- Inappropriate control of the EW
- Wasteful use of reheat
- Improper SAT setpoints
- Loss of virtually all free cooling when cold outside
- Insufficient instrumentation, can't detect poor performance and places system at the risk of freeze-ups
- Little or no interlock between chilled water temperature and the risk of condensation problems

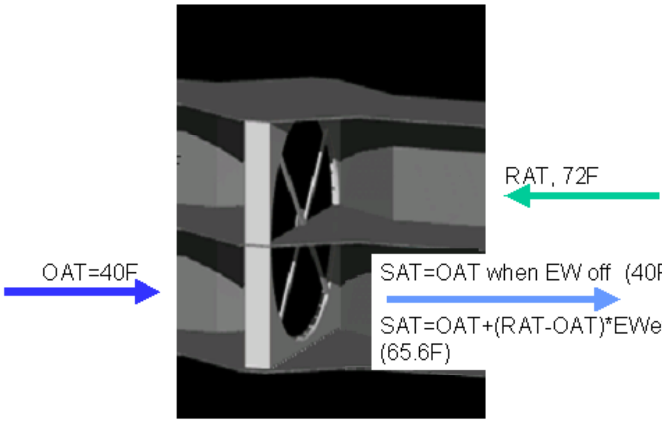
Example of an incorrect EW control logic



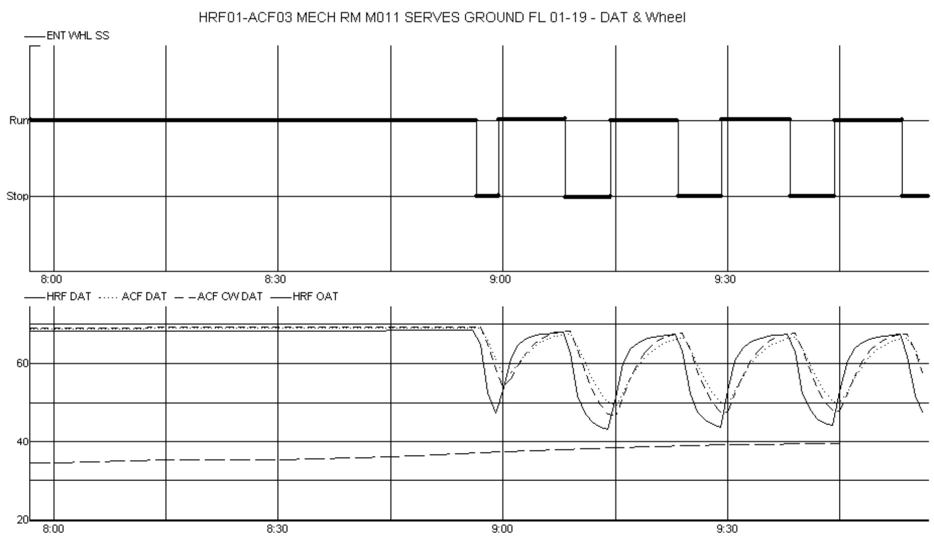
EW control for various OA conditions

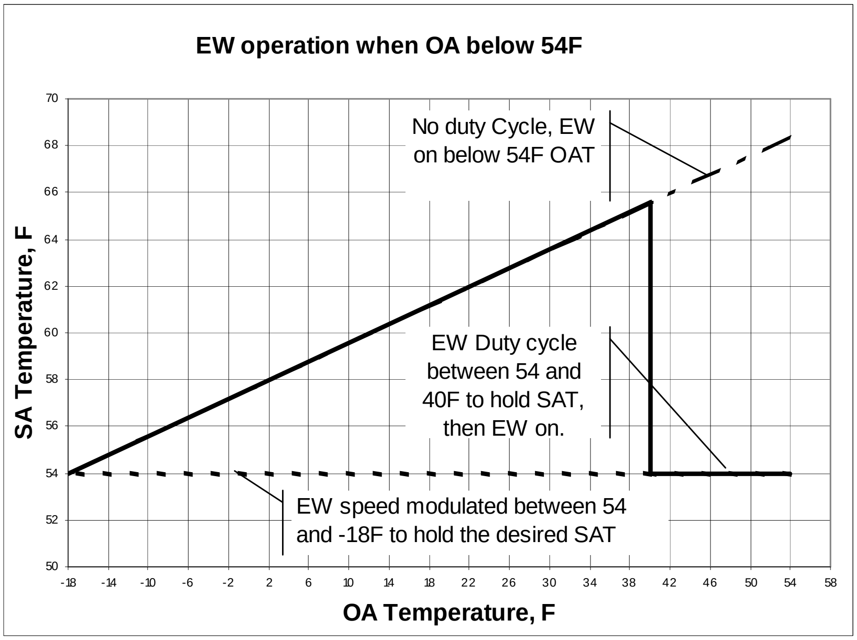


EW Duty cycle defined

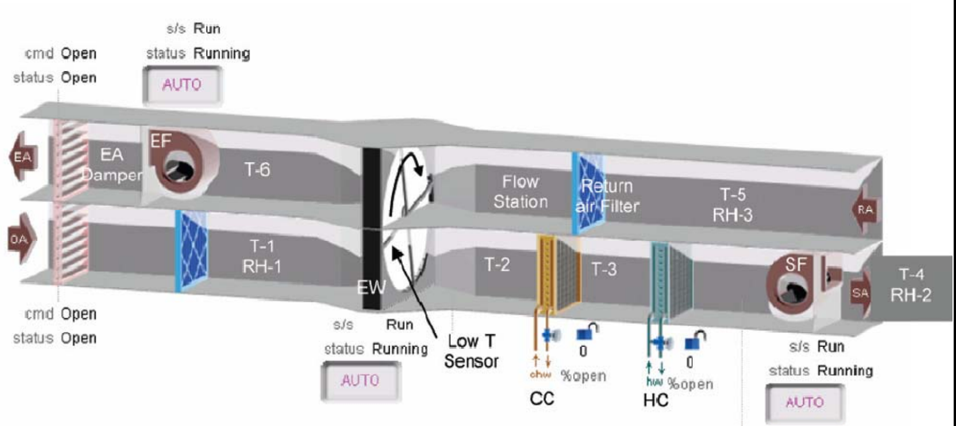


By adjusting the EW ON time (54.7% or 8.2 min) in 1 period (15 min) can get an avg. temperature equal to the desired SAT (54F). Duty cycle changes to 100% ON at 40F OAT to avoid tripping freeze stats. NOTE: HC must be off since when EW off, DAT < DATSP and the CC must be off when the EW on!





EW operation when OA below 54F
SA Temperature, F
OA Temperature, F
No duty Cycle, EW on below 54F OAT
EW Duty cycle between 54 and 40F to hold SAT, then EW on.
EW speed modulated between 54 and -18F to hold the desired SAT
70
68
66
64
62
60
58
56
54
52
50
-18
-14
-10
-6
-2
2
6
10
14
18
22
26
30
34
38
42
46
50
54
58

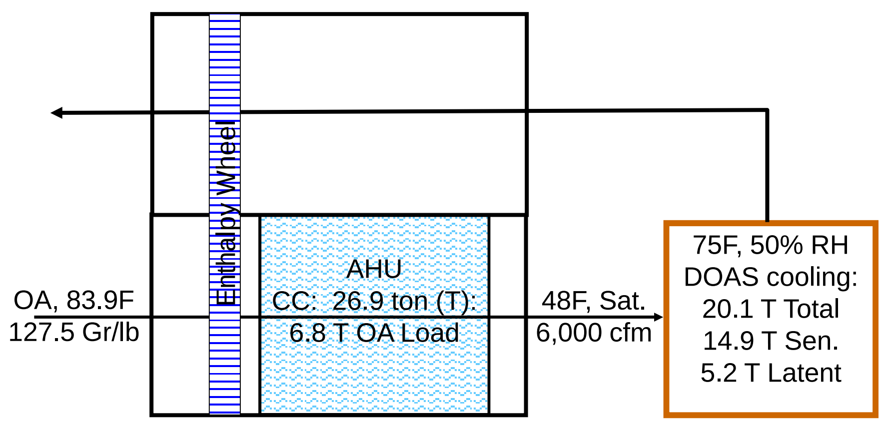


s/s Run
status Running
AUTO
cmd Open
status Open
EA
Damper
EF
T-6
Flow
Station
Return
air Filter
T-5
RH-3
RA
OA
T-1
RH-1
EW
T-2
T-3
SF
SA
T-4
RH-2
cmd Open
status Open
s/s Run
status Running
AUTO
Low T
Sensor
chw
0
%open
CC
hw
0
%open
HC
s/s Run
status Running
AUTO

What are the common pitfalls to be avoided when applying DOAS?

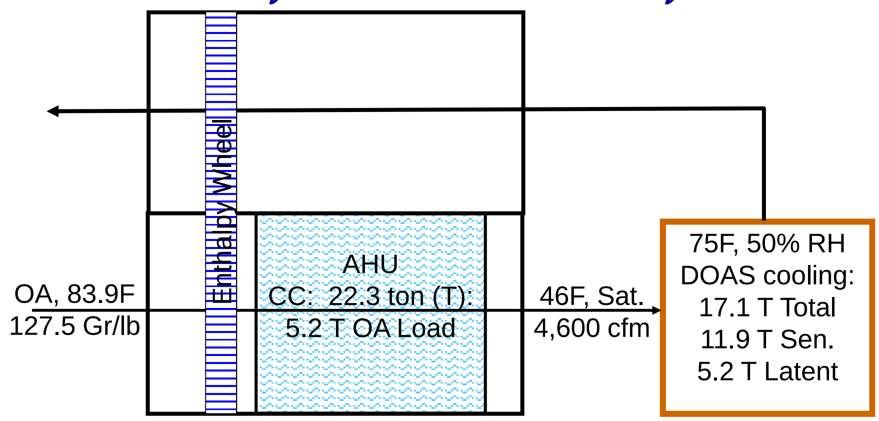
- Controls not tuned—therefore much hunting
- Old attitudes when system found to be functioning improperly: "***The building is quite comfortable*** while operating at these conditions. There is little concern over not operating at the 'ideal' design conditions."
- Reminds me of the time I drove across country with the air pressure in my tires at 10 psig. ***The ride was quite comfortable***, but the gas mileage was pathetic and the tire wear unacceptable.
- For more details, visit: http://doas-radiant.psu.edu/IAQ_Pitfalls_sum_06.pdf

How about first cost, 6,000 cfm? Columbus



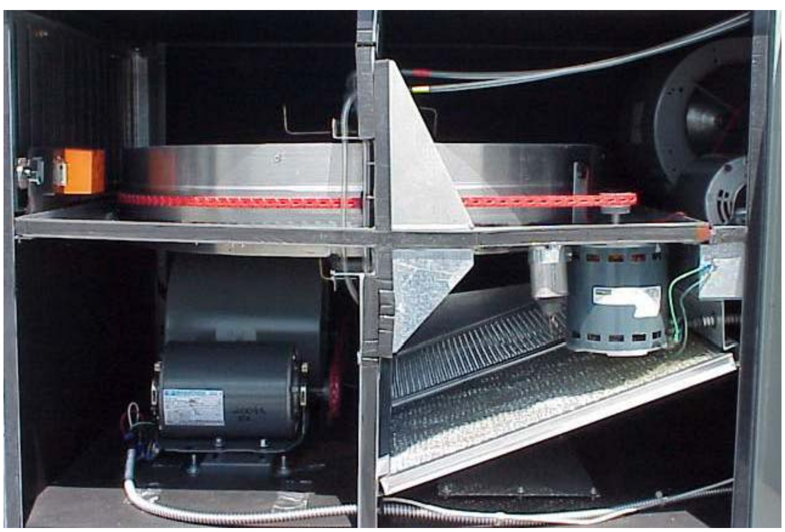
AHU first cost: $19,800 +$12,000 installation.
Air Cooled chiller first cost: $11,400 +$5,000 installation
Total installed cost: $48,200

How about first cost, 4,600 cfm? Col.



AHU first cost: $17,000 +$9,200 installation.
Air Cooled chiller first cost: $11,130 +$5,000 installation
Add FCU's to cover 3 T of lost DOAS space sen.cooling:
first cost: $1,440+($0-$4,300 [3@$1,430 each]) install'n
Total installed cost: $43,770-$48,070

Total Energy Recovery Wheel



Questions?

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Evaluation and Certificate

- Please fill out the course evaluation form and return it to the monitor. Comments and suggestions are welcome.
- You will receive your Certificate of Attendance when you finish the evaluation form.
- If you have any questions about ASHRAE courses, please contact Martin Kraft, Managing Editor, at mkraft@ashrae.org