

## *Understanding & Designing Dedicated Outdoor Air Systems (DOAS)*

ASHRAE CRC  
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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 DOAS equipment choices and Psychrometrics.
- Provide a DOAS design example.
- 30% surplus OA, why and does it use more energy?
- Explain relevance of DOE and ASHRAE Research findings.
- Describe field applications.
- Conclusions.

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### *Current HVAC System of Choice: VAV*

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### Reasons VAV has been 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.

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### 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

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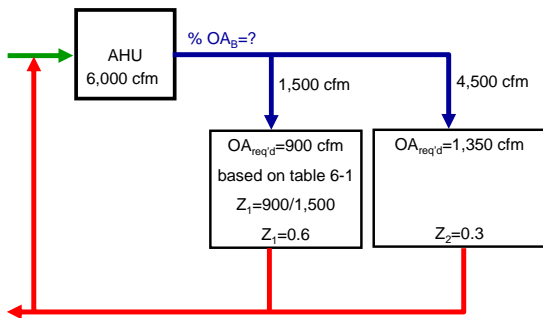
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### Poor & Unpredictable Vent'n Performance



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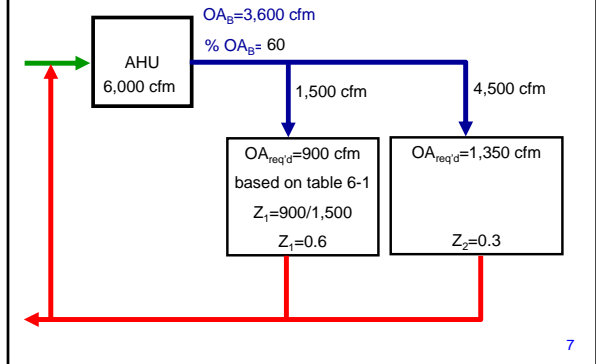
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**Poor & Unpredictable Vent'n Performance**




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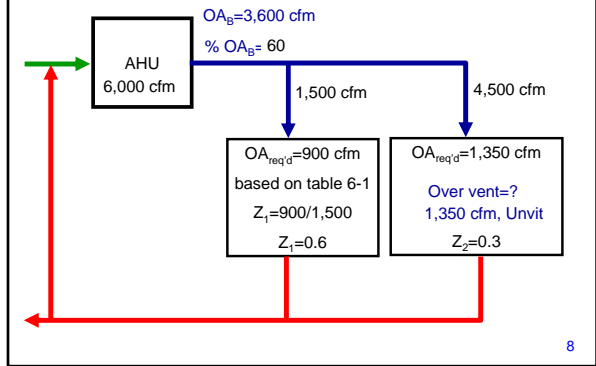
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**Poor & Unpredictable Vent'n Performance**




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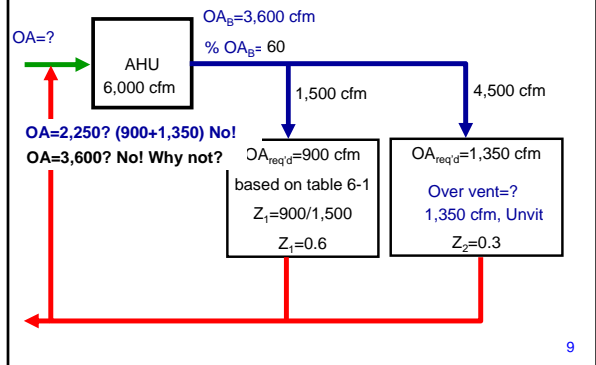
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**Poor & Unpredictable Vent'n Performance**




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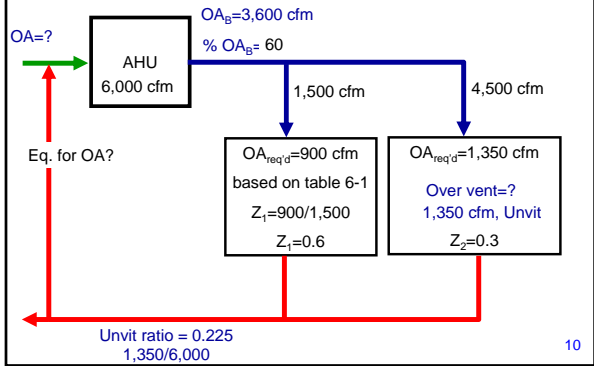
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### Poor & Unpredictable Vent'n Performance




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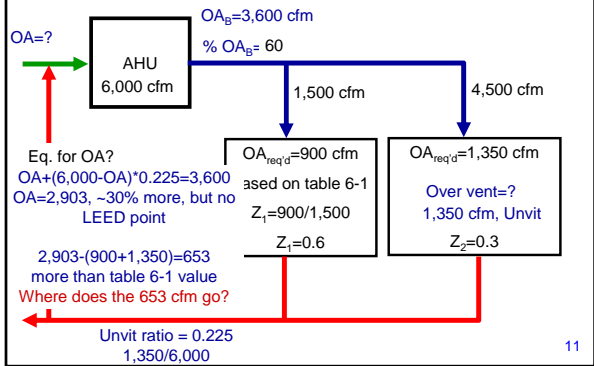
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### Poor & Unpredictable Vent'n Performance




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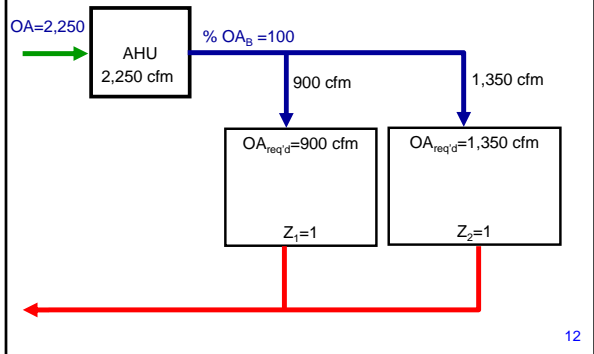
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### Can VAV Limitations be Overcome?




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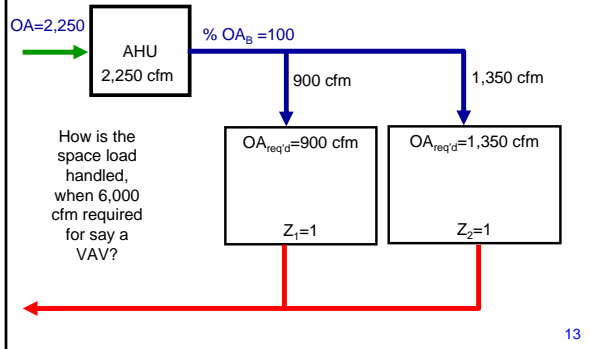
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### Can VAV Limitations be Overcome?




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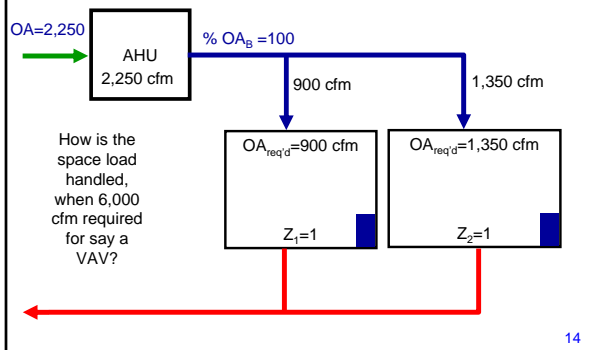
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### Can VAV Limitations be Overcome?




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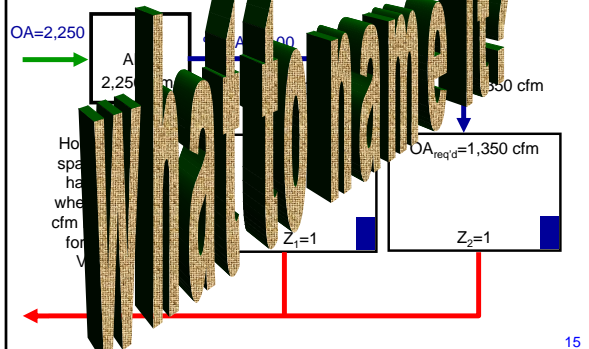
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### Can VAV Limitations be Overcome?




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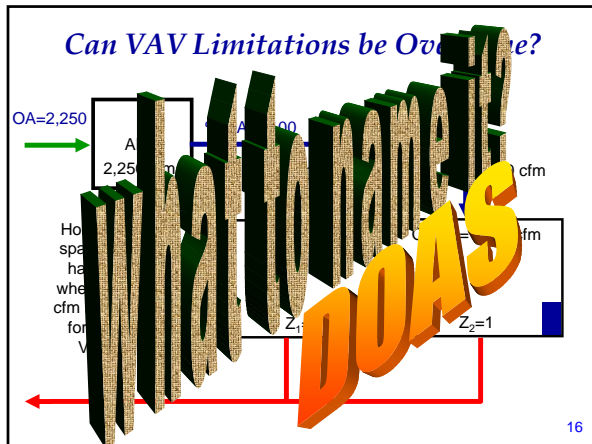
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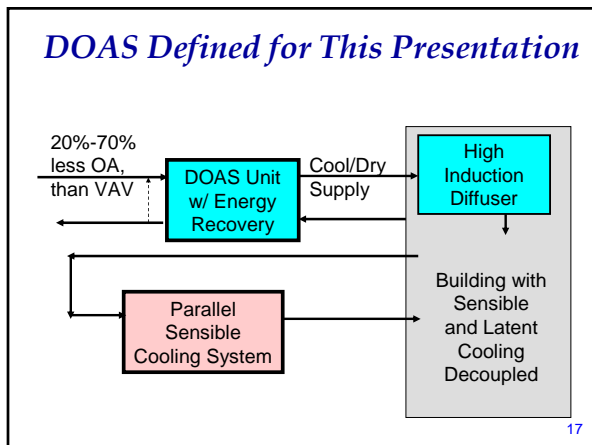
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- ### Key DOAS Points
1. 100% OA delivered to each zone via its own ductwork
  2. Flow rate generally as spec. by Std. 62.1-2007 or greater (LEED, Latent. Ctl)
  3. Employ TER, per Std. 90.1-2007
  4. Generally CV
  5. Use to decouple space S/L loads – Dry
  6. Rarely supply at a neutral temperature
  7. Use HID, particularly where parallel system does not use air
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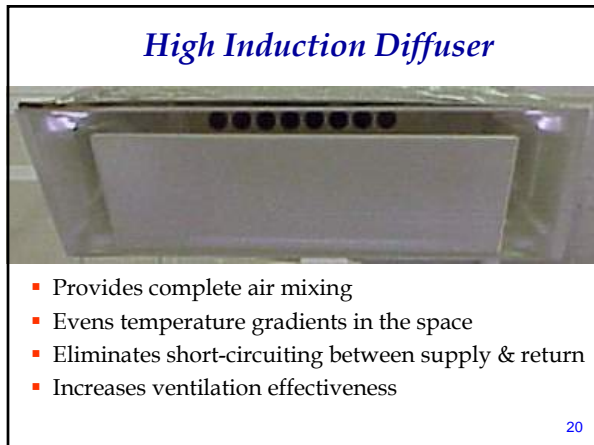
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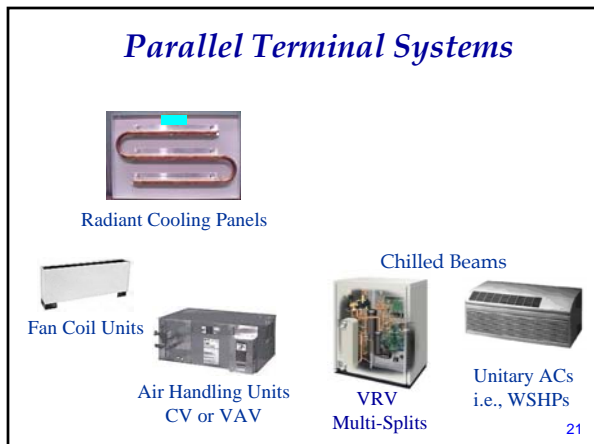
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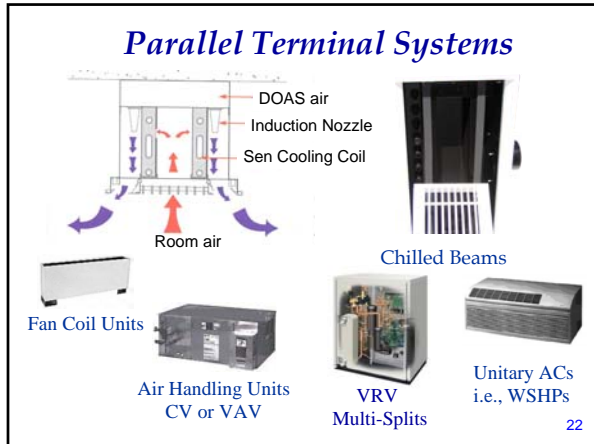
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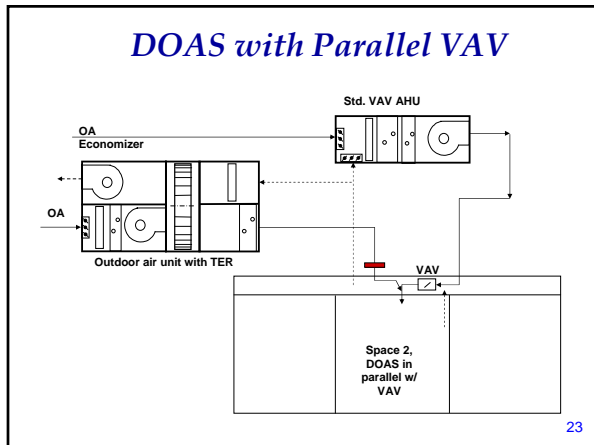
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- ### VAV Problems Solved with DOAS/Parallel VAV
- **Poor air distribution**
  - **Poor humidity control**
  - Poor acoustical properties
  - Poor use of plenum and mechanical shaft space
  - Serious control problems, particularly with tracking return fan systems
  - Poor energy transport medium: air
  - Poor resistance to the threat of biological and chemical terrorism
  - **Poor and unpredictable ventilation performance**
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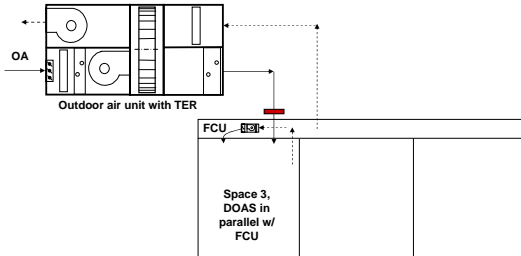
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## DOAS with Parallel FCU



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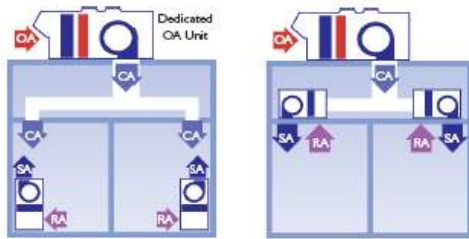
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## Parallel vs. Series OA Introduced for DOAS-FCU Applications?



**Parallel, Good**

**Series, Bad**

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## 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 downsized because 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 because they are handling only warm return air, resulting in smaller coils and further reducing first cost.
- Opportunity for plenum condensation is reduced because the ventilation air is not introduced into the plenum near the terminal equipment, for better IAQ

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### *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

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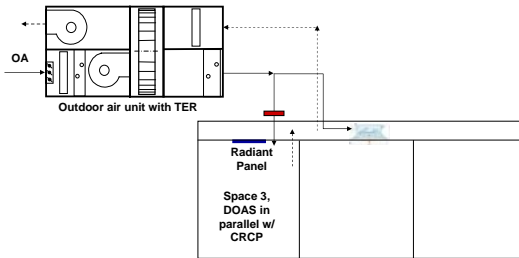
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### *DOAS with Parallel Radiant, or Chilled Beam*



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### *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

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### ***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

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### ***Role of Total Energy Recovery***

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### ***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.

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## DOAS & Energy Recovery

ASHRAE Standard 62.1-2009  
 Exhaust Air Treatment  
 follows:  
 "T. ASHRAE's new Standard for the Design  
 Of High Performance Green Buildings  
 (189.1) tightens the requirements to  
 (increased the minimum effectiveness to  
 60% and requires TER for even the  
 smallest systems in the moist USA--  
 re. located primarily east of the continental  
 divide) allows its use with class 1-3 air.

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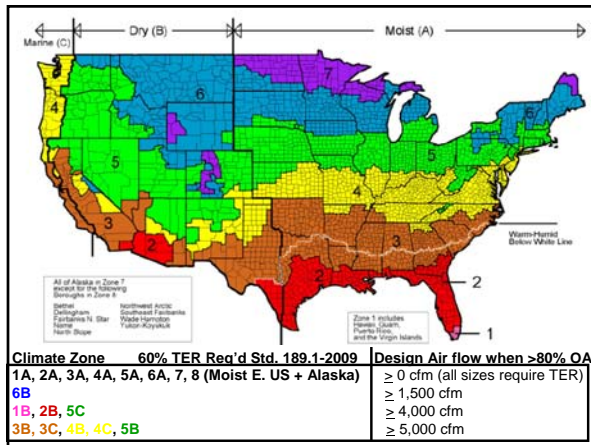
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## Merits of Using a TER (Enthalpy Wheel) with DOAS

- 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.)

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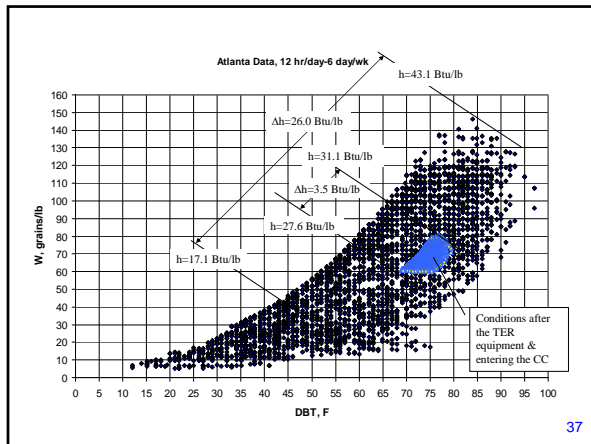
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### *Implications of the Small Area on the Psychrometric Chart Entering the CC*

- 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.

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### *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

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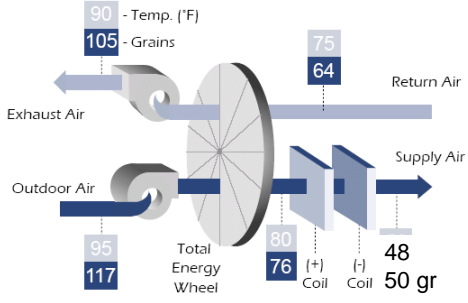
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## DOAS Equipment on the Market Today



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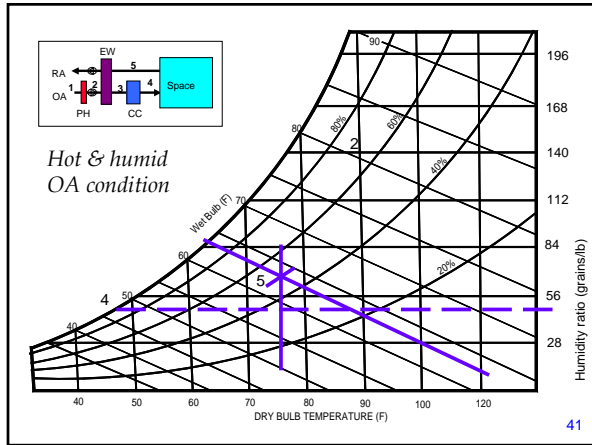
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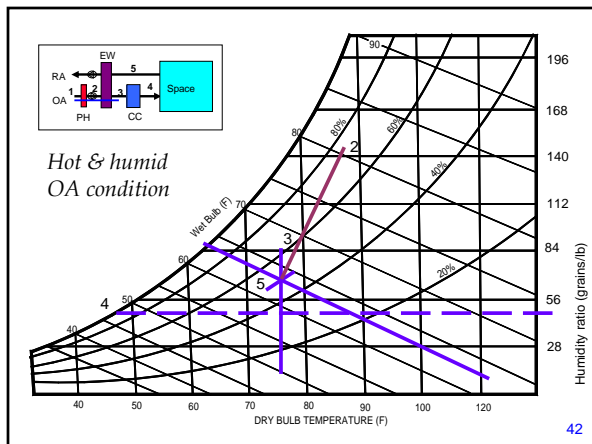
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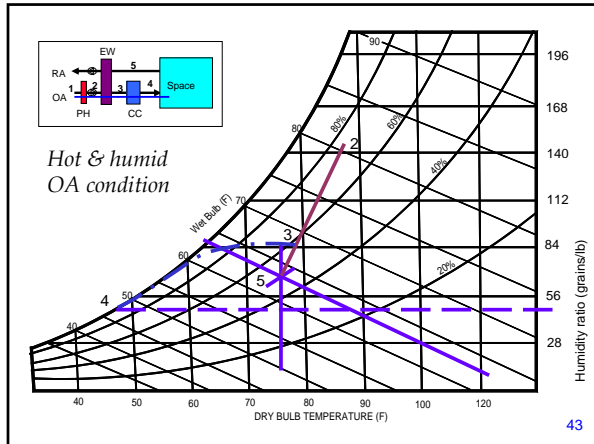
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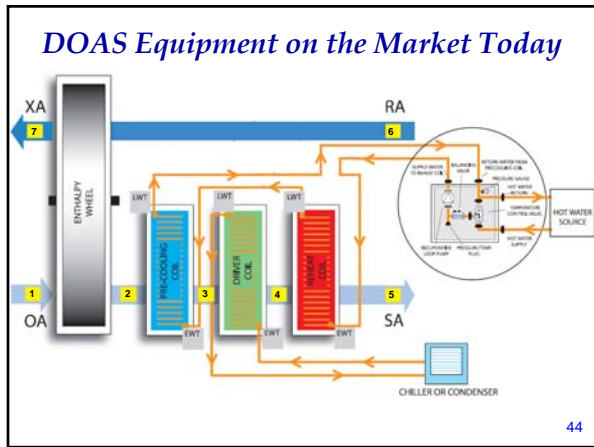
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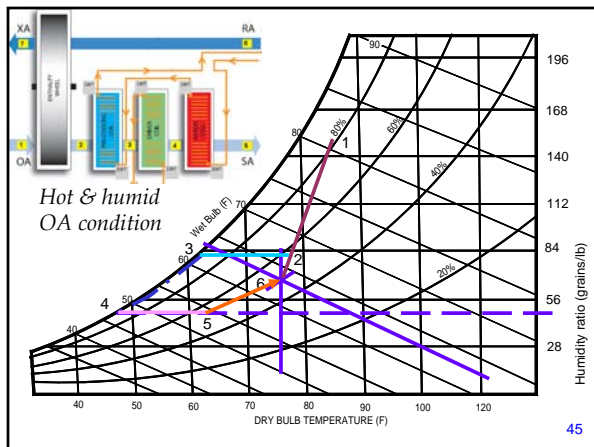
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***A Few Additional Comments  
Regarding DOAS Equipment***

- TER Effectiveness is an important factor
- TER desiccant an important choice
- TER purge, pro and con

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***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

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***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

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### *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

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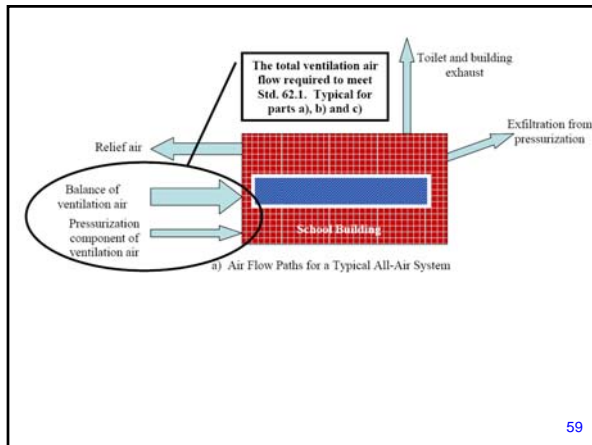
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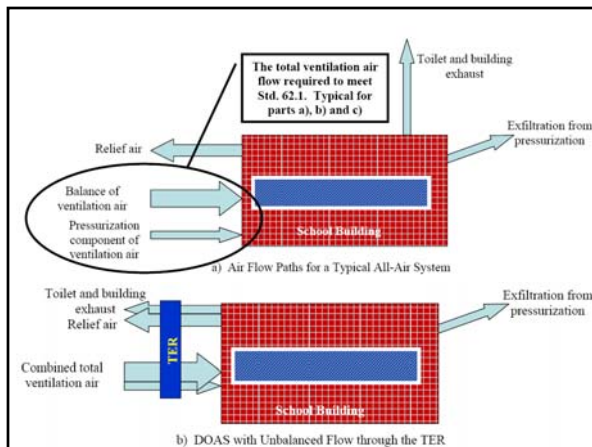
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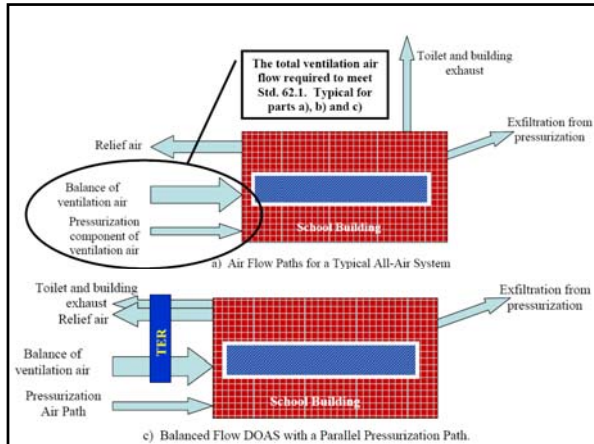
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**Unbalance @ TER if pressurization is 1/2 ACH, based upon Std. 62.1**

Occupancy category	floor frac
edu 5-8	0.3
edu 9+	0.3
lecture	0.1
conf	0.2
office	0.7
retail sales	0.5

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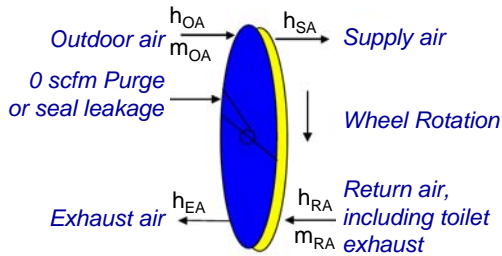
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For unbalanced flow,  $m_{OA} = m_{RA} + m_{Pressurization}$



$$\epsilon = m_{OA}(h_{OA} - h_{SA}) / m_{RA}(h_{OA} - h_{RA}) = (h_{EA} - h_{RA}) / (h_{OA} - h_{RA})$$

$$\epsilon_{\text{apparent}} = \epsilon * m_{RA} / m_{OA} = (h_{OA} - h_{SA}) / (h_{OA} - h_{RA})$$

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**Selecting the Supply Air DPT**

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

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**Selecting the Supply Air DPT**

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

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

*$\Delta w = 15$  gr/lb with 20 scfm/person, requires  
48°F DPT if space 75°F 50% RH*

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**Selecting the Supply Air DPT**

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

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

*$\Delta w = 15$  gr/lb with 20 scfm/person, requires  
48°F DPT if space 75°F 50% RH*

*or  $\Delta w = 10$  gr/lb with 30 scfm/person, requires  
51°F DPT if space 75°F 50% RH*

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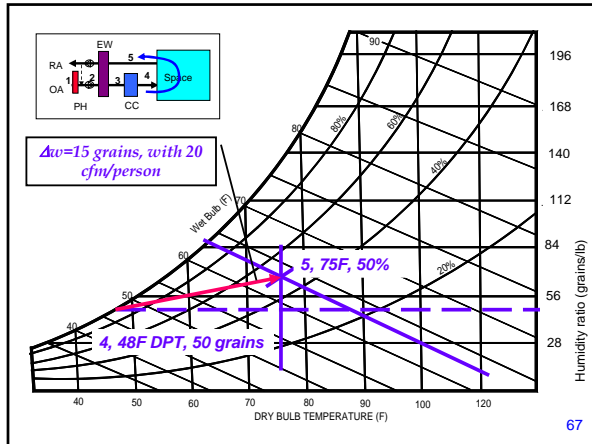
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### Example Design Calculation for DOAS w/ VAV Comparison

**Building Data:**  
 70,000 ft<sup>2</sup> 3-story office building  
 350 occupants, 245 Btu/h sen, 205 Btu/h lat.  
 Uncorrected Ventilation: 350\*5+70,000\*0.06=5,950 scfm  
 Other lat load: 20 Btu/h-person  
 Internal generation, lights & equip: 4W/ft<sup>2</sup> 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/h-ft<sup>2</sup>

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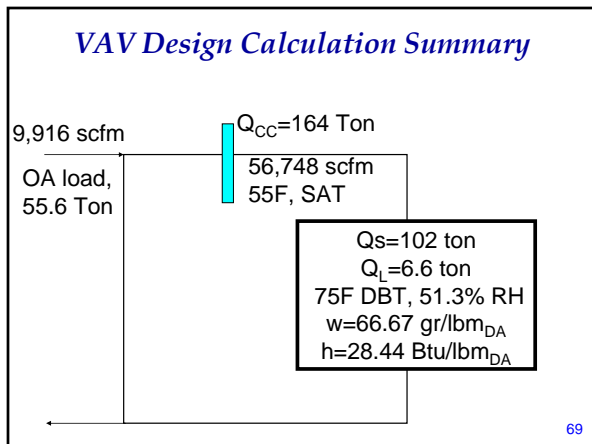
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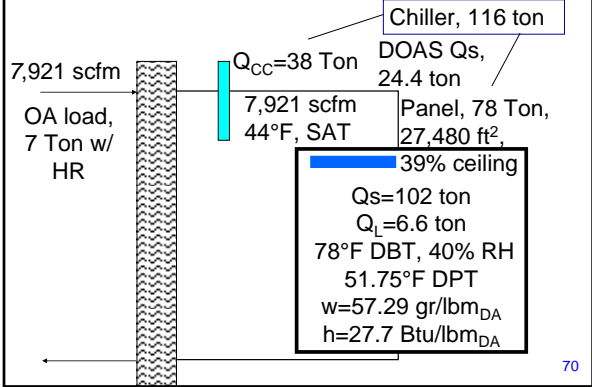
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### DOAS Design Calculation Summary




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### VAV vs. DOAS/Radiant Comparison

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

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### Leadership in Energy and Environmental Design



LEED 2009 for New Construction and Major Renovations

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**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.

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**IE Q Credit 2: Increased Ventilation: 1 Point**

**Intent**

To provide additional outdoor air ventilation to improve indoor air quality (IAQ) and promote occupant comfort, well-being and productivity.

Wellbeing: the state of being happy, healthy, or prosperous

**Requirements**

CASE 1. Mechanically Ventilated Spaces  
 Increase breathing zone outdoor air ventilation rates to occupied spaces by at least 30% above the minimum rates required by ASHRAE Standard 62.1-2007 (with errata but without addenda1) as determined by IEQ Prerequisite 1: Minimum Indoor Air Quality Performance.

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**IE Q Credit 2: Increased Ventilation**

**Intent**

To provide additional outdoor air ventilation to improve indoor air quality (IAQ) and promote occupant comfort, well-being and productivity.

**Requirements**

CASE 1. Mechanically Ventilated Spaces  
 Increase breathing zone outdoor air ventilation rates to occupied spaces by at least 30% above the minimum rates required by ASHRAE Standard 62.1-2007 (with errata but without addenda1) as determined by IEQ Prerequisite 1: Minimum Indoor Air Quality Performance.

Sustainable site	26	24%
H <sub>2</sub> O η	10	9%
Energy & Atmos.	35	32%
Mat'ls & Resource	14	13%
IEQ	15	14%
Innovation	6	5%
Regional Priority	4	4
<b>Max points</b>	<b>110</b>	
<b>Gold: 60-79 points</b>		

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**IE Q Credit 2: Intent**  
 To provide additional...  
 improve indoor air...  
 comfort, well-being

Sustainable site	26	24%
H <sub>2</sub> O η	10	9%
Energy & Atmos		7%
Mat'ls & R	15	14%
Regional Priority	6	5%
	4	4
<b>Max points</b>	<b>110</b>	
<b>Gold: 60-79 points</b>		

Prerequisite 1: Minimum Performance.

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

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**30% Surplus Air Questioned!**

Building Sciences

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**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 [jlstiburek@ashrae.org](mailto:jlstiburek@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?

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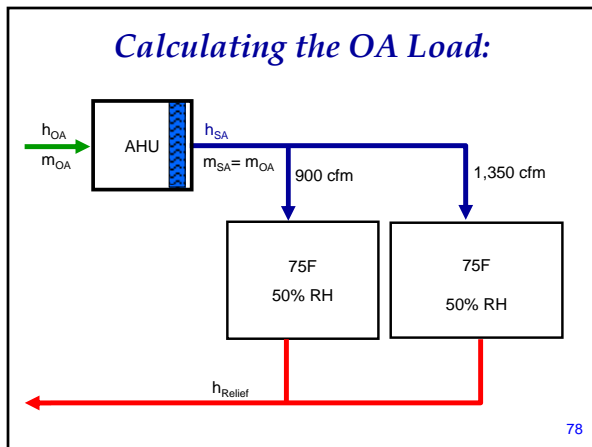
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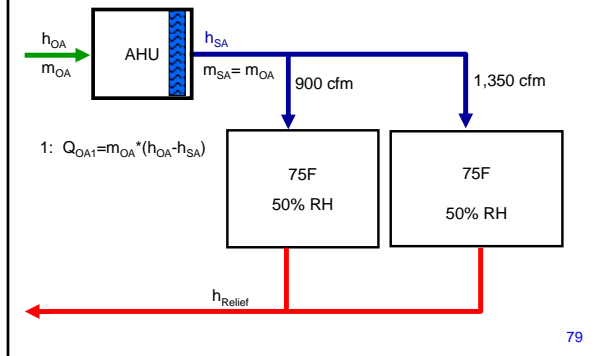
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### Calculating the OA Load:




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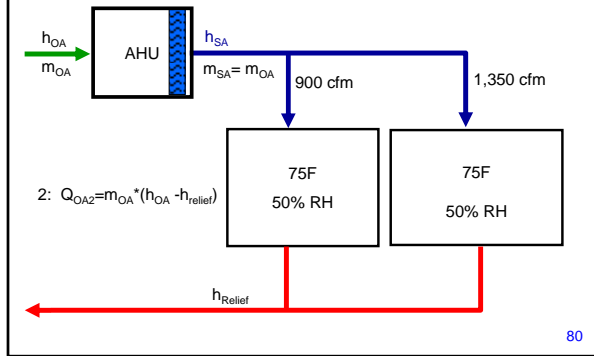
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### Calculating the OA Load:




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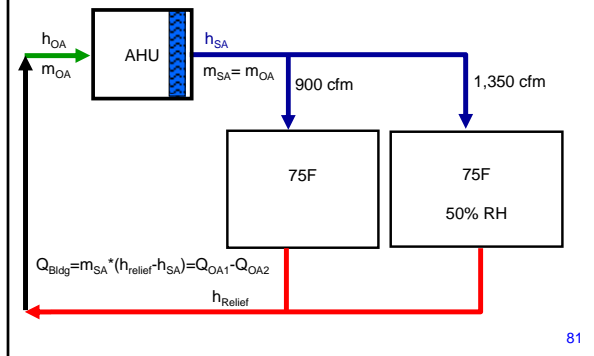
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### Calculating the OA Load:




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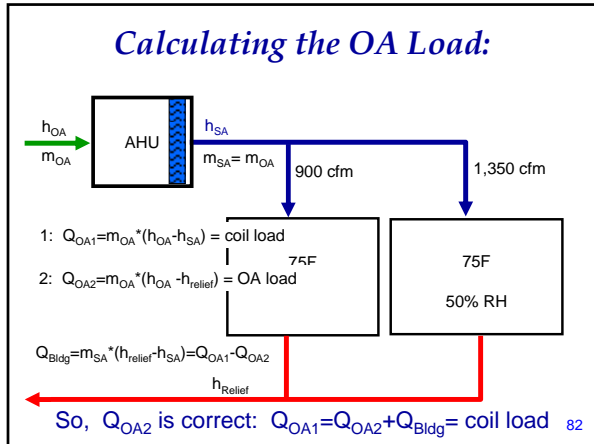
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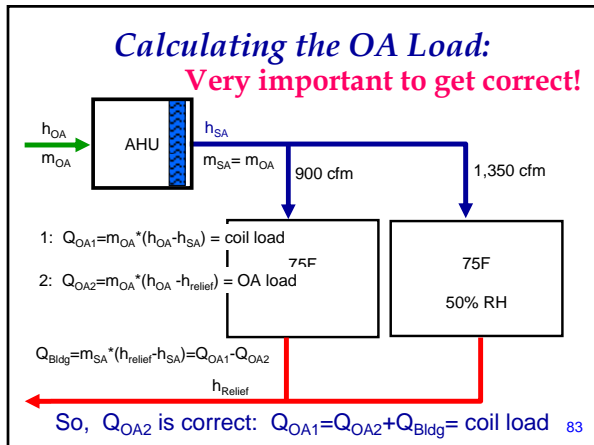
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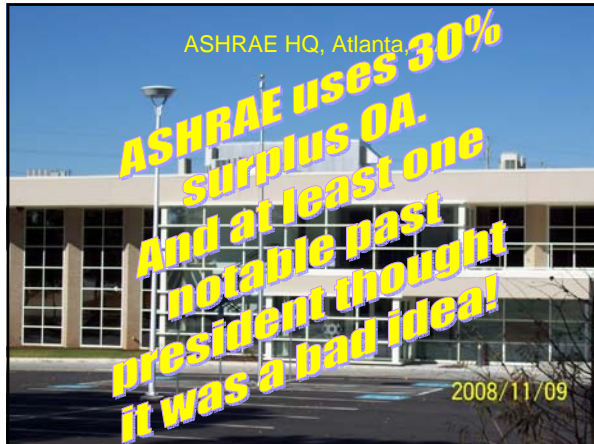
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**Limits of LEED Authority**

- Do you believe there is a **rational basis** for granting a LEED point when the ventilation air flow rate is increased beyond 62.1? Many do not.
- Can LEED be ignored? Yes**, in the sense that the LEED rating systems are not formal standards in and of themselves. Rather they are criteria established by leaders in the industry on what constitutes good practices to protect the environment and enhance the wellbeing of those impacted by development.
- Conclusion: There is **no mandate in LEED**, or the law, to garner this point, and many may in fact choose to garner a LEED point by the much simpler installation of a **bicycle rack**.

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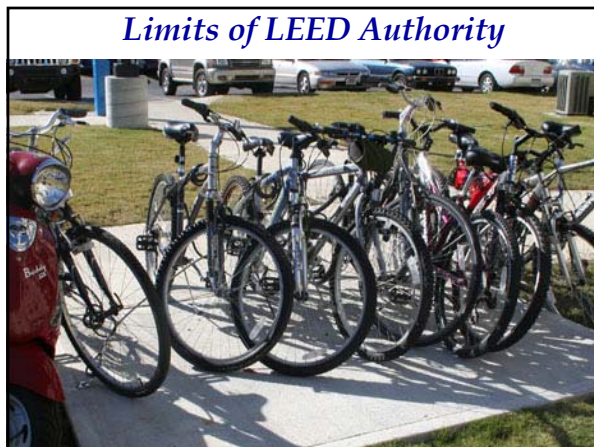
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## Limits of LEED Authority



Sustainable Sites		26 Possible Points
<input checked="" type="checkbox"/>	Prerequisite 1 Construction Activity Pollution Prevention	Required 1
<input type="checkbox"/>	Credit 1 Site Selection	1
<input type="checkbox"/>	Credit 2 Development Density and Community Connectivity	5
<input type="checkbox"/>	Credit 3 Brownfield Redevelopment	1
<input type="checkbox"/>	Credit 4.1 Alternative Transportation—Public Transportation Access	6
<input type="checkbox"/>	Credit 4.2 Alternative Transportation—Bicycle Storage and Changing Rooms	1

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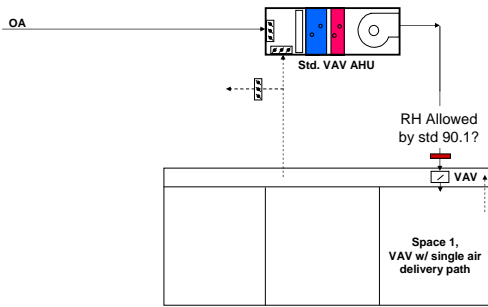
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## Why question 30% surplus OA? 1<sup>st</sup> consider a Standard VAV System



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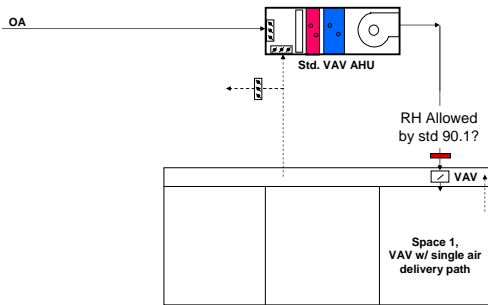
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## Why question 30% surplus OA? 1<sup>st</sup> consider a Standard VAV System



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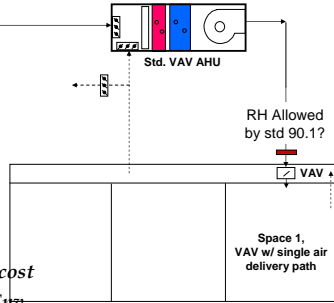
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**Why question 30% surplus OA?  
1<sup>st</sup> consider a Standard VAV System**

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



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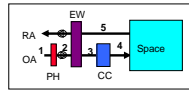
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**Why question 30% surplus OA?  
Consider DOAS.**

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



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**How does the 62.1 flow impact DOAS design – w/ space latent load decoupled?**

	Occ. Category	cfm/p	SA DPT °F
A	Conf. rm	6.2	24.84
B	Lec. cl	8.42	35.9
C	Elem. cl	11.71	42.75
D	Office	17	47.18
E	Museum	9	31.05

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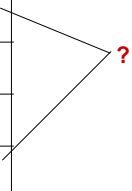
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**How does the 62.1 flow impact DOAS design – w/ space latent load decoupled?**

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E	Museum	9	31.05




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**How does the 62.1 flow impact DOAS design – w/ space latent load decoupled?**

	Occ. Category	cfm/p	SA DPT °F	1.3*cfm/p	SA DPT °F
A	Conf. rm	6.2	24.84	8.06	34.75
B	Lec. cl	8.42	35.9	10.96	41.63
C	Elem. cl	11.71	42.75	15.23	46.08
D	Office	17	47.18	22.1	49.2
E	Museum	9	31.05	11.7	38.56

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**How does the 62.1 flow impact DOAS design – w/ space latent load decoupled?**

	Occ. Category	cfm/p	SA DPT °F	1.3*cfm/p	SA DPT °F
A	Conf. rm	6.2	24.84	8.06	34.75
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C	Elem. cl	11.71	42.75	15.23	46.08
D	Office	17	47.18	22.1	49.2
E	Museum	9	31.05	11.7	38.56

**Key reason to overventilate!  
Elevate SA DPT.**

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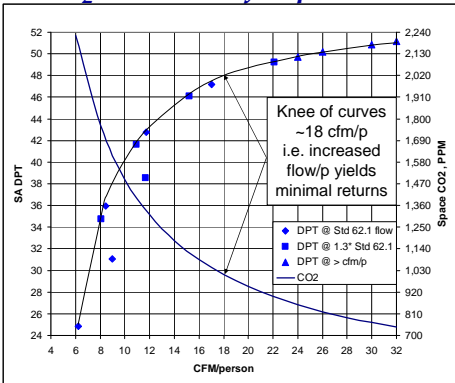
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### S.S. CO<sub>2</sub> PPM vs. cfm/person

Assumes an OA CO<sub>2</sub> conc. of 400 PPM & an occupant CO<sub>2</sub> gen. rate of 0.31 L/min.

**Note: CO<sub>2</sub> conc. is a measure of dilution, i.e. IEQ**




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### 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.

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### 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](http://doas-radiant.psu.edu/mumma_Journal_30_PC_OA_6_09.pdf)

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## *1<sup>st</sup> and Op Cost Summary*

III) Columbus, OH, Economic comparison of 6,000 and 4,600 cfm flow <i>without</i> EW			
Flow	1 <sup>st</sup> 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
<u>Extra \$ for surplus air</u>	<b>\$4,450 to \$150</b>	<b>-\$841</b>	<b>\$280</b>
Payback years with surplus air	<b>8 to 0.3 years</b>		
IV) Columbus, OH, Economic comparison of 6,000 and 4,600 cfm flow <i>with</i> EW			
Flow	1 <sup>st</sup> 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
<u>Extra \$ for surplus air</u>	<b>\$4,430 to \$130</b>	<b>-\$969</b>	<b>\$358</b>
Payback years with surplus air	<b>7 to 0.2 years</b>		

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### *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.

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### *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.

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### 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.

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### 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.

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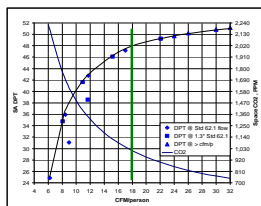
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### 30% Surplus Conclusion #3, cont'd

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



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*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<sup>2</sup>

Retail: 1 story 79,000 ft<sup>2</sup>

May 31, 2006

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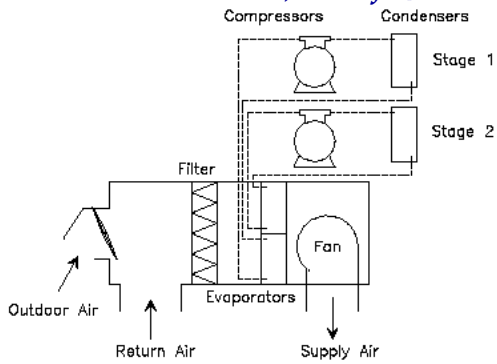
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*Base Case: DX, 350 cfm/ton*



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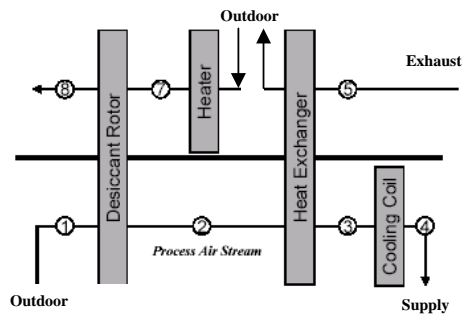
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*DX (400 cfm/ton) with Desiccant*



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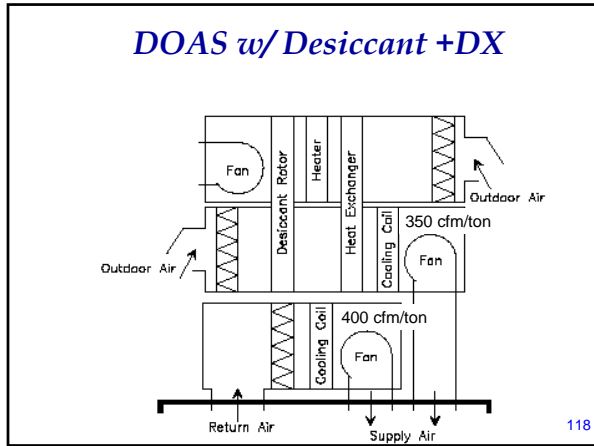
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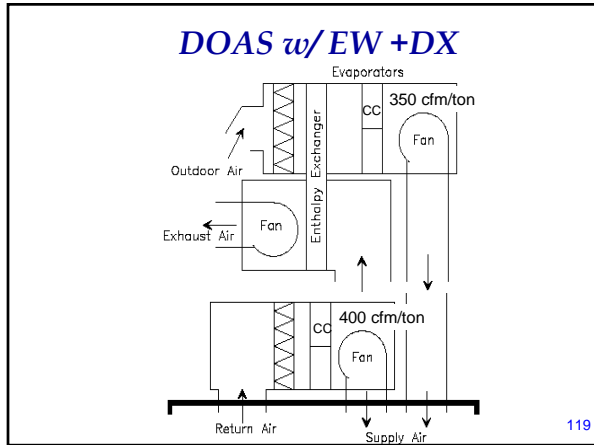
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### Performance for office, based upon 62.1-2007 ventilation req'd

Humidity Control (Occ. Hours >65% RH)

Location	Miami	Hous	Shrev	Fl. 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
<b>DOAS w/ EW +DX</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>

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
<b>DOAS w/ EW +DX</b>	<b>-18%</b>	<b>-21</b>	<b>-20</b>	<b>-19</b>	<b>-19</b>	<b>-23</b>	<b>-26</b>	<b>-19</b>	<b>-26</b>	<b>-14</b>

LCC: Equipment 1<sup>st</sup> + 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
<b>DOAS w/ EW +DX</b>	<b>35</b>	<b>35</b>	<b>33</b>	<b>37</b>	<b>33</b>	<b>37</b>	<b>35</b>	<b>52</b>	<b>37</b>	<b>36</b>

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*A Few Other DOAS Applications*

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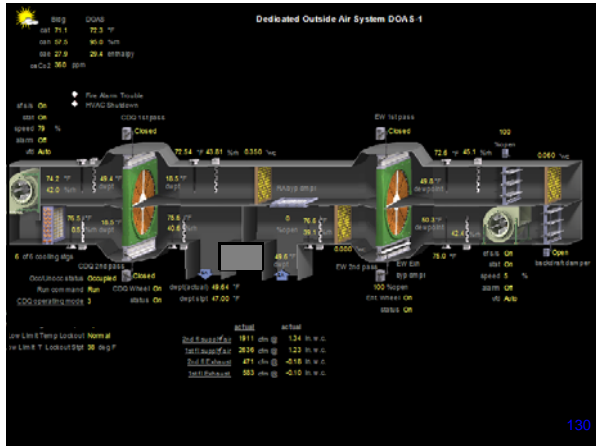
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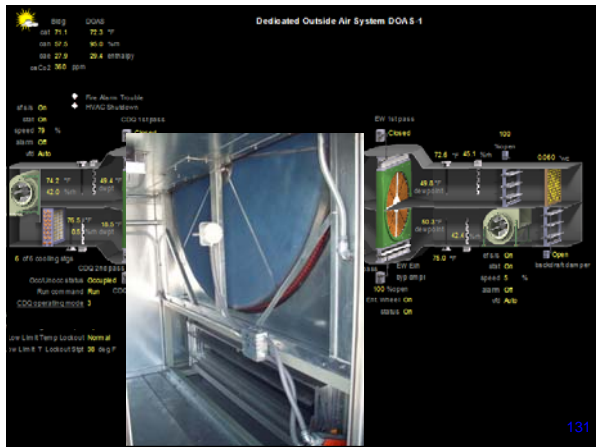
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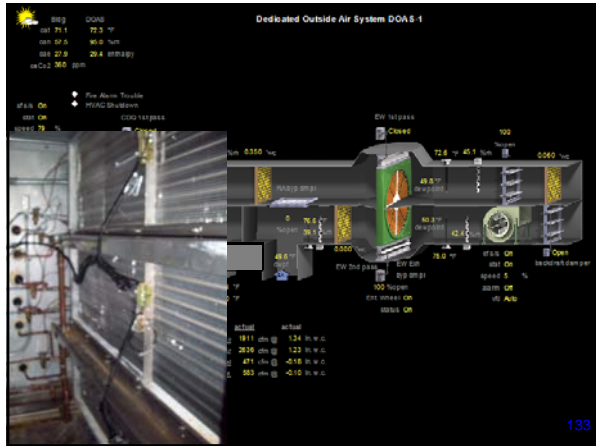
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Middle School w/ DOAS

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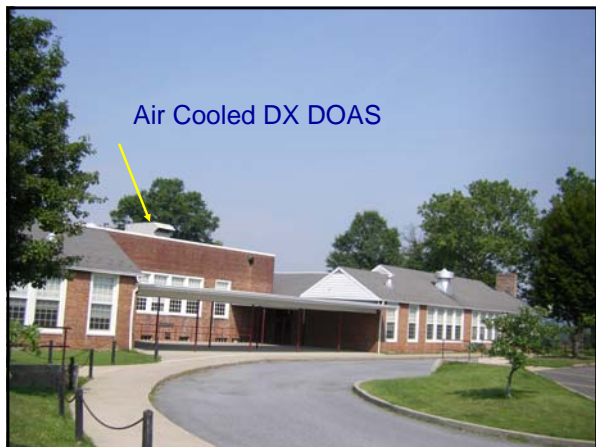
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Air Cooled DX DOAS

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***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.

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*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.

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*Future Questions?*

**Stanley A. Mumma, Ph.D., P.E.**

Penn State University  
sam11@psu.edu  
<http://doas-radiant.psu.edu>

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