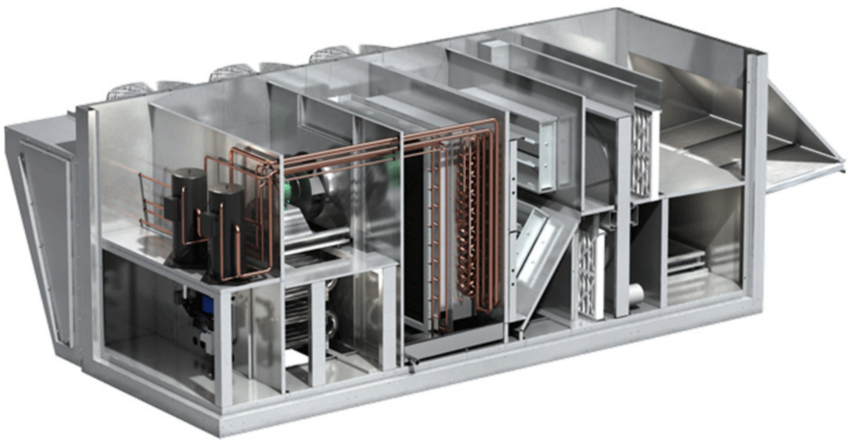


Designing Energy Efficient Outdoor Air Systems

Joseph Thorndal
Applied Products Sales Manager
Greenheck, Schofield, Wisconsin

Joseph Thorndal

- BS Industrial Engineering
  - North Dakota State University
- Work Experience
  - Energy Engineer Johnson Controls
  - Application Engineer McQuay (now Daikin)
  - Senior Application Engineer Mammoth Inc.
  - Applied Products Sales Manager Greenheck Fan Corporation
- ASHRAE Member Since 1991

Agenda

- Energy Recovery Overview
- ASHRAE 90.1
- Systems Overview:
  - Multiple Space Applications
    - VAV
    - DOAS
    - DOAS With Energy Recovery
- DOAS Design Considerations and Application
- AHRI 920 – Performance Rating For DOAS
- DOAS Enhancements – Controlling Humidity

Energy Recovery Types

- Plate Exchangers
- Enthalpy Wheels
- Heat Pipes
- Run Around Coil Loops

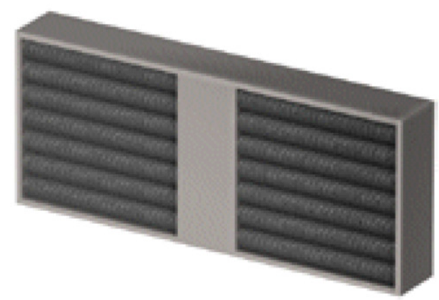
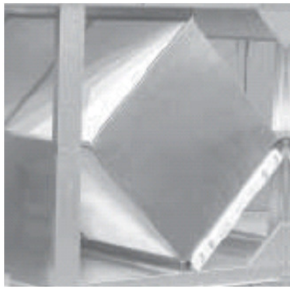


Plate Exchangers

Aluminum

(Sensible only)



Hygroscopic Resin

(Latent + Sensible)

Polymer Membrane

(Latent + Sensible)

Total Effectiveness

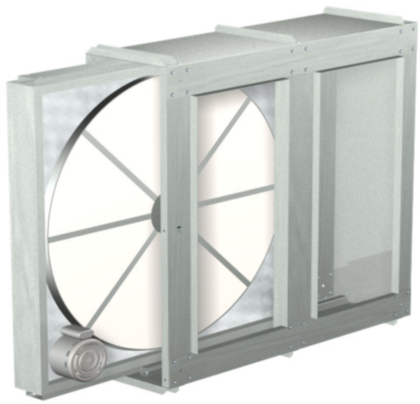
~30%	~40 - 50%	~50 - 60%

ASHRAE

Energy Recovery Technology

- Total Energy Wheels

Polymer



Aluminum or Synthetic Fiber

Recover sensible (heat) & latent (moisture)

Heat Transfer: 70-80%

Moisture Transfer: 70-80%

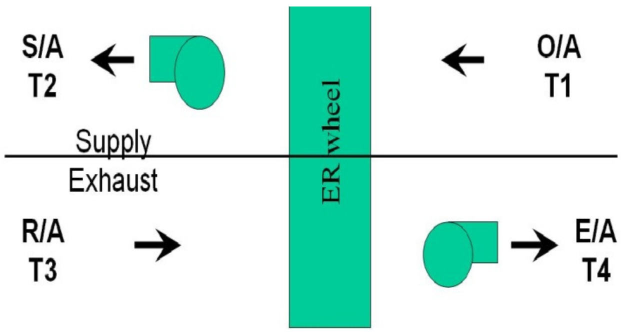
Total Effectiveness: 70-80%

Energy Recovery FAQS
Frequently Asked Questions

- Effectiveness & Heat Transfer Calcs
- Cross Leakage

Energy Recovery FAQS

Heat Transfer Calculation Basics

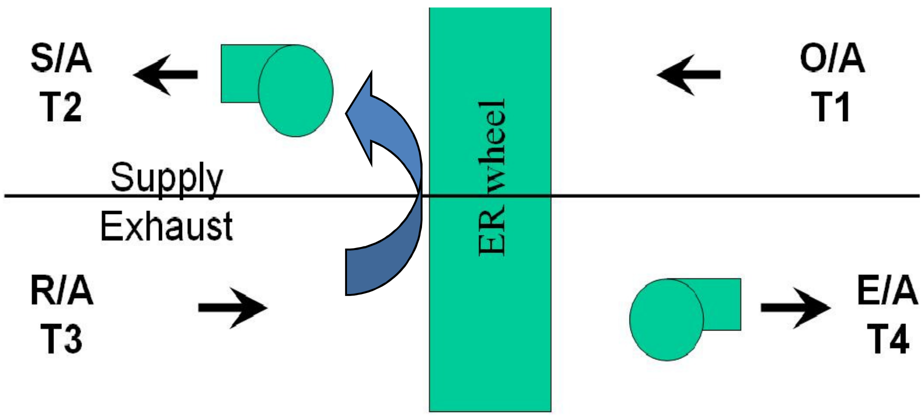


effectiveness, e

$$e = \frac{\text{actual transfer}}{\text{maximum transfer}} = \frac{m_s c_{ps}\,(T2-T1)}{C_{min}\,(T3-T1)}$$

Energy Recovery FAQS

Leakage



Cross Leakage

EATR = Exhaust Air Transfer Ratio

$$=(c_2-c_1)/(c_3-c_1)$$

Air Classes per ASHRAE 62.1-2010

Class of Air		Recirc?	Example
I	Normal Air, non-offensive Low contaminants	100%	O/A
II	Non-harmful, Mildly Offensive	10%	Bathroom
III	Significant contaminants Could be hazardous	5%	Vet office
IV	Hazardous objectionable	NONE	Lab / Bio Medical

Energy Recovery FAQS
Frequently Asked Questions

- Effectiveness & Heat Transfer Calcs
- Cross Leakage
- **Materials of construction & desiccants**

Energy Recovery Technology

- Total Energy Wheels

Polymer

Aluminum or Synthetic Fiber

Energy Recovery FAQS
Frequently Asked Questions

- Effectiveness & Heat Transfer Calcs
- Cross Leakage
- Technologies, materials of construction & desiccants
- **Certified performance**

Energy Recovery FAQS

Certified Performance

- Industry accepted test standards
- Independent third party testing
- Assures accurate manufacturer's published performance
- Not all manufacturers have certified performance!

http://www.ahridirectory.org

AHRI Certification Sheet

www.ahridirectory.org

Type: WHEEL Nominal Airflow: 3000 scfm

Tilt Angle (Heating/Cooling) N / A Deg

Pressure Drop: 1.00 inches

Leakage Ratings

	Pressure Differential	EATR	OACF	Purge Angle or Setting
Test 1:	-0.50 inches	2.7%	1.02	N/A
Test 2:	0.00 inches	1.5%	1.04	N/A
Test 3	0.50 inches	1.3%	1.06	N/A
Optional Add'l Test(s):	inches			

	Net Sensible	Net Latent	Net Total
100% Airflow Heating Condition:	80%	72%	77%
75% Airflow Heating Condition:	83%	77%	81%
100% Airflow Cooling Condition:	80%	72%	75%
75% Airflow Cooling Condition:	83%	77%	79%

Energy Recovery Overview

Supply Air
Dry Bulb 79°F
Wet bulb 66°F (51% RH)
Humidity 74 grains/lb.

Room Air
(to be exhausted)
Dry Bulb 75°F
Wet bulb 62.6°F (50% RH)
Humidity 65 grains/lb.

Outdoor Air
Dry Bulb 96°F
Wet bulb 80°F
Humidity 130 grains/lb.

Exhaust Air
Dry Bulb 87°F
Wet bulb 72.6°F°
Humidity 97 grains/lb.

Energy Recovery

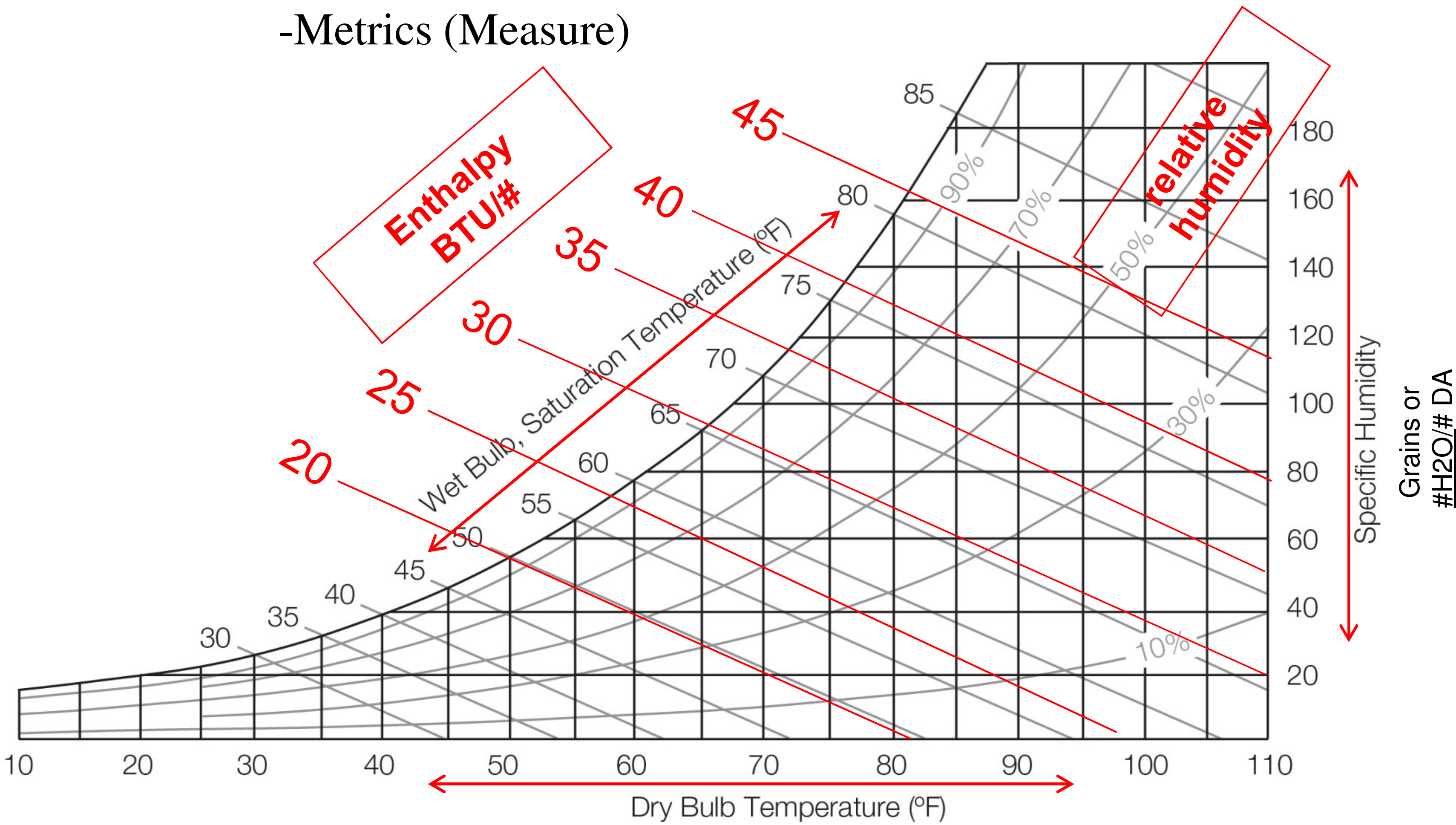
Benefits

- Reduces OA cooling load (3 to 4 tons / 1,000 CFM)

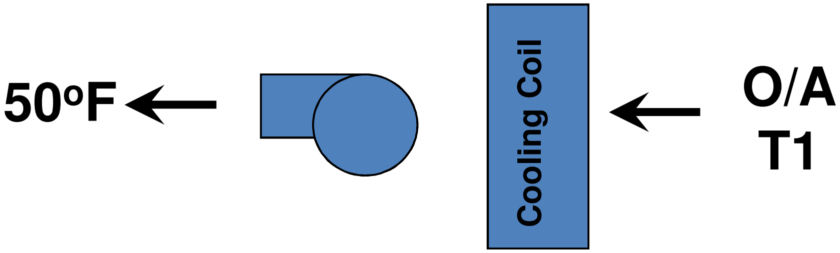
<u>Psychrometric Chart Review</u>

From the Greek…-Psychros (Cold)
-Metrics (Measure)

ERV FAQS

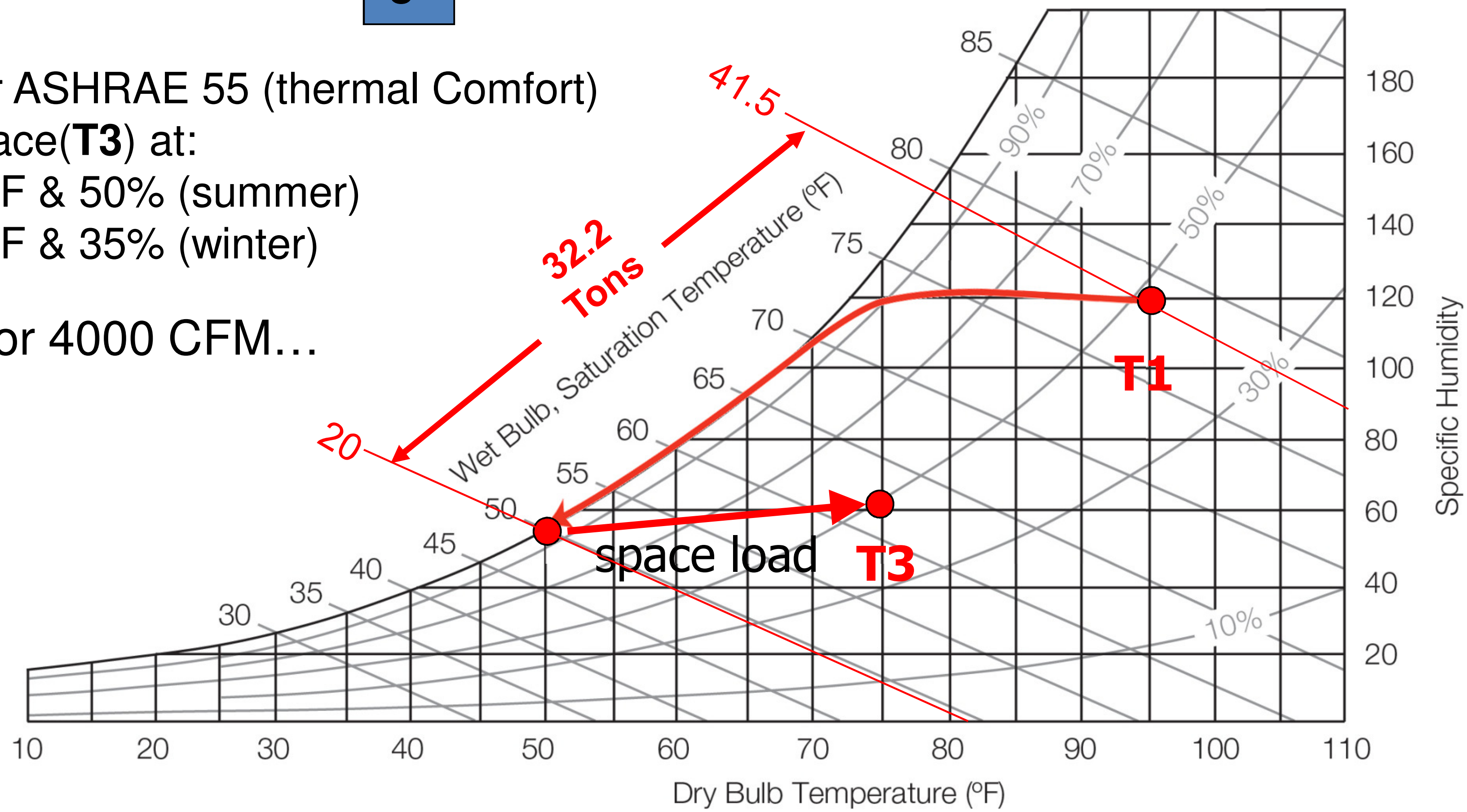


Cooling Process
(without Energy Recovery)



Per ASHRAE 55 (thermal Comfort)
Space(**T3**) at:
75°F & 50% (summer)
72°F & 35% (winter)

For 4000 CFM…

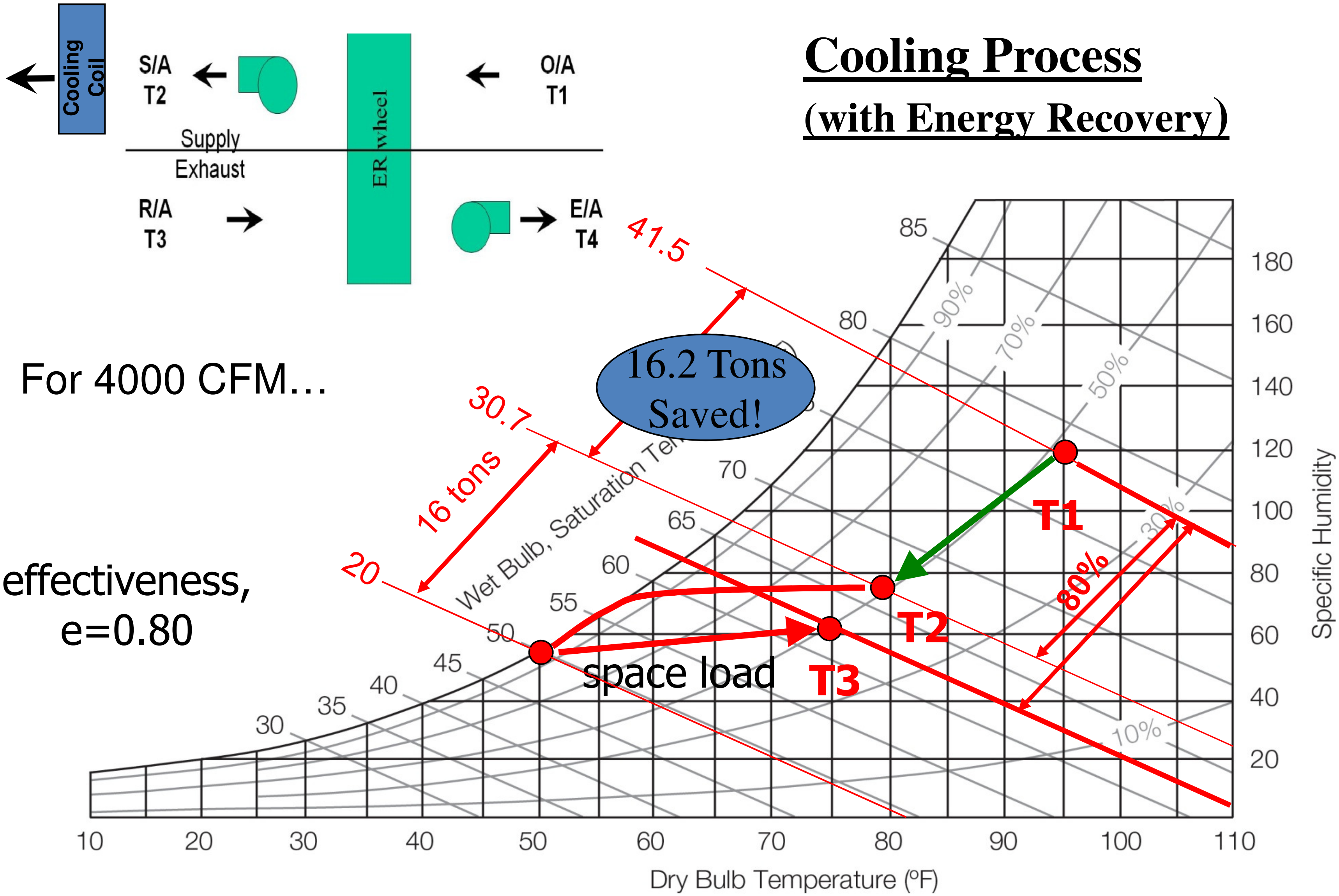


Designing Efficient Outdoor Air Systems

Cooling Process
(with Energy Recovery)

For 4000 CFM…

effectiveness,
e=0.80



Energy Recovery
Benefits

- Reduces OA cooling load by 3 - 4 tons per 1,000 CFM
- Reduced heating and cooling energy consumption

Heating Season

Supply Air
Dry Bulb 54°F
Wet bulb 44.3°F (45% F
Humidity 27.8 grains/lb

Room Air
(to be exhausted)
Dry Bulb 72°F
Wet bulb 55.9°F (35% F
Humidity 41 grains/lb.

Outdoor Air
Dry Bulb 0°F
Wet bulb -1°F
Humidity 3.9 grains/lb.

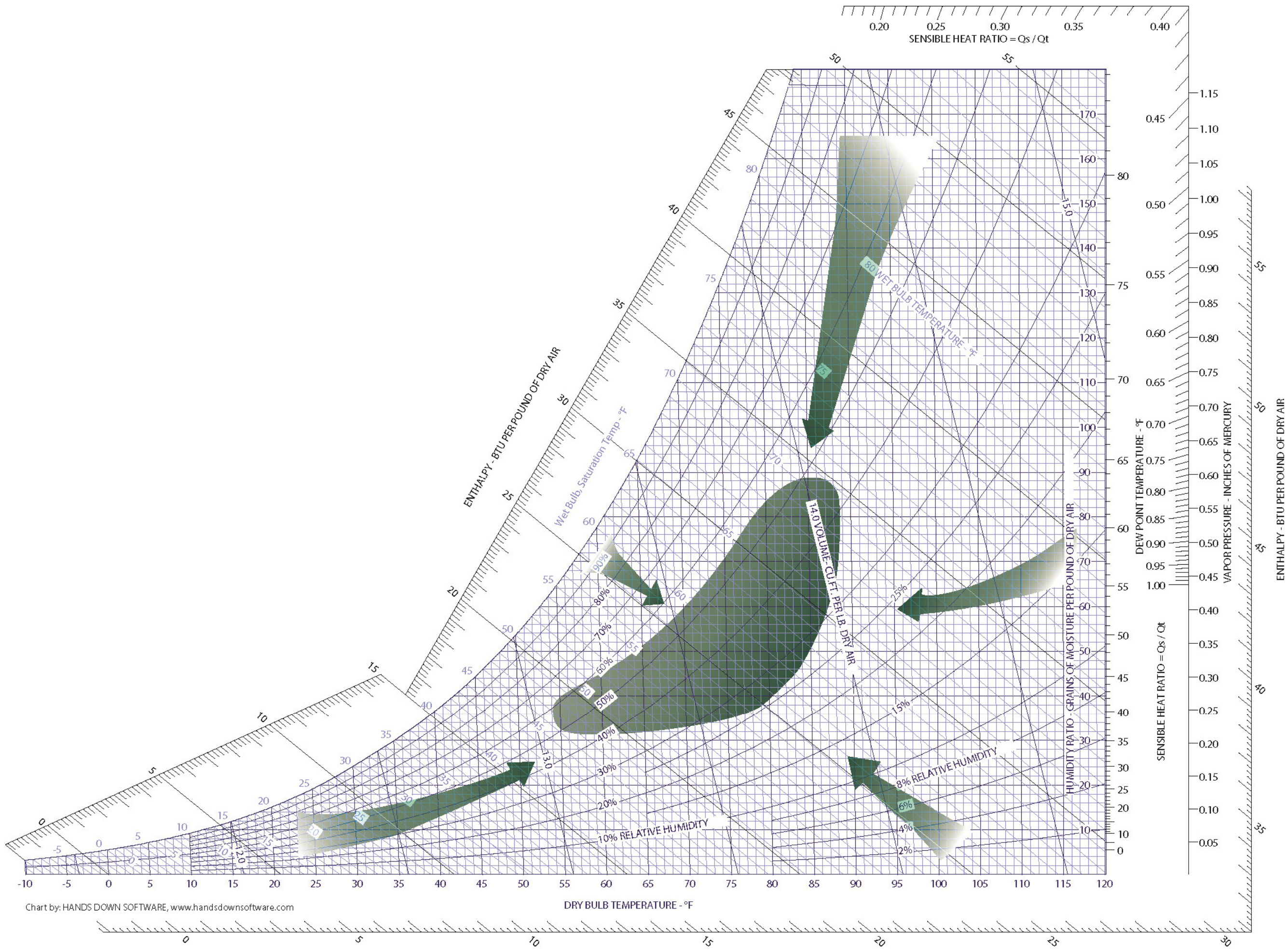
Exhaust Air
Dry Bulb 18°F
Wet bulb 15.8F°
Humidity 9.3 grains/lb.

Winter Wheel Operation

Energy Recovery
Benefits

- Reduces OA cooling load by 3 - 4 tons per 1,000 CFM
- Reduced heating and cooling energy consumption
- Reduced variability in air conditions entering the cooling coil

Reduced Variability



Designing Efficient Outdoor Air Systems

Energy Recovery
Benefits

- Reduces OA cooling load by 3 - 4 tons per 1,000 CFM
- Reduced heating and cooling energy consumption
- Reduced variability in air conditions entering the cooling coil
- Conforms with ASHRAE Standard 90.1-2010 and IECC 2012

ASHRAE 90.1-2007

"Energy Standard for Buildings"

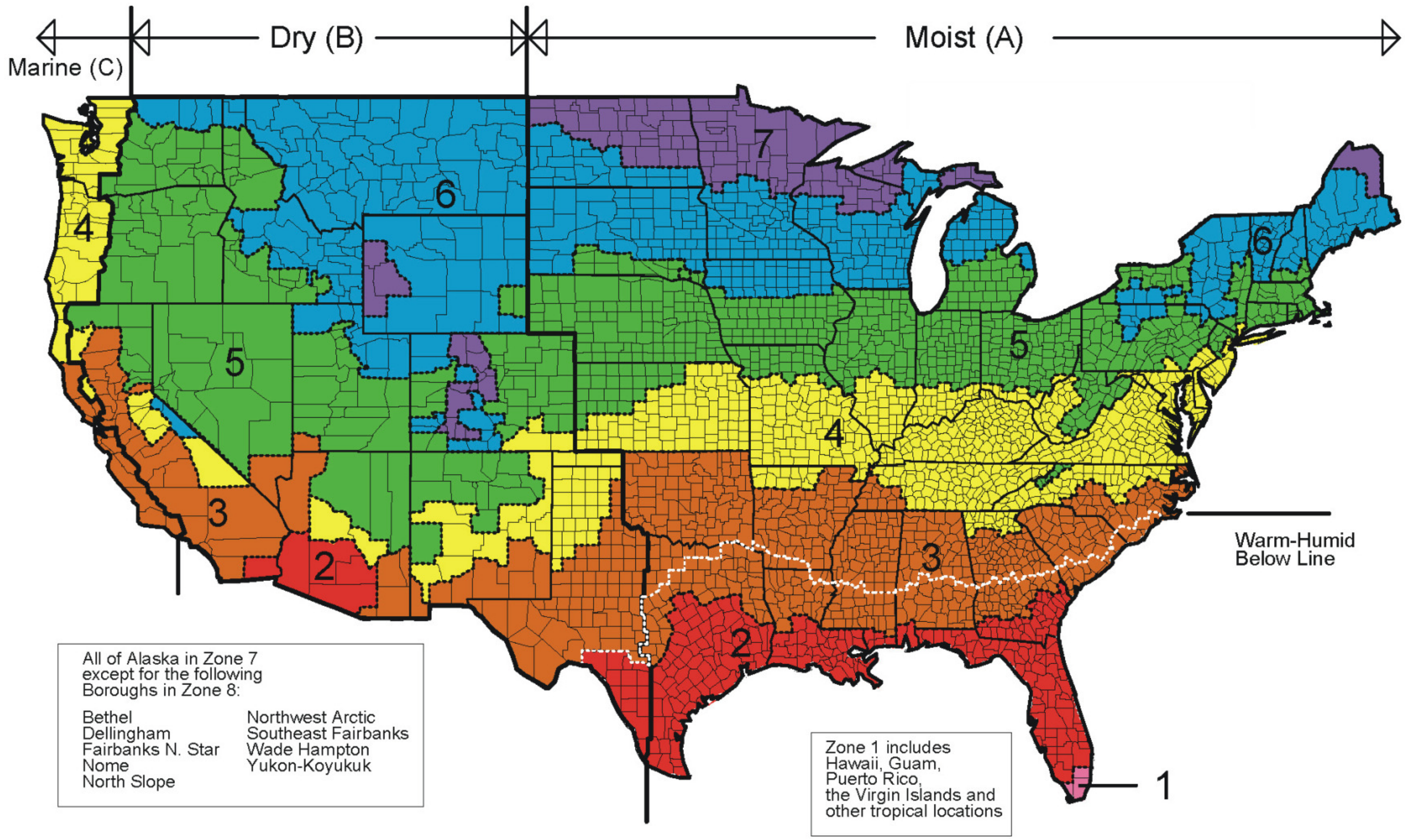
- Exhaust air energy recovery (6.3.6)
  - Supply air is greater than 5,000 CFM
  - 70% or more of supply is outdoor air (3,500 CFM)
- Energy recovery system shall have a total effectiveness of greater than 50%

2009 IECC →

503.2.6 Energy recovery ventilation systems. Individual fan systems that have both a design supply air capacity of 5,000 cfm (2.36 m^3/s) or greater and a minimum outside air supply of 70 percent or greater of the design supply air quantity shall have an energy recovery system that provides a change in the enthalpy of the outdoor air supply of 50 percent or more of the difference between the outdoor air and return air at design conditions. Provision shall be made to bypass or control the energy recovery system to permit cooling with outdoor air where cooling with outdoor air is required.

- ASHRAE 90.1 – 2010 has energy recovery requirements base on geographic location → Language adopted in IECC 2012

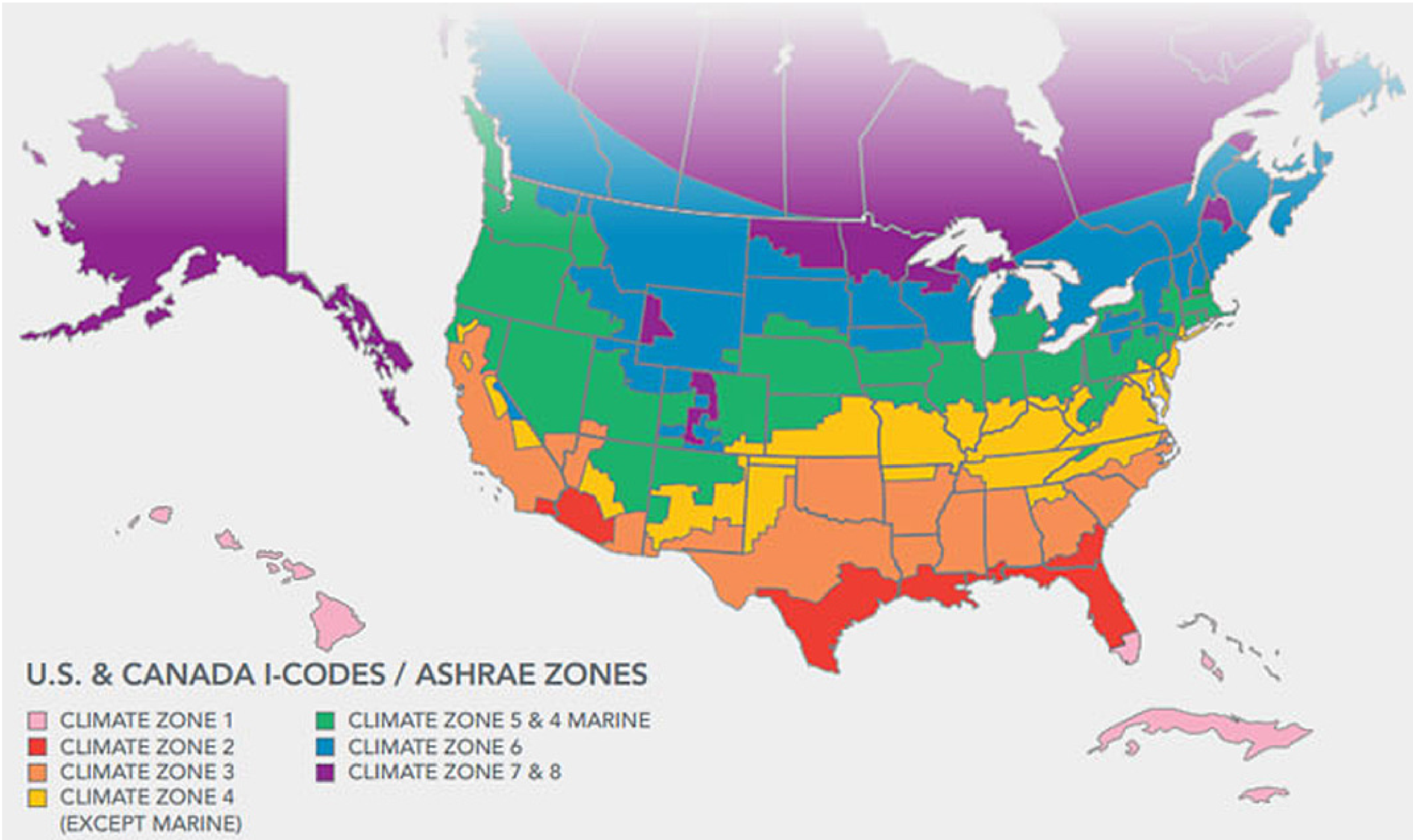
ASHRAE Climate Zones



ASHRAE

Designing Efficient Outdoor Air Systems

ASHRAE Climate Zones
Canada Zones 6, 7, 8



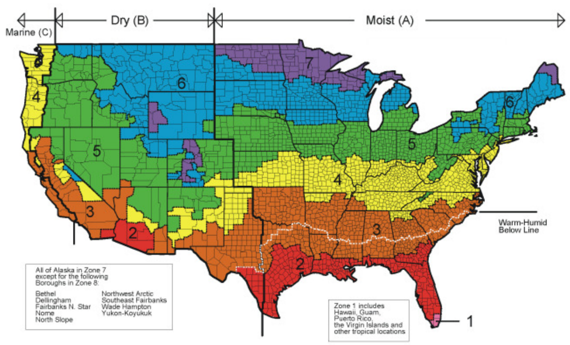
ASHRAE

ASHRAE 90.1-2010

Table 6.5.6.1 Energy Recovery Requirement (IP)

Zone	Percentage of Outdoor Air at Full Design Airflow Rate (cfm)					
	30% ≤ 40%	40% ≤ 50%	50% ≤ 60%	60% ≤ 70%	70% ≤ 80%	≥ 80%
	Design Supply Fan Airflow Rate (cfm)					
3B, 3C, 4B, 4C, 5B	NR	NR	NR	NR	≥ 5,000	≥ 5,000
1B, 2B, 5C	NR	NR	≥ 26,000	≥ 12,000	≥ 5,000	≥ 4,000
6B	≥ 11,000	≥ 5,500	≥ 4,500	≥ 3,500	≥ 2,500	≥ 1,500
1A, 2A, 3A, 4A, 5A, 6A	≥ 5,500	≥ 4,500	≥ 3,500	≥ 2,000	≥ 1,000	≥ 0
7, 8	≥ 2,500	≥ 1,000	≥ 0	≥ 0	≥ 0	≥ 0

NR = Not recommended



Energy recovery device must be at least <u>50%</u> effective!

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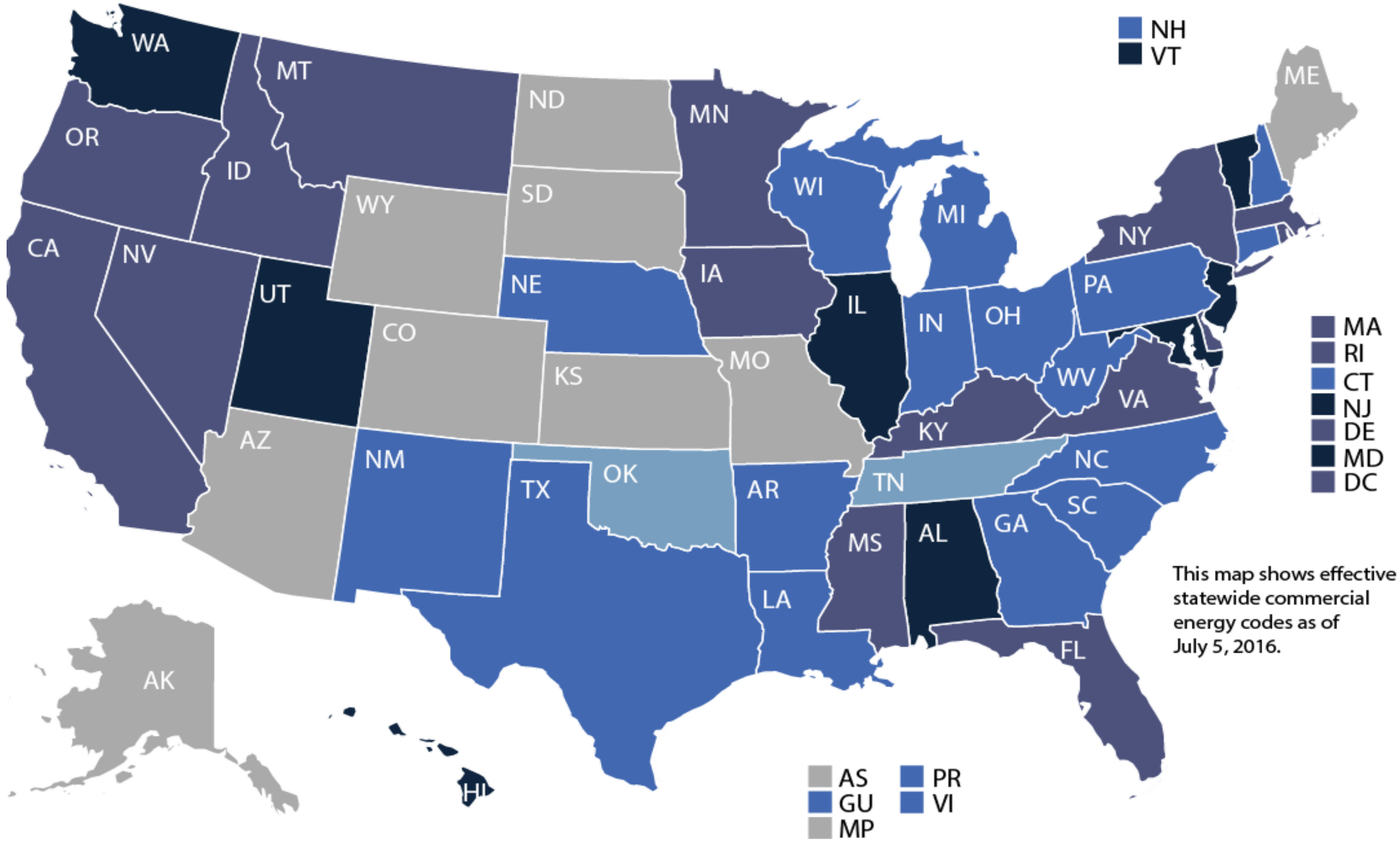
Designing Efficient Outdoor Air Systems

ASHRAE 90.1–2010 / IECC 2012

- IECC C403.2.1 – *"Heating and cooling loads shall be adjusted to account for load reductions achieved where energy recovery systems are required.*
- IECC C403.2.6 – *"Where an air economizer is required, the energy recovery shall include a bypass or controls to permit economizer operation where required"*

Market Trends

ASHRAE 90.1 Adoption by State (July 2016)



- Meets or exceeds **ASHRAE 90.1-2013** or equivalent (8)
- Meets or exceeds **ASHRAE 90.1-2010** or equivalent (16)
- Meets or exceeds **ASHRAE 90.1-2007** or equivalent (19)
- Meets or exceeds **ASHRAE 90.1-2004** or equivalent (2)
- No statewide code or predates ASHRAE 90.1-2004 (11)

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Designing Efficient Outdoor Air Systems

IECC 2012 Exceptions

As it applies to Energy Recovery

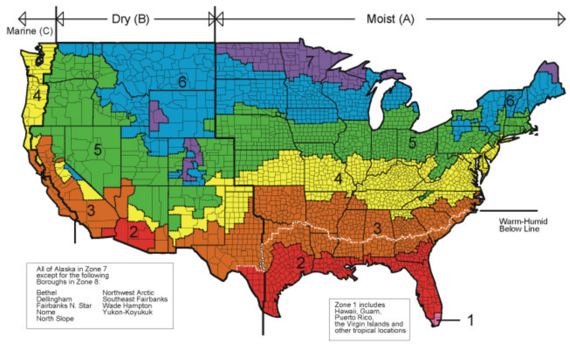
- Exceptions:
  - Lab exhaust, kitchen exhaust, make-up air for process exhaust, spaces heated to less than 60F
  - Cooling energy recovery in climate zones 3C, 4C, 5B, 5C, 6B, 7, 8
  - Heating energy recovery in zones 1 and 2

ASHRAE 189.1

Standard for Design of High-Performance Green Buildings
www.ashrae.org/greenstandard

Table 7.4.3.8 Energy Recovery Requirement (IP)

ZONE	% Outdoor Air at full design airflow rate (cfm)							
	10% ≤ 20%	20% ≤ 30%	30% ≤ 40%	40% ≤ 50%	50% ≤ 60%	60% ≤ 70%	70% ≤ 80%	≥ 80%
	Design Supply Fan airflow rate (cfm)							
3B 3C 4B 4C 5B	NR	NR	NR	NR	NR	NR	≥ 5,000	≥ 5,000
1B 2B 5C	NR	NR	NR	NR	≥ 26,000	≥ 12,000	≥ 5,000	≥ 4,000
6B	NR	≥ 22,500	≥ 11,000	≥ 5,500	≥ 4,500	≥ 3,500	≥ 2,500	≥ 1,500
1A 2A 3A 4A 5A 6A	≥ 30,000	≥ 13,000	≥ 5,500	≥ 4,500	≥ 3,500	2,000	≥ 1,000	≥ 0
7 8	≥ 4,000	≥ 3,000	≥ 2,500	≥ 1,000	≥ 0	≥ 0	≥ 0	≥ 0



Energy recovery device must be at least 60% effective!

ASHRAE

Designing Efficient Outdoor Air Systems

Energy Recovery Economic Benefits

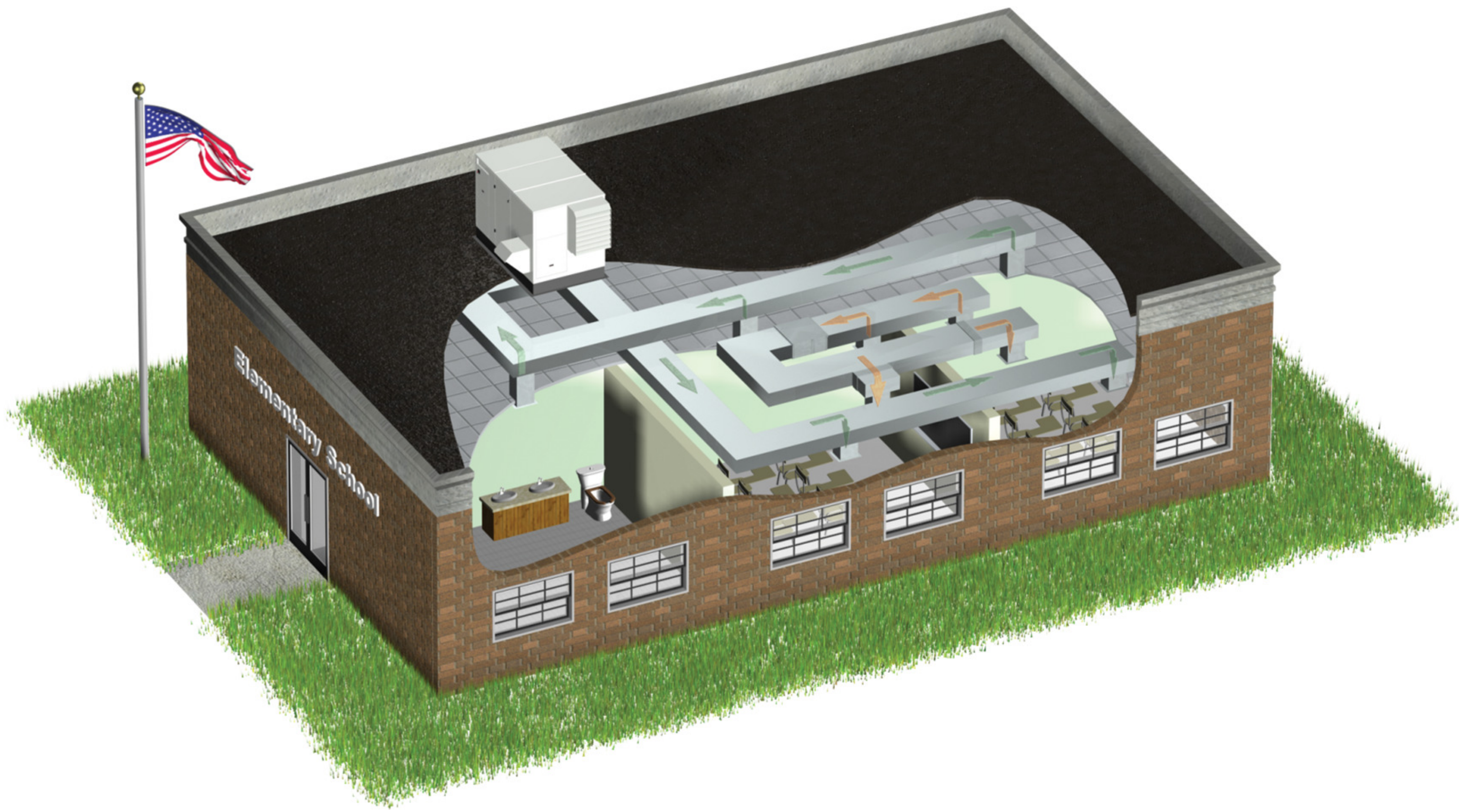
www.dsireusa.org

Tax incentives and utility rebates available by geography

Florida Power and Light reimburses $1 / CFM for ARI Certified Energy Recovery Applications

Outdoor Air Systems

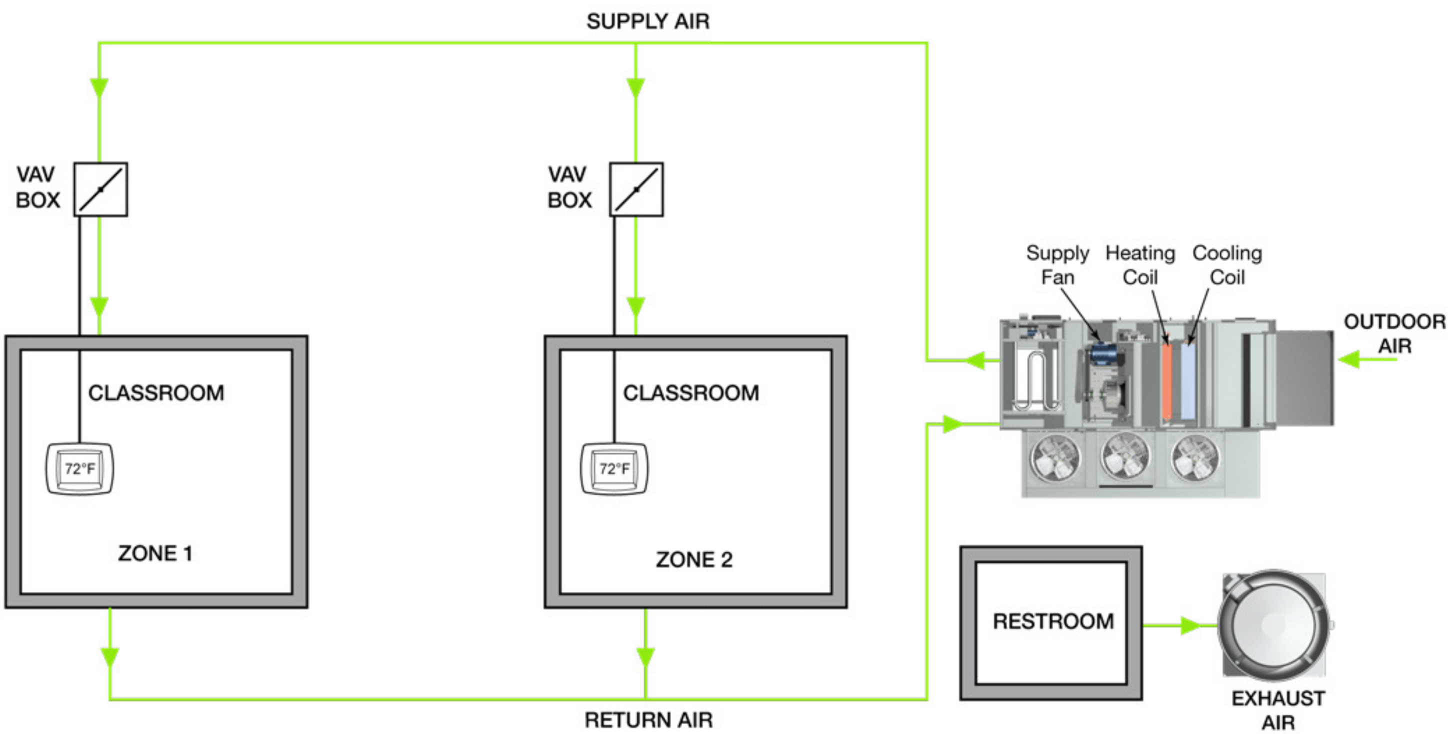
Multi-Space Applications



Multi-Space Applications

- Variable Air Volume (VAV)
- Dedicated Outdoor Air Systems (DOAS)
- DOAS with ERV

Variable Air Volume (VAV)



Key advantages

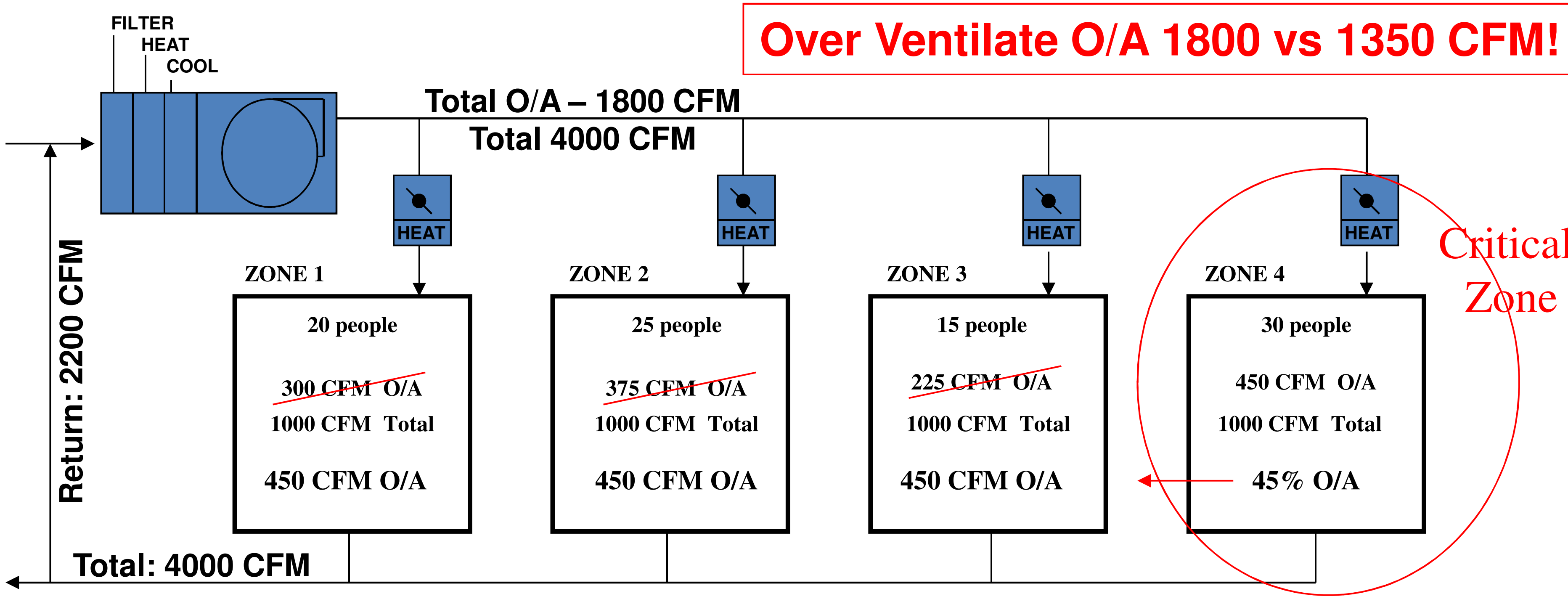
1. Fan power savings at part load
2. Familiarity / ease of design
3. Low first cost

System Design Considerations

1. Indirect humidity control
2. Difficult to prove ASHRAE 62 compliance
3. Potential for over-ventilation
4. Terminal Reheat Considerations

Variable Air Volume (VAV)

Over Ventilate O/A 1800 vs 1350 CFM!

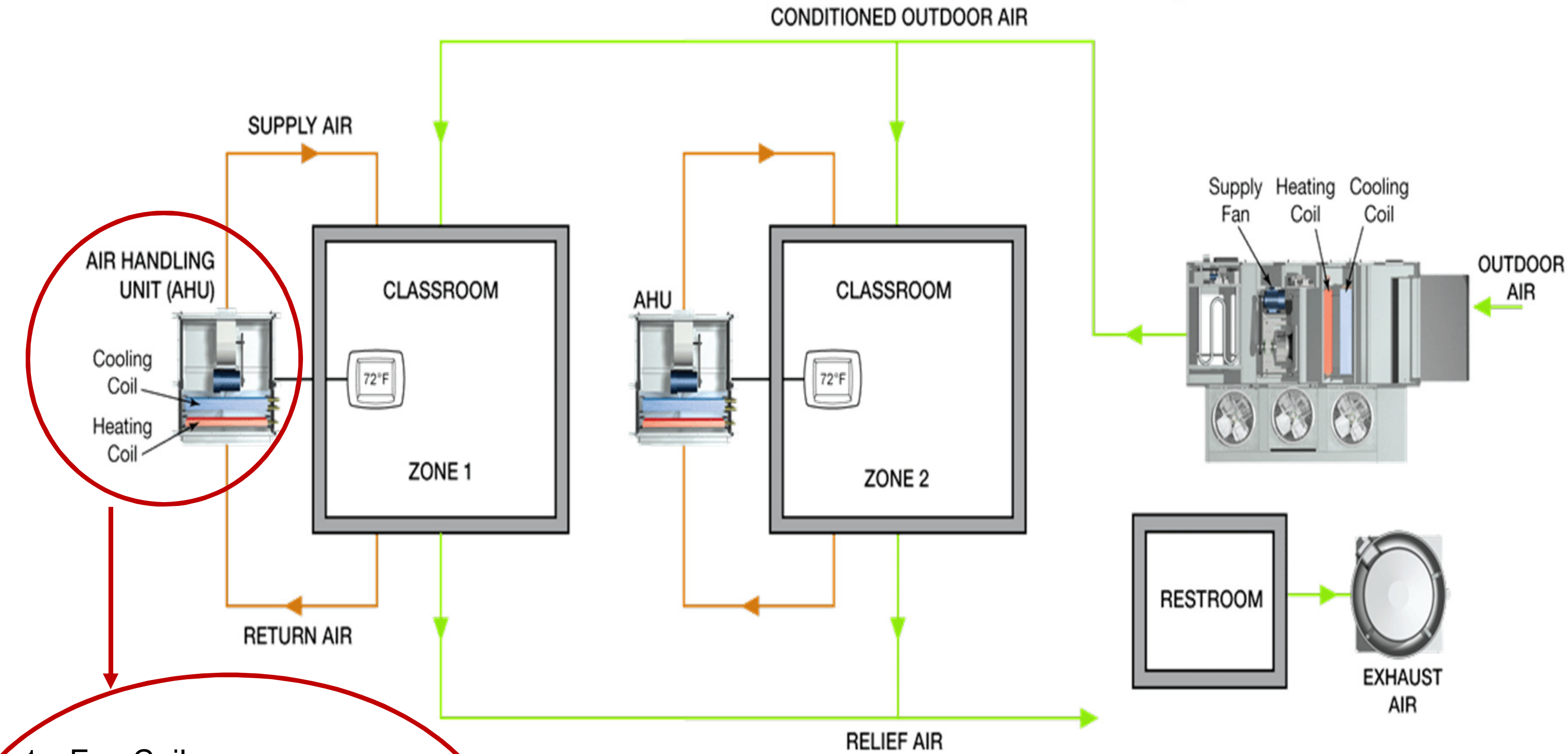


Each room load requires 1000 CFM
15 CFM / Person
O/A: 95/78; 41.5 B/#
Supply 55; 23.2 B/#
R/A: 75 & 50%; 28.1B/#
Mixed Air: 83.2/69.5°F; 33.6 B/#

Total Tons= (4000 x 4.5 x (34.1-23.2))/12000
= <u>16.4</u>

O/A Tons = 1800 x 4.5 x (41.5-23.2)/12000
=<u>12.4</u>

Dedicated Outdoor Air System

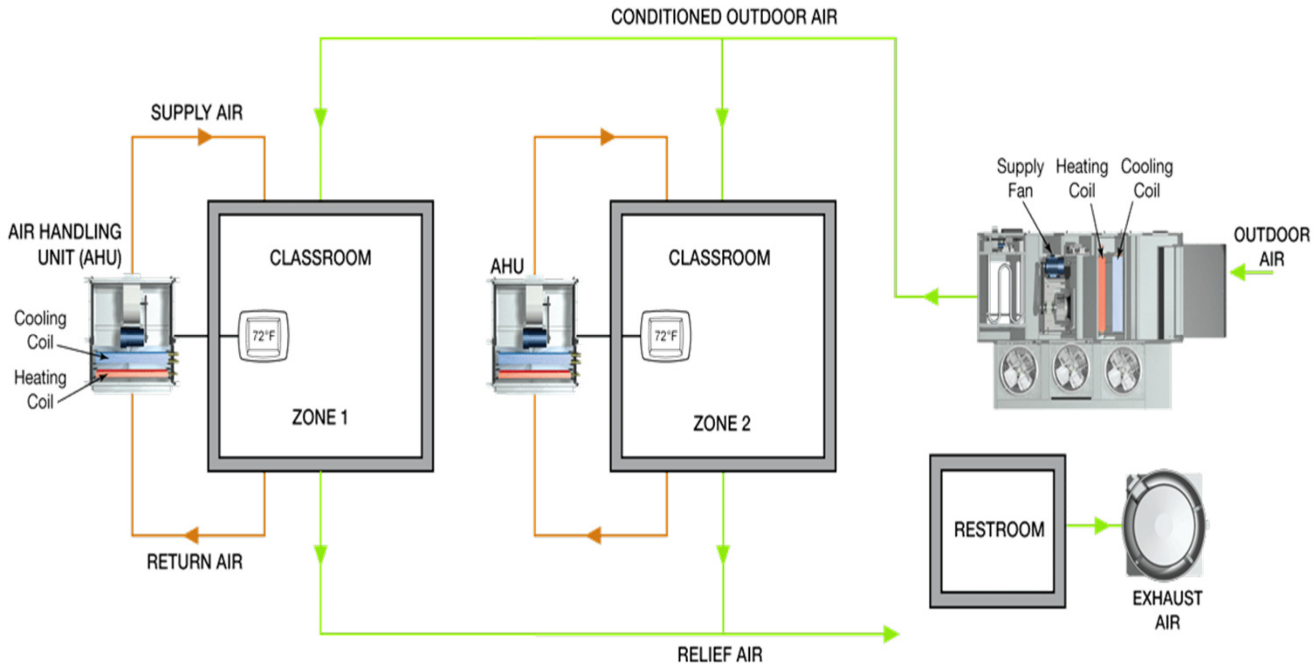


1. Fan Coil
2. Water-source heat pump
3. PTAC
4. Small packaged units
5. Radiant cooling panels
6. VRV Multi-splits

ASHRAE

Designing Efficient Outdoor Air Systems

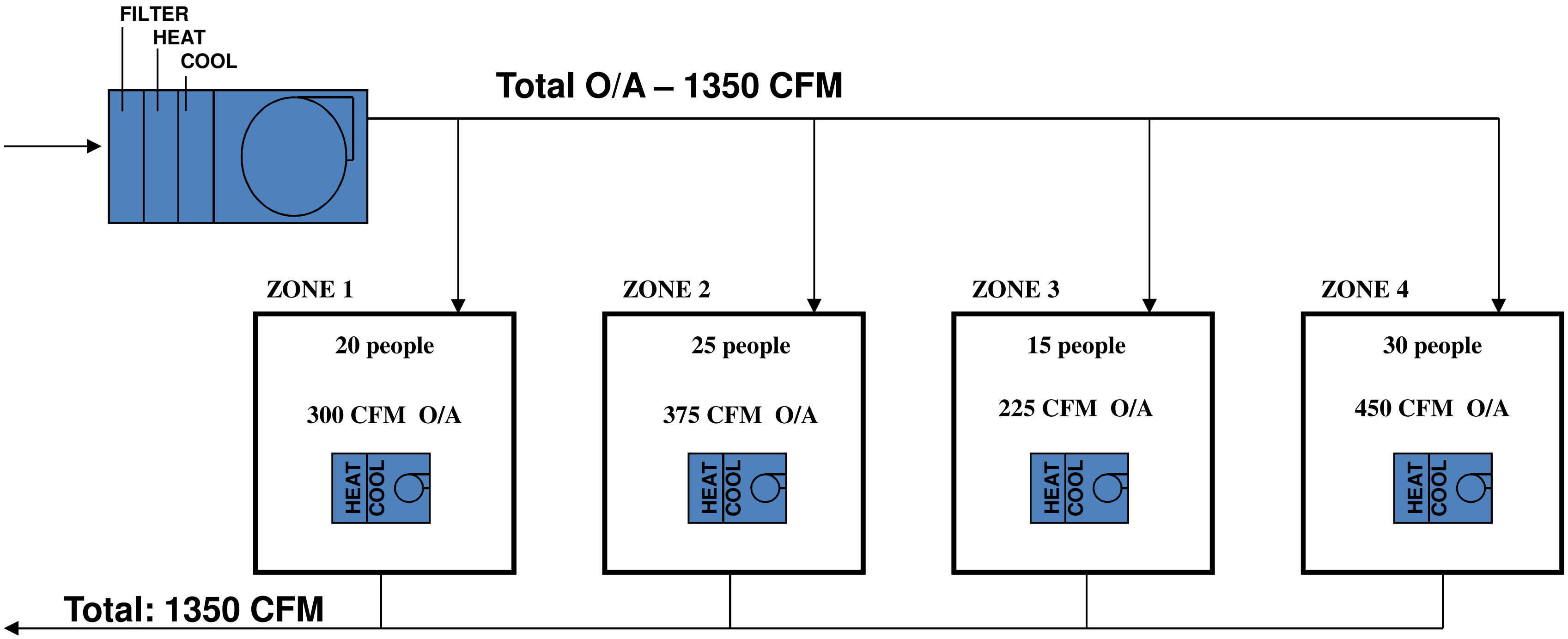
Dedicated Outdoor Air System



DOAS Advantages
1. Direct humidity control
   - Sensible and latent loads are de-coupled
2. Eliminates potential for over-ventilation
3. Easy to prove ASHRAE 62 compliance
4. Minimal reheat required

DOAS Challenges
1. Requires two systems, one to condition OA another to condition individual zones
2. Potential for two sets of duct work
3. Less familiarity/potential higher first cost

Dedicated Outdoor Air System

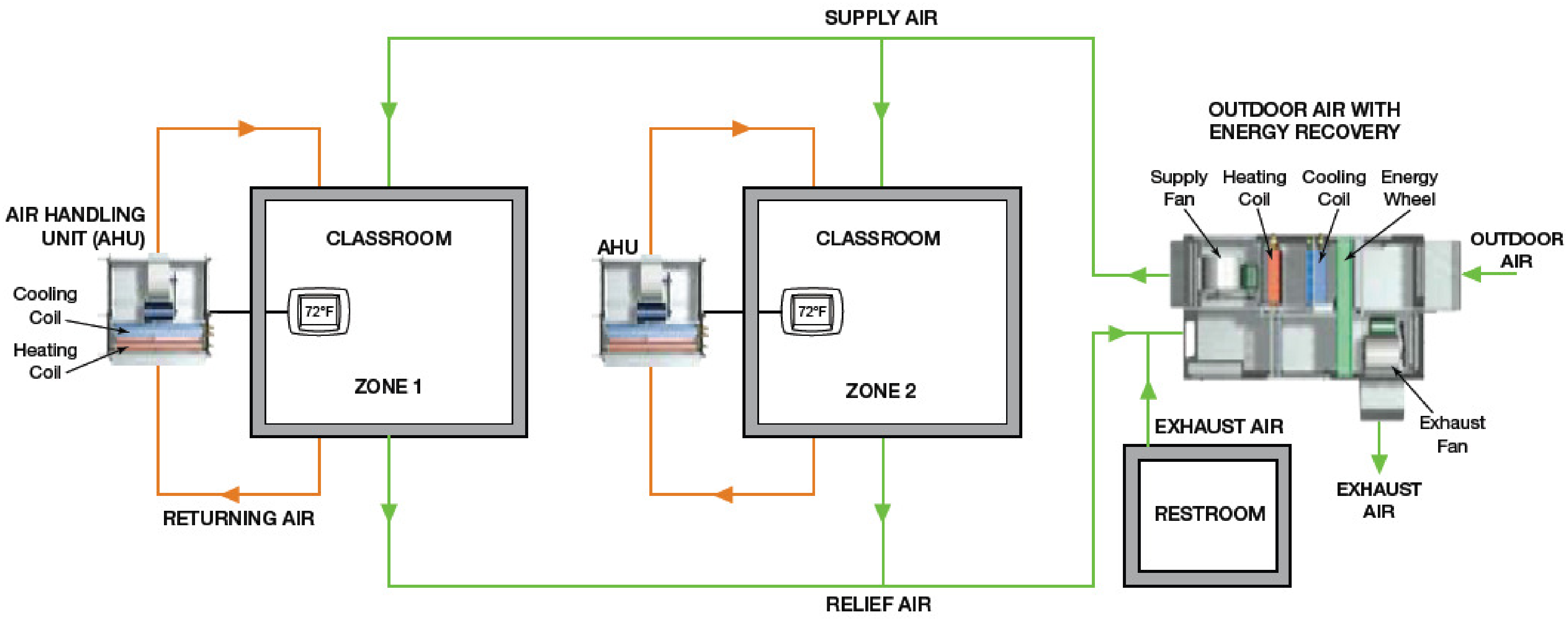


Each room load requires 1000 CFM
15 CFM / Person
O/A: 95/78; 41.5 B/#
Supply 55; 23.2 B/#
Space: 75 & 50%; 28.1B/#

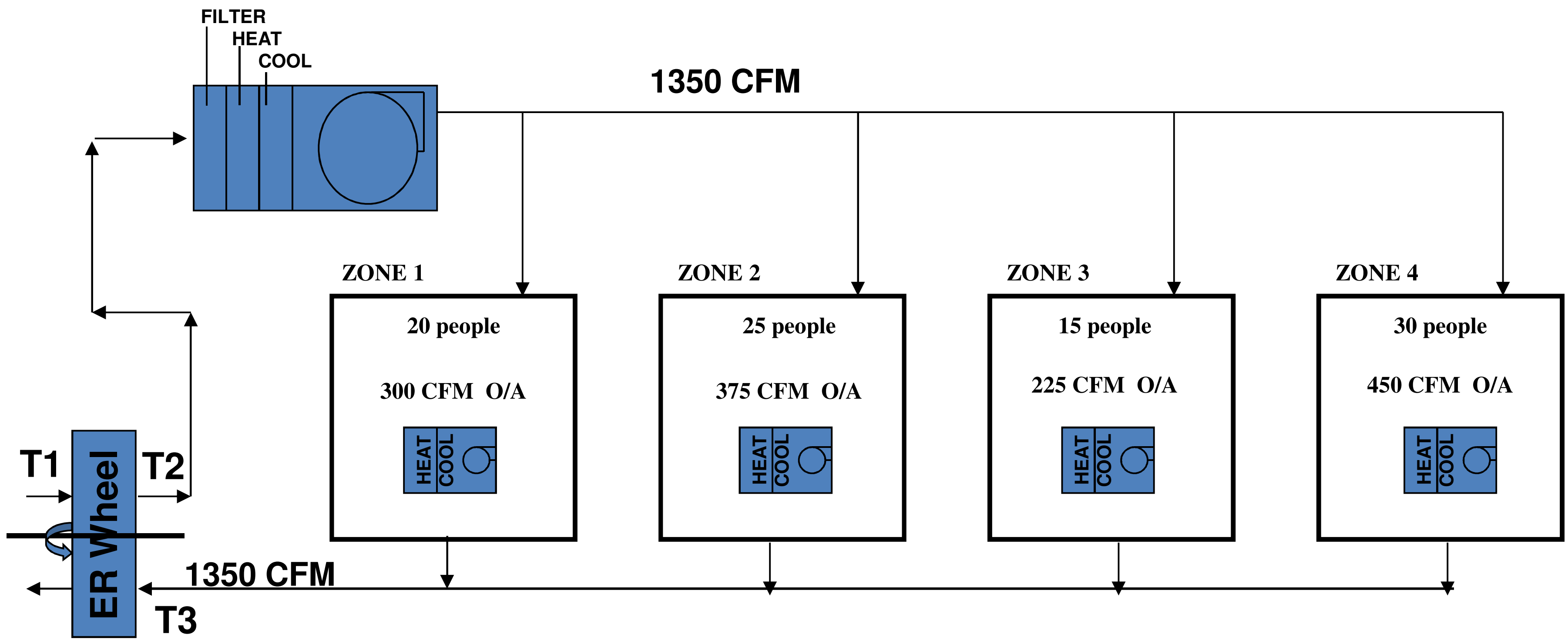
O/A Tons= (1350 x 4.5 x (41.5-23.2))/12000
= 9.3

vs. 12.4 Tons for VAV system!

DOAS with Energy Recovery



D O A S with ER



T1:O/A: 95/78; 41.5 B/#
T2: 80°F; 31.4 B/#
T3: 75°F; 50%
Supply 55°F; 23.2 B/#

O/ATons= (1350 x 4.5 x (31.4-23.2))/12000
= <u>4.2</u>

<u>vs. 9.3 tons for DOAS!</u>

DOAS Control Sequence

Basic Sequence

- Occupied mode
  - DOAS unit is delivering conditioned outdoor air to space
    - Optimum unit discharge dew point and temperature control
  - Local HVAC unit tempers air depending upon the sensible load in space
    - Room thermostat control

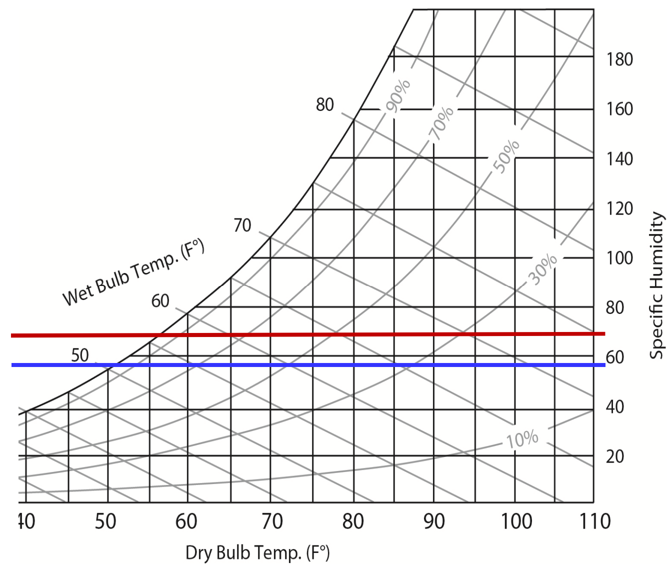
- Unoccupied mode
  - DOAS unit is OFF
  - Local HVAC unit cycles on / off to maintain space temperature

DOAS Cooling Design

DOAS System Leaving Air Dewpoint

- Outdoor air needs to remove outdoor air AND room latent load
  - If space needs to maintain 50% RH (55 dewpoint), outdoor air needs to be delivered at a dewpoint lower than desired space condition

Δ = humidity generated in the space



DOAS Design – Supply Air Dew Point

$$Q_{Latent} = 0.69 \times CFM_{OA} \times (W_{SP} - W_{CA})$$

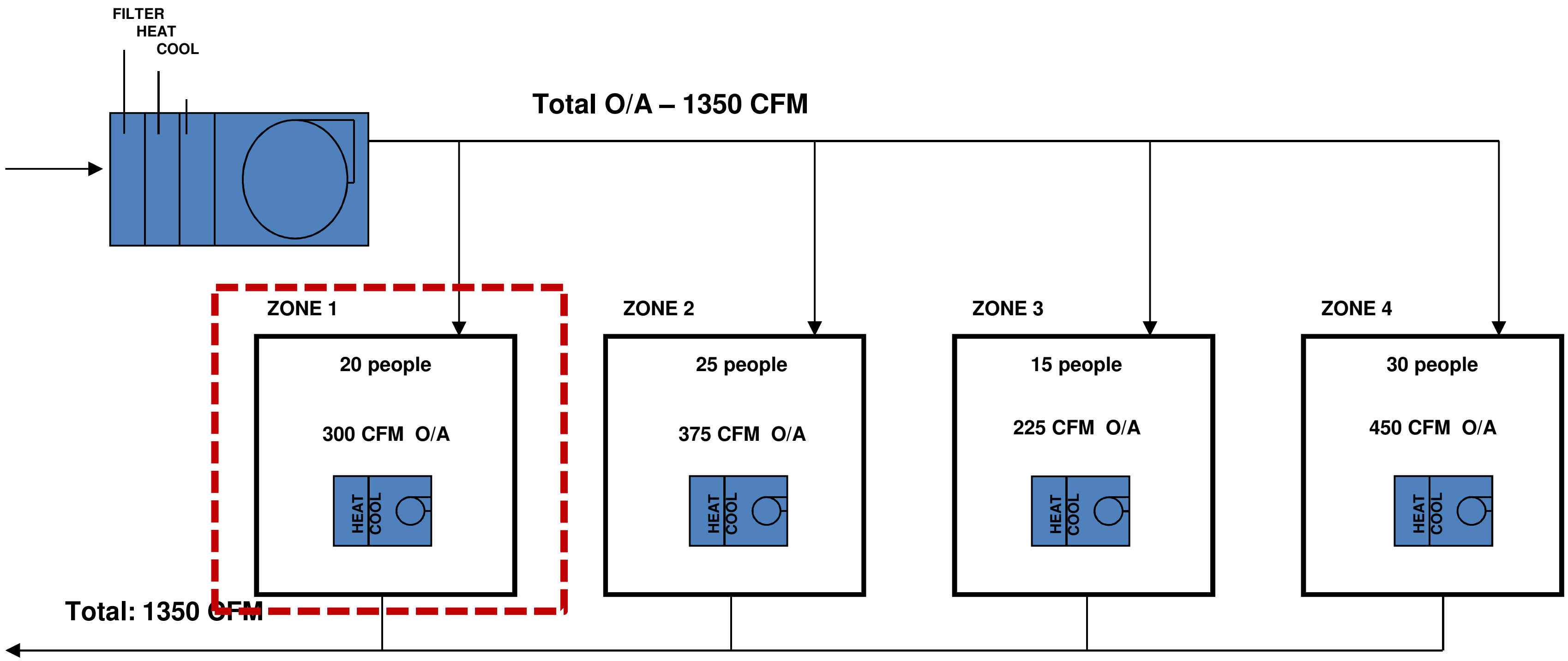
W_{CA} = Humidity Ratio of the Conditioned Air from DOAS

CFM_{OA} = Outdoor Air (required by ASHRAE)

W_{SP} = Humidity Ratio of the Space (ASHRAE suggest 60% RH max)

Q_{Latent} = Space latent load determined by ASHRAE Load Rates

Dedicated Outdoor Air System



Each room load requires 1000 CFM
15 CFM / Person
O/A: 95/78; 41.5 B/#
Supply 55; 23.2 B/#
Space: 75 & 50%; 28.1 B/#

DOAS Design – Latent Space Load

- ASHRAE Load Calculation
  - Classroom Example
    - Latent Load = 200 Btu/h / Person

	Space 1	Space 2	Space 3	Space 4
People	20	25	15	30
Airflow (CFM)	300	375	225	450
Q_{latent} (Btu/h)	4000	5000	3000	6000

DOAS Design – Supply Air Dew Point

- Calculate air conditions

$$Q_{Latent} = 0.69 \times CFM_{OA} \times (W_{SP} - W_{CA})$$

Space 1		
People	20	$Q_{Latent} = 0.69 \times CFM_{OA} \times (W_{SP} - W_{CA})$
Airflow (CFM)	300	$(4000) = 0.69 \times (300CFM) \times (72.9 - W_{CA})$
Q_{latent} (Btu/h)	4000	**W_{CA} = 53.6 GPP**
W_{SP} (GPP)	71.8	

Use humidity ratio to find dew point → 50.0˚F

DOAS Heating Design

DOAS Heating Leaving Air Temperature

- The DOAS unit shall discharge room neutral in heating
- Parallel systems shall handle the space sensible heating loads
- Oversizing heating can result in component cycling and poor discharge temperature control

How does Energy Recovery Impact Heating Control

- Ex. 4,000 CFM DOAS unit
  - 25°F Winter Design, 72°F RA, 75% Effective ER Device

Entering Outdoor Air Temp(°F)	Entering Furnace Temp (°F)
25	60.3
50	66.5
55	67.75
60	69
65	70.25

- What should the heating temperature rise be?
  - 20°F? 30°F? 40°F? 40+°F?
  - Do we size for a energy recovery device failure? 50°F?

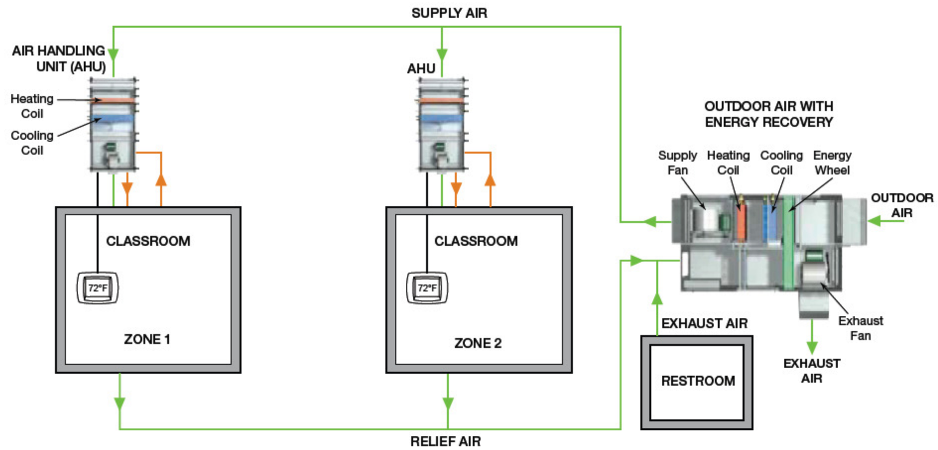
Maximizing Heating Control

- Energy recovery provides most of the heating capacity
- Most manufactures only provide staged or 4:1 modulating control on indirect gas furnaces
- With energy recovery to prevent component cycling 10+:1 should be utilized
- Furnace sized for 40°F temperature rise
  - 4:1 - 10°F minimum fire rate
  - 10:1 - 4°F Minimum fire rate
  - Prevents fluctuating discharge temperatures

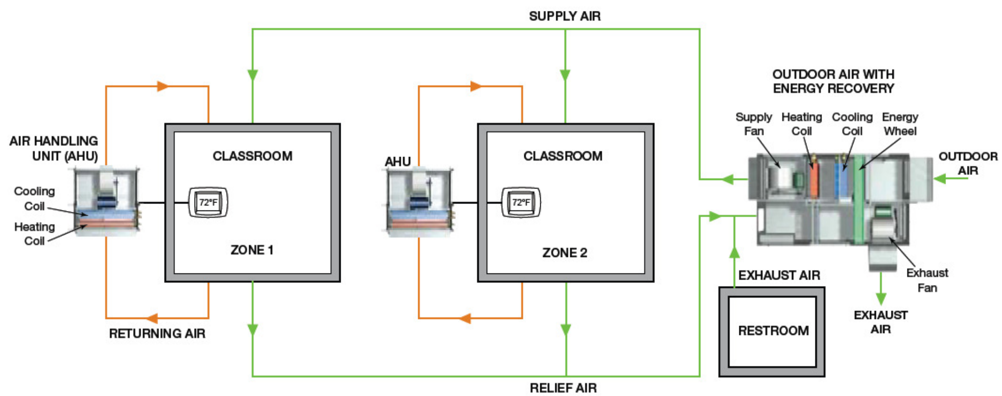
Outdoor Air Delivery

Outdoor Air Delivery Options

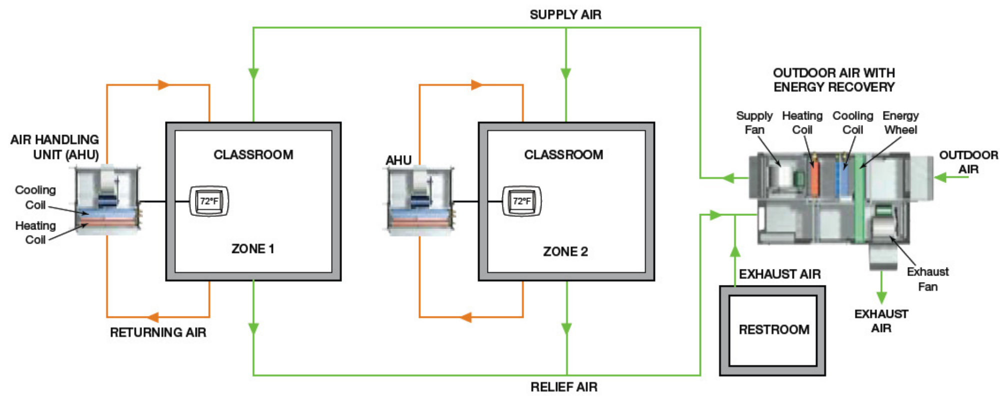
Directly to sensible unit



Directly to space



Directly to Space



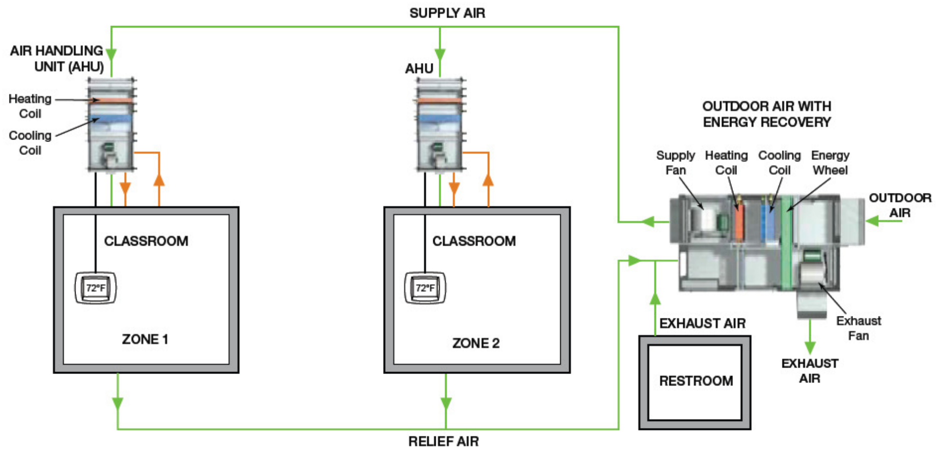
Advantages

- Fan savings during part load (sensible unit can be cycled on/off)
- Can operate DOAS unit during unoccupied without needing to run sensible unit
- Easy measurement of outdoor air

Drawbacks

- Requires additional duct work and diffusers
- May require multiple diffusers to properly disperse the OA

To Intake of Sensible Unit



Advantages

- Avoids cost and space to install additional duct work and separate diffusers
- Easier to ensure that OA is adequately dispersed throughout zone
- Little to no reheat should be required

Drawbacks

- Measurement and balancing of OA is more difficult
- Sensible unit fan must operate continuously to provide the OA during occupancy
- Sensible unit fan must operate if DOAS system operates during unoccupied period

Summary to Maximize DOAS Energy Savings

- Deliver conditioned outdoor air directly to the space
  - Easiest way to ensure proper outdoor air is being delivered
  - System is truly decoupled and provides significant part load energy savings

DOAS Cooling Efficiencies

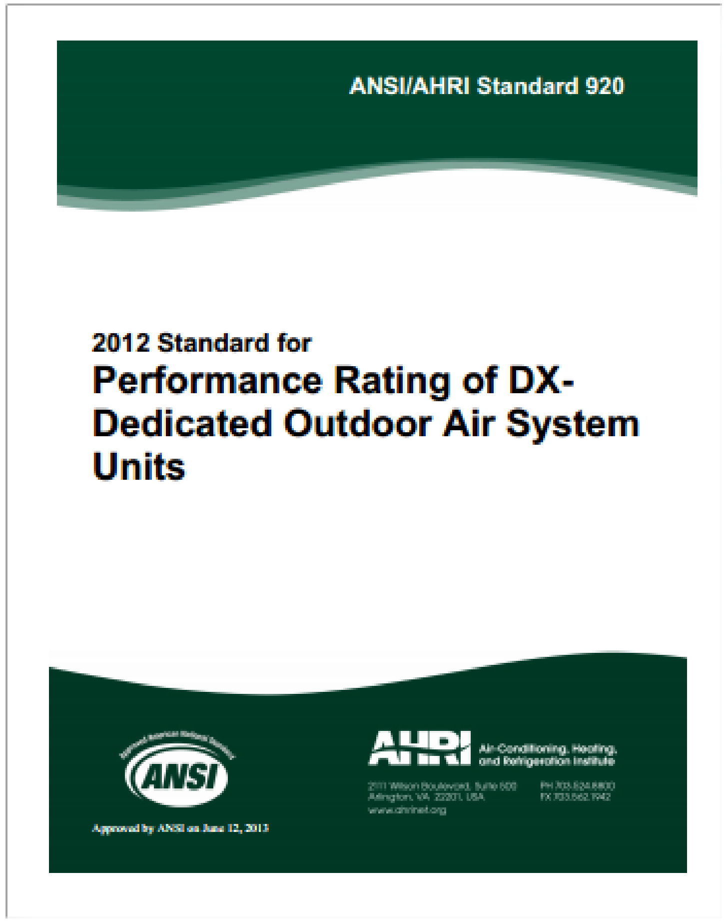
EER/IEER

- Calculated per AHRI 340/360 (Mbh/kW)
- EER calculated at a full load capacity with a 80°F/67°F at a 95°F ambient condition
- What type of unit runs at this condition?
  - Standard RTU's
- IEER is a weighted average at four different ambient conditions (95°F, 81.5°F, 68°F, and 65°F)
  - Entering coil condition always remains 80°F/67°F
  - Supply volume is reduced due to part load condition

The Challenge of EER/IEER

- Great rating for VAV standard RTU's
- Doesn't accurately represent 100% outdoor air units (DOAS)
- Doesn't account for the benefit of an energy recovery device
- When applied to a DOAS unit EER/IEER provides an inaccurate indication of energy efficiency

AHRI 920


ANSI/AHRI Standard 920

2012 Standard for

Performance Rating of DX-Dedicated Outdoor Air System Units

Approved by ANSI on June 12, 2013

Air-Conditioning, Heating, and Refrigeration Institute

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AHRI 920 & DX DOAS

- A dedicated OA unit “operate(s) in combination with a separate sensible cooling system to satisfy the entire building humidity load. The system is sized to maintain a prescribed ventilation rate under any load condition.”
- It may pre-condition outdoor air by containing a heat or energy recovery device
- It may reheat the ventilation air
- New performance metric – Integrated Seasonal Moisture Removal Efficiency (ISMRE)

AHRI 920 & DX DOAS

- Integrated Seasonal Moisture Removal Efficiency(MRE)

$$\text{ISMRE} = \frac{\textit{Moisture Removed (lbs/hr)}}{\textit{Total Power Input (kW)}}$$

- Used instead of EER (AHRI 340/360)
- Can be used with and without energy recovery

AHRI 920/ISMRE

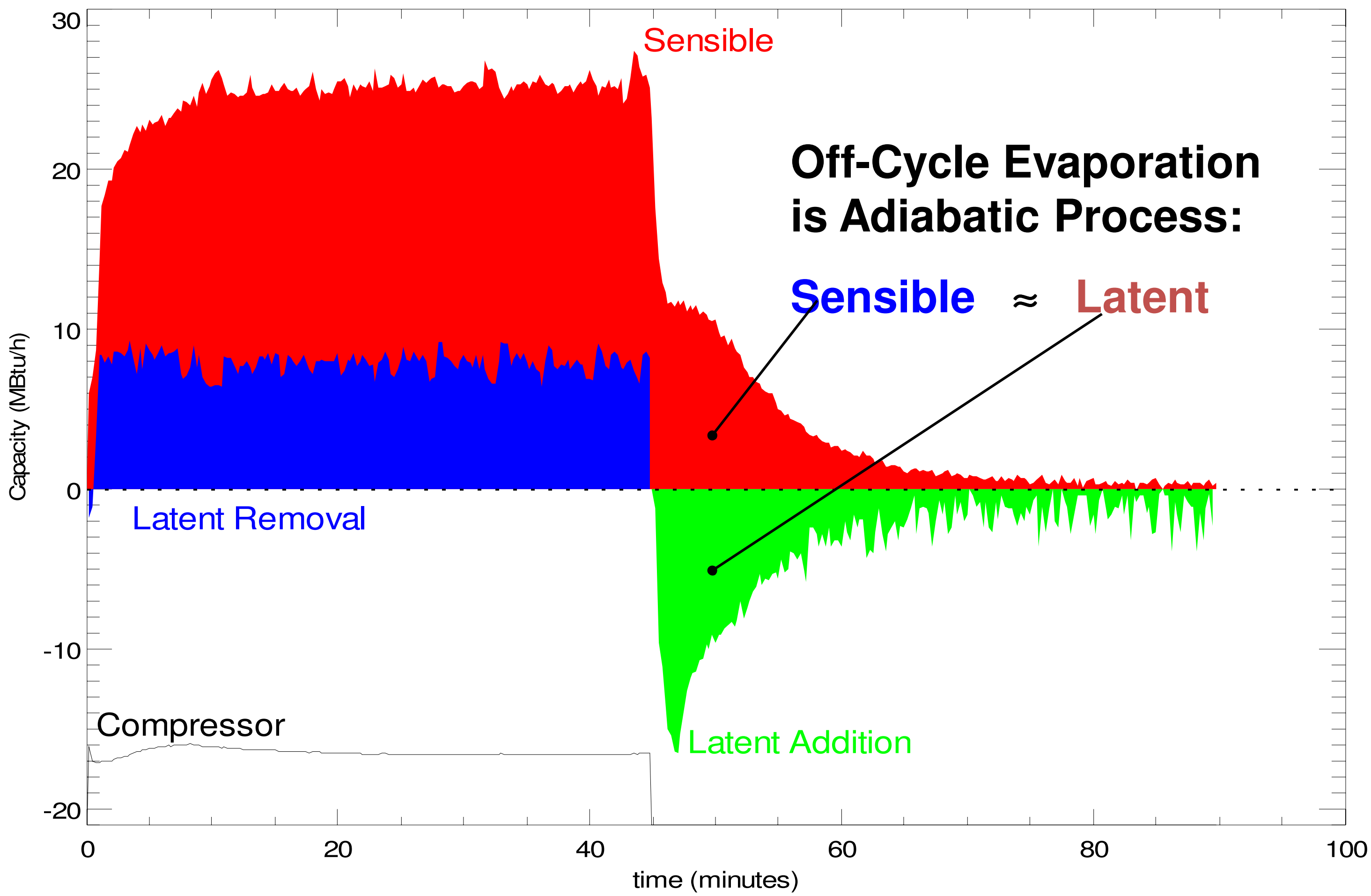
- Ratings have been adopted into ASHRAE 90.1
- Enters 90.1-2013 as an addendum
- Provides a true measurement for DOAS performance

DOAS Enhancements

Controlling Humidity

Sequence of Operation

Controlling Humidity

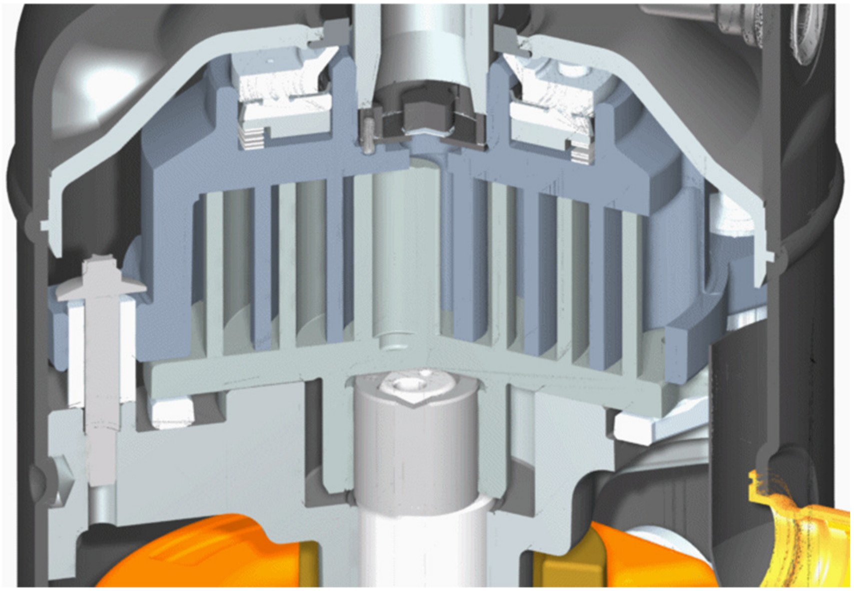


Shirley III, Don and Henderson Jr., Hugh (2004, April) Dehumidification at Part Load, ASHRAE Journal p. 42

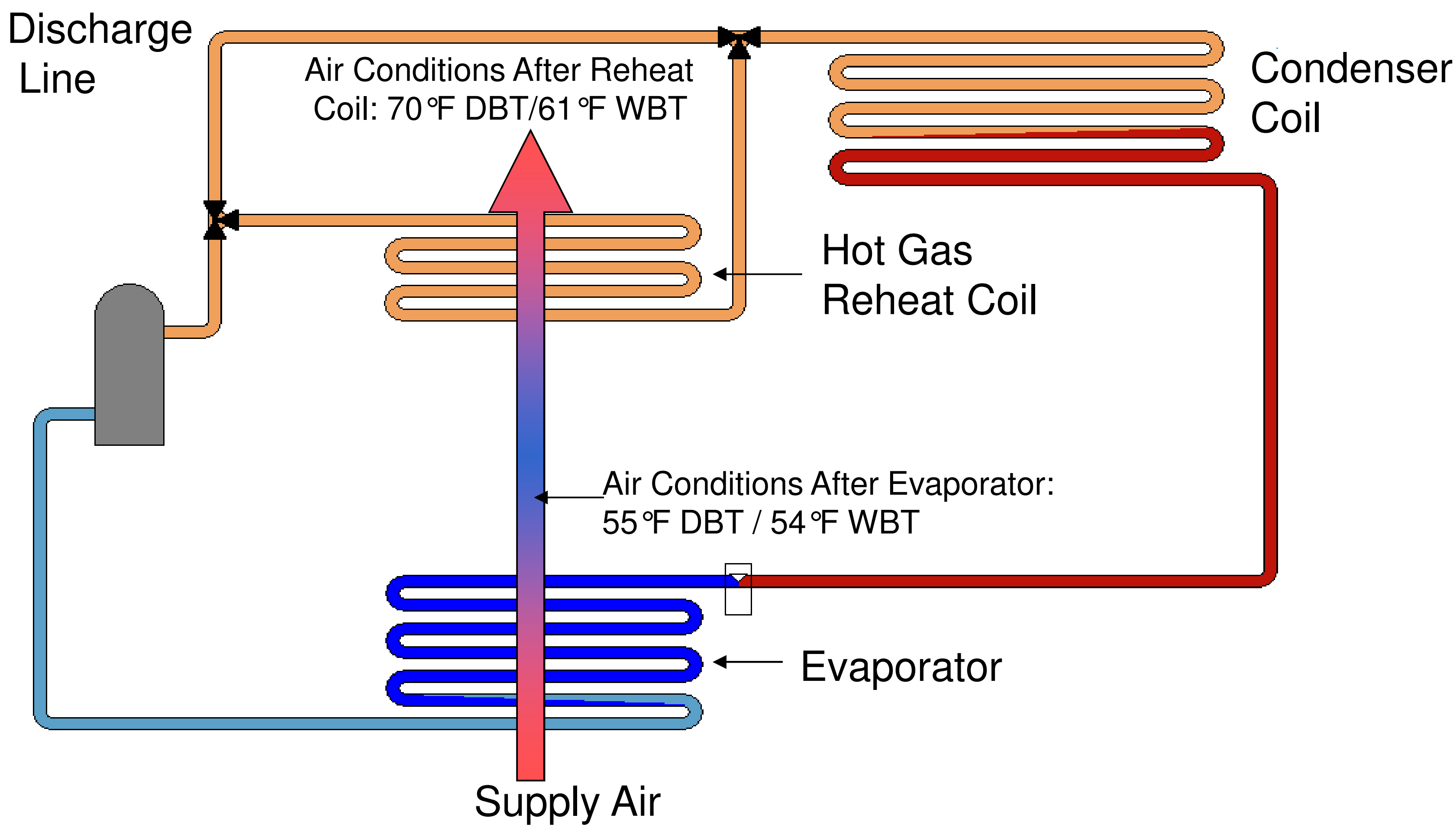
Digital Scroll Compressors

- Ability to adjust compressor output between 10% and 100% of capacity
- Provides tight leaving coil temperature control
- Reduces compressor cycling
  – Longer cycle times reduce wear

Efficiency gains over HGBP



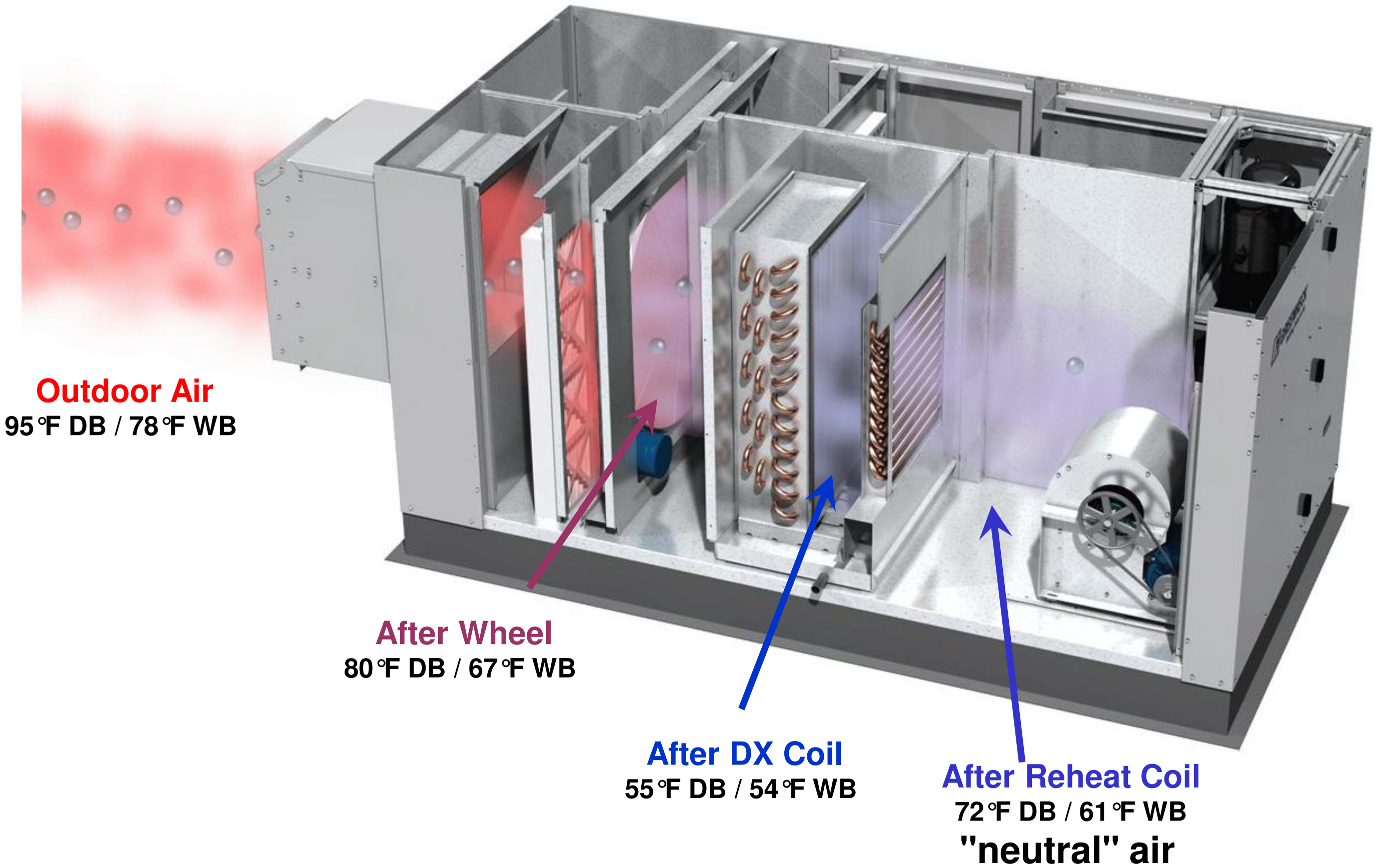
Modulating Hot Gas Reheat



ASHRAE

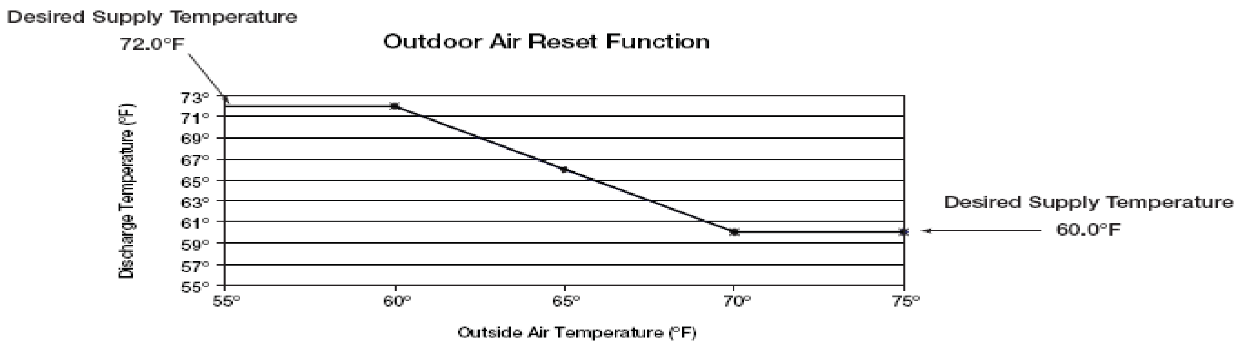
Designing Efficient Outdoor Air Systems

Modulating Hot Gas Reheat



Control Sequence
Cold Air Vs. Neutral Air Delivery

- Employ controls strategies to maximize the sensible cooling from the DOAS unit.
  - Control sequences like outdoor air resets are easy ways to maximize DOAS sensible cooling during part load days
    - No reheat on design days to aid the parallel systems
    - Reheat on shoulder days to prevent overcooling
  - Use BMS system to monitor room conditions and adjust DOAS leaving supply air temperatures



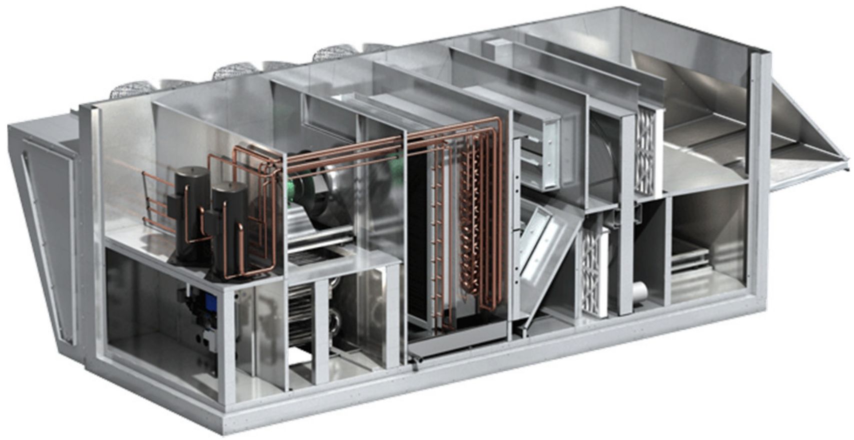
Other Technologies

- Inverter Compressors
  - Variable Speed Compressors For Modulation
    - Energy Savings At Part Load
    - Can Be Used With Single Circuit Units
    - BHP Reduction Compared To Staging Compressors
  - Service Industry Is Learning
    - Learning Curve Similar To Advent Of Digital Scroll Compressors
    - Service Contracts With New Equipment Purchase Desirable
  - Hard Trends In HVAC Industry
    - Inverter Technology Development
    - Increased Energy Efficiency Regulation
    - What Will We See In Five Years…

Ten Years – Twenty Years?

HVAC Industry Is Ever Changing!

Thank You For Your Time!
Questions?



Designing Energy Efficient Outdoor Air Systems

Thank You!