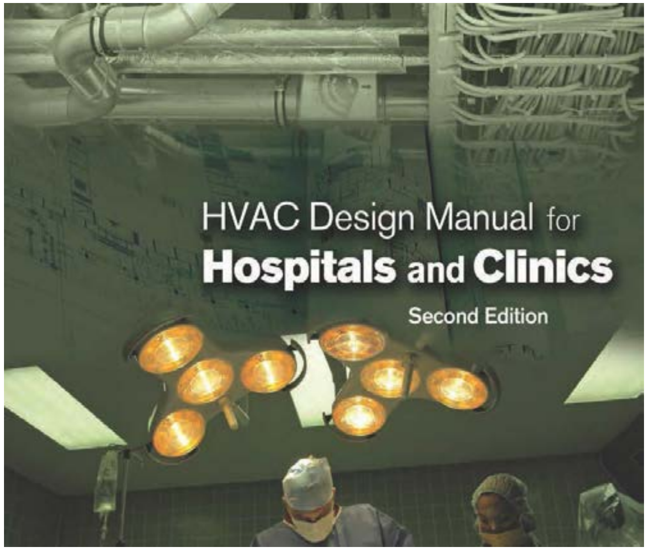
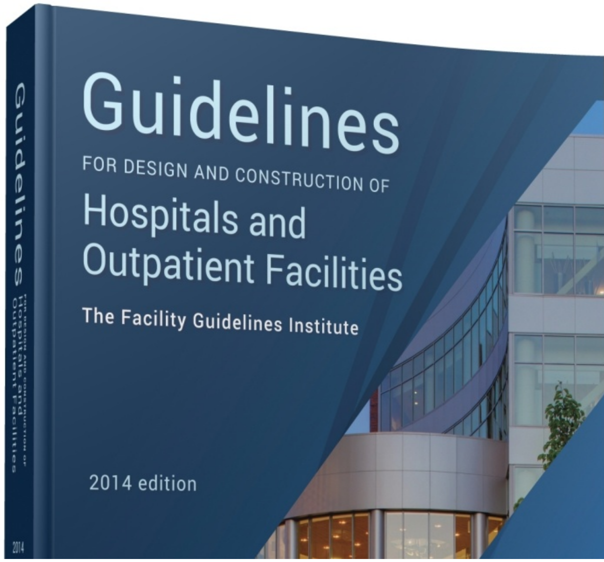




Balancing Energy & Performance in Healthcare

Dan Koenigshofer, PE, MSPH, HFDP, SASHE
Dewberry Engineers Inc.
Raleigh, NC - November 12, 2014

Elements of HPHC HVAC Systems

1. Performance – Infection Control, Comfort, Patient Outcome
2. Safety – Fire, falls, injuries – employees, visitors, patients
3. Reliability – Lost Revenue
4. Maintenance Cost
5. Energy Cost
6. Sustainability

IN THIS ORDER!!

Element #1 – Infection Control

“A great hospital engineer understands airborne infection and psychrometrics.”

Dan Koenigshofer

ASHRAE S-170 - The Bible

Function of Space	Pressure Relationship to Adjacent Areas (n)	Minimum Outdoor ACH	Minimum Total ACH	All Room Air Exhausted Directly to Outdoors (j)	Air Recirculated by Means of Room Units (a)	Design Relative Humidity (k), %	Design Temperature (l), °F/°C
SURGERY AND CRITICAL CARE							
Operating room (Class B and C) (m), (n), (o)	Positive	4	20	NR	No	20-60	68-75/20-24
Operating/surgical cystoscopic rooms, (m), (n) (o)	Positive	4	20	NR	No	20-60	68-75/20-24
Delivery room (Caesarean) (m), (n), (o)	Positive	4	20	NR	No	20-60	68-75/20-24
Substerile service area	NR	2	6	NR	No	NR	NR
Recovery room	NR	2	6	NR	No	20-60	70-75/21-24
Critical and intensive care	NR	2	6	NR	No	30-60	70-75/21-24
Intermediate care (s)	NR	2	6	NR	NR	max 60	70-75/21-24
Wound intensive care (burn unit)	NR	2	6	NR	No	40-60	70-75/21-24
Newborn intensive care	Positive	2	6	NR	No	30-60	70-75/21-24
Treatment room (p)	NR	2	6	NR	NR	20-60	70-75/21-24
Patient Room	NR	2	4	NR	NR	30-60	70-75/21-24

ASHRAE Learning Institute

Excerpt: ASHRAE Standard 170-2013

Hospital Acquired Infections – Cost

- HAI ~$30-$45 Billion/yr, ~ 2 mil cases
  - ✓ Top 5 HAI’s
    - Pneumonia ~ $28,508 per case
    - Bloodstream (central line) ~$29,156 per case
    - Surgical site ~$34,670 per case
    - Gastrointestinal (C. difficile & MRSA) ~$9,124
    - Urinary Tract ~$1007 per case
- Average cost of a Hospital Acquired Infection ~$25,903
- ~$500 Million/yr are airborne

Scott, R.D., II. *The Direct Medical Costs of Healthcare-Associated Infections in U.S. Hospitals and the Benefits of Prevention*. U.S. Centers for Disease Control and Prevention, March 2009.

Science of Infection, Qualitative

$$\text{Infection} = \frac{\text{Dose x Site x Virulence x Time}}{\text{Level of Host Defense}}$$

How People Get Infected

- Inhalation
- Deposition of particles in air esp. skin
- Contact w/ surfaces and other people
- Insects
- “Contact” Exposure (< 6’) to sneezes and coughs, per CDC

How HVAC Systems Reduce Airborne Infections

- Air Change Rates to reduce residence time (dilution)
- Filtration to remove microbes
- UV to kill microbes & prevent growth
- Pressurization to move air – clean → dirty
- Temperature and humidity to reduce propagation
- Exhaust to remove
- Air Distribution to reduce deposition and dispersion
- Pressurize entire building – reduce infiltration

Dilution (Fly in Room)

ACH	Minutes required for removal of 99%	Minutes required for removal of 99.9%
2	138	207
4	69	104
6	46	69
8	35	52
10	28	41
12	23	35
15	18	28
20	14	21
50	6	8

CDC MMWR 1994, assuming perfect mixing with clean air

Filtration ASHRAE 170-2013

Space Designation (According to Function)	Filter Bank #1 (MERV)[a]	Filter Bank #2 (MERV)[a]
Operating rooms (Class B and C surgery); inpatient and ambulatory diagnostic and therapeutic radiology; inpatient delivery and recovery spaces	7	14
Inpatient care, treatment, and diagnosis, and those spaces providing direct service or clean supplies and clean processing (except as noted below); All (rooms)	7	14
Protective Environment (PE) rooms	7	HEPA[c,d]
Laboratories; Procedure rooms (Class A surgery), and associated semirestricted spaces	13[b]	NR
Administrative; bulk storage, soiled holding spaces; food preparation spaces; and laundries	7	NR
All other outpatient spaces	7	NR
Nursing facilities	13	NR
Psychiatric hospitals	7	NR
Resident care, treatment, and support areas in inpatient hospice facilities	13	NR
Resident care, treatment, and support areas in assisted living facilities	7	NR

*N/R = not required

a: The minimum efficiency reporting (MERV) is based on the method of testing described in *ANSI/ASHRAE Standard 52.2-2012, Methods of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size* (in Informative Appendix B).

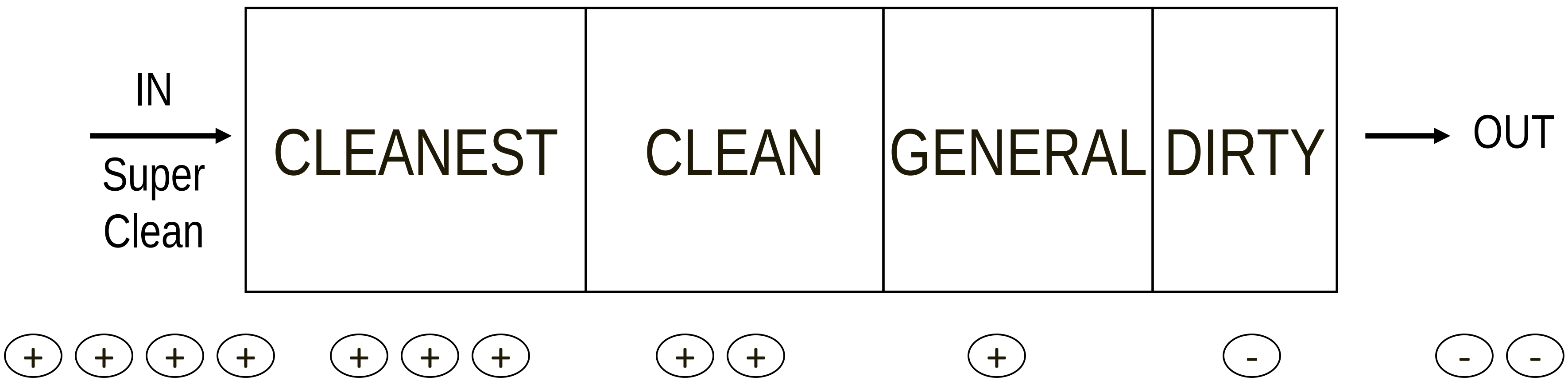
b: Additional prefilters may be used to reduce maintenance for filters with efficiencies higher than MERV 7.

c: As an alternative, MERV-14 rated filters may be used in Filter Bank No. 2 if a tertiary terminal HEPA filter is provided for these spaces.

d: High-Efficiency Particulate Air (HEPA) filters are those filters that remove at least 99.97% of 0.3 micron-sized particles at the rated flow in accordance with the testing methods of IEST RP-CC001.3 (IEST[2005] in Informative Appendix B).

Pressure Difference

- Maintain proper pressurization 24/7
  - ✓ Operating Rooms
  - ✓ Isolation Rooms
  - ✓ Sterile Processing Departments

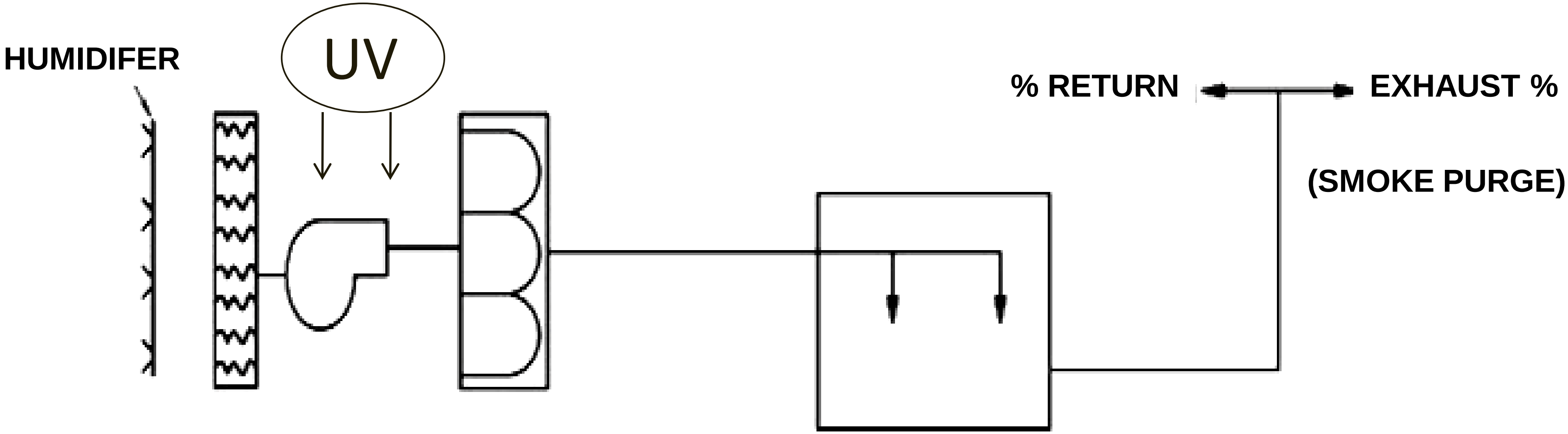


Kill Organisms w/ UV Light

$$\text{UV Kill Effectiveness} = \frac{\text{Dose x Time}}{\text{Virulence}}$$

- Not practical in ductwork
- Effective for stationary mold and mildew on filters, walls, coils, and pans
- Effective in rooms? Beware of human exposure and materials degradation

Effect of Infection Control on HVAC Design



CHW TEMP
SA TEMP
HUMIDITY
FILTRATION

- AIR DISTRIBUTION PATTERNS/LOCATION
- PRESSURE DIFFERENCES
- AIR CHANGE RATE

Variables Determined by Use of Space

Element #2 - Safety

- Smoke and fire controls
- Audio, visual alarms, pull stations, sprinklers
- Security – infants, shooters, terrorists
- Disasters – hurricanes, tornadoes, earthquakes
- Maintenance access
- Exposure to hazardous materials
- Operation during power outages
- See NFPA 25, 99, 101

Element #3 - Reliability

- Reliability ∞ 1 / complexity
- Maintenance ∞ complexity
- Complexity ∞ # of parts
- Complexity ∞ lines of code
- Complexity ∞ unintended consequences
- (Dan's laws)

C-Suite View of Reliability

"What if a system goes down and we have to call off a procedure?"

Example: Power blips causing shutdown of imaging systems

Increase Reliability

- Design for redundancy
- Quality components
- Reduce parts inventory
- Parts & skilled service locally available
- Good & tested emergency operations procedures
- Regular tune-ups
- KISS

Element #4 – Maintenance Cost

- 2-4% of operating cost
- Fewer parts
- Simpler sequences
- Good access and service clearances
- Redundancy (less OT)
- Robust, longer lasting equipment
- Preventive Maintenance program
- KISS

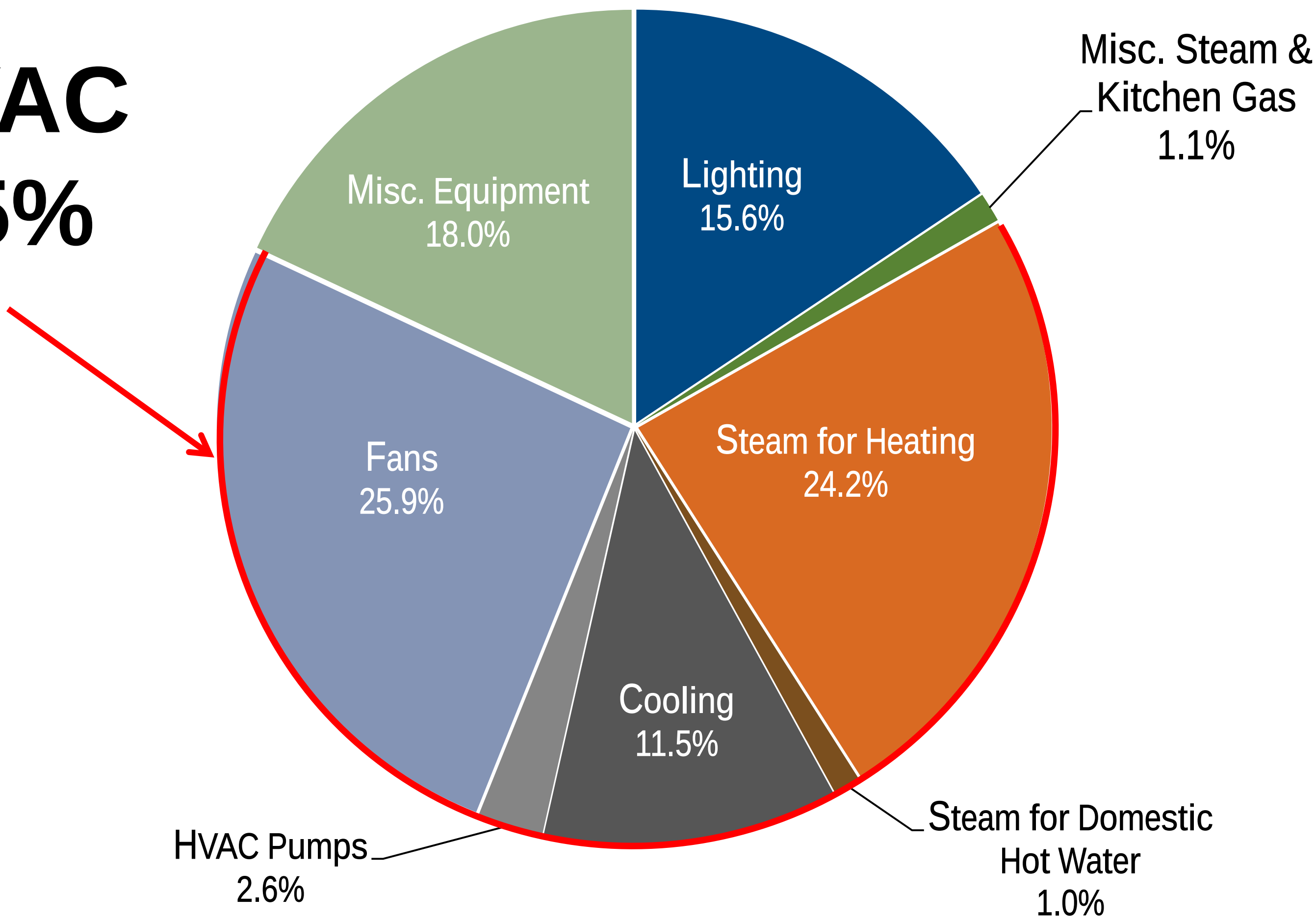
Element #5 - Energy

- EUI = Energy Use Index = kBtu/ft^2/yr
- National Average EUI ~ 250
- EPA Energy Star EUI ~ 170
- Cape Fear Valley Hospital EUI = 165
- Typical $3-5/sf/yr
- 1-2% of hospital cost

* Don’t forget: You can save a given Btu only once

Breakdown of Energy Cost

HVAC 65%



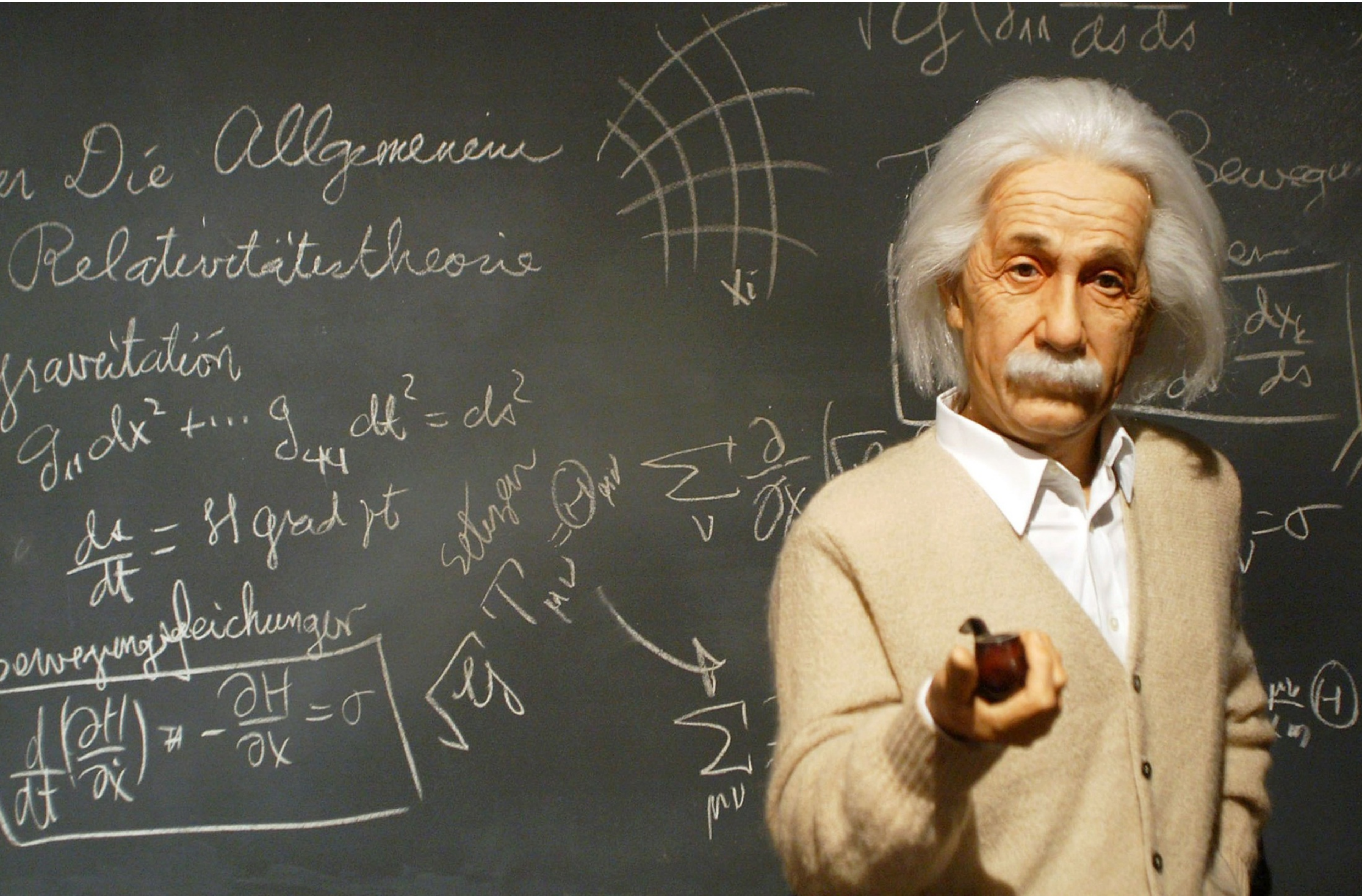
Energy Investment Rules of Thumb

- 500,000 ft^2 hospital @ \$4/ft^2 = \$2 million energy
- HVAC is 65% x \$2 million = \$1.3 million
- Save 15% of HVAC cost ~\$200k
- 3-yr payback = \$600,000 investment

Energy Conservation Measures

- Fluorescent to LED; payback 6 yr
- Heat recovery chiller; payback 3 yr
- DHW flow limiting valves; payback 3 yr
- Pressure independent CHW valves; payback 2 yr
- Rx Controls; payback 1 yr
- Flat plate economizer; payback 5 yr
- Initial commissioning; payback 2 yr
- Our "Competition" New MRI: payback 2 yr
- Interaction & The Perfect Model

Psychrometrics Makes My Head Hurt!



OR Temp / RH Quiz

What is the easiest way to lower the RH in the Operating Room?

A. Lower the temperature

B. Raise the temperature

C. Install a desiccant system

D. Lower the CHW temp

E. Tune the AHU

OR Temp / RH Answer

- Raise the temperature
- At a constant supply air dewpoint, raising the temperature a small amount will lower the relative humidity a large amount
- Relative humidity is very confusing
- No change in SAT required

Where Will You Get Condensation?

Arizona

110˚ 20% humidity

North Carolina

95˚ 50% humidity

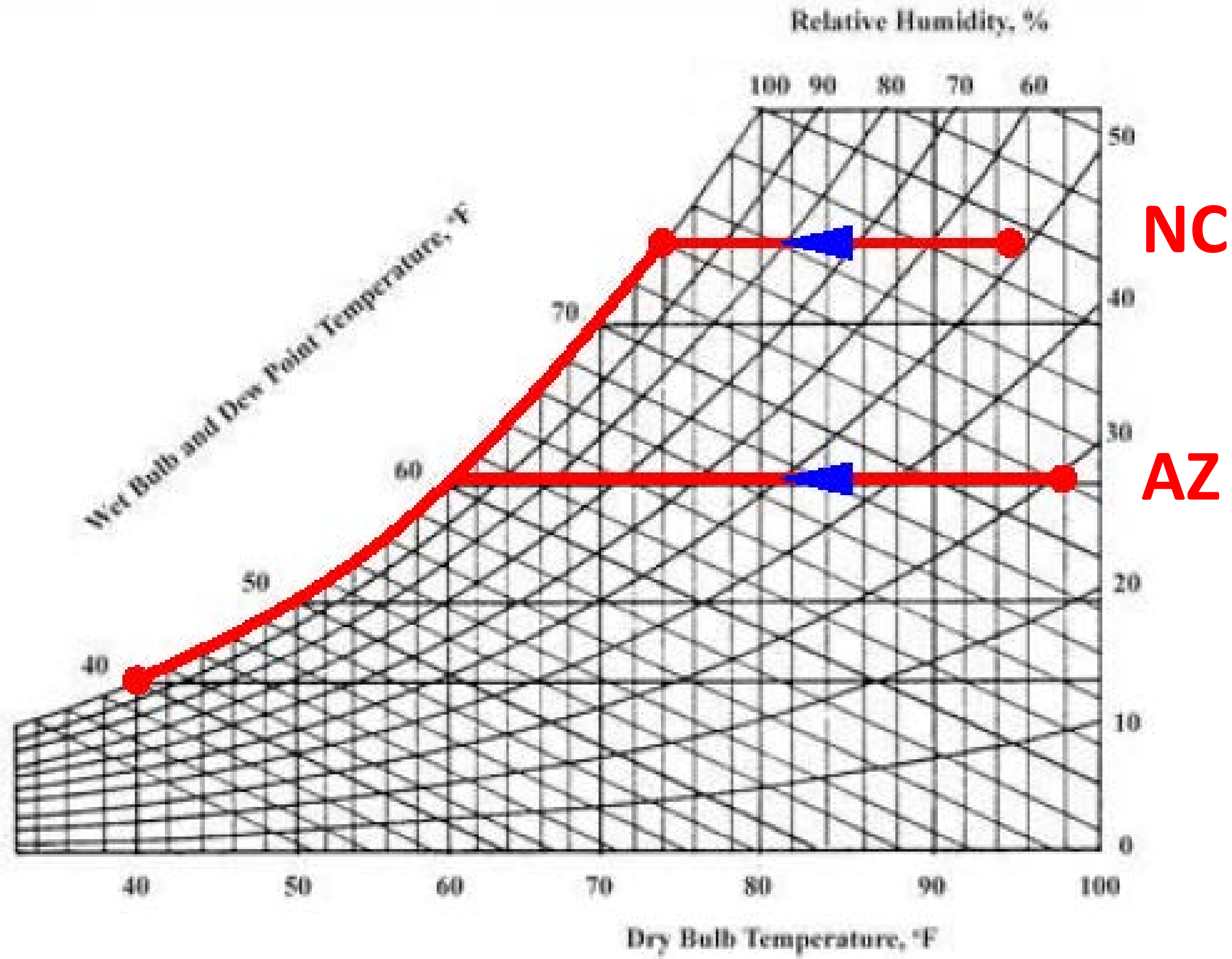
ASHRAE Learning Institute

Both Locations

Arizona **North Carolina**

Dewpoint 60˚ **Ice Tea 40˚** **Dewpoint 70˚**

Condensation Evaporates in AZ – Low RH



RDU Weather Quiz

1. When did we hit 85% RH?
   - July 9, 2014 at 3 pm
   - February 9, 2014 at 9 am
2. When OA is > 85% RH, there is no need to humidify
   - True / False
3. Hot, humid July afternoons reach 90% RH
   - True / False

RDU Weather – July 9, 2014

High Temp, Low Relative Humidity

Time (EDT)	Temp.	Heat Index	Dew Point	Humidity	Pressure	Visibility	Wind Dir	Wind Speed
2:51 PM	93.9 °F	96.1 °F	64.9 °F	38%	29.92 in	10.0 mi	WSW	11.5 mph
3:51 PM	91.9 °F	94.1 °F	64.9 °F	41%	29.94 in	10.0 mi	South	15.0 mph
4:02 PM	86.0 °F	88.2 °F	66.2 °F	51%	29.96 in	10.0 mi	SSW	16.1 mph
4:51 PM	88.0 °F	90.3 °F	66.0 °F	48%	29.94 in	10.0 mi	SSW	11.5 mph
5:24 PM	84.2 °F	86.6 °F	66.2 °F	55%	29.96 in	10.0 mi	SSW	18.4 mph
5:51 PM	75.9 °F	-	70.0 °F	82%	29.97 in	4.0 mi	West	11.5 mph

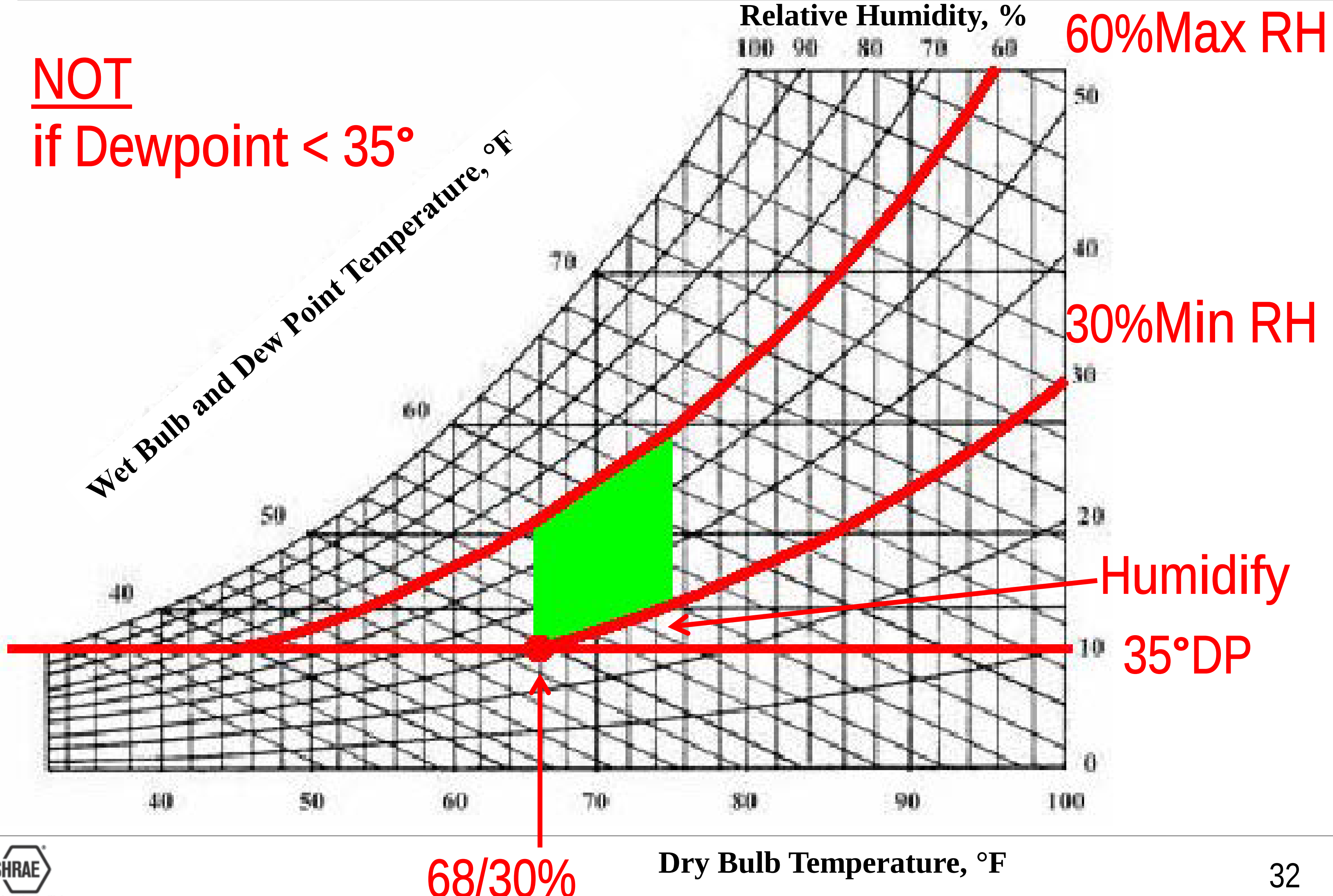
Low Temp, High Relative Humidity

Time (EDT)	Temp.	Heat Index	Dew Point	Humidity	Pressure	Visibility	Wind Dir	Wind Speed
6:17 PM	75.2 °F	-	71.6 °F	89%	29.96 in	7.0 mi	SW	10.4 mph
6:51 PM	75.9 °F	-	70.0 °F	82%	29.94 in	10.0 mi	WSW	8.1 mph

RDU Weather – February 9, 2014

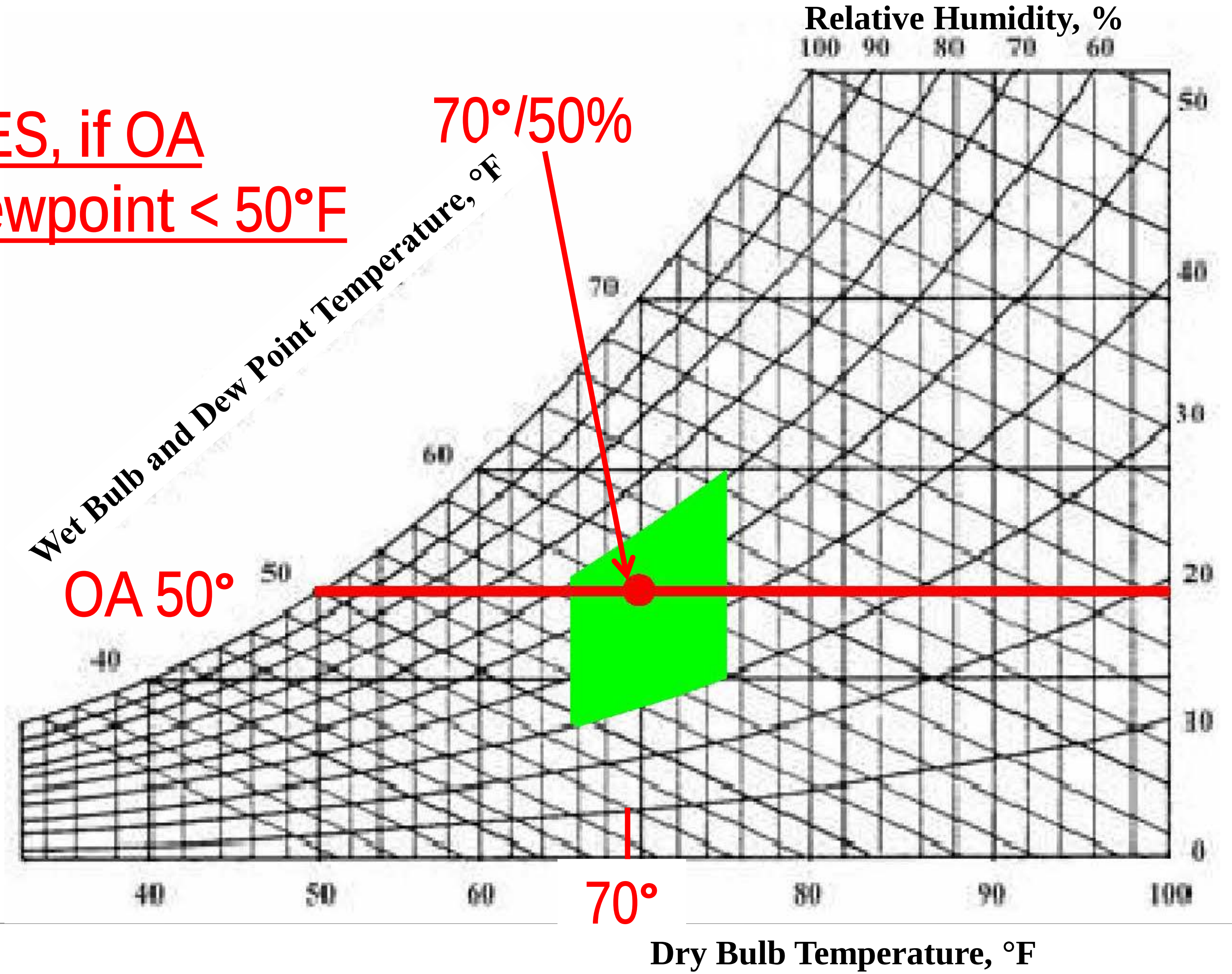
Time (EDT)	Temp.	Heat Index	Dew Point	Humidity	Pressure	Visibility	Wind Dir	Wind Speed
4:51 AM	30.0 °F	-	26.1 °F	85%	30.14 in	7.0 mi	Calm	Calm
5:51 AM	30.0 °F	-	26.1 °F	85%	30.14 in	7.0 mi	Calm	Calm
6:51 AM	33.1 °F	-	28.9 °F	85%	30.15 in	6.0 mi	Calm	Calm
7:51 AM	33.1 °F	-	28.9 °F	85%	30.16 in	6.0 mi	Calm	Calm
8:51 AM	34.0 °F	31.0 °F	30.0 °F	85%	30.19 in	5.0 mi	SE	3.5 mph
9:51 AM	36.0 °F	32.1 °F	30.0 °F	79%	30.19 in	7.0 mi	SE	4.6 mph

Outside Air Economizers – Winter

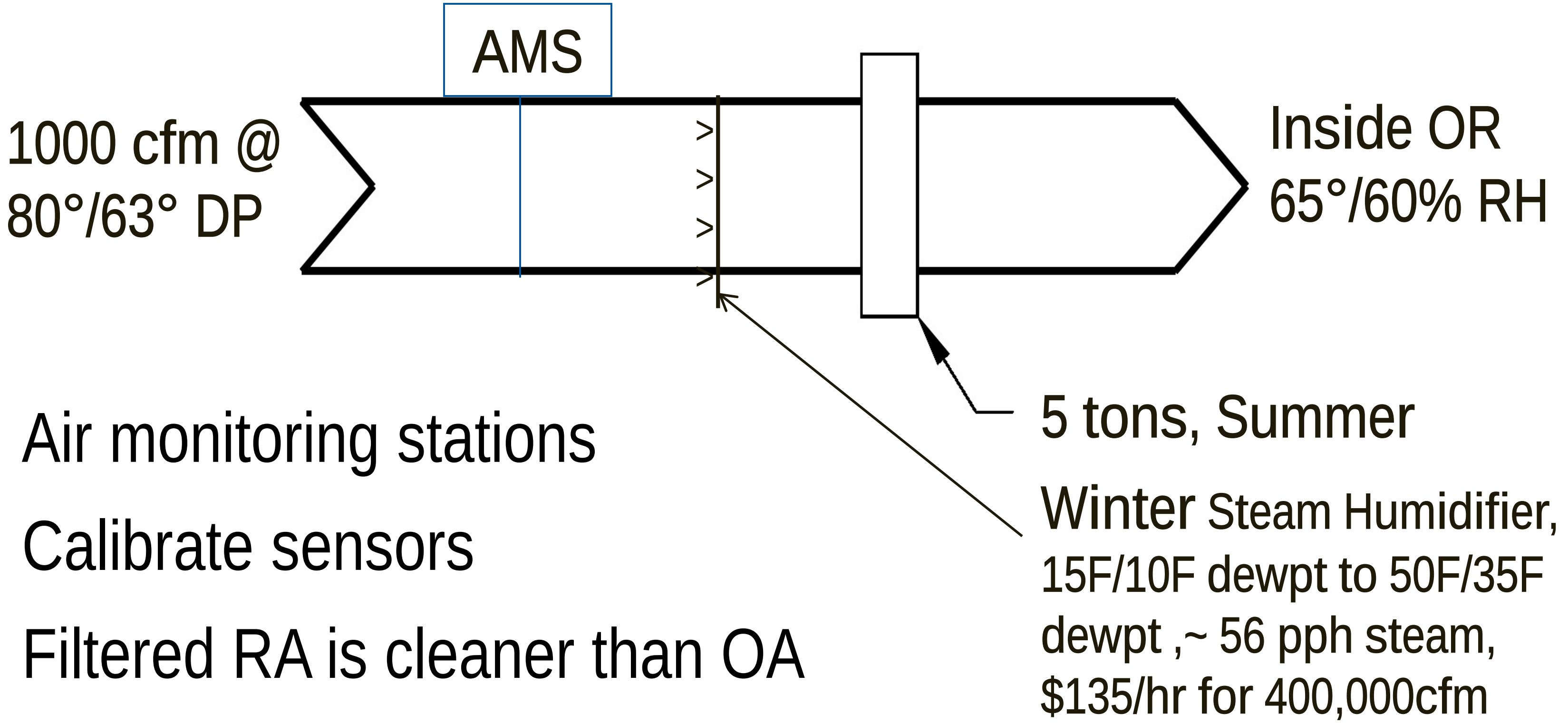


Outside Air Economizers – Spring

YES, if OA dewpoint < 50°F



Minimize OA

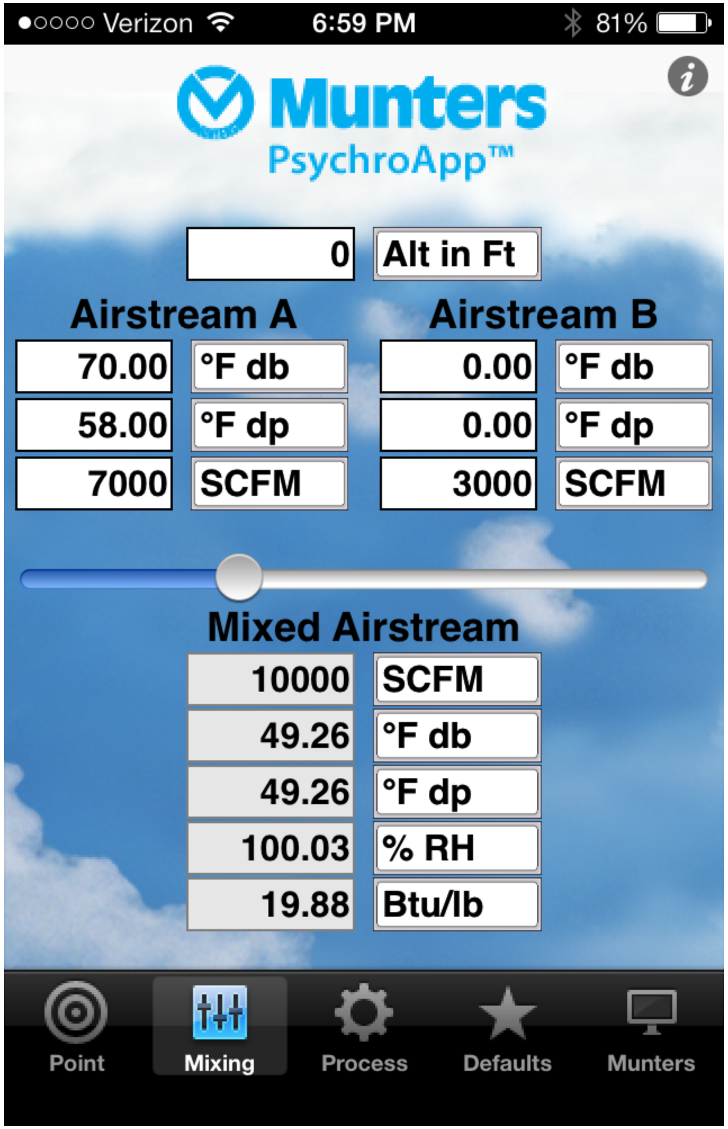


- Air monitoring stations
- Calibrate sensors
- Filtered RA is cleaner than OA
- Use NOAA for OA conditions
- Each cfm of OA costs ~$1.50/yr to condition

Air-Side Economizer Analysis

- Large OA and relief louvers, dampers and ducts
- Preheat coil
- Return air fan
- Enthalpy controls
- Energy waste of pressure drop on PHC
- Energy waste if dampers out of calibration
- Control points = maintenance, complexity, lower reliability
- Consider flat plate, waterside economizer

Do You Need a Preheat Coil?

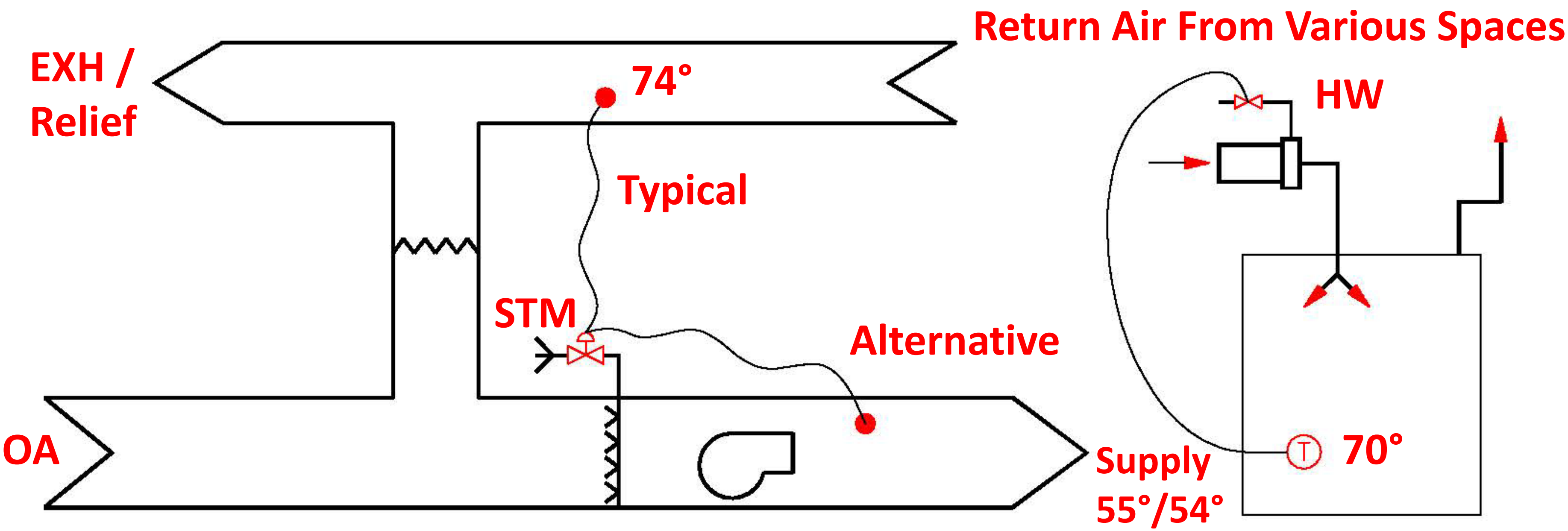


- Main reason for PHC is failure of economizer dampers or smoke purge when OA< 32°F
- Run cooling coil full flow during emerg smoke purge
- Eliminate cost, dP, space, complexity
- Many PHCs freeze
- Weigh against air economizer

Optimize Humidification

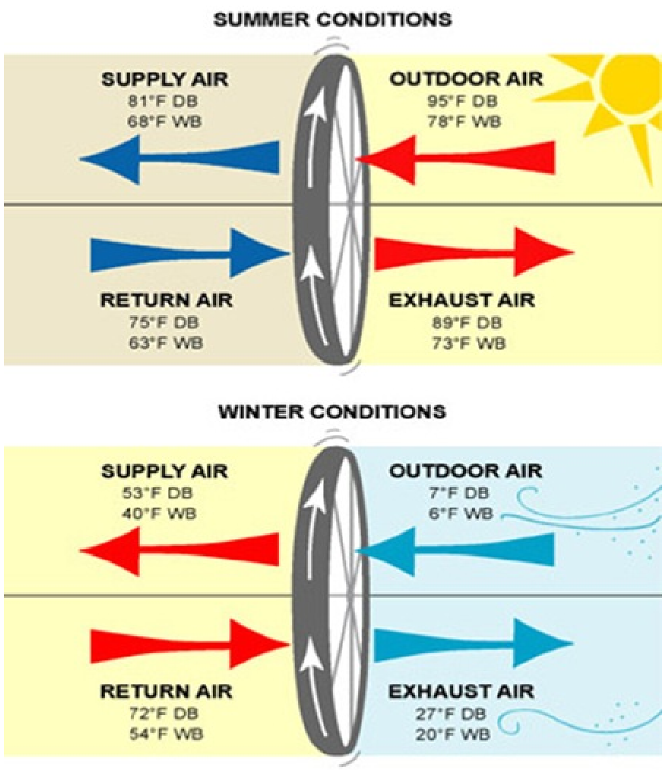
- Boiler steam OK with FDA-approved chemicals
- “Clean steam” not required – cost, space, maintenance, heat
- Avoid terminal humidifiers
- Locate humidifier before cooling coil in AHU
- Keep RH sensors in calibration
- Use accurate instruments to test (sling)
- Large RH display but no control by user

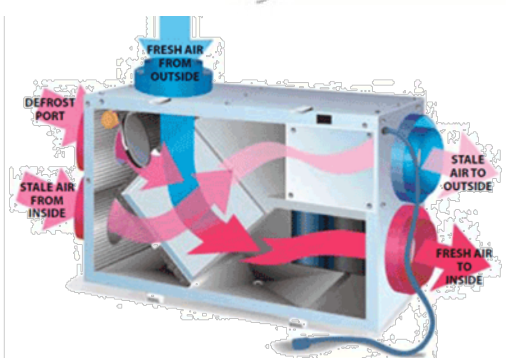
Humidifier Control



- Humidifier set for 50% in RA, will maintain 74°/50% ⇒ 54° Dewpoint. This will cause condensation on surfaces below 54°.
- Humidity controls are typically unreliable and crude. Significant swings in humidity are common.
- *Solution:* Lower RA setpoint to 30% ; or control to 35°F dp in SA.

Air-Side Energy Recovery



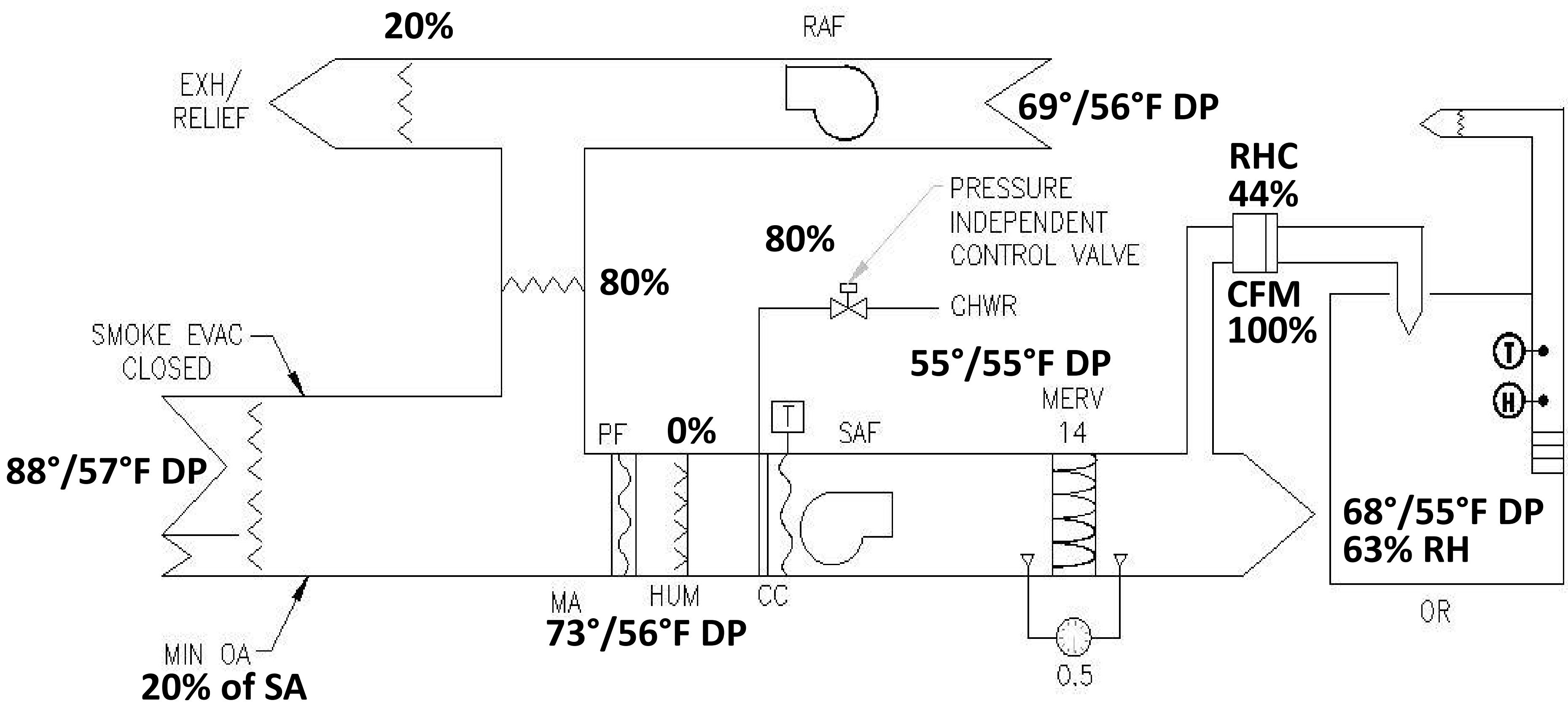


- SA, Exh Duct proximity
- No cross-contamination allowed
- Good with 100% OA systems
- Good with DX
- Eliminates preheat
- Good with extreme OA temps
- Upstream of FF

SA Temp Reset

- Will raise space RH, if MAT dewpoint > 50°F
- Do not Raise SAT unless OA dewpoint < 50°F
- Control CHW flow to meet SA setpoint, not CHW temp
- Higher CHW temp likely will cause higher dewpoint
- Saves energy by reducing reheat and cooling

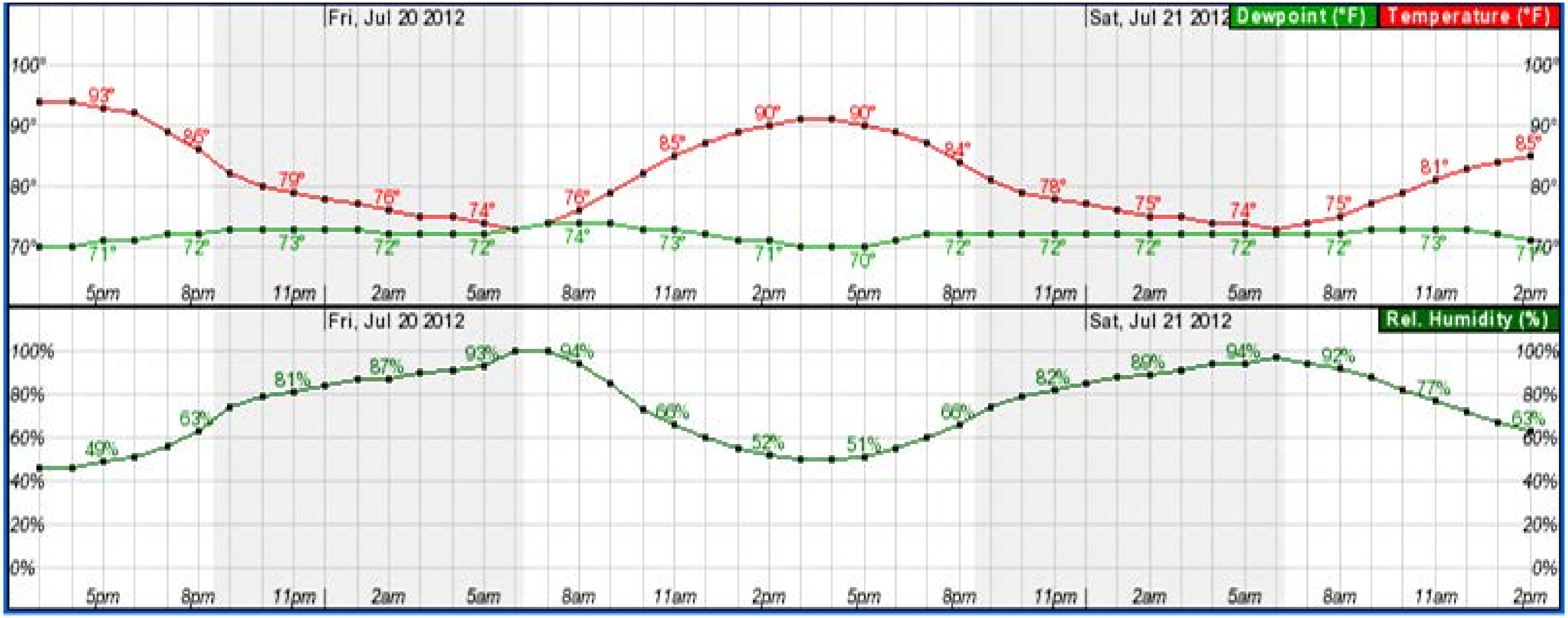
Raise SAT With Care



55°F SAT will barely satisfy patient rooms.

Beware of high RH below ~70°F

Chilled Water Reset, Summer in SE



- OA Temp varies, but dewpoint ~ constant
- <u>DON'T</u> raise CHWS Temps in summer, even at night
- Raise CHWS Temp only when OA < 50° dewpoint

Benefits of Low Temp / High dT CHW

- More tons in same size pipe
- Better humidity control
- Lower first cost – equipment is smaller
- Lower dP in coil
- Lower CFM
- Less pump energy offsets chiller efficiency loss
- Per Trane report for 400-ton CHW system
  - ✓ 44/54F => 337 kW
  - ✓ 41/57F => 325 kW

Low Temp / High dT CHW Performance

Table 12. Impact of entering fluid temperature and flow rate on cooling coil

Constants	“Conventional” System Design	“Low-flow” System Design
Coil face area, ft^2	29.90	29.90
Face velocity, fpm	435	435
Coil rows	6 rows	6 rows
Fin spacing, fins/ft	83	83
Total cooling capacity, MBh	525	525
Variables		
Entering fluid temperature, °F	44	40
Leaving fluid temperature, °F	54	55.5
Fluid ΔT, °F	10	15.5
Fluid flow rate, gpm	105	67.5
Fluid pressure drop, ft H_2O	13.6	6.2

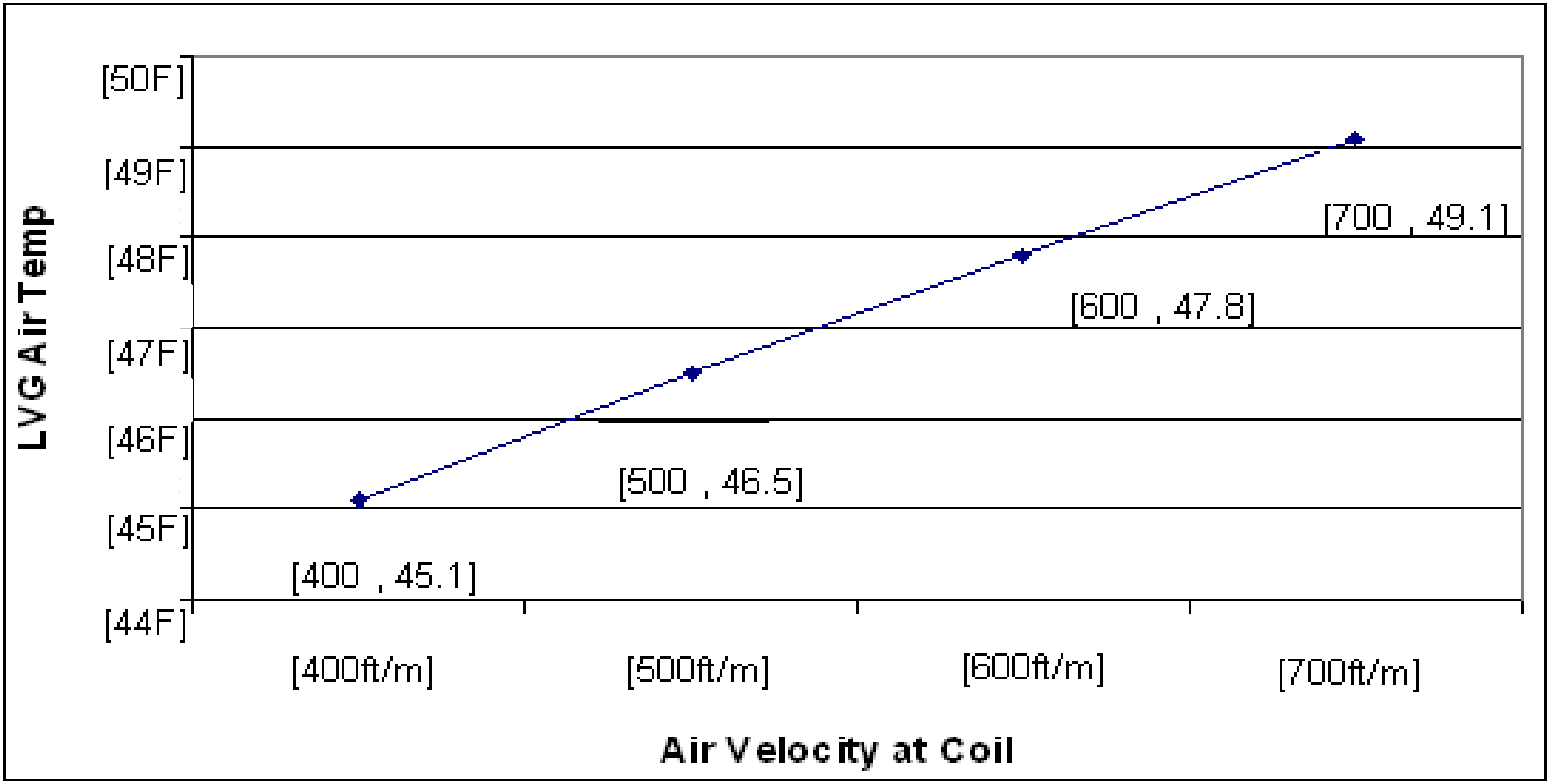
Variable Primary

- Fewer pumps
- More complicated to balance
- No secondary bypass – no wasted pump energy, no diluted CHWS temp
- Maintain minimum flow through chillers ~30%
- PIC valves on all AHUs

Meeting Fan Power Limitation

- The Fan System horsepower is the ***sum*** of all fans for the system including supply, return, exhaust and fan-powered boxes.
- Very difficult with MERV 14 filters and long dist ducts
- Large ducts, smooth fittings especially at AHU
- Slot diffusers twice dP of 4-way
- Multiple AHU to reduce duct runs, 20,000 cfm sweet spot
- <400 fpm velocity – coils, filters
- New exception where RA duct is required

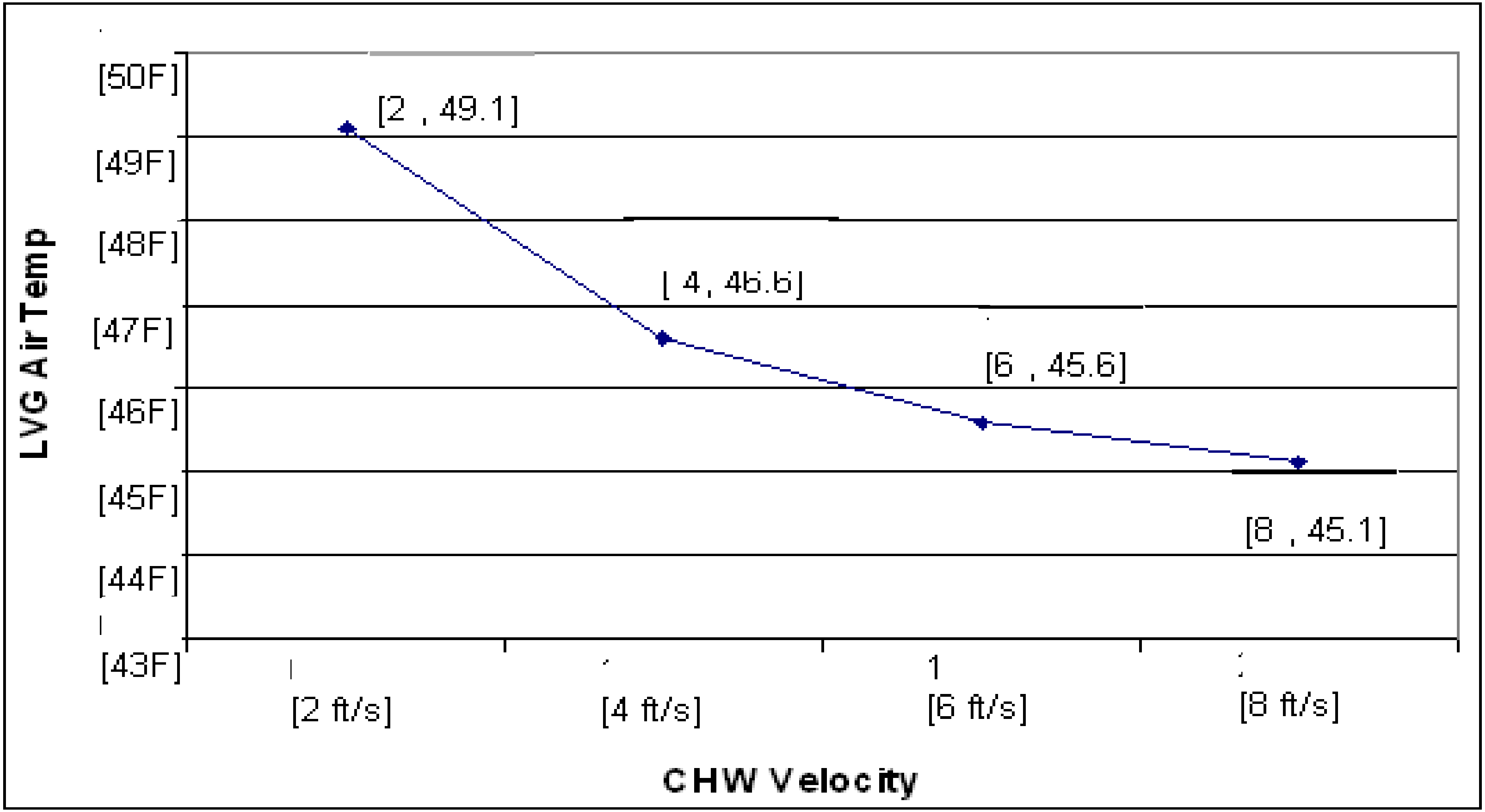
Minimize Coil Face Velocity



* Trane PRIMA-FLO

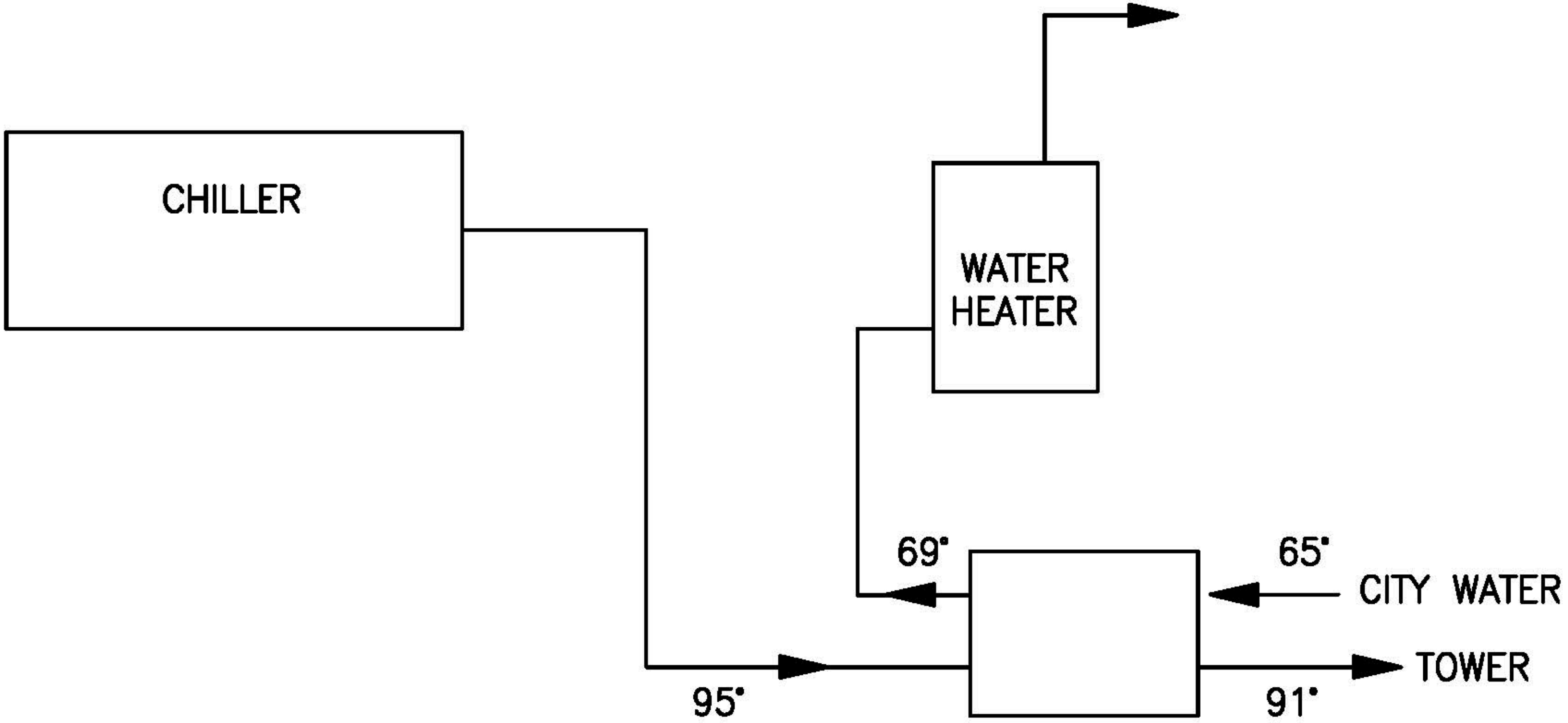
42/50F CHW@ 8 fps; 95/75Fwb EA; 8 Row, 13 FPI

Optimize CHW Flow



PRIMA-FLO 42/50 CHW; 95/75Fwb EA; 8 Row, 13 FPI, 400fps

Chiller ⟶ DHW Recovery



- Requires DHW near Chillers
- ~ 5-year Payback
- Simple & Reliable

Optimize Chiller Plant

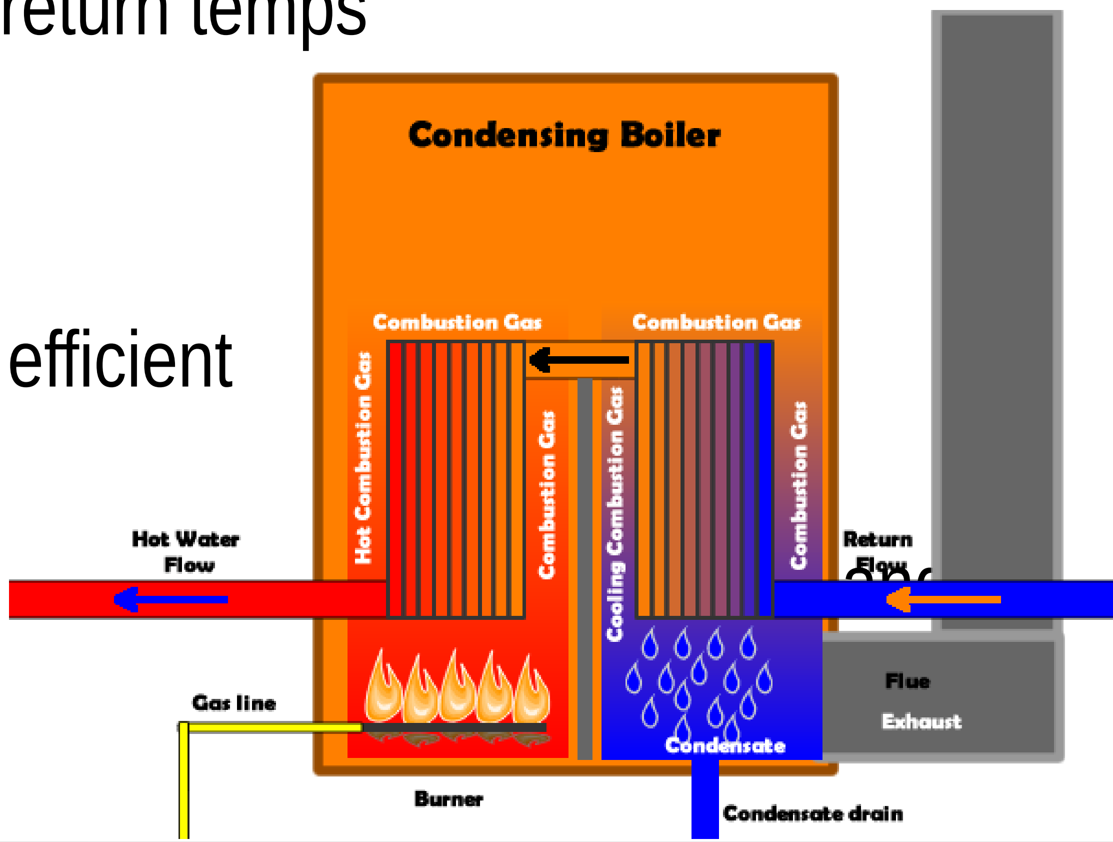
- Variable primary, tune dP’s
- Heat recovery chiller size for heating
- CHWS temp set to meet lowest space dewpoint required
- Pressure independent control valves
- BTU meters
- Condenser temp reset on WB
- VFD’s
- EPS
- Sequence on TOTAL plant energy use

Heating Water Temp Reset

- Reduce boiler and pipe standby losses
- Increase boiler efficiency
- High ΔT = less pumping, smaller pipes
- With constant SAT, reheat steady year round
- Hospitals are factories = internal load driven
- Be careful of need for fast warm-up
- Need 2-4 row RHC w/ lower HHW temp

Hot Water vs. Steam Boilers

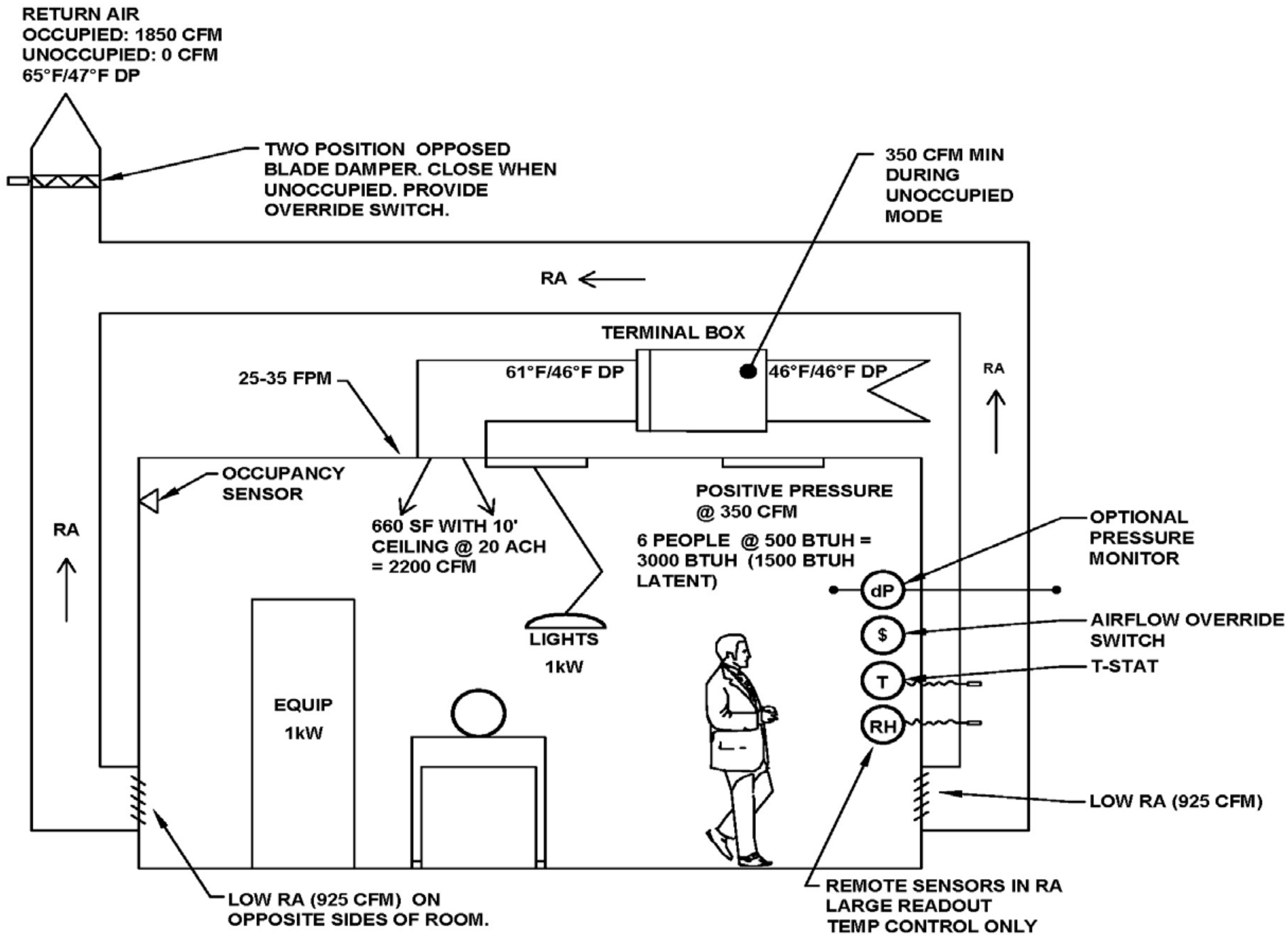
- Can use for small HW loads; burn gas only
- Fast startup
- High efficiency at lower return temps
- Must select coils for HHW temperatures
- HW system much more efficient than steam
- Steam for sterilizers humidifiers?



OR Air Flow Setback

- Saves fan and reheat energy ~ $2500/yr per OR
- Must maintain + pressure at all times
- Requires RA boxes, air valves, or dampers
- Ensure system reaches full flow in minutes
- Foolproof overrides with indicator lights
- Tie to BAS
- Provide adequate air during cleaning of room
- Easier to lower temp at night to reduce reheat ~67% of savings

Typical OR with Air Flow Setback



Get & Keep the Systems Running Well

- Initial Cx including functional tests (all scenarios)
- Document setpoints and final sequences
- Periodic tune-ups
- Clean all coils - cooling, preheat, reheat, UV lights
- Duct cleaning is controversial
- Operator training
- Set alarms as value approaches red line (yellow caution)
- Trends
- Dashboards

HP Healthcare HVAC Checklist – 1 of 3

- Water cooled imaging, compressors, etc = year round cooling
- Water side economizer
- Set SAT to meet lowest dewpoint req'd for each AHU
- SA flow reset in OR's need RA boxes, dampers, or air valves
- Variable primary CHW
- VFD/high efficiency chillers
- VFD's on CT fans, pumps, CHW pumps, fans
- Exhaust = 95% x OA, so bldg 5% positive pressure
- Don't return air to AHU, then relieve – Exhaust @ source
- Oversize Exhaust: breakrooms, WC, vending machines, etc.

HP Healthcare HVAC Checklist – 2 of 3

- Humidifier in AHU, upstream of cooling coil; not in duct
- Use boiler steam
- Lower room temp at night to reduce reheat
- Use flow monitors on OA, set to min OA, lock damper
- Large ducts, smooth bends
- Space around VAV box control
- Power to VAV box controllers, 120V
- Dashboards
- Plant optimization programming

HP Healthcare HVAC Checklist – 3 of 3

- Recover AHU condensate
- Heat recovery chiller
- Dual flush toilets
- Low temp CHW = low space RH @ low temp
- High dT CHW & CW = lower pumping, higher eff
- UV lights in AHUs
- HHW 140/110 F, 2-3 row RHC

Summary – Six Elements of High-Performance HC HVAC System

1. Infection control and comfort – Patient Outcome
2. Safety – Finances, Morality
3. Reliability – Finances
4. Maintenance Cost – Finances
5. Energy Efficiency – Finances, Morality
6. Sustainability – Morality, Good Public Relations

Thank You!

Dan Koenigshofer, PE, MSPH, HFDP, SASHE

Dewberry Engineers Inc.

dkoenigshofer@dewberry.com

919-425-7616