HVAC Innovation

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Drivers of Technology

- Increasing government standards
- Changes in standards
  - ASHRAE 90.1
  - ASHRAE 189.1
- Industry drivers
  - LEED
  - CEE rebate levels
- Requirements for better control of temperature and humidity
- Desire to reduce energy costs

Key Technologies

- Variable Capacity Compressors
- Modulating reheat for humidity control
- Higher efficiency fans
- Direct drive fans
- Construction improvements
- System types: Dual Path vs. Package Return Air Bypass

Government Standards

- Department of Energy (DOE) mandated all states must use ASHRAE 90.1-2004 as their state energy code, or a code more stringent.
- ASHRAE 90.1-2004
  - EER – Energy efficiency ratio
  - Package equipment EER 9.0 – 10.3

ASHRAE 90.1

- 2004
  - Package equipment EER 9.0 – 10.3
- 2010
  - Package equipment EER 9.5 – 11.2

ASHRAE 189.1

- Standard for the Design of High-Performance, Green Buildings, is the first code-intended commercial green building standard in the United States.
  - Illuminating Engineering Society of North America (IES)
  - U.S. Green Building Council (USGBC)

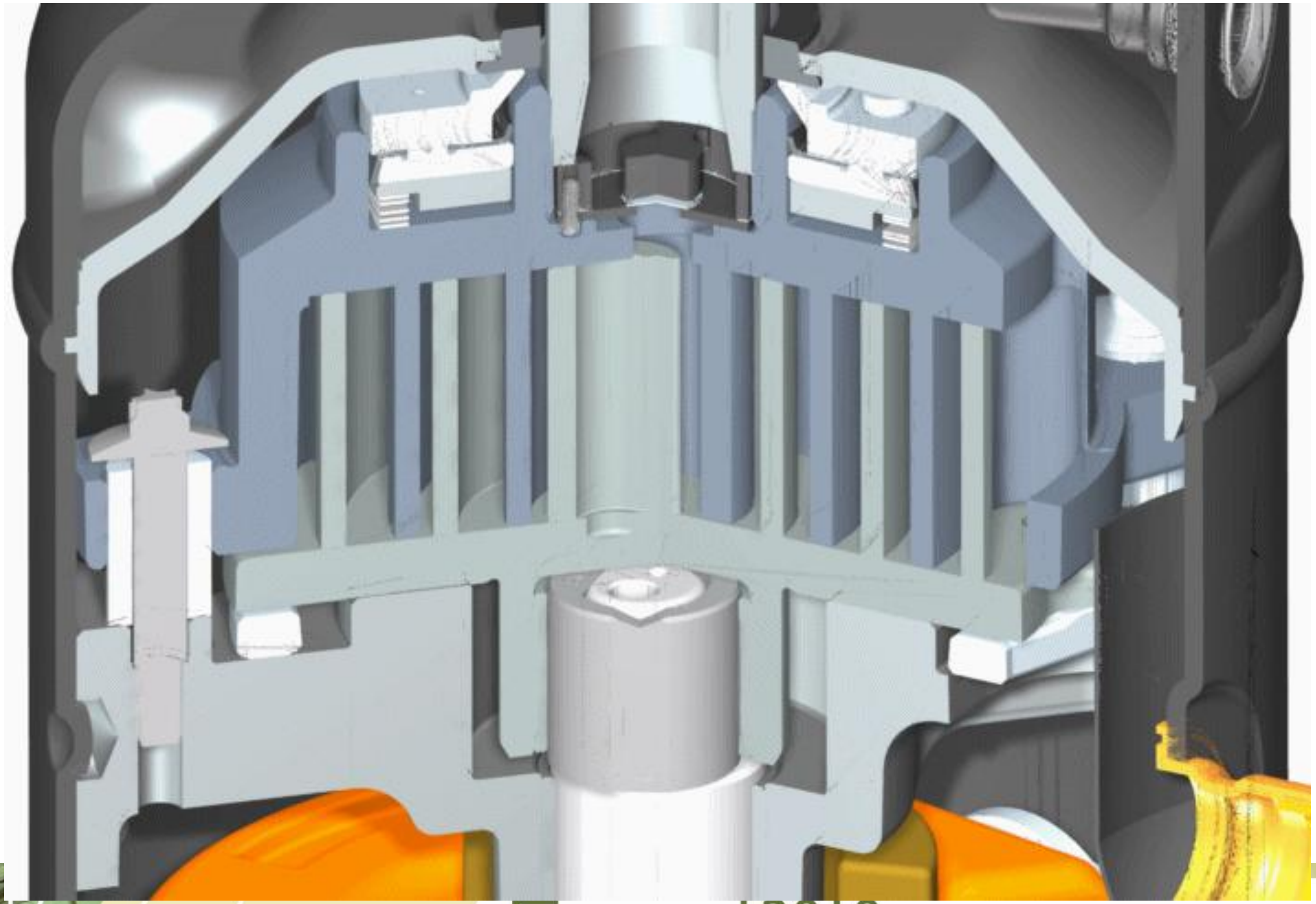
LEED

- U.S. Green Building Council (USGBC)
- Leadership in Energy and Environmental Design
- Holistic approach
- Efficient products contribute to the effort

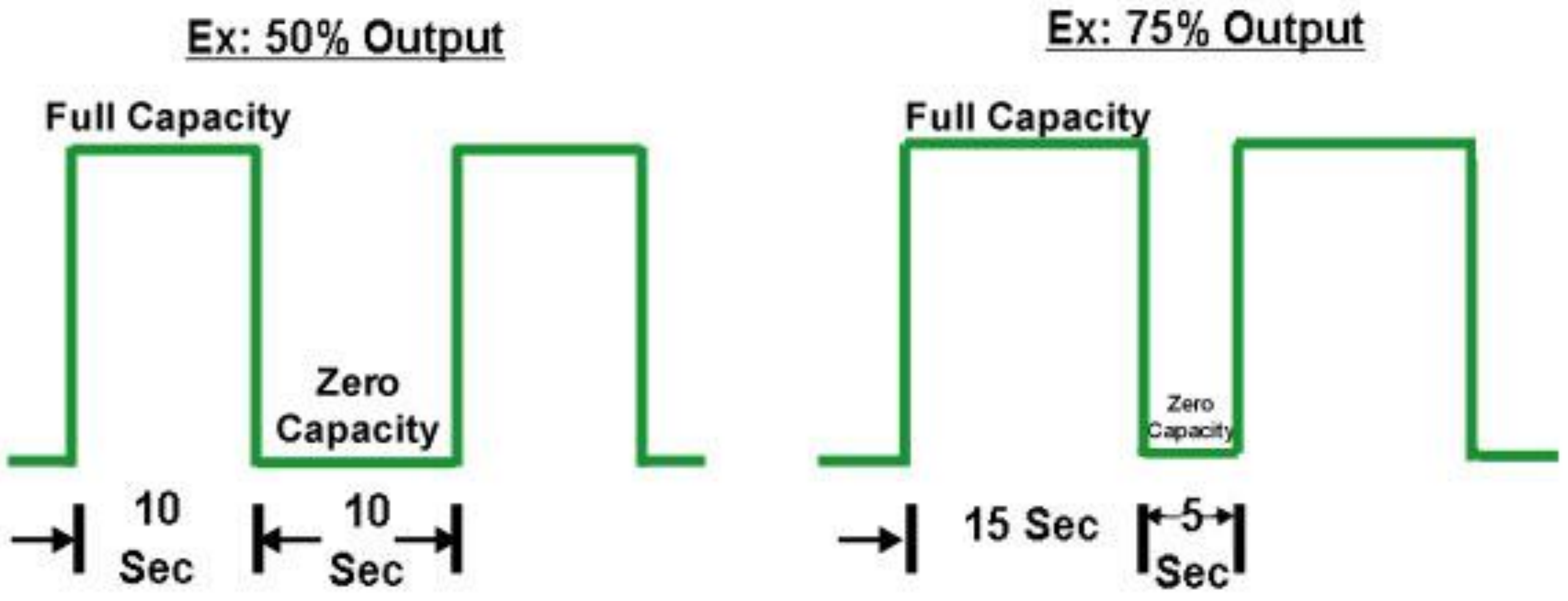
Key Technologies - Variable Capacity Compressors

- Scroll Compressor
- Modulates mass flow of refrigerant from 10% to 100%
- Never a problem with oil return
- Increase part load efficiencies
- Keeps the coil cold for longer periods of time improving humidity control
- Eliminates hot gas bypass

Variable Capacity Compressors

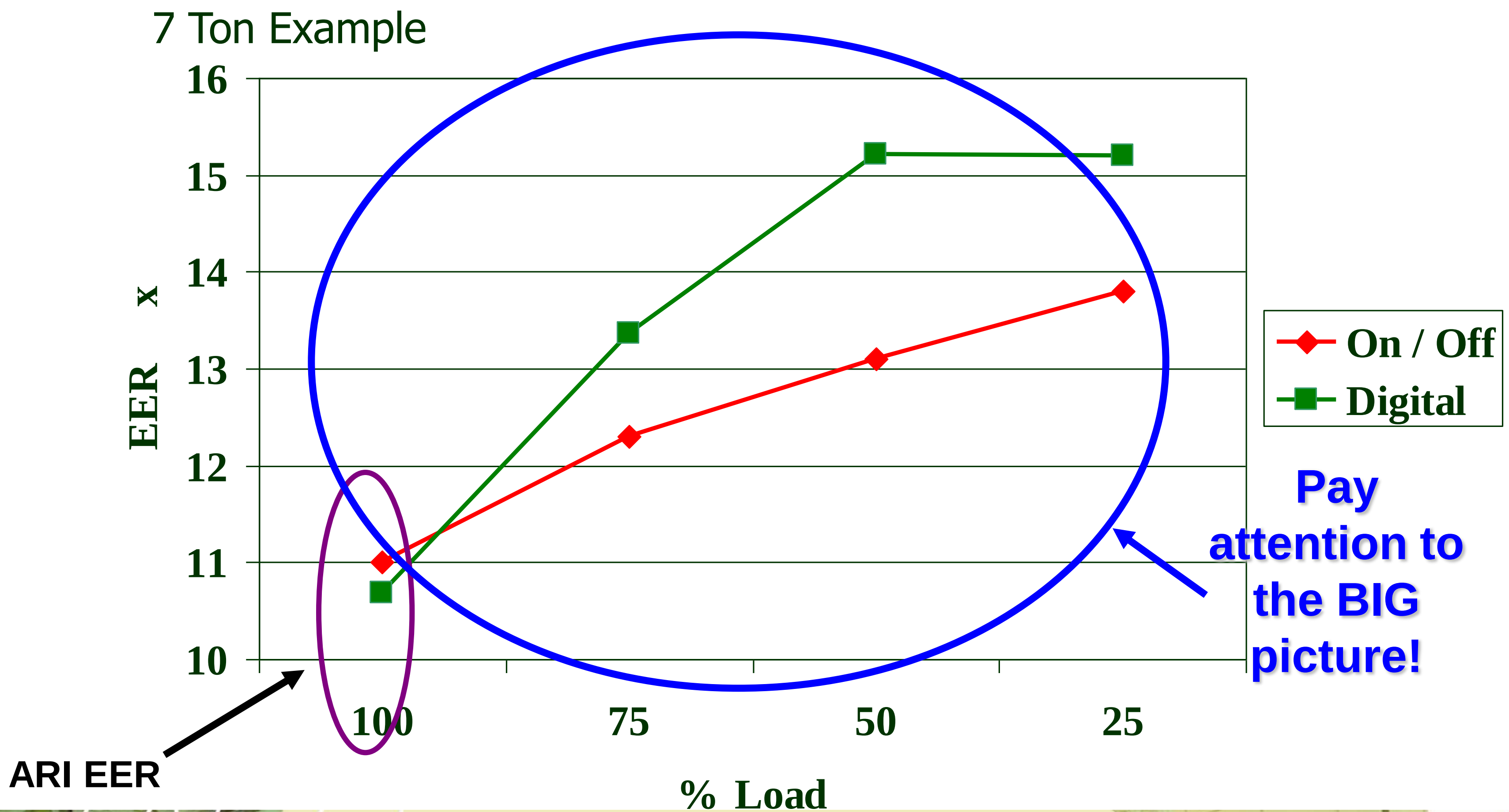


Variable "Pumping" Diagram

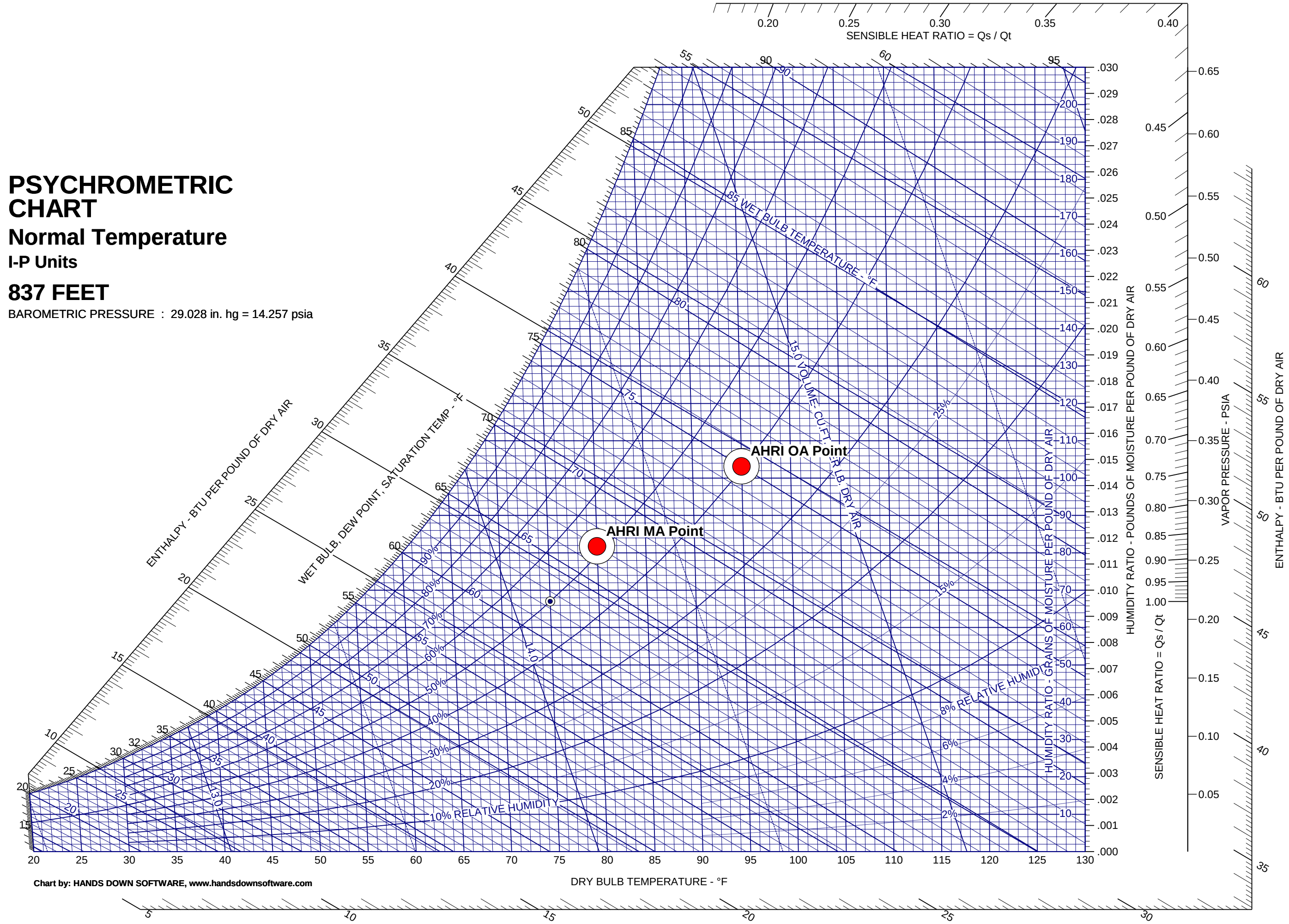


Pulse-Width Modulation

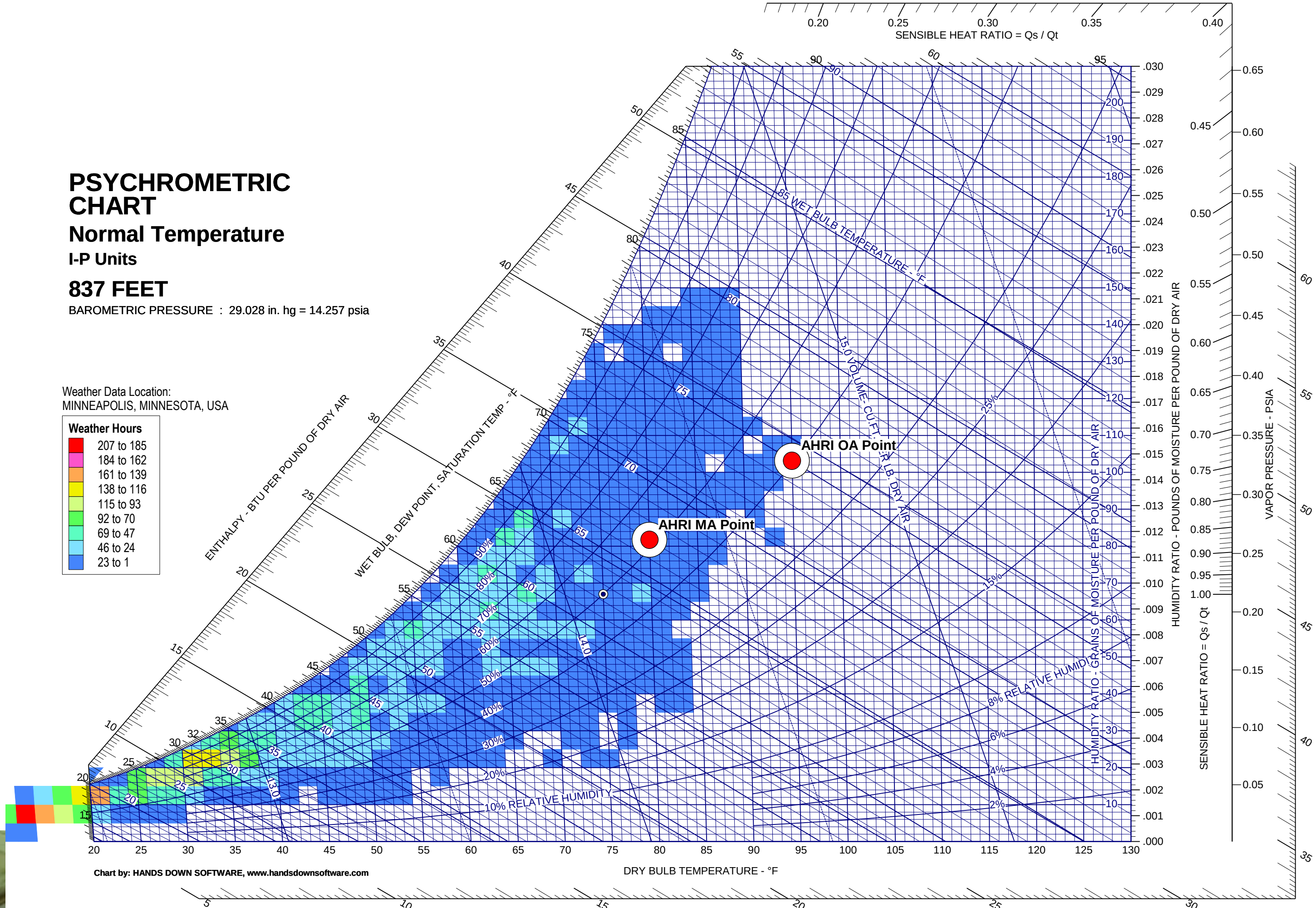
Impact on Efficiency



Appropriateness of EER



Appropriateness of EER



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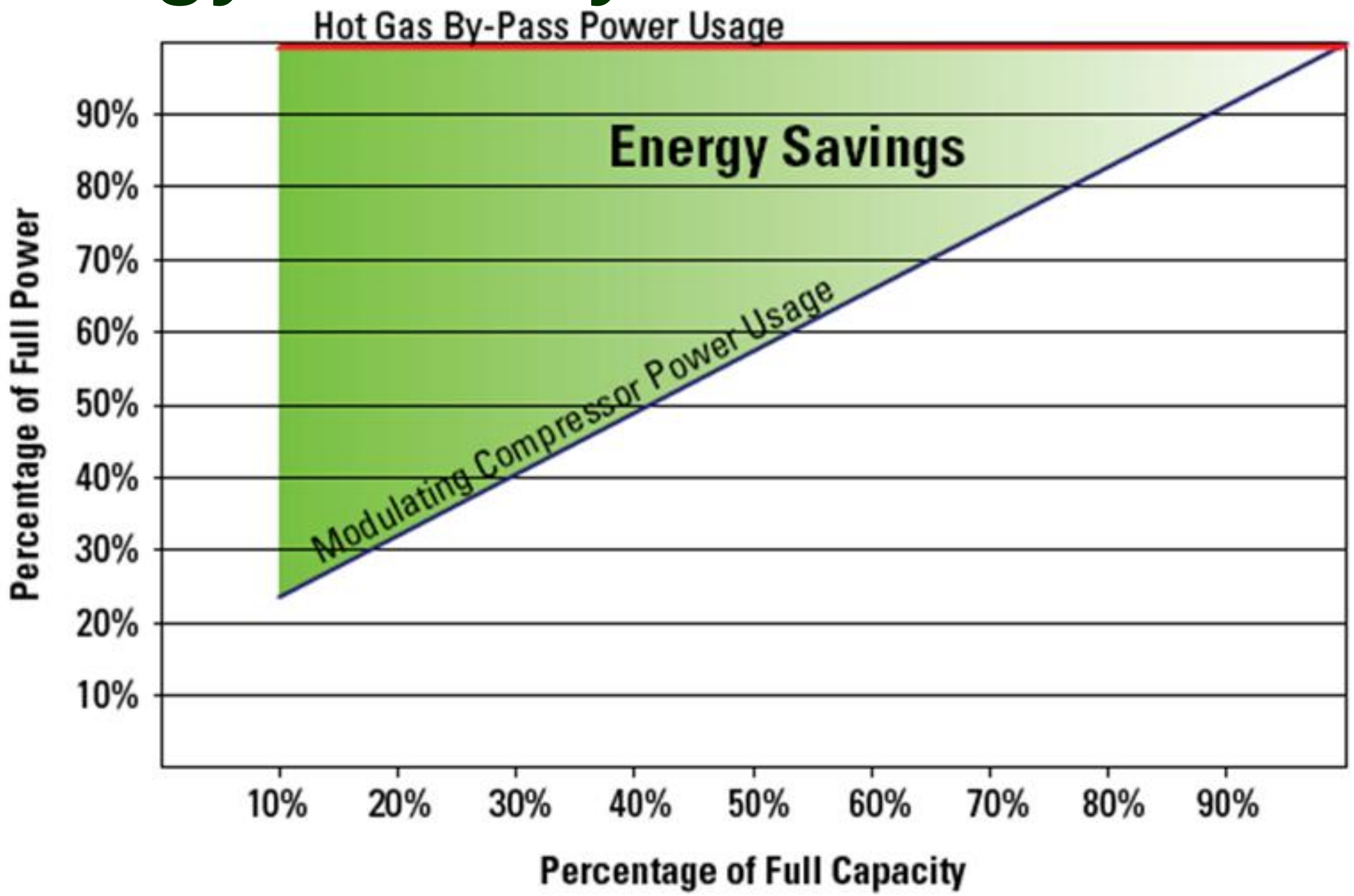
Hot Gas Bypass

- Hot gas bypass has been appropriate for cooling applications that demand tight, continuous, thermal control—particularly if large amounts of outdoor air, widely varying loads, or excessive compressor on/off delays are involved.
  - HGBP prevents excessive compressor cycling
  - HGBP can help match system capacity to load
  - HGBP can allow the system to operate at safe balance points during low loads

Energy Penalty



Savings Example

Variable Capacity Compressor (VCC) vs On-Off or HGB Controlled Compressor Control

Equivalent Rated ARI EER to Equal VCC Rated EER Based on an Annual Analysis

UnitModel$= RM-015 EvaporatorRows$= Standard Operation$= 12 Hour DaysPerWeek$= Seven

Location	MINNEAPOLIS_MN			Nominal Tons =		15	Supply Fan Control Type =			CAV		
OADB (°F)	97.0	92.0	87.0	82.0	77.0	72.0	67.0	62.0	57.0	52.0	Total	
Load Hours (hrs)	0	53	145	222	288	359	273	256	275	197	2068 [hrs]	
Load (tons)	15.0	13.5	12.0	10.5	9.0	7.5	6.0	4.5	3.0	1.5	13981 [ton-hrs]	
Base Unit												
Base Unit Compressor	Lead	Lag										
Base Unit Compressor Control Type	HGB	Standard		Base Unit Condenser Fan Control Type				Cycling				
EER Total Unit Base Unit (Btu/(W-hr))	10.6	10.4	10.1	9.6	8.8	11.7	10.2	8.4	6.1	3.3	ARI Unit EER	10.60
Power Base Unit (kW)	17.0	15.5	14.3	13.2	12.3	7.7	7.1	6.5	5.9	5.5		
Energy Base Unit (kWh)	0	823	2067	2922	3533	2766	1928	1655	1634	1087	Annual (kWh)	18414
Variable Capacity Compressor Unit												
VCC Unit Compressor	Lead	Lag										
VCC Unit Compressor Control Type	Digital	Standard		VCC Unit Condenser Fan Control Type					Cycling			
EER Total Unit VCC (Btu/(W-hr))	10.4	11.1	11.5	11.7	11.3	11.6	11.6	10.8	8.9	5.4	ARI Unit EER	10.40
Power VCC (kW)	17.3	14.6	12.5	10.8	9.6	7.8	6.2	5.0	4.0	3.3		
Energy VCC (kWh)	0	773	1810	2398	2751	2793	1699	1286	1111	655	Annual (kWh)	15275

Annual Energy Savings VCC vs Base =	3139 [kWh] 17.0 [%]

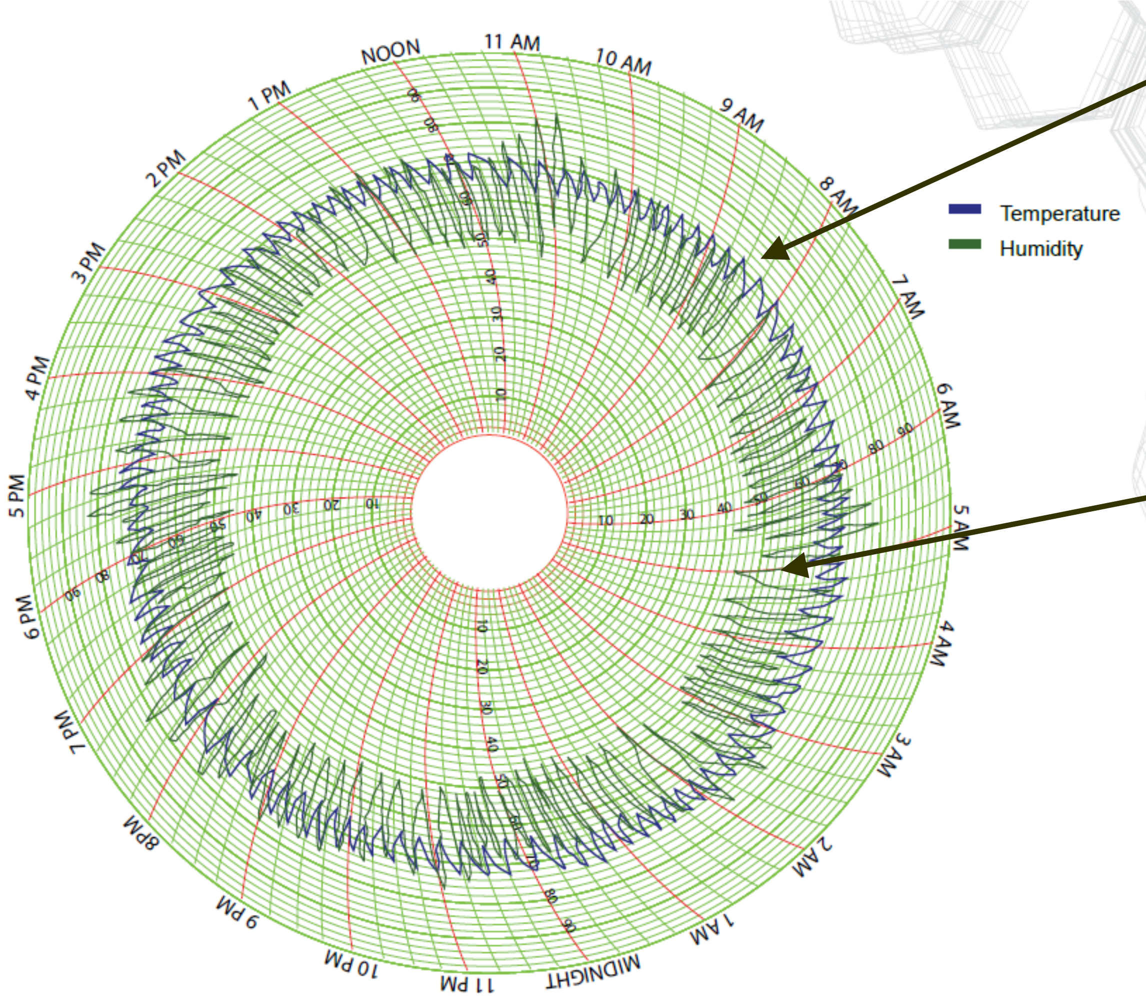
Required Base Unit Rated EER to Equal VCC Rated EER For Equal Annual Energy Usage	12.5 [Btu/(W-hr)]

Values shown are estimates, actutal performance may differ due to ambient conditions, load, air flow, and control methods.

Modulating Hot Gas Reheat

- Using heat of refrigerant for temperature control
- Hot gas reheat is not new but modulating reheat is
- Precisely match requirements for temp and humidity control
- On-off reheat is like a broken clock

DX On-Off Compressor Control



DB Temperature
70F +/-3
67F – 73F

Relative Humidity
60% +/-14%
46% - 74%

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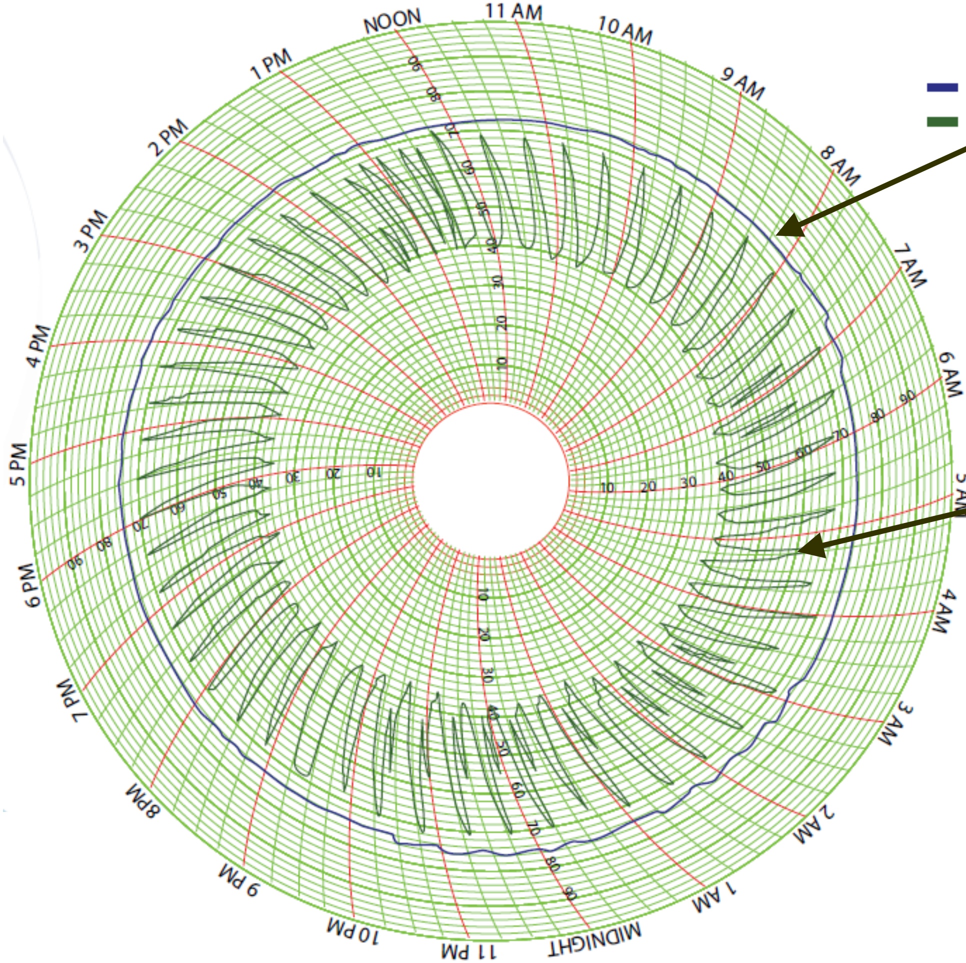
Modulating Reheat & On-Off Compressor



DB Temperature
72F +/-0.5

Relative Humidity
64% +/-16%
38% - 70%

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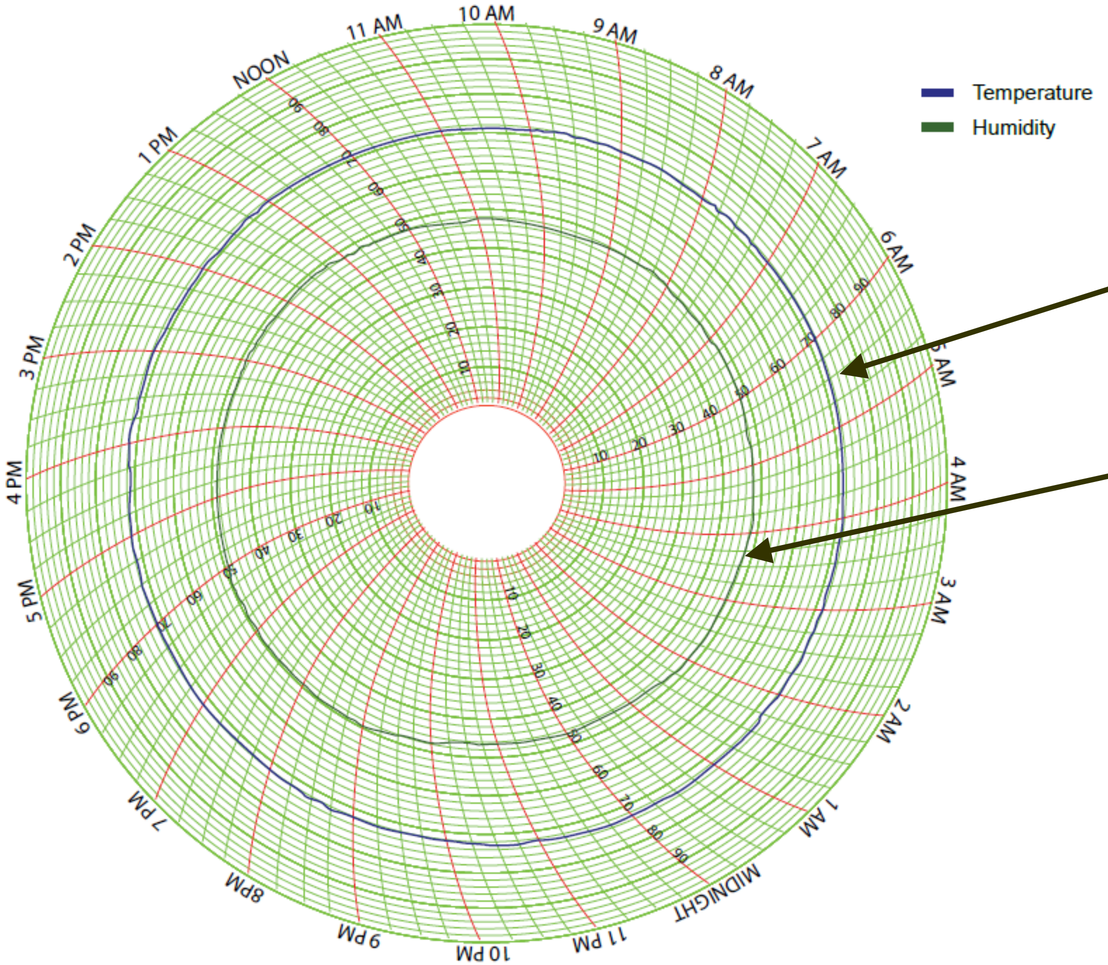
Variable Compressor Modulating Reheat



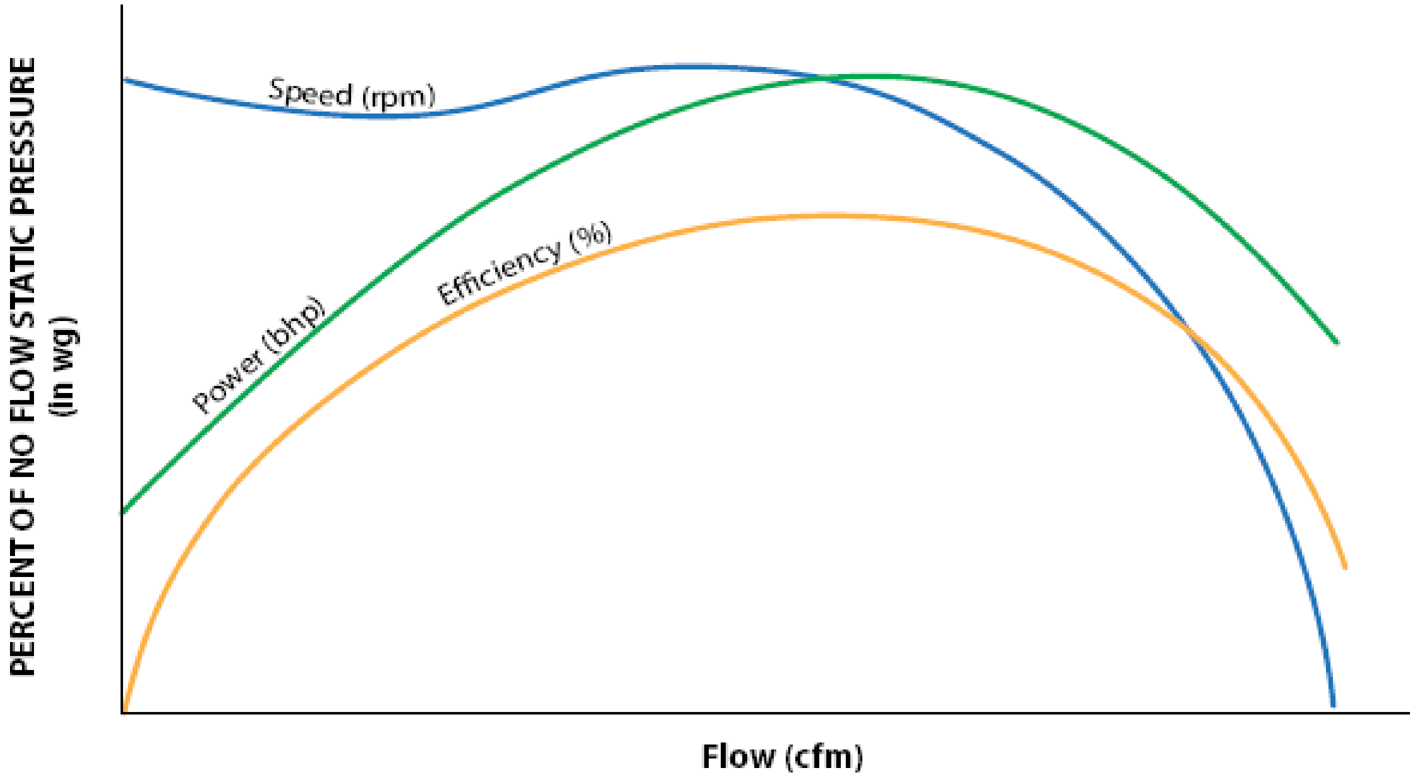
DB Temperature

Relative Humidity

Higher Efficiency Fans

- Forward curve fans
  - Inexpensive
  - Most Common type in packaged equipment
  - For low static pressure applications that are typical in comfort HVAC
  - Peak air moving efficiency ranges from 65% to 70%
- Backward incline fans
  - Can produce greater static pressures
  - Peak air moving efficiency ranges from 75% to 80%

Backward Incline Fans



Characteristic Performance Curve of a Backward Curved Centrifugal Fan

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Direct Drive Fans

- No belt service, reduced maintenance
- No belt vibration and noise
- No belt losses, higher efficiency
- Reduced bearing stress
- No belt dust, residue

Direct Drive BI Fans

Calculated Application Efficiency

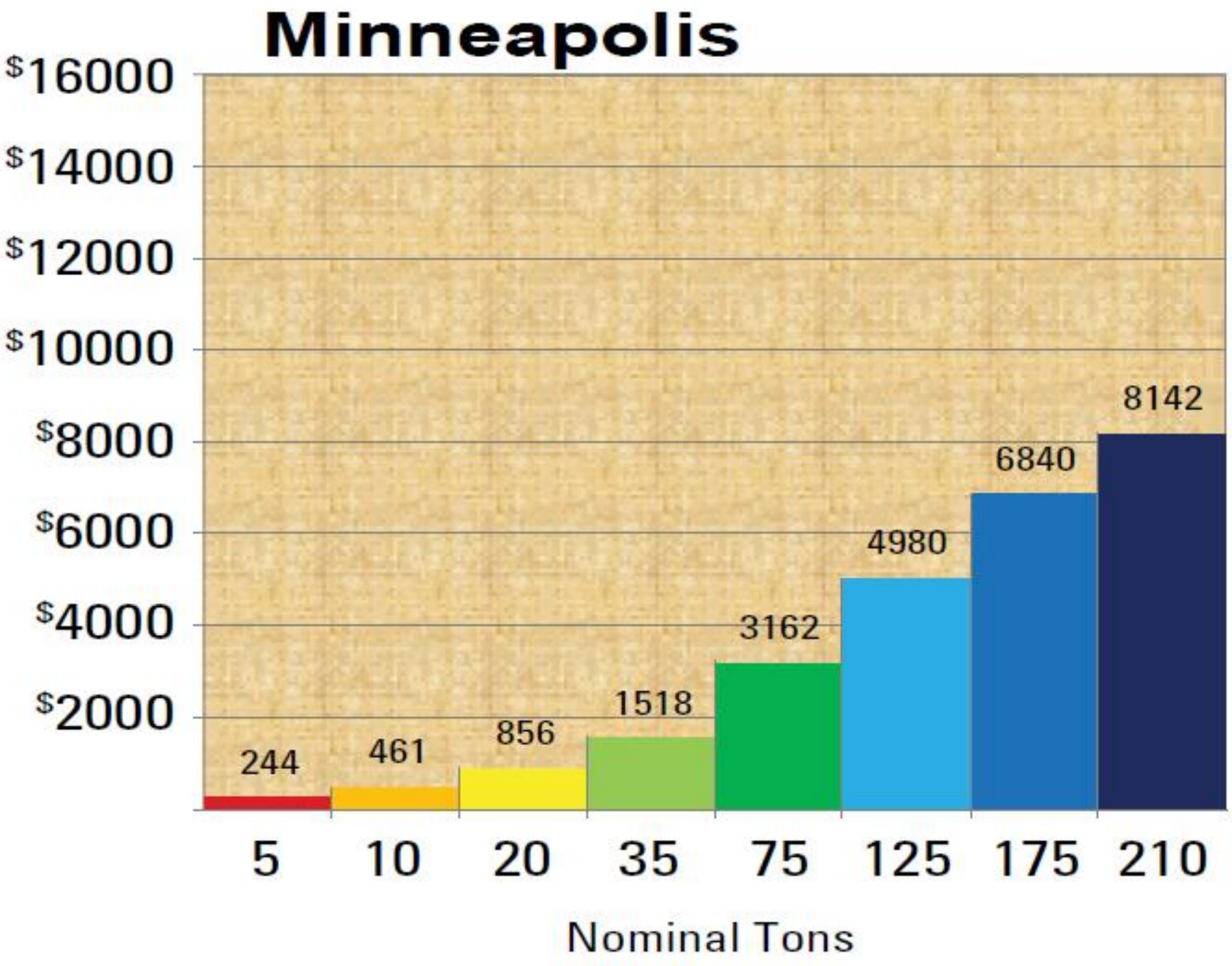
	Motor Efficiency		Belt Efficiency		Fan Efficiency		System Effects		Total System Efficiency
Belt-Driven, Housed, Forward Curved Total Efficiency =	(0.90)	•	(0.87)	•	(0.60)	•	(0.70)	=	**33%**
Belt-Driven, Housed, Backward Curved Total Efficiency =	(0.90)	•	(0.87)	•	(0.75)	•	(0.80)	=	**47%**
Direct Drive, Unhoused Backward Curved, Total Efficiency =	(0.90)	•	(1.00)	•	(0.70)	•	(1.00)	=	**63%**

- *Using the same 15hp motor in each example, the direct drive, backward curved fan is 91% more efficient than the belt driven, housed forward curved fan. It is 34% more efficient than the belt driven, housed backward curved fan.*

Construction Choices

- Typical in the industry
  - 1 inch fiberglass has an R value of 3 typical of industry
  - Upgrade to double wall to protect insulation
- Truly insulated rooftop equipment
  - Two inch foam panel with R value of 13
  - Thermal break, yielding no thermal path through the panel
  - Reduced exterior condensation
  - No air leakage through the panel
  - Improved mechanical strength and rigidity
  - Enhanced energy performance and equipment life

Foam Panel Construction



System Types

- Dual path system
  - Return air and outdoor air go through separate cooling and reheat coils.
- Return air bypass reheat system
  - Part of the return air is mixed with outside air
  - Part of the return air is mixed with air coming off the cooling and reheat coils

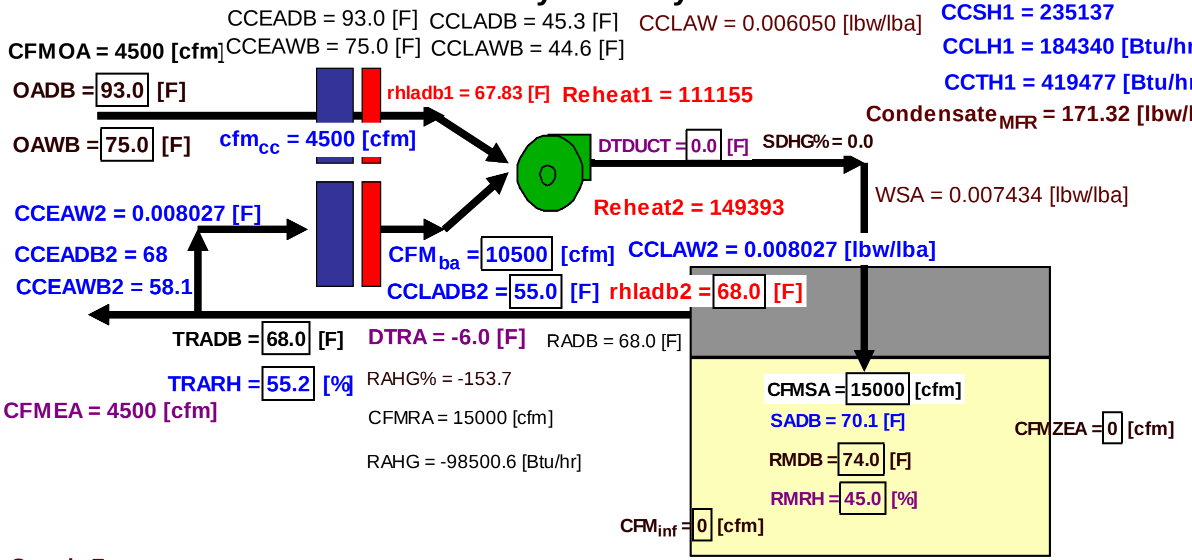
Construction Choices

- Dual Path Systems
  - Advantages
    - Provides direct control of ventilation air quantity
    - Provides excellent humidity control at all times, including part load
    - Energy efficient while assuring an acceptable humidity level at all ventilation air volumes.
    - Can use rejected heat from refrigeration sources
  - Disadvantages
    - There is a first cost premium since two coils and compressors are used.

Construction Choices

- Return Air Bypass Systems
  - Advantages
    - Typically lower first cost compared to dual path systems
    - Energy efficient when combined with other technologies (variable scroll, modulating hot gas reheat)
    - Can use rejected heat from refrigeration sources
  - Disadvantages
    - Limits to the amount of level of bypass/ dehumidification

Dual Path System Psychrometrics



CCSH1 = 235137
CCLH1 = 184340 [Btu/hr]
CCTH1 = 419477 [Btu/hr]
$Condensate_{MFR}$ = 171.32 [lbw/h

CCSH2 = 149393 [Btu/hr]
CCLH2 = 0 [Btu/hr]
CCTH2 = 149393 [Btu/hr]

CCSH1 = 235137
CCLH1 = 184340 [Btu/h
CCTH1 = 419477 [Btu/

CCTH = 568869.8 [Btu/hr]

CCSH = 384529.8 [Btu/hr]

CCLH = 184340.0 [Btu/hr]

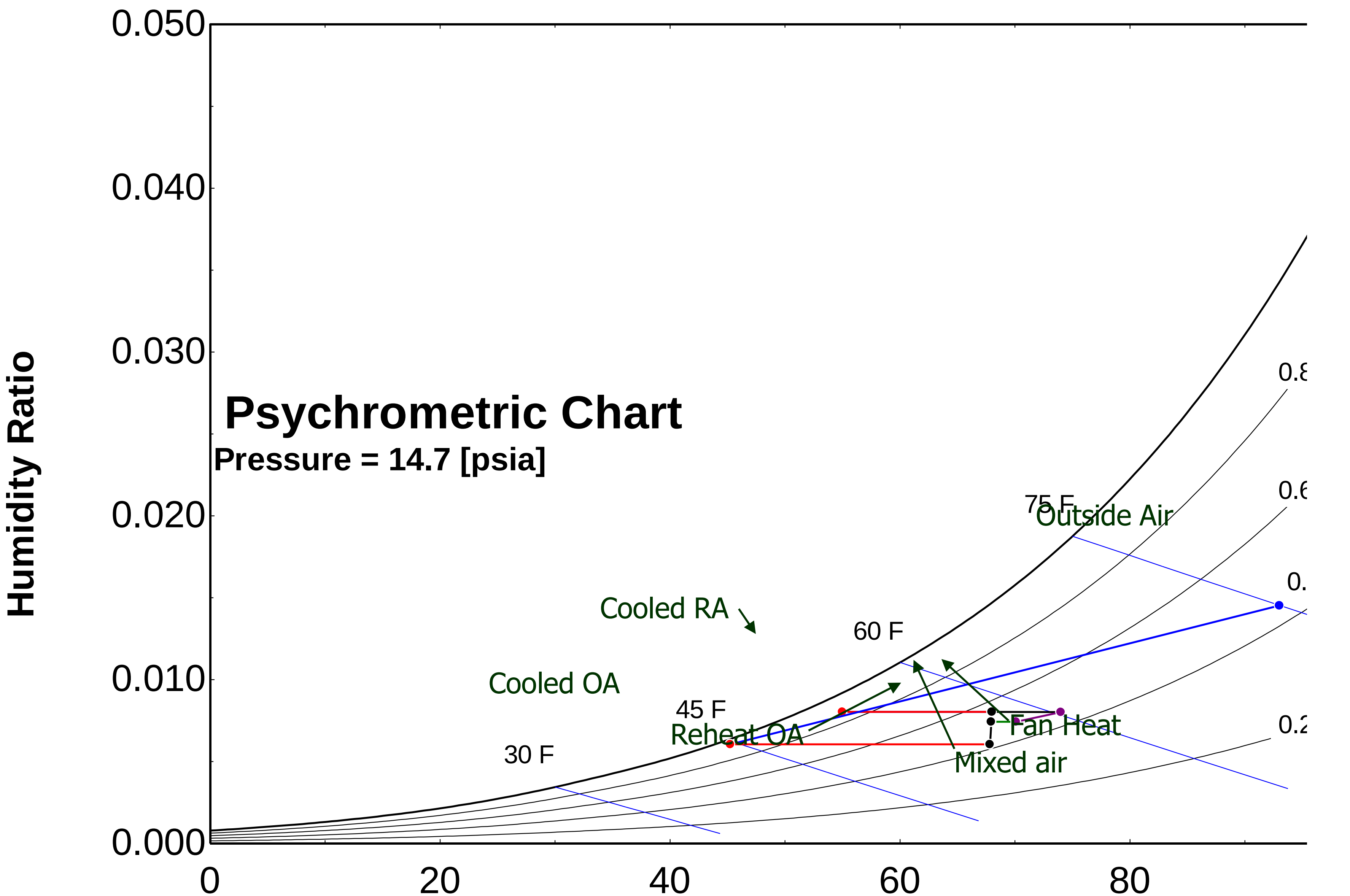
Supply Fan

FAN_{EFF} = 0.55
$MOTOR_{EFF}$ = 0.93
FAN_{DP} = 3.0 [in. wg.]
SFHG% = 55
DTFAN = 2.1 [F]
FNPWR = 10.33 [kW]
HP_{fan} = 12.87 [hp]

RSH_{sub} = 64100 [Btu/hr] $RSH_{infiltration}$ = 0 [Btu/hr] RSH = 64100.0 [Btu/hr]
RLH_{sub} = 42733 [Btu/hr] $RLH_{infiltration}$ = 0 [Btu/hr] RLH = 42733 [Btu/hr] RSHR = 0.6

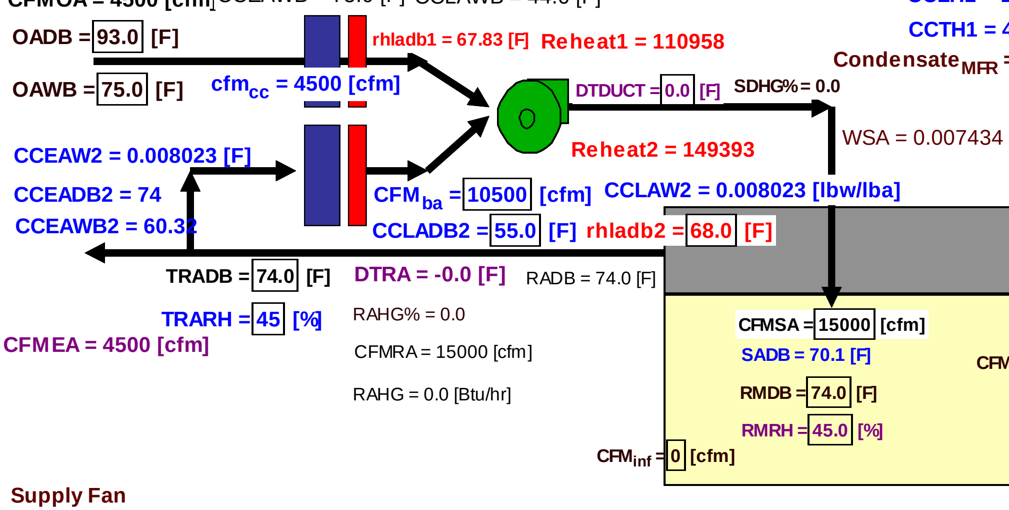
MADB = 93.0 [F]
MAWB = 75.0 [F]

ALTITUDE = 0 [ft]
PB = 14.696 [psia]
AltStdDen = 0.075 [ft^3/lba]
K_{sens} = 1.09
K_{lat} = 4835



Psychrometric Chart
Pressure = 14.7 [psia]
Humidity Ratio
0.050
0.040
0.030
0.020
0.010
0.000
0
20
40
60
80
30 F
45 F
60 F
75 F
Outside Air
Cooled RA
Cooled OA
Reheat OA
Fan Heat
Mixed air

Dual Path System Psychrometrics



CCSH1 = 234940
CCLH1 = 184138 [Btu/hr]
CCTH1 = 419078 [Btu/hr]
Condensate$_{MFR}$ = 171.13 [lbw/h

CCSH2 = 218343 [Btu/hr]
CCLH2 = 0 [Btu/hr]
CCTH2 = 218343 [Btu/hr]

CCSH1 = 234940
CCLH1 = 184138 [Btu/h
CCTH1 = 419078 [Btu/h

CCTH = 637421.2 [Btu/hr]

CCSH = 453283.3 [Btu/hr]

CCLH = 184137.9 [Btu/hr]

Supply Fan

FAN$_{EFF}$ = 0.55
MOTOR$_{EFF}$ = 0.93
FAN$_{DP}$ = 3.0 [in. wg.]
SFHG% = 55
DTFAN = 2.1 [F]
FNPWR = 10.33 [kW]
HP$_{fan}$ = 12.87 [hp]

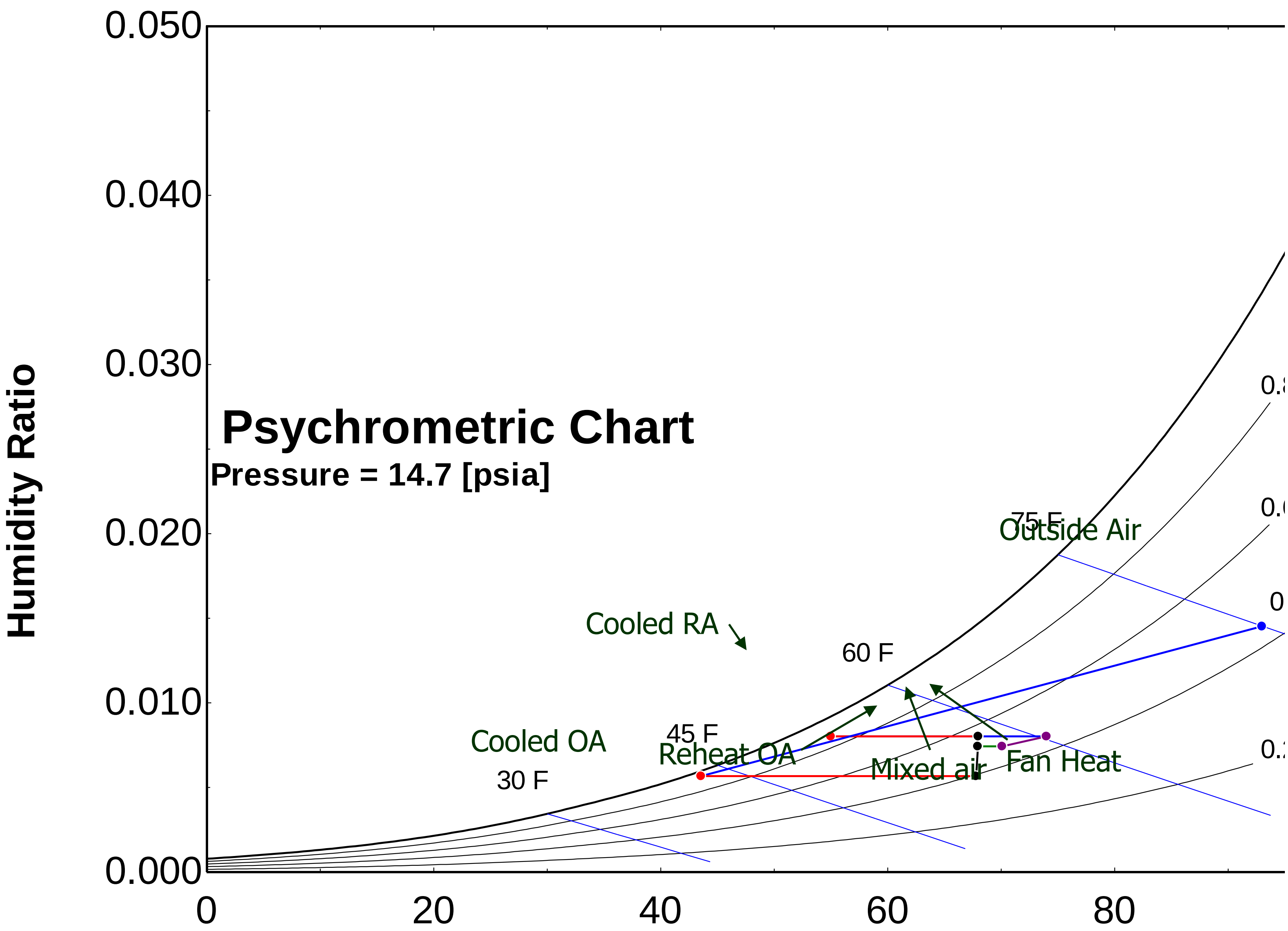
RSH$_{sub}$ = 64100 [Btu/hr]
RLH$_{sub}$ = 42733 [Btu/hr]

RSH$_{infiltration}$ = 0 [Btu/hr]
RLH$_{infiltration}$ = 0 [Btu/hr]

RSH = 64100.0 [Btu/hr]
RLH = 42733 [Btu/hr]
RSHR = 0.6

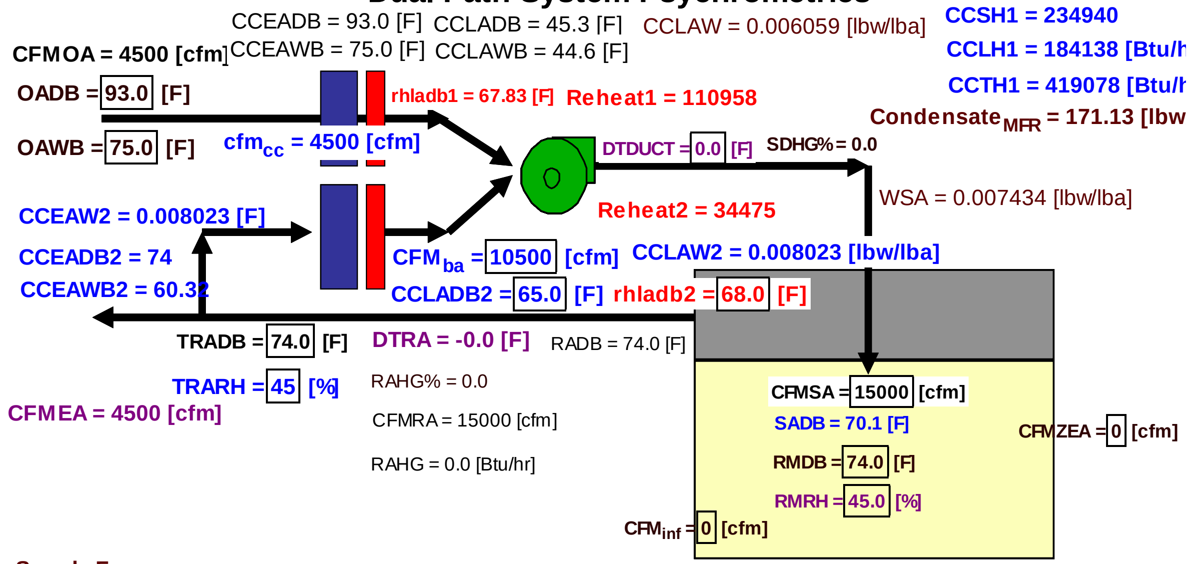
MADB = 93.0 [F]
MAWB = 75.0 [F]

ALTITUDE = 0 [ft]
PB = 14.696 [psia]
AltStdDen = 0.075 [ft^3/lba]
K$_{sens}$ = 1.09
K$_{lat}$ = 4835



Psychrometric Chart
Pressure = 14.7 [psia]
Humidity Ratio
0.050
0.040
0.030
0.020
0.010
0.000
0
20
40
60
80
Outside Air
75 F
Cooled RA
60 F
45 F
Cooled OA
Reheat OA
30 F
Mixed air
Fan Heat

Dual Path System Psychrometrics



CCSH1 = 234940
CCLH1 = 184138 [Btu/h
CCTH1 = 419078 [Btu/h
Condensate$_{MFR}$ = 171.13 [lbw

CCSH2 = 103426 [Btu/hr]
CCLH2 = 0 [Btu/hr]
CCTH2 = 103426 [Btu/hr]

CCSH1 = 234940
CCLH1 = 184138 [Btu/h
CCTH1 = 419078 [Btu/h

CCTH = 522503.8 [Btu/hr]

CCSH = 338366.0 [Btu/hr]

CCLH = 184137.9 [Btu/hr]

Supply Fan

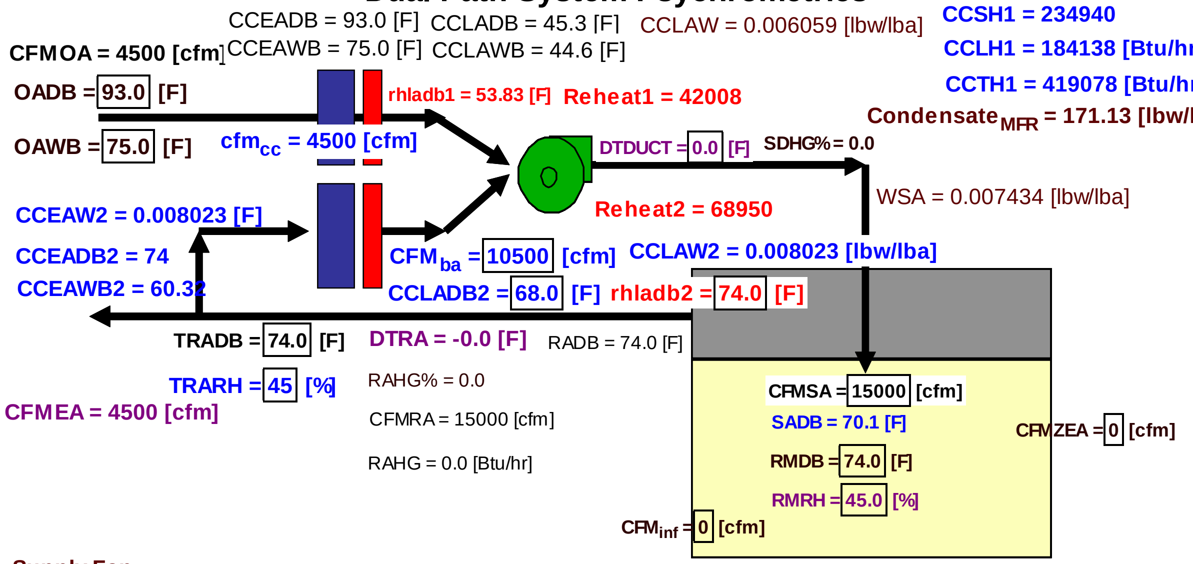
FAN$_{EFF}$ = 0.55
MOTOR$_{EFF}$ = 0.93
FAN$_{DP}$ = 3.0 [in. wg.]
SFHG% = 55
DTFAN = 2.1 [F]
FNPWR = 10.33 [kW]
HP$_{fan}$ = 12.87 [hp]

RSH$_{sub}$ = 64100 [Btu/hr]
RLH$_{sub}$ = 42733 [Btu/hr]
RSH$_{infiltration}$ = 0 [Btu/hr]
RLH$_{infiltration}$ = 0 [Btu/hr]
RSH = 64100.0 [Btu/hr]
RLH = 42733 [Btu/hr]
RSHR = 0.6

MADB = 93.0 [F]
MAWB = 75.0 [F]

ALTITUDE = 0 [ft]
PB = 14.696 [psia]
AltStdDen = 0.075 [ft^3/lba]
K$_{sens}$ = 1.09
K$_{lat}$ = 4835

Dual Path System Psychrometrics



CCSH1 = 234940

CCLH1 = 184138 [Btu/hr]

CCTH1 = 419078 [Btu/hr]

$Condensate_{MFR}$ = 171.13 [lbw/h

CCSH2 = 68950 [Btu/hr]

CCLH2 = 0 [Btu/hr]

CCTH2 = 68950 [Btu/hr]

CCSH1 = 234940

CCLH1 = 184138 [Btu/h

CCTH1 = 419078 [Btu/h

CCTH = 488028.6 [Btu/hr]

CCSH = 303890.7 [Btu/hr]

CCLH = 184137.9 [Btu/hr]

Supply Fan

FAN_{EFF} = 0.55

$MOTOR_{EFF}$ = 0.93

FAN_{DP} = 3.0 [in. wg.]

SFHG% = 55

DTFAN = 2.1 [F]

FNPWR = 10.33 [kW]

HP_{fan} = 12.87 [hp]

RSH_{sub} = 64100 [Btu/hr]

RLH_{sub} = 42733 [Btu/hr]

$RSH_{infiltration}$ = 0 [Btu/hr]

$RLH_{infiltration}$ = 0 [Btu/hr]

RSH = 64100.0 [Btu/hr]

RLH = 42733 [Btu/hr]

RSHR = 0.6

MADB = 93.0 [F]

MAWB = 75.0 [F]

ALTITUDE = 0 [ft]

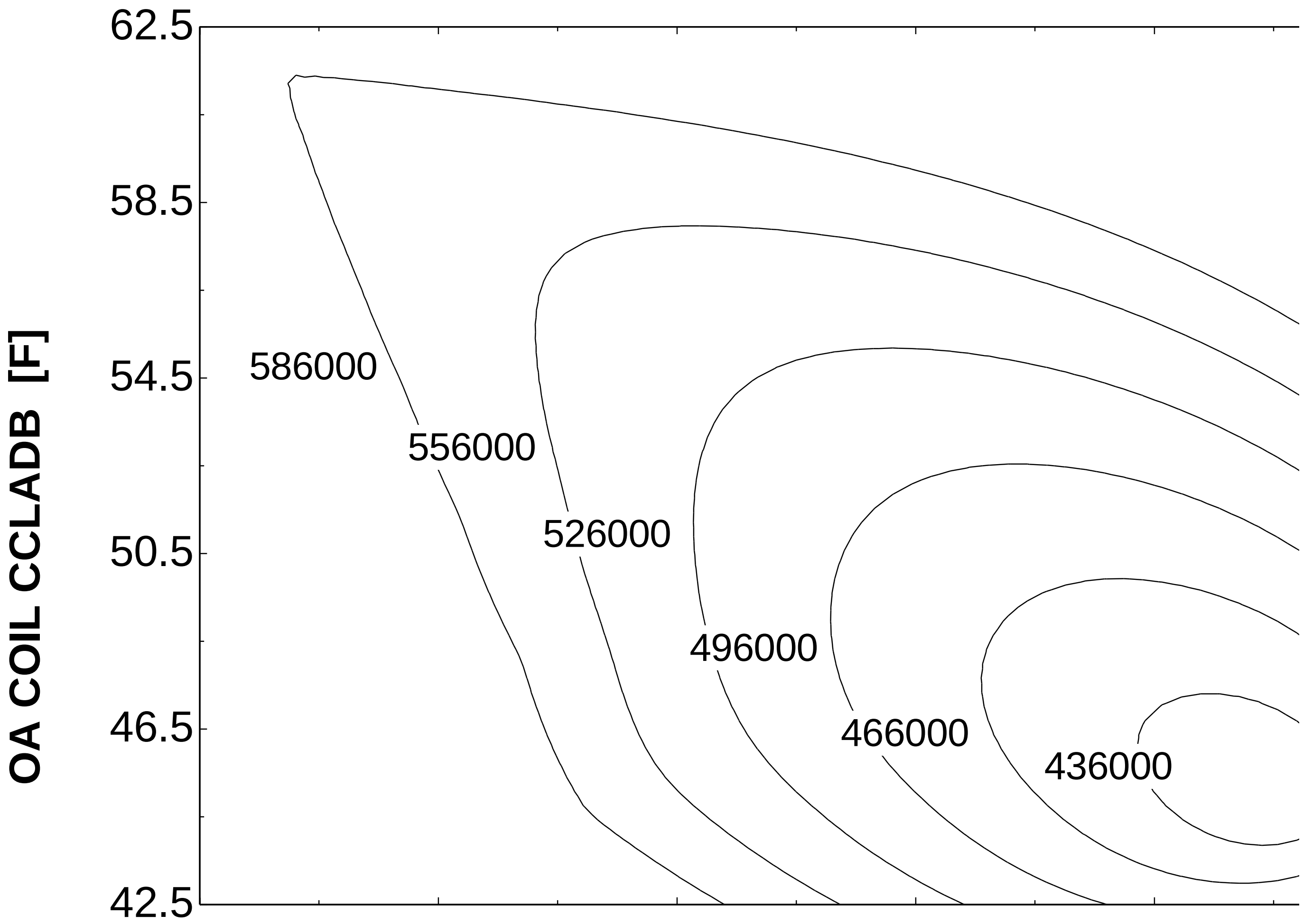
PB = 14.696 [psia]

AltStdDen = 0.075 [ft^3/lba]

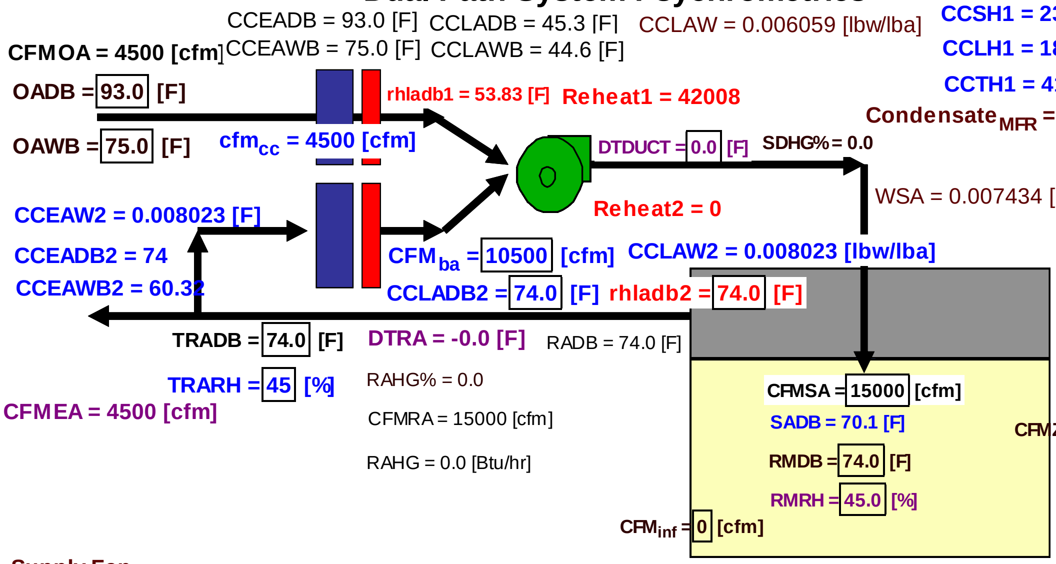
K_{sens} = 1.09

K_{lat} = 4835

Total Cooling vs OA & RA COIL LADB



Dual Path System Psychrometrics



CCSH1 = 234940
CCLH1 = 184138 [Btu/hr]
CCTH1 = 419078 [Btu/hr]
Condensate$_{MFR}$ = 171.13 [lbw/h

CCSH2 = 0 [Btu/hr]
CCLH2 = 0 [Btu/hr]
CCTH2 = 0 [Btu/hr]

CCSH1 = 234940
CCLH1 = 184138 [Btu/hr]
CCTH1 = 419078 [Btu/hr]

CCTH = 419078.2 [Btu/hr]

CCSH = 234940.3 [Btu/hr]

CCLH = 184137.9 [Btu/hr]

Supply Fan

FAN_{EFF} = 0.55

$MOTOR_{EFF}$ = 0.93

FAN_{DP} = 3.0 [in. wg.]

SFHG% = 55

DTFAN = 2.1 [F]

FNPWR = 10.33 [kW]

HP_{fan} = 12.87 [hp]

RSH_{sub} = 64100 [Btu/hr] | $RSH_{infiltration}$ = 0 [Btu/hr] | RSH = 64100.0 [Btu/hr]

RLH_{sub} = 42733 [Btu/hr] | $RLH_{infiltration}$ = 0 [Btu/hr] | RLH = 42733 [Btu/hr] | RSHR = 0.6

MADB = 93.0 [F]

MAWB = 75.0 [F]

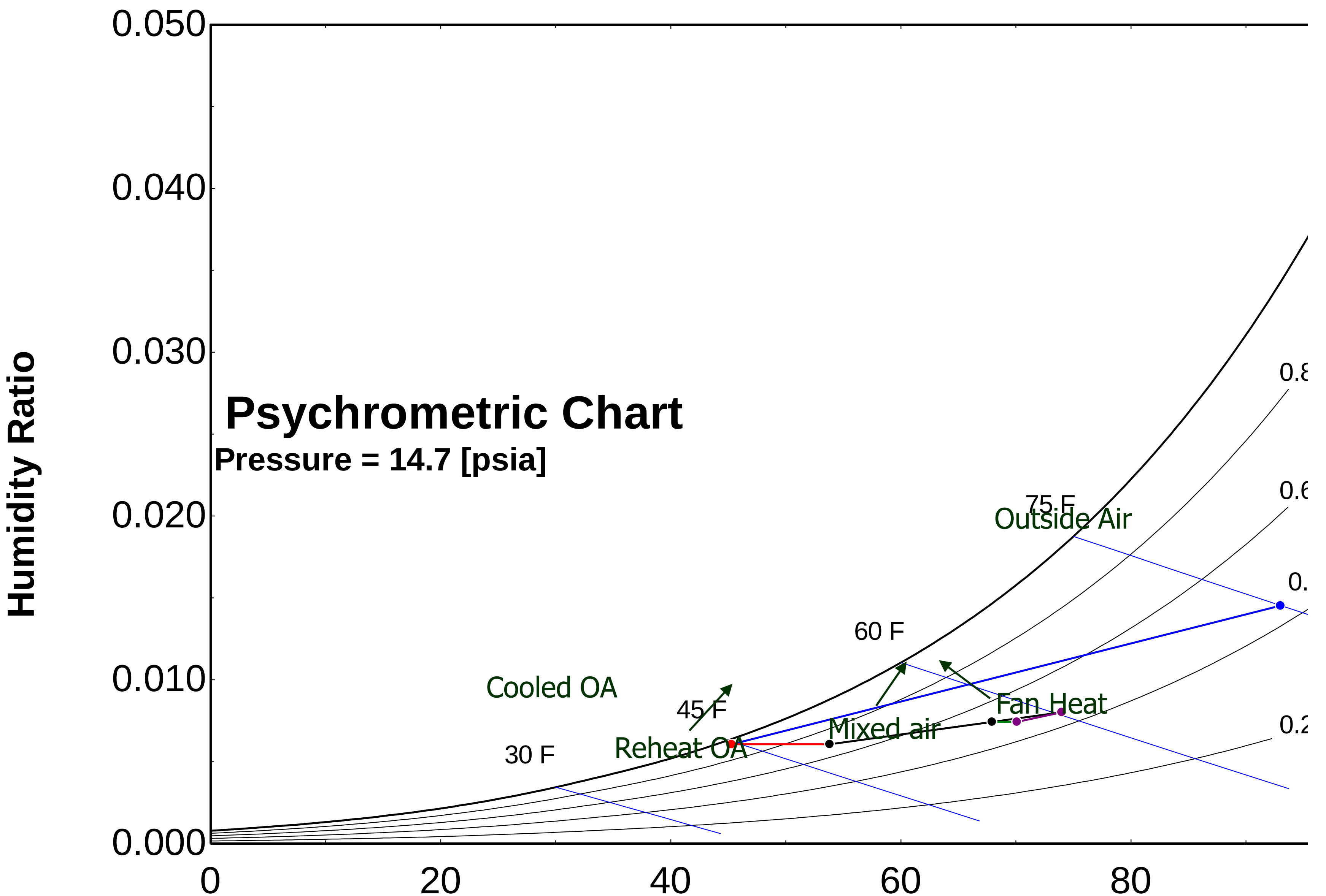
ALTITUDE = 0 [ft]

PB = 14.696 [psia]

AltStdDen = 0.075 [ft^3/lba]

K_{sens} = 1.09

K_{lat} = 4835


Psychrometric Chart
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60 F
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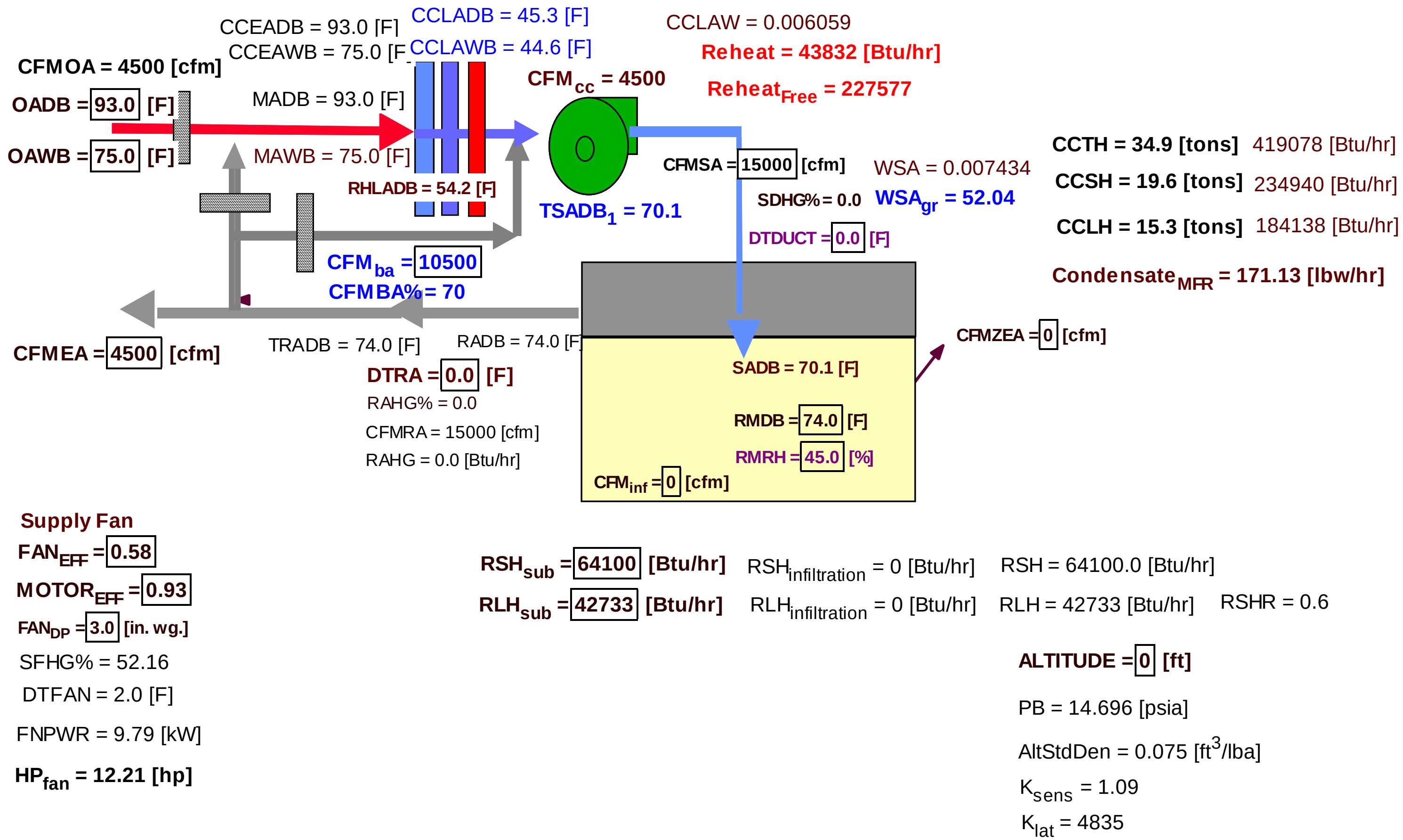
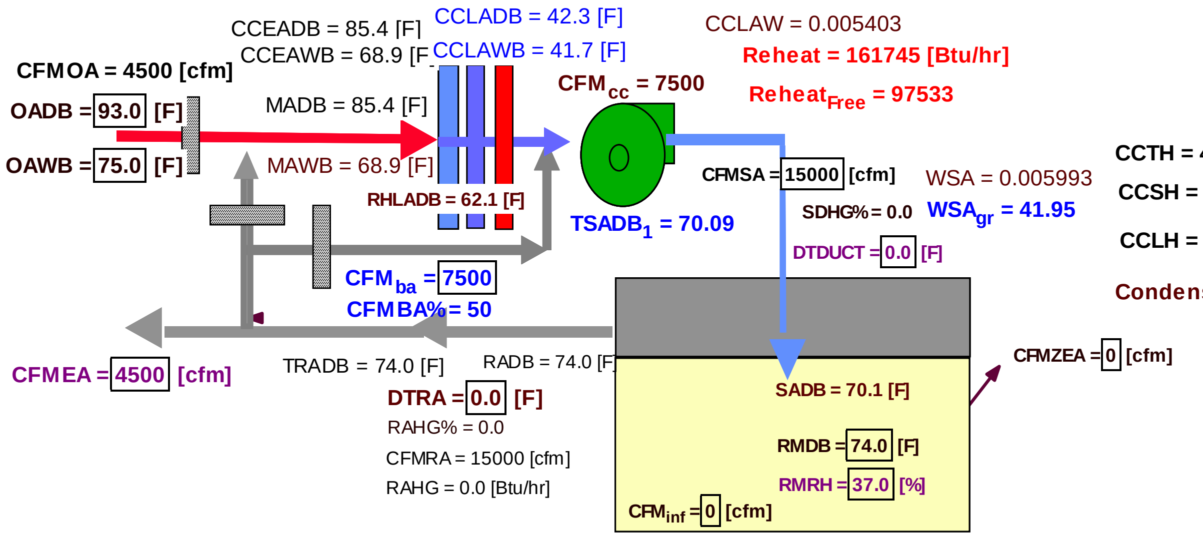
Cooled OA
Reheat OA
Mixed air
Fan Heat

Return Air Bypass Reheat System Psychrometrics



Return Air Bypass Reheat System Psychrometrics



CCTH = 47.3 [tons] 568108 [Btu/hr]

CCSH = 29.4 [tons] 352608 [Btu/hr]

CCLH = 18.0 [tons] 215500 [Btu/hr]

Condensate$_{MFR}$ = 200.28 [lbw/hr]

Supply Fan

FAN$_{EFF}$ = 0.58

MOTOR$_{EFF}$ = 0.93

FAN$_{DP}$ = 3.0 [in. wg.]

SFHG% = 52.16

DTFAN = 2.0 [F]

FNPWR = 9.79 [kW]

HP$_{fan}$ = 12.21 [hp]

RSH$_{sub}$ = 64100 [Btu/hr] RSH$_{infiltration}$ = 0 [Btu/hr] RSH = 64100.0 [Btu/hr]

RLH$_{sub}$ = 42733 [Btu/hr] RLH$_{infiltration}$ = 0 [Btu/hr] RLH = 42733 [Btu/hr] RSHR = 0.6

ALTITUDE = 0 [ft]

PB = 14.696 [psia]

AltStdDen = 0.075 [ft^3/lba]

K_{sens} = 1.09

K_{lat} = 4835

Summary

- Variable (digital) scroll compressors
- Direct drive backward incline fans
- Modulating hot gas reheat
- Insulation construction
- Return air bypass with reheat, a less expensive alternative