I Fought the Law (and the Law Won)

The second law that is.

Written by Sonny Curtis from Buddy Holly's group, sung by Bobby Fuller

I'm breakin' rocks in the hot sun
I fought the law and the law won
I fought the law and the law won

I needed money 'cause I had none
I fought the law and the law won
I fought the law and the law won

I left my baby and I feel so sad
I guess my race is run
But she's the best girl I've ever had
I fought the law and the law won
I fought the law and the law won

Robbin' people with a six-gun
I fought the law and the law won
I fought the law and the law won

I miss my baby and the good fun
I fought the law and the law won
I fought the law and the law won

I left my baby and I feel so sad
I guess my race is run
But she's the best girl I've ever had
I fought the law and the law won
I fought the law and the law won

About Ultra-Aire

- A Divisions of Therma-Stor
- Established in 1977
- Made in Madison, WI
- We specialize in dehumidification & heat reclaim products
- Pioneers of whole-house dehumidifiers and crawl space dehumidifiers

PHOENIX RESTORATION EQUIPMENT

Therma-Stor

HI-E DRY
HIGH EFFICIENCY DEHUMIDIFICATION

Ultra·Aire

Santa·Fe

Before

After

Before

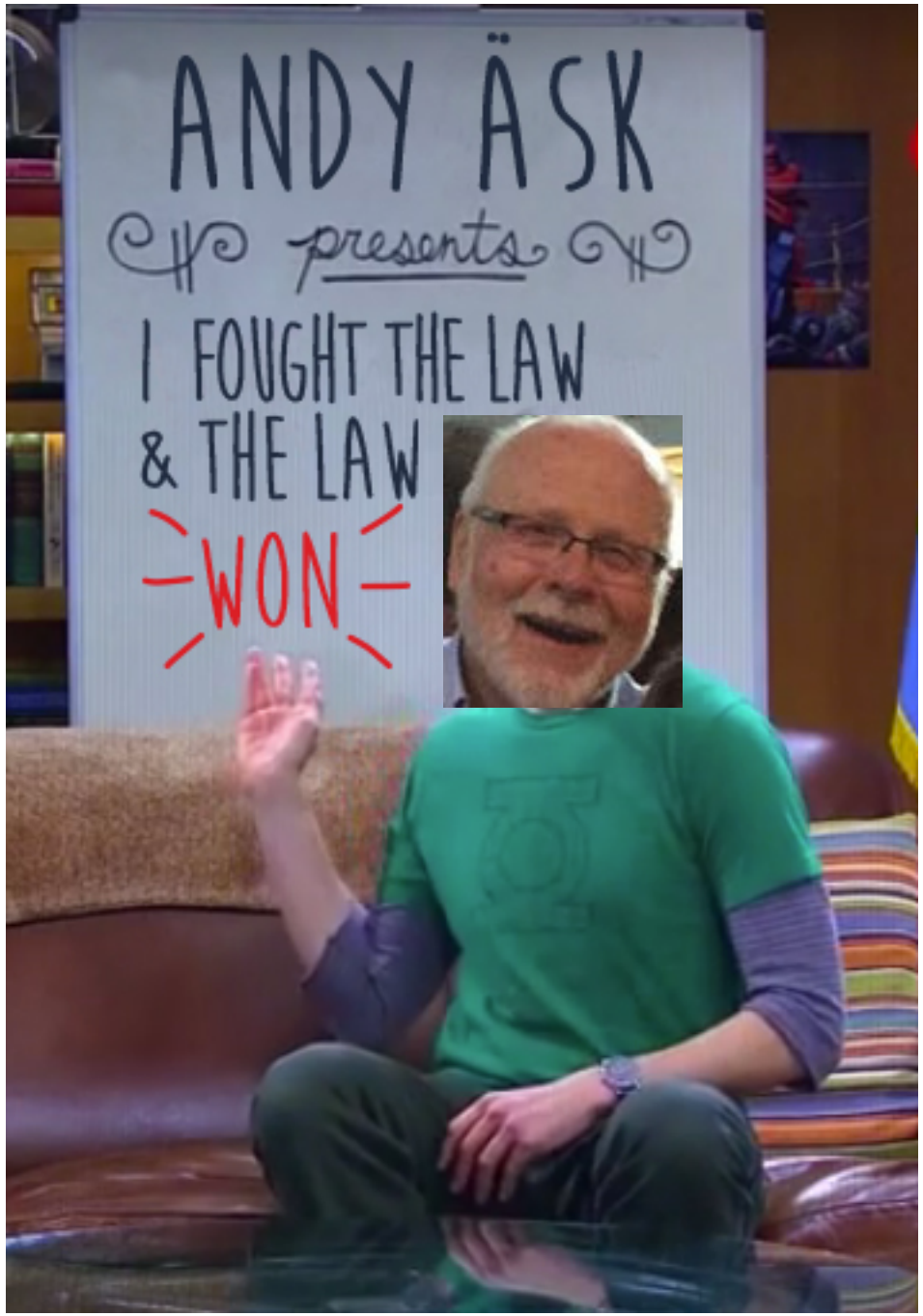
After

Second Law

- High to Low
- Warm to Cold
- Wet to Dry

But what are the other Law’s of Thermodynamics?

“All energy deserves the same entropy!”


ANDY ÄSK
presents
I FOUGHT THE LAW
& THE LAW
WON

The Commonwealth of Massachusetts

The House of Representatives

Be it hereby known to all that:
The Massachusetts House of Representatives
offers its sincerest congratulations to:

JOSEPH WILLIAM LSTIBUREK

in recognition of
RECEIVING YOUR UNITED STATES CITIZENSHIP,
AND CONGRATULATIONS TO OUR NEWEST AMERICAN
ON THIS MOST AUSPICIOUS OCCASION!
The entire membership extends its very best wishes
and expresses the hope for future good fortune
and continued success in all endeavors.

Given this 26TH day of JULY, 2017
At the State House, Boston, Massachusetts

by: _____
Robert A. DeLeo
Speaker of the House

Offered by: _____
State Representative
JAMES ARCIERO

Laws of Thermodynamics

Neil Moyer (and some dead guys)

Thermodynamics is a funny subject:

- The first time you go through it, you don't understand it at all.

- The second time you go through it, you think you understand it

- The third time you go through it, you know you don't understand it, but by that time you are so used to it, you don’t care anymore.

History of Thermodynamics

- 1824 Sadi Carnot: Cycle, T Source and T Sink – Thermal Efficiency
- 1850 Rudolf Clausius: Heat cannot, of itself, pass from a lower to a higher temperature. Entropy. 2nd Law
- 1852 William Thomson (Lord Kelvin): Absolute Temperature.
- 1906 Walther Nernst: Entropy at absolute zero is a constant. 3rd Law
- 1935 Ralph Fowler names Zeroth Law

Laws of Thermodynamics

- 1st – Energy can be neither created nor destroyed; only converted.
- 2nd – The available energy of the isolated system decreases in all real processes (and is conserved in reversible processes).
- 3rd – the entropy of a pure substance in complete thermodynamic equilibrium becomes zero at the absolute zero of temperature
- Zeroth: If a body is in equilibrium with two others, they are in equilibrium with each other.

Laws of Thermodynamics

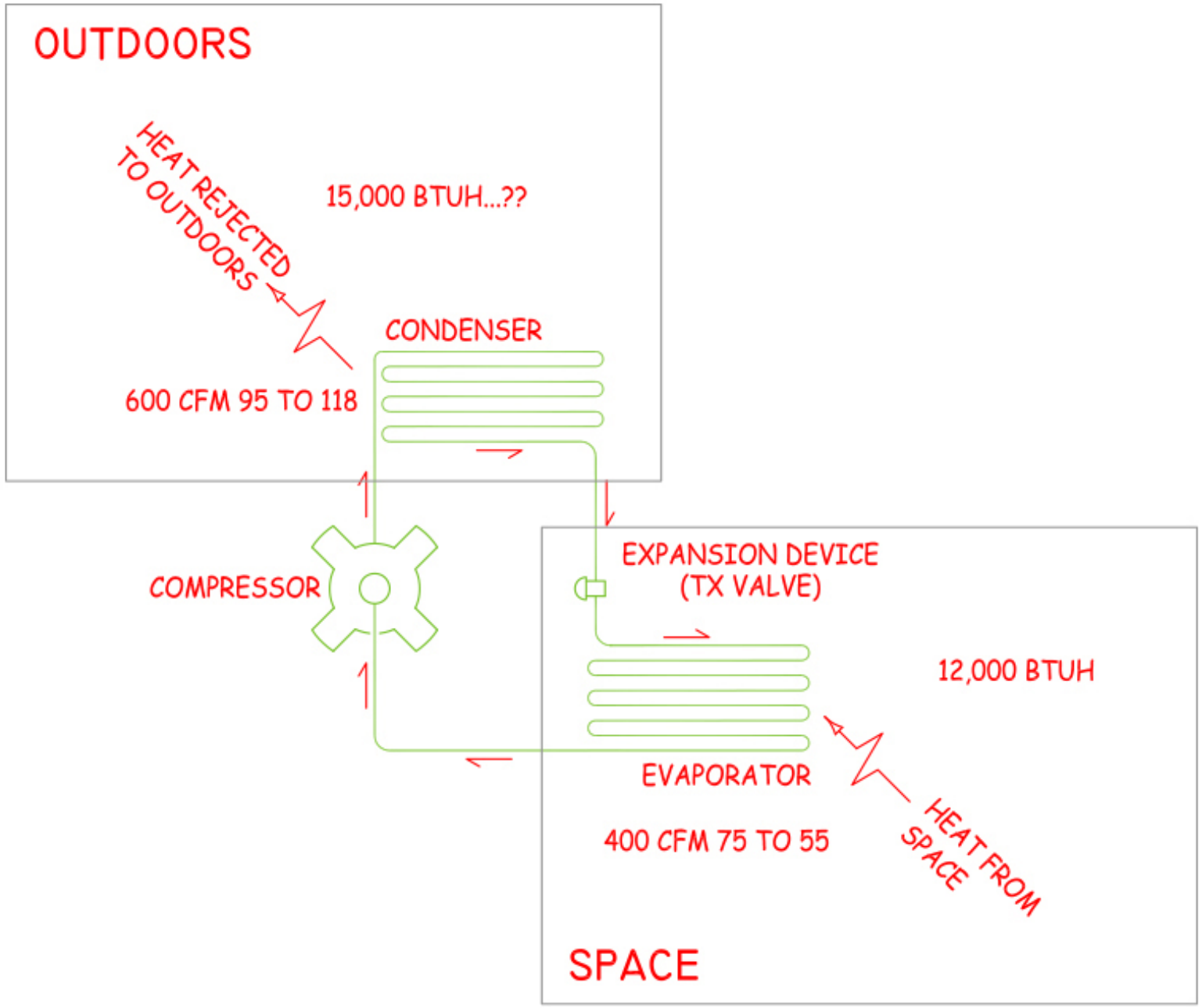
- You can’t win
- You can’t even break even
- And you can’t get out of the game.
- Heavyweights fight to a draw.

What We Need to Know

- 1st : Conservation of Energy
- 2nd : Entropy increases, available energy decreases in real processes.
- 3rd : Absolute zero cannot be attained.
- Zeroth: no $\mathrm{D}T$, no $\mathrm{D}Q$.

Basic Refrigeration

Basic Refrigeration Cycle



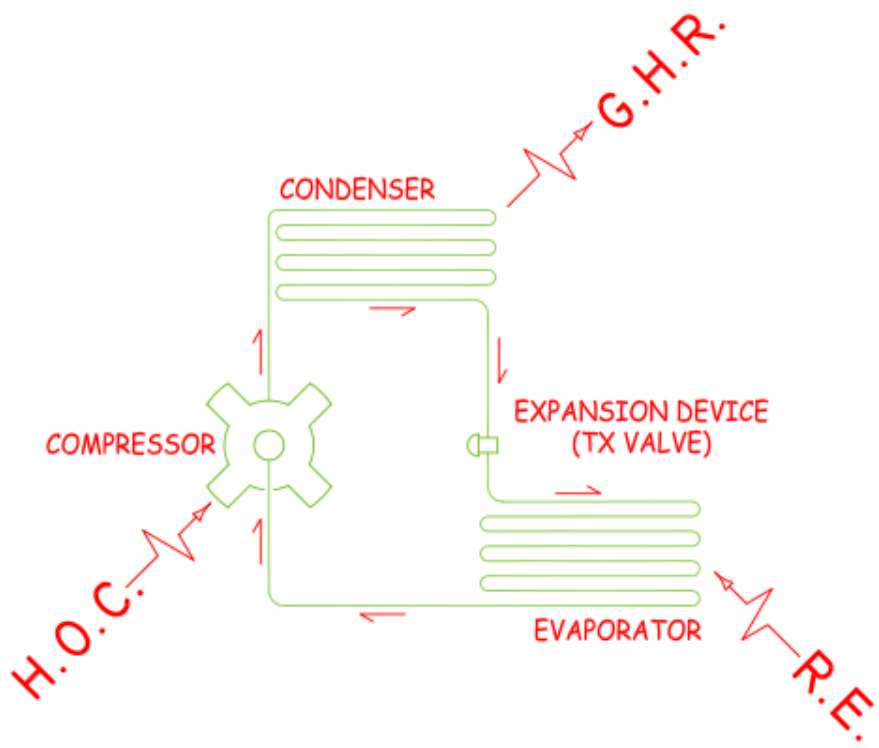
Basic Refrigeration Cycle

R.E. = REFRIGERATION EFFECT

+

H.O.C. = HEAT OF COMPRESSION

G.H.R. = GROSS HEAT REJECTION



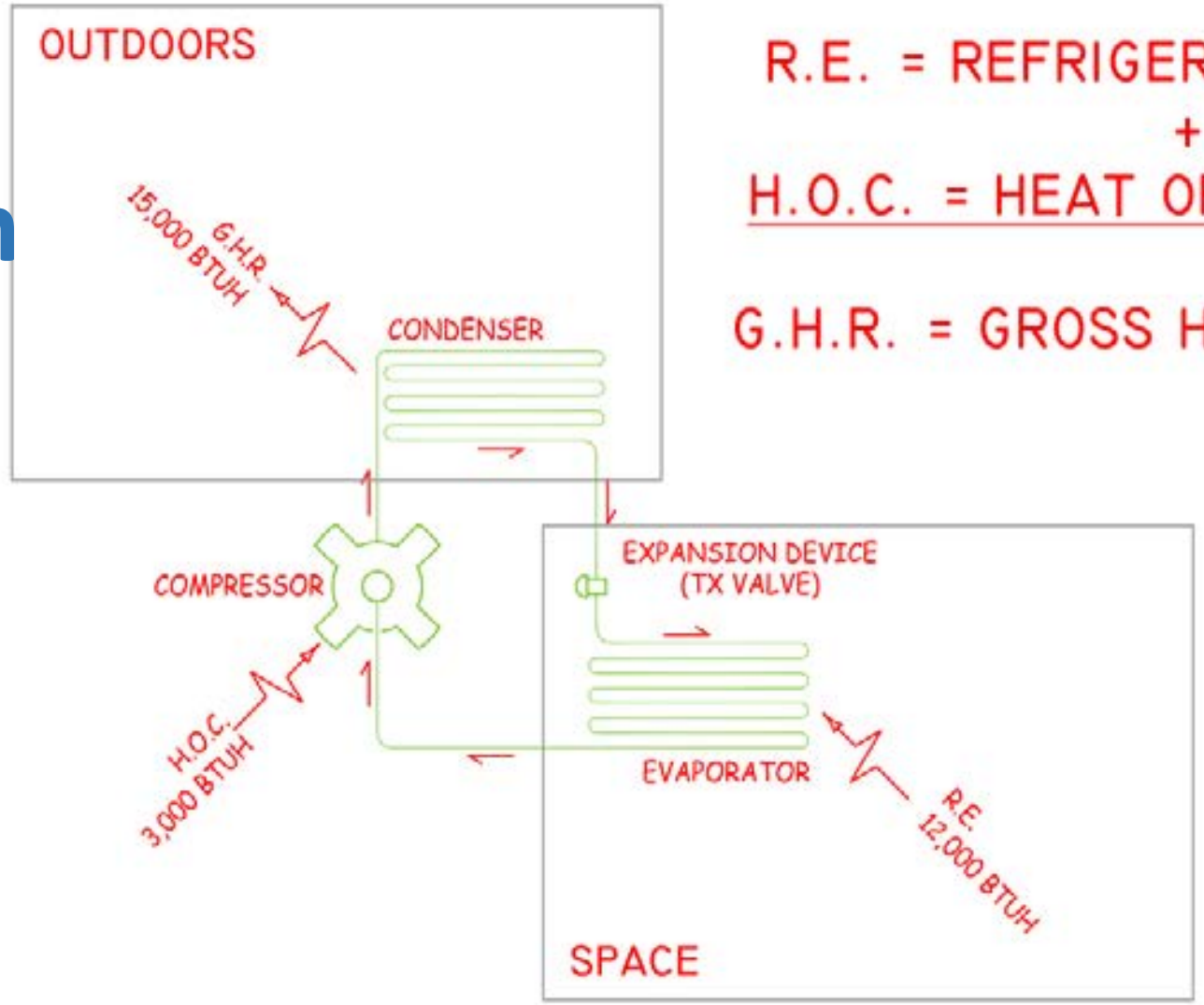
BASIC REFRIGERATION CYCLE

R.E. + H.O.C. = G.H.R.

Basic Refrigeration Cycle

Carnot Axiom:

A cycle not receiving work cannot transfer heat from the cold to the hot reservoir.



R.E. = REFRIGERATION EFFECT

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BASIC REFRIGERATION CYCLE

R.E. + H.O.C. = G.H.R.

Gross Heat Rejection

If Cooling: GHR is “gross” – waste

If Heating: GHR is “gold” – the end product

Coefficient of Performance

$$\frac{\text{12,000 BTUH}}{\text{3,000 BTUH}} = \text{4.0 C.O.P.}$$

Cooling

$$\frac{\text{15,000 BTUH}}{\text{3,000 BTUH}} = \text{5.0 C.O.P.}$$

Heating

EPA Mileage for Air Conditioners

We can use C.O.P. as "EPA Mileage"

(But I'm too lazy to convert Watts to BTUH, so…)

12,000 Apples

1,000 Oranges x 1,000 = 12.0 Apples/Oranges x 1,000

OR

- **12.0 Energy Efficiency Ratio = 12.0 EER**

- But that's just in town. How about "Highway Mileage?"
- Just factor in how the A/C works at part load in different seasons, and we have: Seasonal Energy Efficiency Ratio (SEER)

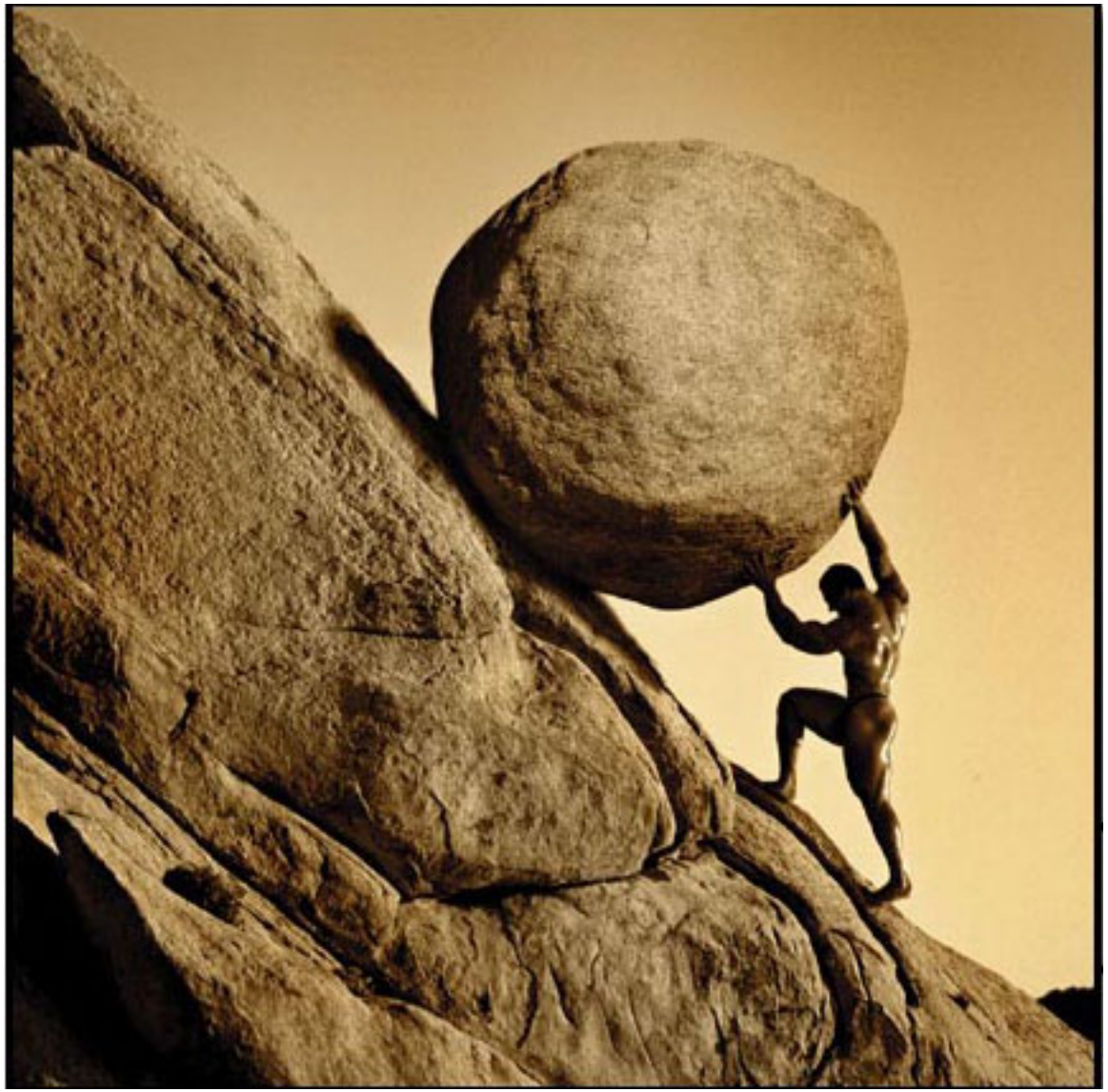
What We've Heard

- There's no such thing as a free thermodynamic lunch.
- The three biggest problems in buildings are WATER, WATER, and WATER.
- When the rater of entry is greater than the rate of removal, accumulation occurs.
- Don't be a dope…slope.
- Drain the Rain Mainly on the Plane.
- If you want to save cash, flash.
- If someone invented wood today, it would never be approved as a building material. It burns, it rots, it has different properties based upon orientation, and worst of all it sees relative humidity and not vapor pressure.
- OBS is the Spam of wood. SPAM is the OSB of luncheon meats.

- Engineered wood is an insult to engineers and wood.
- Cellulose Insulation: the best use for the New York Times.
- Old mold with no teeth can eat paper.
- Greenboard: coloring paper green to protect it from mold is like putting lipstick on a pig.
- Even the dumbest of the three little pigs did not build his house out of paper.
- The folks that can sense vapor pressure differences also see dead people.
- Concentration Gradients – Water moves from more to less. You can do this experiment at home. Take a dry thing and touch a wet thing. The dry thing becomes wet.
- There are only two kinds of windows in the world…those that leak and those that will leak.

- A leak is not a leak unless the client sees it.
- ASTM stands for “Another Stupid Testing Method”
- Congress sucks.
- Don’t fight Mother Nature.
- We have the technology.
- Money for nothin' and the chicks for free.
- You don’t get the dough unless you do the show.
- Betsy Rules.

Sisyphus



“…the maintenance of desired humidity limits under certain load conditions may only be possible by using reheat.”

- Willis Carrier, *Modern Air Conditioning*, 1940

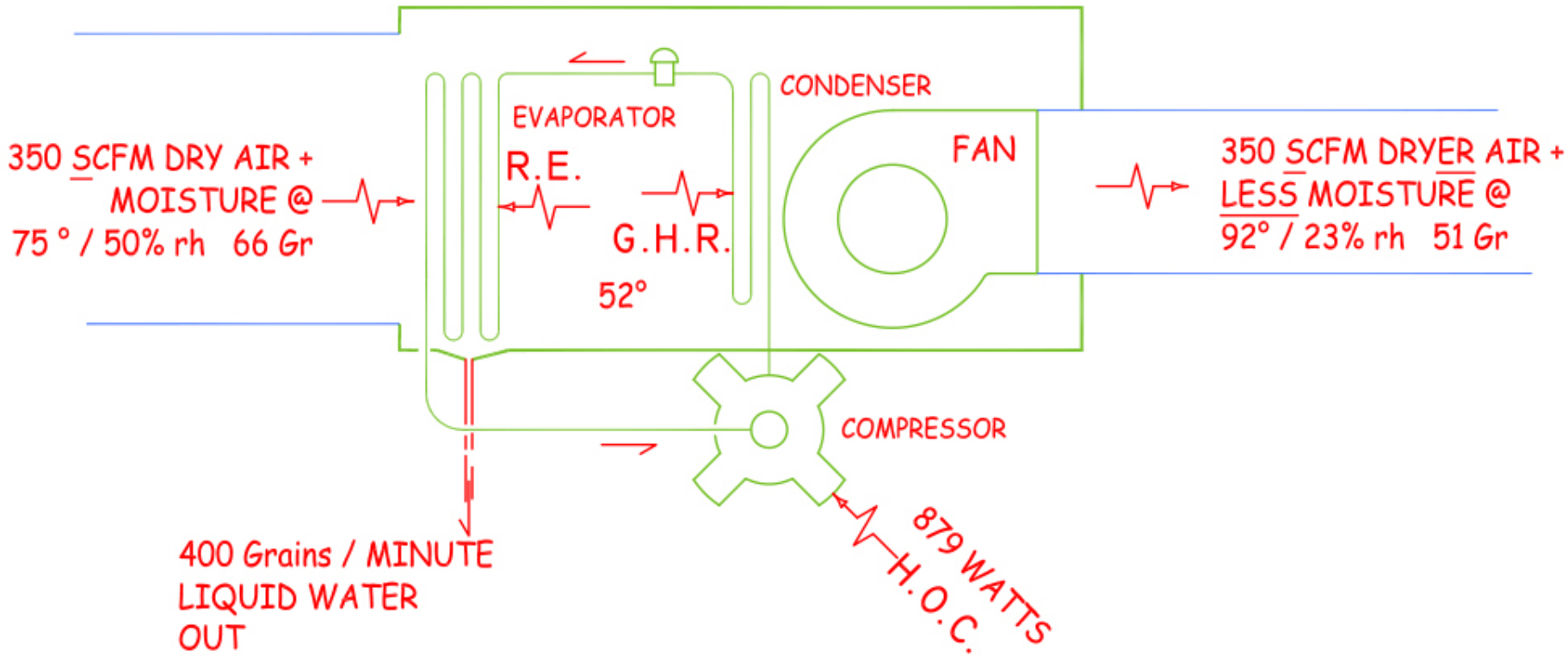
And he went on to say:

“One of the more convenient sources of reheat energy is the hot gas discharged by the refrigerant compressor.”

Evolution of Dehumidification

- 1900 Carrier dehumidifies Brooklyn printing plants
- 1940 Carrier writes reheat and hot gas is solution
- WWII Vapor compression DH cycle
- 1950's Small dehumidifiers in basements
- 1973 Oil embargo, no reheat, no dehumidification
- 1990's Ken Gehring and others develop whole house dehumidifier

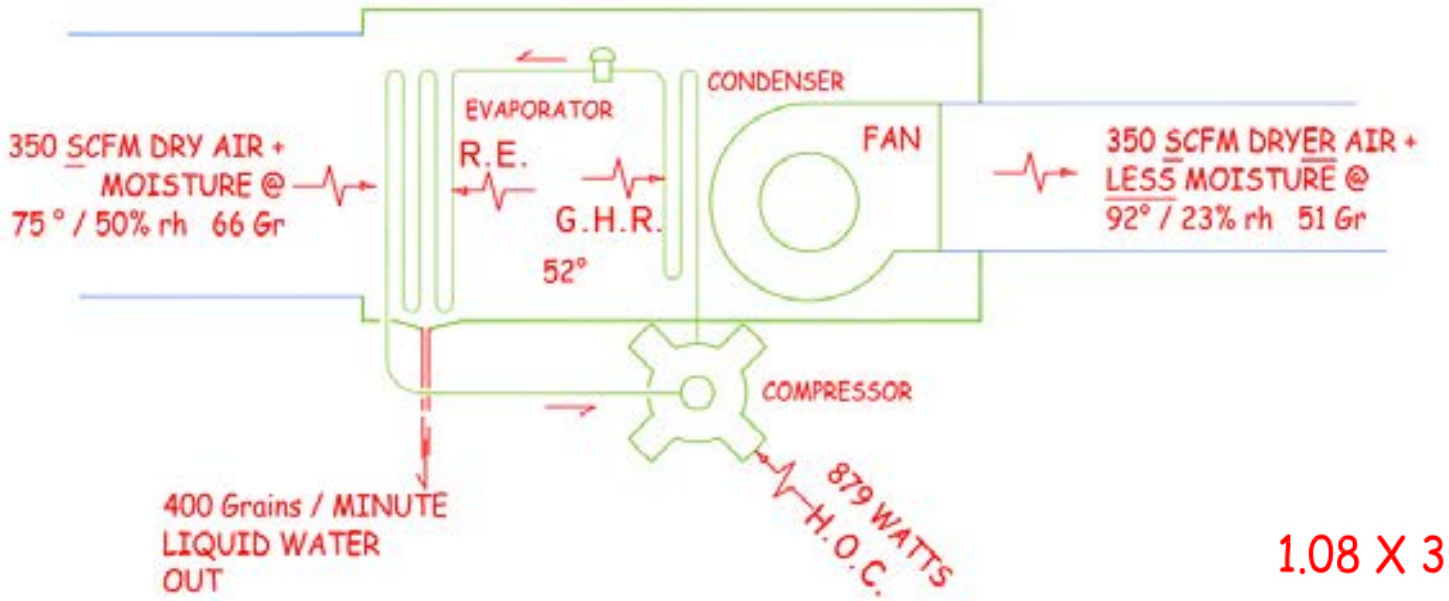
R.E. + H.O.C. = G.H.R.



3.5 LB/HR DEHUMIDIFIER

(AKA 132 PINT PER DAY)

R.E. + H.O.C. = G.H.R.



3.5 LB/HR DEHUMIDIFIER
(AKA 132 PINT PER DAY)

1.08 X 350 SCFM X 23° = 8,500 SBTUH

$$\frac{4.5 \times 350 \text{ CFM} \times (66-52) \text{ Grains}}{7{,}000 \text{ Gr / LB.}} = 3{,}500 \text{ LBTUH}$$

R.E. (REFRIGERATING EFFECT) = 12,000 BTUH

H.O.C. (879 Watts X 3.413) = 3,000 BTUH

G.H.R. (Gross Heat Rejection) = 15,000 BTUH

1.08 X 350 SCFM X 23° = 8,500 SBTUH

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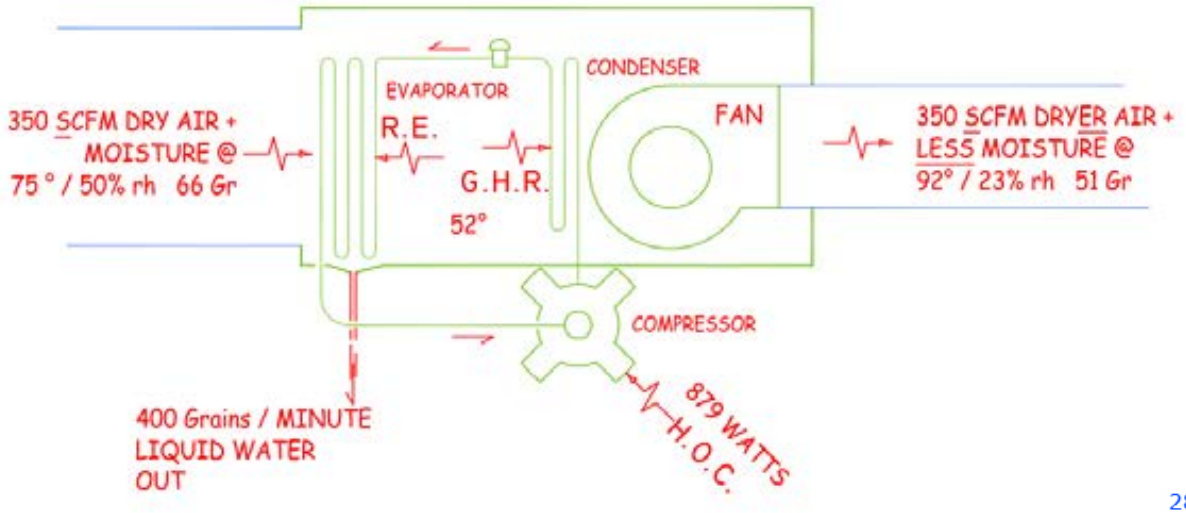
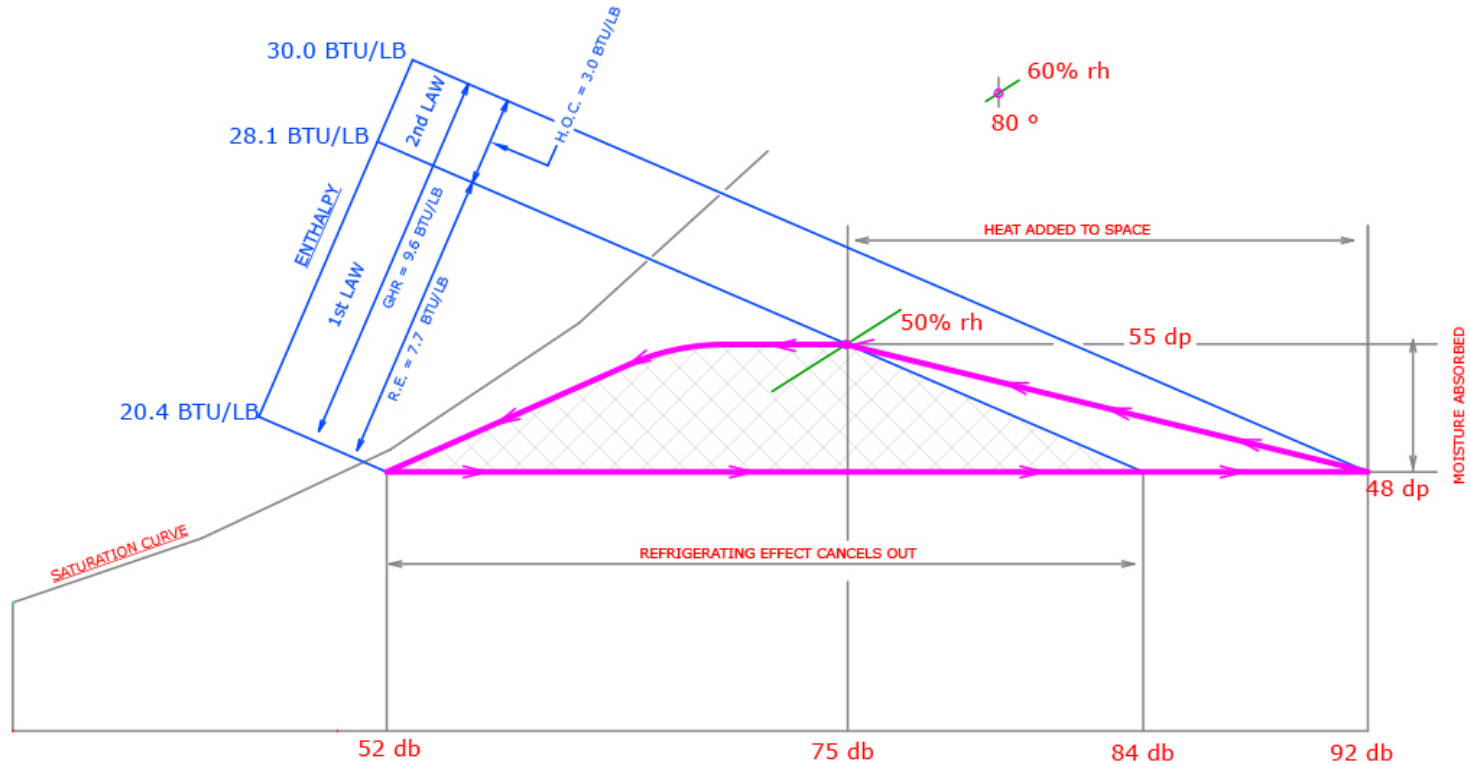
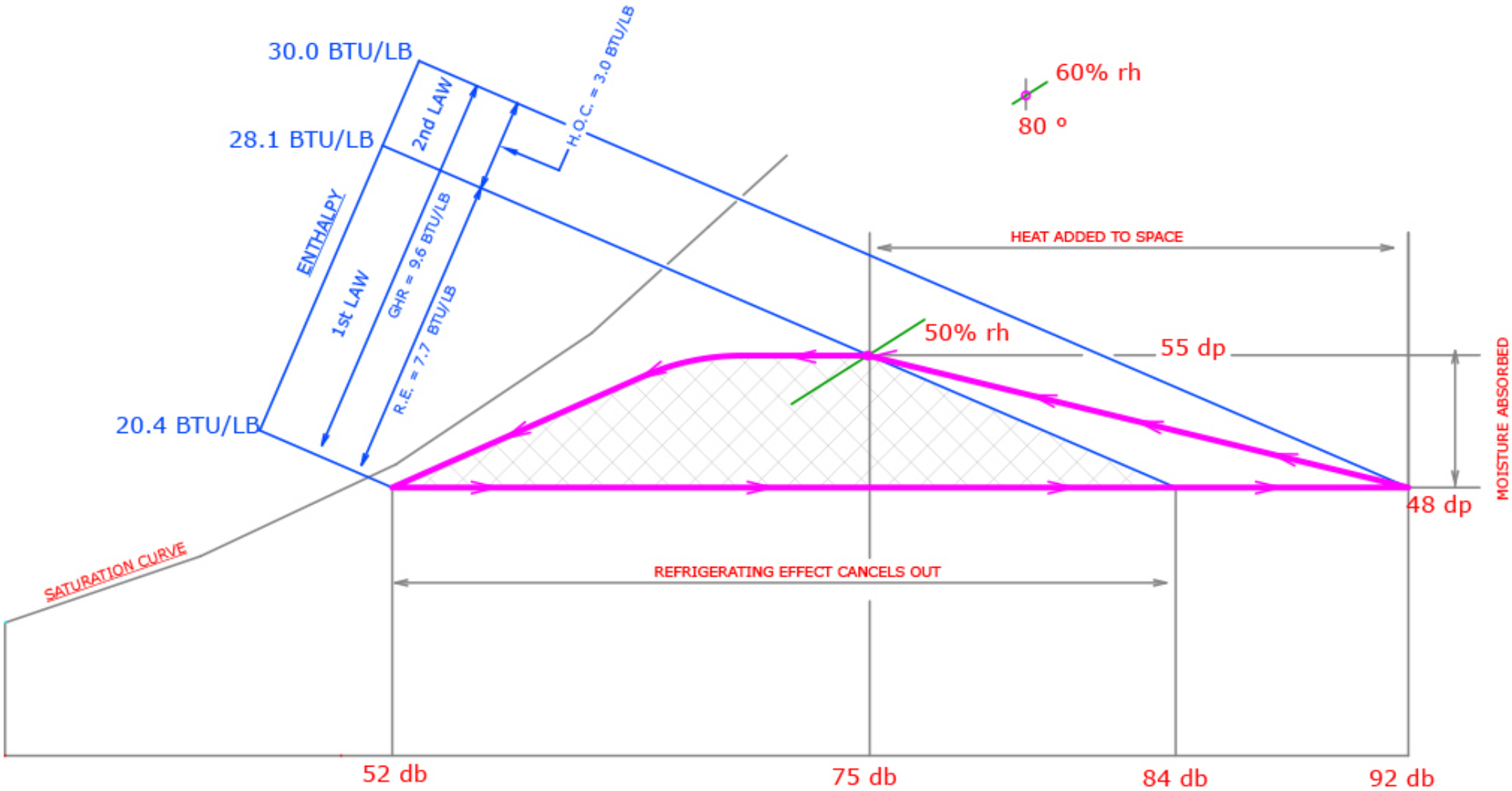
R.E. + H.O.C. = G.H.R.



3.5 LB/HR DEHUMIDIFIER
(AKA 132 PINT PER DAY)



CLASSIC DEHUMIDIFICATION CYCLE - PSYCHROMETRIC CHART



CLASSIC DEHUMIDIFICATION CYCLE - PSYCHROMETRIC CHART

Enthalpy

Wet Bulb (wb) and Enthalpy (h)

- Carrier discovered that wet bulb temperature was an excellent indicator of Enthalpy

But not exactly…

- We now have the means to calculate and read-out Enthalpy directly with economical instruments, so…

- wb should go away; there is no need to measure

Enthalpy of Moist Air

Working Definition:
Energy content of air due to combined effect of heat and moisture.

Units:
BTU/lbm-Dry Air

DATUM:
Air - 0 ºF.
Water - Liquid @ 32 ºF.

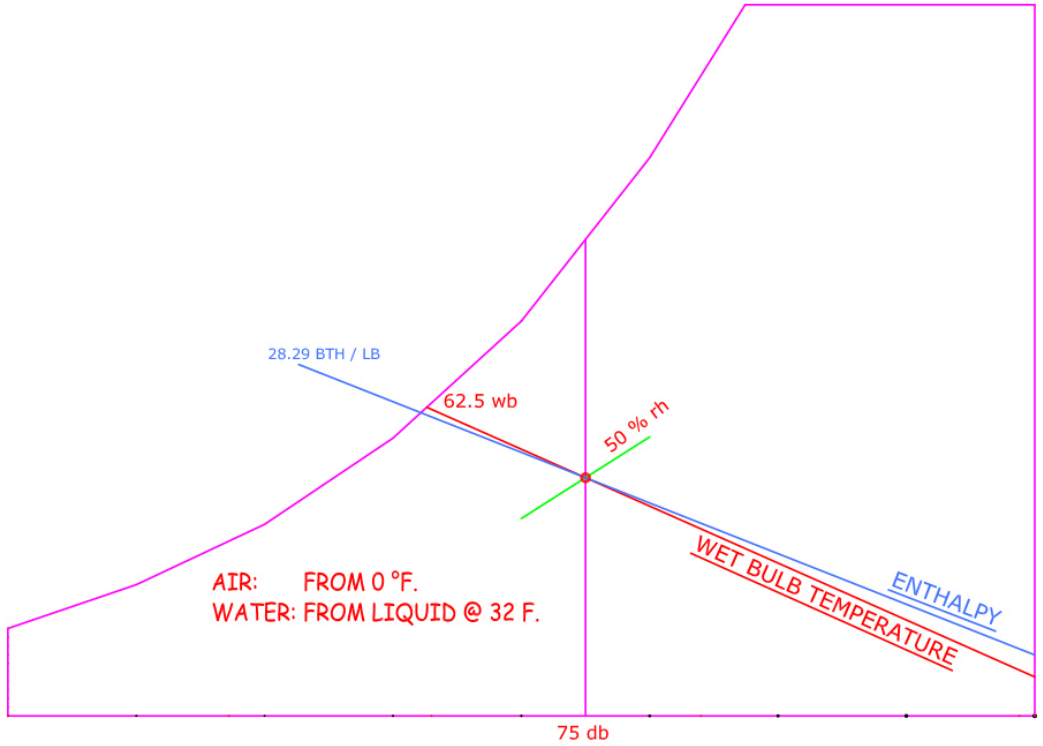
Example: **BTUH /lb.**

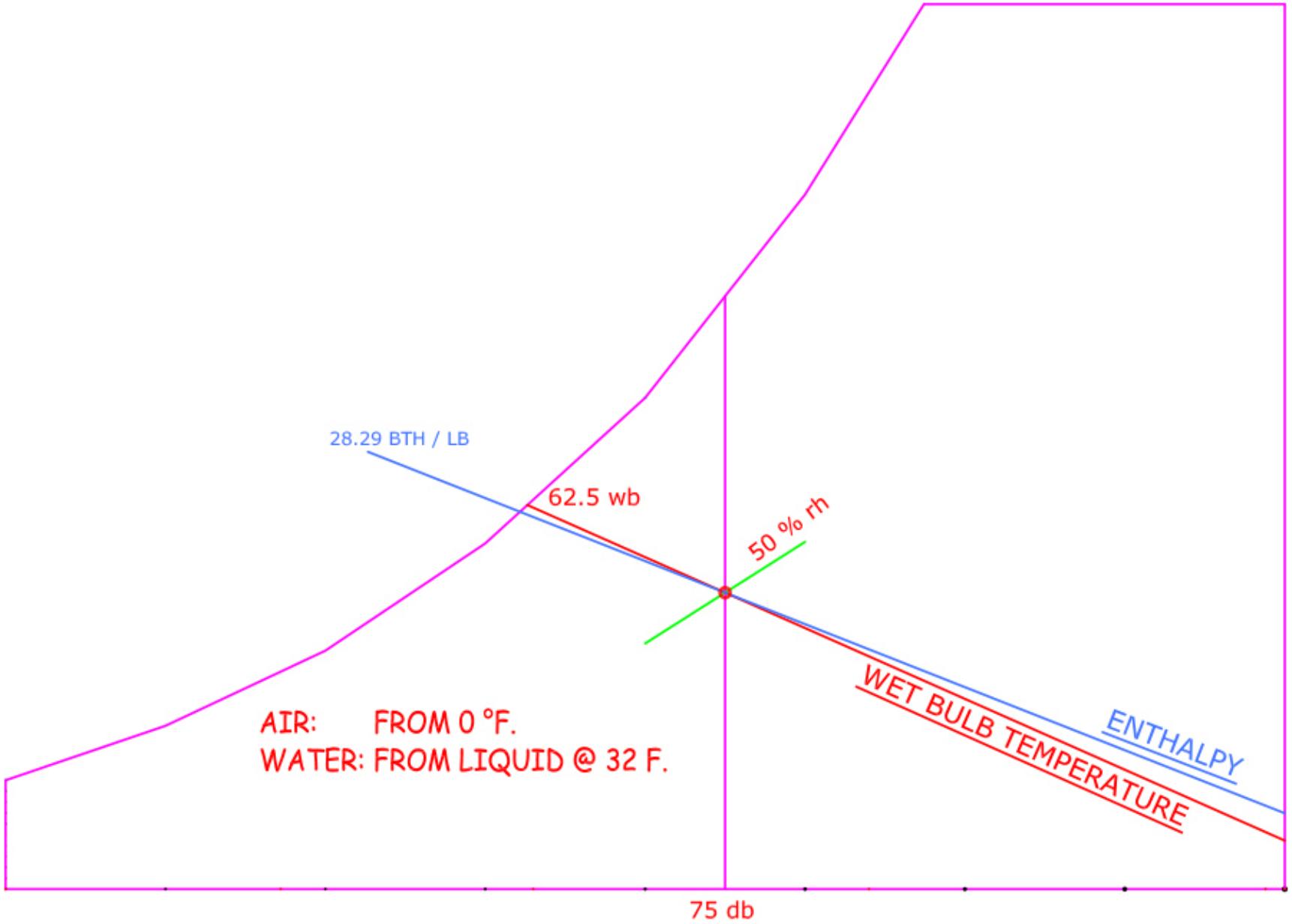
Air at 75 ºF. / 50% RH / HR = 66 Gr/lbm Dry Air

Start With Water:	Heat Liquid H_20 (55 – 32) =	23.00
	Evaporate Water @ 55 ºF. :	1062.18
	Heat Vapor to 75: .489 X (75-55) =	9.78
	SUB-TOTAL, H_2O, BTU/lb:	1094.96
	X Mass of Water: 66/7,000:	X .0094
	Heat Content of Water:	10.29
	Then heat air to 75 ºF. : .24 X (75-0) =	+18.00
	TOTAL HEAT CONTENT, OR ENTHALPY – h:	**28.29 BTUH /lb.**

Enthalpy Example

HEAT WATER FROM 32 TO 50:		23.00
EVAPORATE WATER @ 55 °F.		1062.18
HEAT VAPOR TO 75:		9.78
SUB-TOTAL,WATER, BTU PER LB:		1094.96 BTU/LB
X MASS OF WATER, 66/7,000:		X .0094
HEAT CONTENT OF WATER:		10.29 BTU/LB
HEAT AIR 0 °F. TO 75 ° F.:	.24 X 75	18.00BTU/LB
TOTAL HEAT CONTENT PER LB, ENTHALPY:		28.29 BTU/LB




28.29 BTH / LB
62.5 wb
50 % rh
AIR: FROM 0 °F.
WATER: FROM LIQUID @ 32 F.
WET BULB TEMPERATURE
ENTHALPY
75 db

Compare:

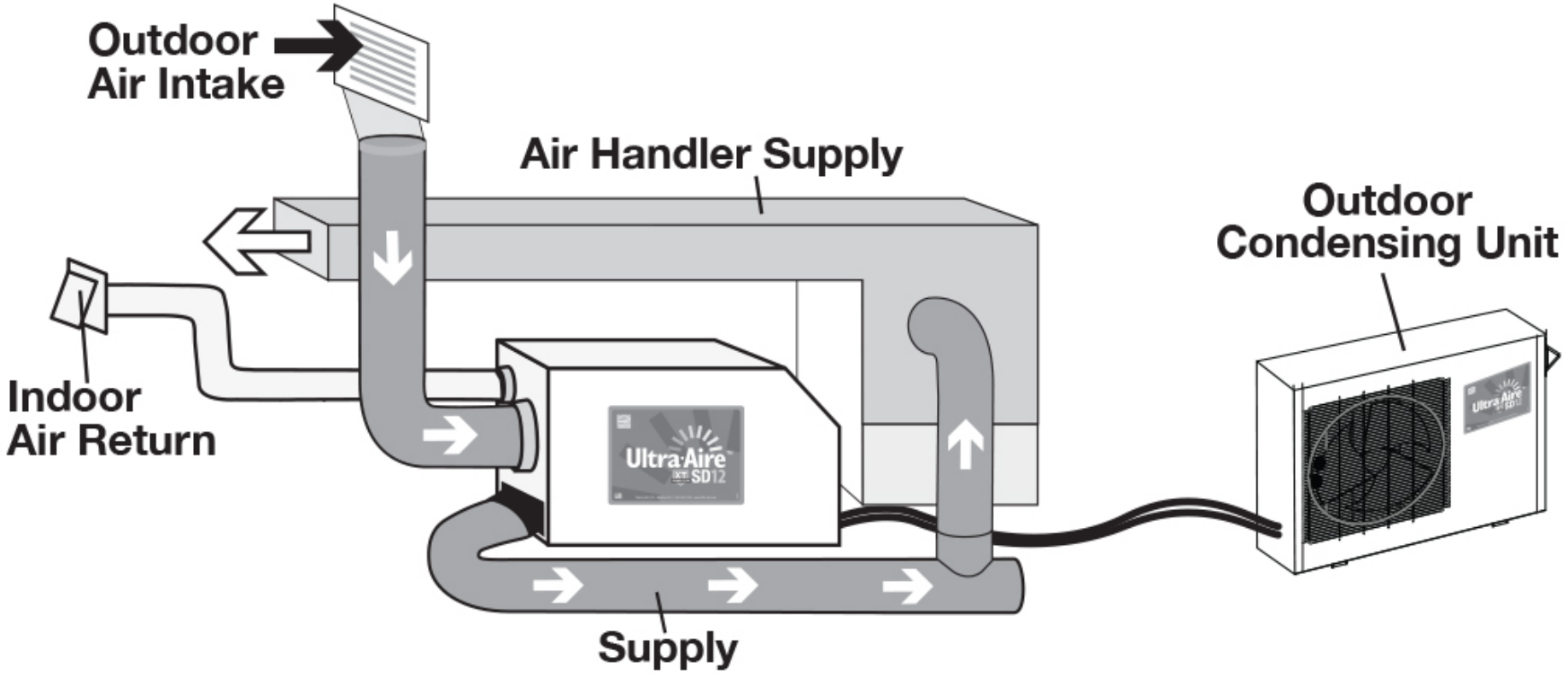
Psych Chart:	28.6 BTU/LB
Moist Air Saturated 62.5 ºF. wb:	28.2 BTU/LB

How Do We Introduce Warm, Dry Air?

- Directly to / from the space
- Whole house dehumidifier – connect to HVAC
- Dedicated outdoor air system (D.O.A.S.)

- And don’t forget…we’re doing reheat so it has to go into the Supply air.

D.O.A.S. Can Reject Excess GHR – Split Dehu



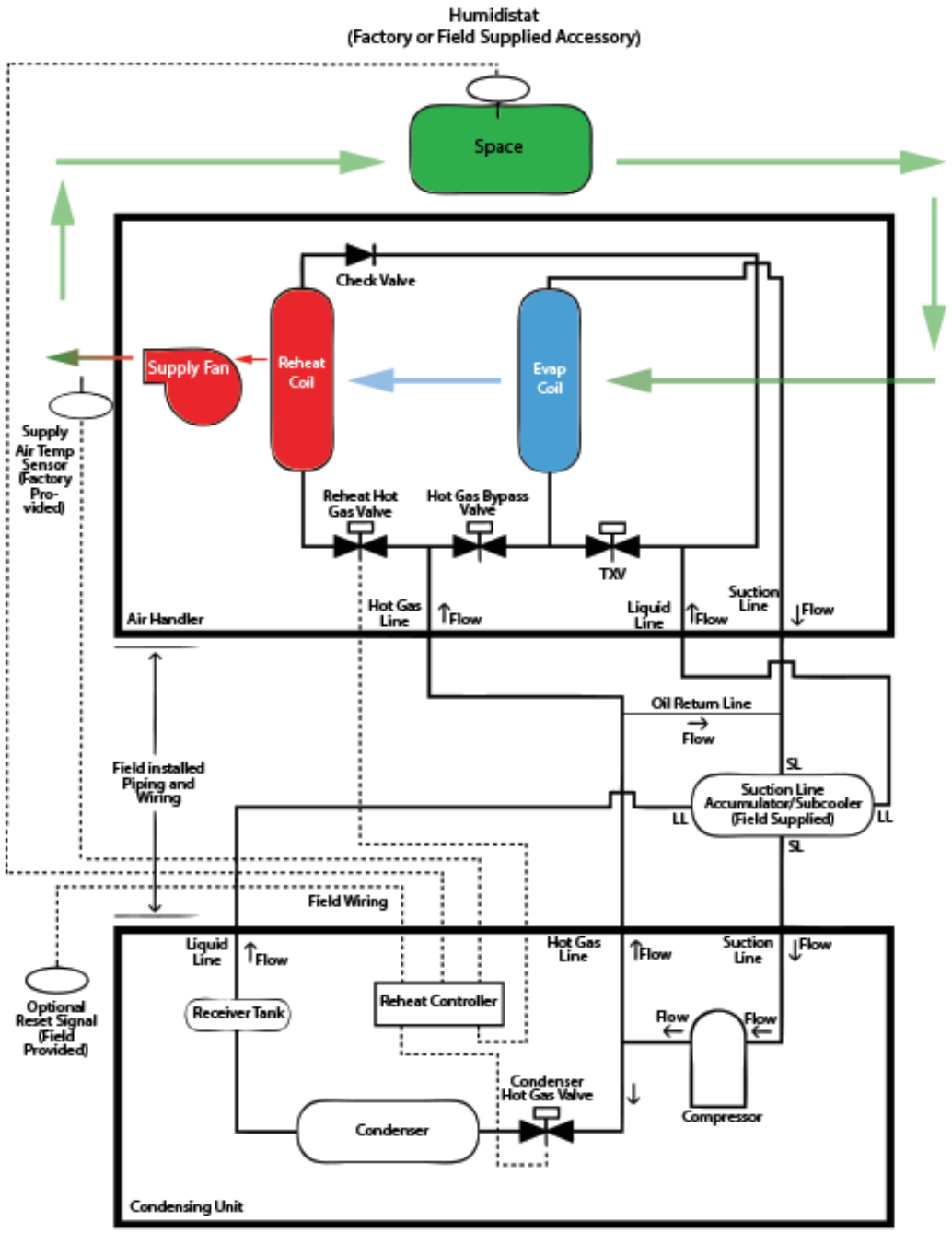
Dedicated Outdoor Air System (D.O.A.S.)

- By 2000: The Dedicated Outdoor Air System
- Aka Outdoor Air Pre-Treatment System
- D.O.A.S.: Sophisticated refrigeration cycle that cools and dehumidifies outside air from summer design 92 db / 79 wb down to 50 ºF. Dew Point (or lower) and reheats that air to room temperature, 72 ºF. (“Neutral”)
- Very sophisticated controls to modulate capacity across wide range of entering air conditions.

A “Simple and Effective” Modulating Hot Gas Reheat System

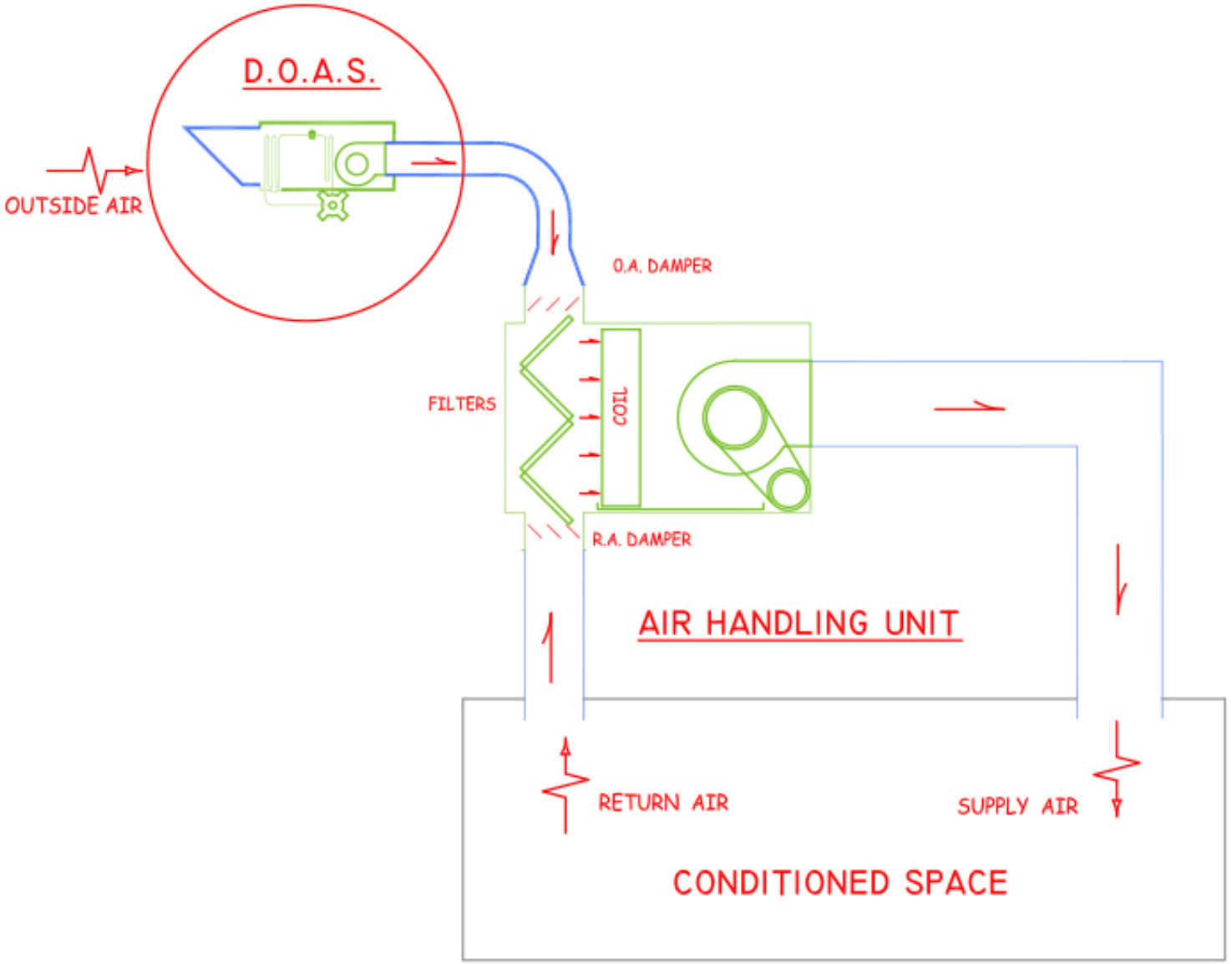
The Split System Humidity Solution

- Controls are factory configured and ready to accept inputs from the field mounted, factory provided supply air temperature sensor in the ductwork, supply air temperature and reset supply air temperature DIP switch set points, and field wiring of a humidistat and a field provided 0-10 VDC supply air temperature reset signal.

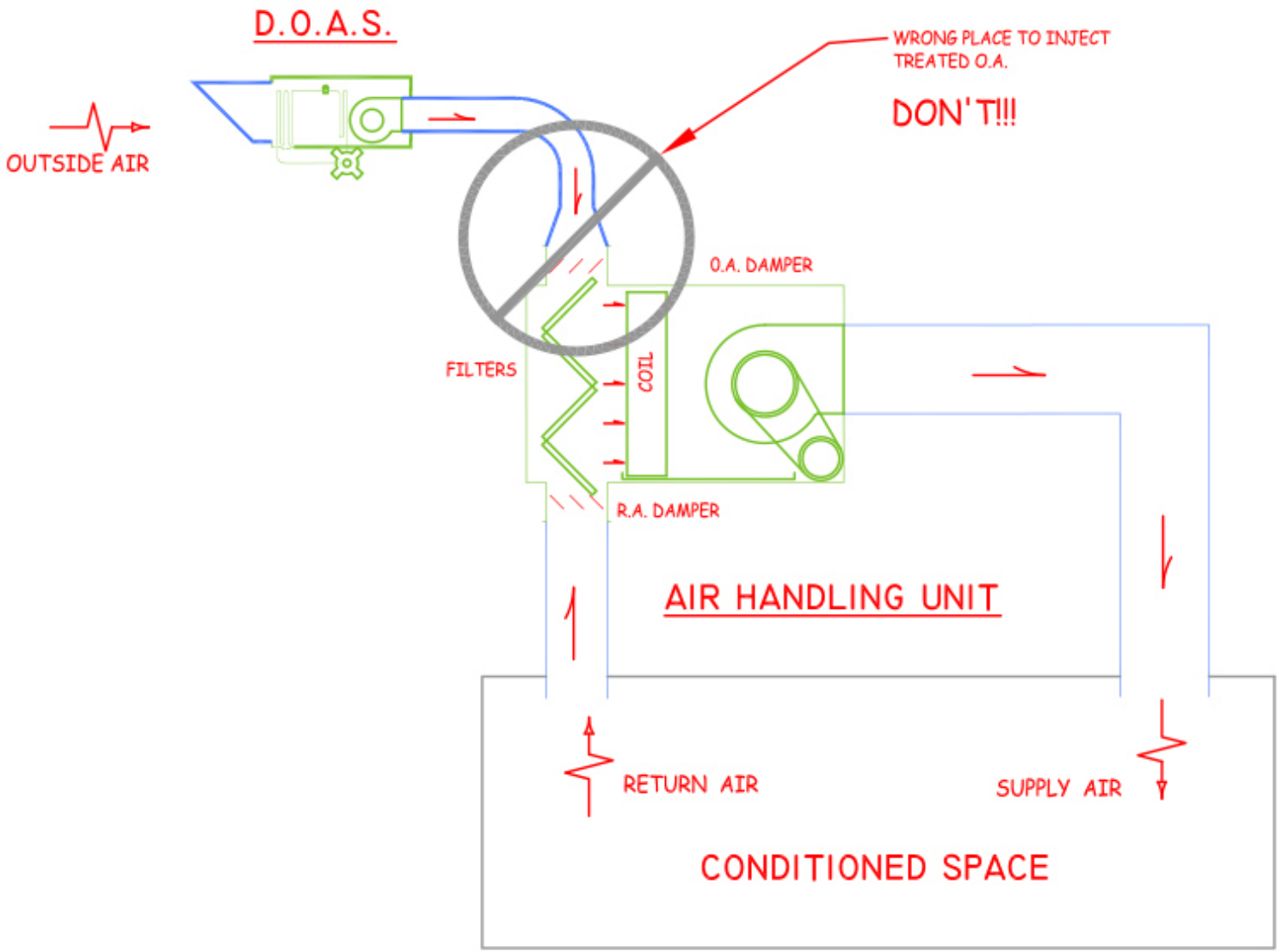


Split System Refrigerant Piping

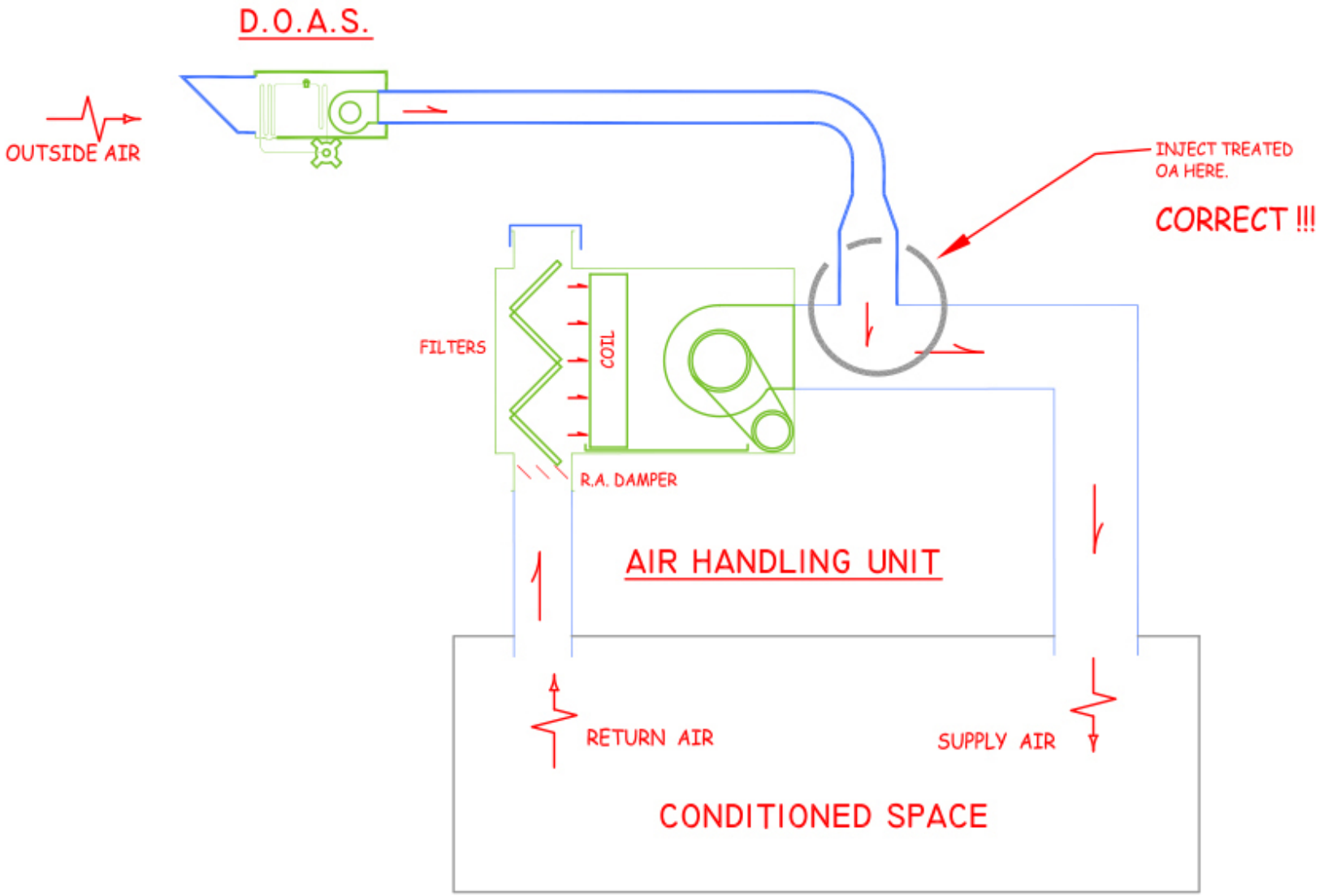
D.O.A.S. – Typical Installation



D.O.A.S. – Inject to Return Air - Wrong



D.O.A.S. – Inject to Supply Air - Correct



D.O.A.S. – With Return Air – Dehumidifier Mode

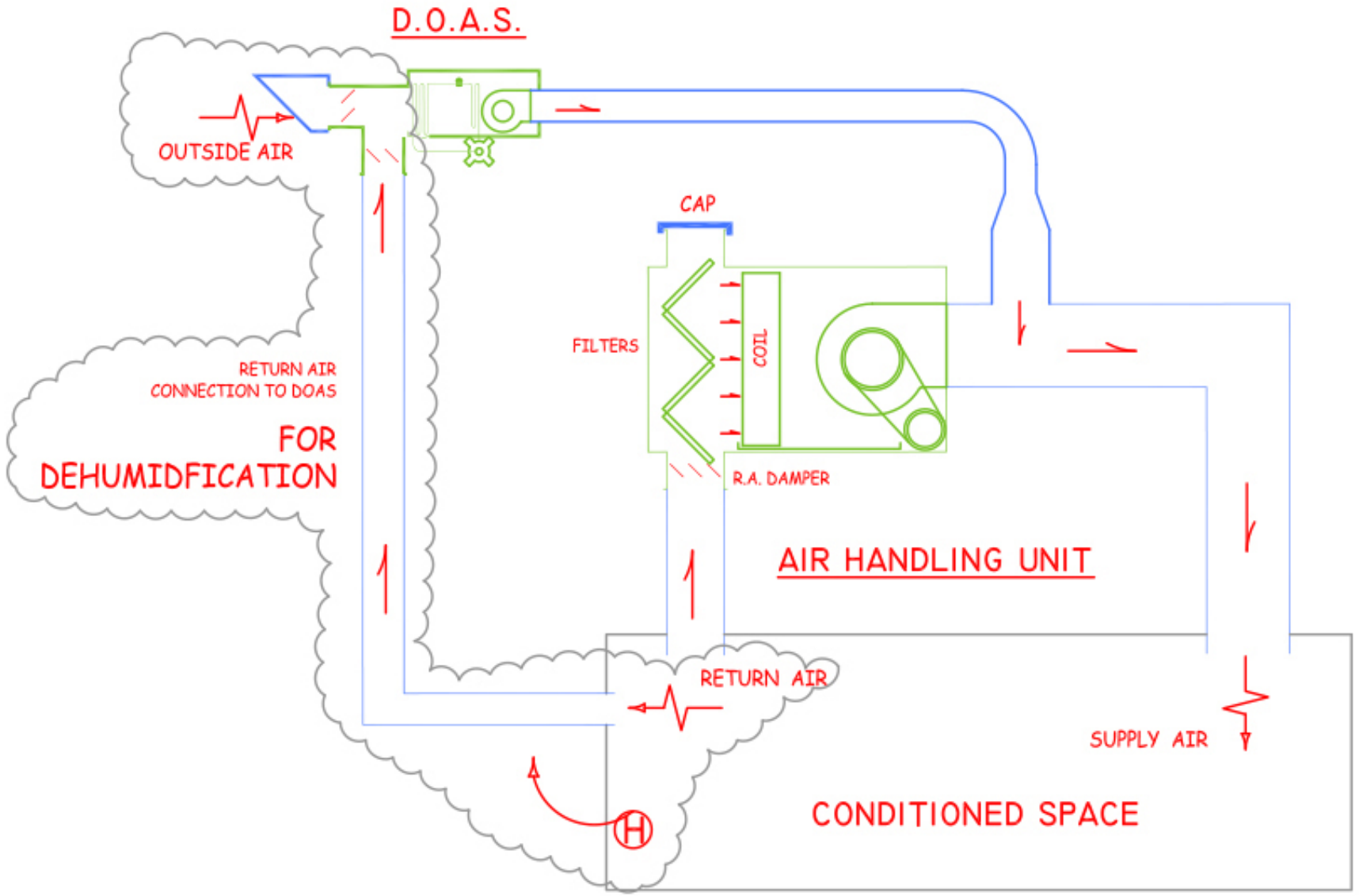
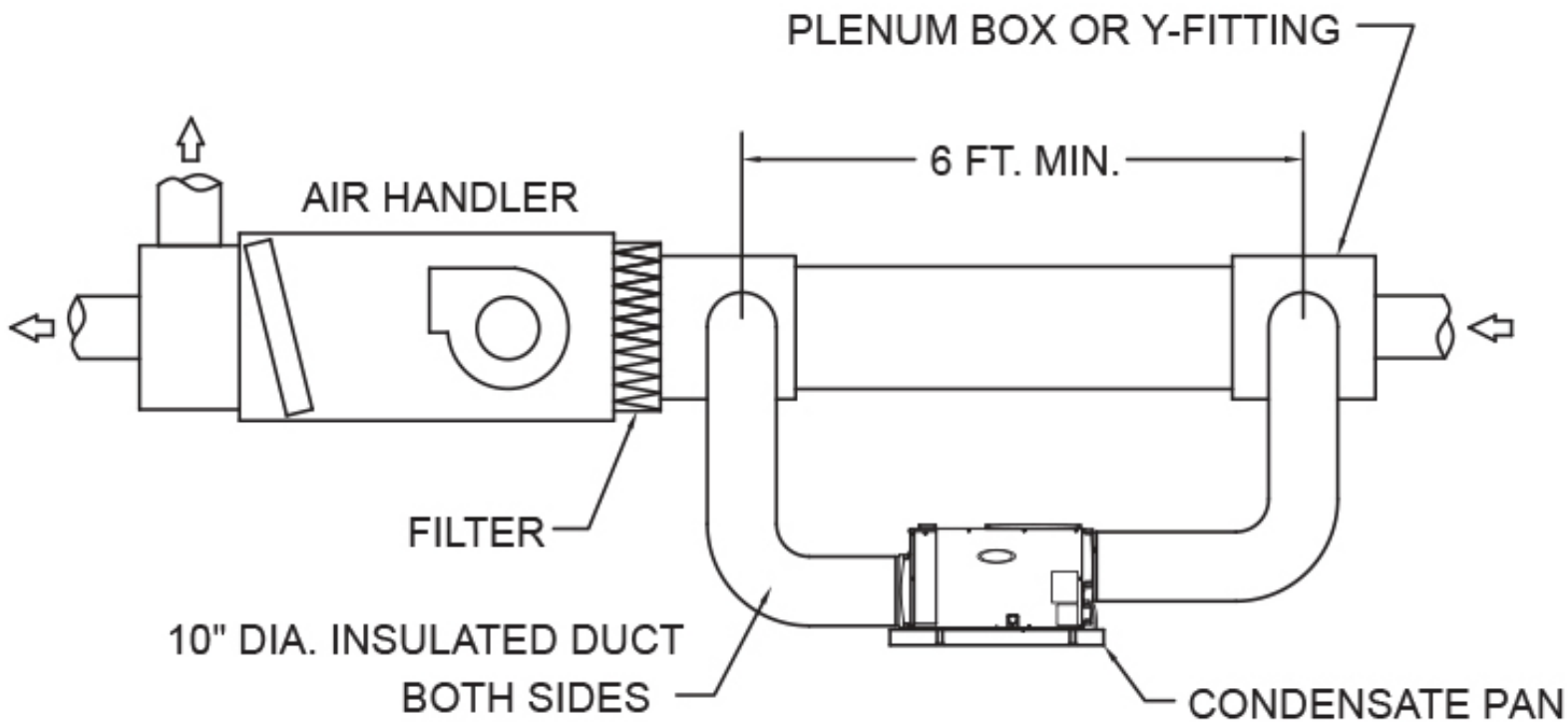
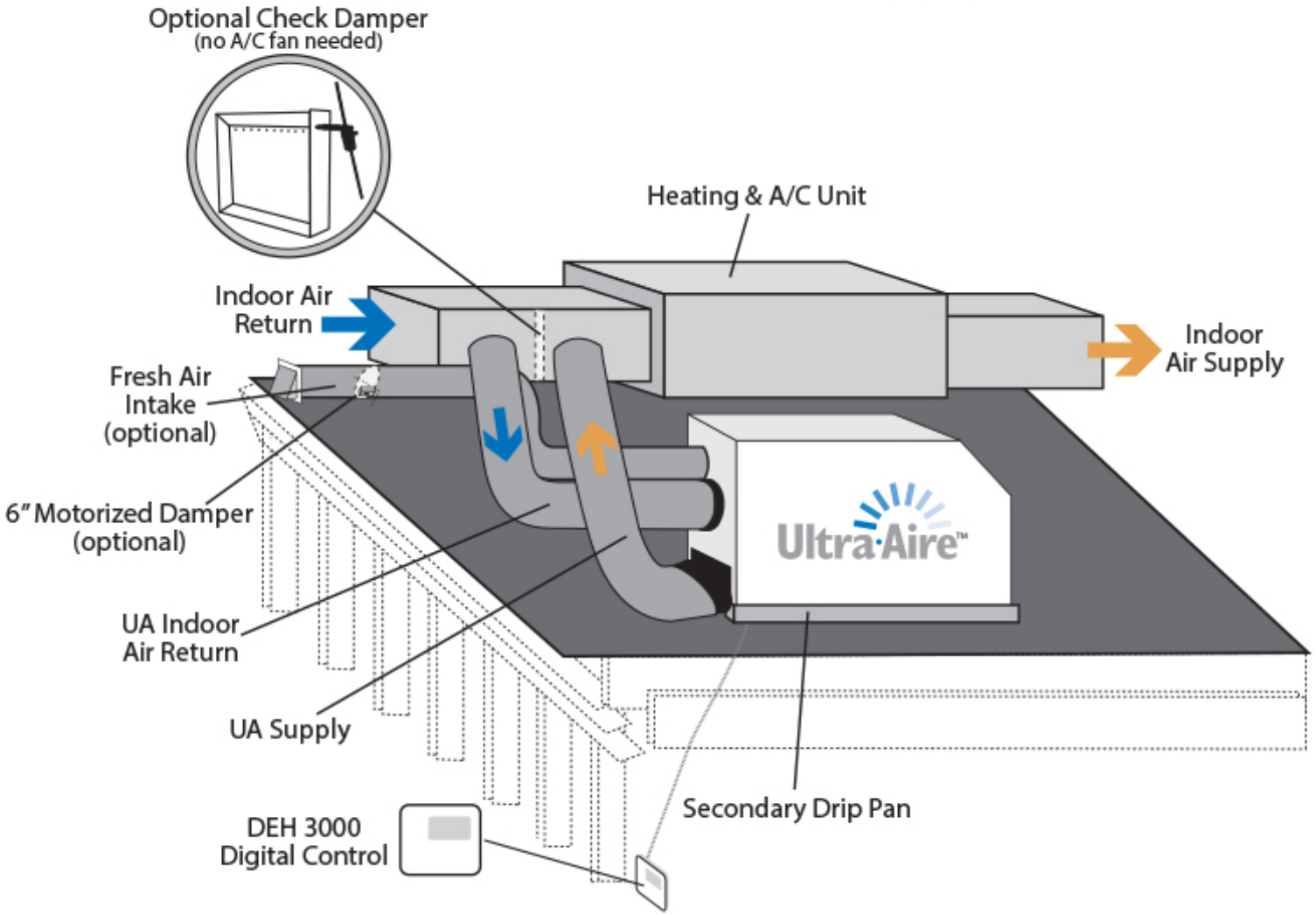


FIGURE 13 – Preferred Attic Installation



90-1888

A/C Return to A/C Return



Check damper should be in place between the return and supply connections of the dehumidifier. If check damper is not in place, the A/C fan must turn on when the dehumidifier is in operation.

D.O.A.S. Do's and Don'ts

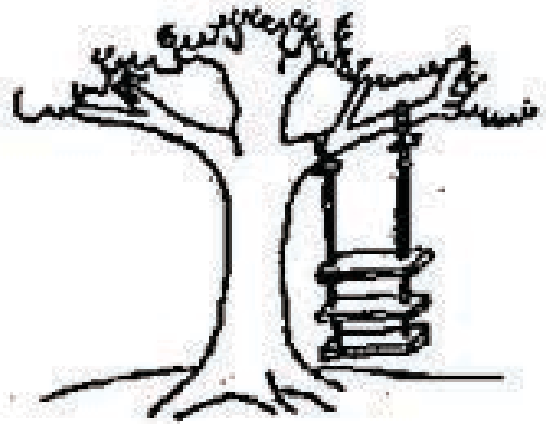
Don't:

- Use a split system – no heat
- Discharge to AHU inlet – sends reheat to dumpster

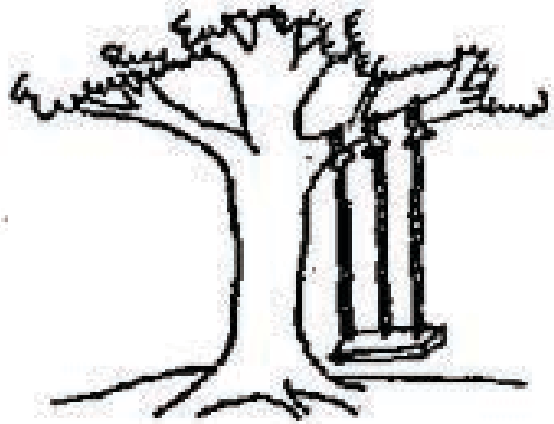
Do:

- Use a self contained package unit —"rooftop"
- Inject treated air downstream of cooling coil
- Install a return air connection and dehumidistat

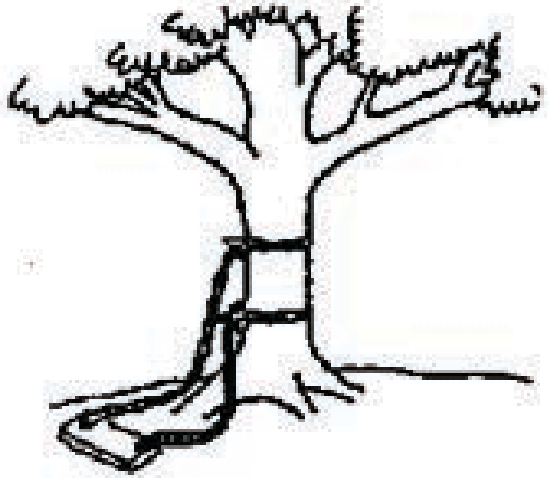
The Double Wide Lab Experience



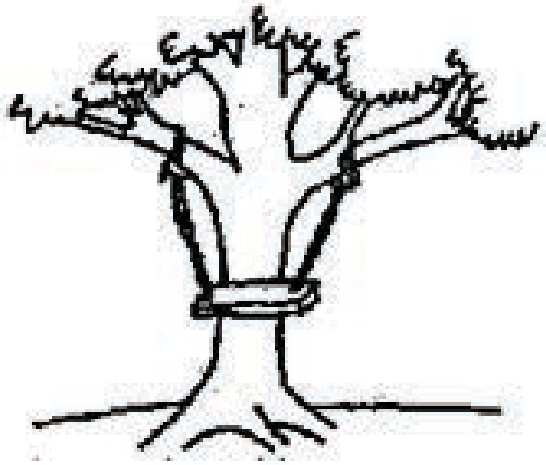
As marketing requested it



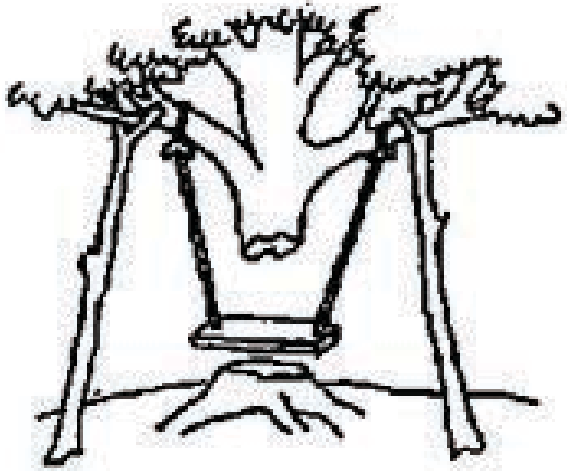
As sales ordered it



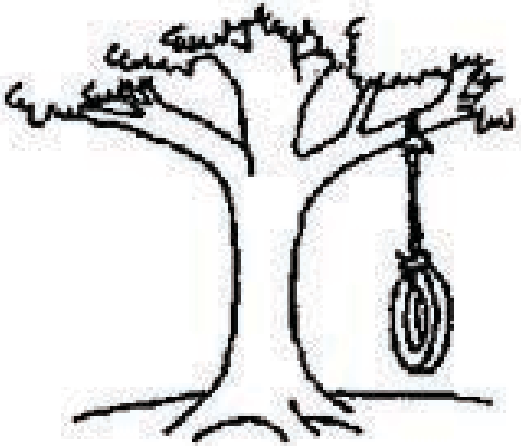
As engineering designed it



As production made it

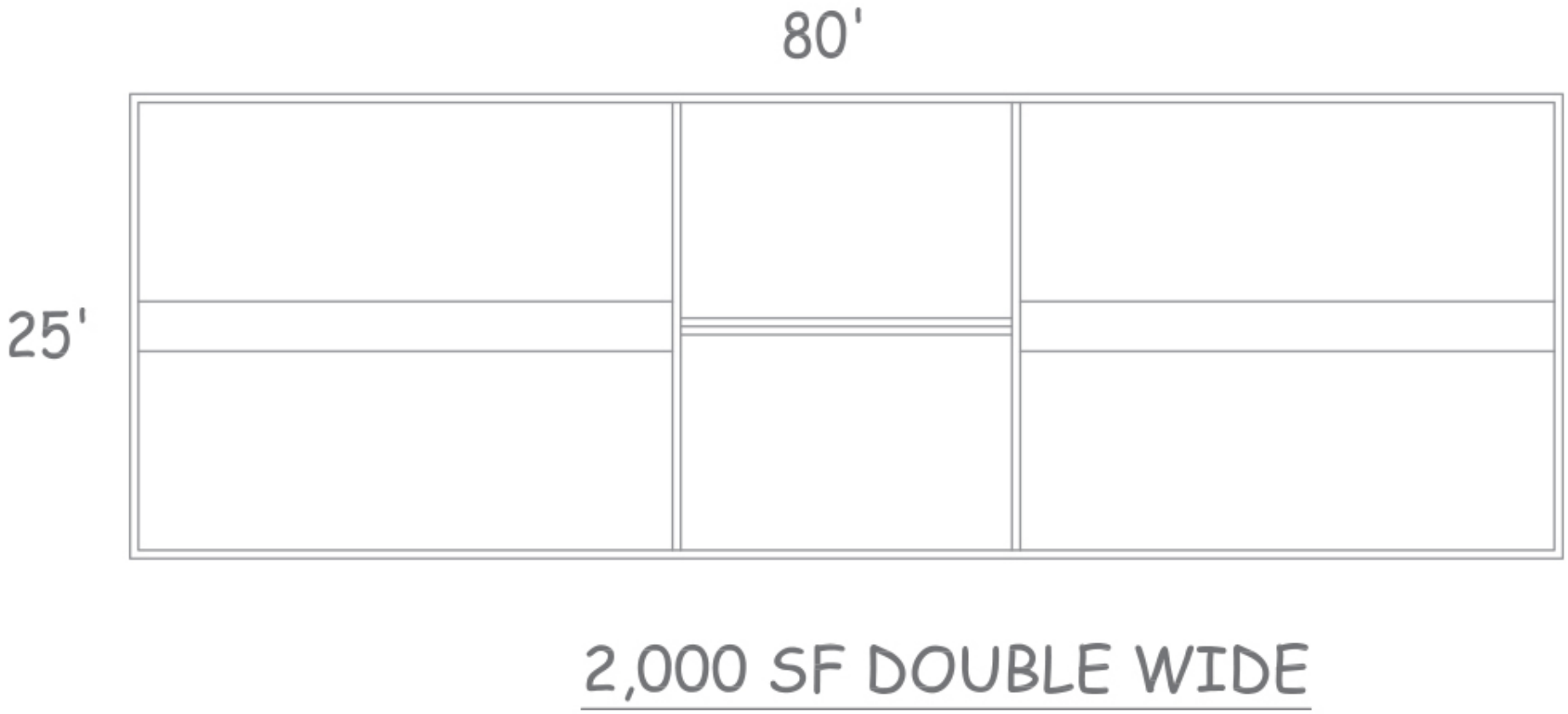


As the dealer installed it

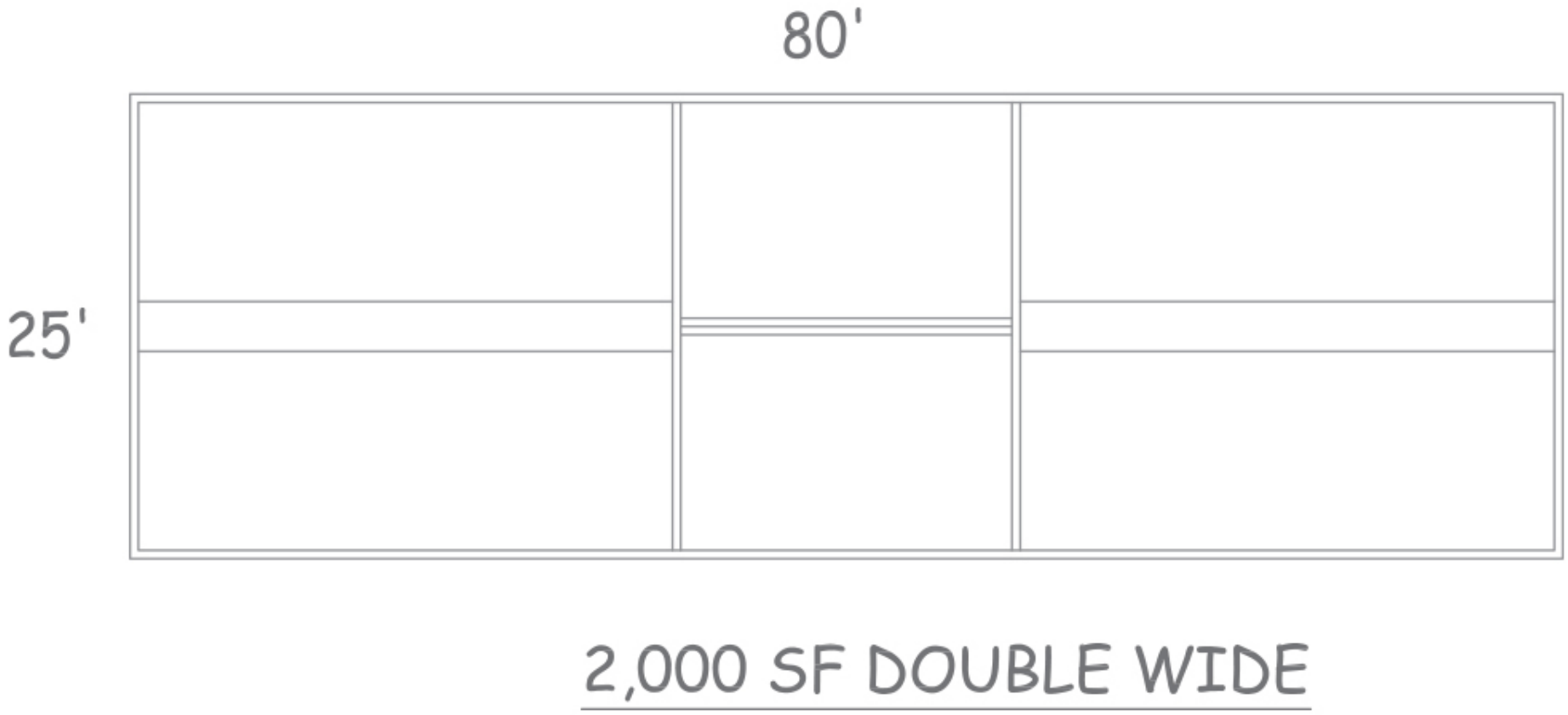


As the customer wanted it

I can cool this double wide with ____Tons?

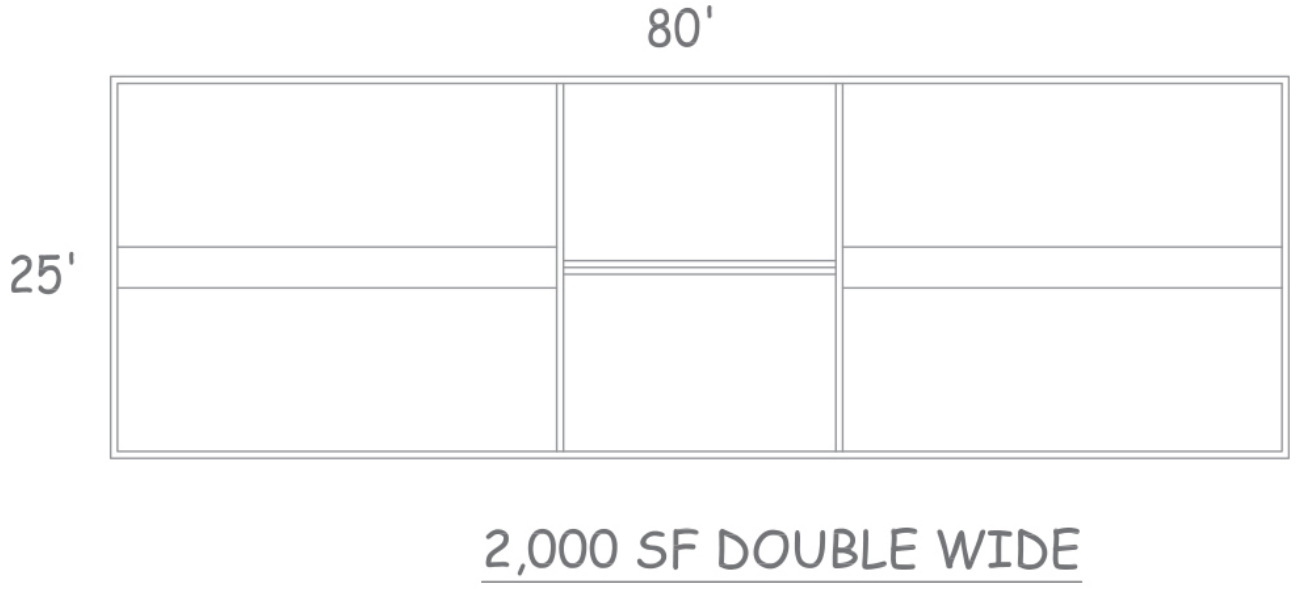


I can cool this double wide with…about 3 tons



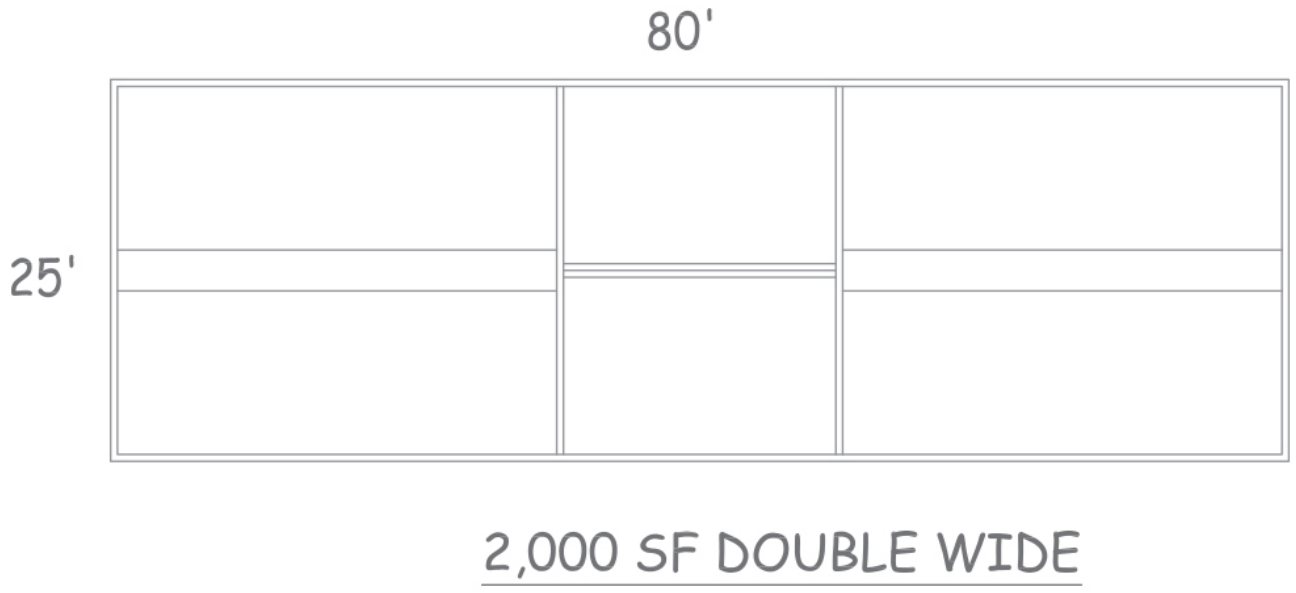
It’s an Animal Lab

- 1,000 Sq. Ft. Lab Required
- Need 100% Standby, so…
- 2 X 1,000 Sq. Ft. = 2,000 Sq. Ft.
- 20,000 CFM
- 335 CFM PER ACH

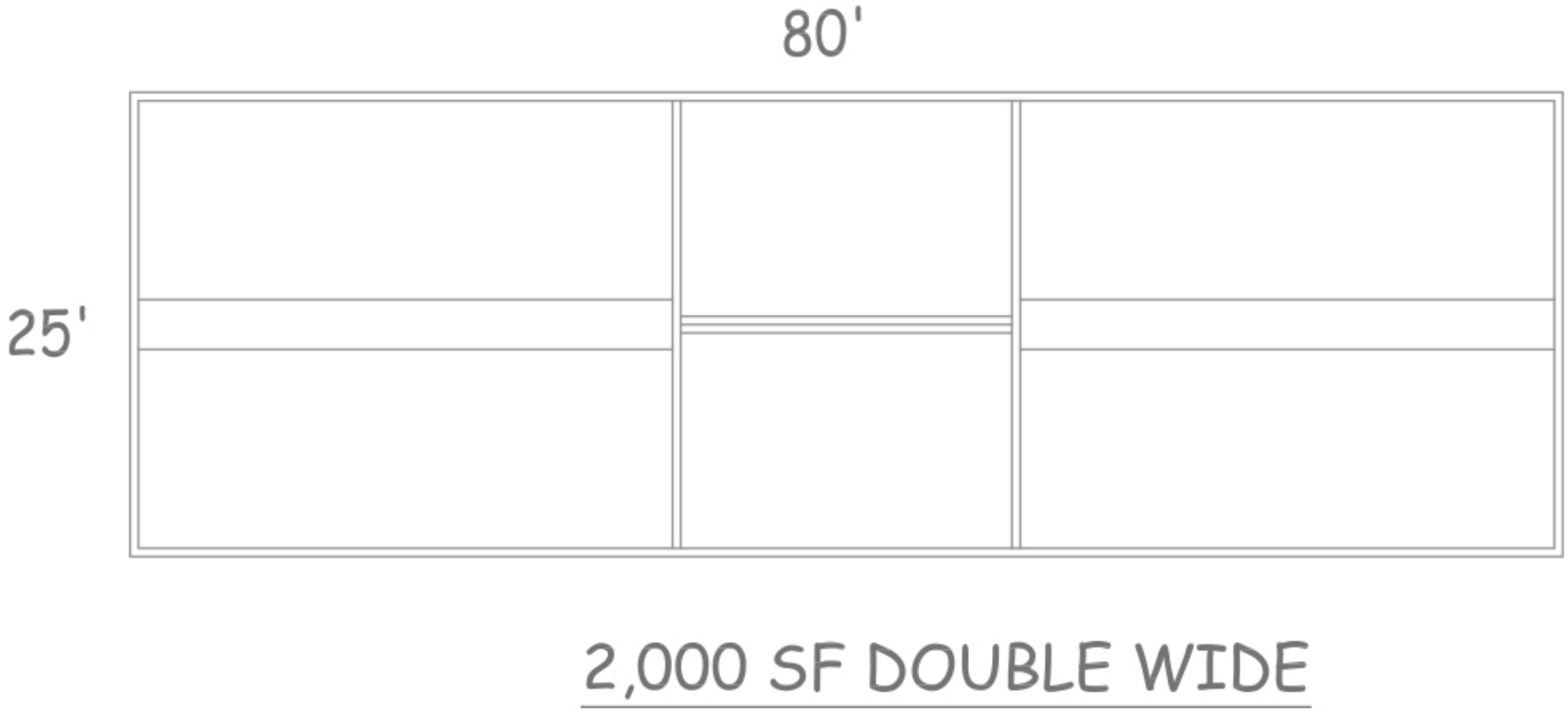


Guide for Use and Care of Laboratory Animals, 1996

- 40 – 85 ºF.
- 30 – 70% rh
- 10-15 ACH Fresh Air, so
- 3,330 to 5,000 CFM
- 50% Fresh / 50% re=cycled
- HEPA Filtered
- (48) Occupants @ 50 BTUH



Did I mention 100% Stand by?



So, what did we get?

(4) 28-Ton Condensing Units

(2) 56-Ton AHU's

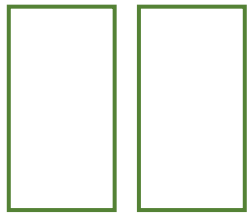
28

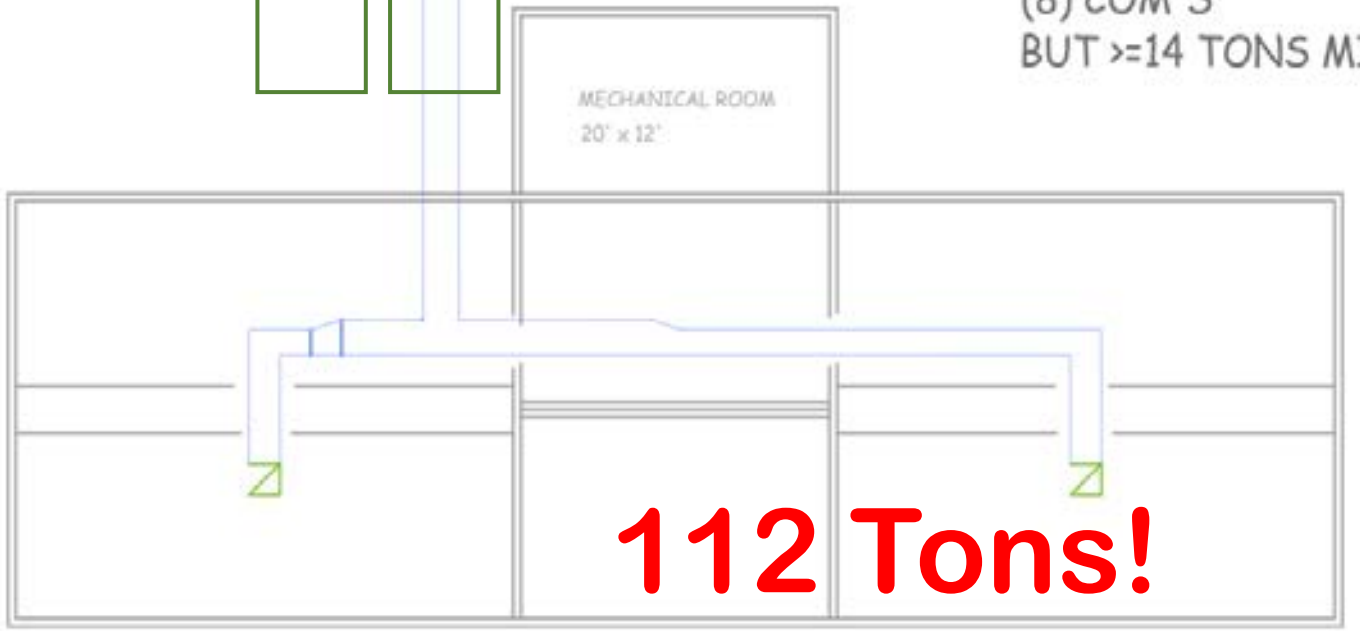
28

28

28

(2) Generators

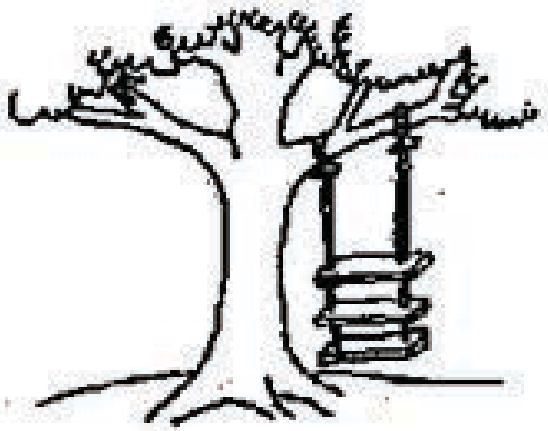




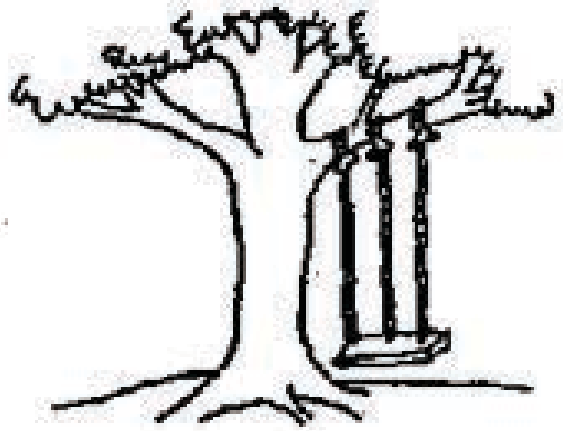
5,200 CFM
56 TONS
(2) 28 TON CU
(2) 14-TON COM/EA
ALL X 2 FOR +100%
(2) AHU'S W/ HEPA FILTERS
(8) COM'S
BUT >=14 TONS MIN PART LOAD

112 Tons!

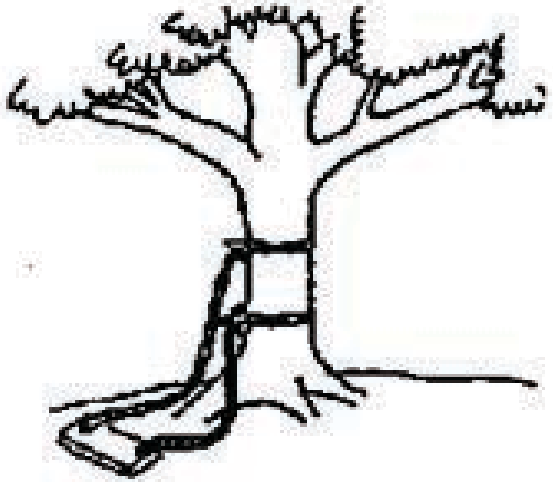
ANIMAL LAB



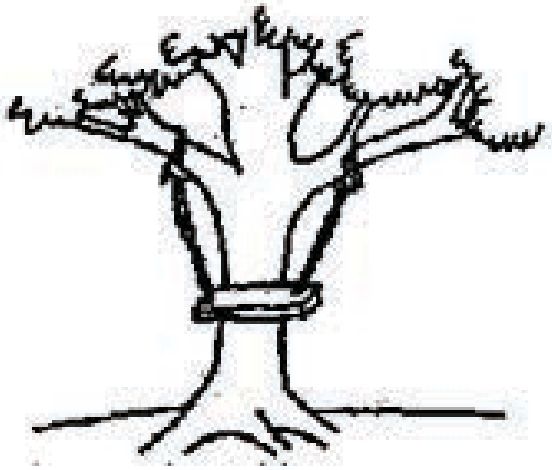
As marketing requested it



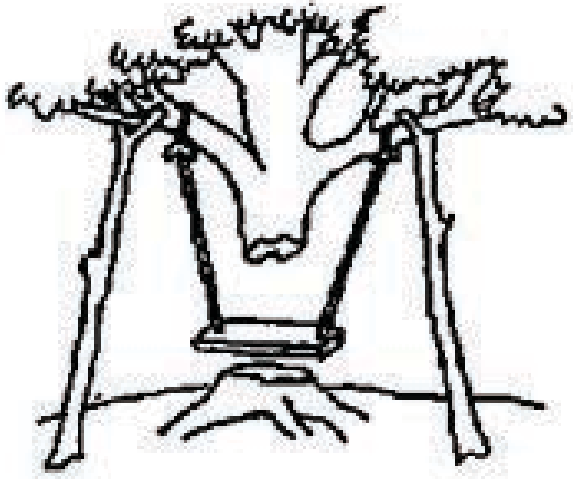
As sales ordered it



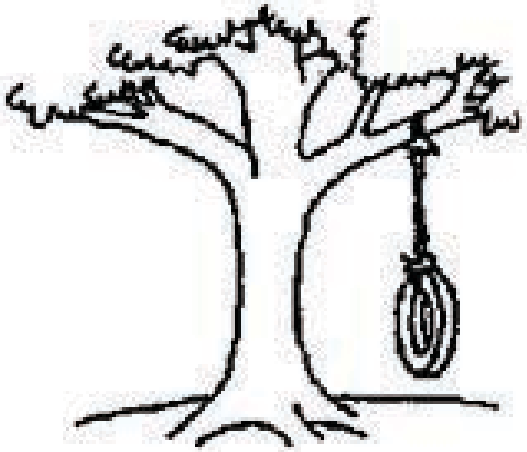
As engineering designed it



As production made it



As the dealer installed it



As the customer wanted it

HOUSES IN SOUTH FLORIDA

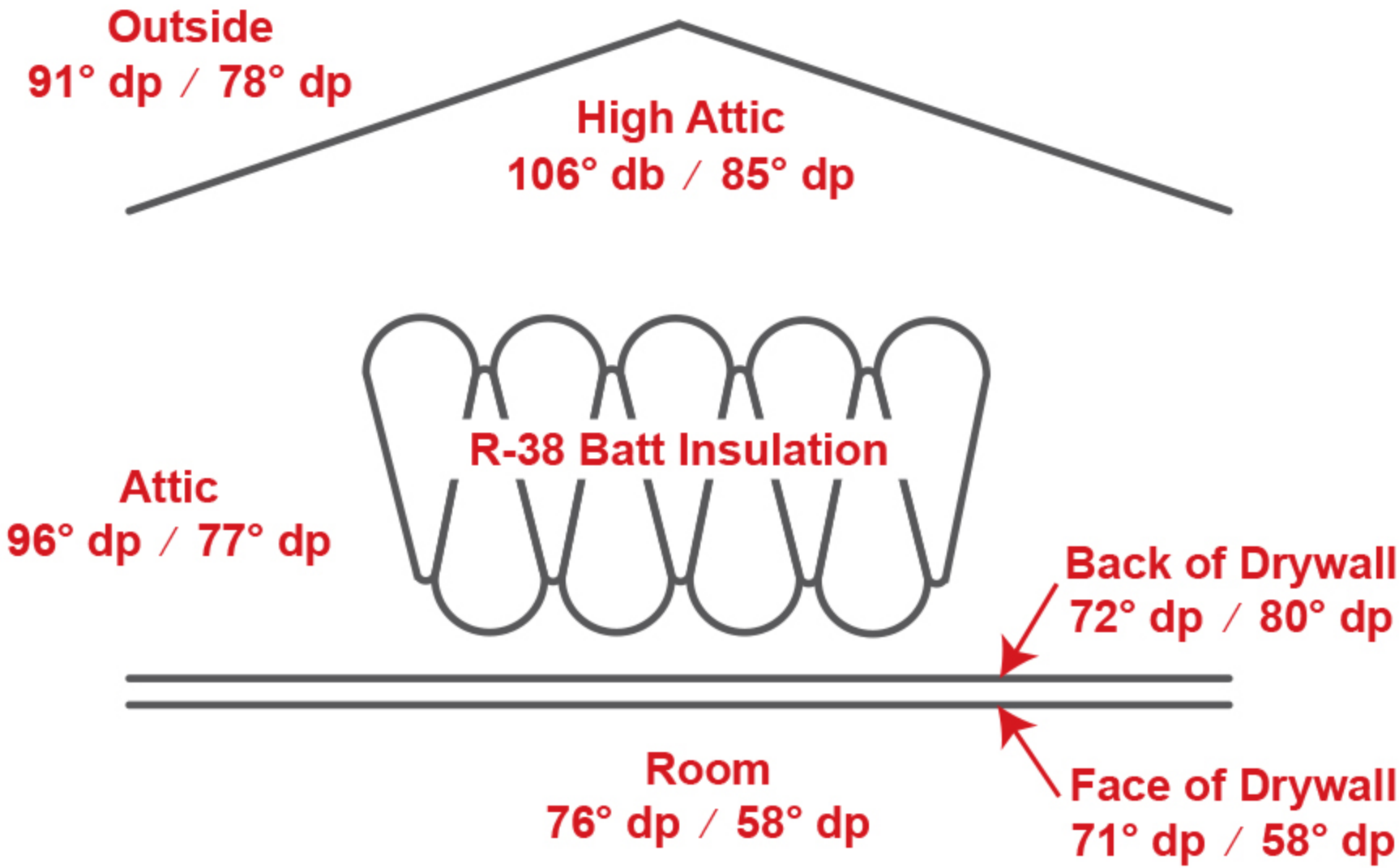
Single Story - 3 Bedrooms - 2.5 Baths - 2,700 ft^2

Remote Monitoring
Houses in South Florida

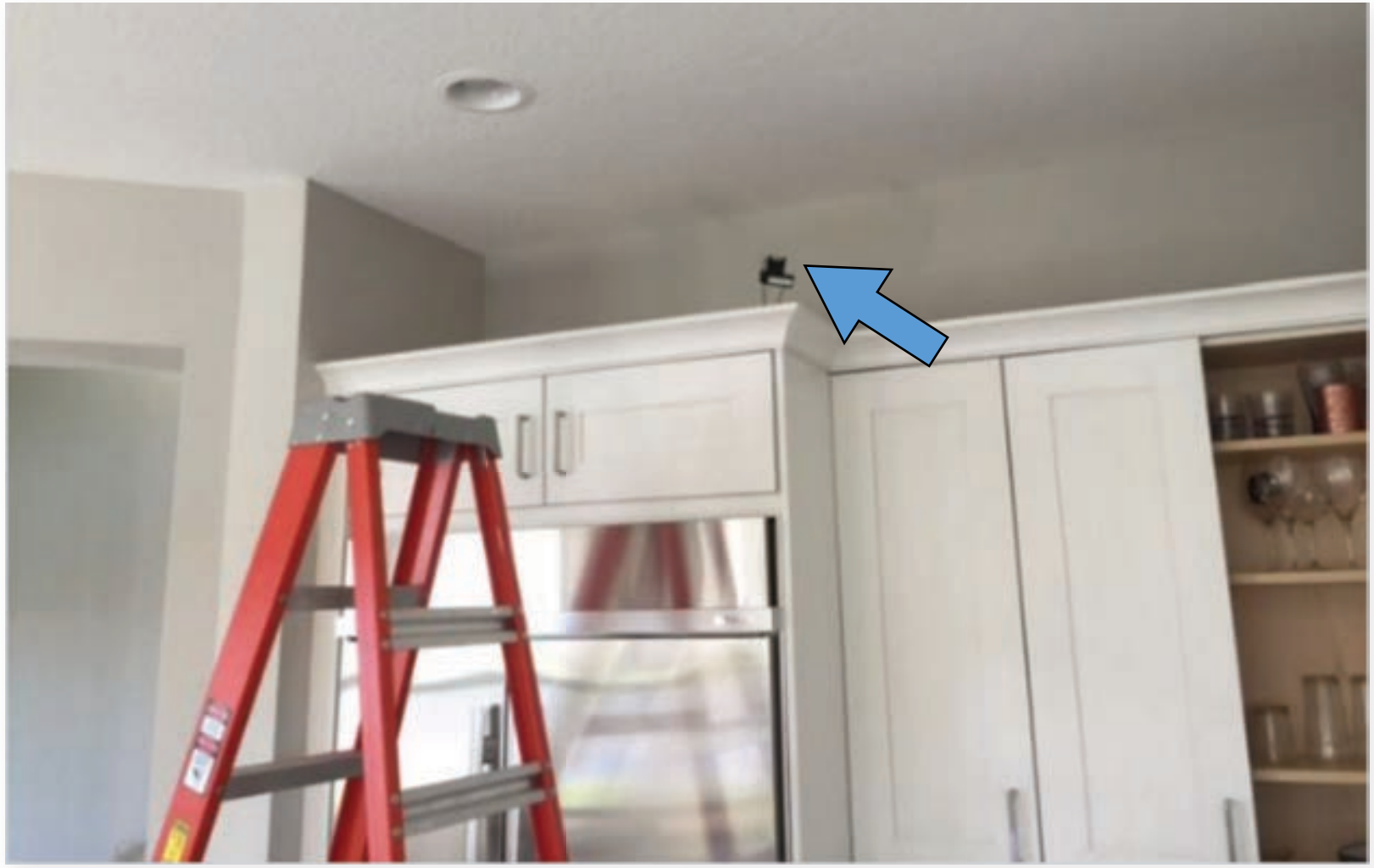

WERNER

What We Were Told

- Changed to R-38 attic insulation
- No ridge vent: Miami / Dade practice.
- AC supply in closets.
- AHU’s now in closets, not in attic.
- Fully ducted return to MER + jump ducts
- Solid doors on MER for noise control.


Outside
91° dp / 78° dp
High Attic
106° db / 85° dp
R-38 Batt Insulation
Attic
96° dp / 77° dp
Back of Drywall
72° dp / 80° dp
Room
76° dp / 58° dp
Face of Drywall
71° dp / 58° dp

Kitchen Air - Above the Cabinets

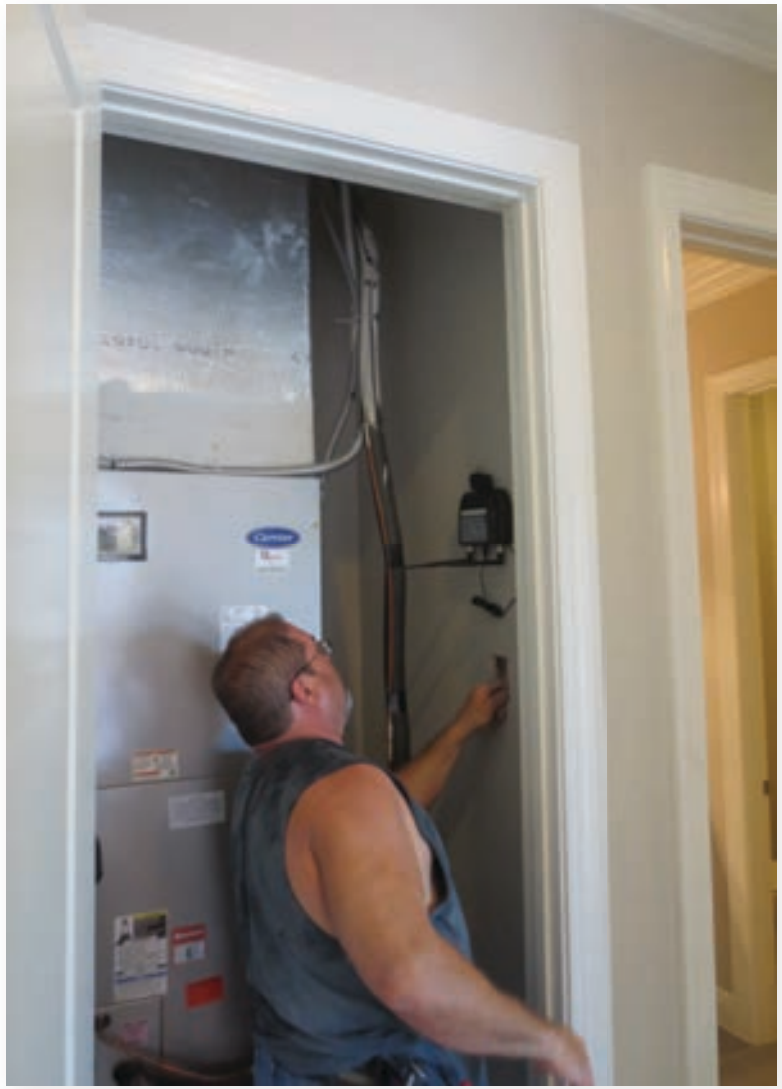


Remote Monitoring
Houses in South Florida

Attic Air Sensors: T + RH + Dpt + gr/lb

Remote Monitoring
Houses in South Florida

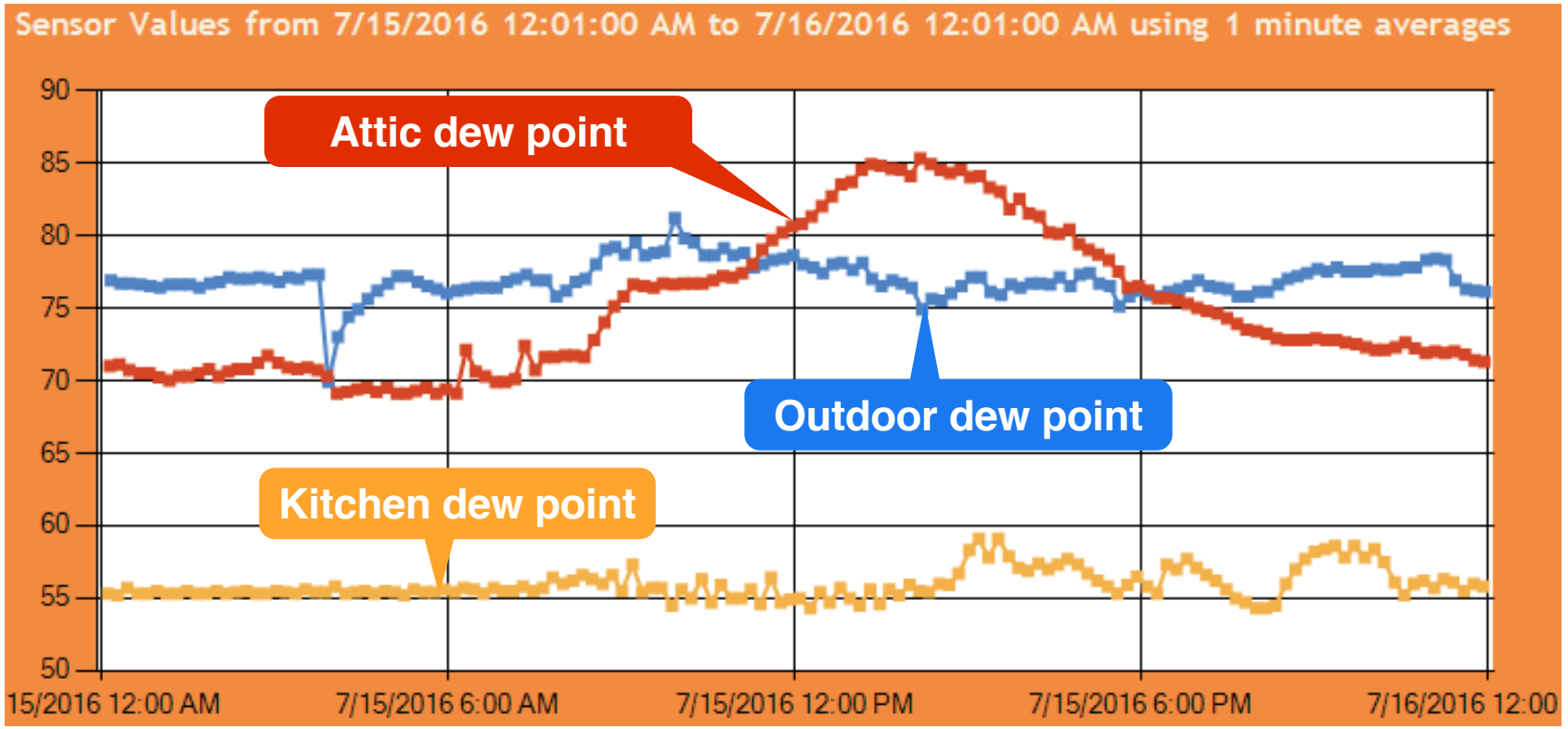
Sensor on the Ceiling - Inside the Mechanical Closet



Remote Monitoring
Houses in South Florida

Air Dew Points

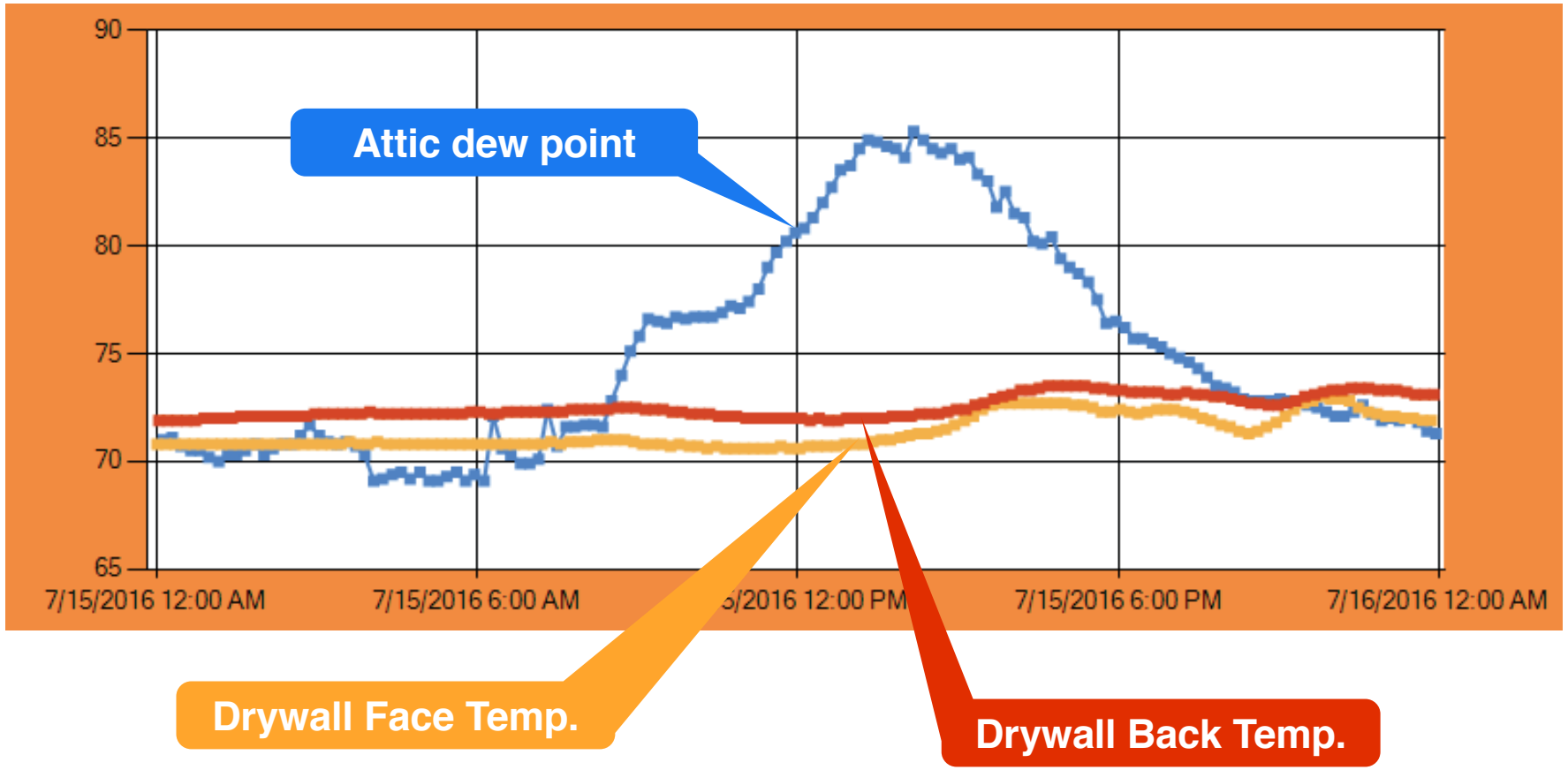
One Day - July 15th: Midnight to Midnight



Remote Monitoring
Houses in South Florida

Attic Dew Point v. Drywall Surface Temps

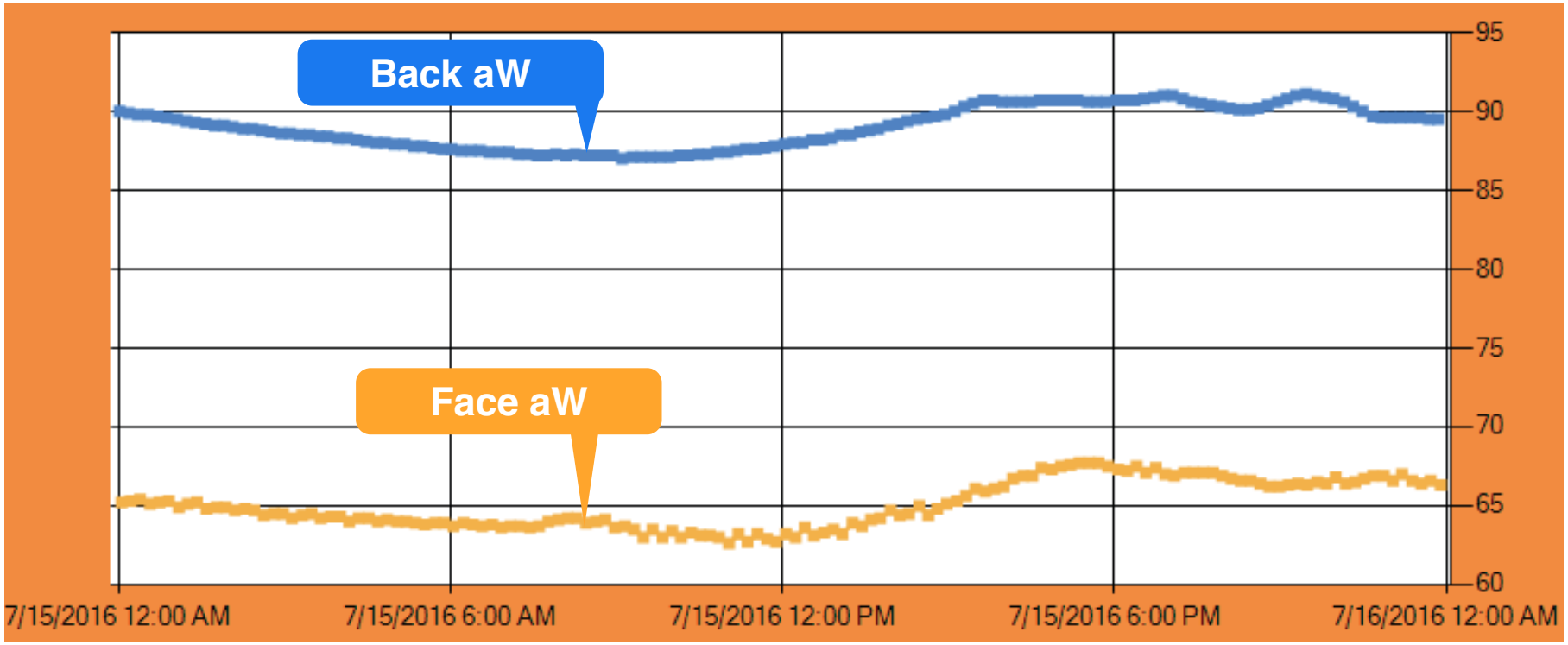
One Day - July 15th: Midnight to Midnight



Remote Monitoring
Houses in South Florida

Face vs. Back of Drywall - aW (Water activity)

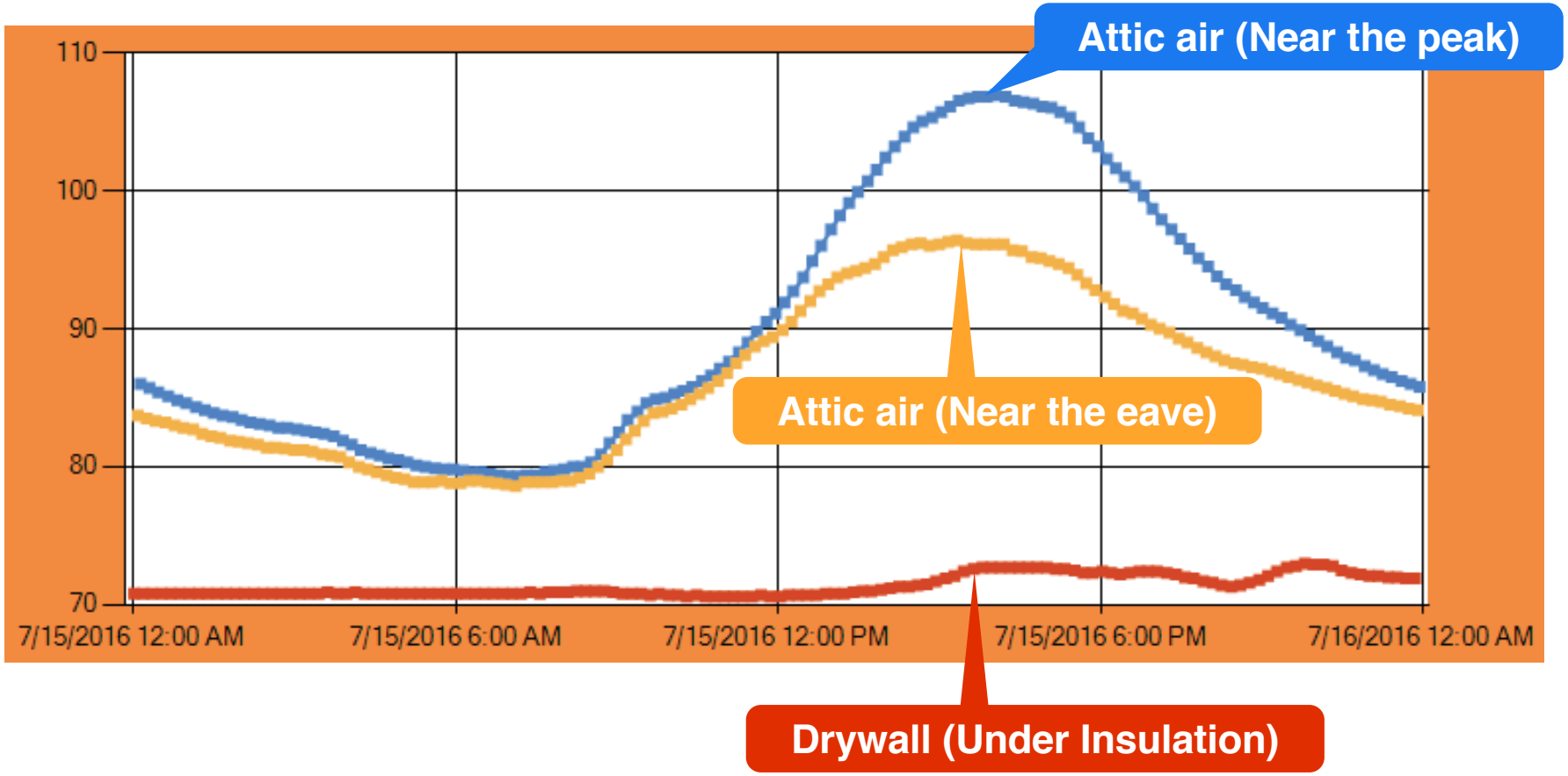
One Day - July 15th: Midnight to Midnight - 5/8” gypsum board ceiling



Remote Monitoring
Houses in South Florida

Attic Stratification (Air Temp)

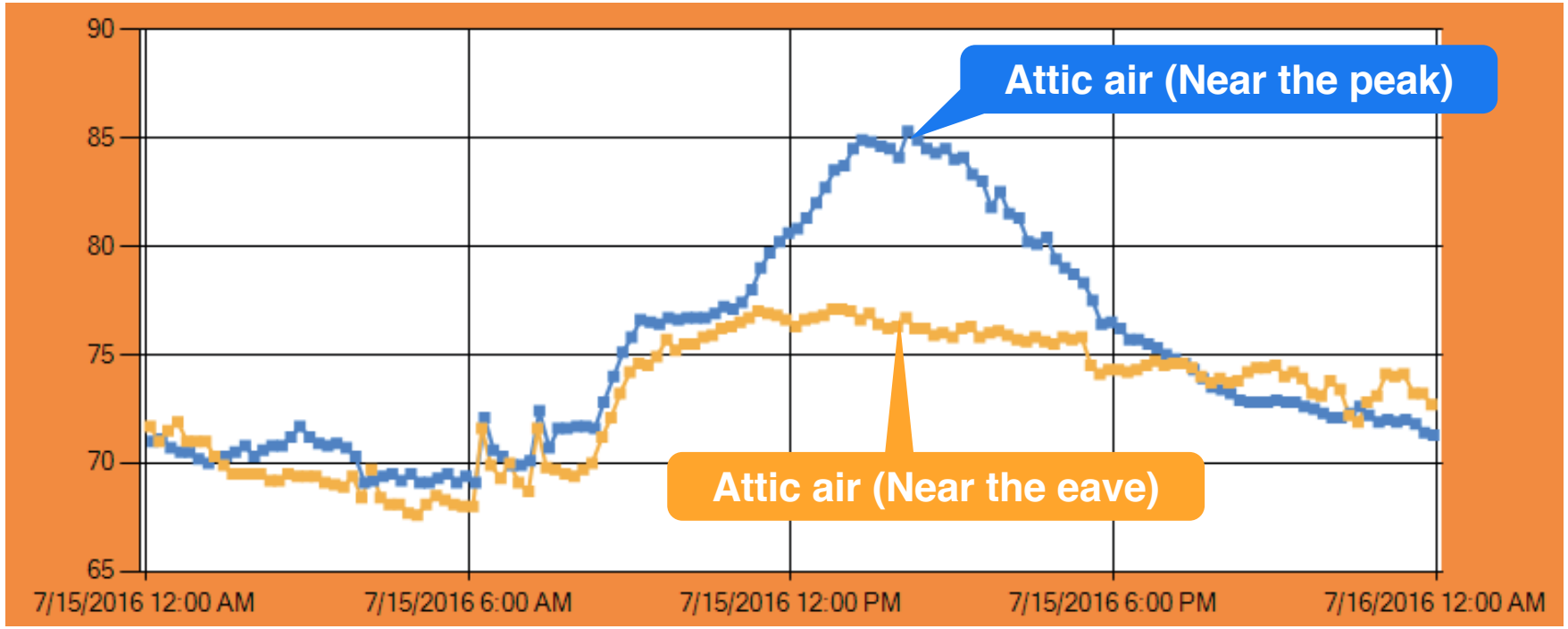
One Day - July 15th: Midnight to Midnight



Remote Monitoring
Houses in South Florida

Attic Stratification (Air Dew Point)

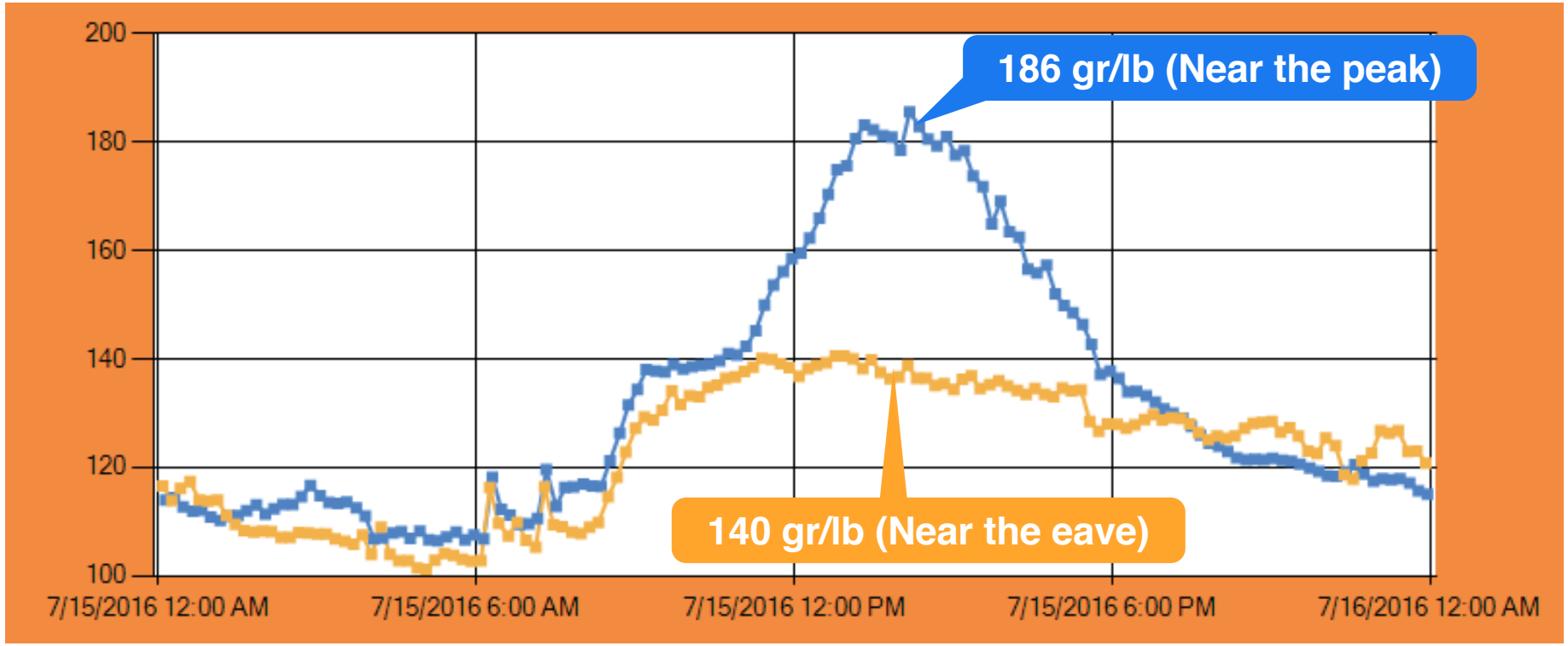
One Day - July 15th: Midnight to Midnight



Remote Monitoring
Houses in South Florida

Attic Stratification (Air Humidity Ratio)

One Day - July 15th: Midnight to Midnight



ASHRAE Design (Sensible)
92F 78wb = **123gr/lb**

ASHRAE Design (Dew Point)
85F 79dpt = **152gr/lb**

Remote Monitoring
Houses in South Florida

What Did We Learn From Monitoring?

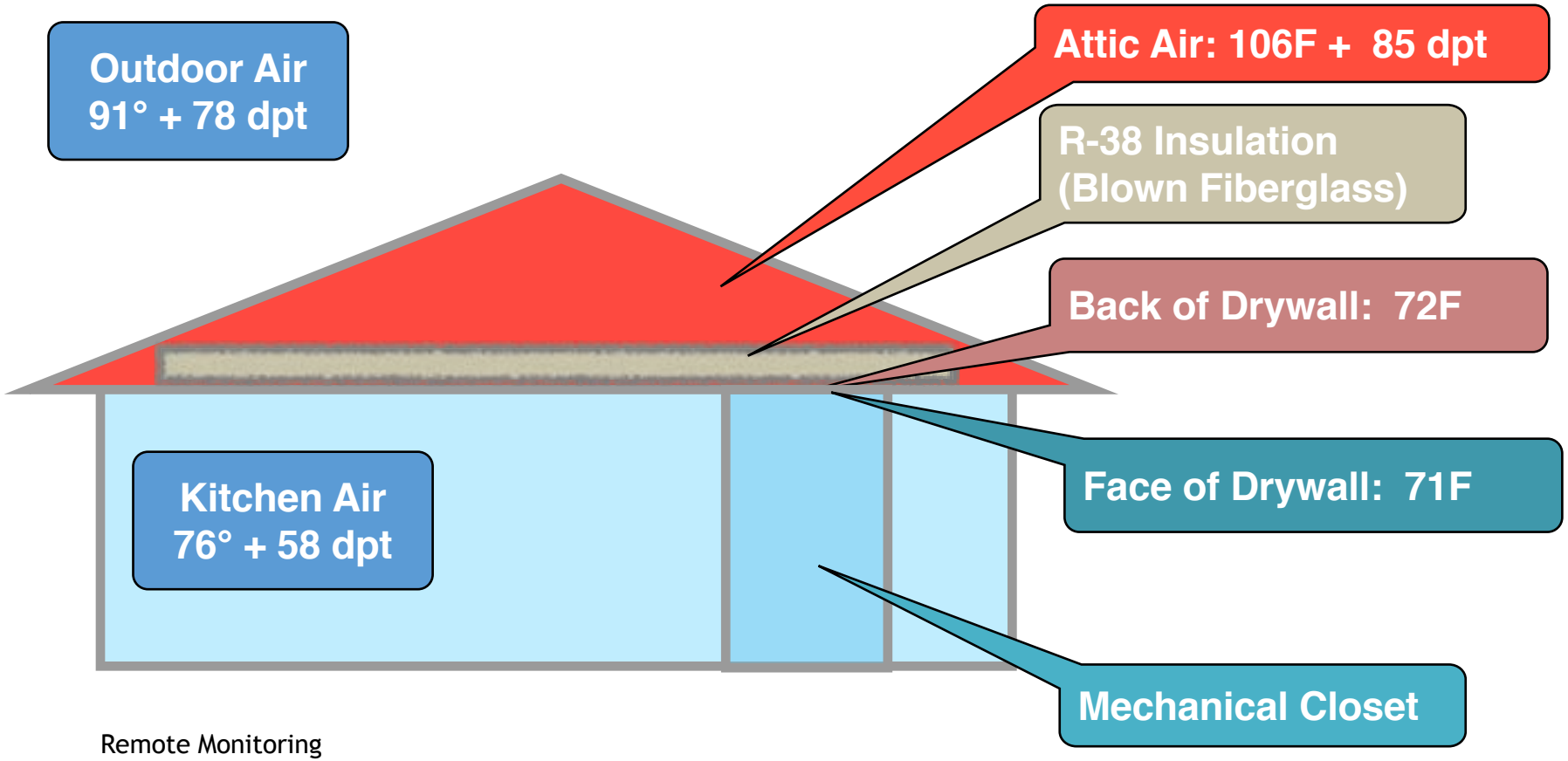
- High attic dew point, 85
- Ceilings were at 70 ºF.
- Back of drywall was at 72 ºF.
- High water activity—66 face, 90 on topside of ceiling
- Attic Stratification: 108 ridge, 90 center, 72 under insulation
- Dew Point Stratification; 85 ridge, 75 eaves
- Humidity Ratio stratification: 186 Gr ridge, 140 Gr eave
- Compare: 123 Gr HVAC design, 152 Gr humidity design.

Lew Harriman's Findings

- High attic dew point
- Cold ceilings in closets, bathrooms, and MER's
- High surface water activity

Typical Summer Afternoon

July 15th 2016 at 3:00pm



Remote Monitoring
Houses in South Florida

Joe Lstiburek's Recommendations:

- O'Hagin ridge vents, 1:300, 50/50%
- Fan cyclers
- Jump duct: improve circulation, warm ceilings

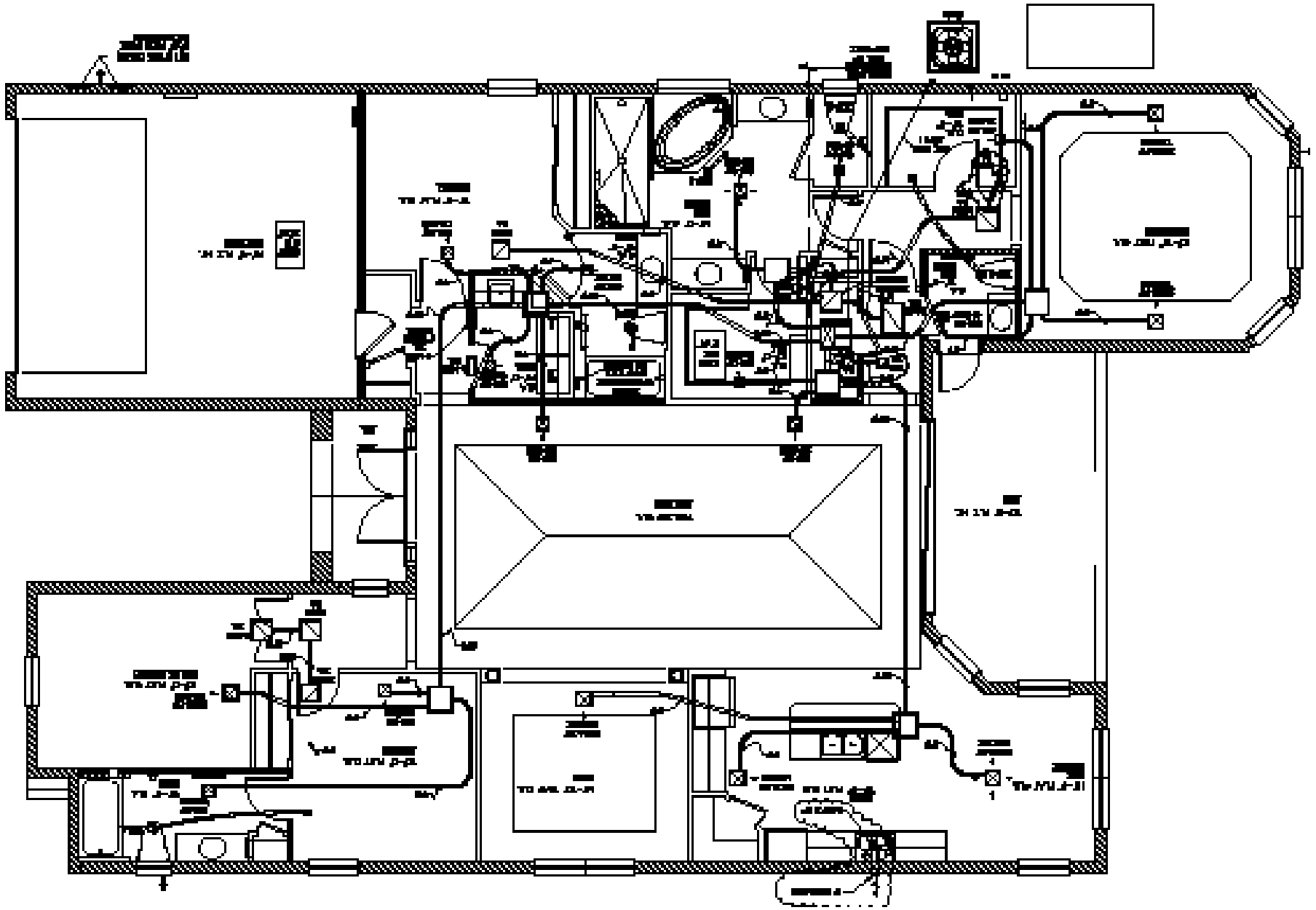
O’Hagin Ridge Vents

Vented Attic:

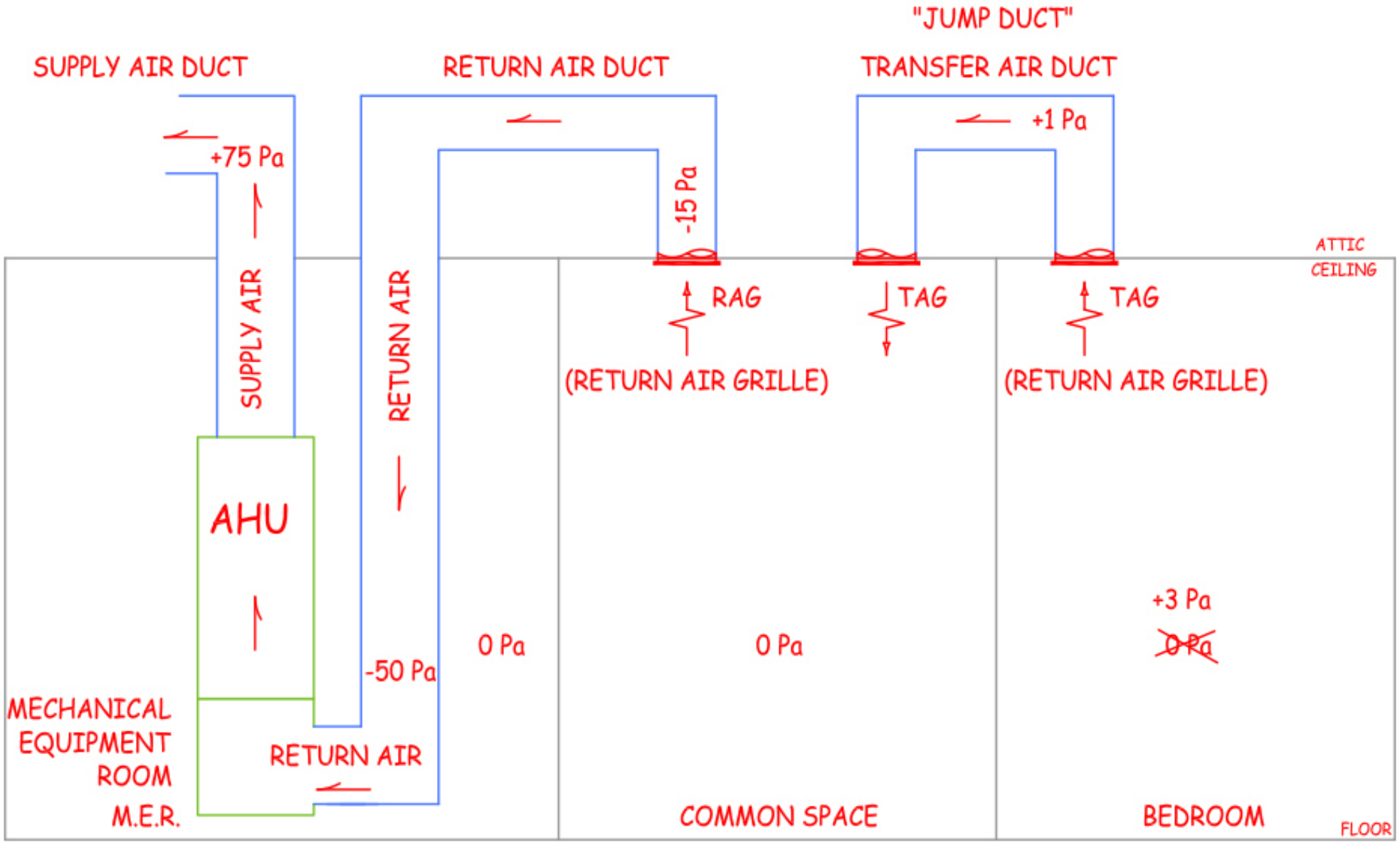
1:300

50% Soffit

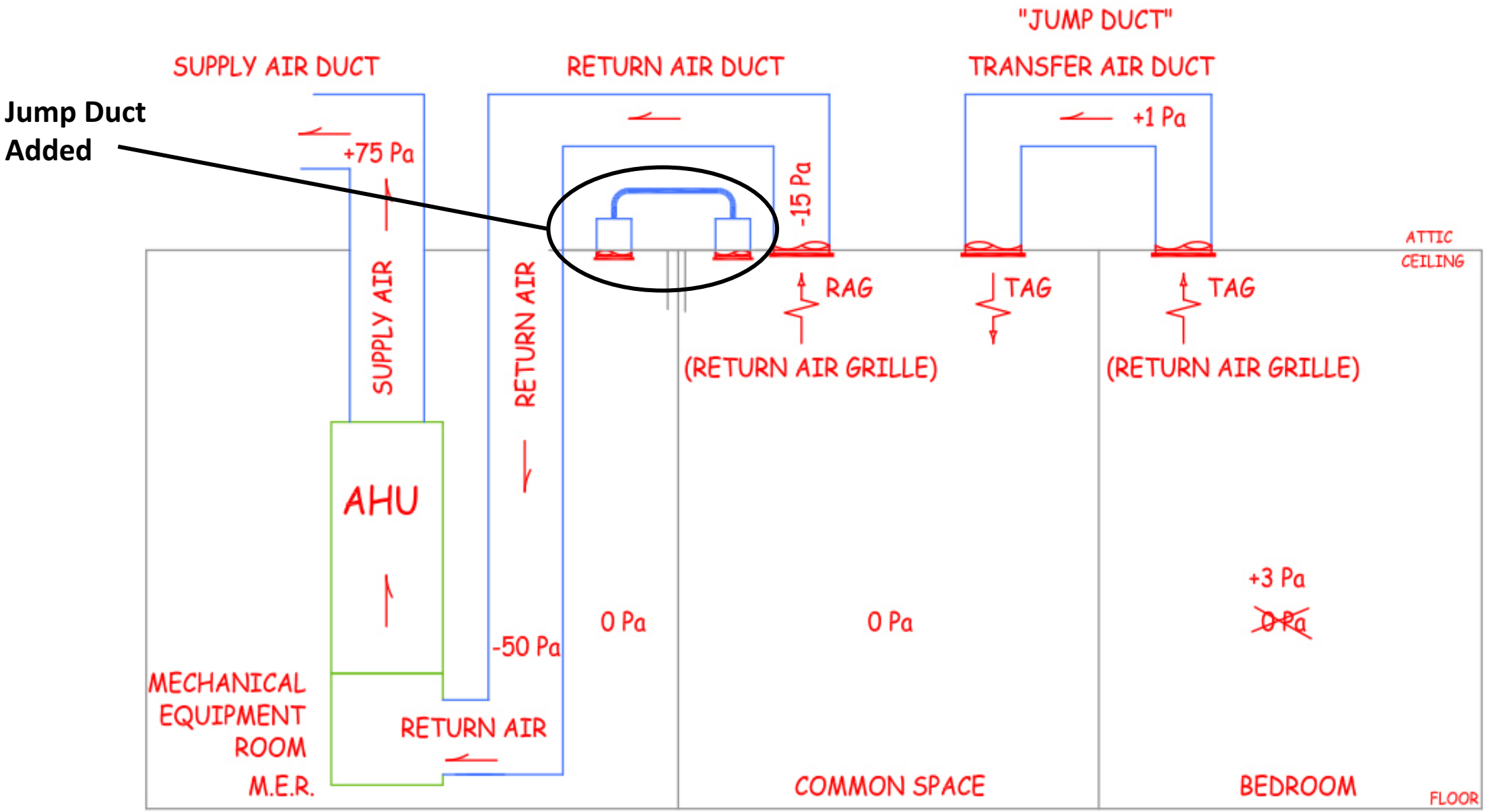
50% Ridge



HVAC Diagram – Return Air Path

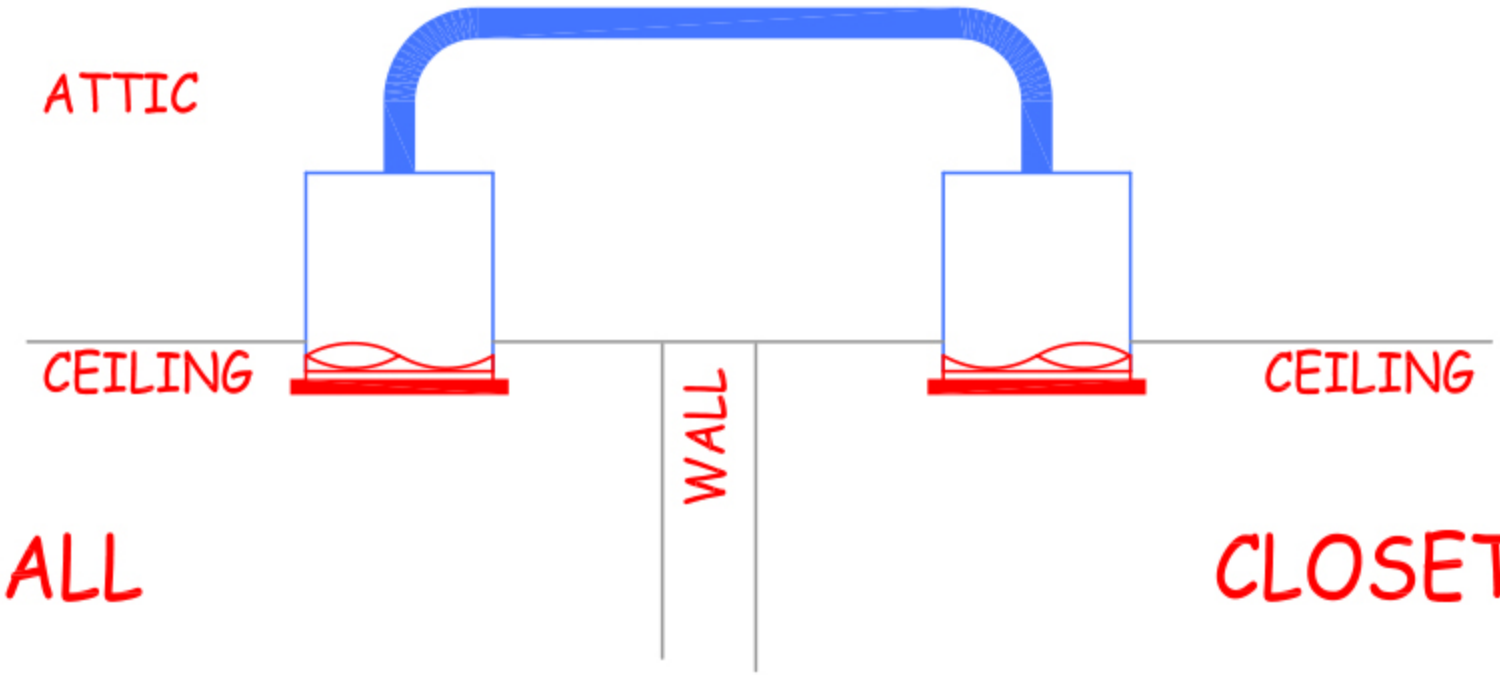


HVAC Diagram – Jump Duct



JUMP DUCT

6" FLEX



8" X 8" GRILLES

Figure 2, page 16.2 in ASHRAE Fundamentals. Phil and Todd both own that book should you want to try a better scan. I think Nikki has already gotten a better image from her digital version of Fundamentals.

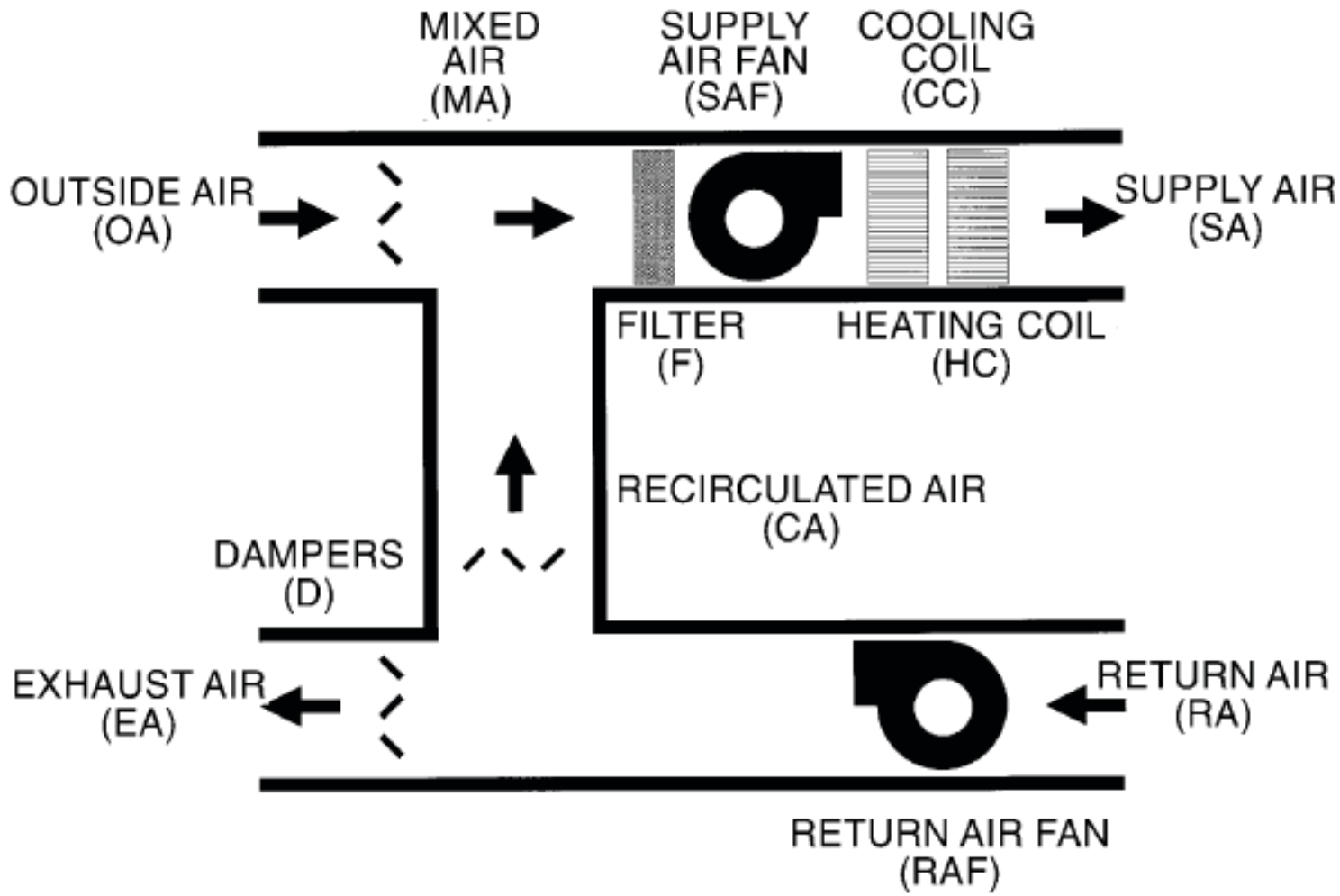
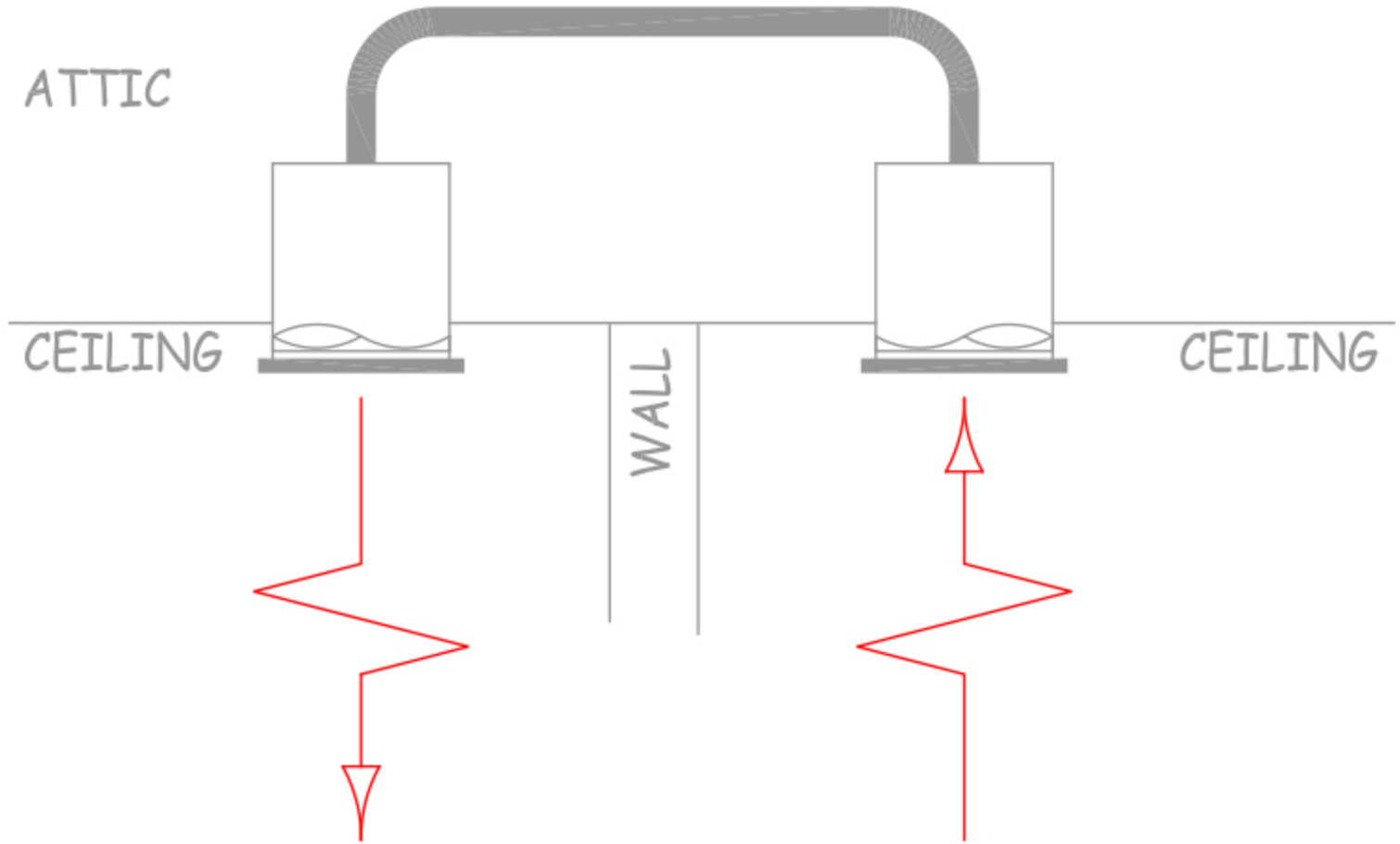
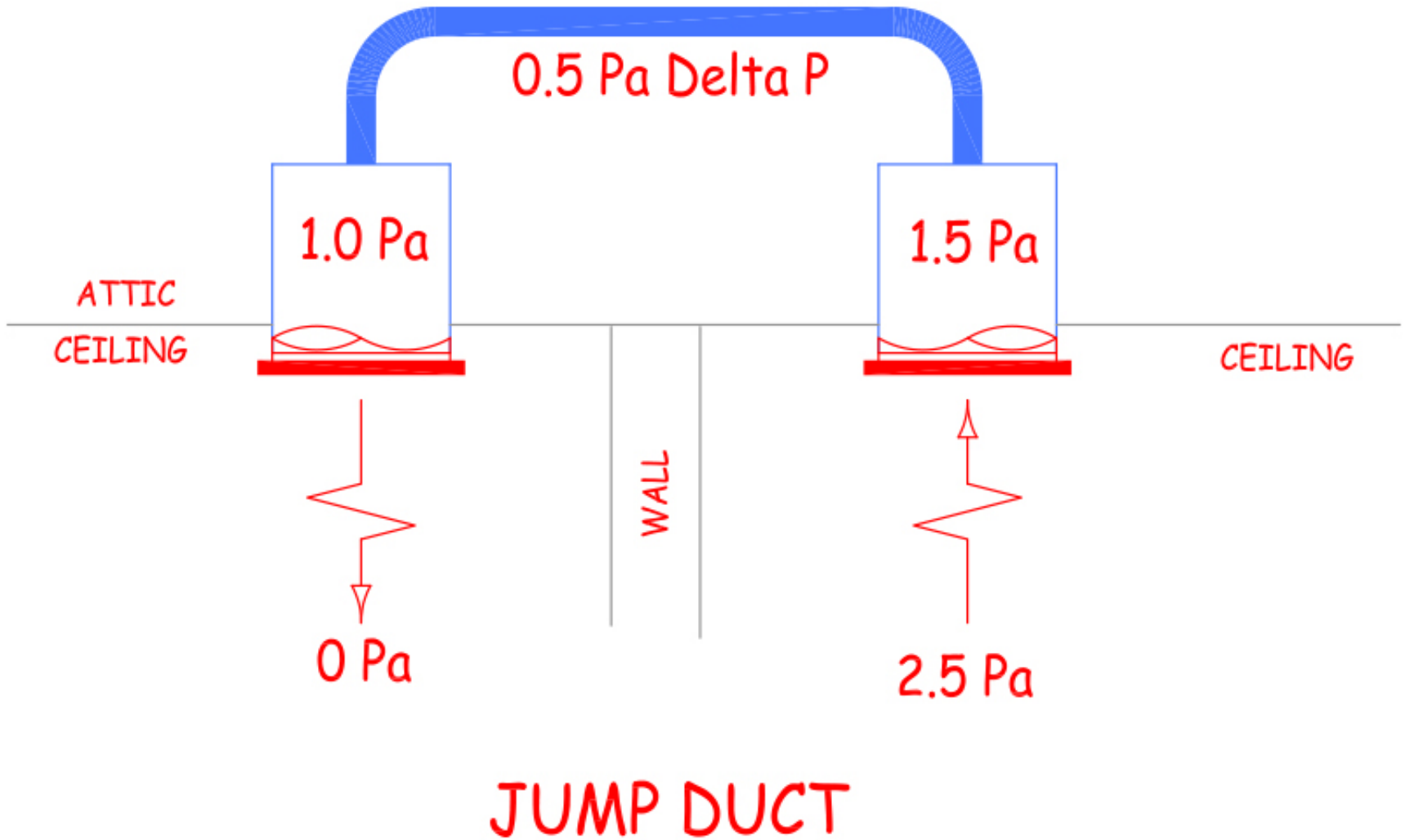


Fig. 2 Simple All-Air Air-Handling Unit with Associated Airflows

JUMP DUCT

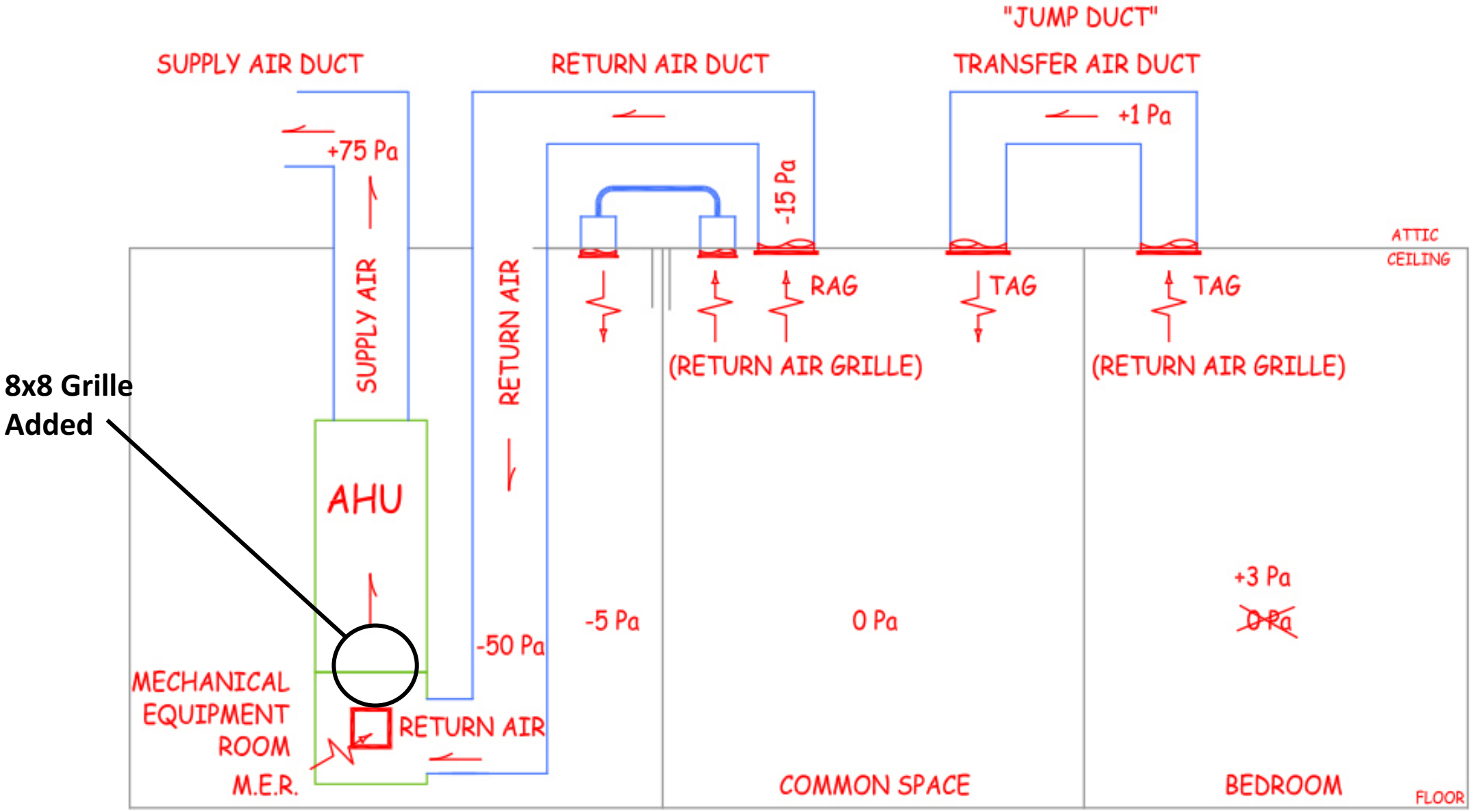
6" FLEX



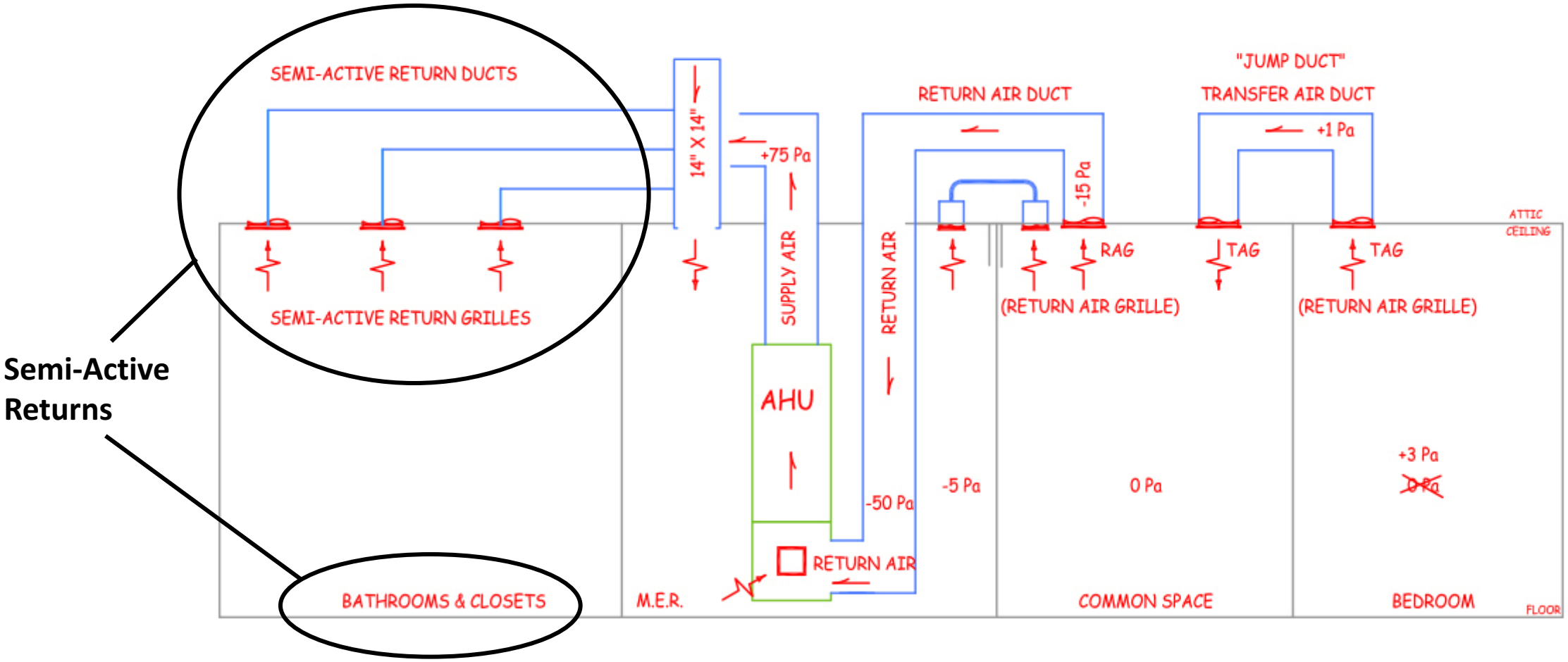


JUMP DUCT

HVAC Diagram – 8 x 8

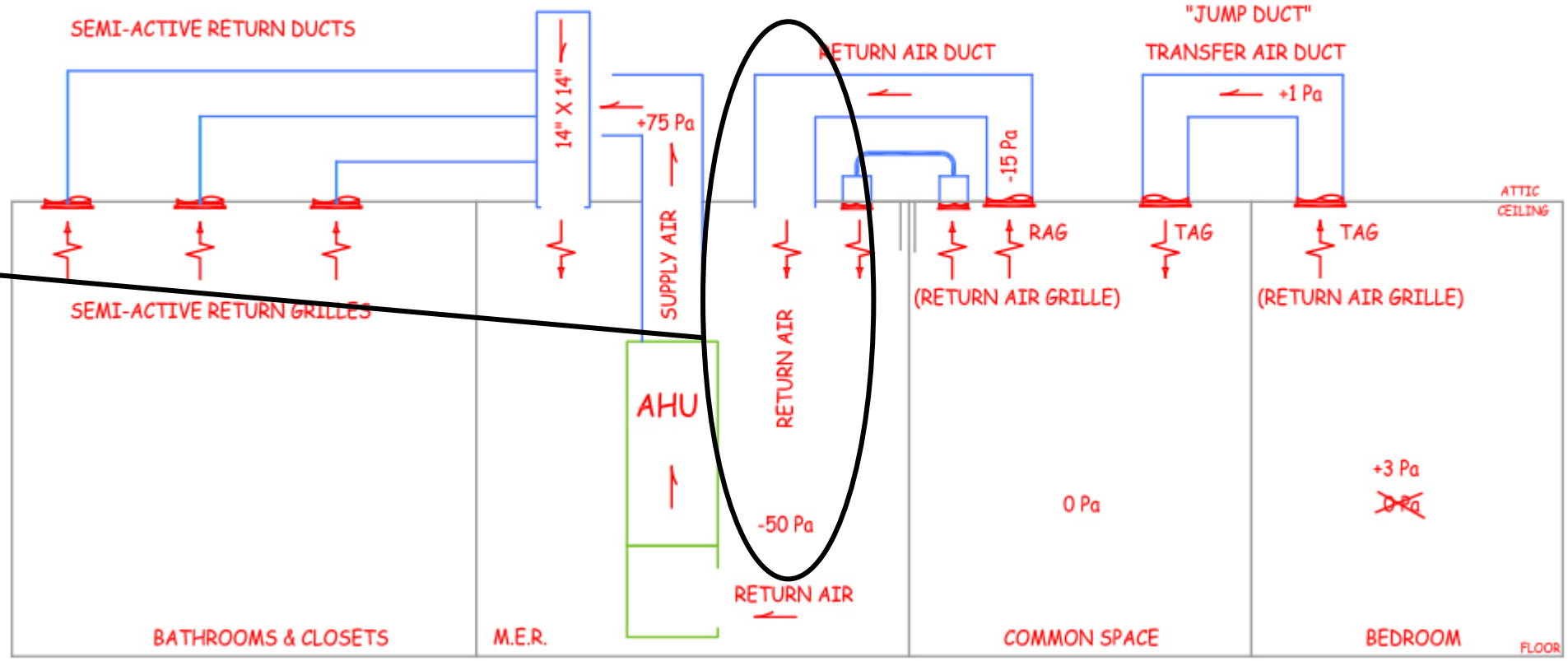


HVAC Diagram – Semi-Active Return Ducts

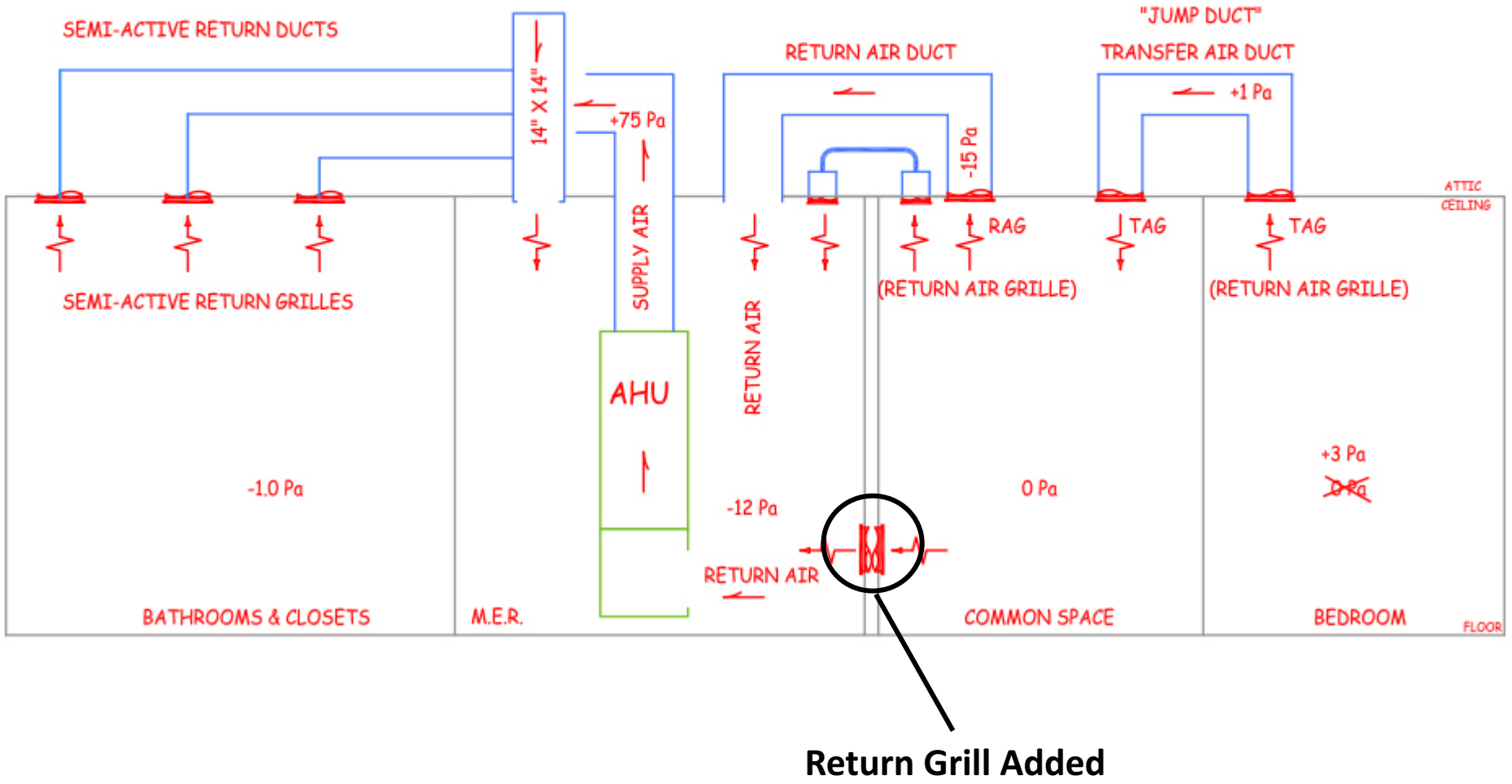


HVAC Diagram – Free Return

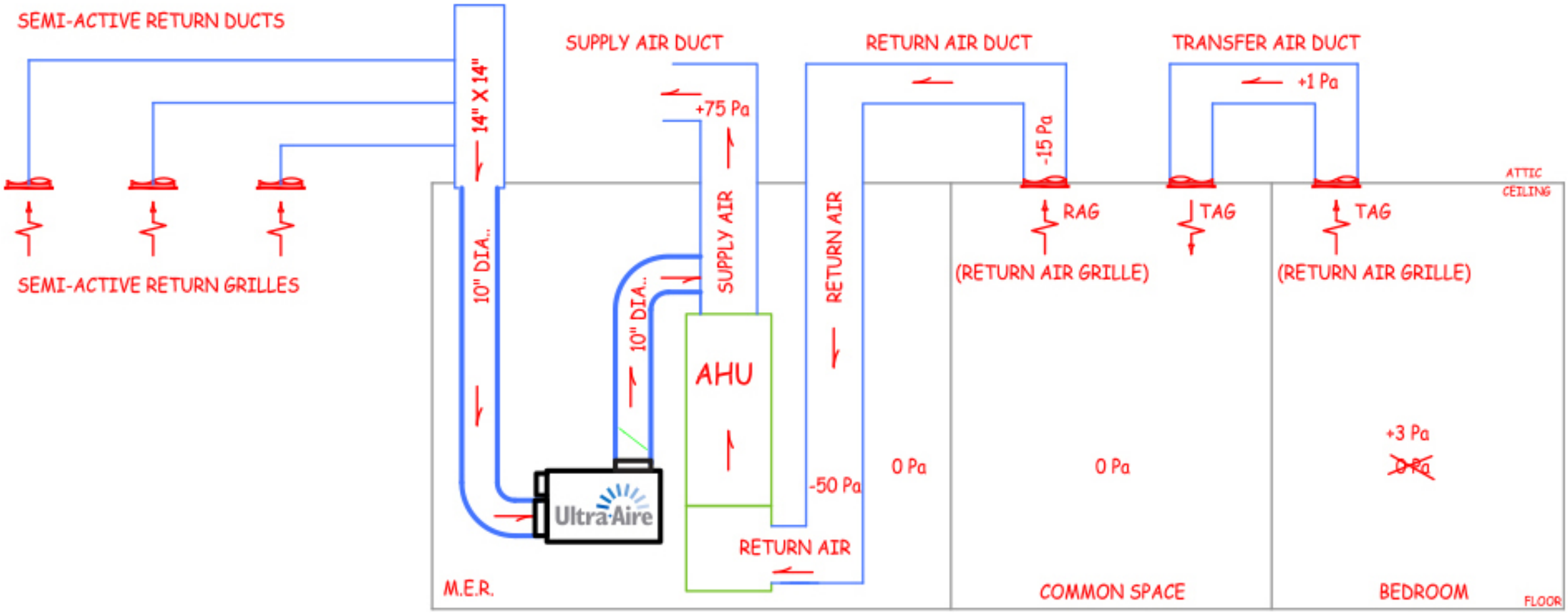
Return Air Duct Removed



HVAC Diagram – Increase Return Path

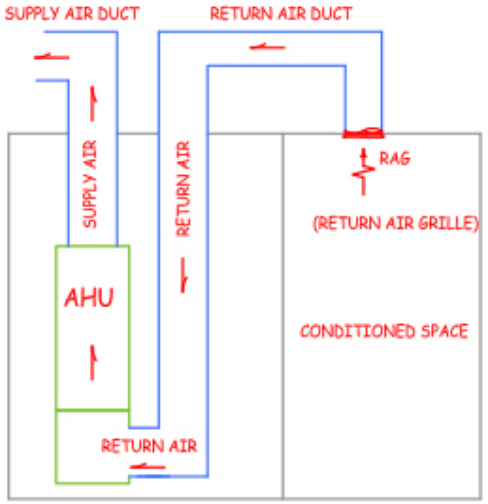


HVAC Diagram – The Solution

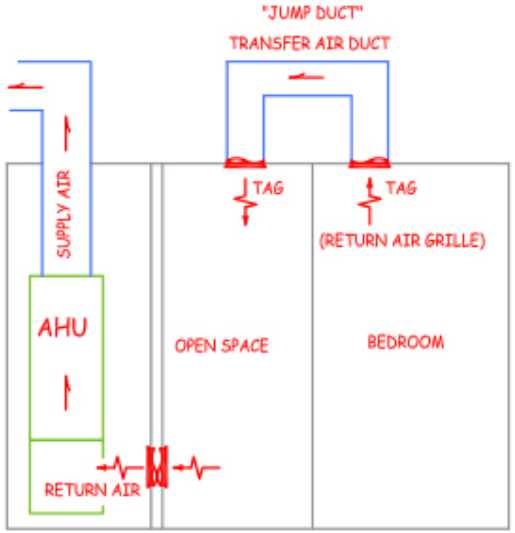


DEC Statement

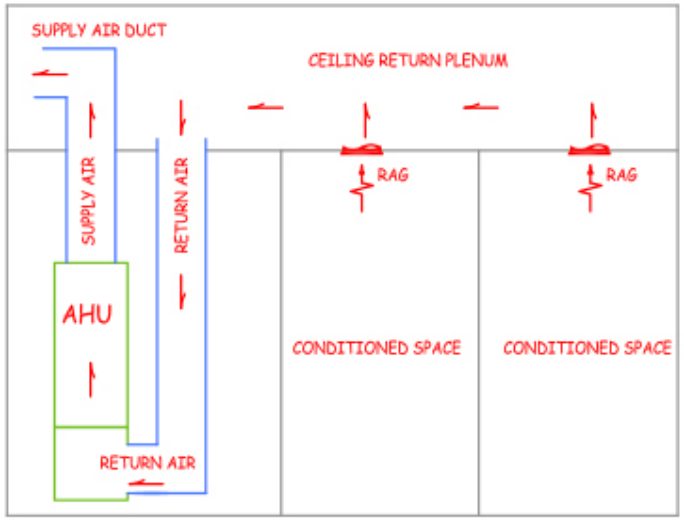
- Need to warm ceilings.
- Remove humidity from closets and baths.
- Semi-Active Return ducts (Dehumidifier Inlets).
- Treat air from closets and baths in dehumidifier.
- Discharge dehumidifier to A/C.
- Approved by state, embraced by building official.



FULLY DUCTED RETURN



FREE RETURN + JUMP DUCTS

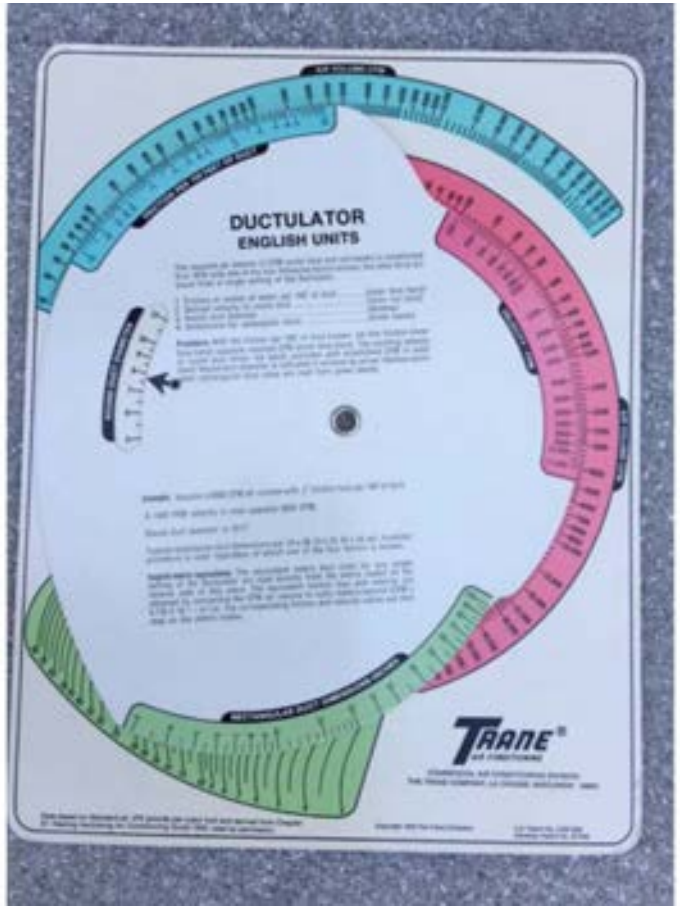


PLENUM RETURN

MINI SPLIT AHU

Tools


DG-700 Pressure & Flow Gauge
DEVICE
CONFIG
0.0
0.0
MODE
TIME AVG
DEVICE
UNITS
CONFIG
MODE
CLEAR
TIME AVG
BASE LINE
START
ENTER
INPUT
A
B
ON/ OFF
LIGHT
HOLD
The ENERGY CONSERVATORY


DUCTULATOR
ENGLISH UNITS
TRANE

DUCT SIZING CHART

RIGID SHEETMETAL DUCT					FLEXIBLE DUCT			
MAXIMUM CFM								
Dia. Size	Supply Duct @.10" S.P.	Runout = 15' Max	Return Duct @.08" S.P.	Transfer Duct @ 2.5 Pa	Supply Duct @.06" S.P.	Runout = 15' Max	Return Duct @.03" S.P.	Transfer Duct @ 2.5 Pa
4"	40	70	30	10	30	65	20	10
6"	110	150	85	40	85	150	60	40
8"	230	280	180	70	180	200	125	70
10"	410	440	320	110	310	350	225	110
12"	680	N/A	540	150	520	550	360	150
14"	1,000	N/A	800	210	780	N/A	540	210
16"	1,400	N/A	1,100	250	1,150	N/A	750	250
18"	1,800	N/A	1,500	360	1,600	N/A	1,050	360

ACA August 1, 2017

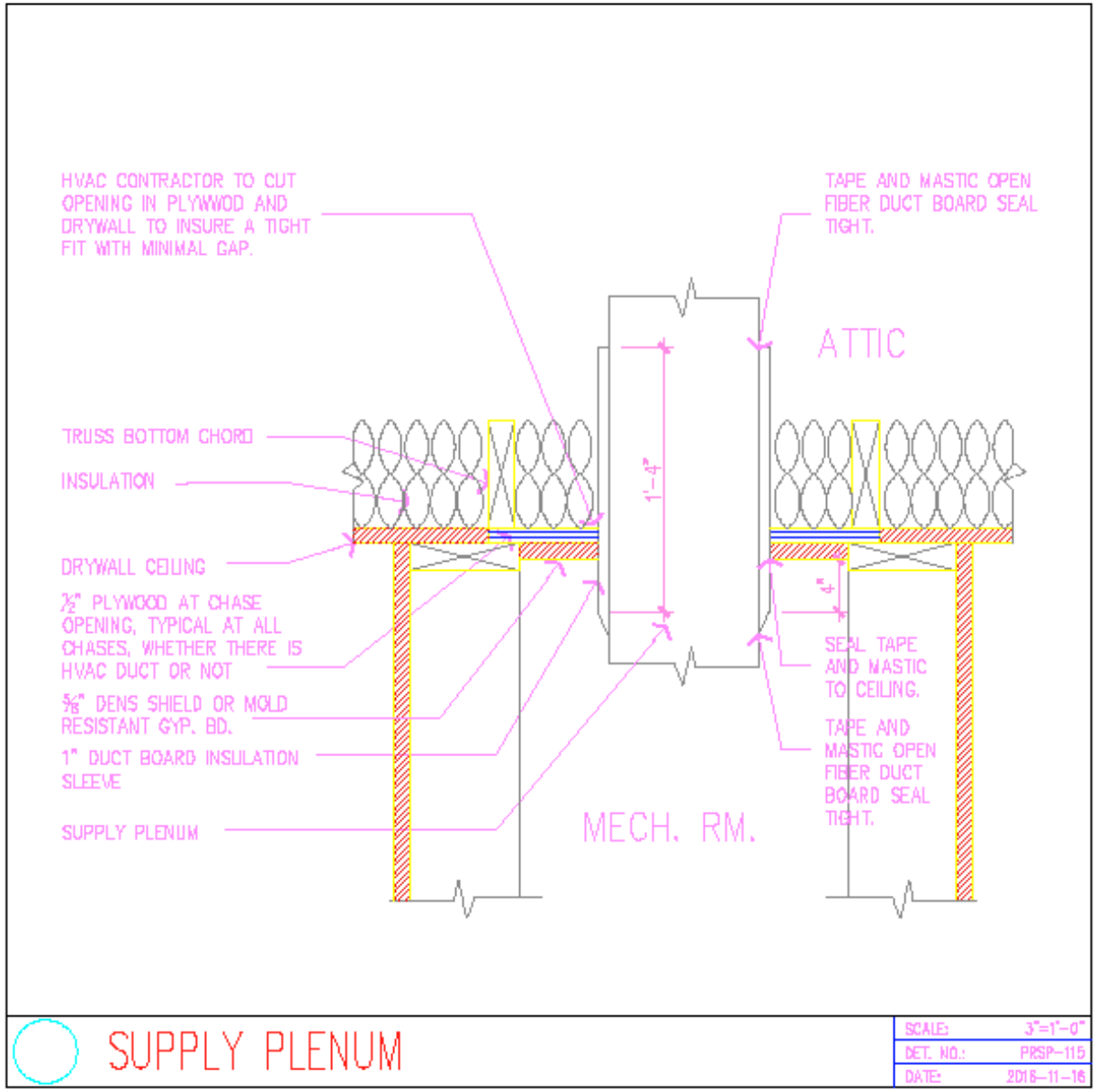
TSTAT $40

AIR CYCLER $100

DEHUMIDISTAT $150

Honeywell TH8321R1001 $162.00

Supply Duct Ceiling Penetration



Summary: What We Did

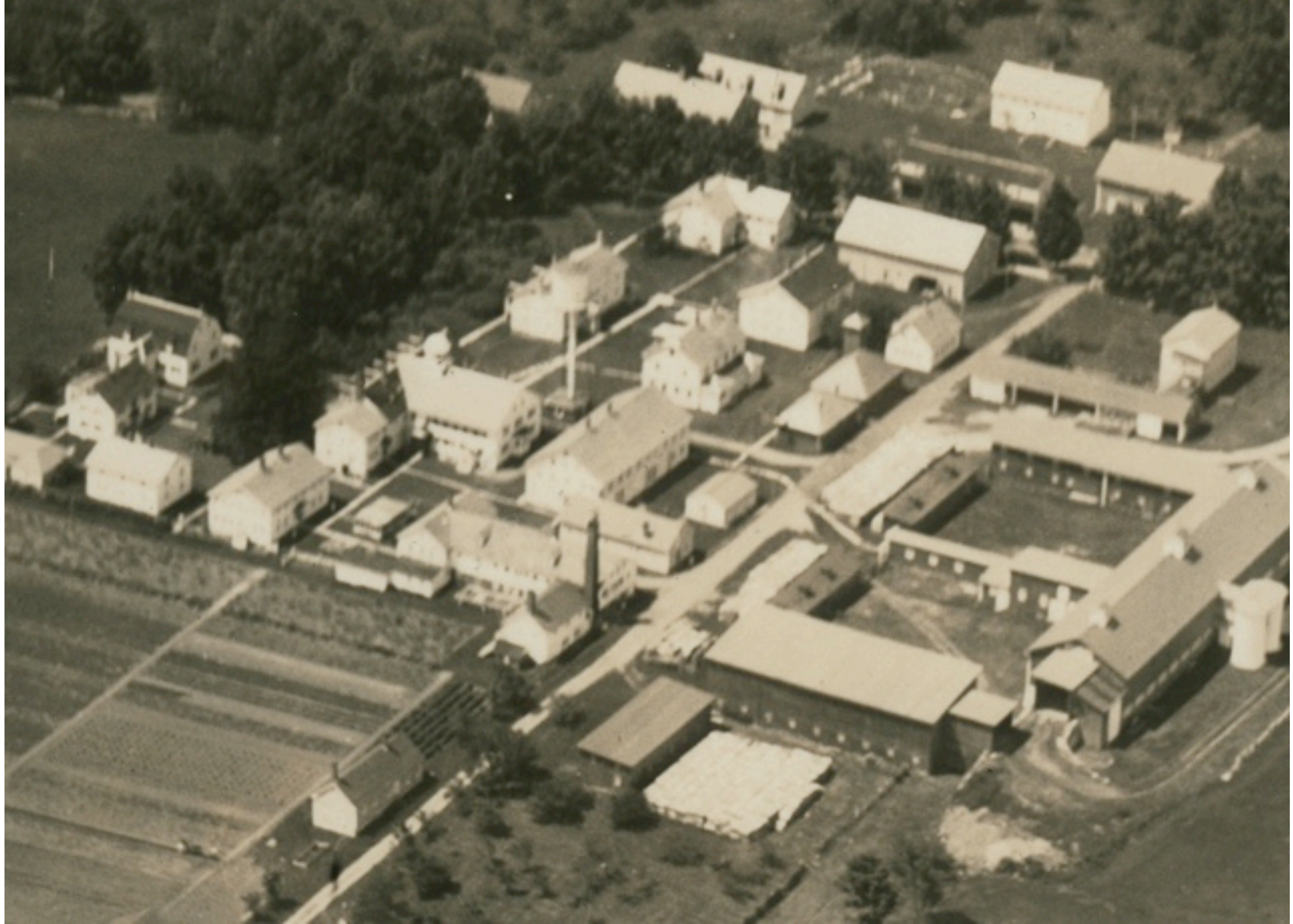
- Ridge Vents
- Dehumidifiers
- Fan Cyclers
- Tweaked Return Air

Epilogue:
The Dog

Canterbury Shaker Village

Canterbury Shaker Village

RETHINK TRADITION



Vitruvius

- Firmitas
- Utiilitas
- Venustas

OR

- Firmness
- Commodity
- Delight

Shakers

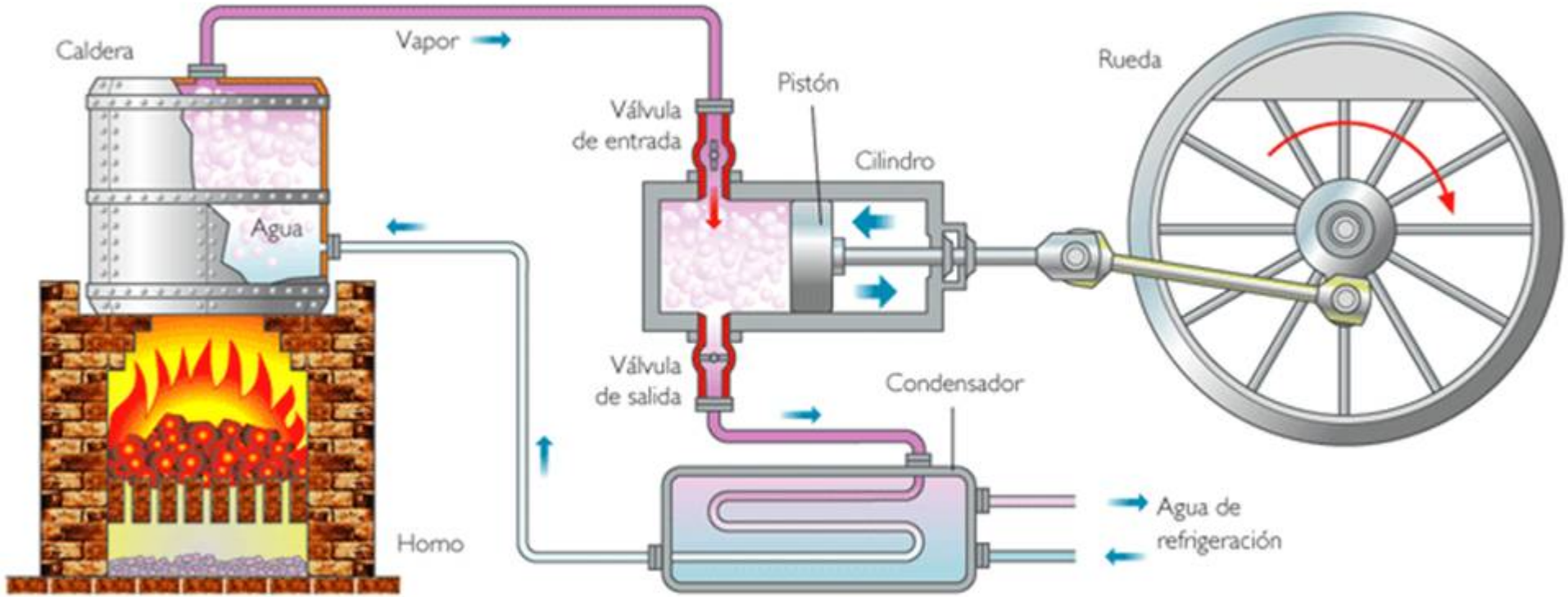
- Useful
- Good
- Beautiful

Shaker Products

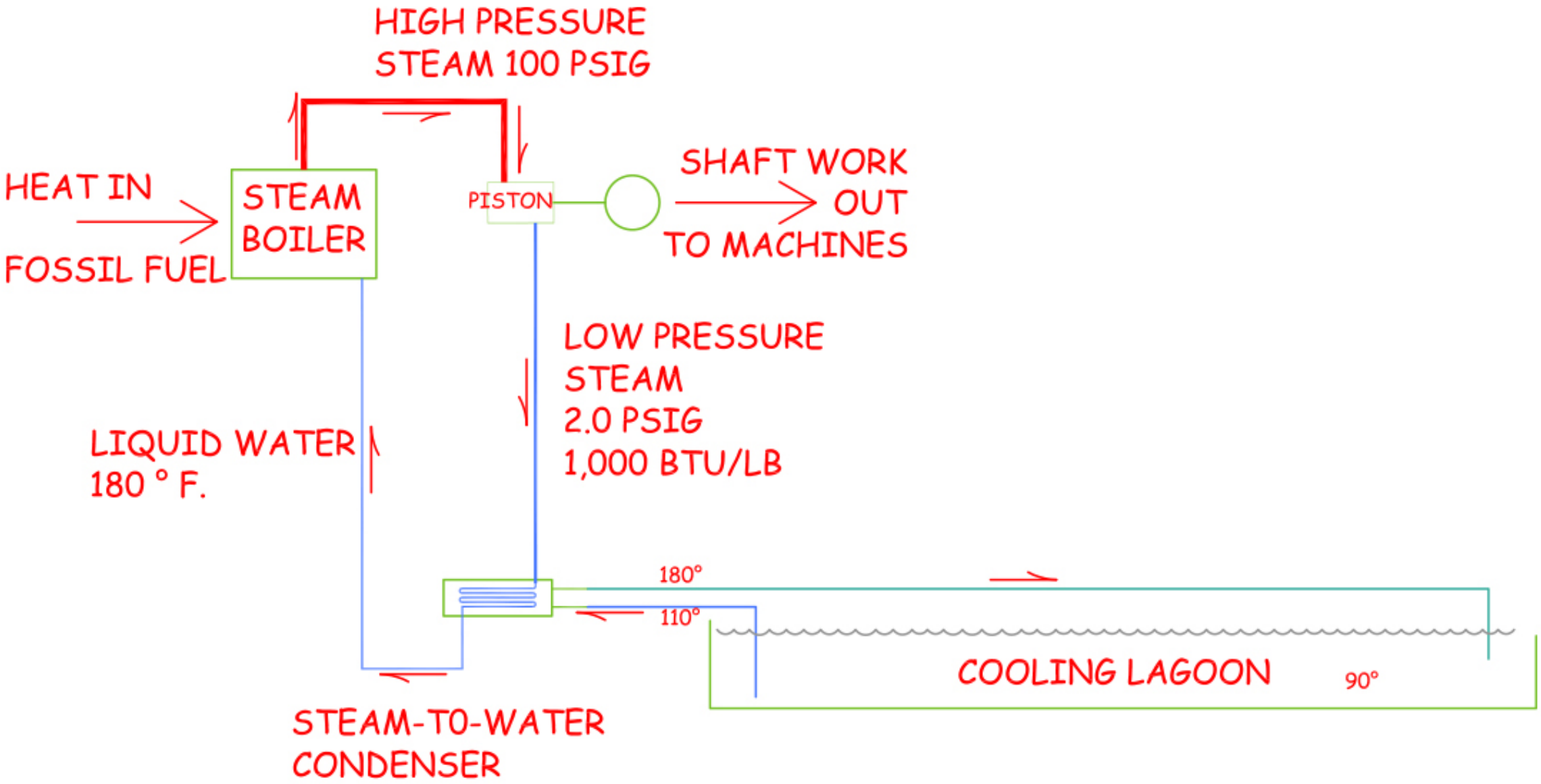
- Brooms
- Buckets
- Tubs
- Dresses
- Ivy League Sweaters
- Furniture


GARDNER

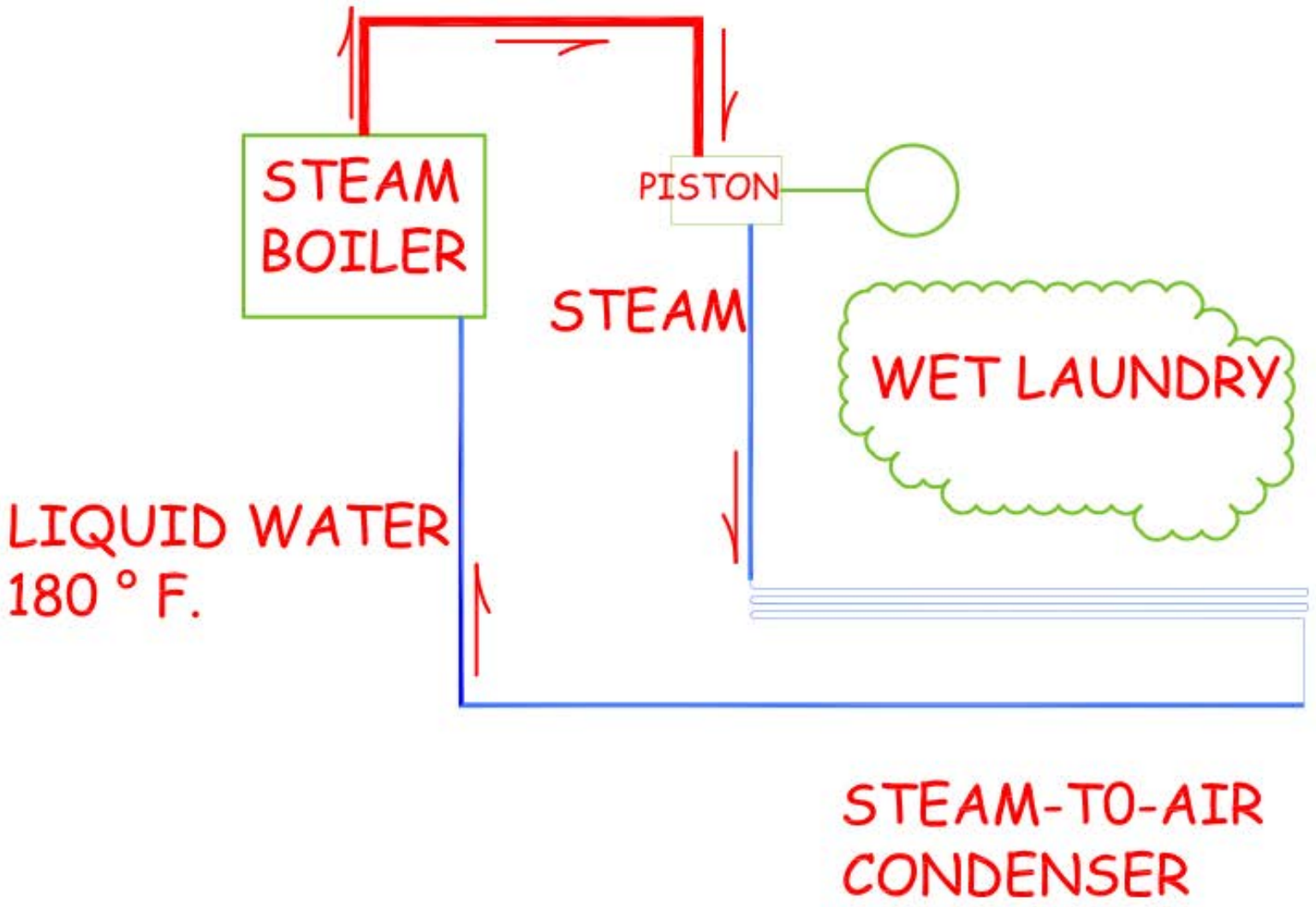
MÁQUINA DE VAPOR



Laundry Steam Engine – Water Cooled



Laundry Steam Engine – Air Cooled




Runaway Pond
Gues Meadow Brook
Long Pond
Center Pond
North Family Farm
Canterbury
Shaker Village
West Turning
Pond
Google

Shaker Mills

- Saw
- Grist
- Turning
- Carding
- Threshing Machine

Shaker Water - Shaft Work +

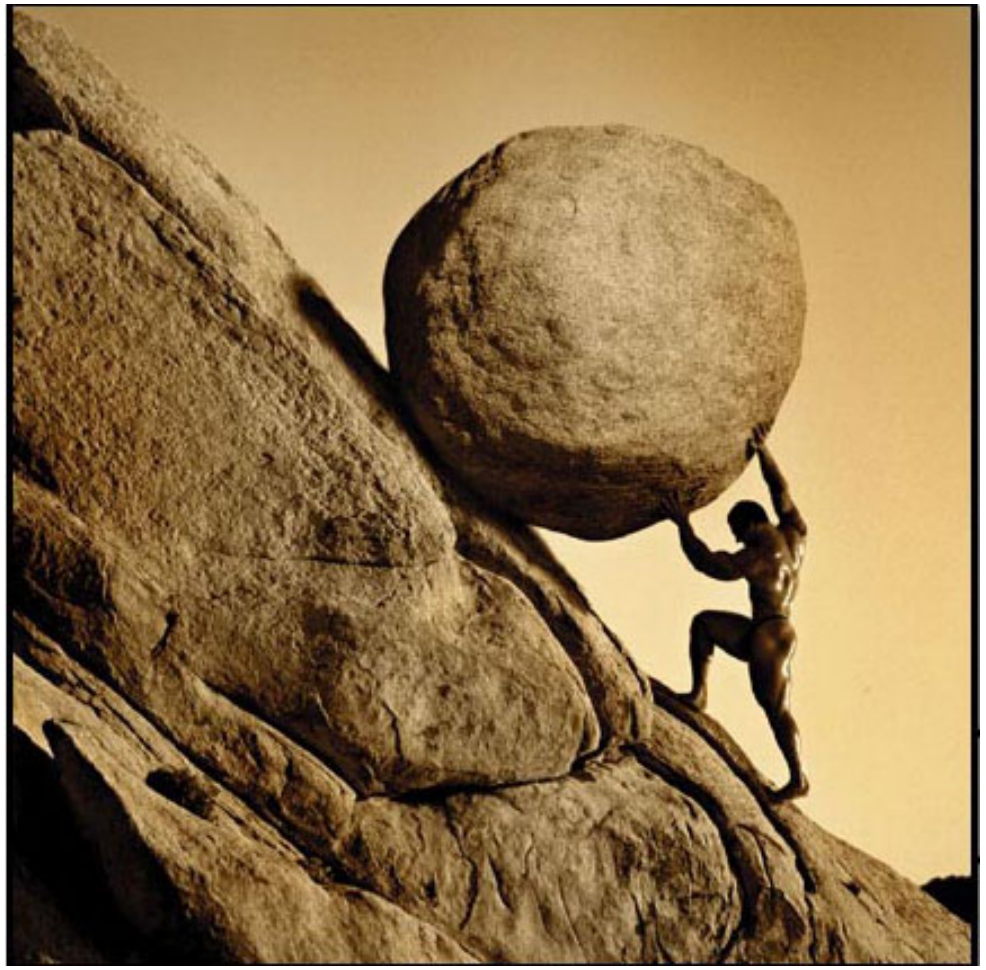
- Ice in winter
- Drink
- Cook
- Laundry
- Livestock
- Irrigation

Shaker Pond System

- (7) Ponds
- About 50 acres
- 2 miles of ditches
- 170’ fall
- 1.6% grade


Runaway Pond
Gues Meadow Brook
Long Pond
Center Pond
North Family Farm
Canterbury
Shaker Village
West Turning
Pond
Google

What We've Learned



- I know it as "HOC", the energy it takes to drive a refrigeration cycle.
- It's why 14 SEER A/C's become 13, not 15 SEER.
- It's what's in the dumpster at the end of a construction project.
- It's why glasses don't unbreak.
- It's why stuff doesn't unburn.
- It's why 14 socks become 12, not 14.
- It's why jelly bread always lands jelly side down.
- It's why I don't get younger.
- It's what you leave in the toilet bowl after you go to the bathroom.

When you are done with your energy, be sure it is all worn out!

Fundamentals - HVAC Formulas

I've built my career on (4) formulas:

- 1.085 x SCFM x Delta T ºF. = BTUH
- 4.5 x SCFM x Delta h – BTU/LB = BTUH
- 500 x GPM x Delta T ºF. = BTUH
- R.E. BTUH + H.O.C. BTUH = G.H.R. BTUH
- Add a Trane Ductulator and I was armed and dangerous

Refrigeration Math

R.E. BTUH + H.O.C. BTUH = G.H.R. BTUH

OR

RE + HOC = GHR

12,000 BTUH + 3,000 BTUH = 15,000 BTUH

Transporting Heat

BTU: Heat 1.0 lb. Water 1.0 ºF.

Ton of Cooling:
Melt 2,000 lb. Ice @144 BTU/lb. in 24 hours
= 12,000 BTU/HR = 12,000 BTUH

Energy We Buy at the BTU Store:
Watt-Hours X 1,000 = Kilowatt-Hours = Kwh

Convert Watts to BUTH:
1.0 Watt = 3.413 BTUH 1.0 Kw = 3,413 BTUH

In Andymath:

1,000 Watts = 3,413 BTUH = 3,000 BTUH

- R.E. = Refrigeration Effect
- Transmission
- Lights
- People
- O.A.
- A/C Loads
- Energy Transported
- Removed from Cold Reservoir

- + H.O.C. = Heat of Compression = Compressor kW +Auxiliaries (Fans & Pumps)
- = G.H.R. = Gross Heat Rejection = Energy transported to Hot Reservoir
- If cooling: GHR is “gross” – waste
- If heating: GHR is “gold” – the end product

- R.E. = Refrigeration Effect
- Transmission
- Lights
- People
- O.A.
- A/C Loads
- Energy Transported
- Removed from Cold Reservoir

- + H.O.C. = Heat of Compression
- = Compressor kW +Auxiliaries (Fans & Pumps)

- = G.H.R.
- = GROSS HEAT REJECTION

- = Energy transported to Hot Reservoir

Buying Energy at the BTU Store

(aka THE POWER COMPANY)

- How much energy do we buy at the BTU Store? (aka the Power Company)
- We have to buy the H.O.C.: energy that drives the compressor and auxiliaries
- 1970: ABOUT 1.0 Kw per ton of cooling.
  (old hermetic tin can compressors were worse: up to 1.4 kW per ton)

Refrigeration Efficiency

We can express efficiency as the ratio of:

- R.E. / H.O.C. – What We Get/What We Buy (Higher is Better)

Or

- R.E. ÷ H.O.C. and What We Get ÷ What We Buy

In my example:

- R.E. + H.O.C. = G.H.R.
- 12,000 BTUH + 3,000 BTUH = 15,000 BTUH (About 1.0 kW per ton)
- R.E. ÷ H.O.C. = 12,000 ÷ 3,000 = 4.0 Coefficient of Performance (C.O.P. Cooling)

Heat Pump Efficiency

For Heating:

- G.H.R. ÷ H.O.C. = 15,000 ÷ 3,000 = 5.0 C.O.P. Heating

AND

- C.O.P. Heating ALWAYS = C.O.P. Cooling + 1