Small

Simple

Serviceable

HVAC Solutions for Multi-Family Housing

James Petersen, PE - Principal

Petersen Engineering

https://youtu.be/035tT_DvJGs

PE | Petersen Engineering

26,000+ units of new or renovated housing

Engineer of Record

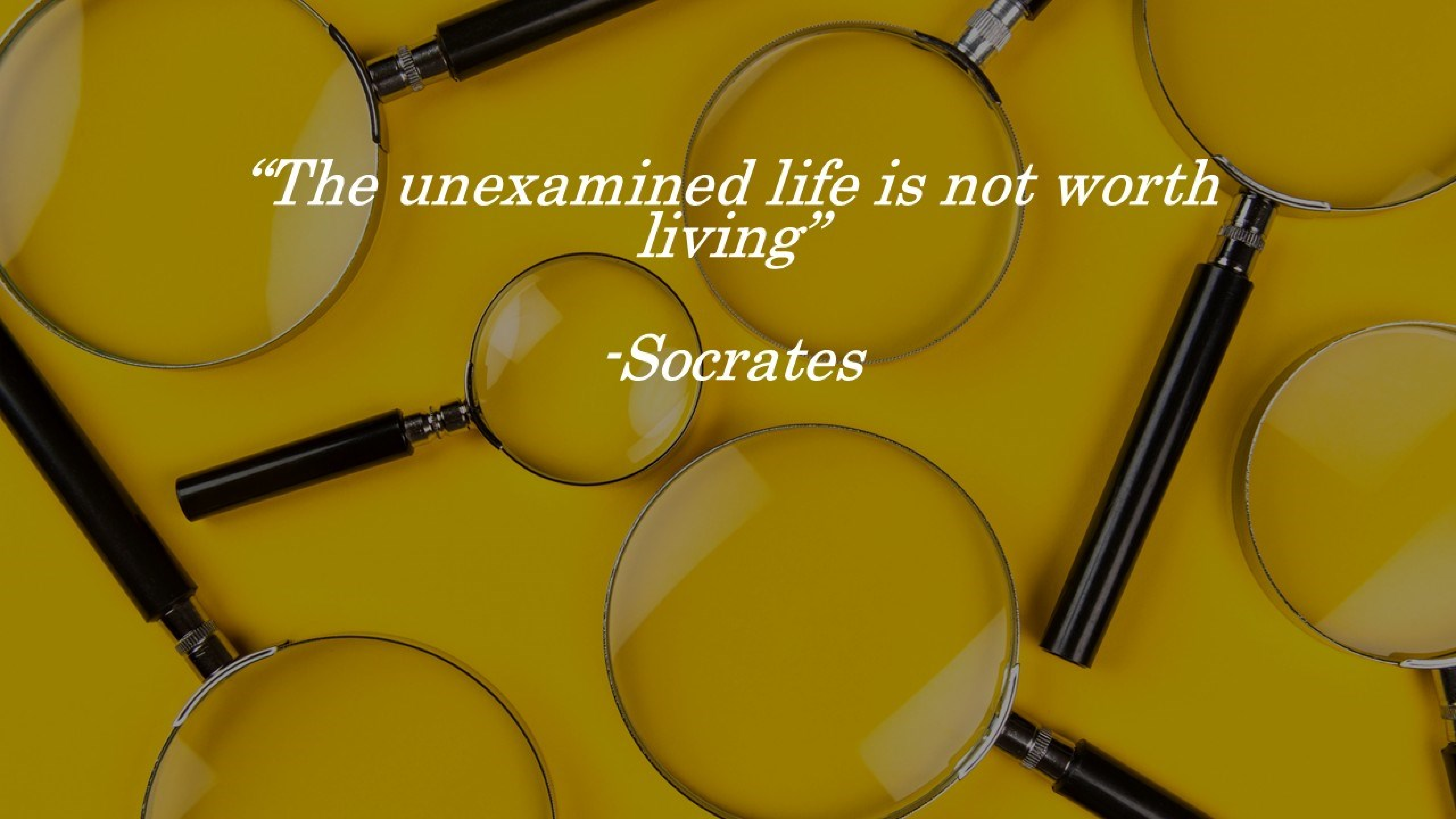
69 Passive House Projects

5,340 dwelling units

28 Design Certified

5,481,187 SF

19 Final Certified


"The unexamined life is not worth living"
-Socrates

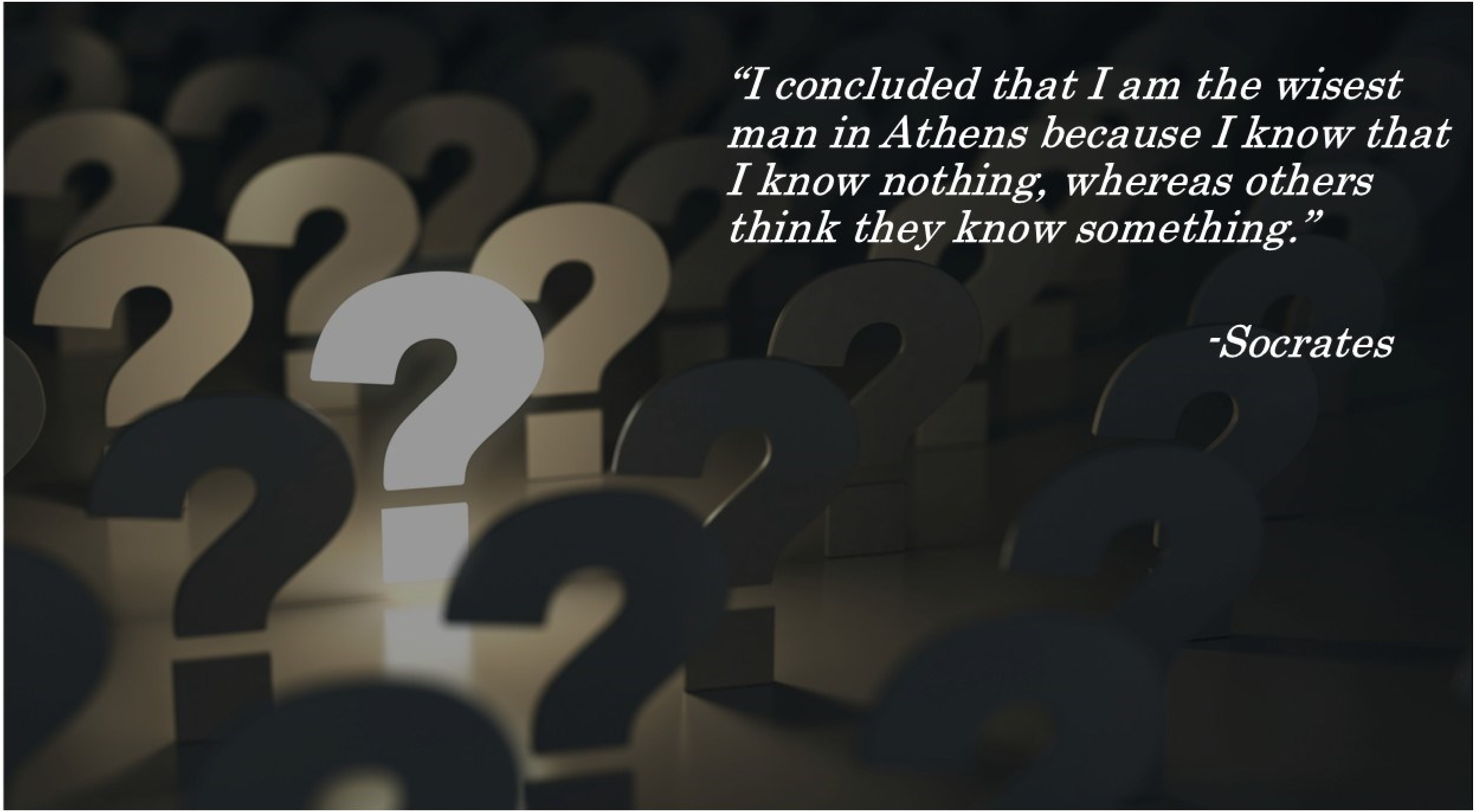

EnergyShield

EnergyShield


This is Milo!
Milwaukee


VINEGAR


SEAMEN

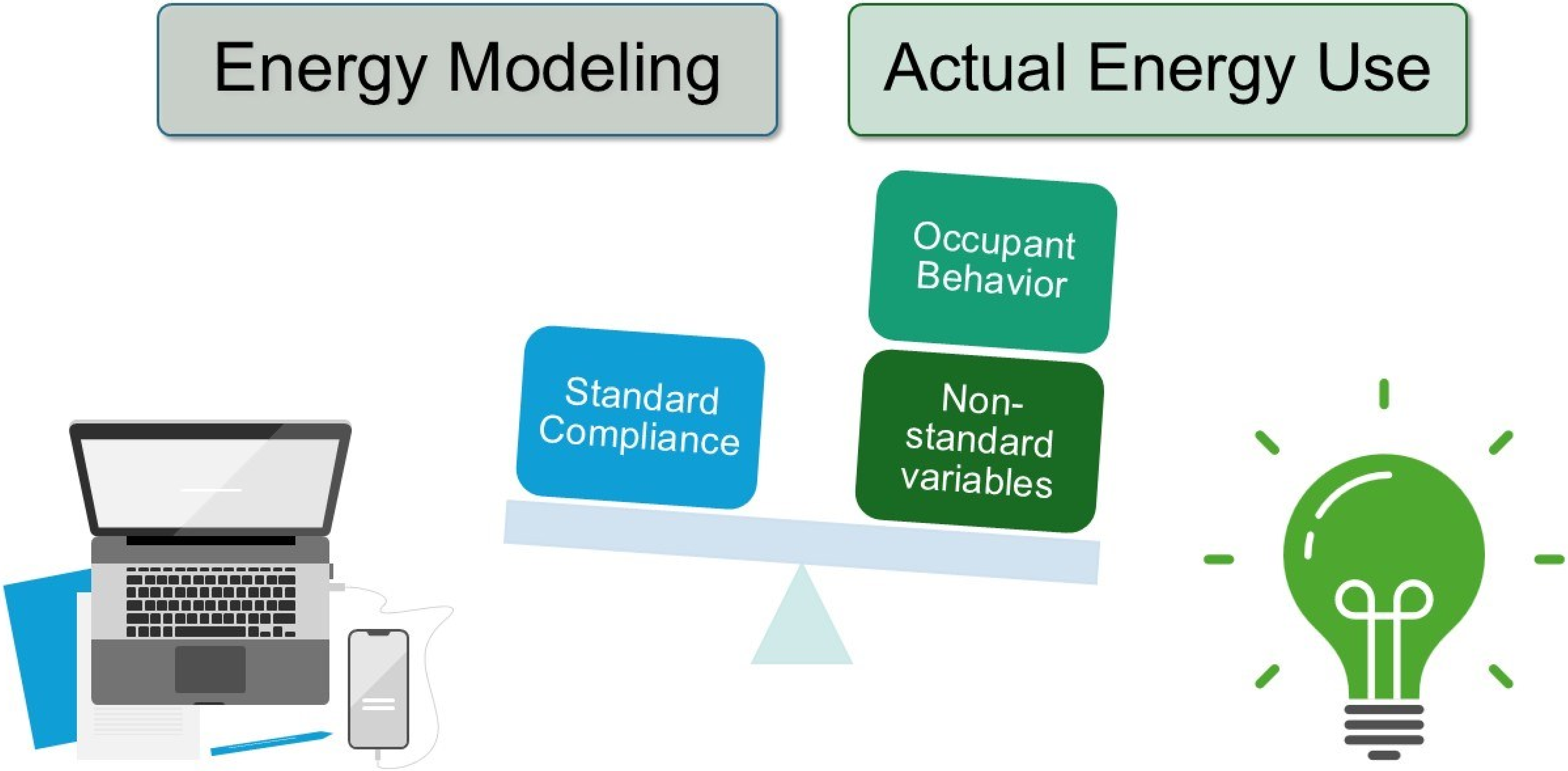

"I concluded that I am the wisest man in Athens because I know that I know nothing, whereas others think they know something."
-Socrates

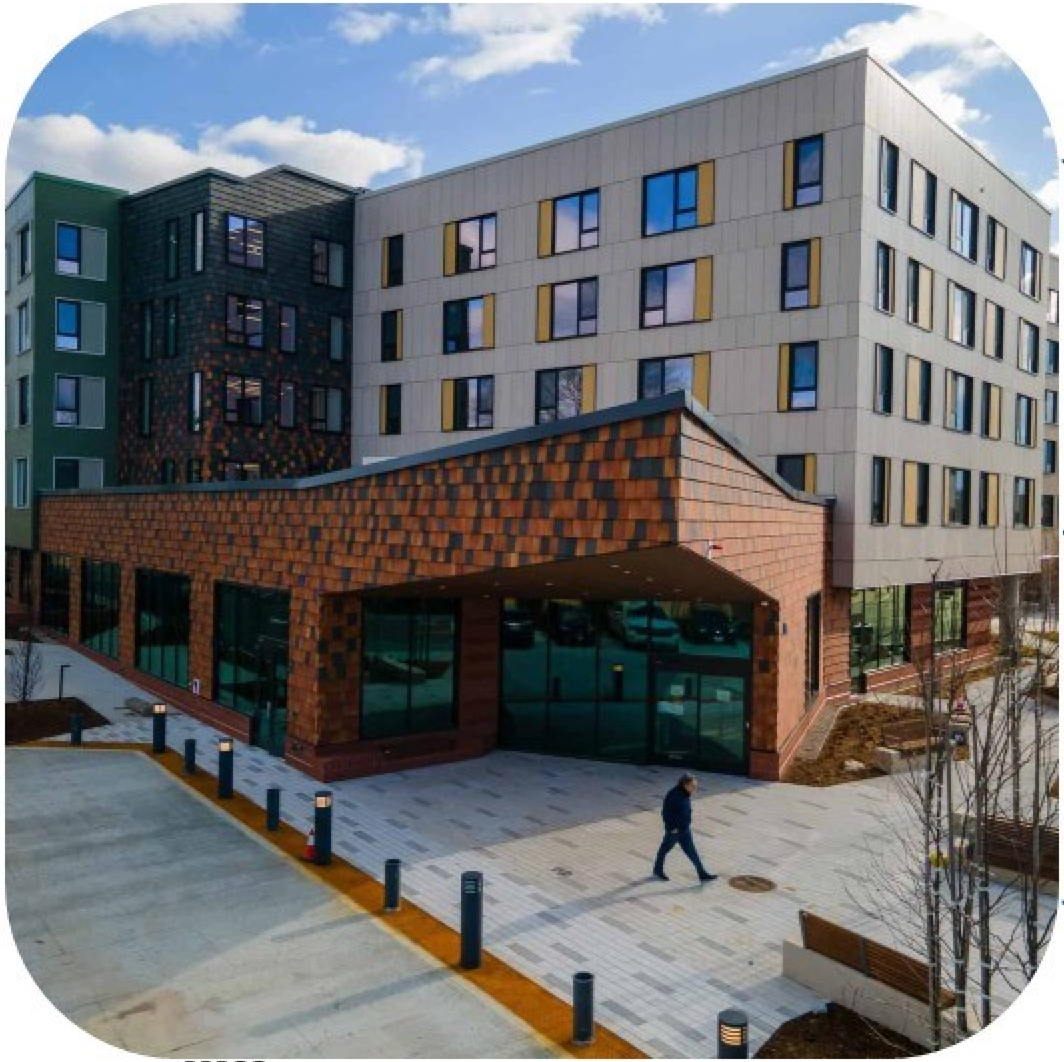
Integrative Design

FORM

ENVELOPE

SYSTEMS


Energy Modeling
Actual Energy Use
Occupant Behavior
Standard Compliance
Non-standard variables



MASS.

165 Residents

142 Units

143,202 SF

Envelope

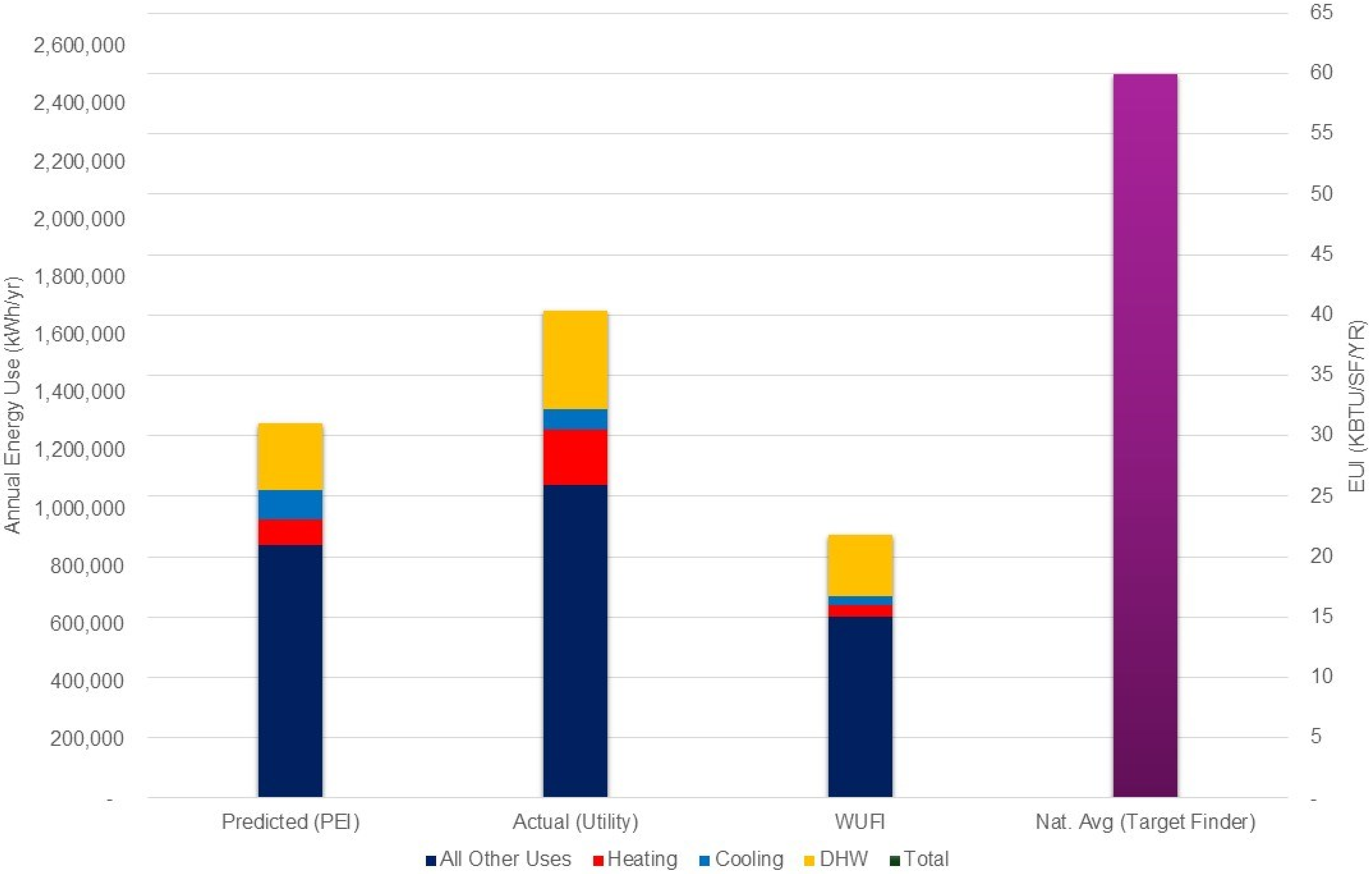
R-47

SHGC 0.4
Fixed: U0.13
Operable: U0.15
Triple Glazed

R-30 (2 1/2” continuous, R-10.5)

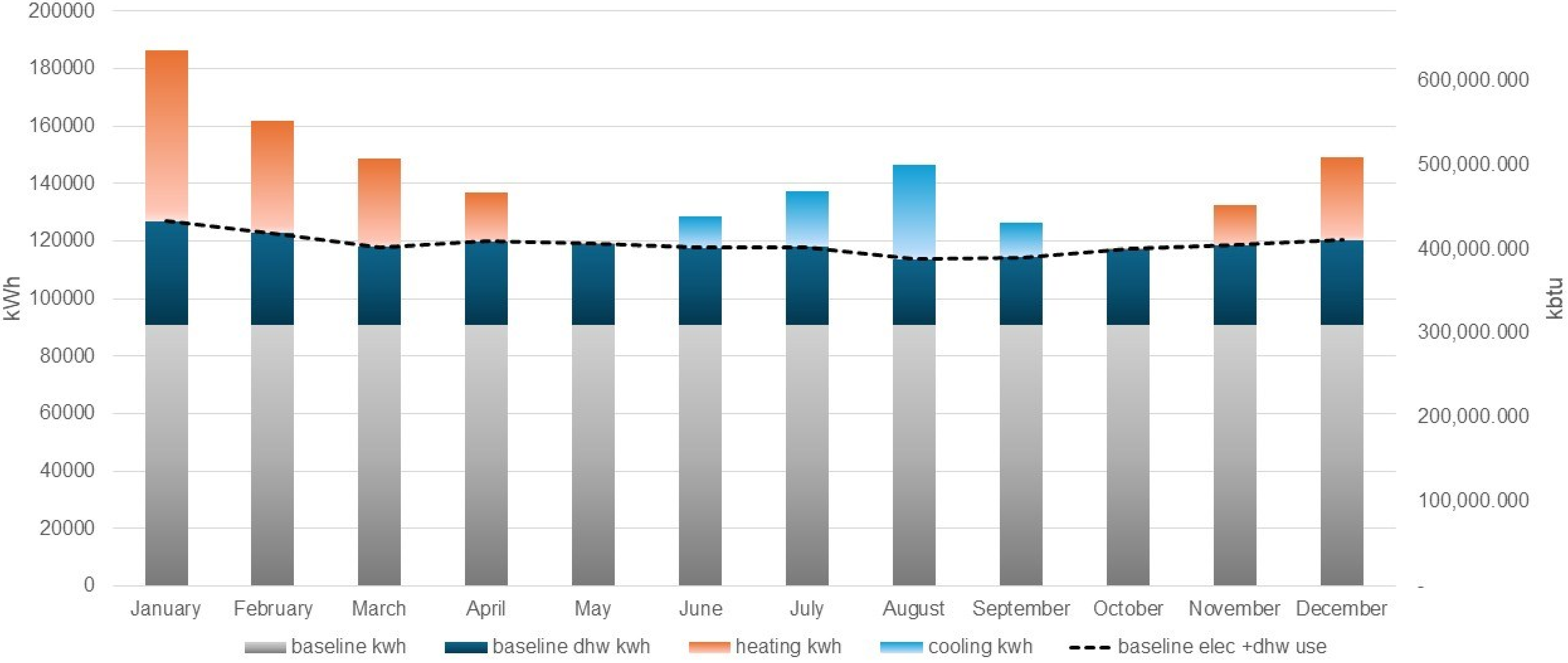
Systems

Energy Use



Annual Energy Use (kWh/yr)
2,600,000
2,400,000
2,200,000
2,000,000
1,800,000
1,600,000
1,400,000
1,200,000
1,000,000
800,000
600,000
400,000
200,000
-
EUI (KBTU/SF/YR)
65
60
55
50
45
40
35
30
25
20
15
10
5
-
Predicted (PEI)
Actual (Utility)
WUFI
Nat. Avg (Target Finder)
All Other Uses
Heating
Cooling
DHW
Total

Utility Data



Electricity
$0.28/kWh

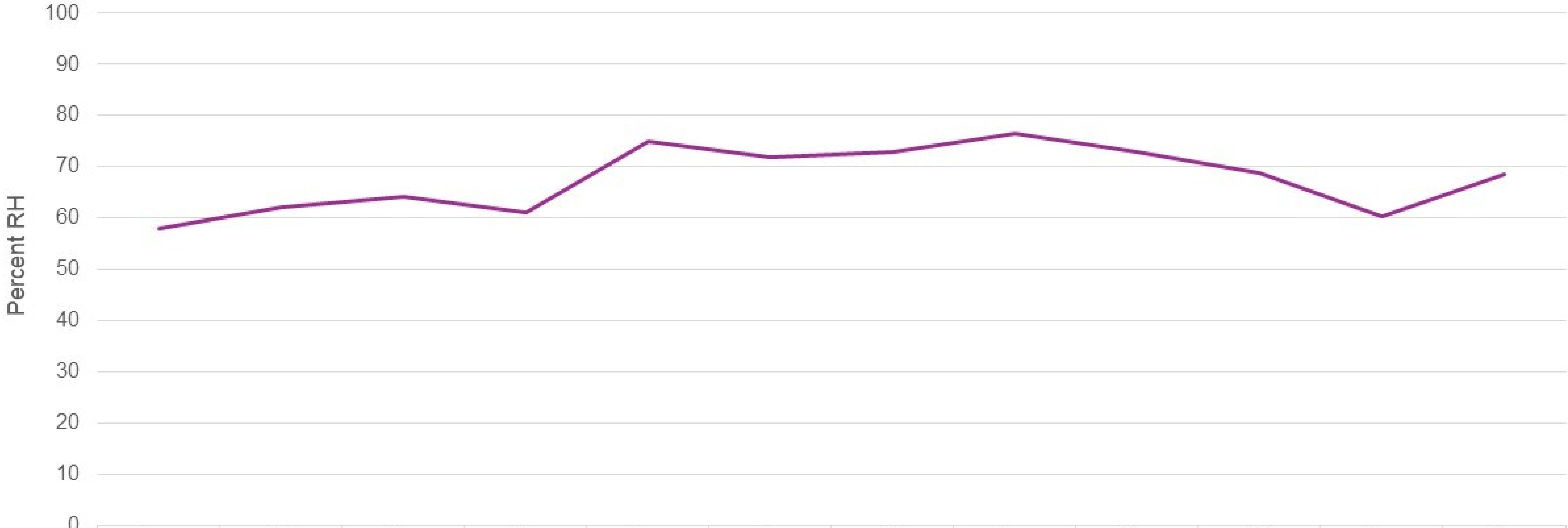
Gas
$0.05/kWh

Electricity
= **5x**
Gas

HEATING

Comfort

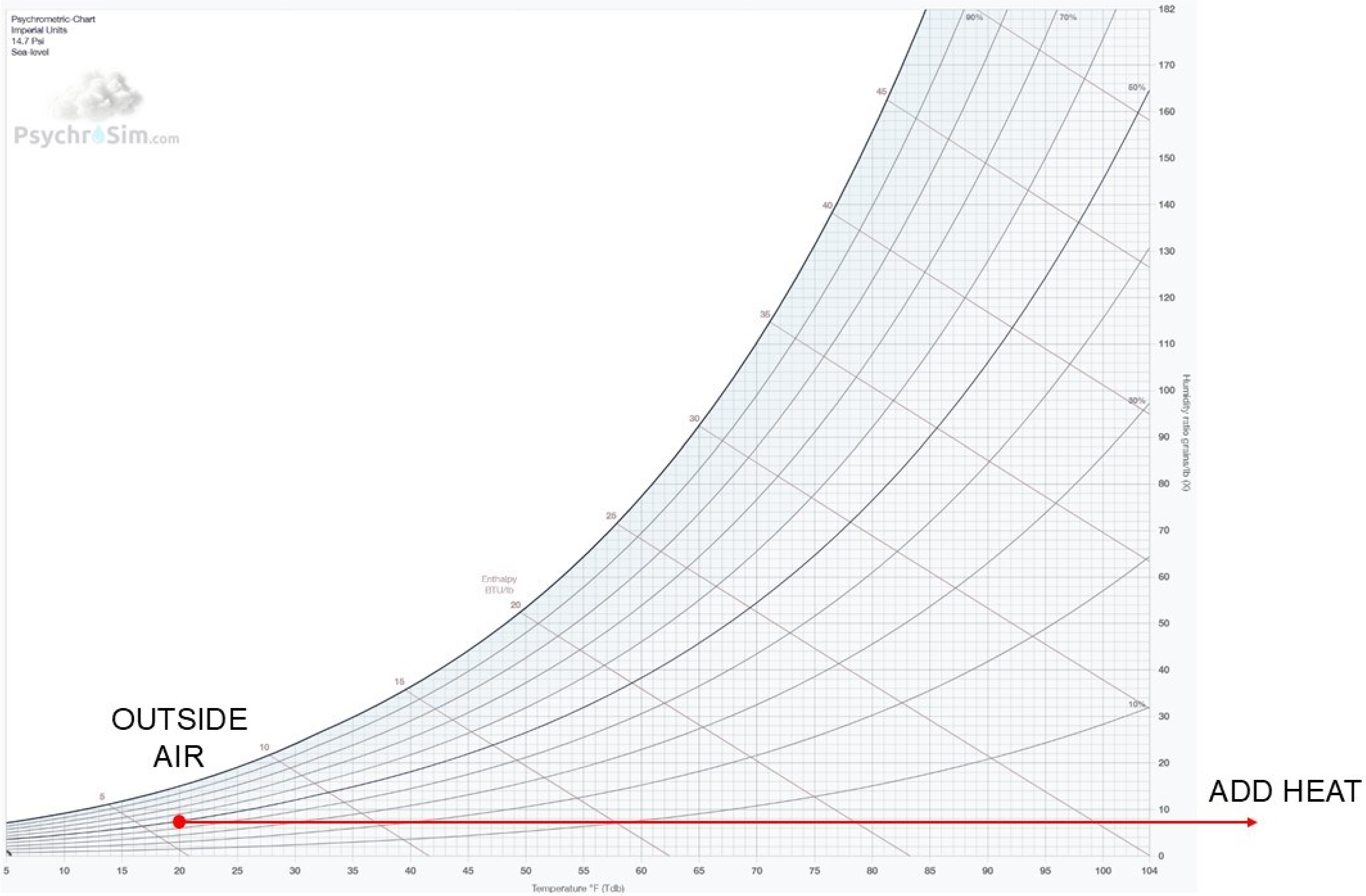
Portsmouth, NH, Avg RH per Month, July 2024-July 2025



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Outdoor RH	58.13	62.01	64.16	61.15	74.83	71.77	72.93	76.6	72.86	68.86	60.31	68.64

Source: https://www.wunderground.com/history/daily/us/nh/newington/KPSM

Comfort

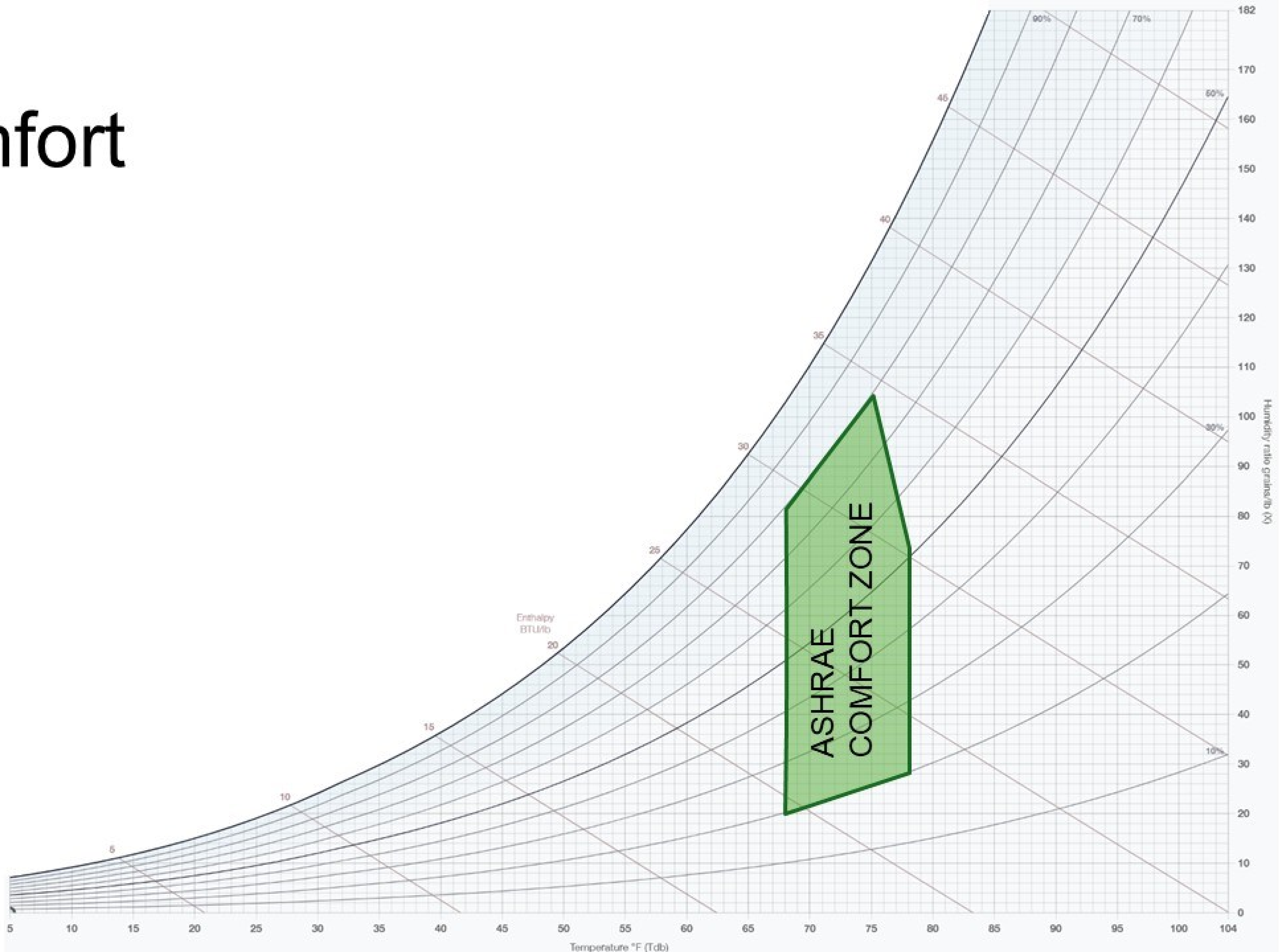

Psychrometric-Chart
Imperial Units
14.7 Psi
Sea-level
Enthalpy BTU/lb
Humidity ratio grains/lb (X)
Temperature °F (Tdb)
OUTSIDE AIR
ADD HEAT

Comfort

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Outdoor RH	58.13	62.01	64.16	61.15	74.83	71.77	72.93	76.6	72.86	68.86	60.31	68.64
Indoor RH	6.9	9.6	17.4	25.8	44.6	64.3	80.3	74.7	56.2	36.2	24.4	15.1

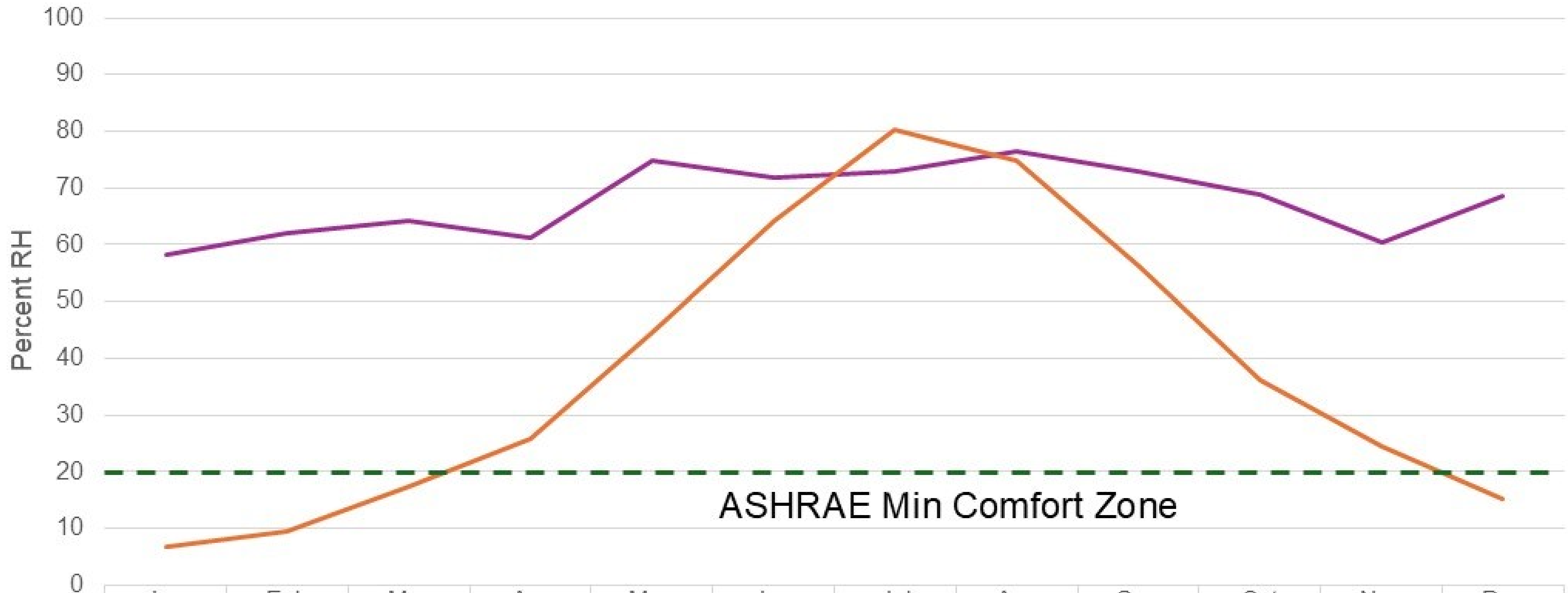
Source: https://www.wunderground.com/history/daily/us/nh/newington/KPSM

Comfort



ASHRAE
COMFORT ZONE
Enthalpy
BTU/lb
Humidity ratio grains/lb (X)
Temperature °F (Tdb)
90%
70%
50%
30%
10%
5
10
15
20
25
30
35
40
45
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
182
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
104

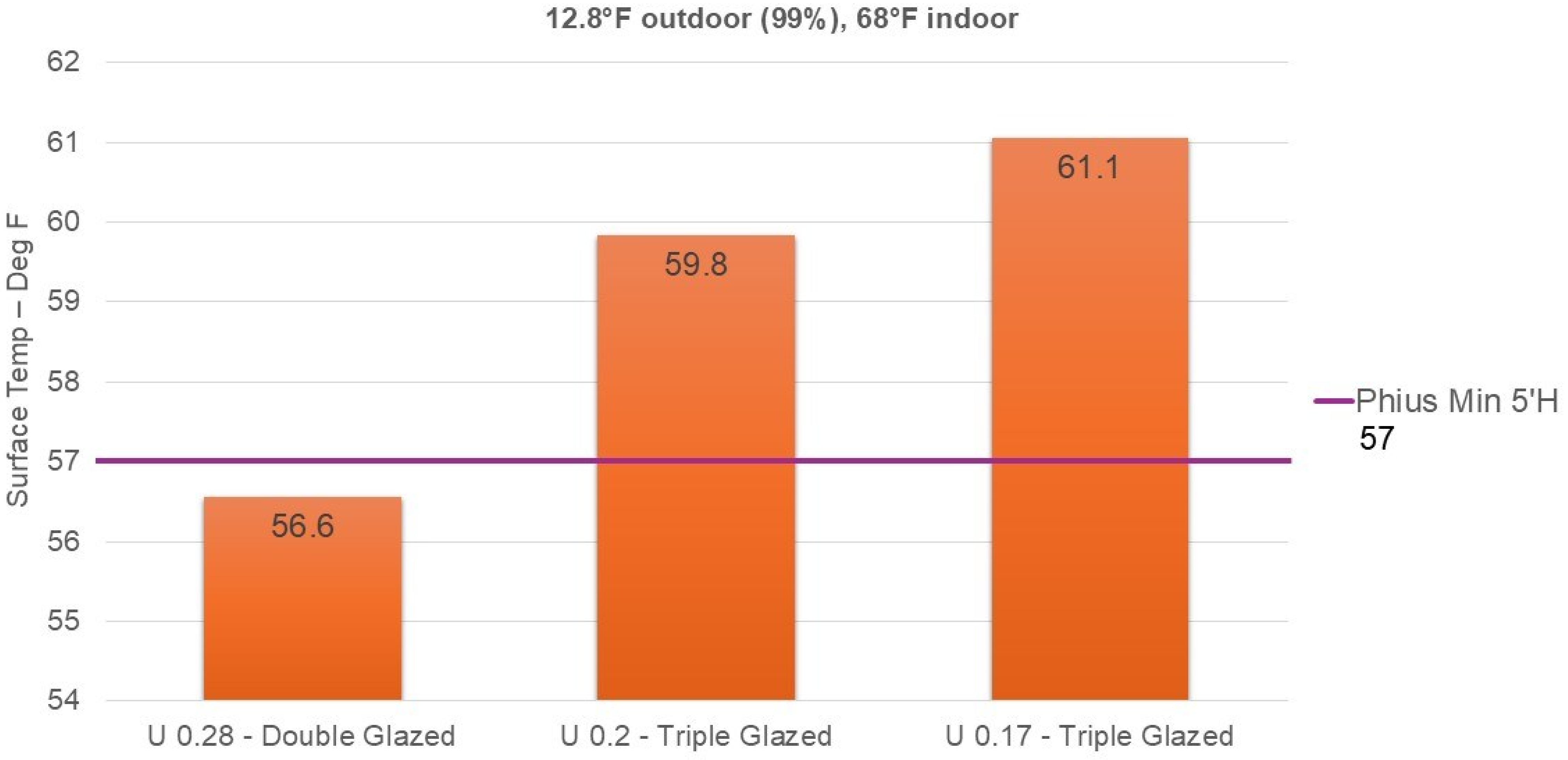
Comfort



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Outdoor RH	58.13	62.01	64.16	61.15	74.83	71.77	72.93	76.6	72.86	68.86	60.31	68.64
Indoor RH	6.9	9.6	17.4	25.8	44.6	64.3	80.3	74.7	56.2	36.2	24.4	15.1

Source: https://www.wunderground.com/history/daily/us/nh/newington/KPSM

Surfaces



12.8°F outdoor (99%), 68°F indoor
Surface Temp – Deg F
62
61
60
59
58
57
56
55
54
61.1
59.8
56.6
Phius Min 5'H
57
U 0.28 - Double Glazed
U 0.2 - Triple Glazed
U 0.17 - Triple Glazed

Surfaces

- Radiant Heat Transfer

$$Q = \sigma \, \varepsilon \, A(T^4 - T_0^4)$$

Q = Heat Transfer (W)
σ = Stefan-Boltzman Constant
ε = Emissivity
A = Surface Area (m^2)
T = Temperature (K)

$$Q = \sigma \varepsilon A(T^4 - T_0^4)$$

$\sigma = 5.6703\times10^{-8}$ W/m^{2}K^4
$\varepsilon = .9$ (glass)

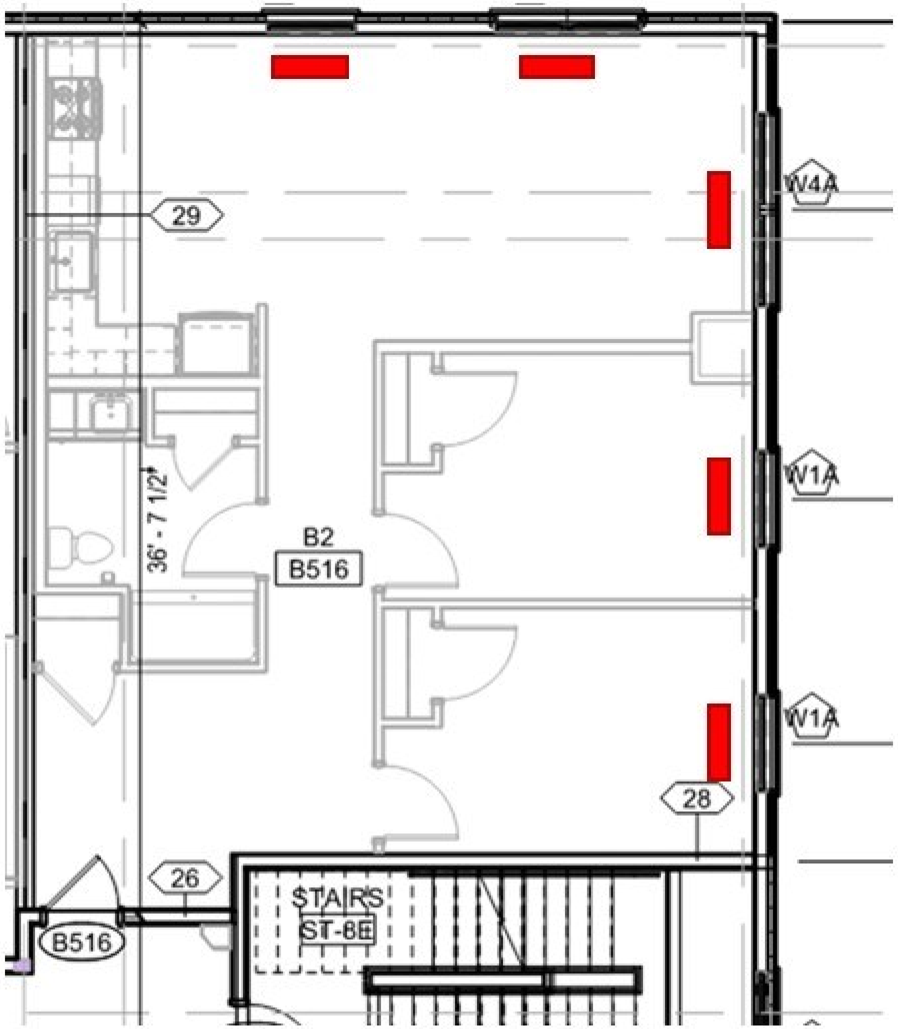
Double Pane Window – U0.28

- $Q = 5.1\times10^{-8} * 1(300^4 - 288^4) = 6{,}223{,}493{,}606\text{x}10^{-8} =$ **62.235W**

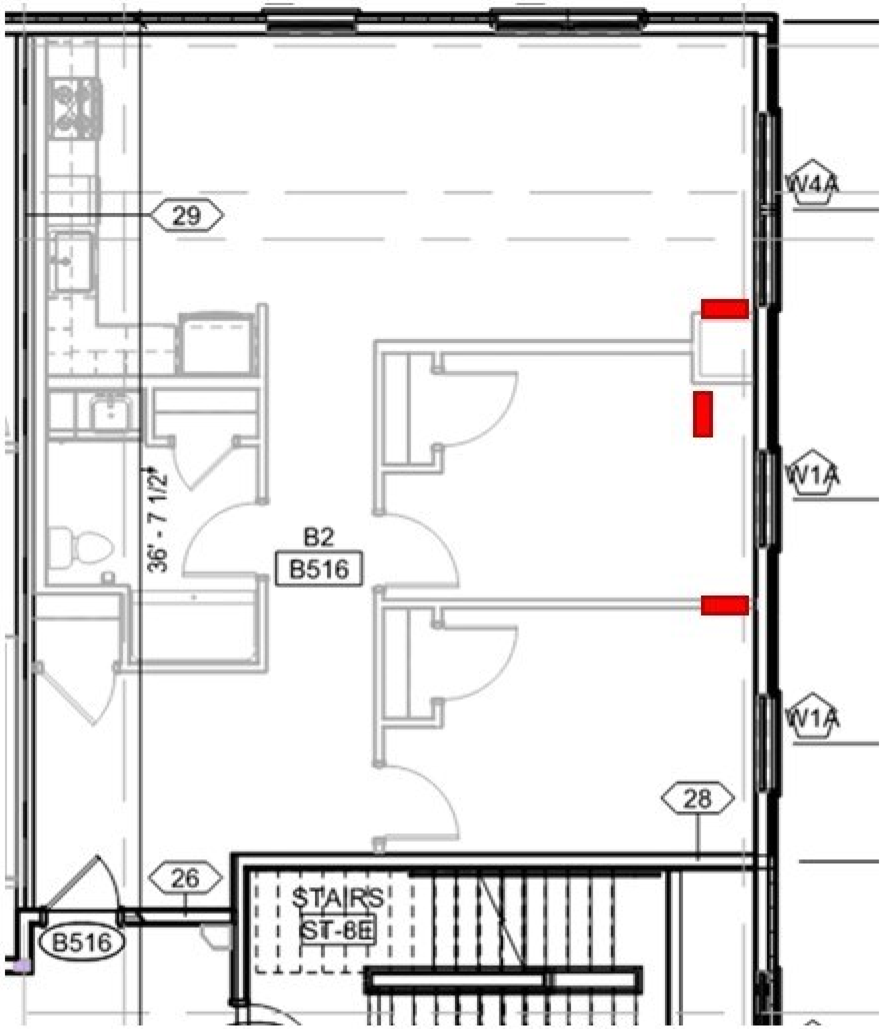
Triple Pane Window – U0.17

- $Q = 5.1\times10^{-8} * 1(300^4 - 290^4) =$ **52.387W**

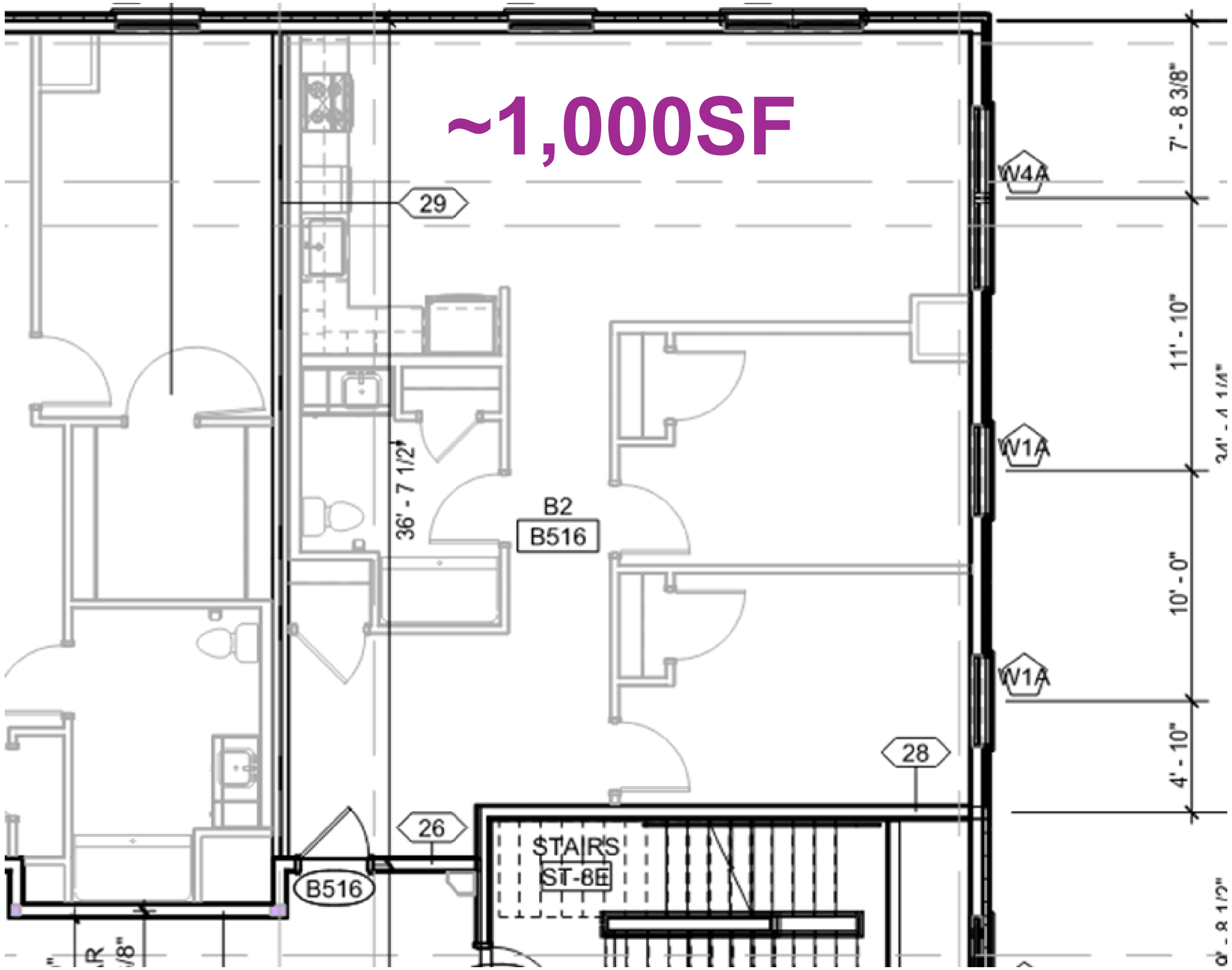
~~Energy~~ Comfort



VS



Heating – Rule of Thumb



LOAD =

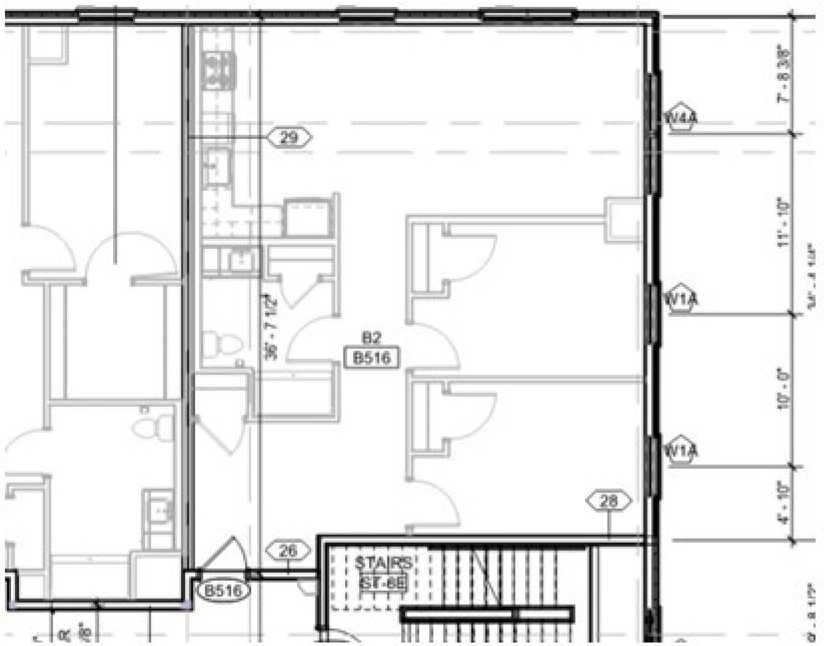
35 BTU/HR/SF =

35 X 1000=

35,000 BTU

Heating – Rules of Thumb

	DESIGN HEATING		
	HEATING DATA AT DES HTG HEATING OA DB / WB 0.0 °F / -1.6 °F OCCUPIED T-STAT 70.0 °F		
		Sensible	Latent
SPACE LOADS	Details	(BTU/hr)	(BTU/hr)
Window & Skylight Solar Loads	164 ft²	-	-
Wall Transmission	781 ft²	1818	-
Roof Transmission	991 ft²	2313	-
Window Transmission	164 ft²	2640	-
Skylight Transmission	0 ft²	0	-
Door Loads	0 ft²	0	-
Floor Transmission	0 ft²	0	-
Partitions	0 ft²	0	-
Ceiling	0 ft²	0	-
Overhead Lighting	0	0	-
Task Lighting	0	0	-
Electric Equipment	0	0	-
People	0	0	0
Infiltration	-	1589	-21
Miscellaneous	-	0	0
Safety Factor	10%	836	-2
>> Total Zone Loads	**-**	**9197**	**-23**



9,197/1,000 =

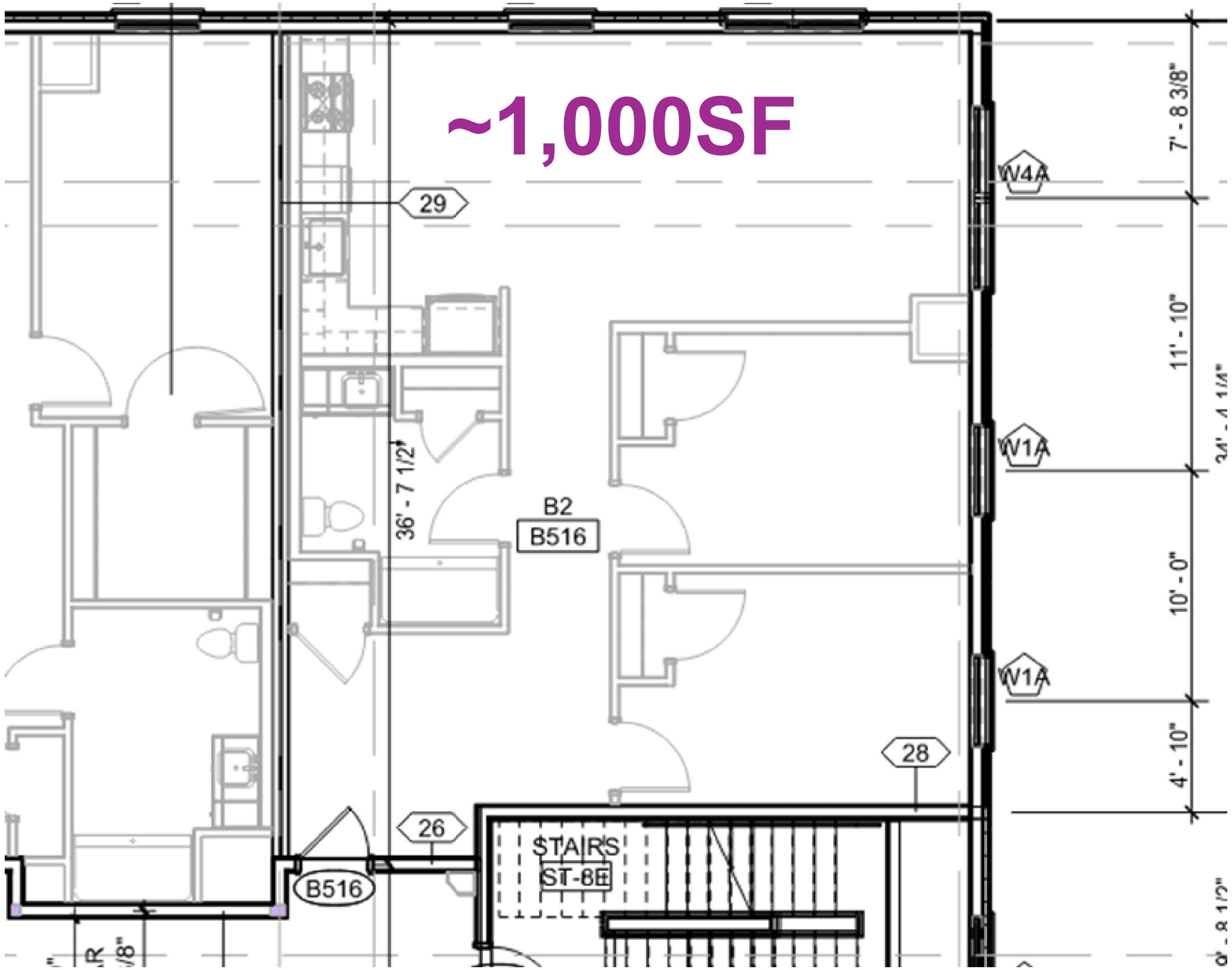
9.2 BTU/HR/SF

35/9.2 =

3.8x Oversized

COOLING

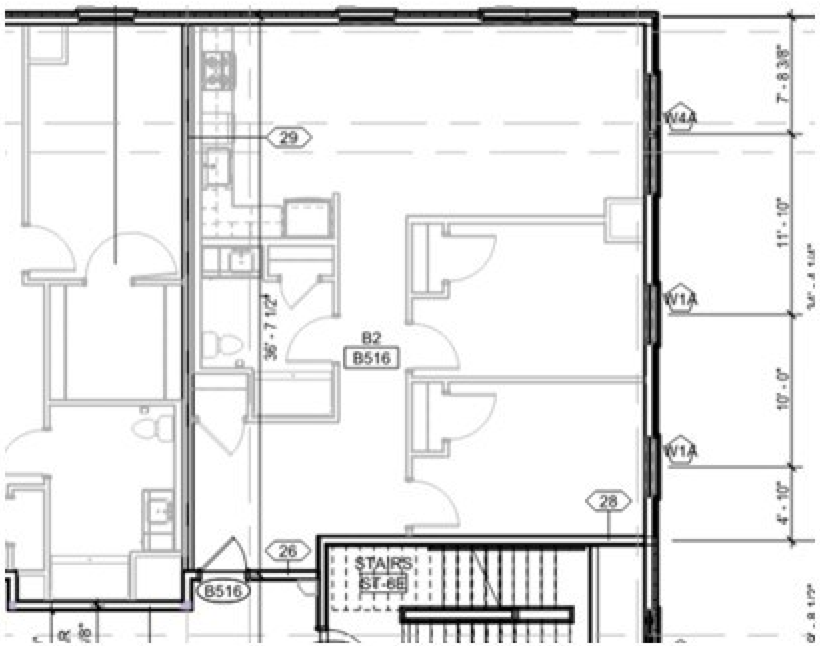
Cooling – Rule of Thumb



LOAD =
400SF/TON=
1000/400=
2.5 TON
30,000 BTU

Cooling – Rule of Thumb

	DESIGN COOLING		
	COOLING DATA AT Jul 1600 COOLING OA DB / WB 84.5 °F / 70.9 °F OCCUPIED T-STAT 75.0 °F		
		Sensible	Latent
SPACE LOADS	Details	(BTU/hr)	(BTU/hr)
Window & Skylight Solar Loads	164 ft²	4704	-
Wall Transmission	781 ft²	314	-
Roof Transmission	991 ft²	1739	-
Window Transmission	164 ft²	260	-
Skylight Transmission	0 ft²	0	-
Door Loads	0 ft²	0	-
Floor Transmission	0 ft²	0	-
Partitions	0 ft²	0	-
Ceiling	0 ft²	0	-
Overhead Lighting	793 W	2705	-
Task Lighting	0 W	0	-
Electric Equipment	496 W	1691	-
People	3	735	615
Infiltration	-	216	290
Miscellaneous	-	0	0
Safety Factor	5% / 5%	618	45
>> Total Zone Loads	-	12981	951



12,981 = 1.08 TON

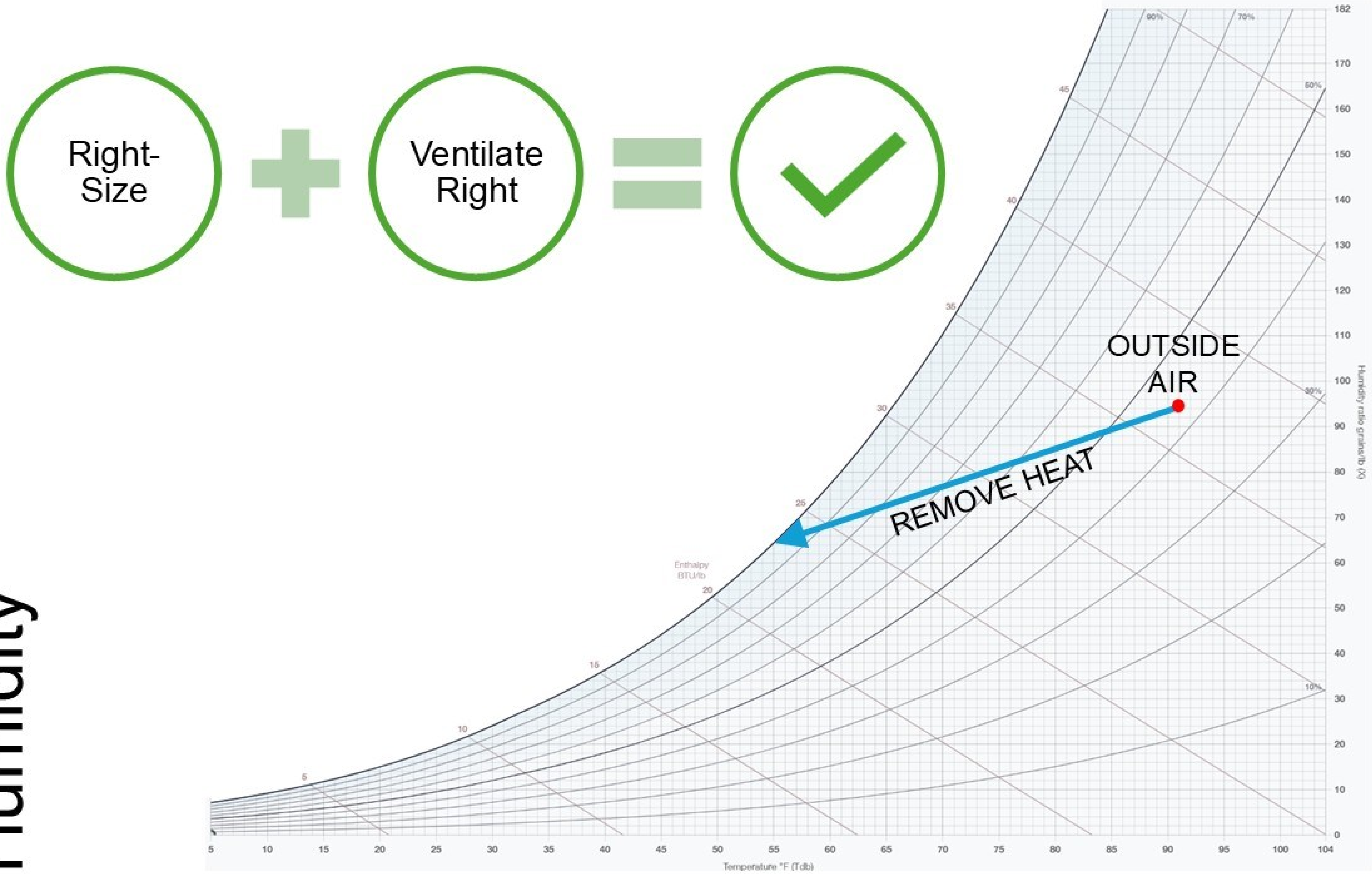
1,000/1.08 =

926 SF/TON

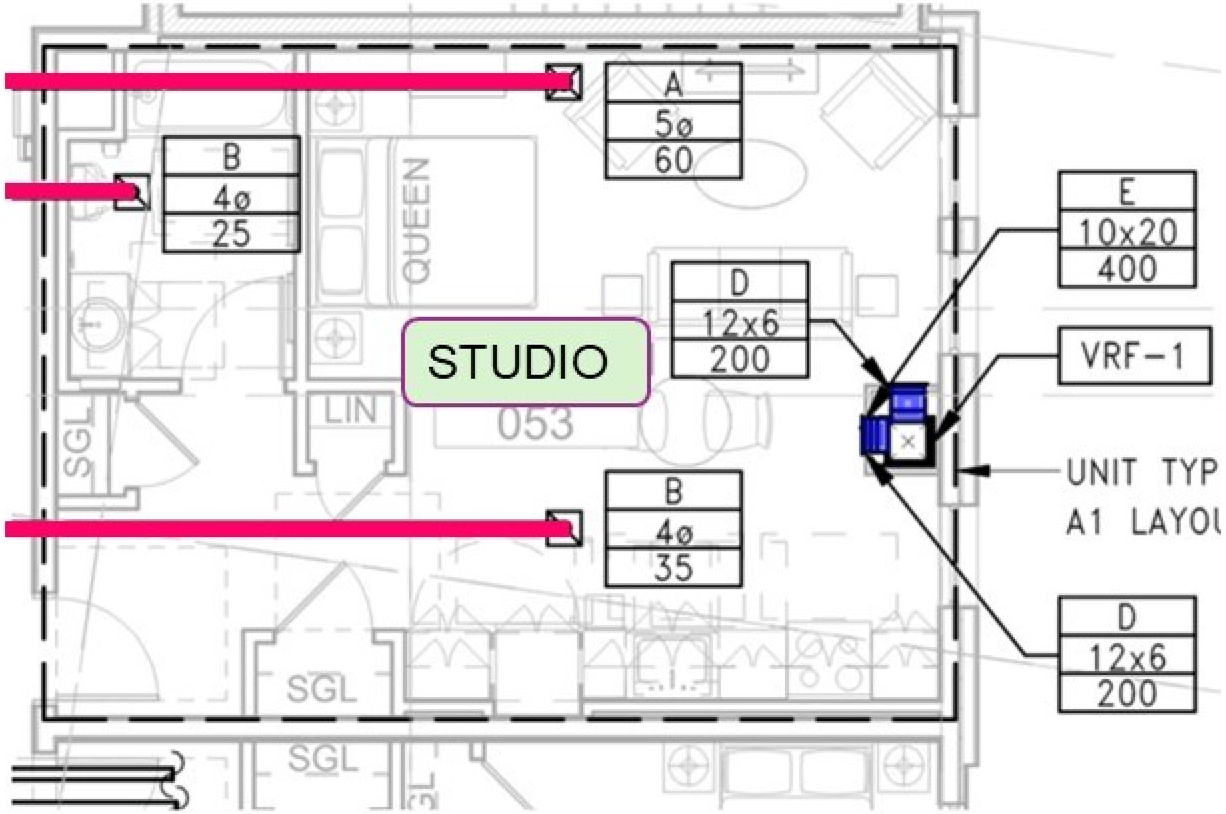
926/400 =

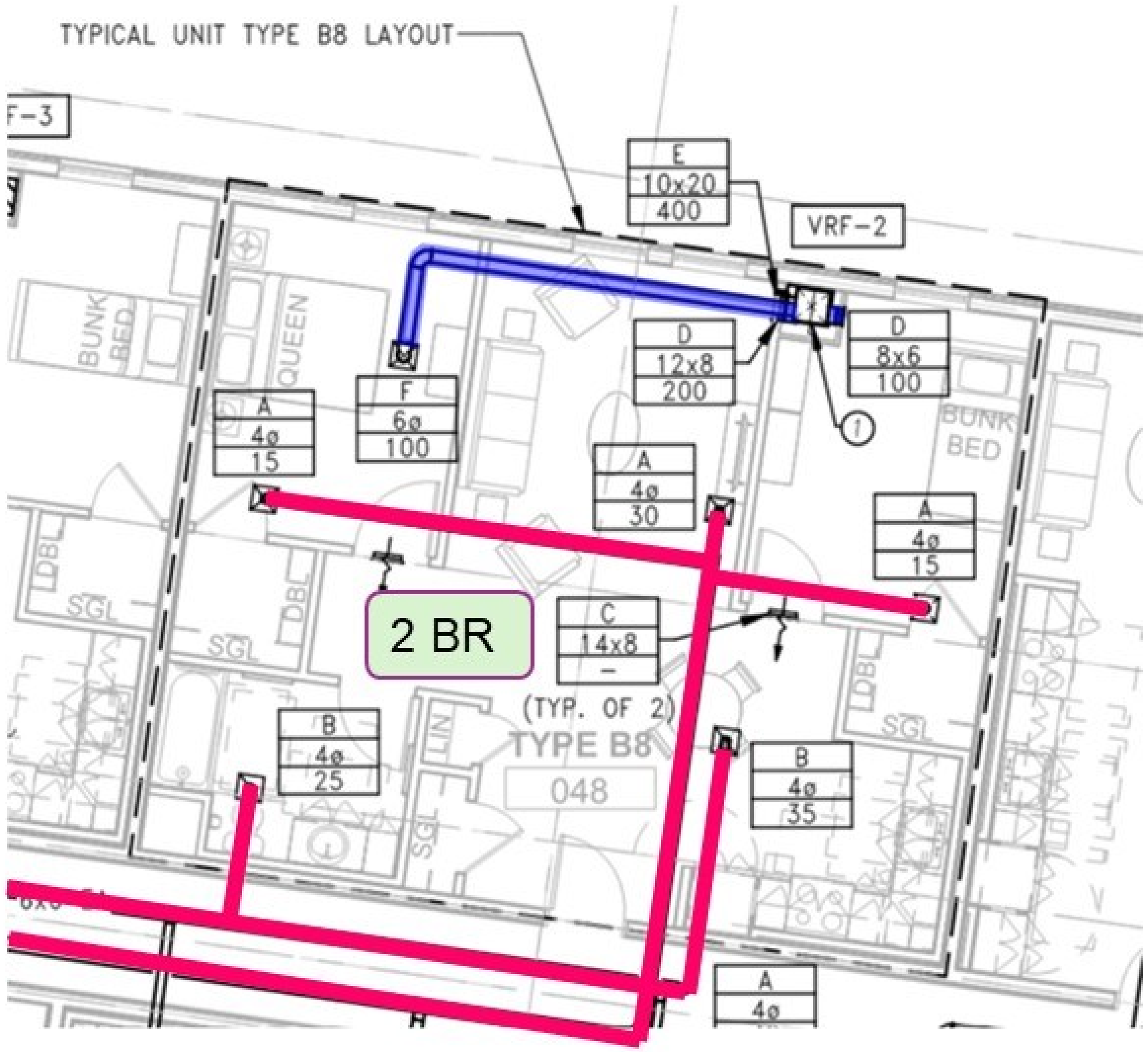
2.3x oversized

Humidity


Right-Size
Ventilate Right
OUTSIDE AIR
REMOVE HEAT
Enthalpy BTU/lb
Temperature °F (Tdb)
Humidity ratio grains/lb (X)

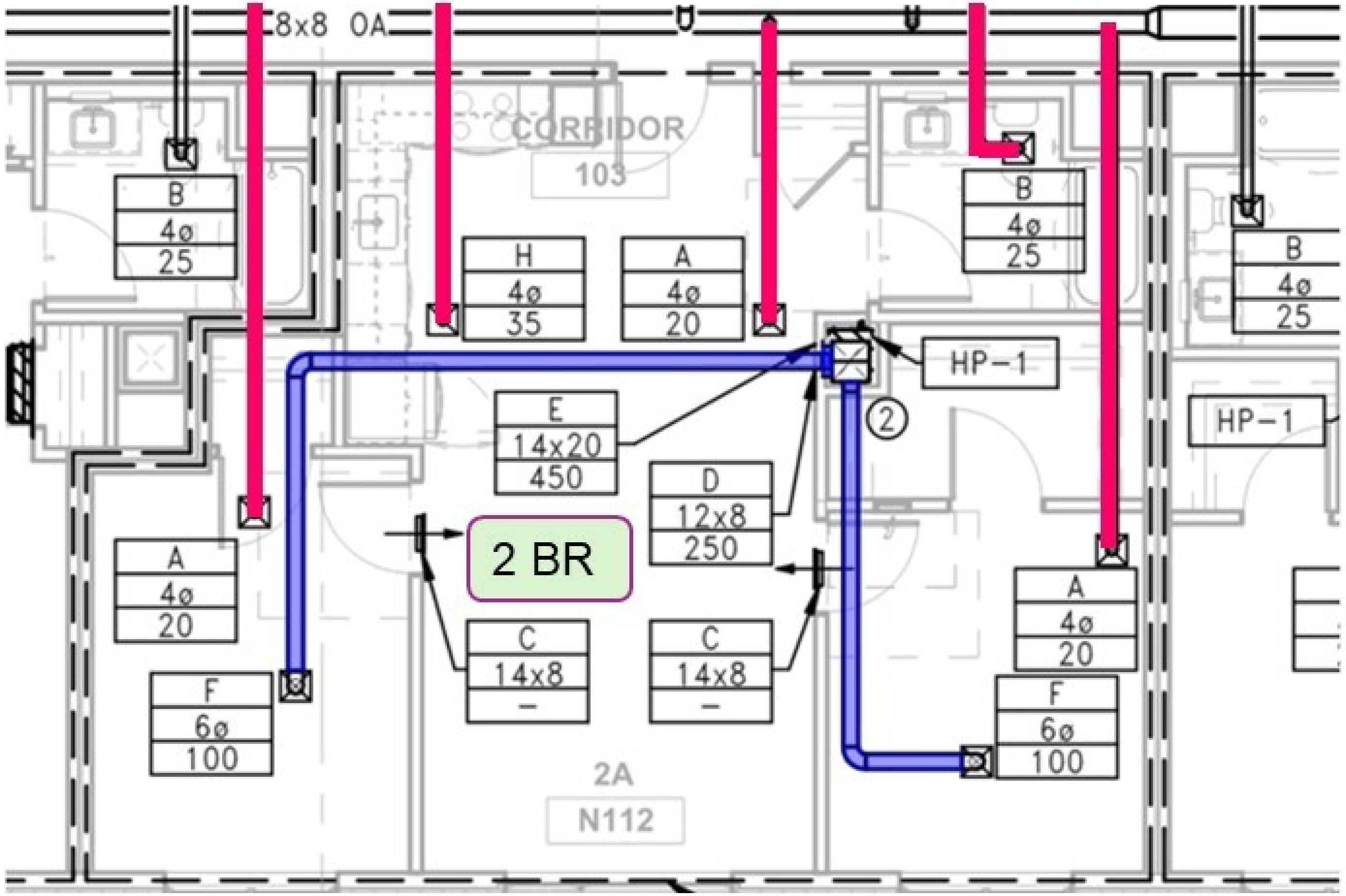

Serviceability
High Quality Equipment
Great Support

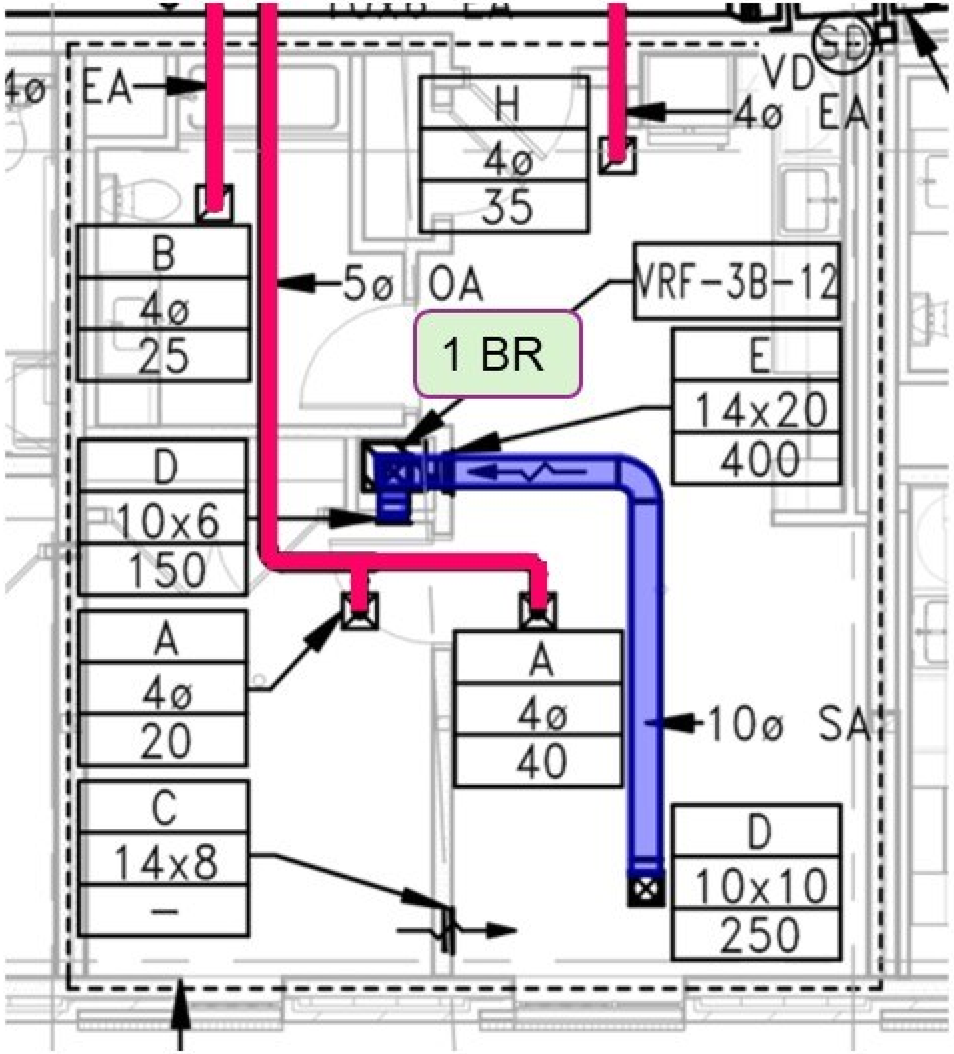


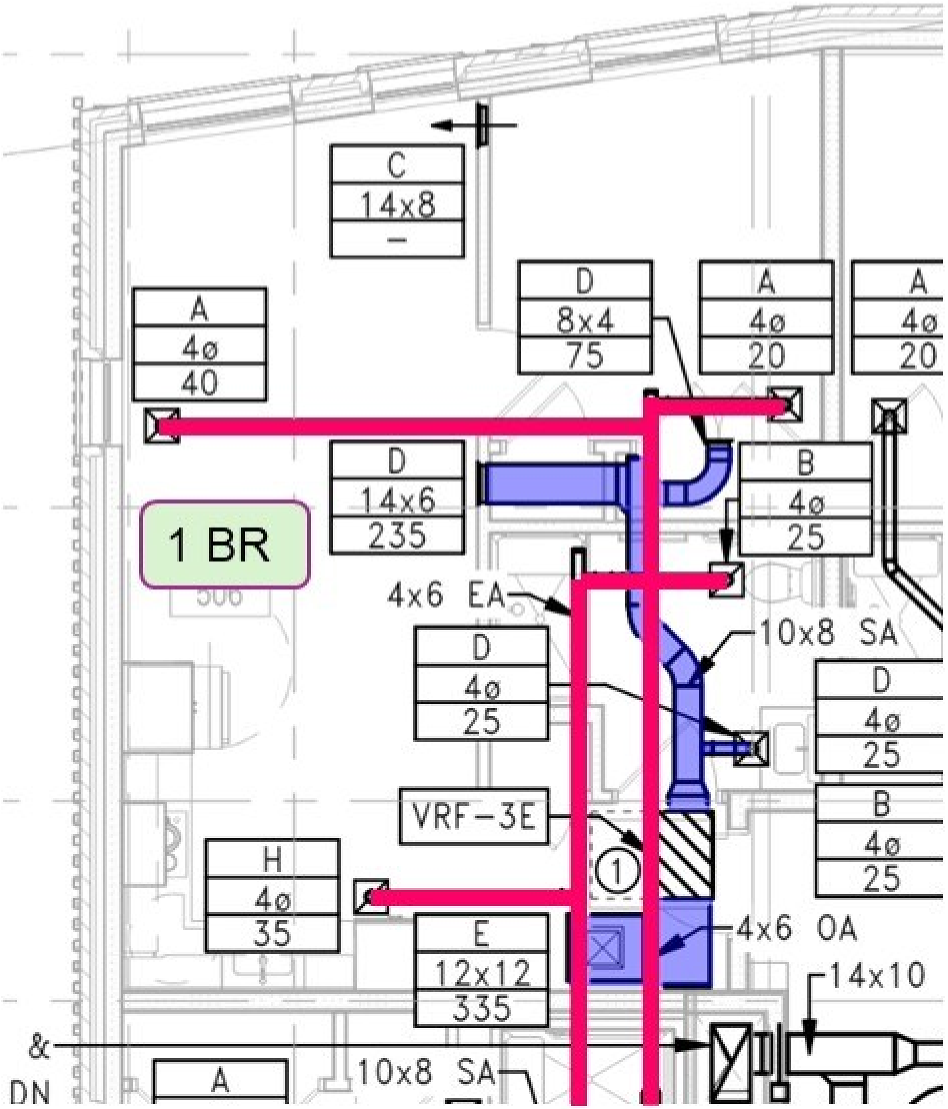


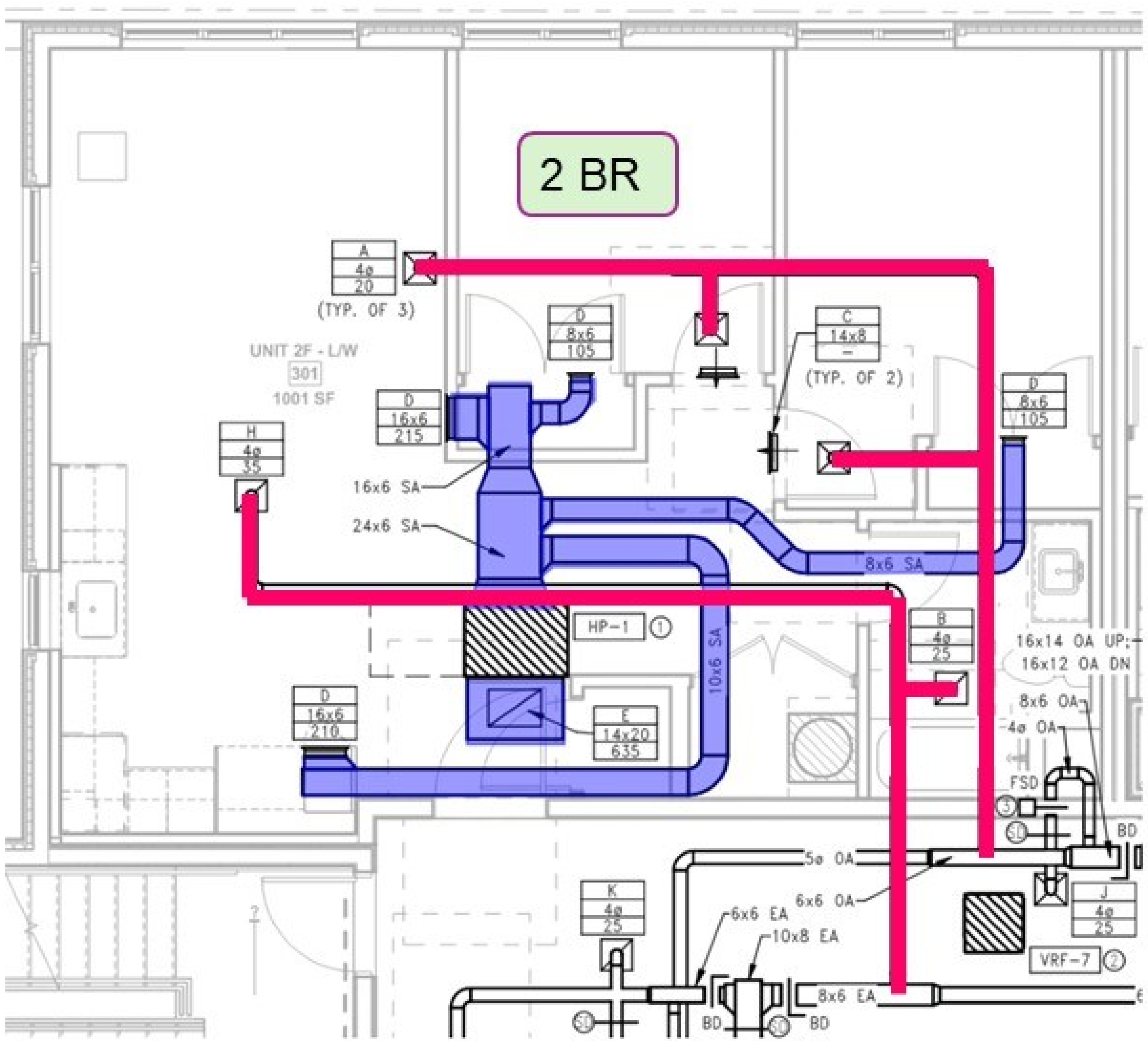
Heating/Cooling Distribution - Simple

Heating/Cooling Distribution – More Complex

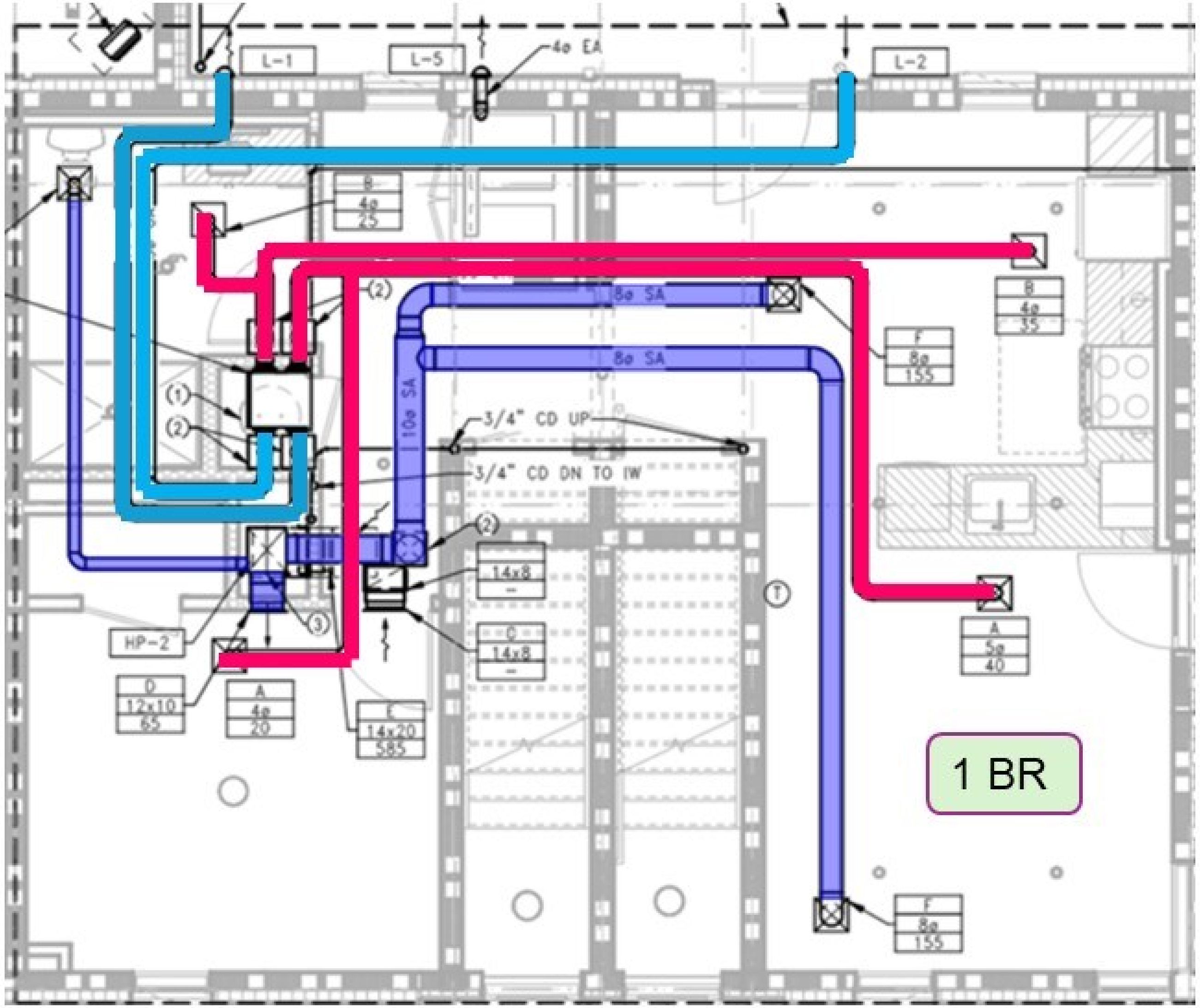


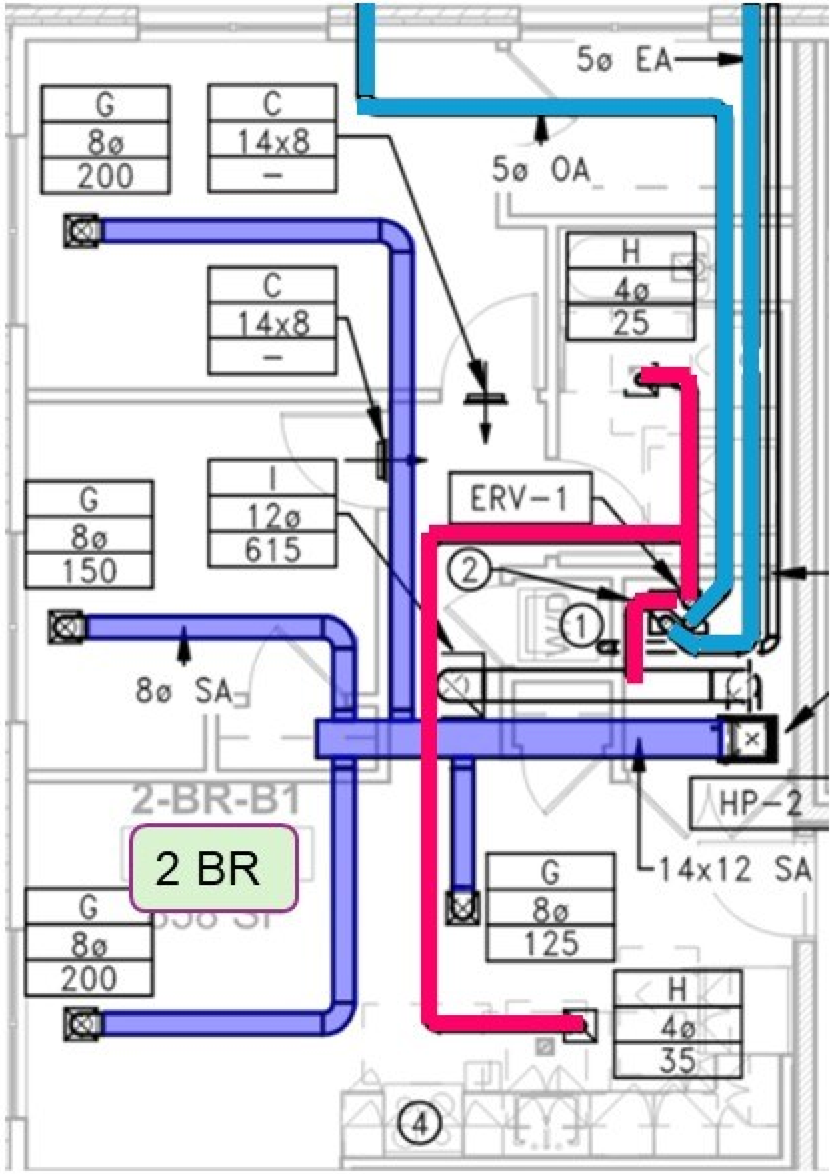






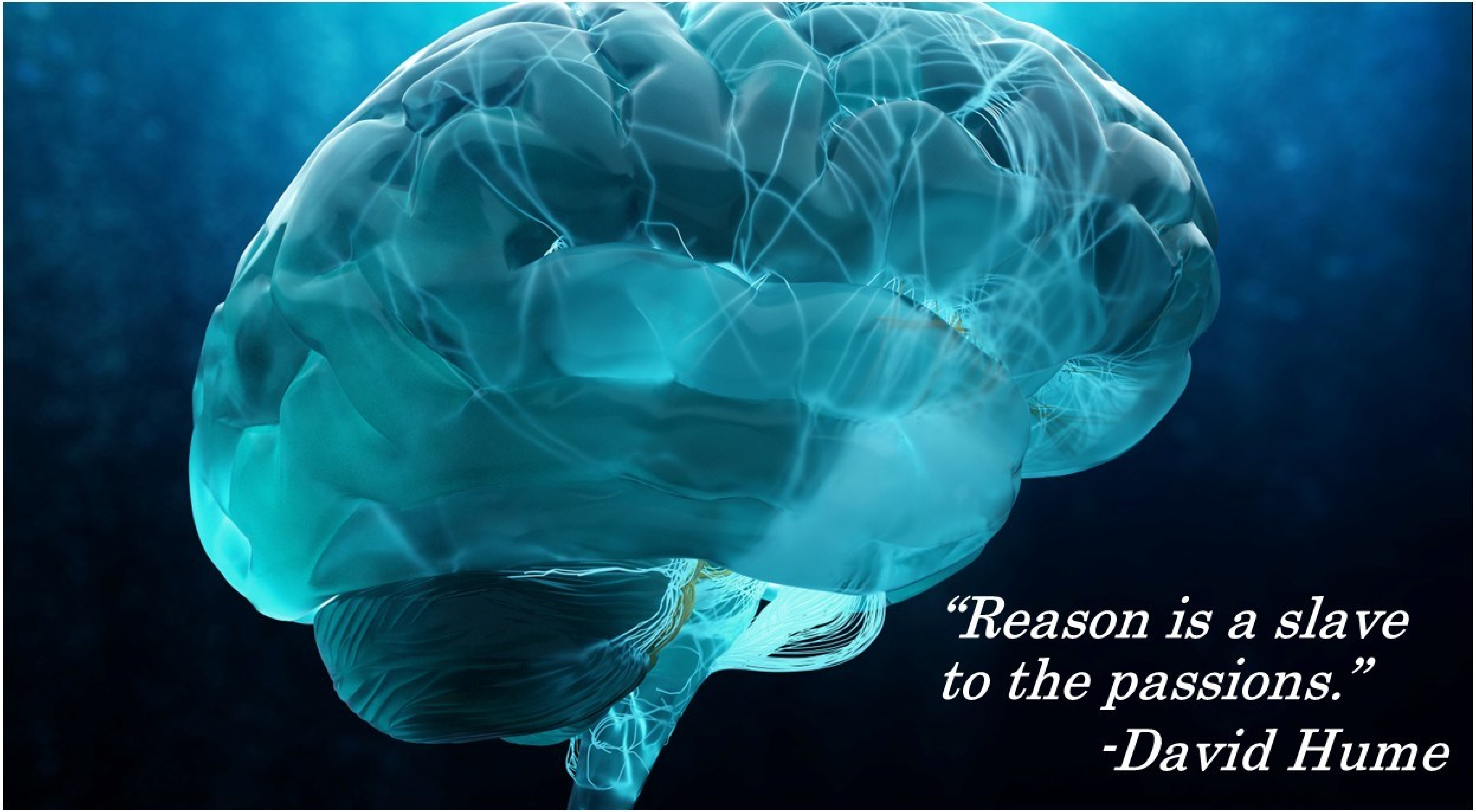
Heating/Cooling Distribution – Max Complex



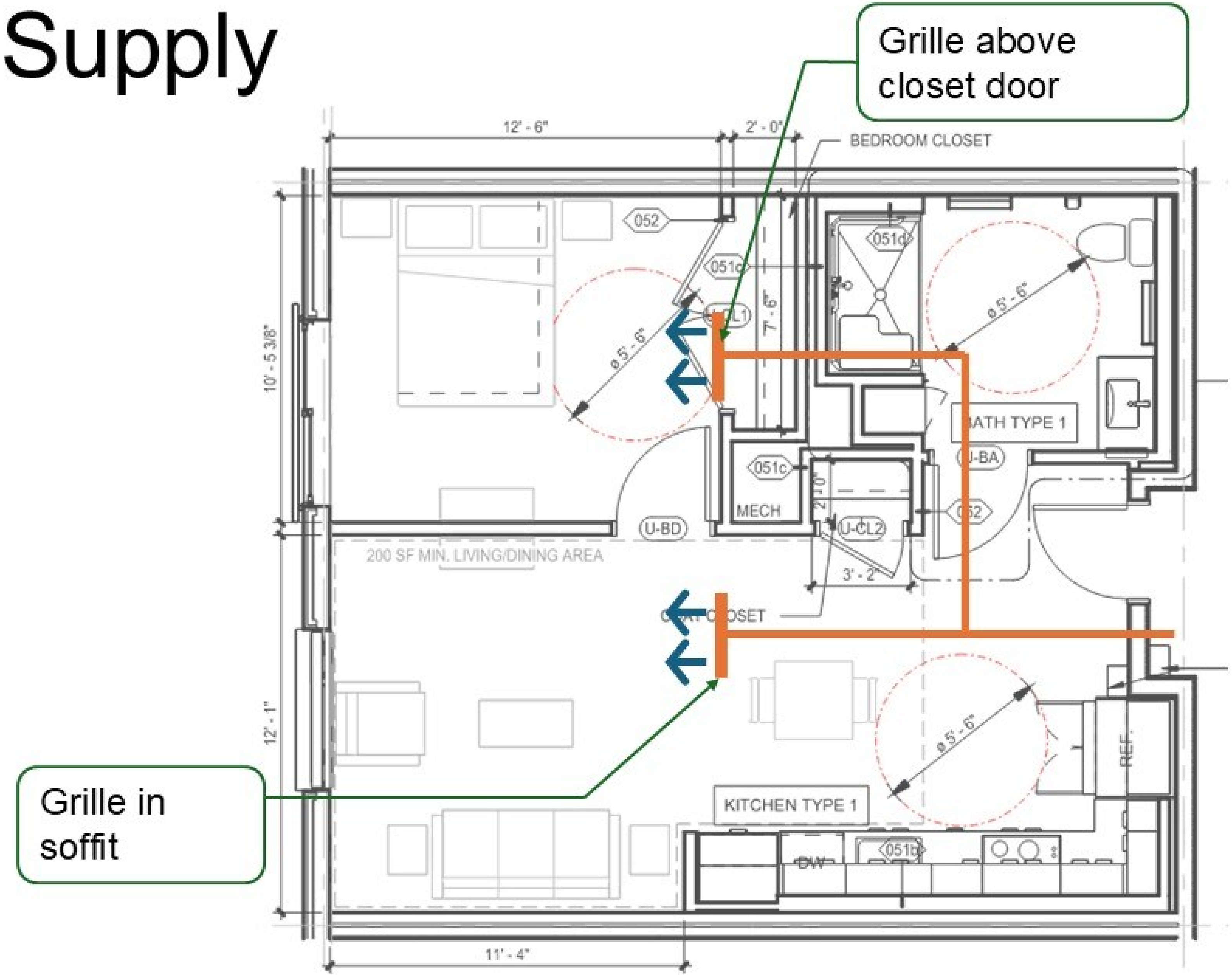


Ventilation – In-Unit – This is out of hand…

VENTILATION


"Reason is a slave
to the passions."
-David Hume

High Sidewall Supply



Central Ventilation

- Less Penetrations
- Reduced risk of Water Damage
- Accessible – Serviceable
- Easy to Replace at EOL

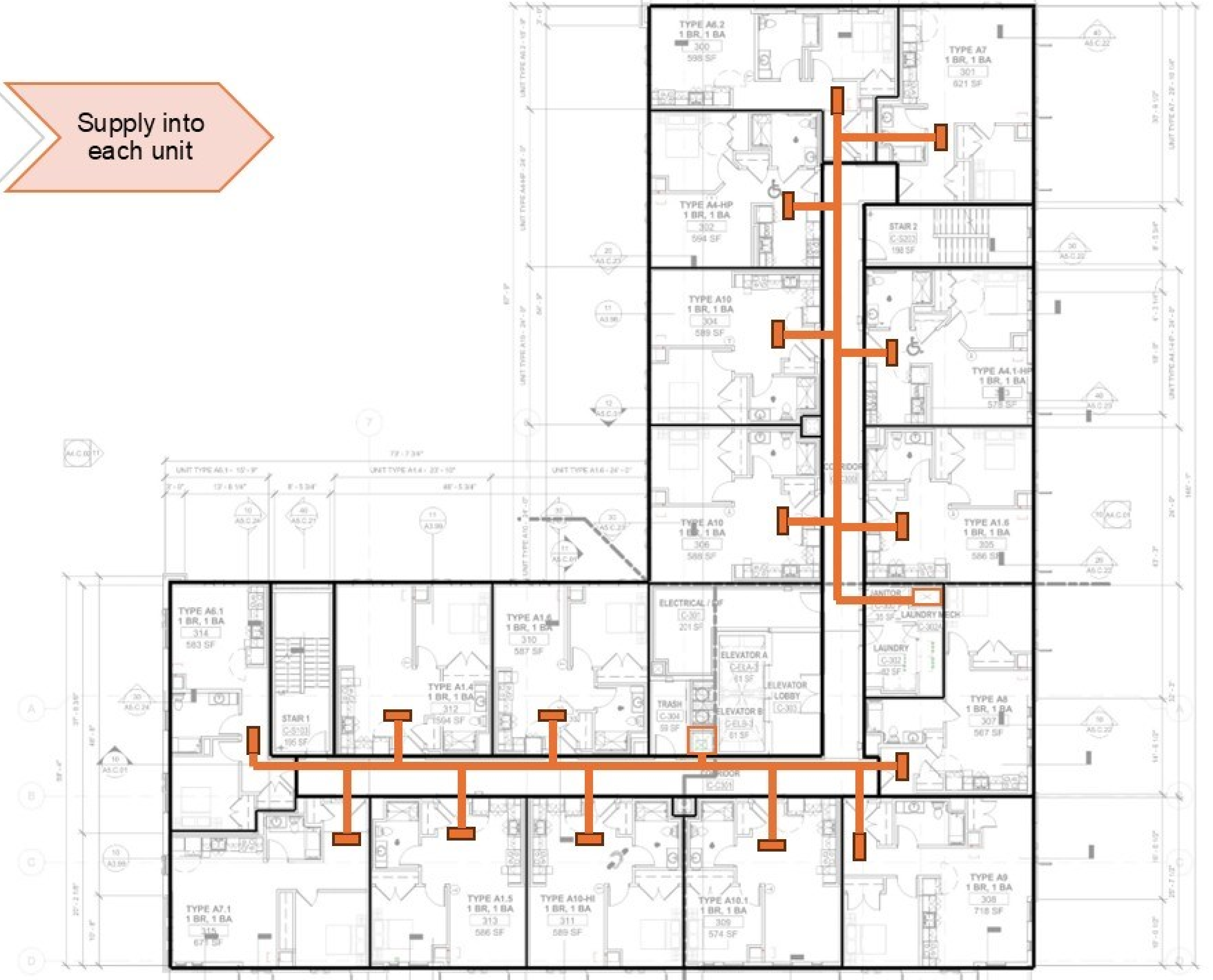
Ventilation Evolution

MAU with supply into corridor

Ventilation Evolution

MAU with supply into corridor

Supply into each unit



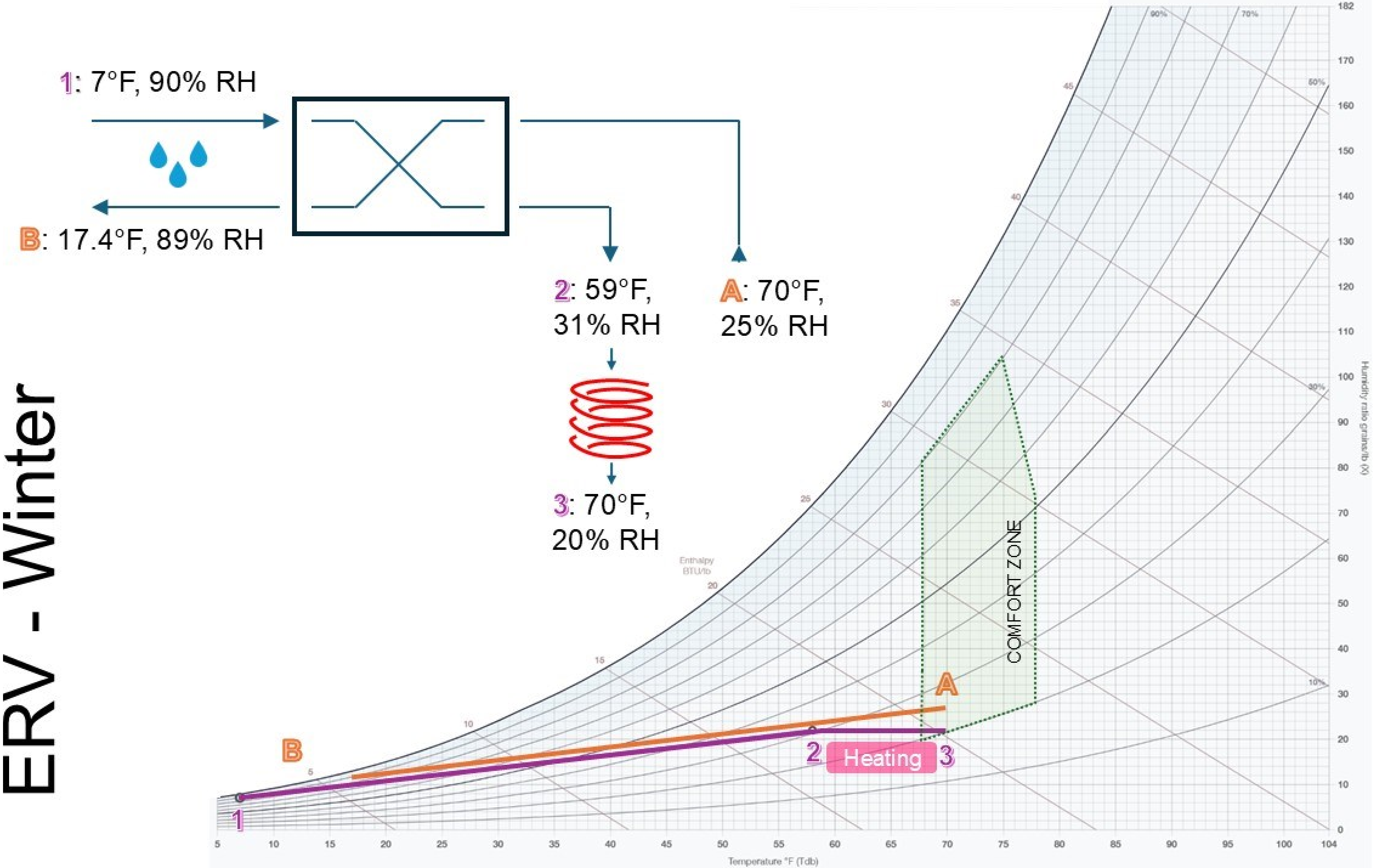
Ventilation Evolution

MAU with supply into corridor

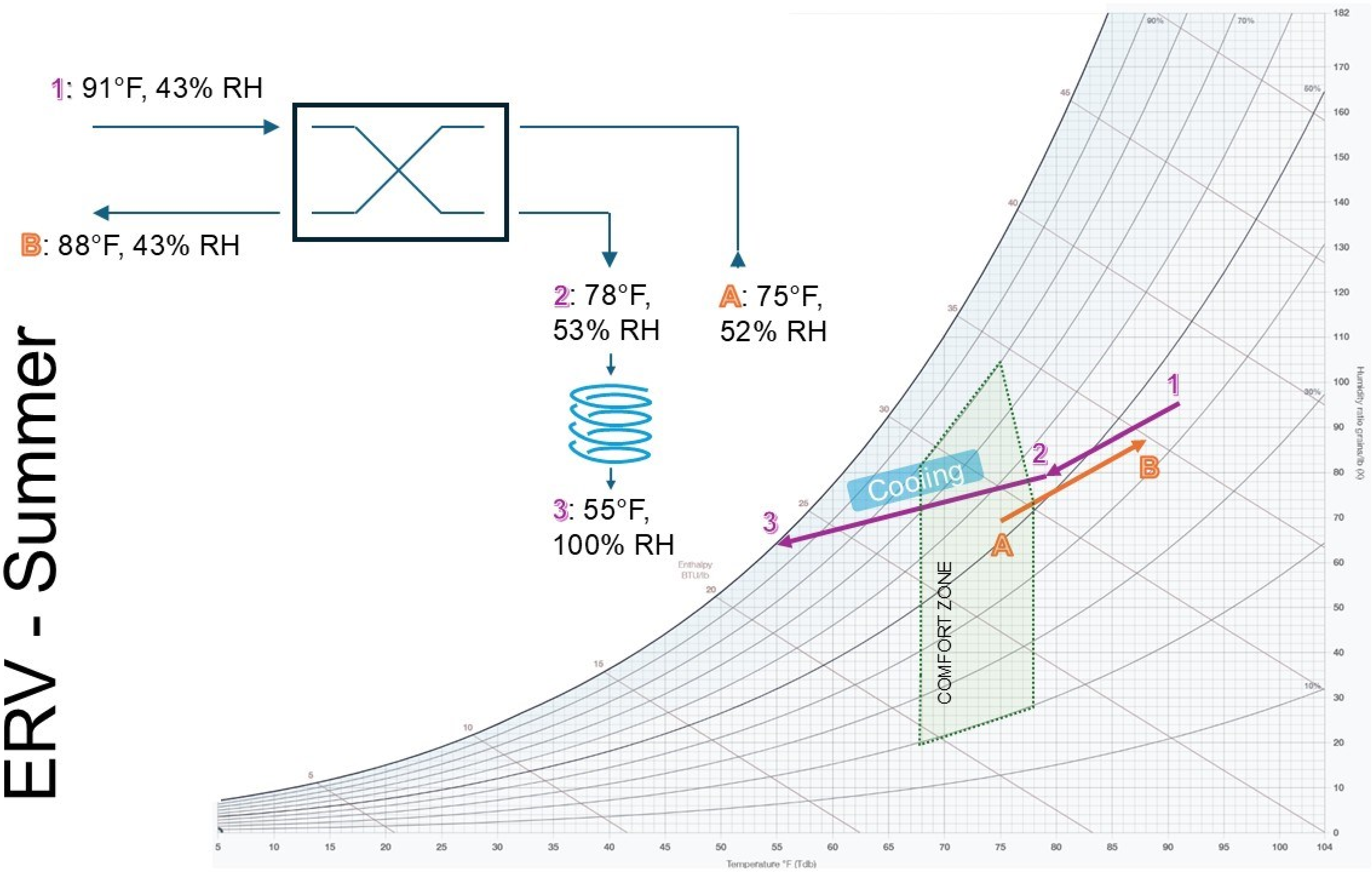
Supply into each unit

Supply into all Occupied Spaces

ERV - Winter


1: 7°F, 90% RH
B: 17.4°F, 89% RH
2: 59°F, 31% RH
A: 70°F, 25% RH
3: 70°F, 20% RH
Enthalpy BTU/lb
COMFORT ZONE
A
B
1
2
Heating
3
Humidity ratio grains/lb (X)
Temperature °F (Tdb)

ERV - Summer



1: 91°F, 43% RH
B: 88°F, 43% RH
2: 78°F, 53% RH
A: 75°F, 52% RH
3: 55°F, 100% RH
Cooling
COMFORT ZONE
1
2
3
A
B
Enthalpy BTU/lb
Humidity ratio grains/lb (X)
Temperature °F (Tdb)

Duct Sealing

aeroseal. DUCT

COMMERCIAL LEAKAGE REPORT

Seal Specifics
System Description: ERV-3
Operating Pressure (wg): 1 Inches
Fan Capacity: 2730 CFM
Seal Description: 5th Floor Exhaust Air
Seal Type: Exhaust
Seal CFM: 480 CFM

Duct Class (wg): 1 Inches
Seal Class: A

Building Type: Commercial Building
Seal Date: 5/28/2025
Barometric Pressure (Inches in HG): 29.90

Aeroseal Gen2 Case ID: 7020
Manometer Model: -
Manometer Serial Number: -

	Rectangle	Round
Test Duct Surface Area (ft²)	368.3	432.0
SMACNA Leakage Class	6	3
Leakage Allowed at 1" WG	22.1	13.0

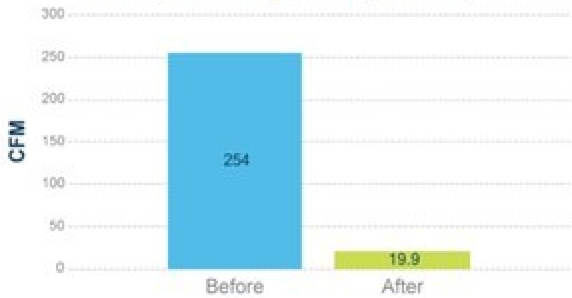
Allowable Leakage at 1" WG (duct class test pressure)
35.1 CFM

Leakage Before Sealing
254.5 CFM

Leakage After Sealing
19.9 CFM

Leakage Test
PASS

Leakage at 1" WG (operating pressure)



Duct sealing performed by:

Aeroseal Technician
Aspen Air Duct
270 Lawrence St.
Methuen, MA 01844
Phone: 9786815023

ASPEN
AIR DUCT CLEANING LLC

Note: Duct leakage results reported by Aeroseal conform to the calculations laid out in method D of ASTM E 1554: Standard Test Methods for determining air leakage of air distribution systems by fan pressurization.

CAR Dampers


SAMPLE
aldes
800.255.7749
aldes-na.com
LP


LP
15
25
35
45
55
65
75
85
cfm

At the Beginning

(1) DUE TO VARIATIONS IN FLOW HOOD READINGS MEASURED AT ALDES REGULATORS FRM VALUES ARE BASED ON STATIC PRESSURE READ THRU SUPPLIED AIR FLOW PRESSURE TAPS ON HRV UNIT.

AIR OUTLET TEST REPORT

SYSTEM: BUILDING 'M' UNIT- 02 (H105)

TEST APPARATUS: ADM-860

AREA	OUTLET				DESIGN		PRELIMINARY		FINAL	
SERVED	NO.	TYPE	SIZE	AK	VEL	AIRFLOW	VEL	AIRFLOW	VEL	AIRFLOW
HRU-4 SUPPLY										
LIVING ROOM	1	CD	6"x6"	.15	233	35	96	14		(1)
BEDROOM 1	2	CD	6"x6"	15	100	15	46	7		(1)
BEDROOM 2	3	CD	6"x6"	FH	FH	15	FH	84	FH	(1)
BEDROOM 3	4	CD	6"x6"	FH	FH	15	FH	74	FH	(1)
BEDROOM 4	5	CD	6"x6"	FH	FH	15	FH	8	FH	(1)
TOTAL						95		187		95(1)
HRU-4 EXHAUST										
KITCHEN	1	ER	6"x6"	FH	FH	25	FH	37	FH	(1)
BATHROOM	2	ER	6"x6"	FH	FH	35	FH	53	FH	(1)
MASTER BATH	3	ER	6"x6"	FH	FH	35	FH	41	FH	(1)
TOTAL						95		131		95(2)
HP-4										
BEDROOM 2	1	CD	6"0	FH	FH	90	FH	90	FH	90
BEDROOM 3	2	CD	6"0	FH	FH	115	FH	106	FH	106
BEDROOM 4						115		105		105(2)
TOTAL						320		301		301

REMARKS: (1) DUE TO VARIATIONS IN FLOW HOOD READINGS MEASURED AT ALDES REGULATORS CFM VALUES ARE BASED ON STATIC PRESSURE READ THRU SUPPLIED AIR FLOW PRESSURE TAPS ON HRV UNIT. SET STATIC AND BALANCED SUPPLY AND EXHAUST AIR BASED ON CHART ON UNIT. SUPPLY SET TO .30" WC AND EXHAUST TO .34" WC.
(2) HIGH SPEED.

TEST DATE: 08-21-13 / 09-06-13

"Homemade Air Flow Diagnostic Tools Get Professionally Tested"

Iain Walker

November 2003

Home Energy Magazine

Joe Lstiburek and Gary Nelson work with an early air flow measuring device.

LBNL 51551

ERNEST ORLANDO LAWRENCE
BERKELEY NATIONAL LABORATORY

Evaluation of Commercially Available Techniques and Development of Simplified Methods for Measuring Grille Airflows in HVAC Systems

I.S. Walker, C.P. Wray, C. Guillot and S. Masson

Environmental Energy Technologies Division

August 2003

This work was supported by the Assistant Secretary for Energy Efficiency and Renewable Energy, Building Technologies Program, of the U.S. Department of Energy under contract No. DE-AC03-76SF00098. The research reported here was also funded by the California Institute for Energy Efficiency (CIEE), a research unit of the University of California, under Contract No. S9902A. Publication of research results does not imply CIEE endorsement of or agreement with these findings, nor that of any CIEE sponsor.

1

ABSTRACT

In this report, we discuss the accuracy of flow hoods for residential applications, based on laboratory tests and field studies. The results indicate that commercially available hoods are often inadequate to measure flows in residential systems, and that there can be a wide range of performance between different flow hoods. The errors are due to poor calibrations, sensitivity of existing hoods to grille flow non-uniformities, and flow changes from added flow resistance. We also evaluated several simple techniques for measuring register airflows that could be adopted by the HVAC industry and homeowners as simple diagnostics that are often as accurate as commercially available devices. Our test results also show that current calibration procedures for flow hoods do not account for field application problems. As a result, organizations such as ASHRAE or ASTM need to develop a new standard for flow hood calibration, along with a new measurement standard to address field use of flow hoods.

"The results indicate that commercially available **hoods** are often **inadequate** to measure flows in **residential** systems."

"We also evaluated several **simple** techniques for measuring register airflows that could be adopted by the HVAC industry…as simple diagnostics that are often **as accurate as commercially available devices**."

Bag and Stopwatch Early Days

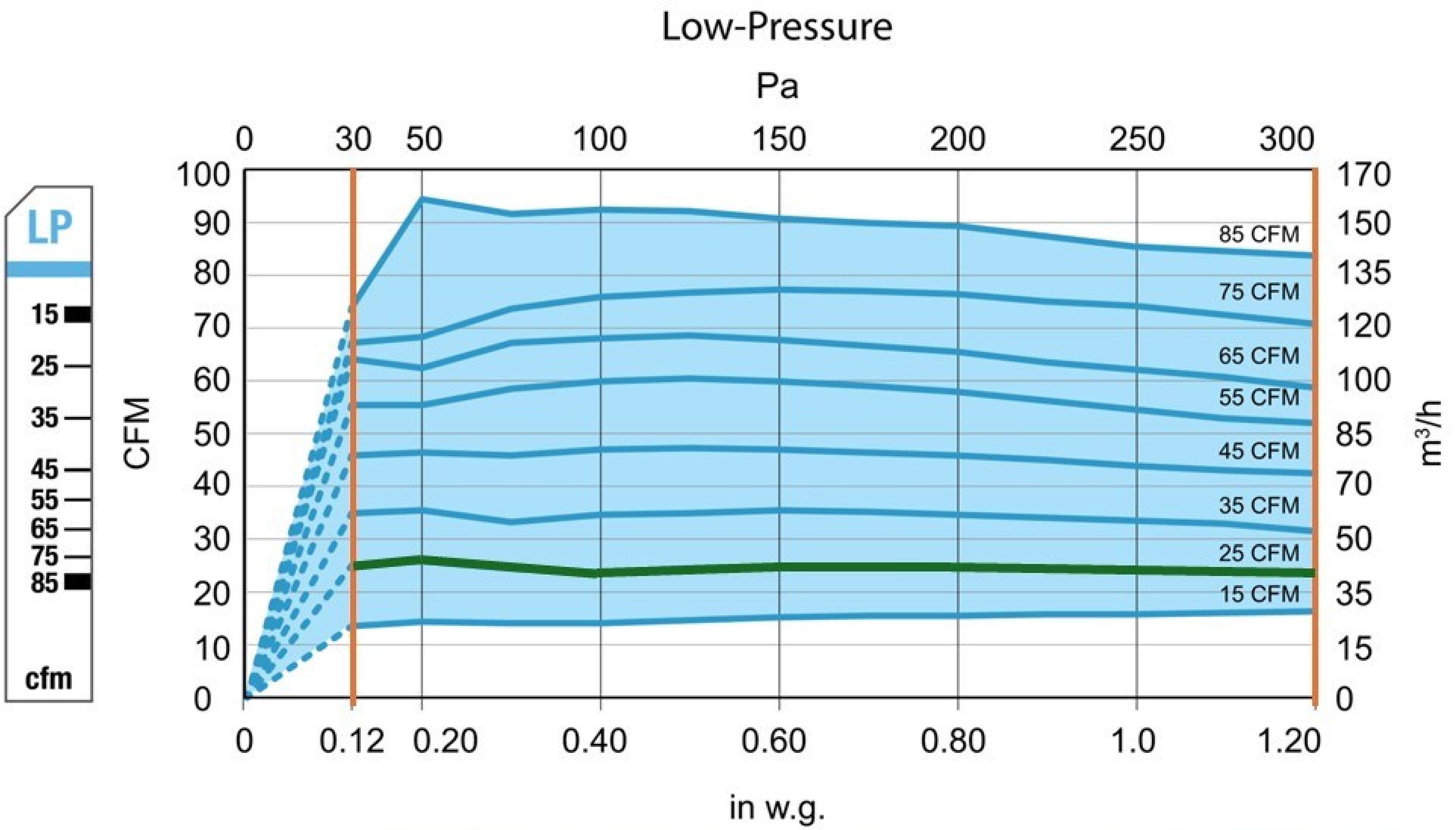
Room	Air Flow (CFM)		
	Trial 1	Trial 2	Trial 3
LR	34	32	32.4
BDR 1	16	-	-
BDR 2	16	14	20 (hood measurement)
BDR 3	11.8	12.6	12.7
BDR 4*	-	11.5	14.7
Exhaust Outlet @ Exterior	85	83	-
Intake Inlet @ Exterior**	140	100 (hood measurement)	-
Kitchen Exhaust	41	37	25 (hood measurement)
1st flr Bath Exhaust	49	35 (hood measurement)	-

Note: High fan speed setting, integral HRV dampers fully open

+/-0.45CFM (+/-4%)

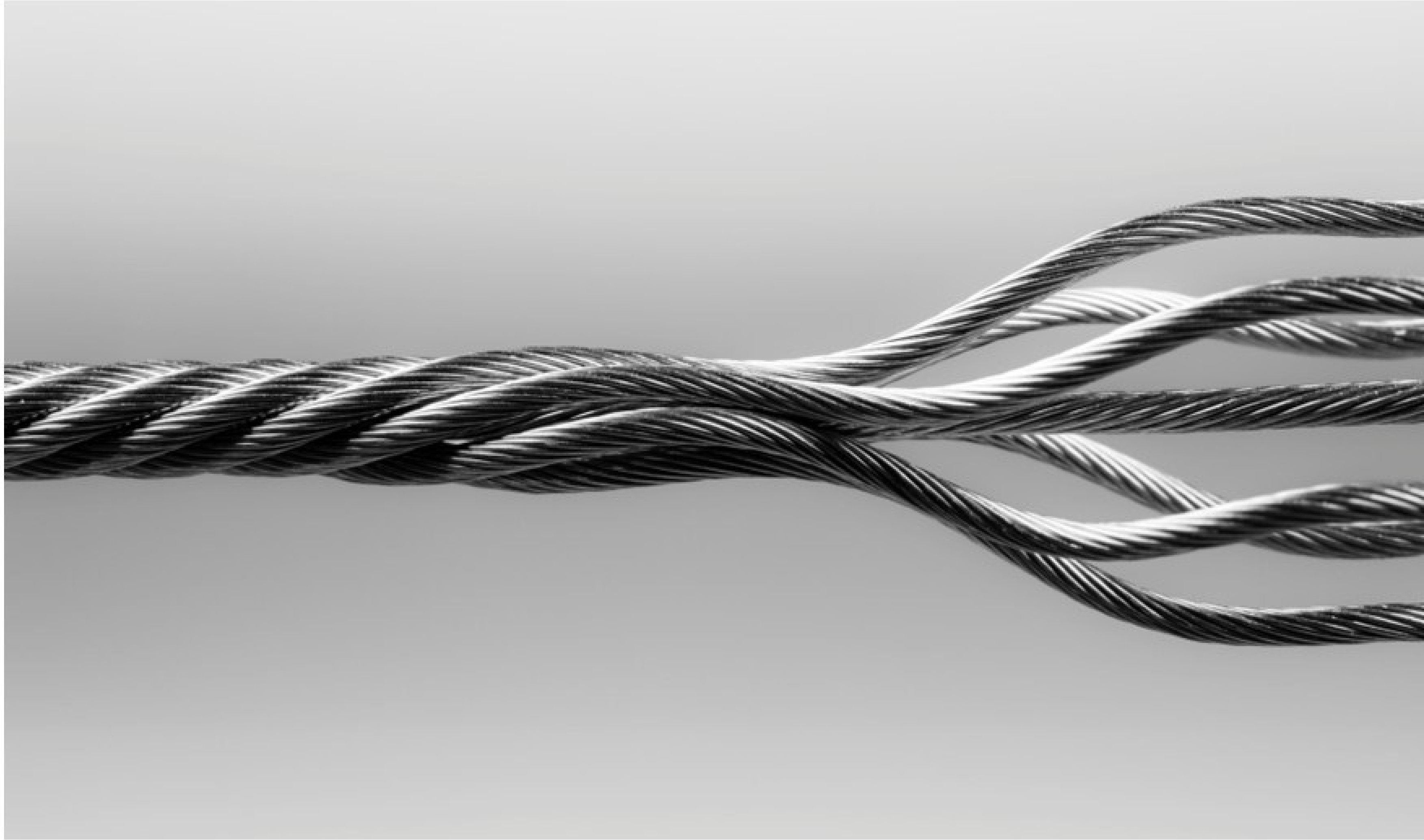
+/-2CFM (+/-6%)

14CFM diff



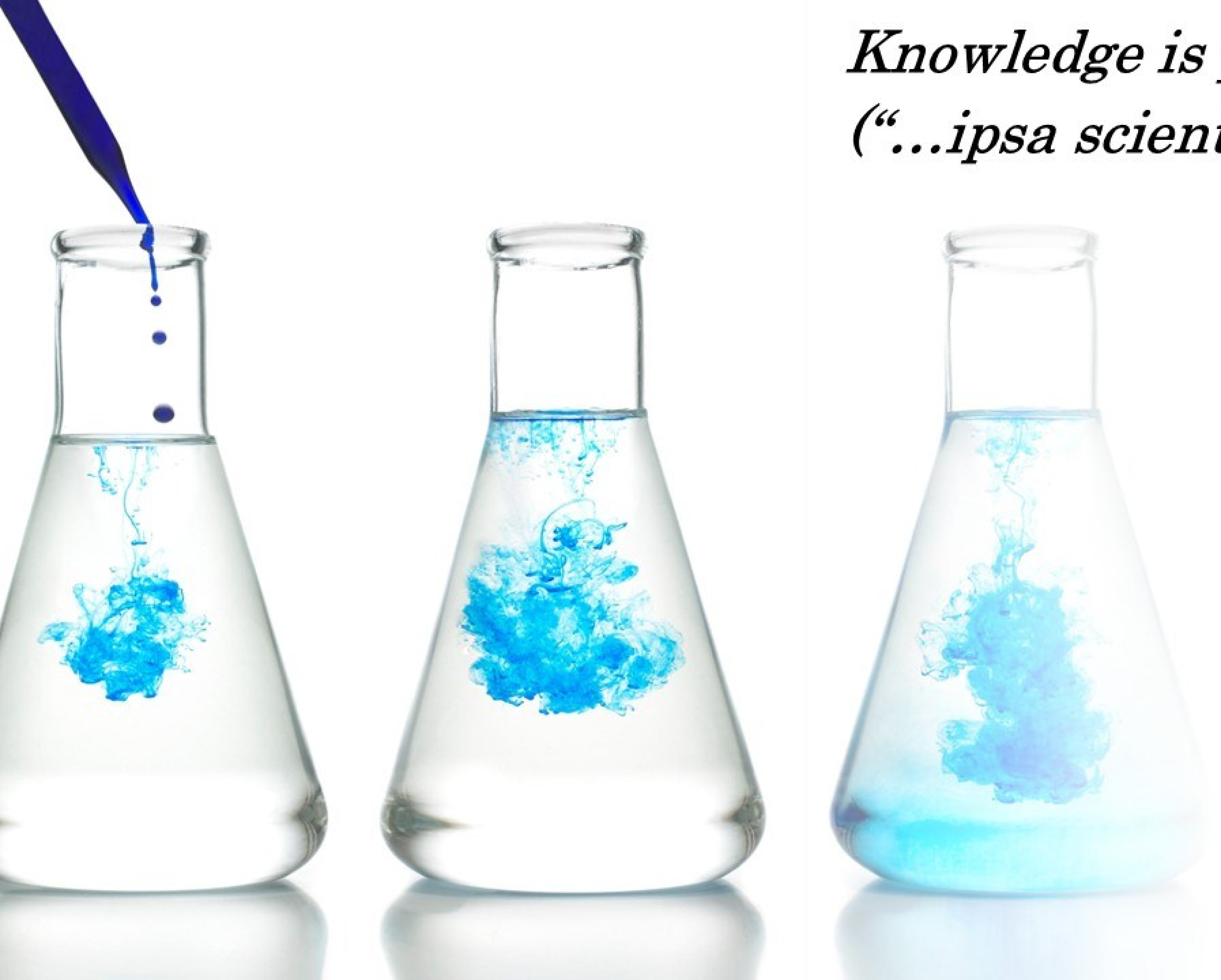
How do they work?

As Time Went On…



Knowledge is power
("...ipsa scientia potestas est.")

-Sir Francis Bacon



Flow Rate Testing – ANSI/RESNET/ICC 380

Inlet

- Powered Flow Hood
- Airflow Resistance Device
- Passive Flow Hood
- Vane Anemometer with Hood

Outlet

- Powered Flow Hood
- Bag Inflation Device
- Vane Anemometer with Hood

Midstream

- Airflow Measurement Station
- Velocity Pressure Probe
- Hot Wire Anemometer

Flow Rate Testing – ANSI/RESNET/ICC 380

Inlet

- Powered Flow Hood
- ~~Airflow Resistance Device~~
- Passive Flow Hood
- Vane Anemometer with Hood

Outlet

- Powered Flow Hood
- Bag Inflation Device
- Vane Anemometer with Hood

Midstream

- Airflow Measurement Station
- ~~Velocity Pressure Probe~~
- ~~Hot Wire Anemometer~~

Here I am!

And Greg!

Airflow Measurement Station
(Static Pressure, midstream)

Bag Inflation Device
(Bag and Stopwatch, outlet)

Flow Hood
(inlet, outlet)

There's Sarah!

Bag Inflation Device (Bag and Stopwatch)

6.3. Procedure to measure airflow at outlet terminal.

This Section defines procedures to measure the airflow of a mechanical Ventilation system at an outlet terminal. The airflow is permitted to be measured using a powered flow hood (Section 6.3.1), a bag inflation device (Section 6.3.2), or a vane anemometer with hood (Section 6.3.3).

*Excerpts from ANSI/RESNET/ICC 380

6.3.2. Bag inflation device.

6.3.2.1.Equipment needed.

6.3.2.1.1. Bag inflation device. A flow capture element capable of creating an airtight perimeter seal around the outlet terminal that is connected to a plastic bag of known volume and holding the bag open[67] and a shutter that controls airflow into the bag.

The plastic bag shall be selected such that three or more measurements of a single outlet terminal produce results that are within 20 percent of each other.

The volume of the plastic bag shall be selected such that the bag will completely fill with air from the outlet terminal in the range of 3 to 20 seconds.

6.3.2.1.2. Stopwatch. A stopwatch capable of recording elapsed time +/- 0.1 seconds.

Bag Inflation Device

LBNL 51551

ERNEST ORLANDO LAWRENCE
BERKELEY NATIONAL LABORATORY

Evaluation of Commercially Available Techniques and Development of Simplified Methods for Measuring Grille Airflows in HVAC Systems

I.S. Walker, C.P. Wray, C. Guillot and S. Masson

Environmental Energy Technologies Division

August 2003

This work was supported by the Assistant Secretary for Energy Efficiency and Renewable Energy, Building Technologies Program, of the U.S. Department of Energy under contract No. DE-AC03-76SF00098. The research reported here was also funded by the California Institute for Energy Efficiency (CIEE), a research unit of the University of California, under Contract No. S9902A. Publication of research results does not imply CIEE endorsement of or agreement with these findings, nor that of any CIEE sponsor.

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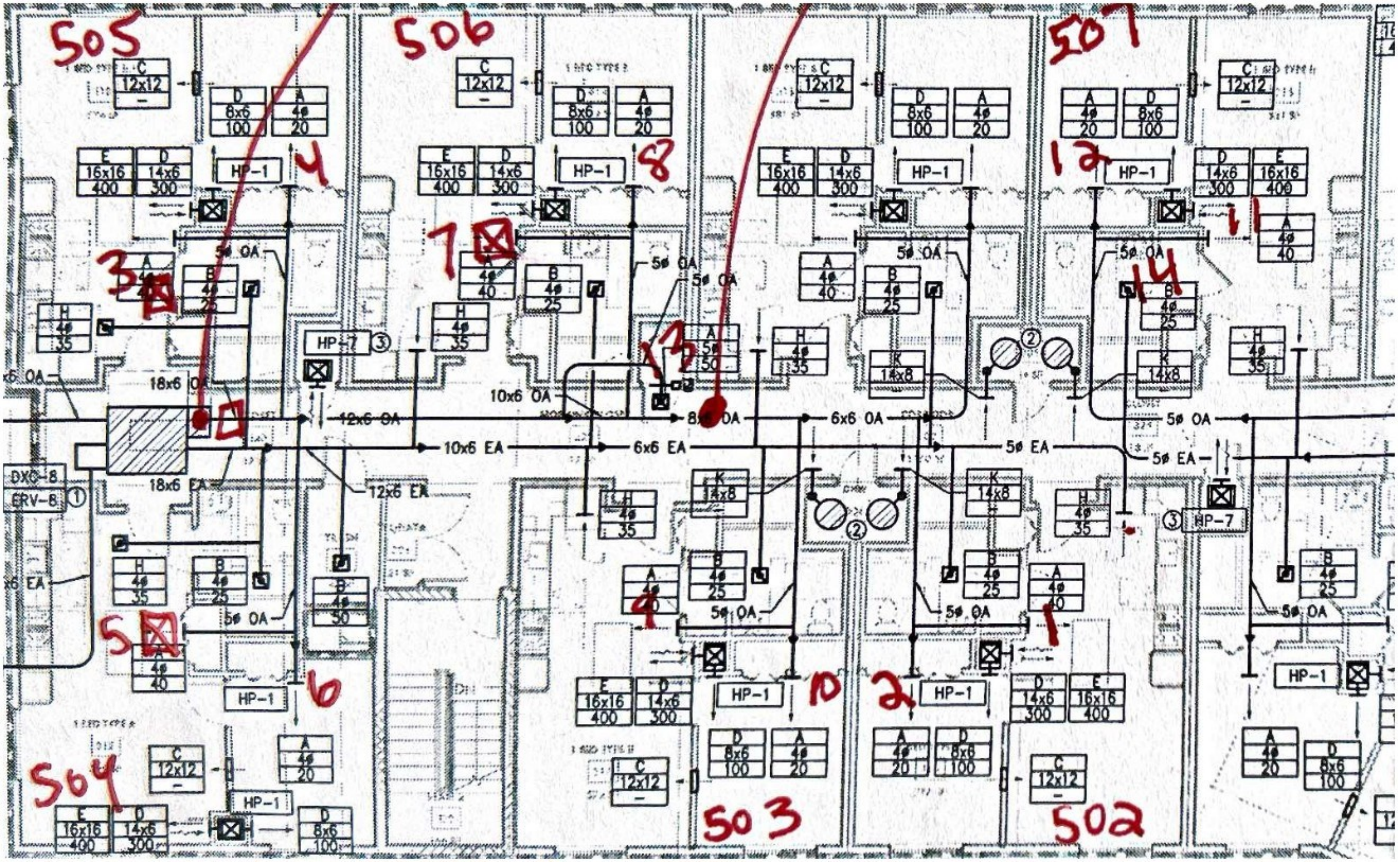
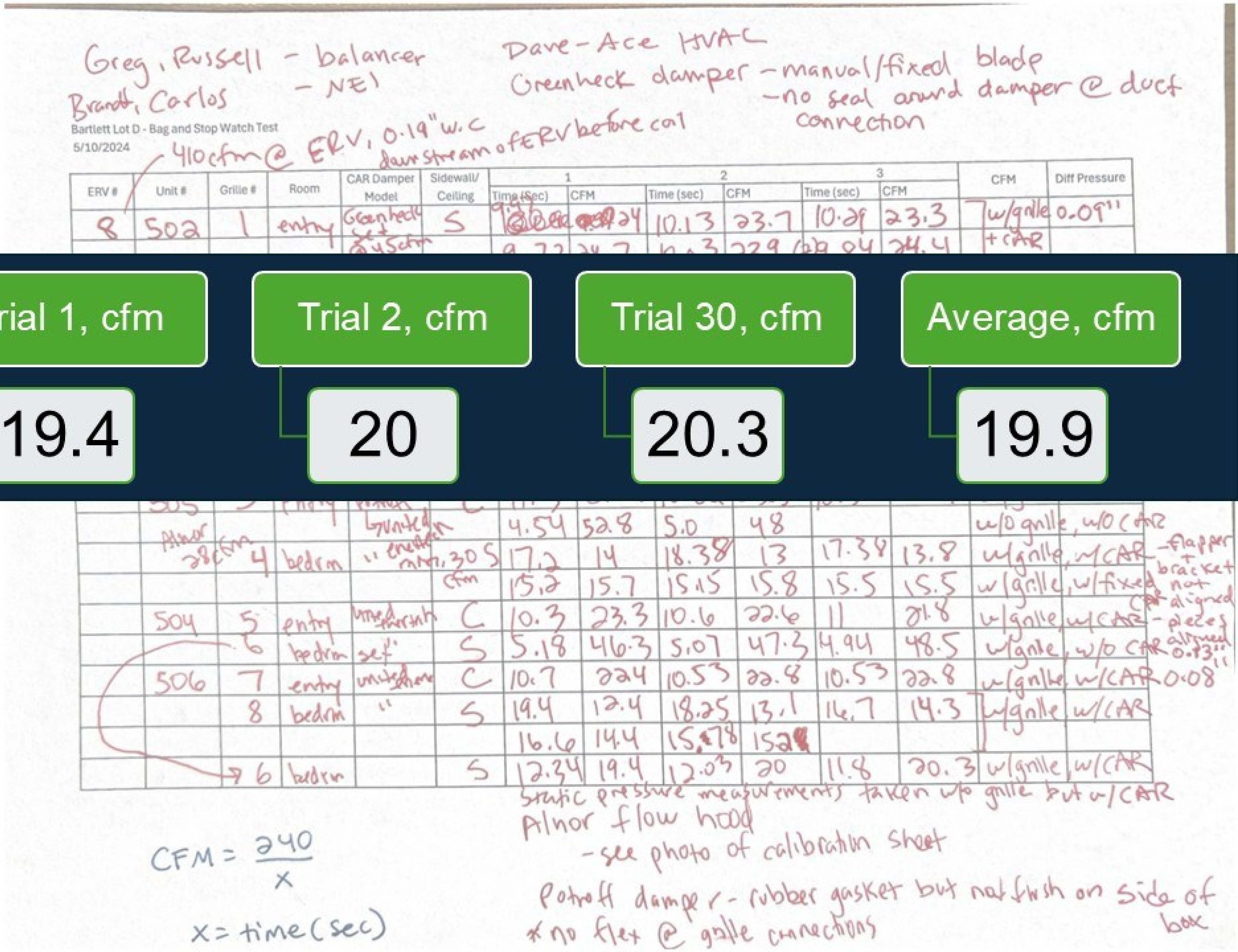
"We also evaluated several **simple** techniques for measuring register airflows that could be adopted by the HVAC industry…as simple diagnostics that are often **as accurate as commercially available devices**."

Bag and Stopwatch



Bag and Stopwatch



Bedroom, Unit 504	Trial 1, cfm	Trial 2, cfm	Trial 30, cfm	Average, cfm
	19.4	20	20.3	19.9

Flow Rate Testing – ANSI/RESNET/ICC 380

Inlet

- Powered Flow Hood
- ~~Airflow Resistance Device~~
- Passive Flow Hood
- Vane Anemometer with Hood

Outlet

- Powered Flow Hood
- Bag Inflation Device
- Vane Anemometer with Hood

Midstream

- Airflow Measurement Station
- ~~Velocity Pressure Probe~~
- ~~Hot Wire Anemometer~~

Iain Walker

Degrees

- PhD – University of Alberta, Edmonton, Canada
- MSc – University of Alberta, Edmonton, Canada
- BSc – University of Alberta, Edmonton, Canada

Leader of Residential Buildings team at LBNL

ASHRAE Fellow

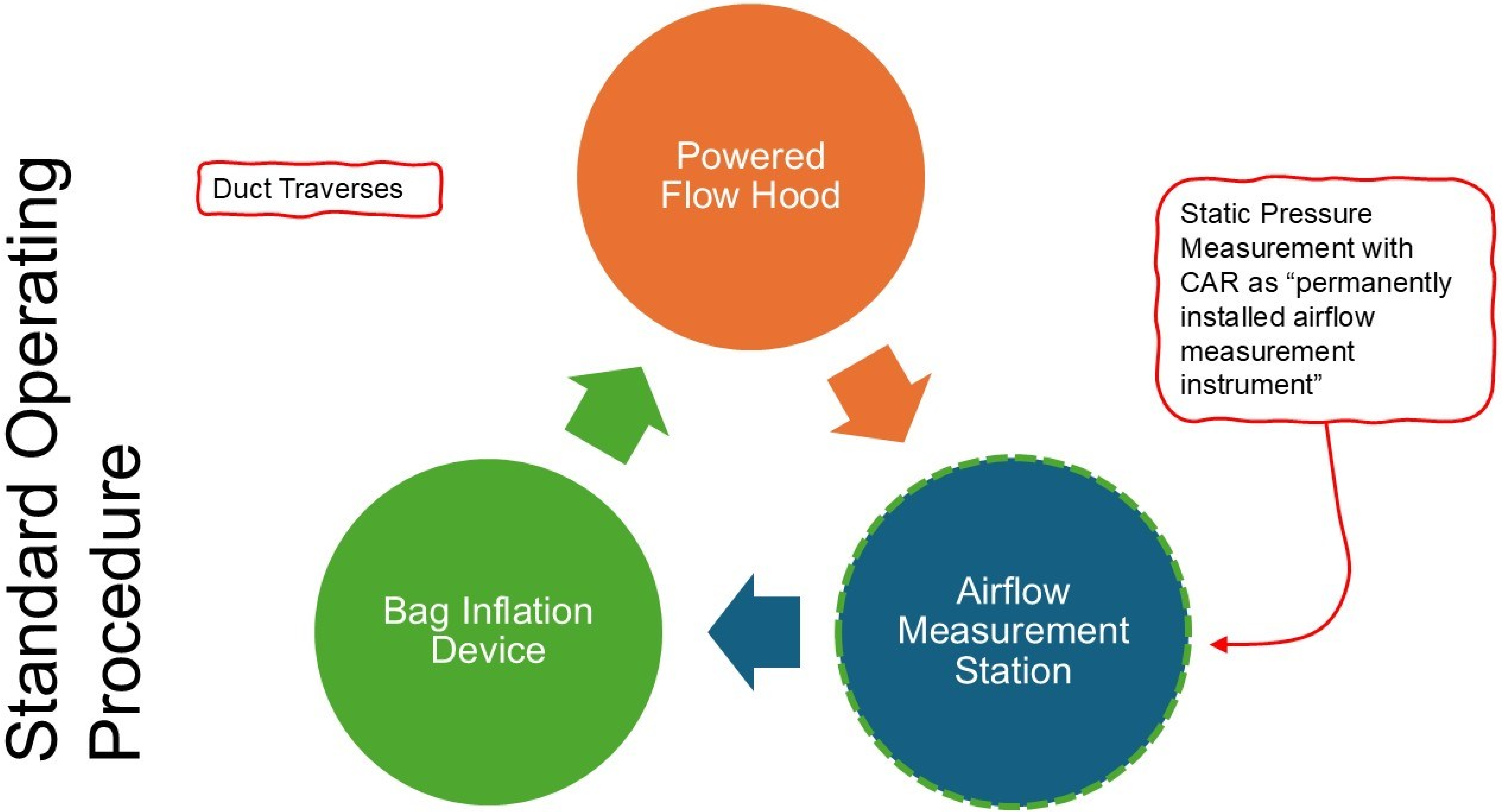
Deputy Department Head for Whole Building Systems Department of BTUS

Leader of DOE core National Laboratory IAQ team

Leader and developer on standards and technical committees for ASHRAE, ASTM, RESNET, IEC, the IEA, and others

Member of RESNET Standards Management Board

Authored over 60 journal articles, 90 conference papers, and 70 research reports.


Standard Operating Procedure
Duct Traverses
Powered Flow Hood
Static Pressure Measurement with CAR as “permanently installed airflow measurement instrument”
Airflow Measurement Station
Bag Inflation Device

Phius Verification Requirements

*Excerpt from Phius 2024 Certification Guidebook v24.1.1

1.5.2.4 Ventilation

Unless noted otherwise, the sections below apply to all project types.

Ventilation System Airflow Testing Verification

Room-by-room balancing

Testing shall be performed using devices noted below:

- Retrotec Flow Finder
- Energy Conservatory Flowblaster
- Energy Conservatory Exhaust Fan Flow Meter (for flows under 35 CFM)
- Testo 417 (for flows under 100 CFM) with flow straightener and capture hood
- CFM-range appropriate non-powered flow hood
- Duct tester devices with custom capture hood attachment

Process Tip: Any other device or methodology must be preapproved by Phius and listed in ANSI/RESNET/ICC Standard 380-2022 (or later version)

Verification Requirements

<u>Individual room supply and exhaust airflows:</u>
This is automatically calculated within the QA Workbook once design and measured values are input.

*Excerpt from Phius 2024 Certification Guidebook v24.1.1

Airflow		Room Pressure Difference	Status	
Design (cfm)	Verified (cfm)		≥Design	Within +5cfm or +20%
20	19		Not acceptable.	Not acceptable.

*From Phius MF Quality Assurance Workbook v24.10_2024.08.27

Tolerances

- Calculated error (Uc) on flow measurement:

$$Uc = \sqrt{(u1^2 + u2^2 + u3^2 + u4^2 + u5^2 + ux^2)}$$

u1 = tolerance of the product

u2 = tolerance of the measurement tool

u3 = error due to method repeatability

u4 = error due to leakage

u5 = installation uncertainties

ux = … any other elements which could impact the reading

Then the measured value (Mv) based on the reading (Re) is expressed as below:

$$Mv = Re \pm Uc$$

Tolerances

- Calculated error (Uc) on flow measurement:

$$Uc = \sqrt(\mathbf{u1}^2 \ + \mathbf{u2}^2 + \mathbf{u3}^2 + \mathbf{u4}^2 + \mathbf{u5}^2 + \mathbf{ux}^2)$$

u1 = tolerance of the product = 0.1

u2 = tolerance of the measurement tool = 0.09

u3 = error due to method repeatability = 0.09

u4 = error due to leakage = 0

u5 = installation uncertainties = 0

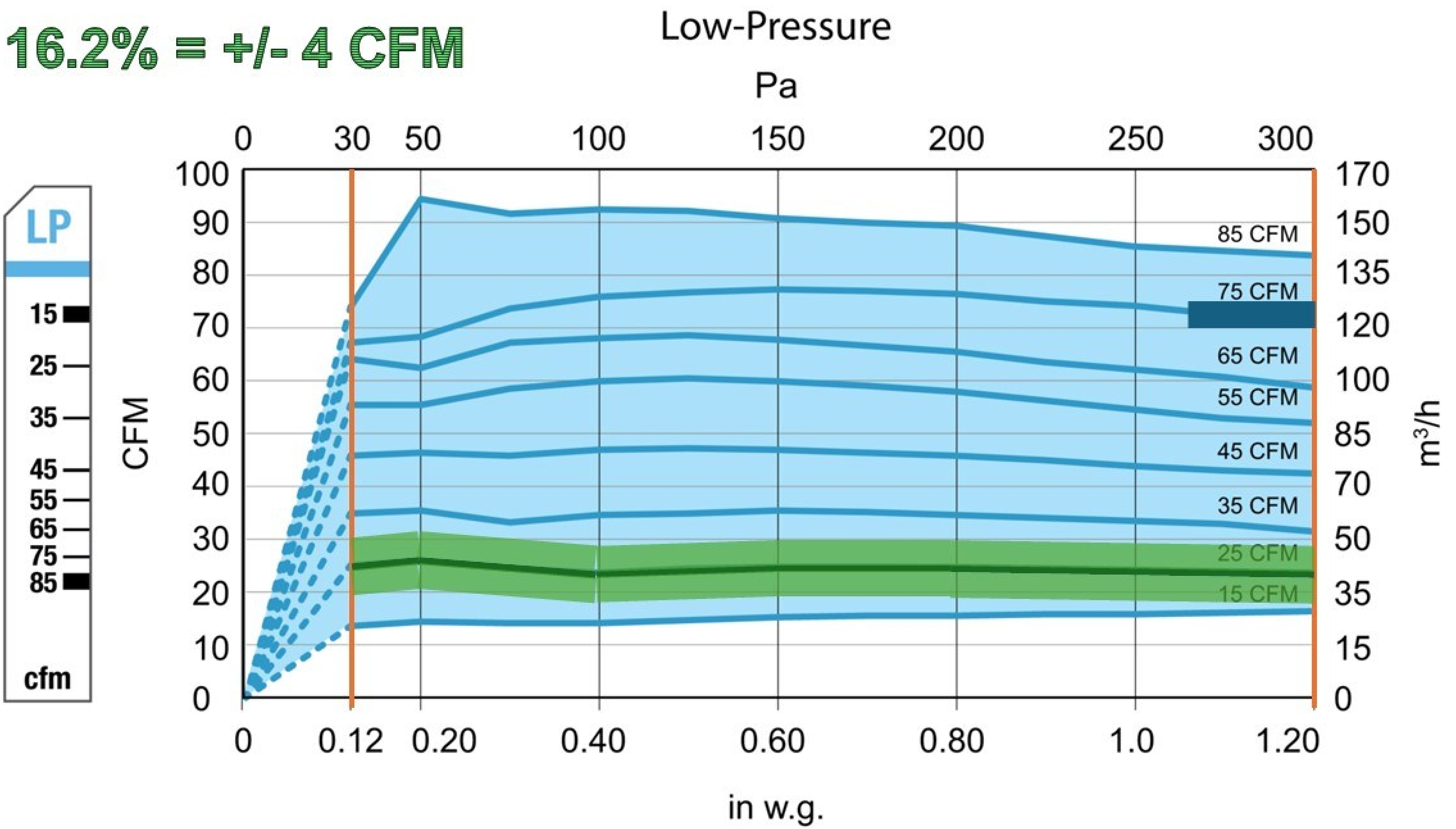
ux = … any other elements which could impact the reading = 0

Uc = 0.162 (16.2%)

Then the measured value (Mv) based on the reading (Re) is expressed as below:

$$Mv = Re \pm Uc$$

16.2% = +/- 4 CFM

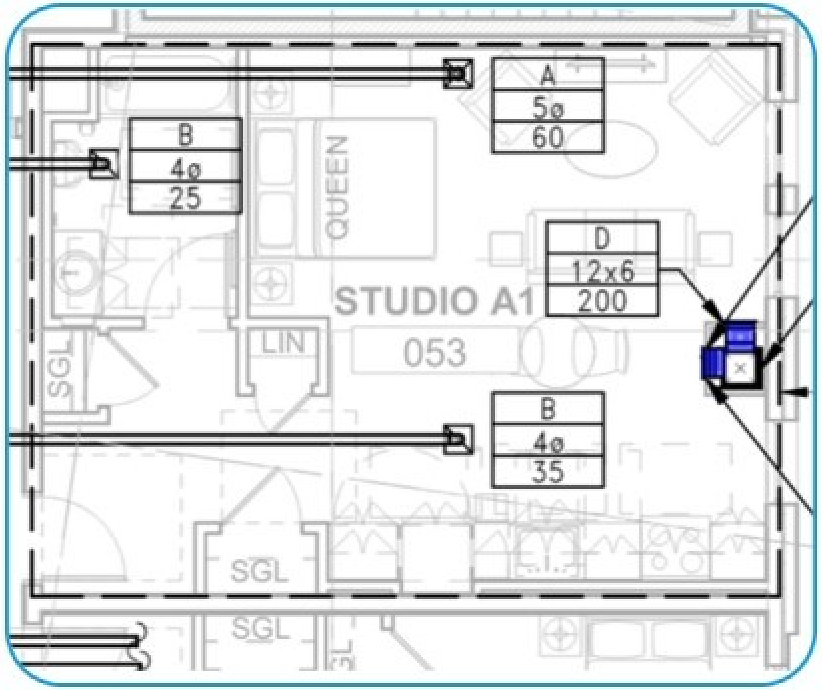

Low-Pressure
Pa
0
30
50
100
150
200
250
300
LP
15
25
35
45
55
65
75
85
cfm
CFM
100
90
80
70
60
50
40
30
20
10
0
85 CFM
75 CFM
65 CFM
55 CFM
45 CFM
35 CFM
25 CFM
15 CFM
170
150
135
120
100
85
70
50
35
15
0
m³/h
0
0.12
0.20
0.40
0.60
0.80
1.0
1.20
in w.g.

Target vs Intent

Small

Simple

Serviceable



Questions?

Petersen
Engineering

James Petersen, PE - Principal
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