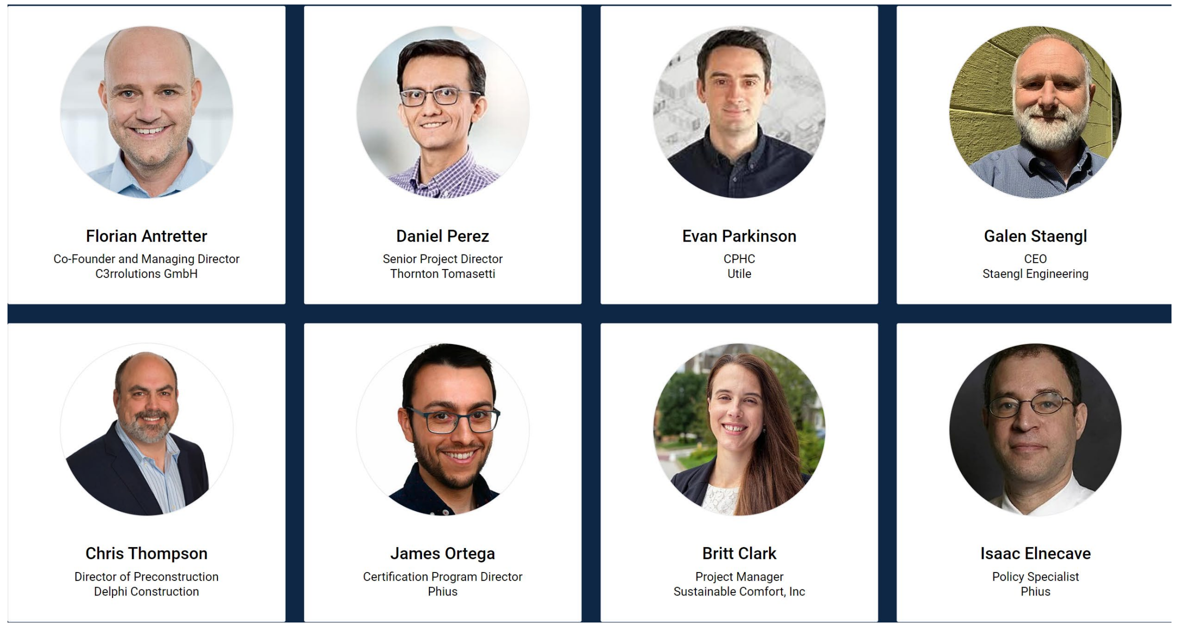
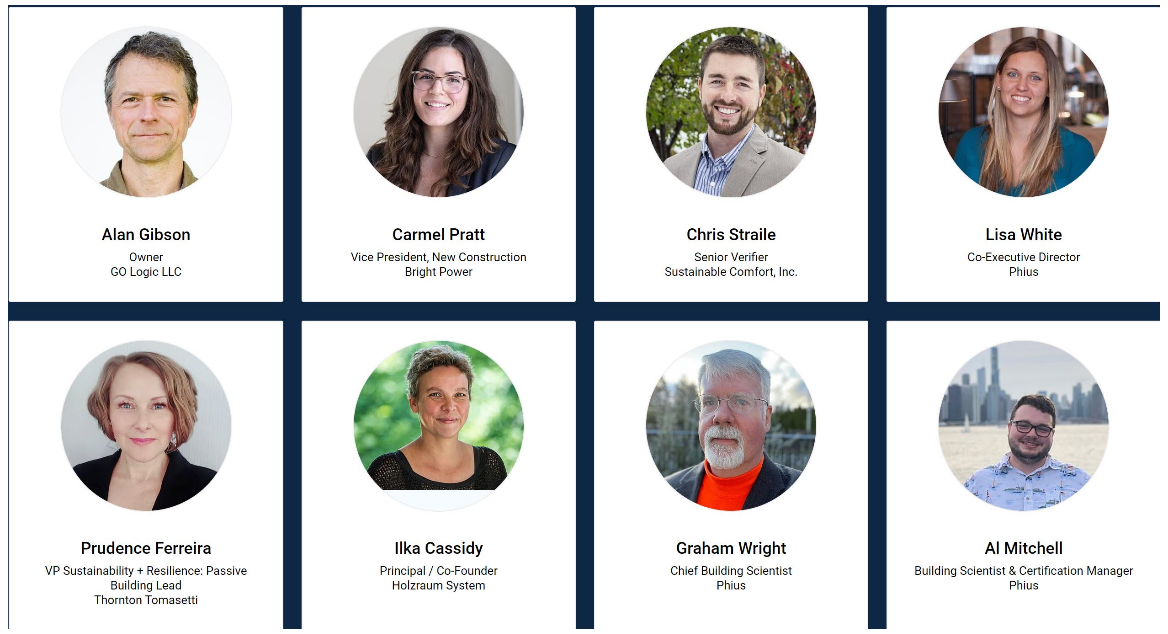
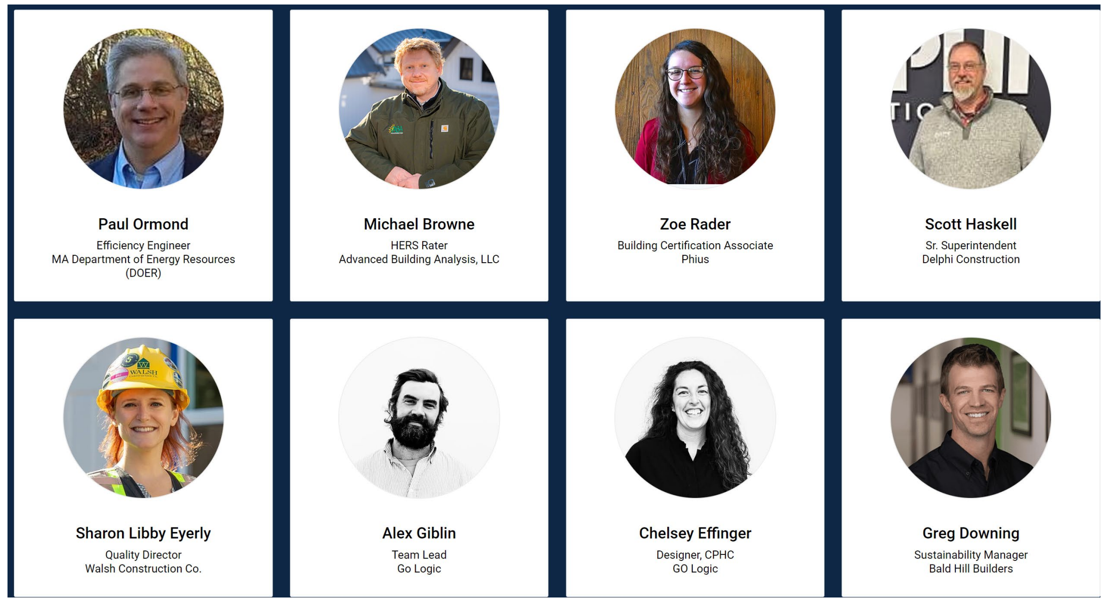

BILTMORE
phius
PRO FORUM

Good Morning!

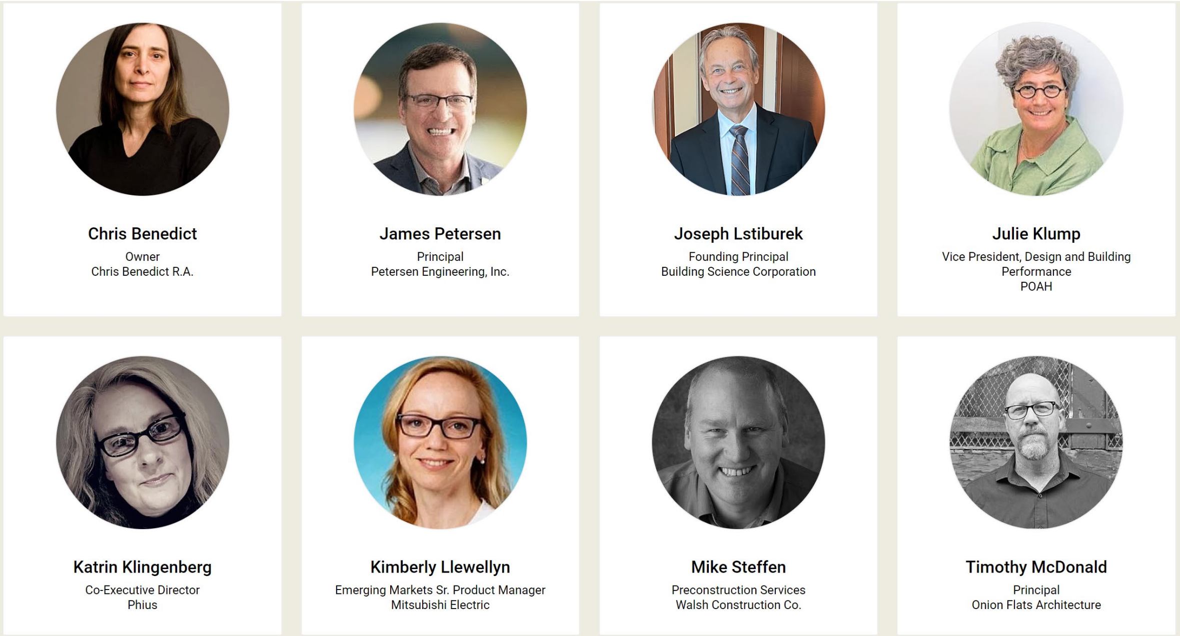
Who Are We - Who Are You?

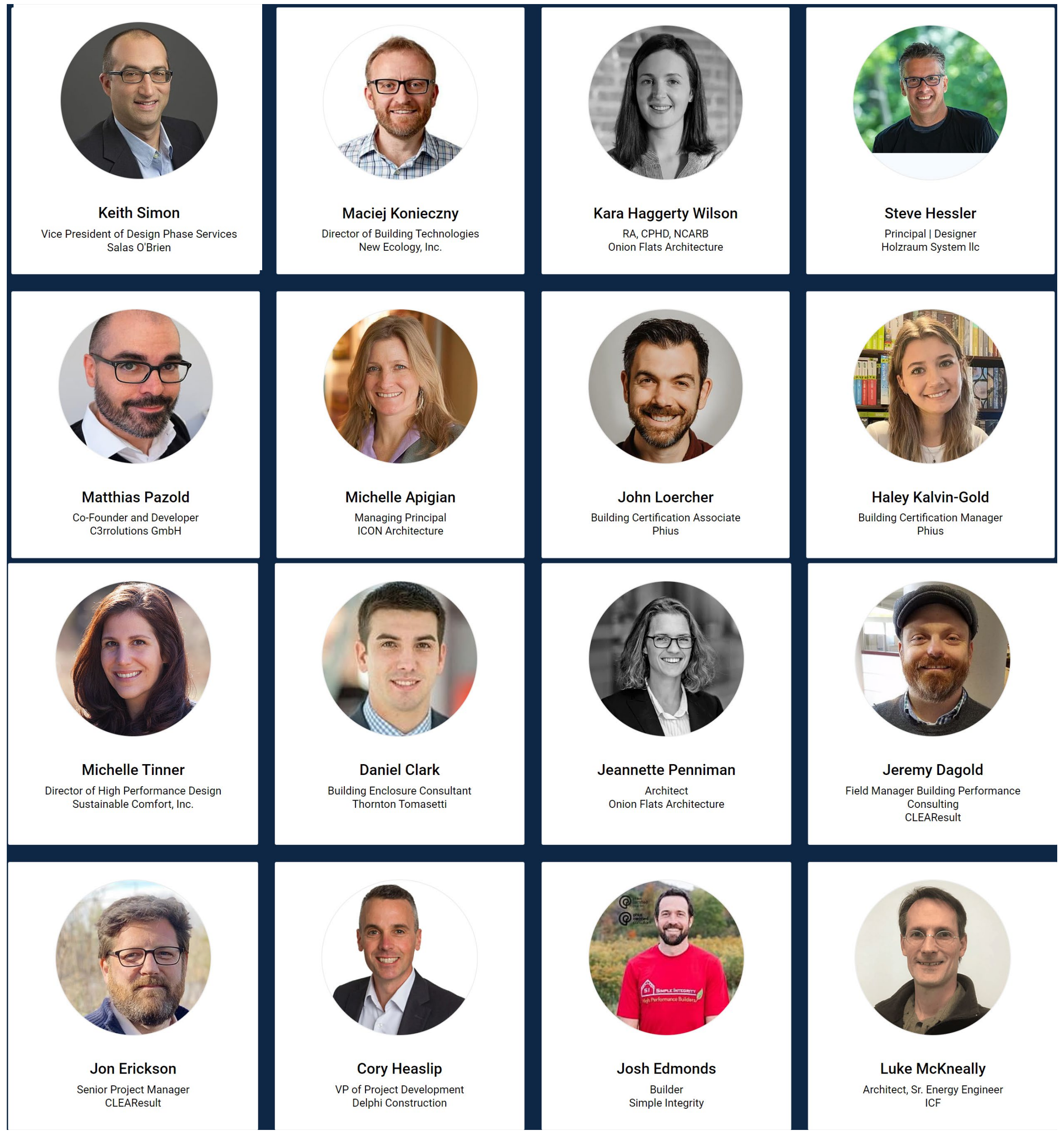






We are part of this amazing, vibrant, Phius community that is constantly evolving, challenging status quo, dogma and each other. We have created an information exchange network really comes to life at events like the Pro Forum where we can share knowledge and experience. That is what we're here to do today.





Why Are You Here?

Design	Modeling	Fundamentals
Ventilation	DHW	Heating/Cooling
Specific Project Questions	Multifamily	Climate Based Questions

Why Now?

Incentives for Phius Projects in Massachusetts

Phius projects qualify for a wide range of incentives offered by utility providers, local municipalities and the federal government. Below is a brief rundown of some of these incentives. For more information on available incentives and their requirements, visit www.phius.org.

Most Phius Projects are Eligible for:

- Mass Save New Construction Incentive
- Mass Save Training Incentive
- Low Income Housing Tax Credit Incentive
- Stretch Code
- Opt-in Net Zero Code
- Inflation Reduction Act
  - 45L for buildings 3 stories or less
  - 179d for buildings 4 stories or more
  - Clean energy Credit
  - High Efficiency Electric home Rebate Program

Passive House Incentive Structure for Multifamily Buildings (5 units or more)

Incentive Timing	Activity	Incentive Amount	Max. Incentive
Pre-Construction	Feasibility Study	Up to 100% of Feasibility Study Cost	$5,000
Pre-Construction	Energy Modeling	Up to 75% of Energy Modeling Costs	$500/unit, max of $20,000
Pre-Construction	Pre-Certification	$500/unit	N/A
Post-Construction	Certification	$2,500/unit	N/A
Post-Construction	Net Performance Bonus	$0.75/kwh OR $7.50/therm	N/A

High-Efficiency Electric Home Rebate Program

Measure	Rebate
Heat Pump Water Heater	$1,750
Heat Pump	$8,000
Electric Stove, Cook-top, Range, Oven	$840
Electric Wiring	$2,500
Electric Heat Pump Clothes Dryer	$840
Electric Load Service Upgrade	$4,000
Insulation, Air Sealing and Ventilation	$1,600

ENERGY STAR Programs | Through December 32, 2032

New Construction Program and Manufactured New Homes Program		
ENERGY STAR	$2,500	
DOE Zero Energy Ready Home	$5,000	
Multifamily New Construction	**Projects Not Using Prevailing Wage**	**Projects Using Prevailing Wage**
ENERGY STAR	$500/unit	$2,500/unit
DOE Zero Energy Ready Home	$1,000/unit	$5,000/unit

SPC 227P, Proposed Standard authorized January 16, 2019. Revised TPS approved June 22, 2021
Passive Building Design Standard

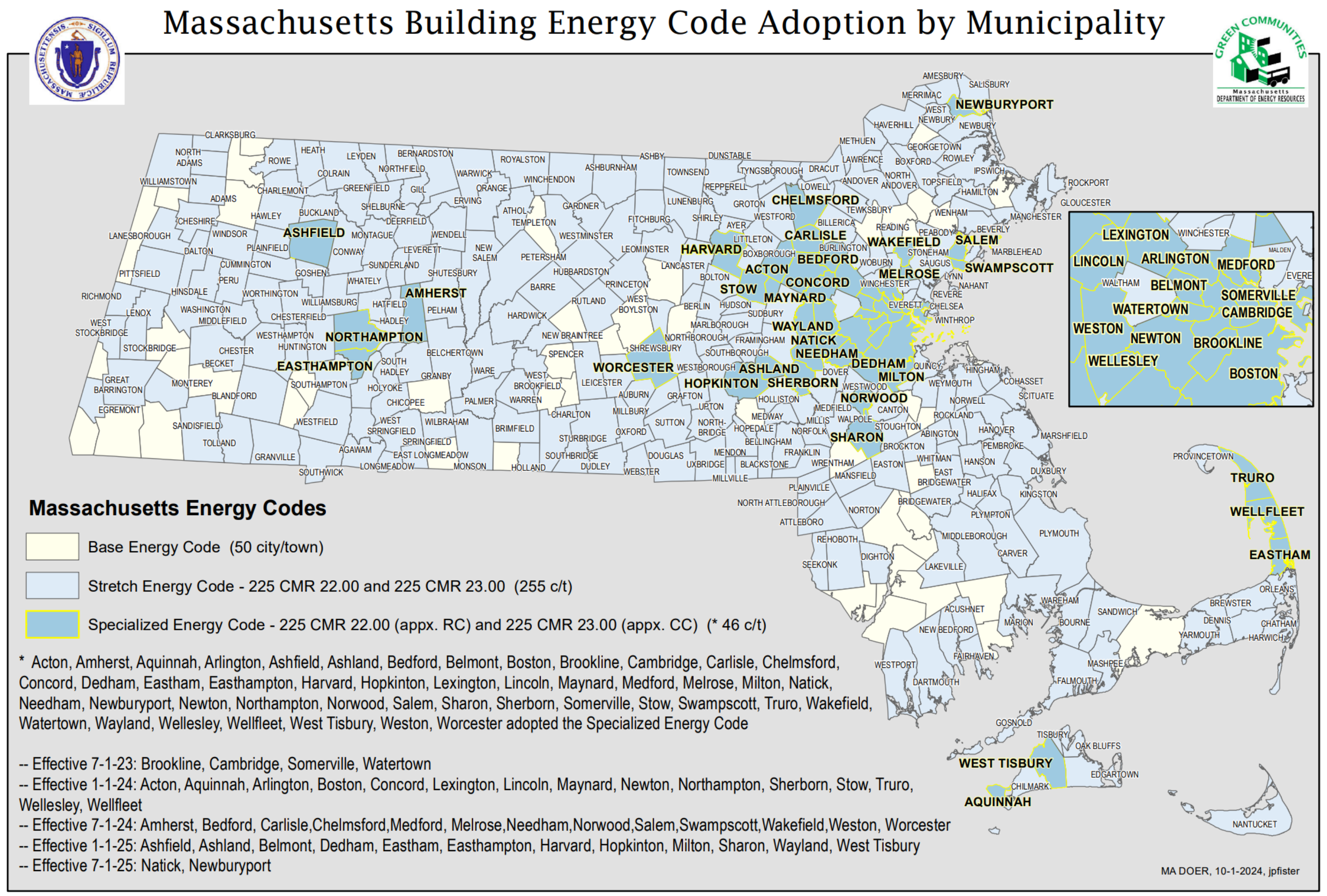
PURPOSE: This standard provides requirements for the design of buildings that have exceptionally low energy usage and that are durable, resilient, comfortable, and healthy.

SCOPE:
2.1 This standard is applicable to all new and existing buildings intended for human occupancy.
2.2 This standard provides requirements for the design, construction and plans for operation of the:

1. building envelope,
2. heating and cooling equipment and systems,
3. ventilation systems,
4. service hot water systems,
5. interior and exterior lighting systems, and
6. plug and appliance loads.

ASHRAE® Shaping Tomorrow's Built Environment Today

2.3 This standard does not provide requirements for the use of buildings.
2.4 This standard does not apply to process related systems or equipment.
2.5 This standard shall not be used to circumvent any safety, health, or environmental requirements.



Agenda

Morning

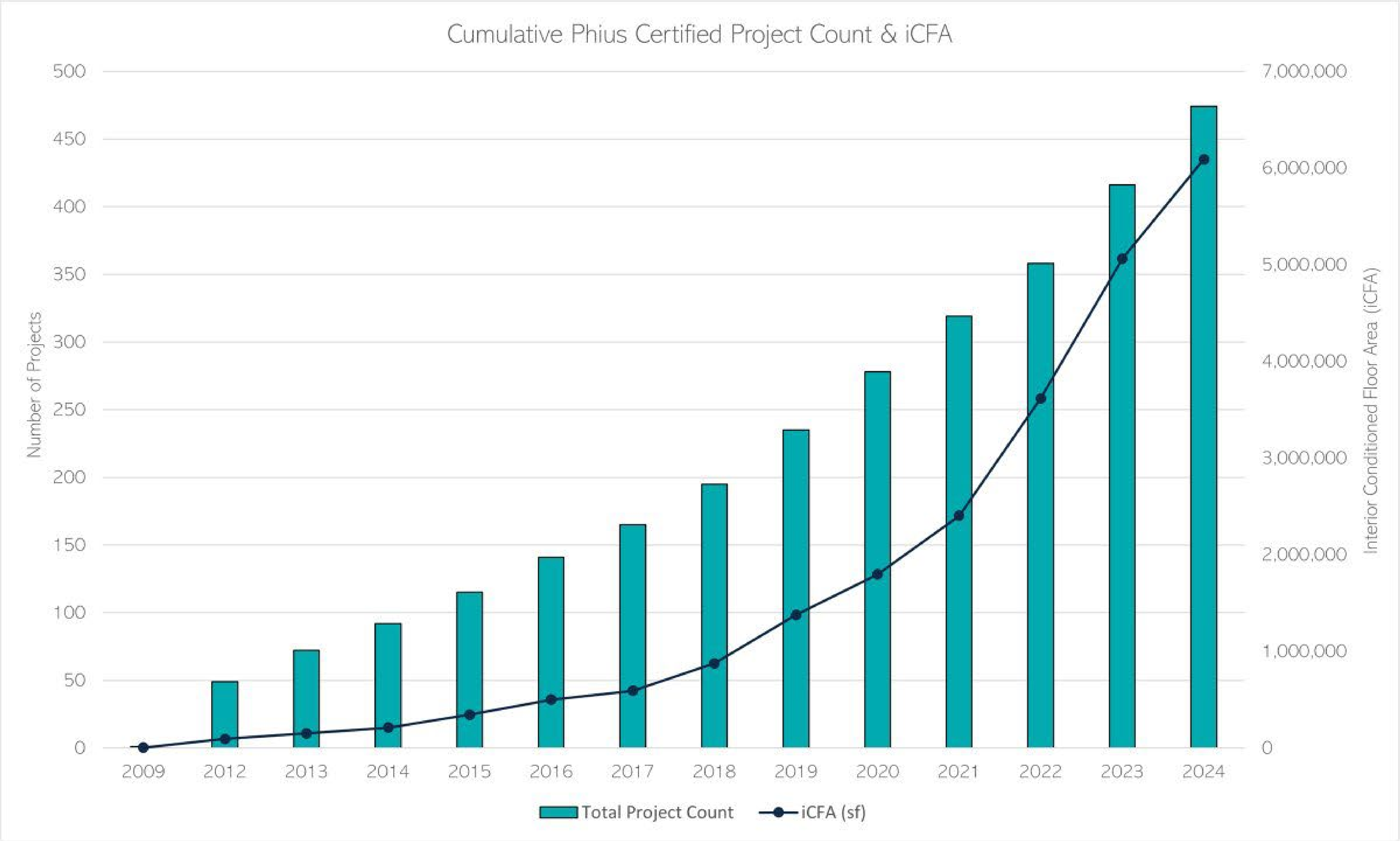
- Introduction to Team and Attendees
- Phius Project Stats
- Building Systems – Basic Concepts / Fundamentals
- Multi-family Design
- Q & A Throughout

Afternoon

- Commercial Design- Office
- Design Exercise- School, Multifamily
- Wrap-up

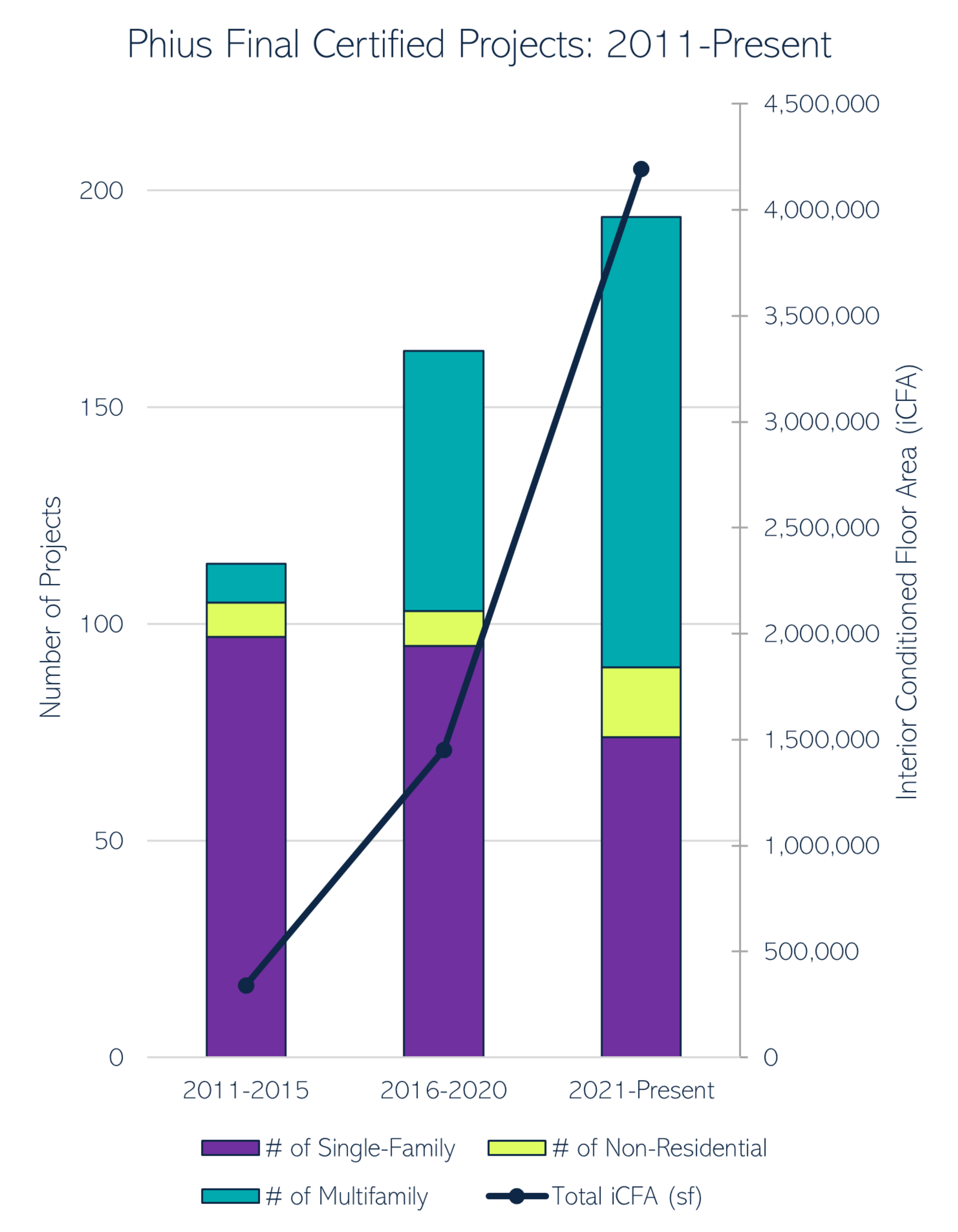
Phius Certification Stats| Exponential Growth Continues

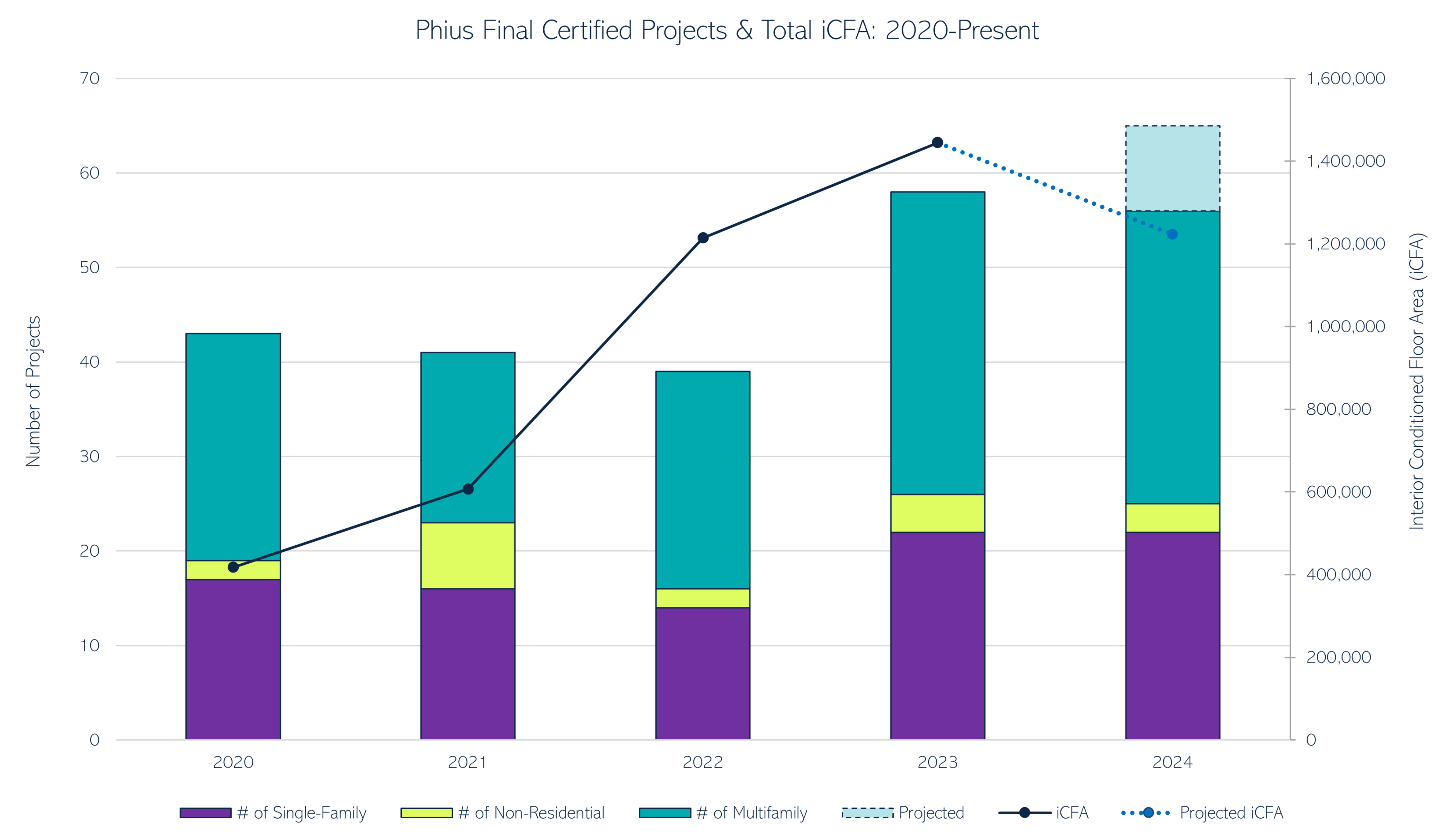
Cumulative Phius Phigures (Final Certified)



Graph Credit for Phius Stat Slides
Haley Kalvin-Gold
Phius, Building Certification Manager

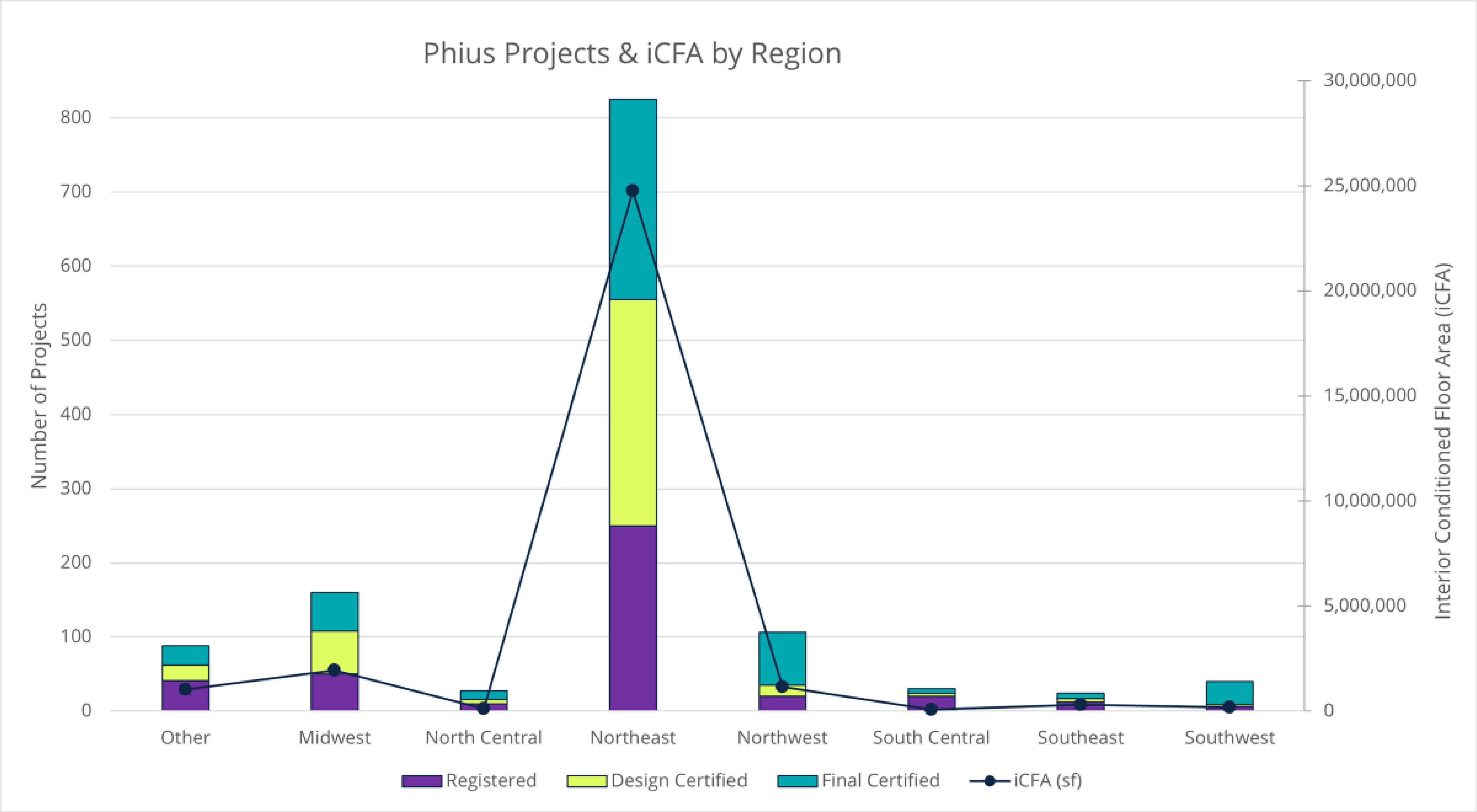
Phius Certification Stats| Multifamily Accounts for Majority



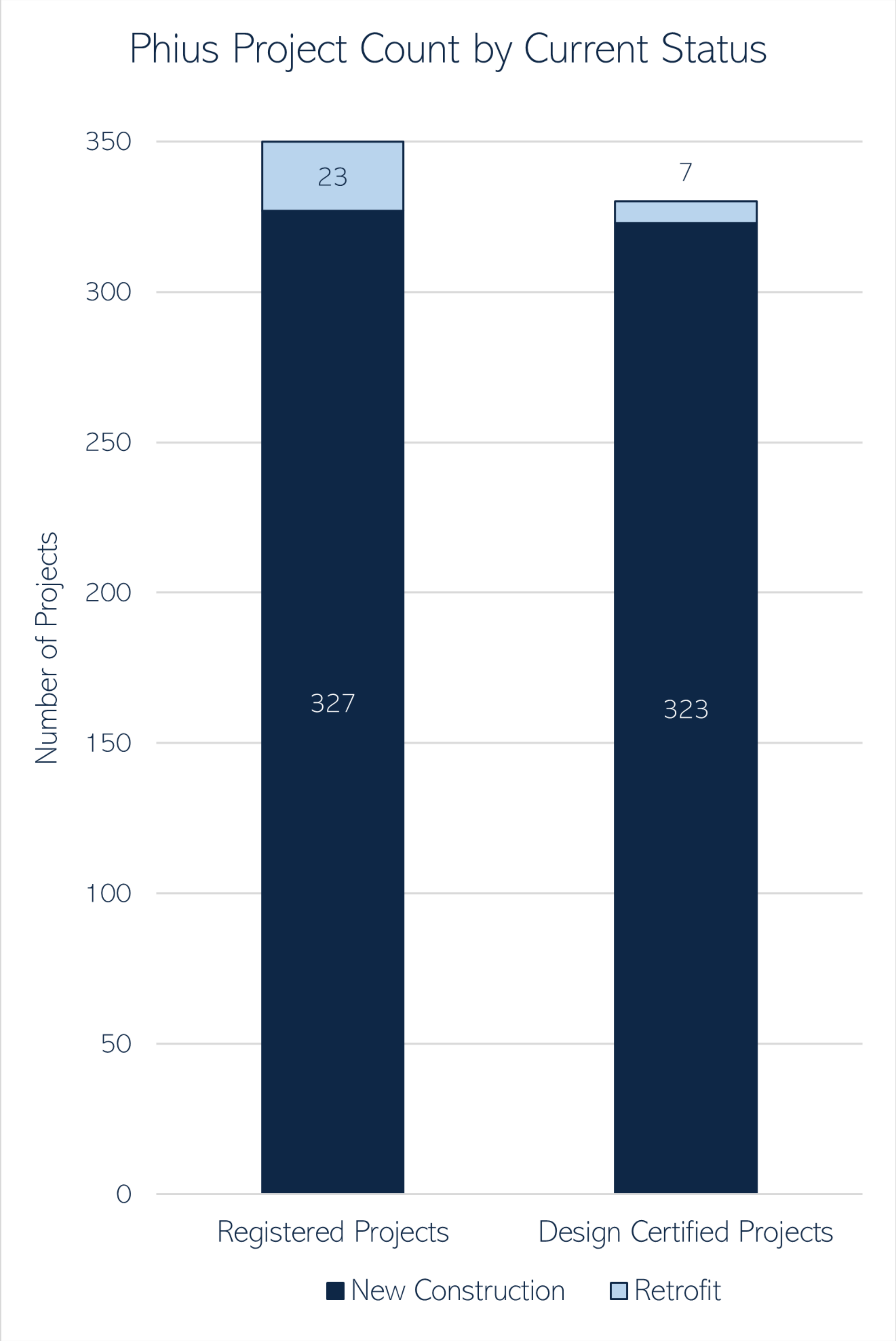


Phius Certification Stats| Northeast Accounts for Vast Majority of Projects

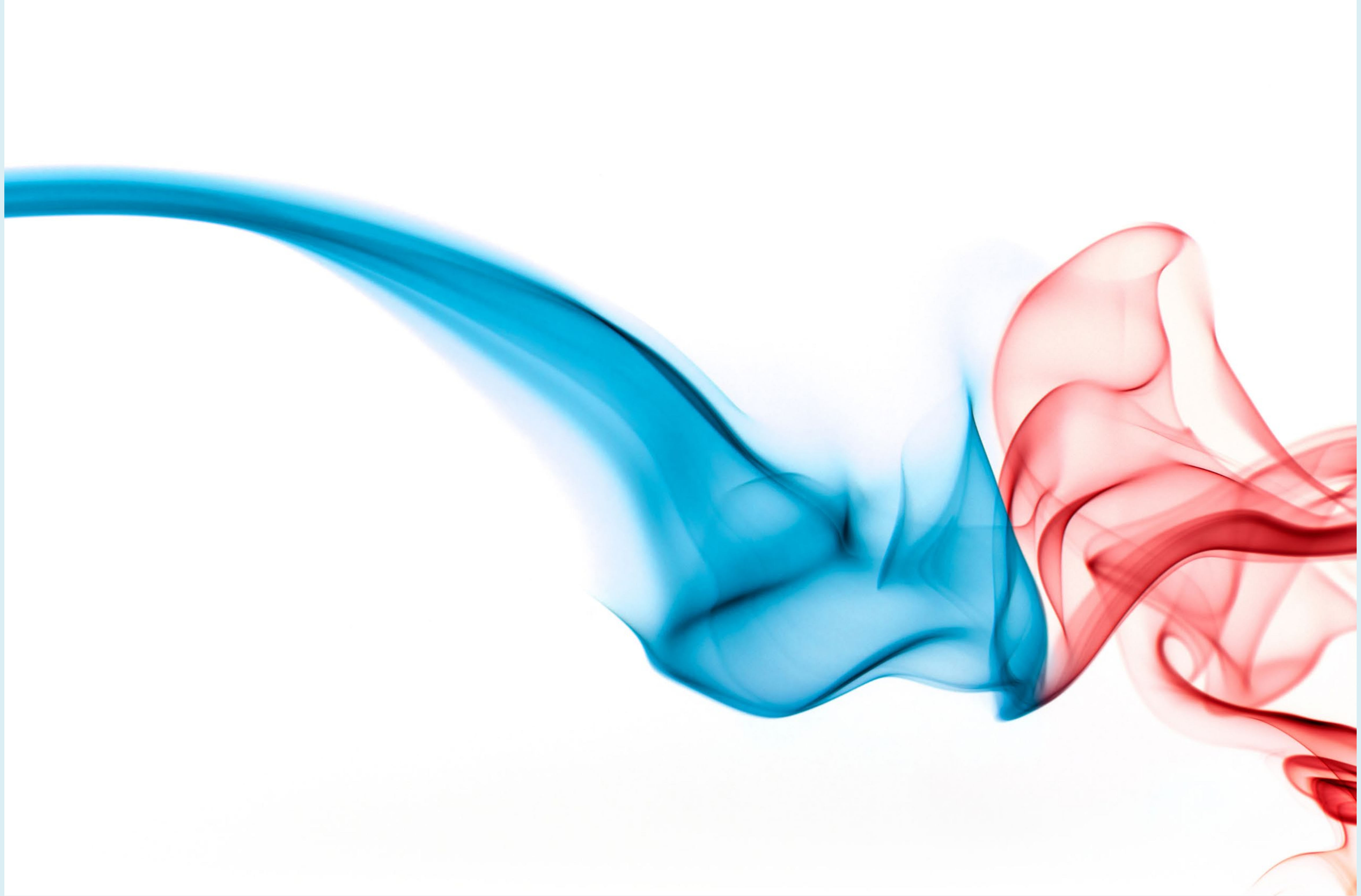
Phius Projects & iCFA by Region



Phius Current Active Project Stats| Predominantly MF New Construction



Phius Loads & System Fundamentals



General: Energy Flows

HVAC Basics

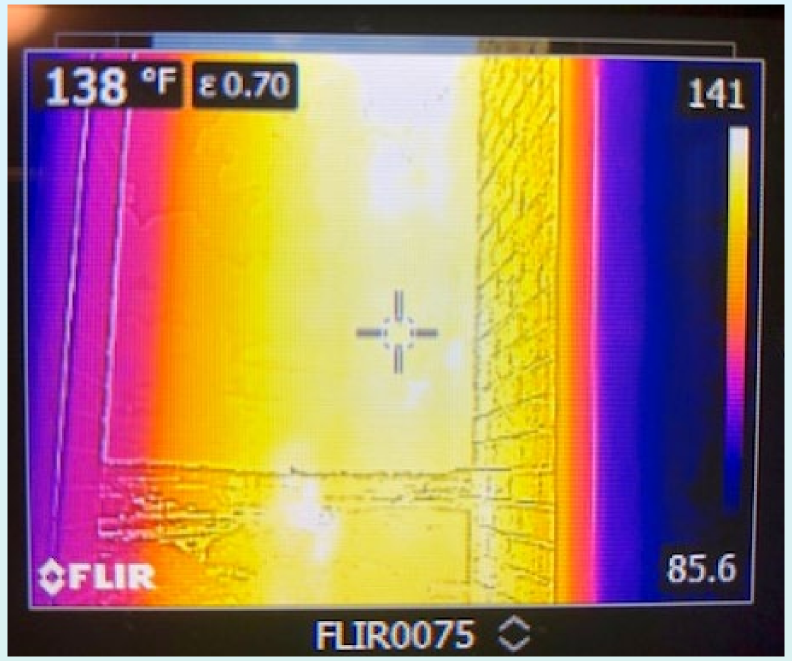
- Sensible, Latent
- Ventilation Loads
- Phius Load Differences
- HVAC Load Inputs

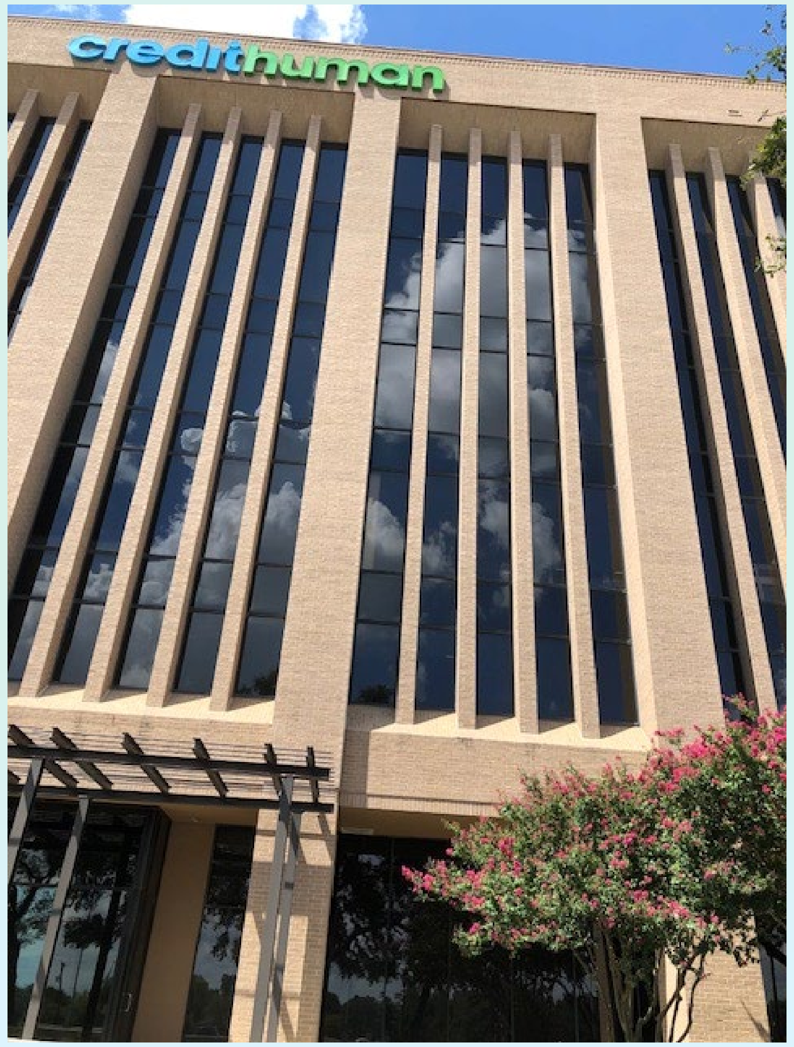
DHW Basics

- Efficient Layouts
- Recirc Loops
- DHW Loads

Energy Always Flows from Higher to Lower Concentrations

Radiative Heat Transfer





Skin to Glass 40°F ΔT

$Q = \sigma * F * (T_1^4 - T_2^4)$

Q = 165 W/m² or 15 W/ ft²

Q = 52 Btu/h/ft²

Wall R10 @40°F ΔT

Q = 10 Btu/h/ft²

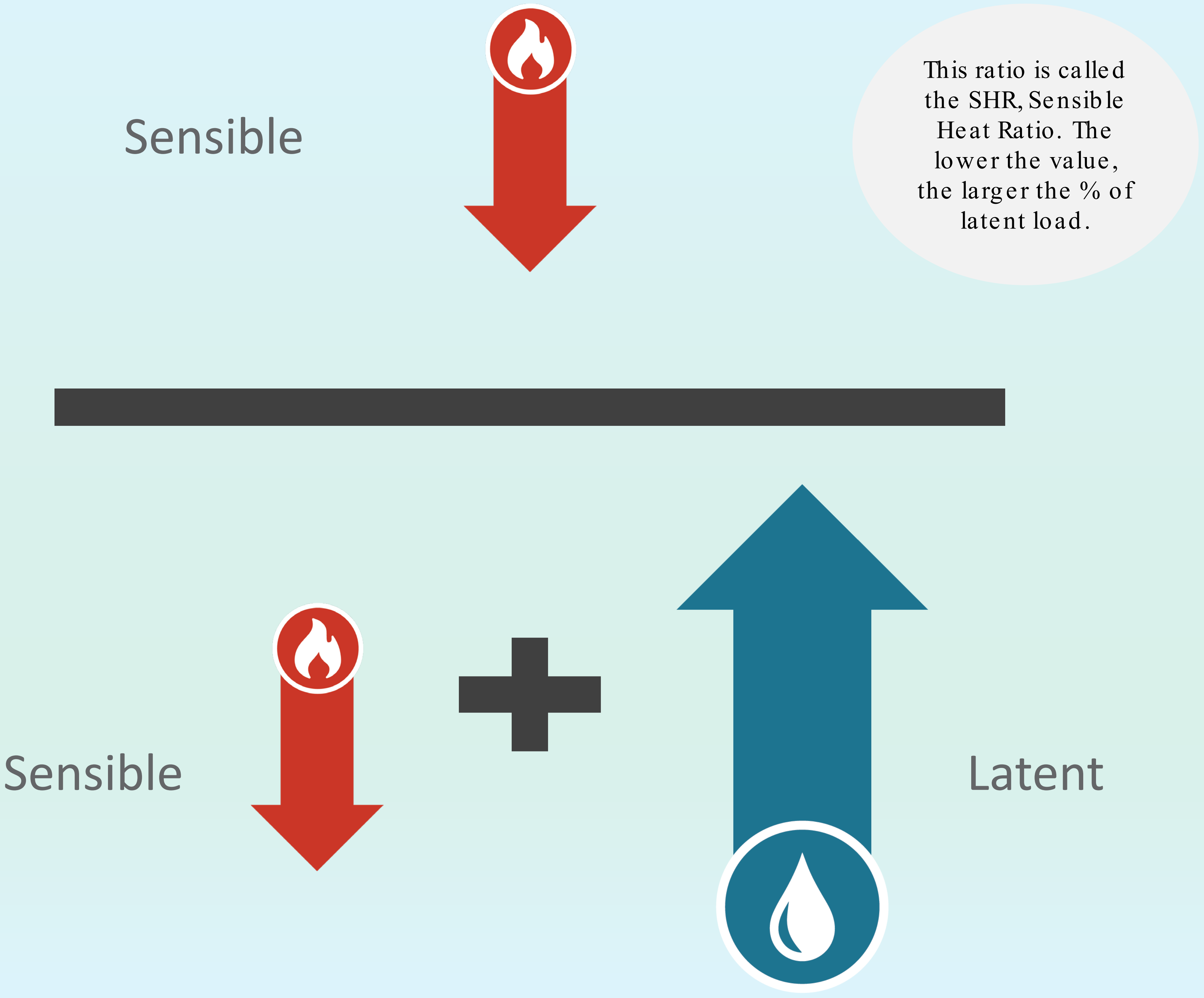
Lighting Load 90.1-2022

Office = 1.00 W/ft²

Take-away:

The comparative impact on a net basis may not show up even in models that account for radiative heat transfer. However, the localized impact on comfort can be very significant.

Cooling Loads Often Dominant



Take-away:

Even in cold climates, cooling loads are usually dominant. While sensible loads can be significantly reduced, latent loads cannot. This means humidity loads and system latent control capabilities must be evaluated. This especially holds true for high occupancy density spaces.

Water is Neither Created Nor Destroyed Spontaneously

Attendees

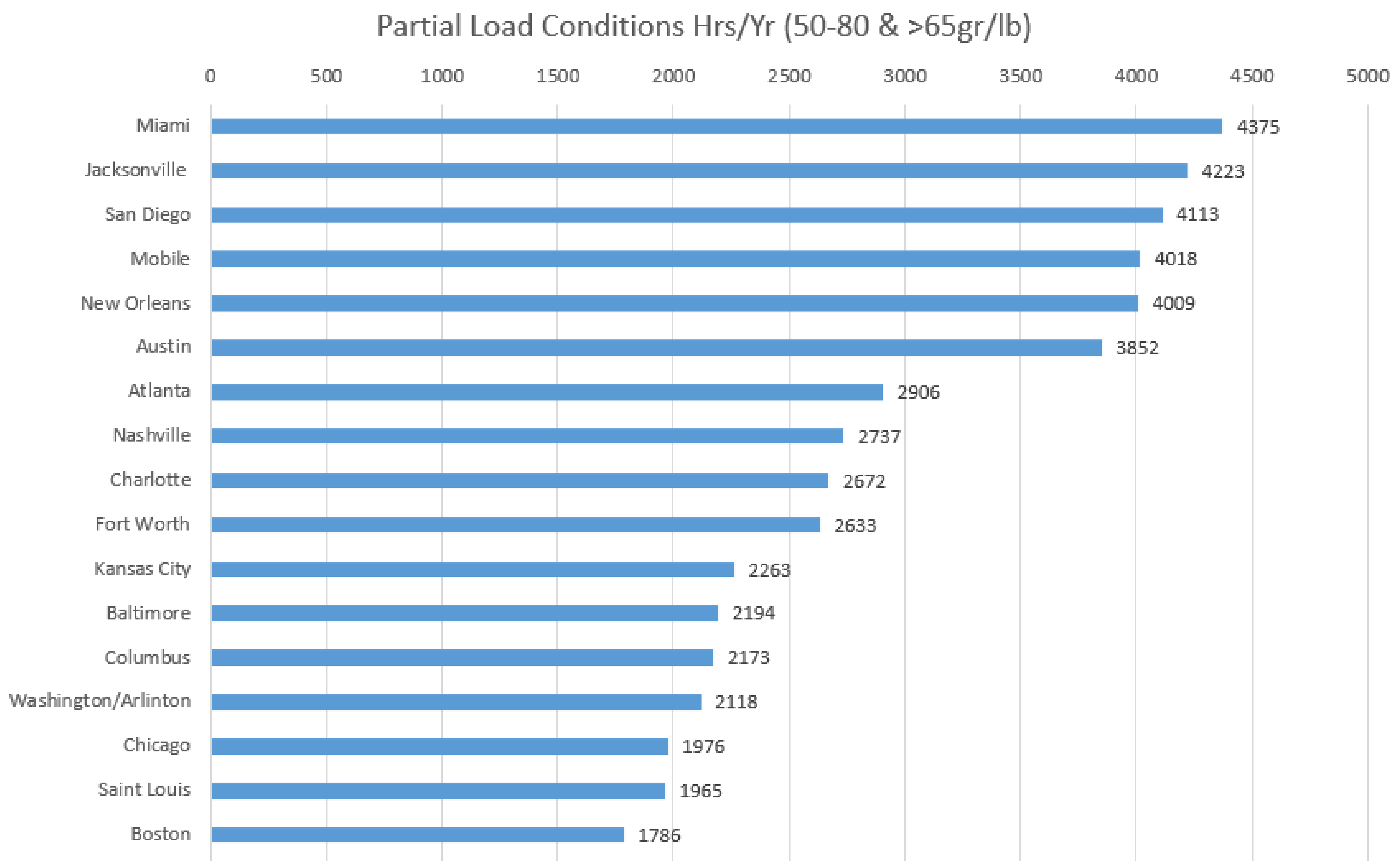
Why are latent loads a bigger challenge in PH buildings?

1	2	3

Why are latent loads a bigger challenge in PH buildings?

1	2	3
Ventilation Loads	Lower Sensible Loads	Equipment Latent Capacity

Partial Loads are Frequent



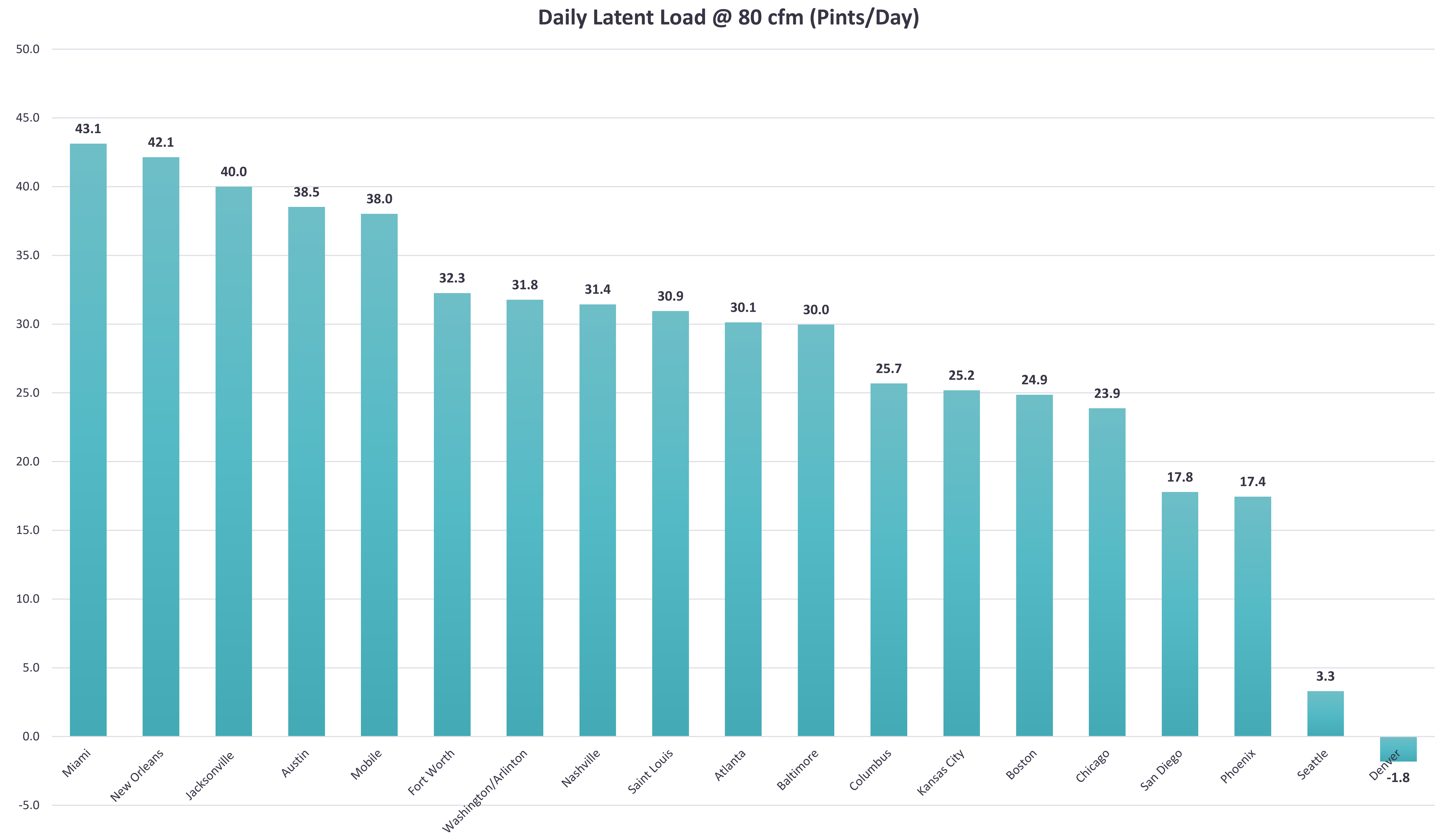
Partial Load Conditions
Occur in Spring, Fall and mild Summer days/evenings.

Temperatures are warm but not hot and humidity is often high.

Sensible loads are low
Humidity loads are high

75F and 50% RH= 65 grains/lb

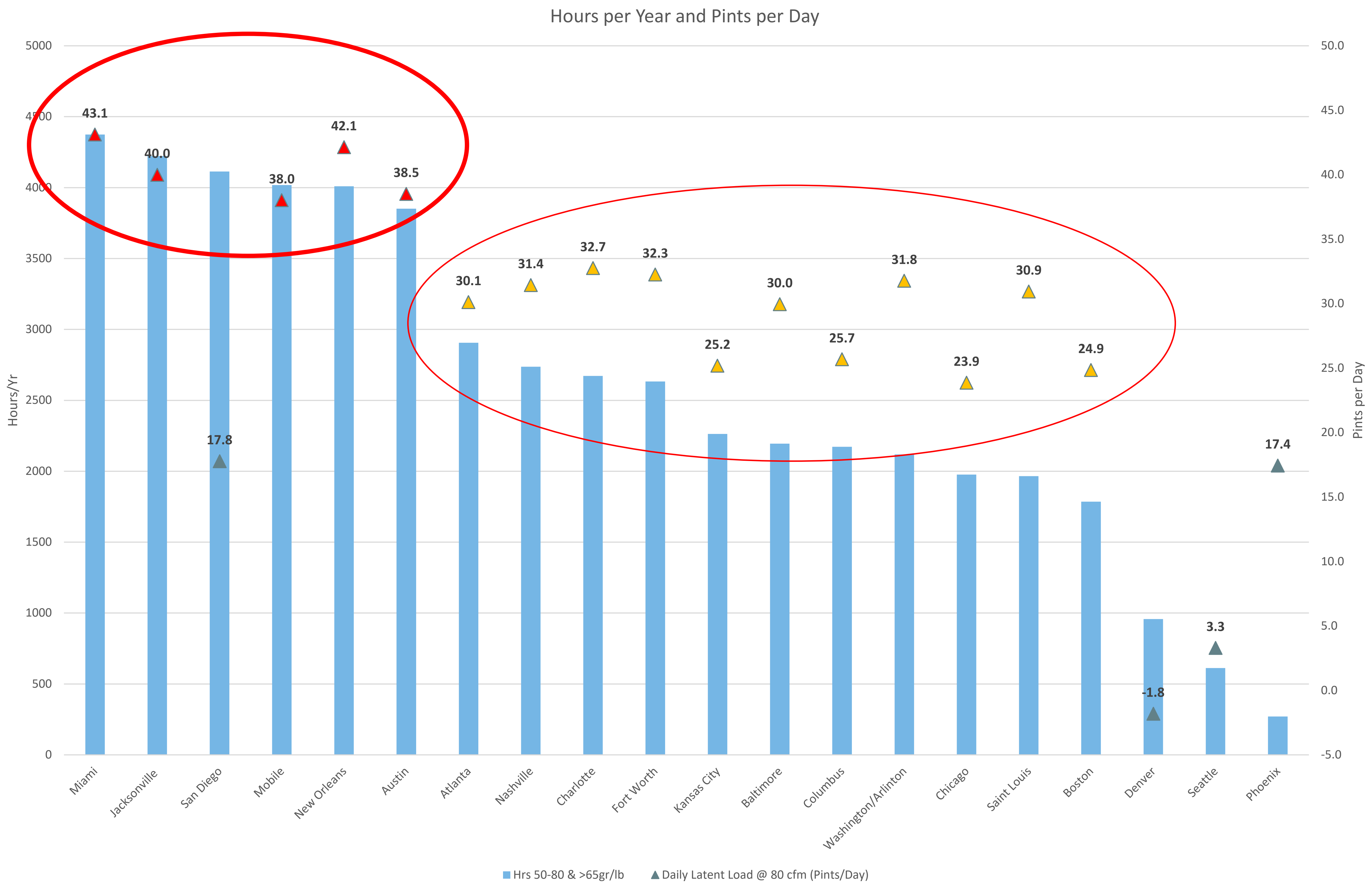
Ventilation Latent Loads @80 cfm



80 cfm, splitting the difference for >4 story multi-family building.

Phius CORE Ventilation Requirements			
Single or Multi-family <4		Exhaust*	Supply**
# Bedrms (Nbr)	# Baths	Design cfm	Design cfm
1	1	45	30
2	1	45	45
2	2	65	45
3	2	65	60
Multi-family >4 floors		Exhaust***	Supply**
# Bedrms (Nbr)	# Baths	Design cfm	Design cfm
1	1	70	30
2	1	70	45
2	2	90	45
3	2	90	45

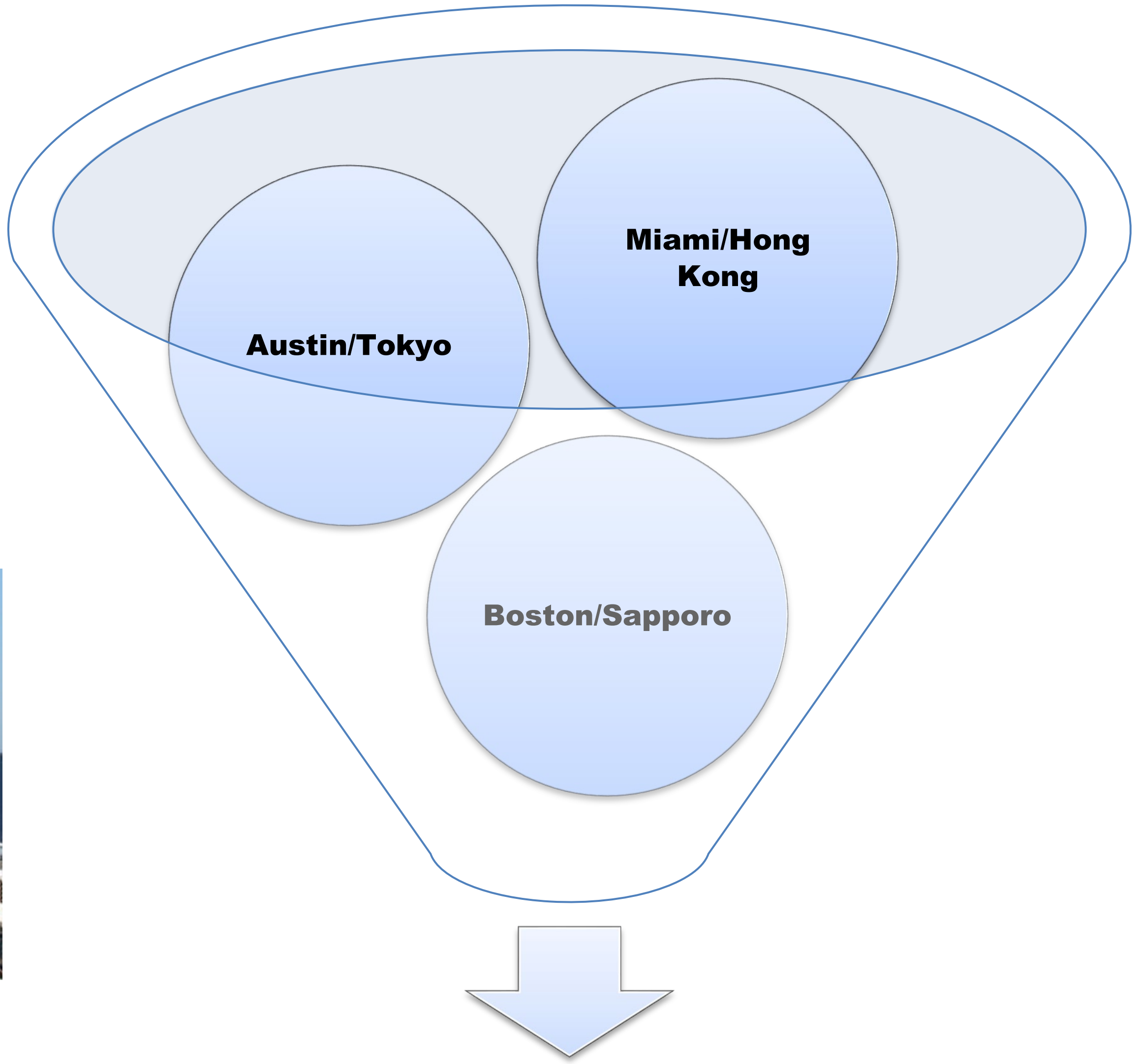
Frequency and Amount of Load @80 cfm



High Performing Envelopes

TOKYO

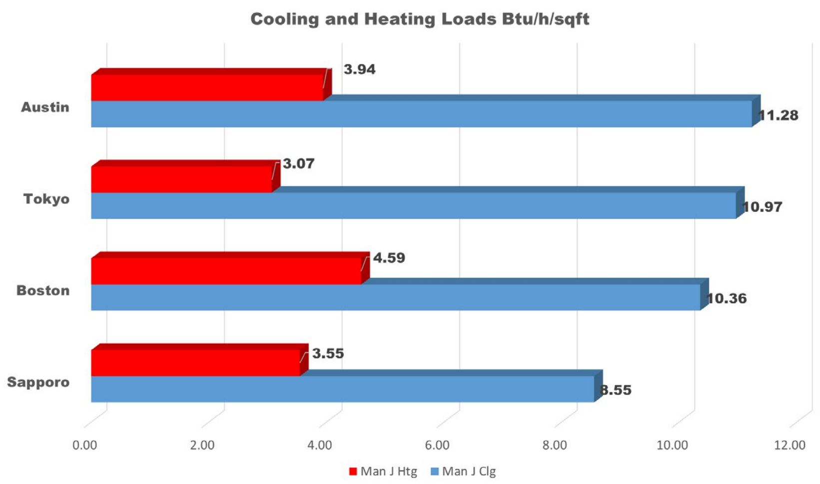
SAPPORO



Load Convergence
Across Climate Zones

AUSTIN

BOSTON



Sayo Okada,
AIA, CPHC

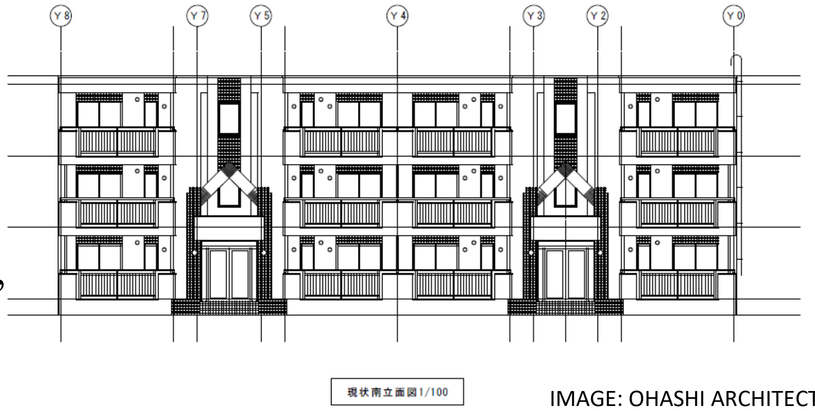
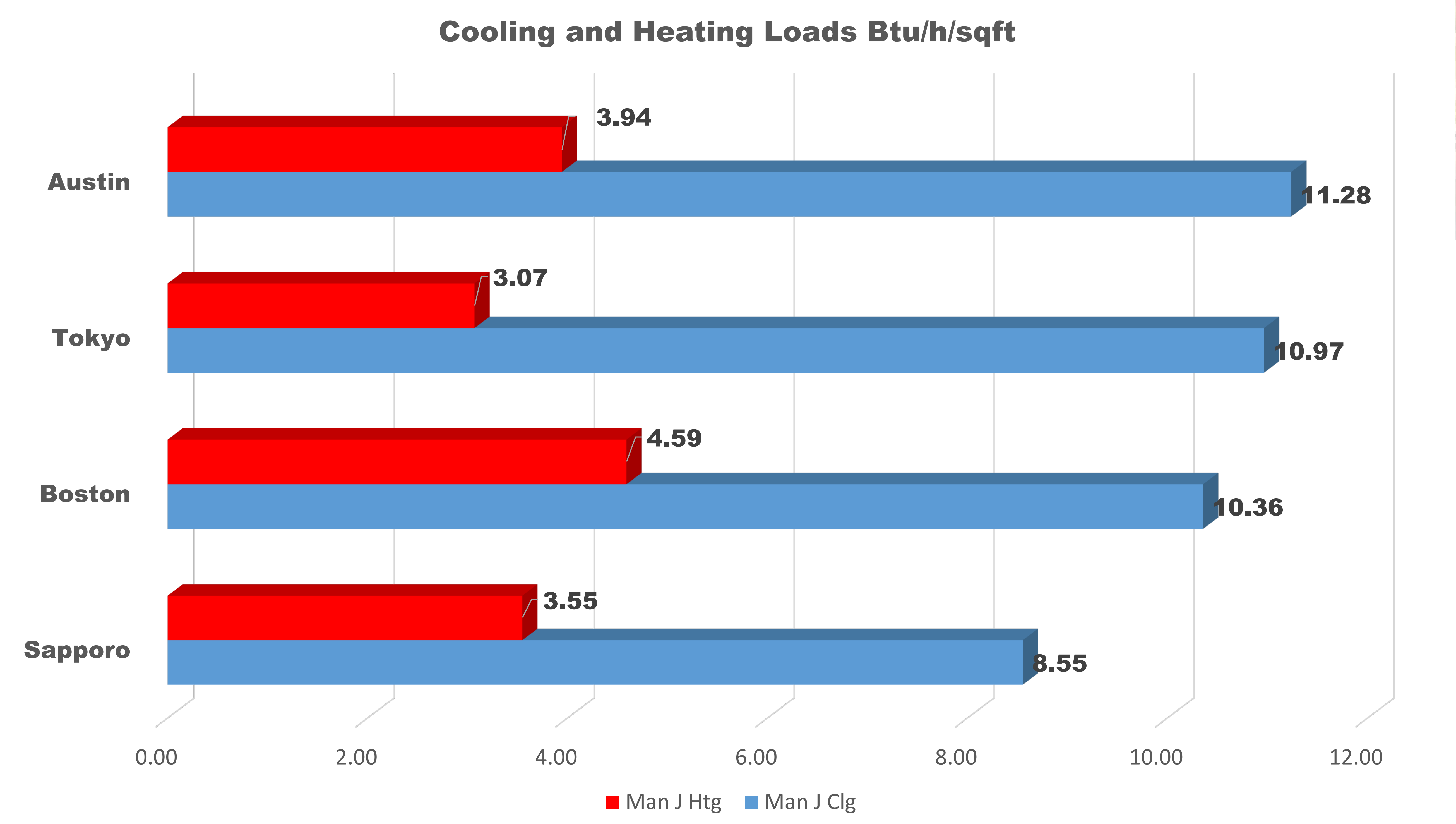
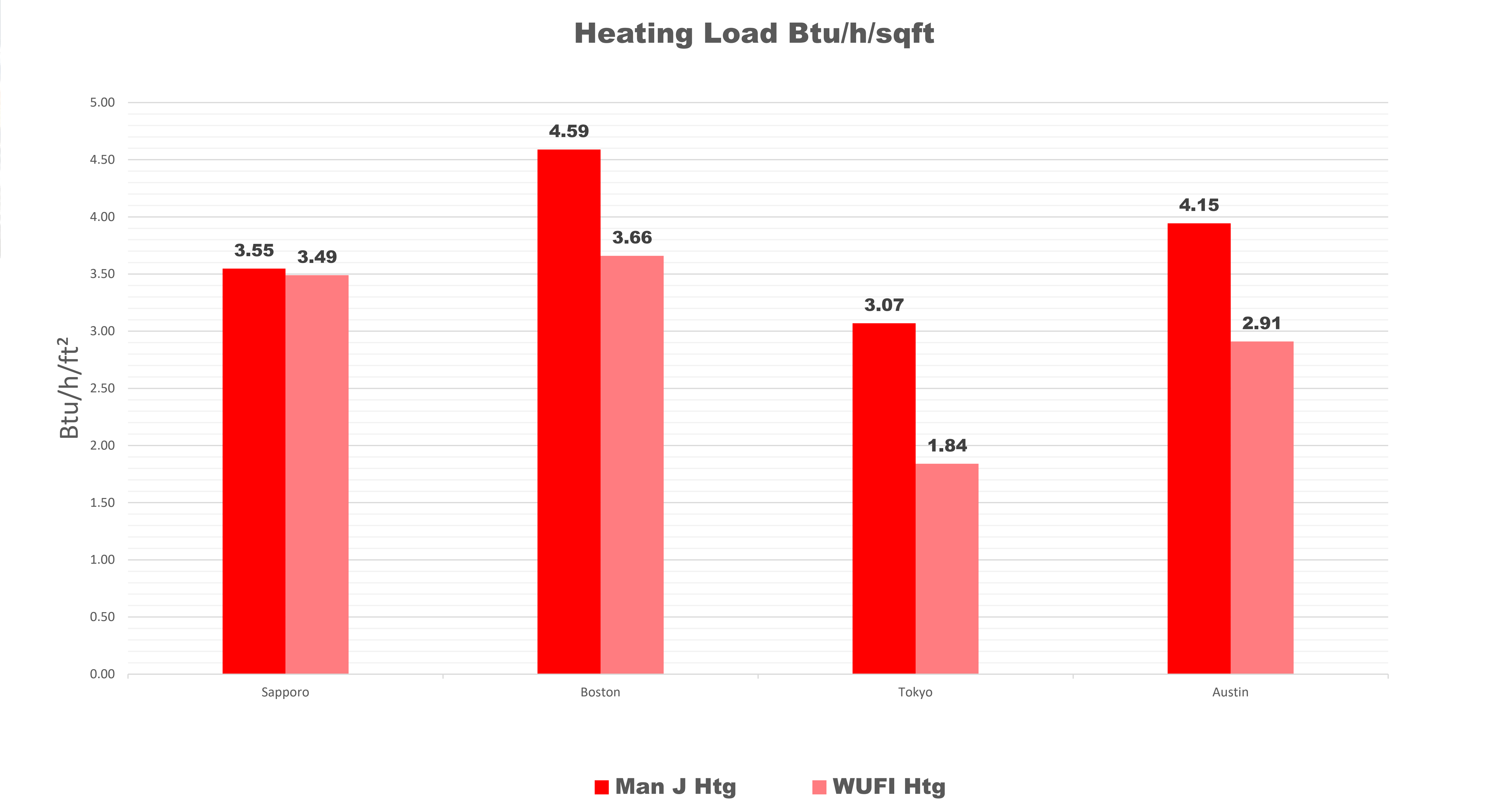


IMAGE: OHASHI ARCHITECTURE OFFICE
□ □ □ □ □ □ □ □ □ □

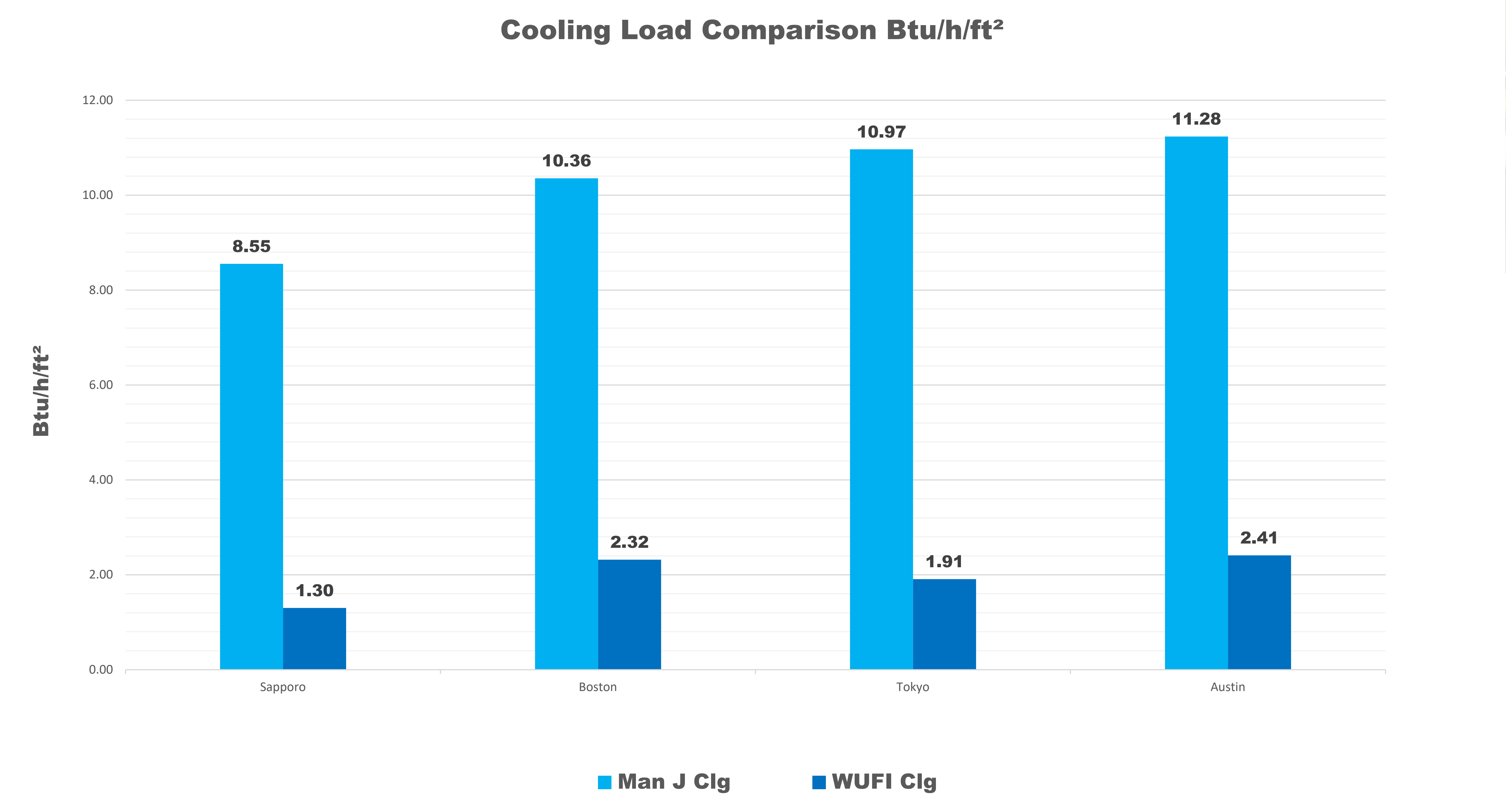
Building Load Totals



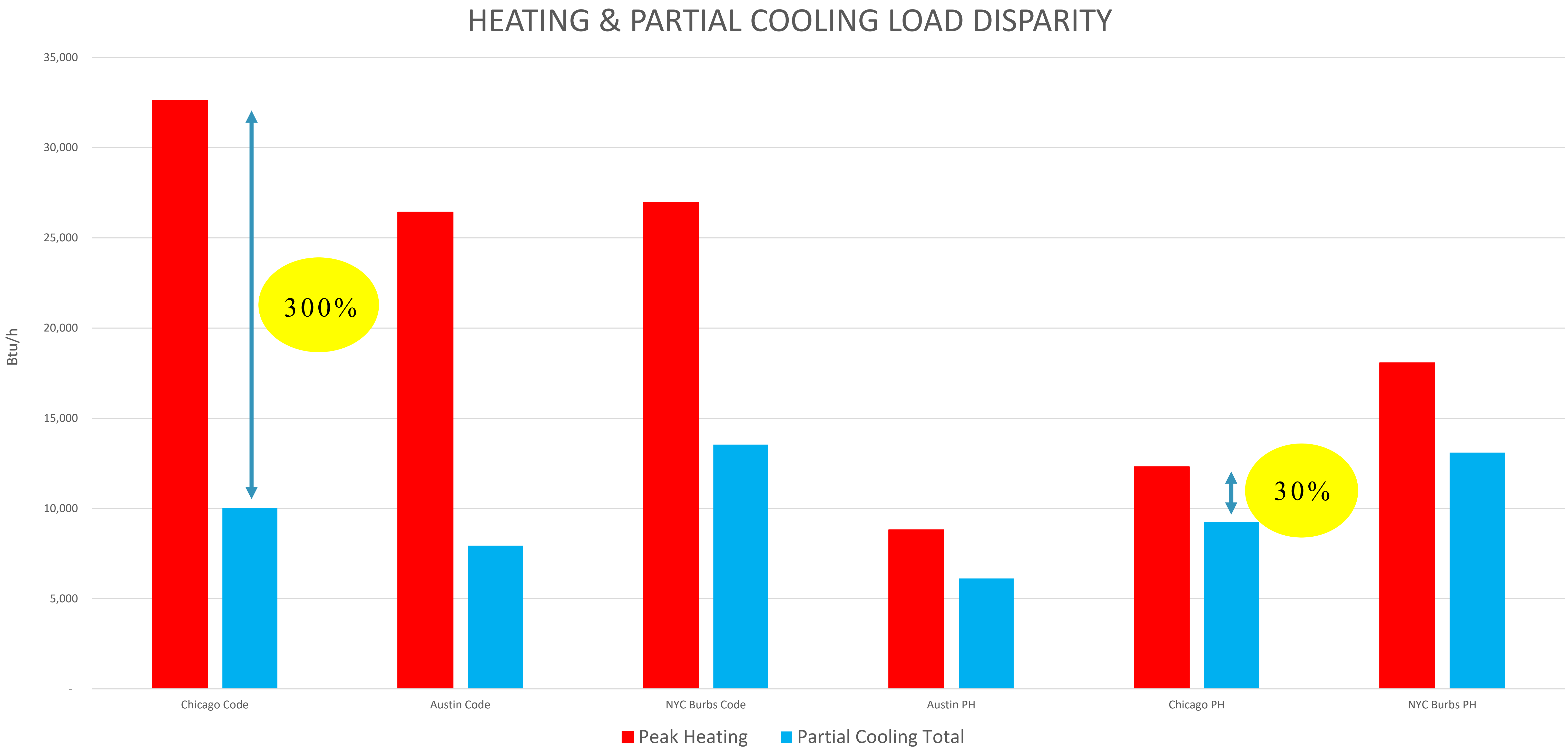
WUFI vs Man J Load Comparison



WUFI vs Man J Load Comparison



Less Δ Between Heating and Cooling Loads

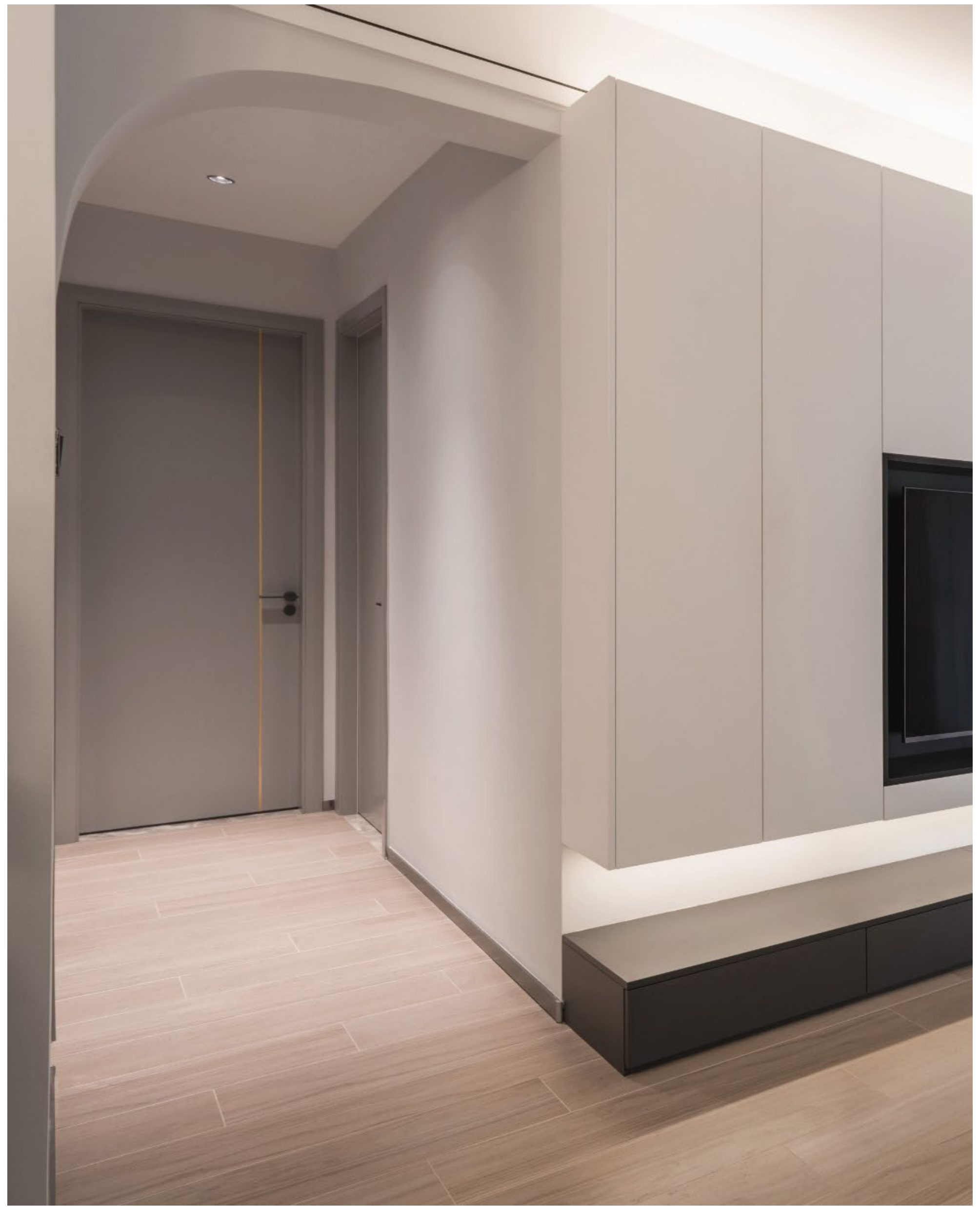


Inputs Impacting Loads

Load Input	Default Might Be…	Problem
Window Specs- SHGC	0.39 for CZ 5A 90.1-2022 for 10-40% window-wall	Even cold climate projects with low sensible loads, higher occupancy density, little to no shading need lower SHGC
Occupancy	Fire Code Prescribed	
Schedules	Based on Max Use, Worst Case or Your Last Project	
Ventilation Rates	2-3 times higher than necessary	
Internal Loads	Office 90.1-2022 1.1 W/ft^2	

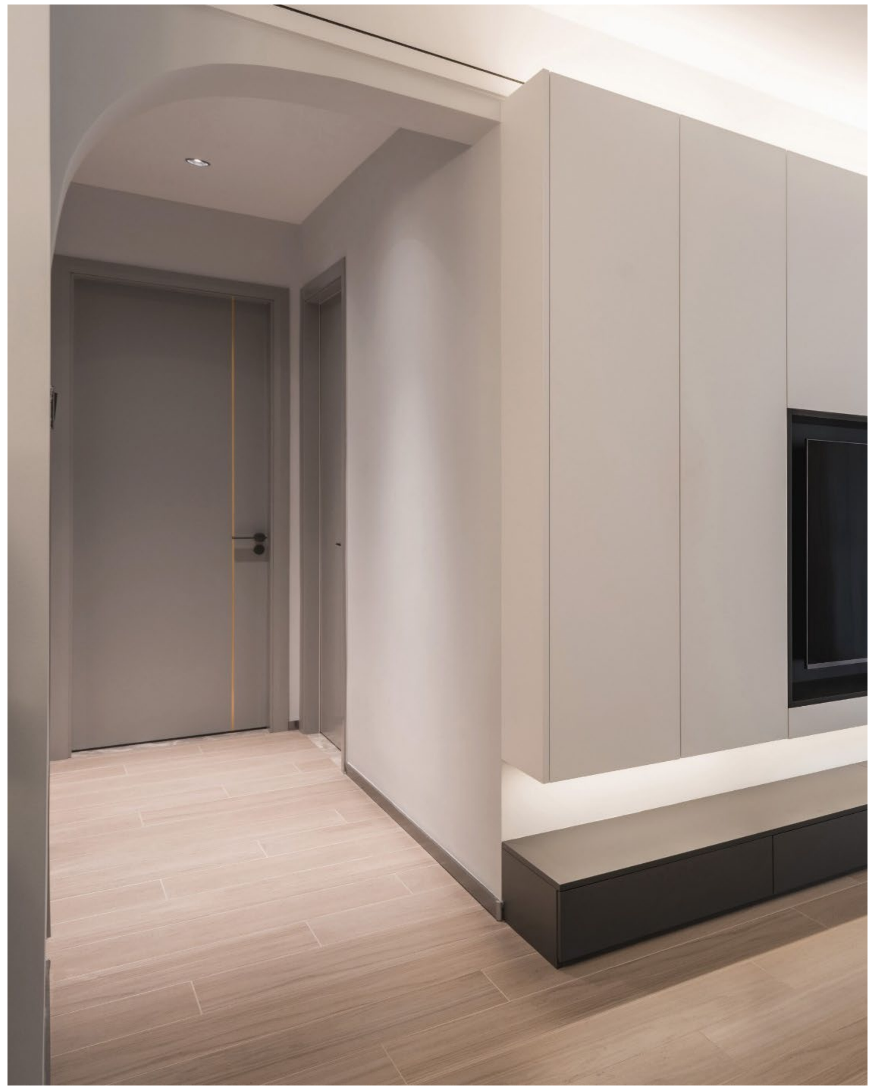
Check with Galen and James for an EIS or e+ multi-family load

I LOVE Magic Tricks But…



Unless your ERV has a Recirculation mode that is operating on demand not just for defrost, they do not move conditioned air into rooms with closed doors. This can be a BIG comfort problem in bedrooms and especially in humid climates.

Heat Recovery VRF Systems...



Might be the right choice for your project. For example, when you have applications where it is required to have centralized systems that can provide heating and cooling at the same time. However, this is comfort choice NOT an efficiency choice. It is important to commission operating parameters to limit certain modes of operation as much as possible in partial load conditions.

DISCUSSION/ QUESTIONS

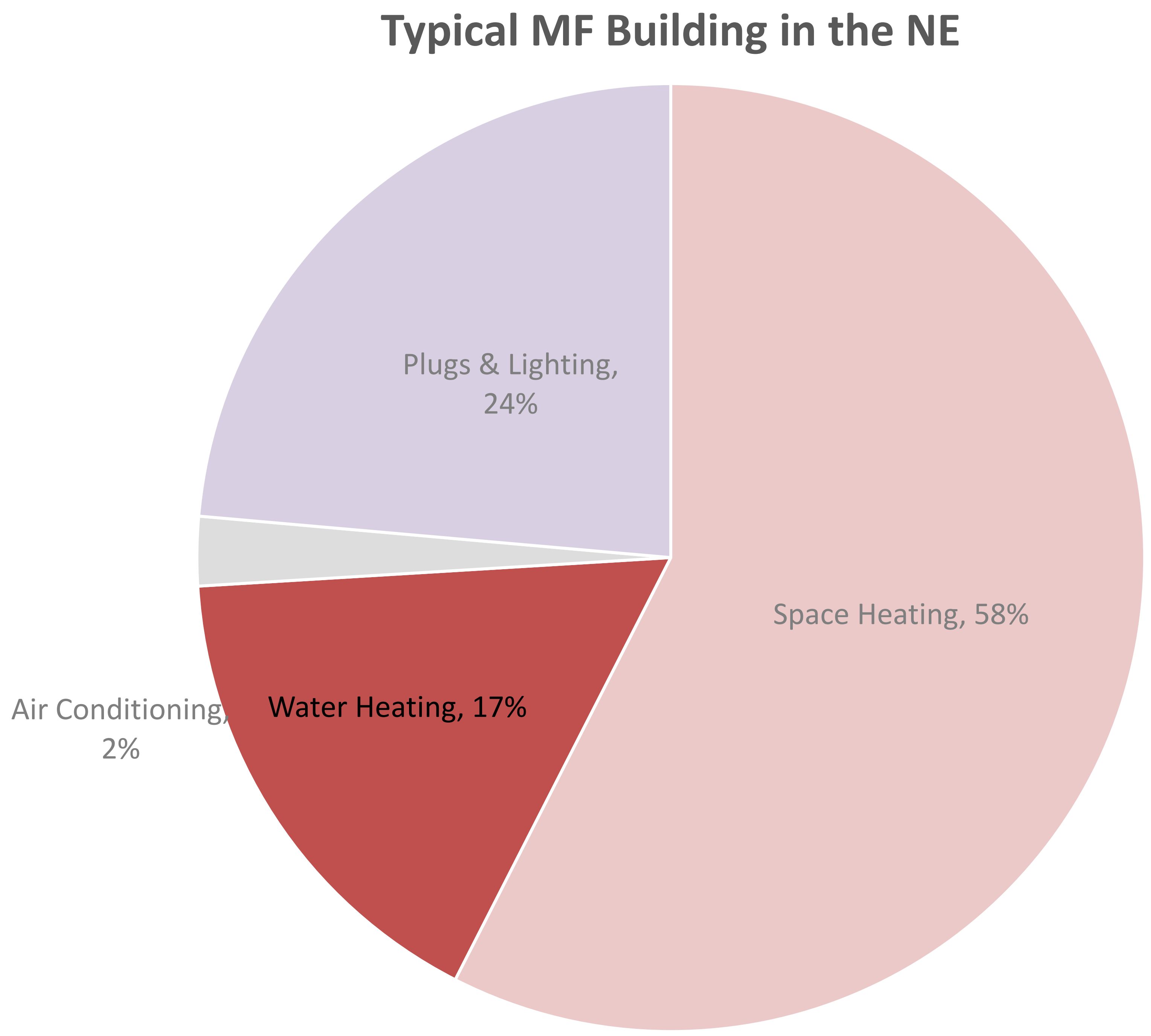
DHW Phius Basics

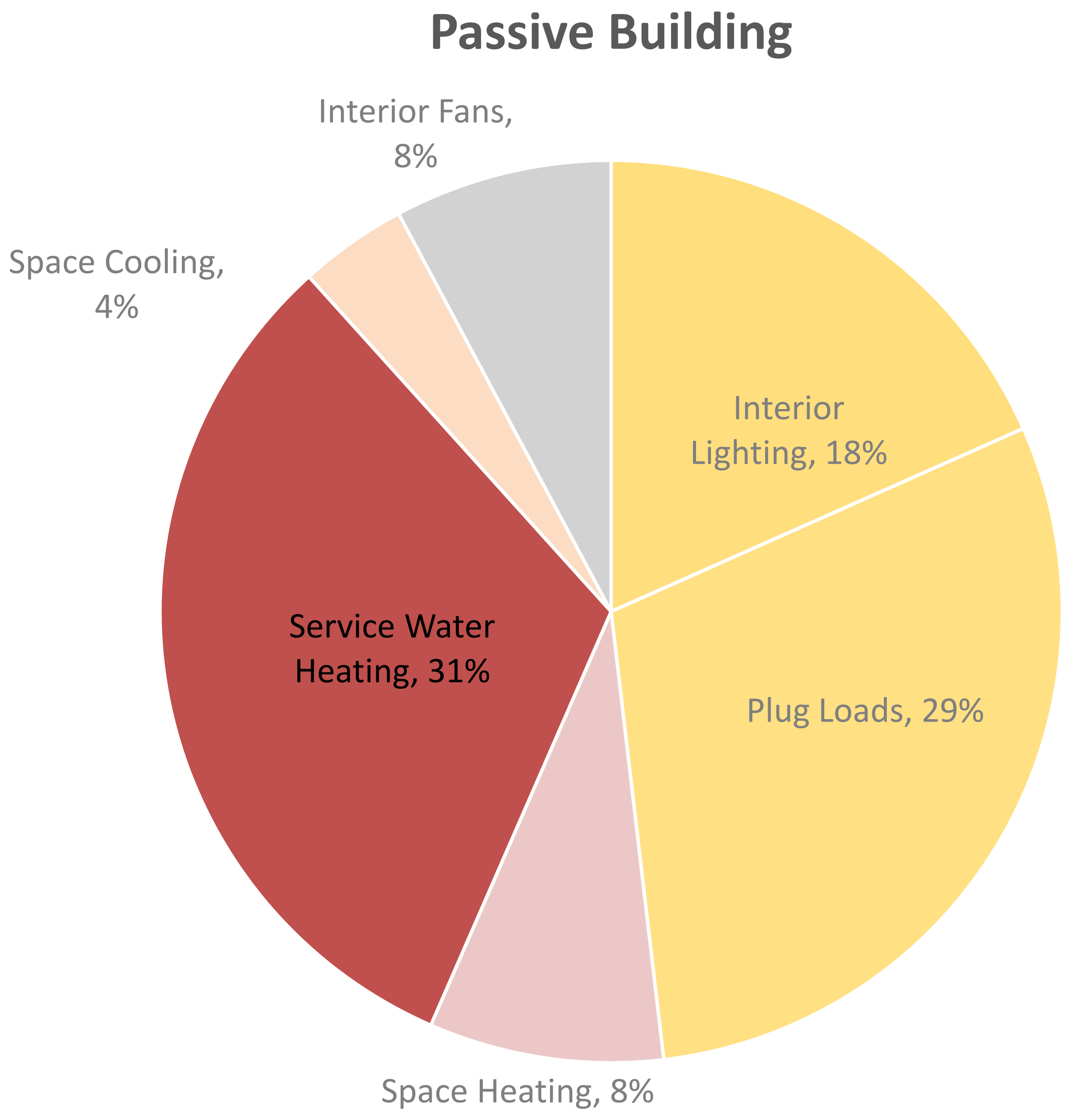
Hot Water in Multi-Family

Agenda

1. Is Hot Water Heating Energy a Big Deal?
2. Heating Energy, Recirculation Energy, and Parasitic Loads
3. Multi-Family Heat Pump Strategies – Central vs. Distributed
4. Sizing and Piping Network Design Considerations
5. Heat Recovery Opportunities

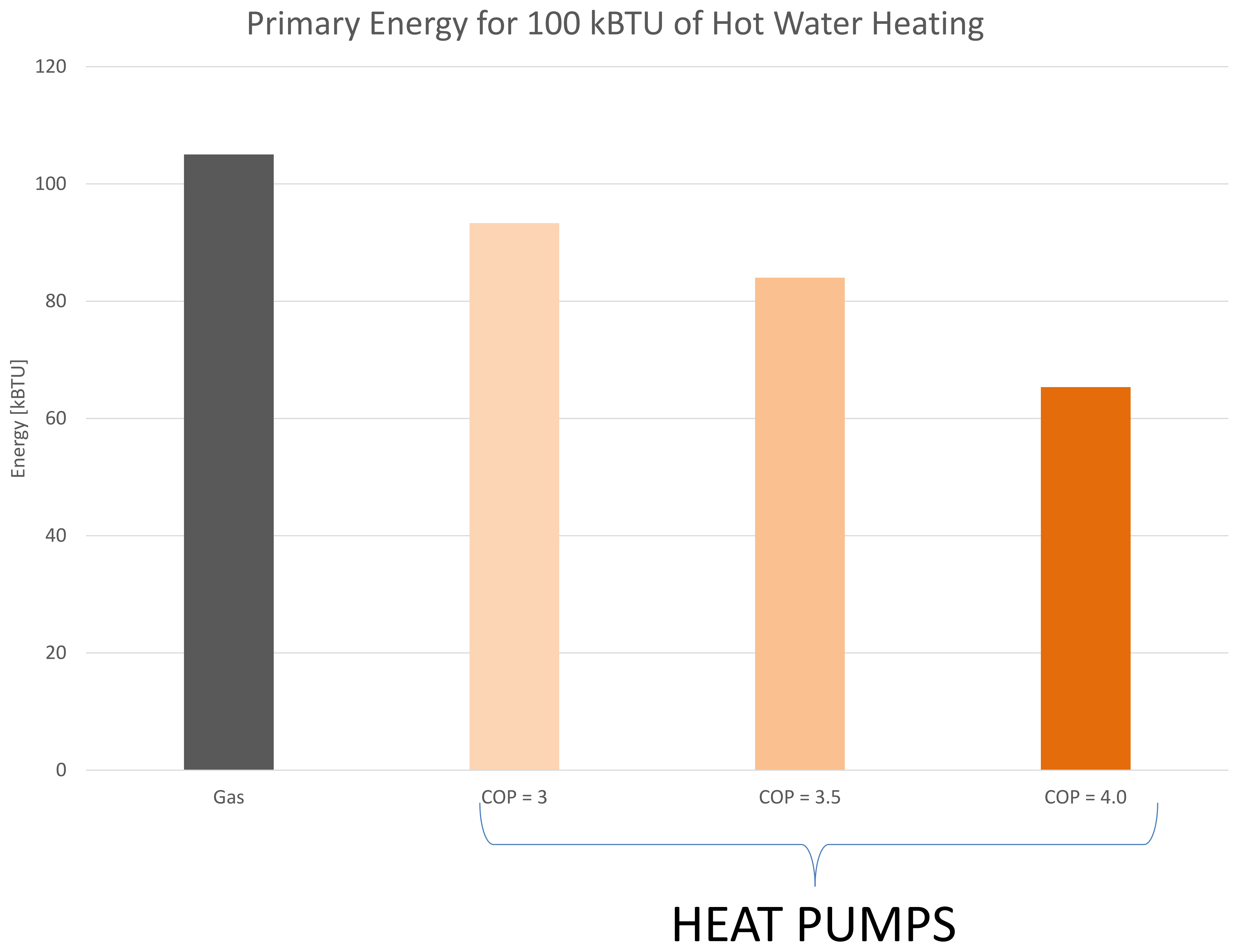
Hot Water in Multi-Family in the North East





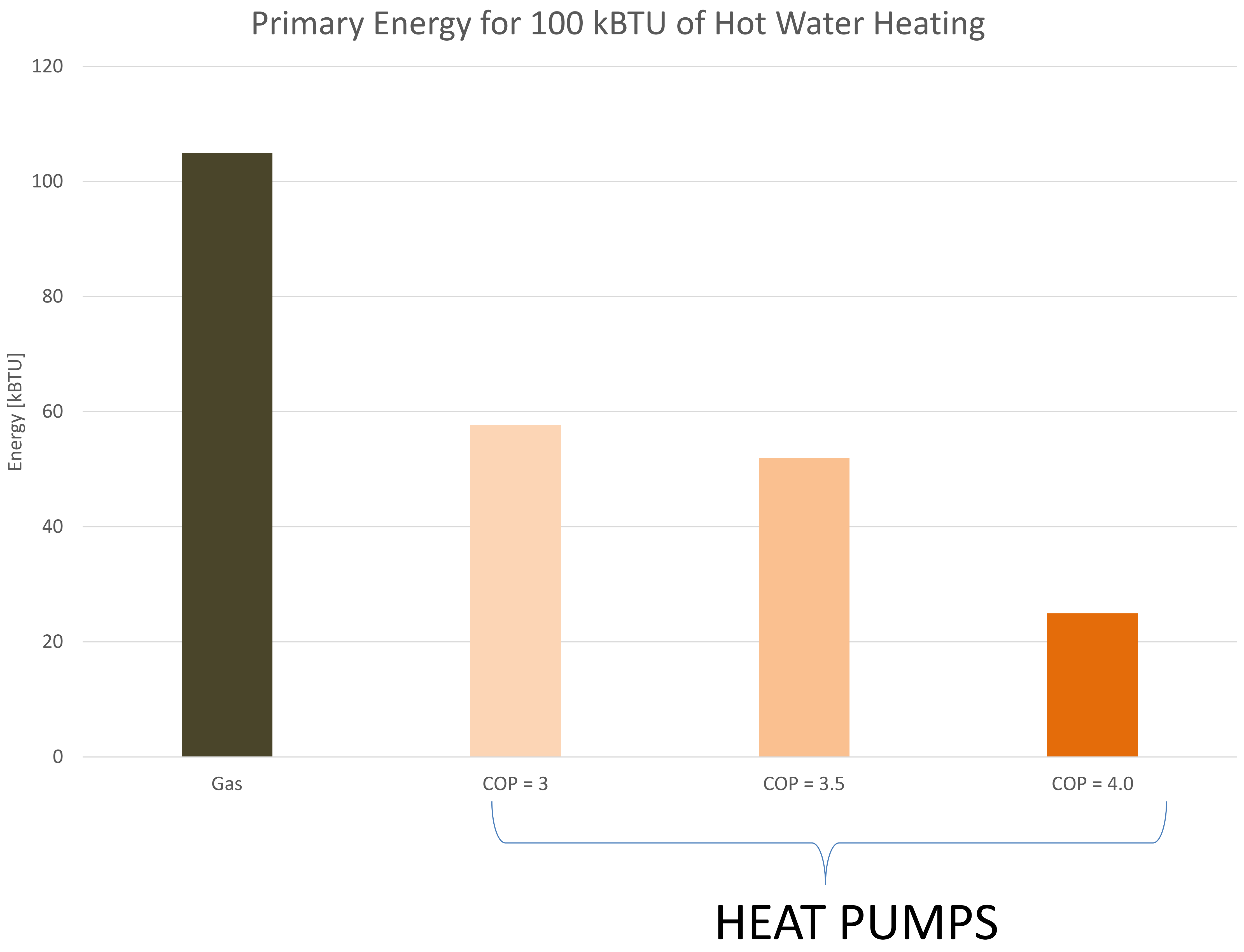
Does Heating DHW with Heat Pumps Reduce Carbon?

- Gas Primary Energy Factor = 1.05
- Electricity Primary Energy Factor = 2.8

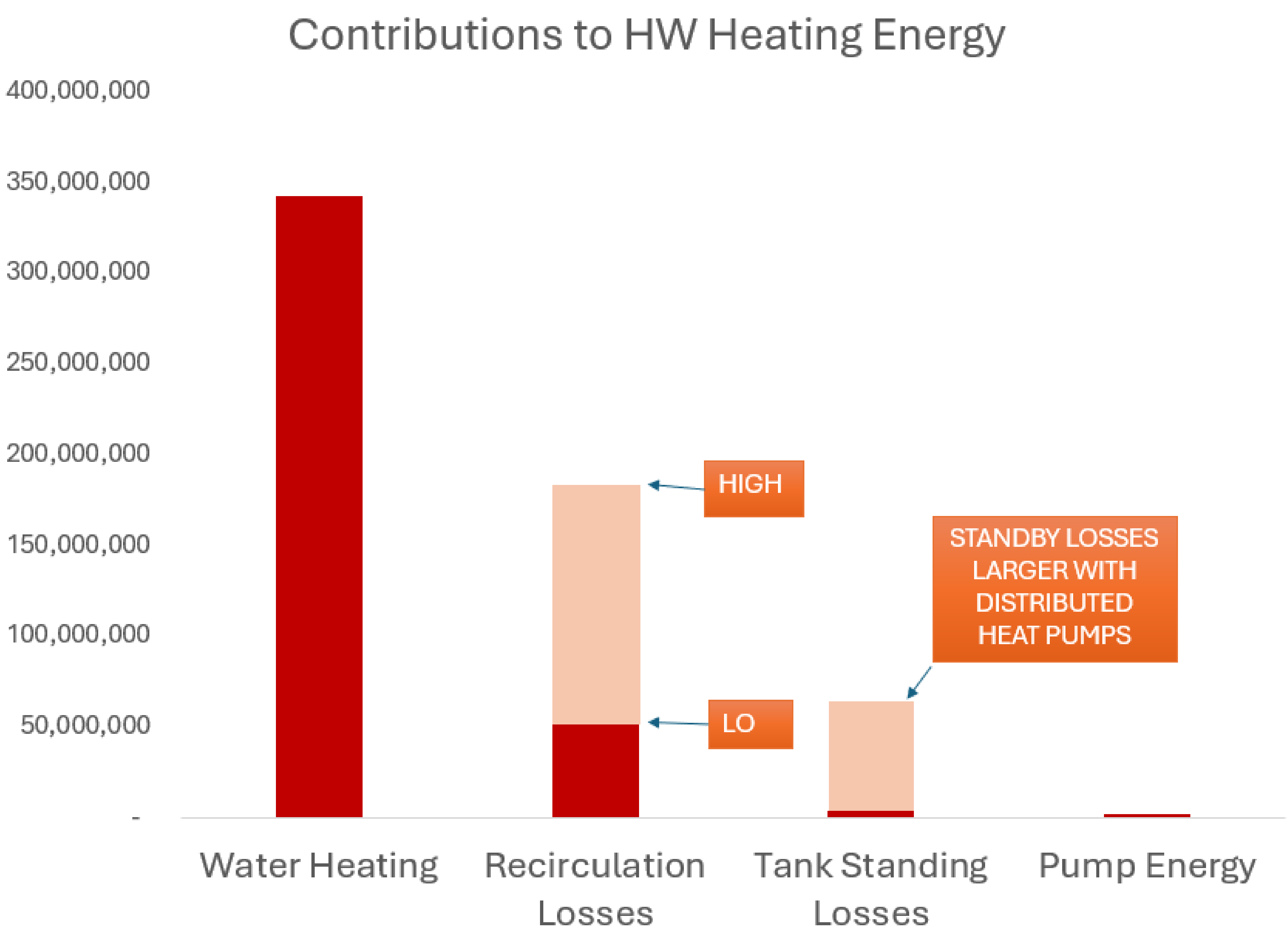


Does Heating DHW with Heat Pumps Reduce Carbon?

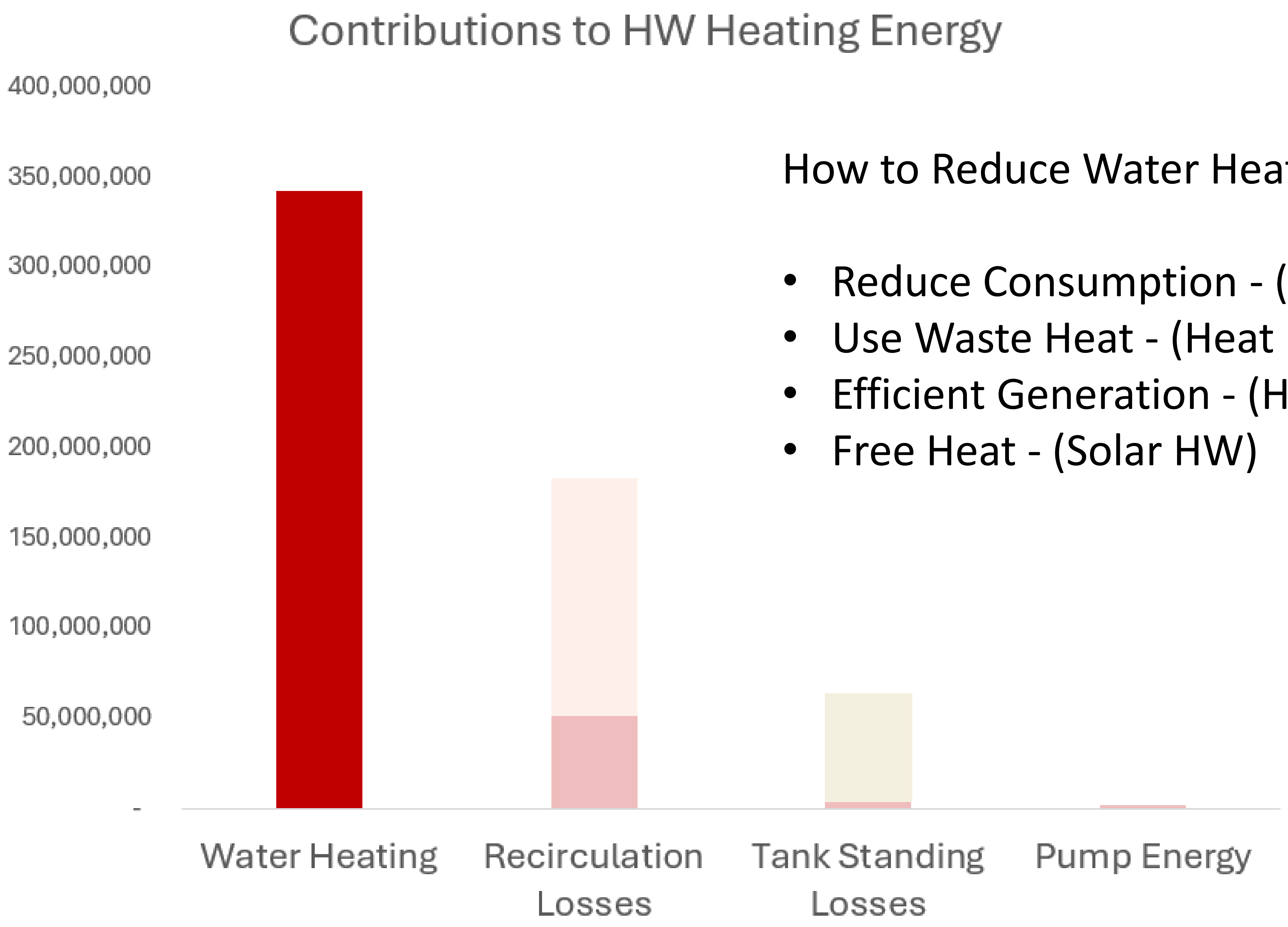
- Gas Primary Energy Factor = 1.05
- Electricity Primary Energy Factor = 1.73



2050 Comparison – Cleaner Grid

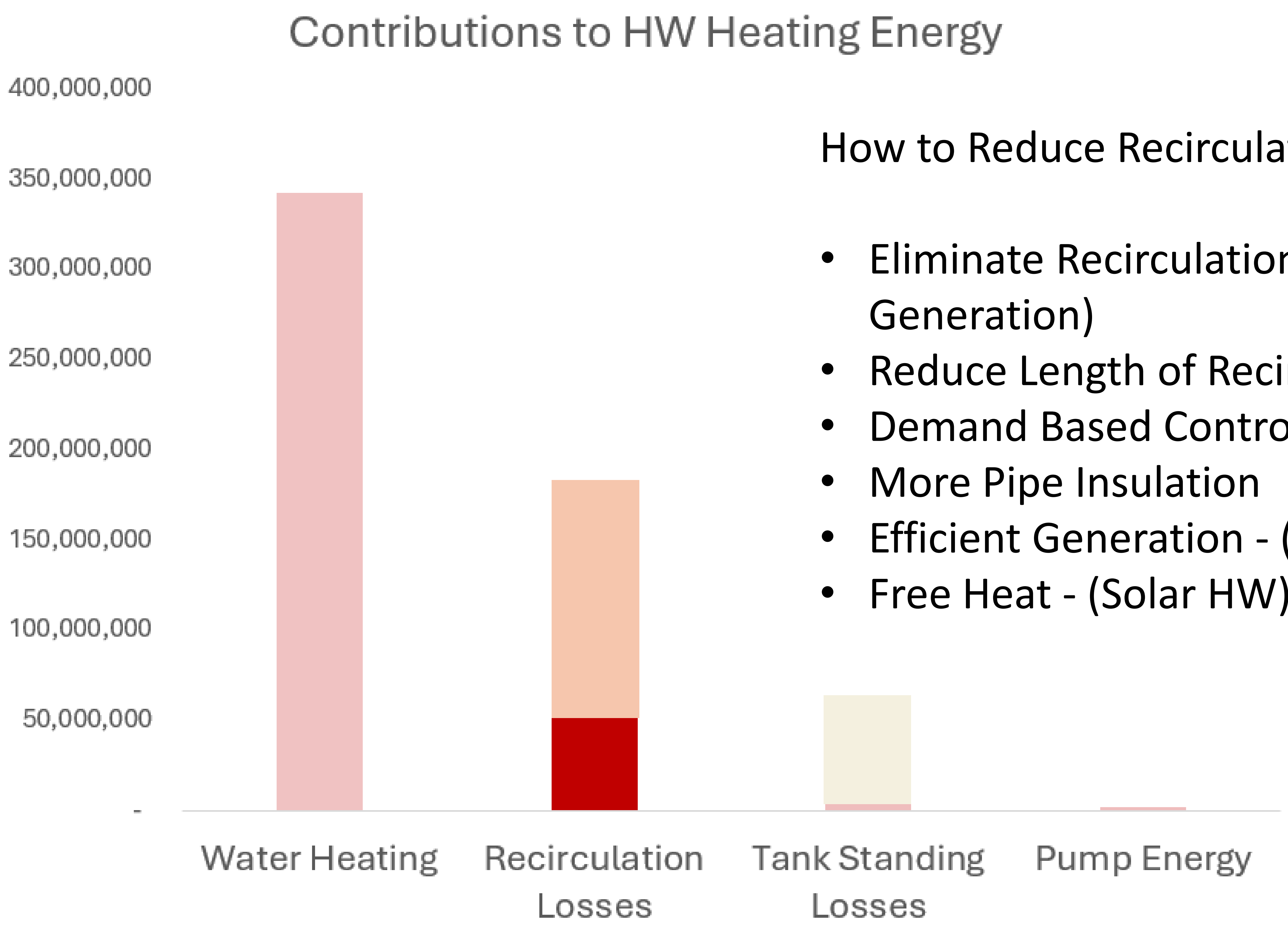


Contributions to HW Heating Energy
400,000,000
350,000,000
300,000,000
250,000,000
200,000,000
150,000,000
100,000,000
50,000,000
-
HIGH
LO
STANDBY LOSSES LARGER WITH DISTRIBUTED HEAT PUMPS
Water Heating
Recirculation Losses
Tank Standing Losses
Pump Energy



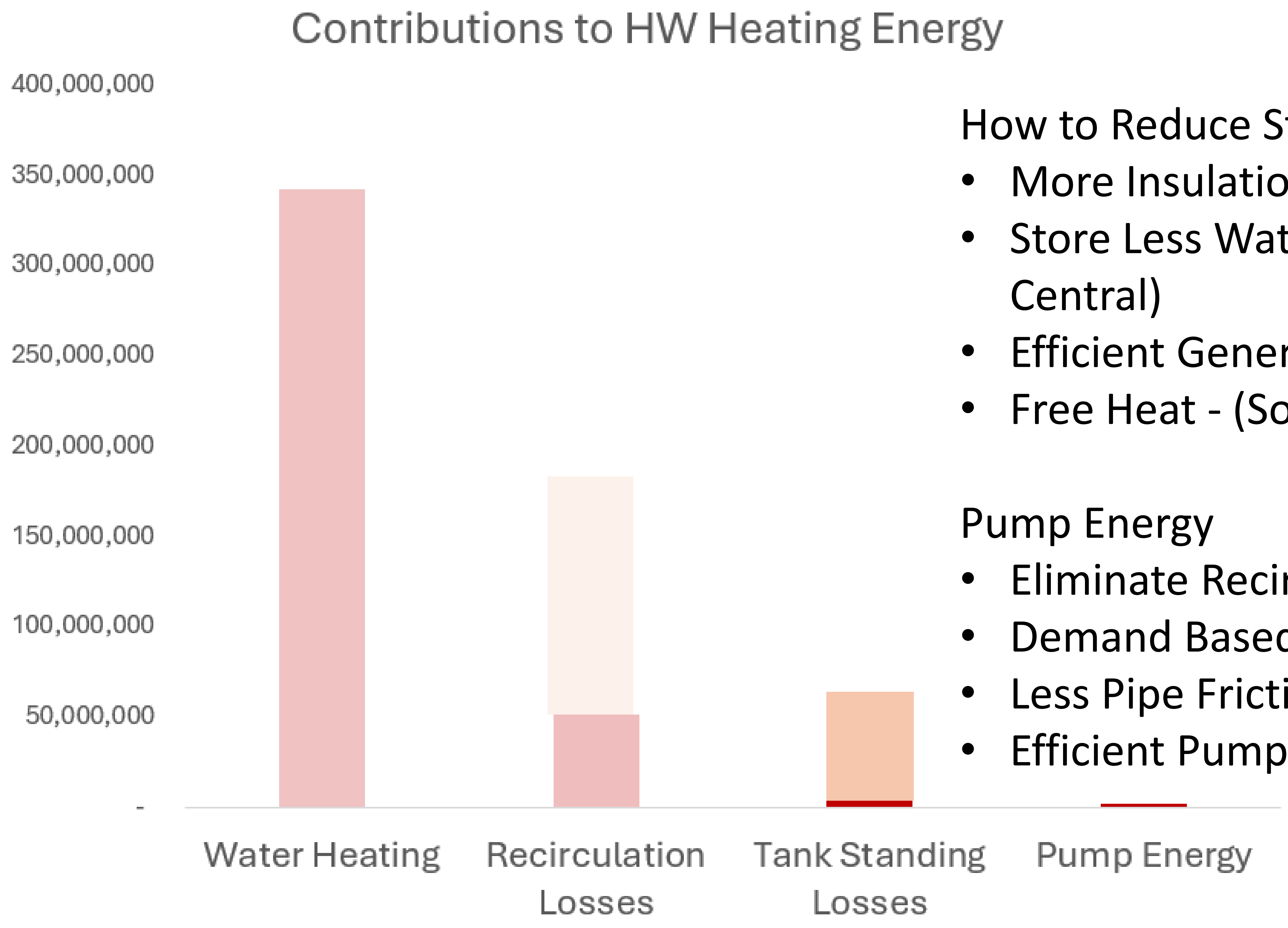
How to Reduce Water Heating Energy:

- Reduce Consumption - (Low flow)
- Use Waste Heat - (Heat Recovery)
- Efficient Generation - (Heat Pumps)
- Free Heat - (Solar HW)



How to Reduce Recirculation Losses:

- Eliminate Recirculation - (Distributed Generation)
- Reduce Length of Recirculation - (Layout)
- Demand Based Controls
- More Pipe Insulation
- Efficient Generation - (Heat Pumps)
- Free Heat - (Solar HW)



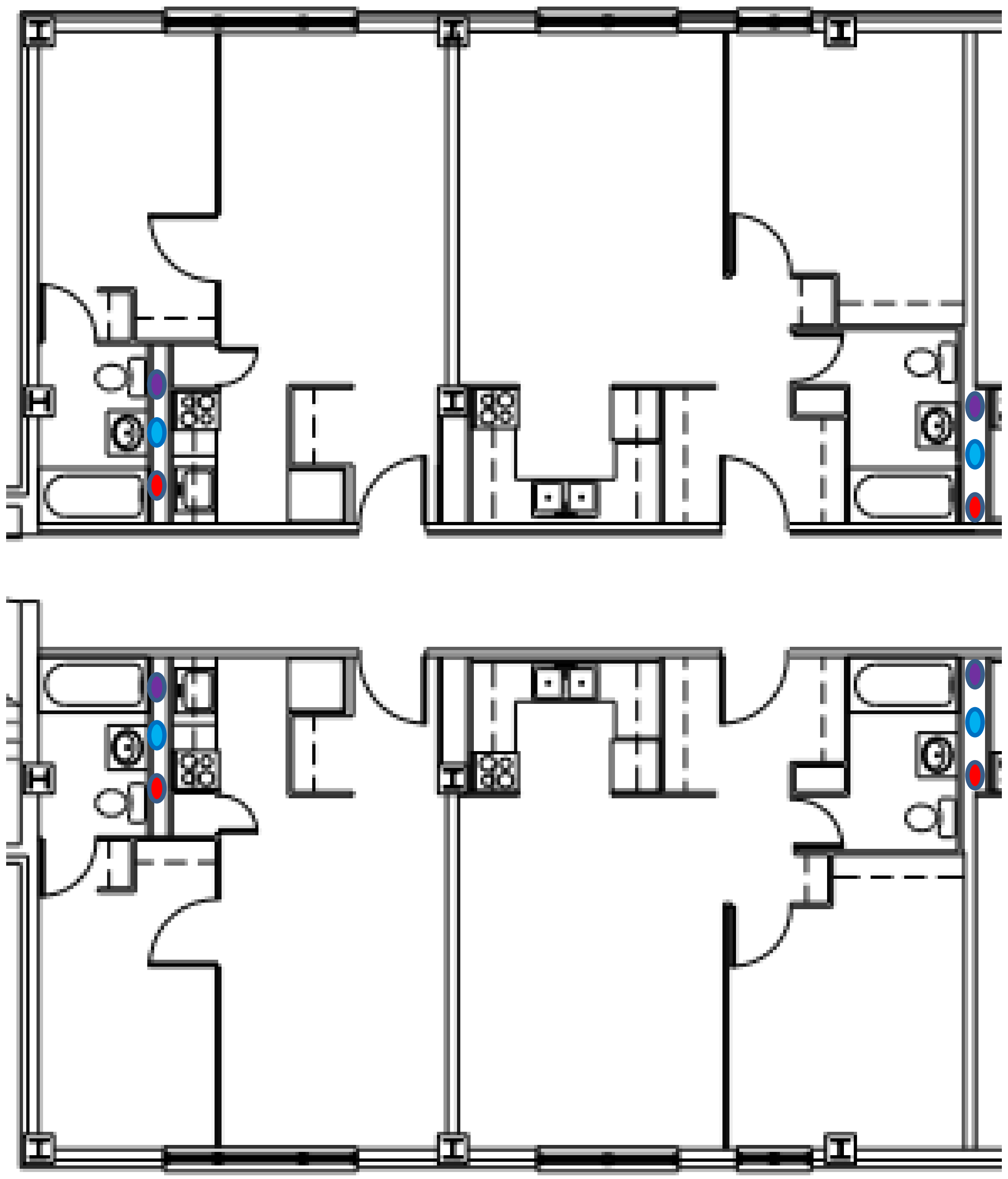
How to Reduce Standing:

- More Insulation
- Store Less Water - (Central or Semi-Central)
- Efficient Generation - (Heat Pumps)
- Free Heat - (Solar HW)

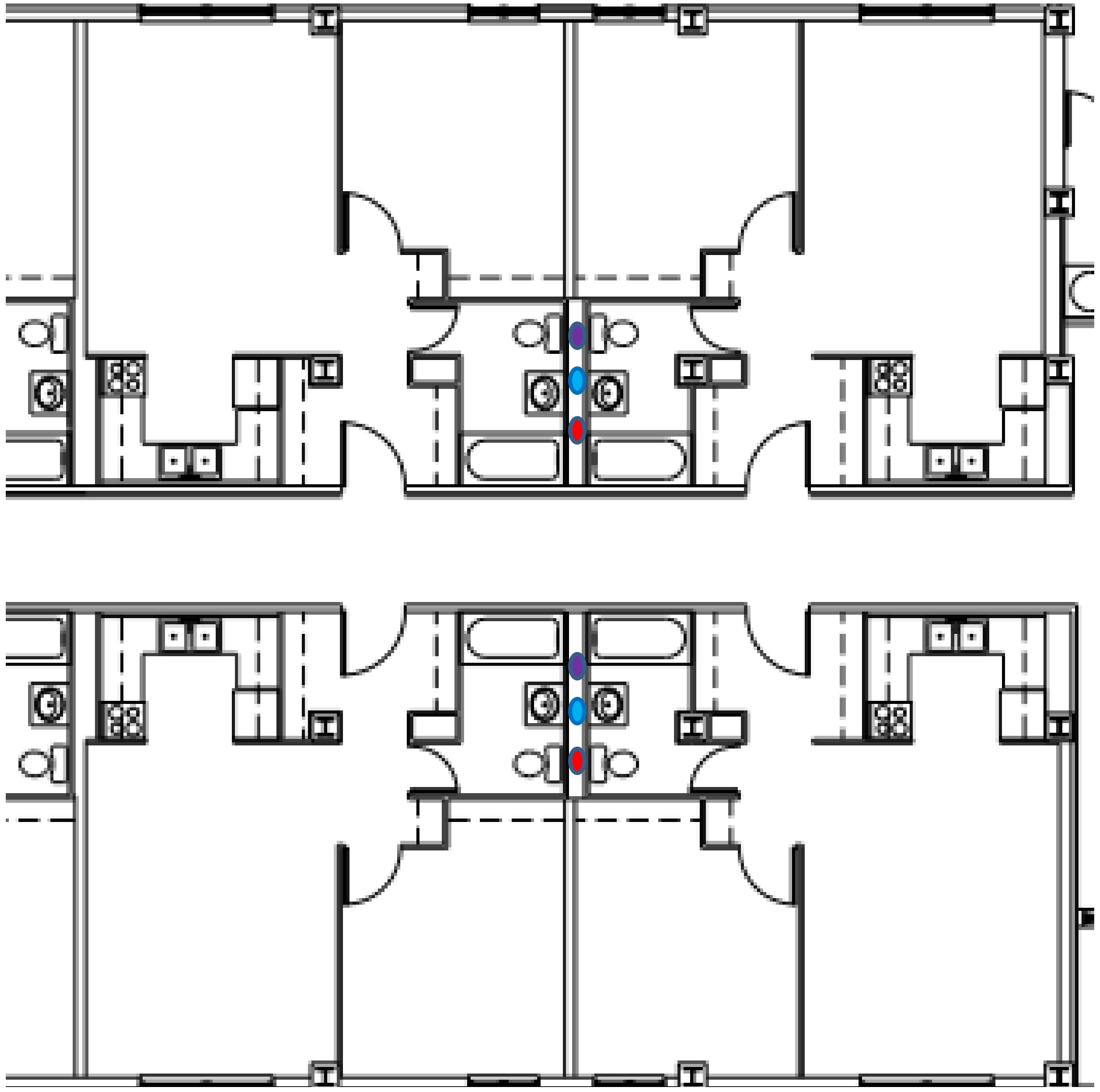
Pump Energy

- Eliminate Recirculation
- Demand Based Controls
- Less Pipe Friction
- Efficient Pumping

Smart Architectural Layout



2x DCW, DHW & SAN



Be Smart!

DHW Sizing | Actual Loads >40% Less

HW heaters are oversized based on outdated assumptions for fixture flow, and occupant diversity.

Example:

- 60 occupant apartment building
- Standard ASHRAE assumptions:
  - 210 gallons storage
  - 82,000 BTU/HR heater
- Adjusted for modern fixtures and Diversity:
  - 110 gallons storage
  - 41,000 BTU/HR heater

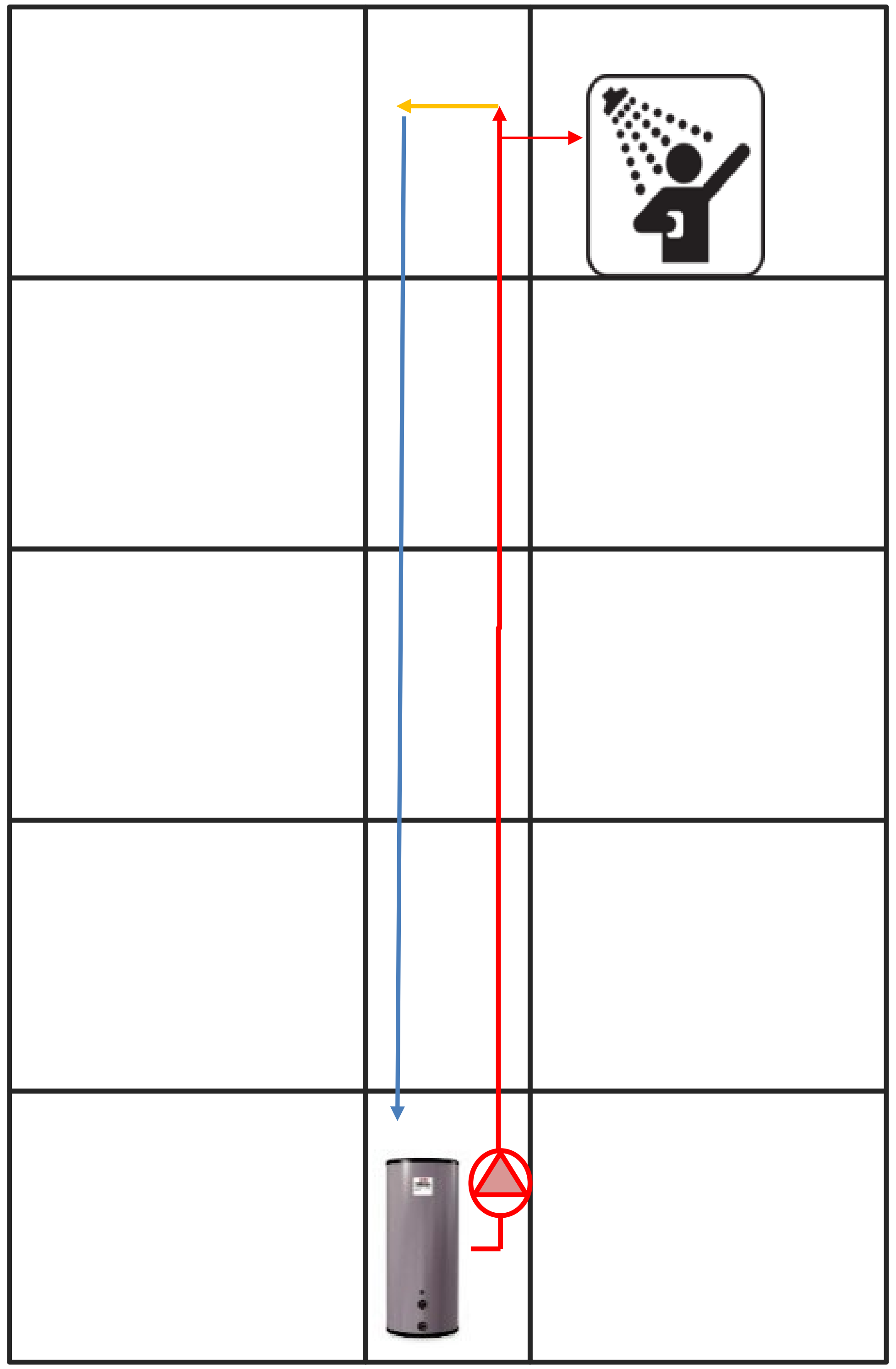
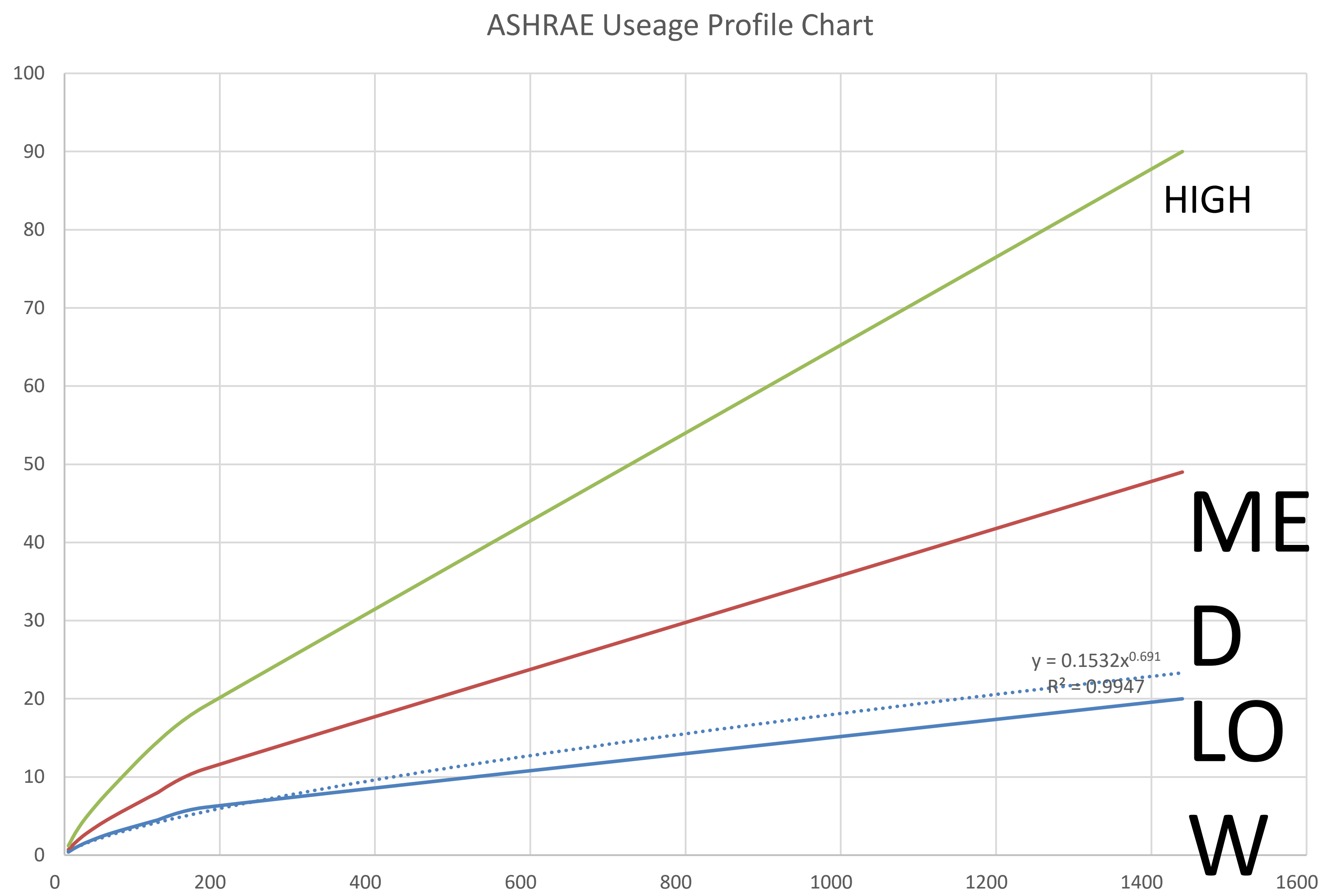


Table 1. Demographic Characteristics Correlation to DHW Consumption

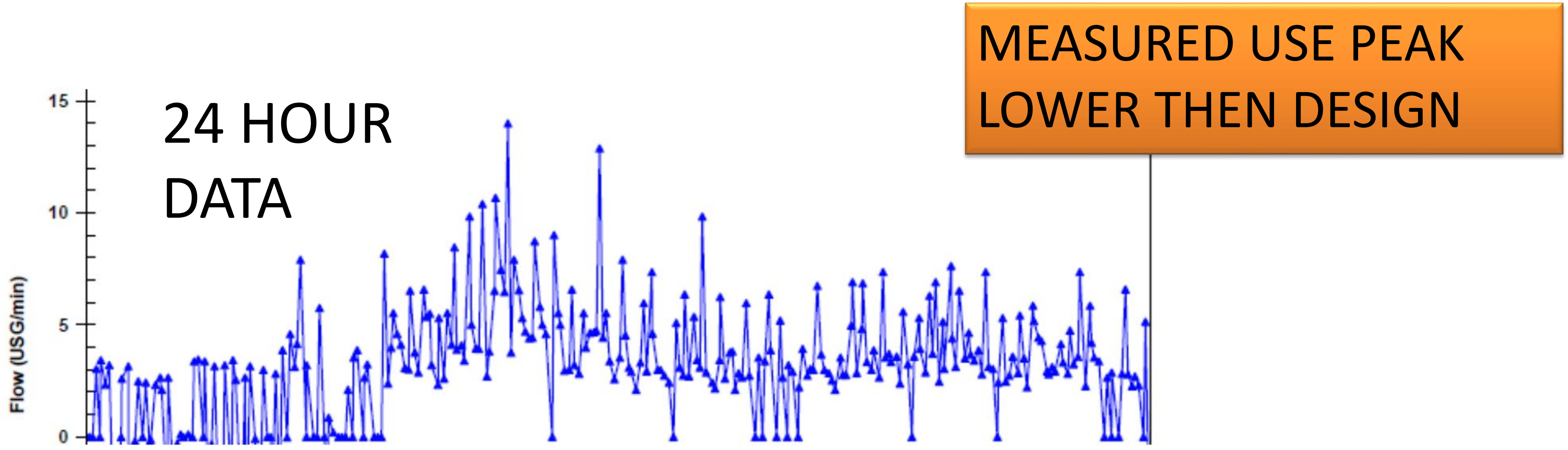
Demographic Characteristics	LMH Factor
No occupants work Public assistance & low income (mix) Family & 1 parent households (mix) High % of Children Low income	HIGH
Families Public assistance Singles 1 parent households	MEDIUM
Couples Higher population density Middle income Seniors One person works, 1 stays home All occupants work	LOW

Reprinted from: Goldner, F.S., and Price, D.C. - *Domestic Hot Water Loads, System Sizing and Selection for Multifamily Buildings*



Adapted from ASHRAE Handbook

HW Consumption
Measured Data



HW Consumption Study for 95 unit Senior Housing apartment building.

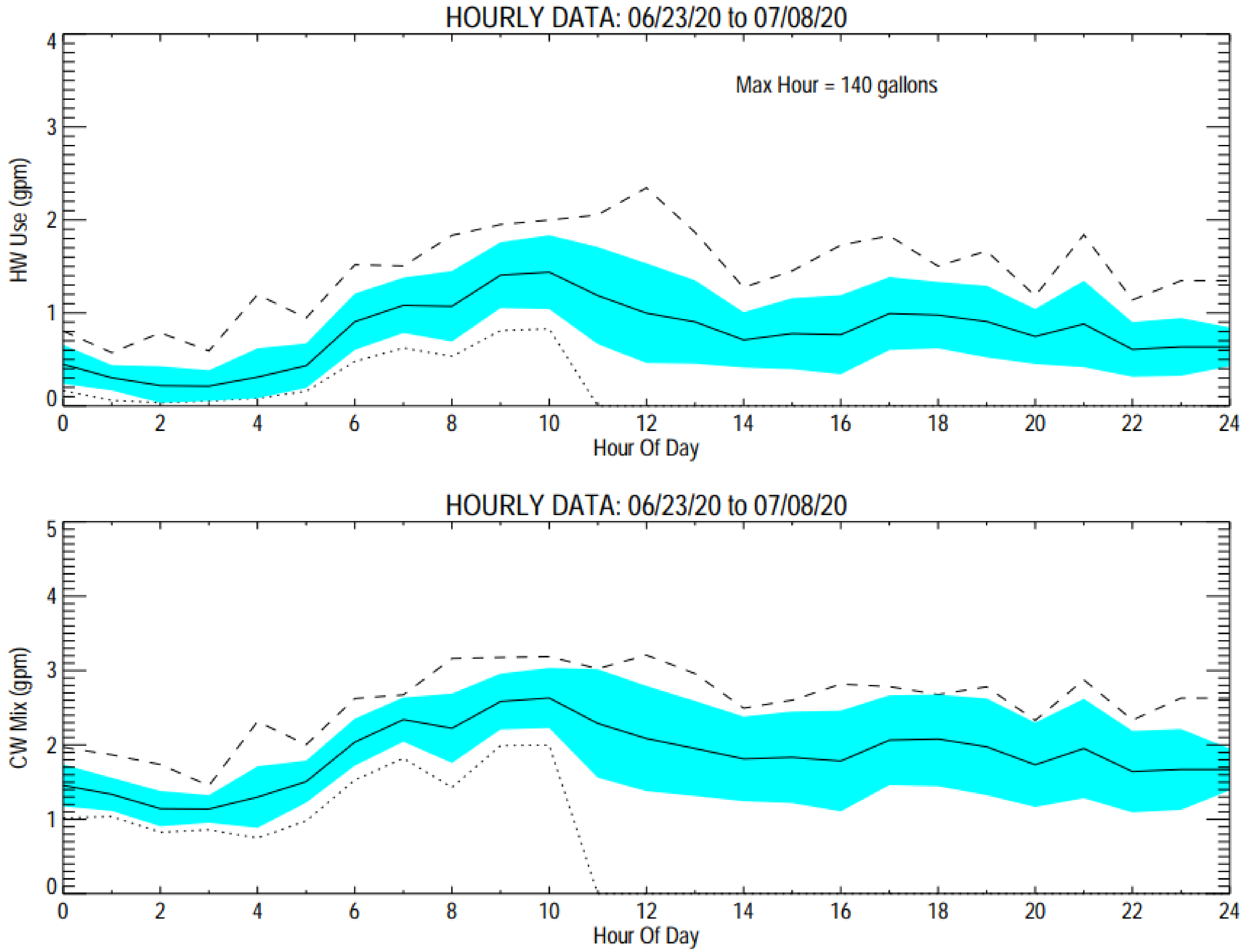
	Range (GPM)	Duration (Minutes/day)	%	Cumulative Flow (Gallons)
Low Draw	0-3	1152	80%	1,400
Med Draw	3-6	230	16%	280
High Draw	6-9	43	3%	53
Peak Draw	9+	14	1%	18

Total Gallons per day	1,750

24 hour monitoring study. Courtesy of IntelliHot

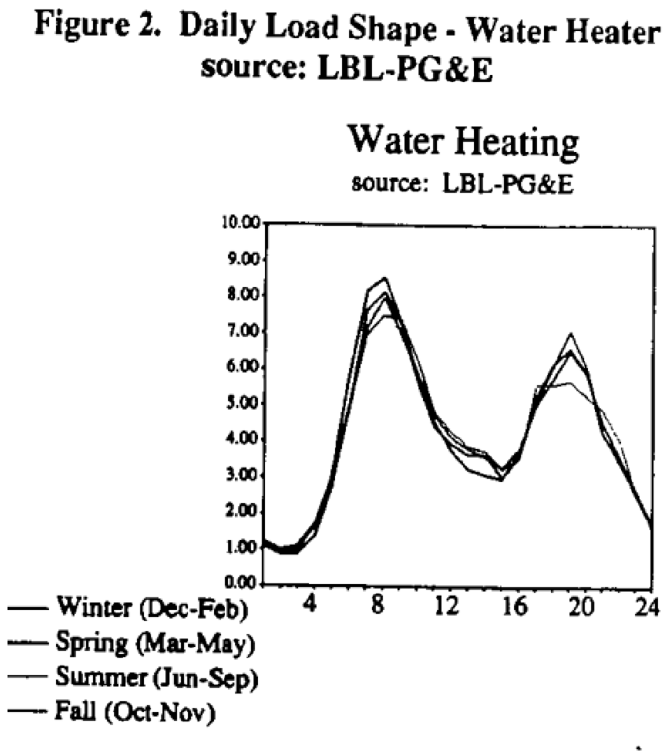
HW Consumption
Measured Data

HW Consumption Study for 99 unit Senior Housing apartment building in NY.



Colonial I monitoring study. Courtesy of P. Skinner & G. Klein.

More Data



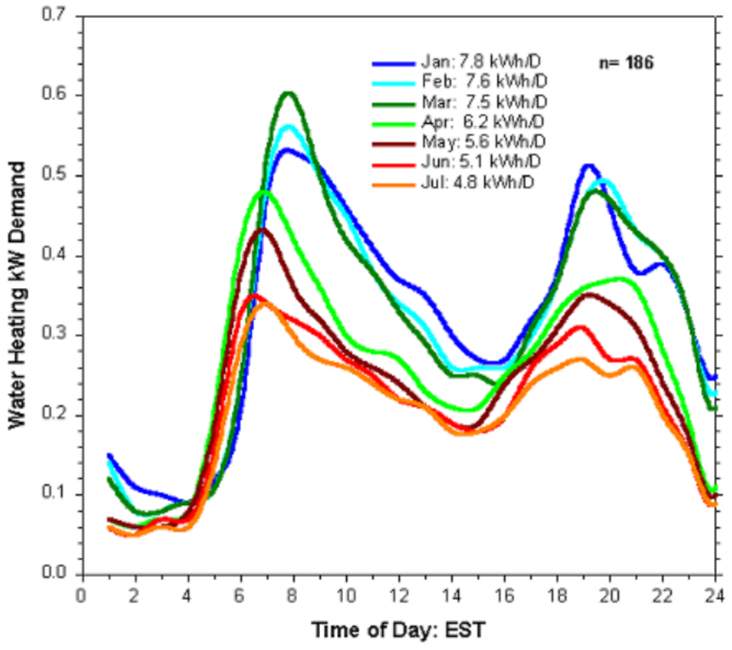


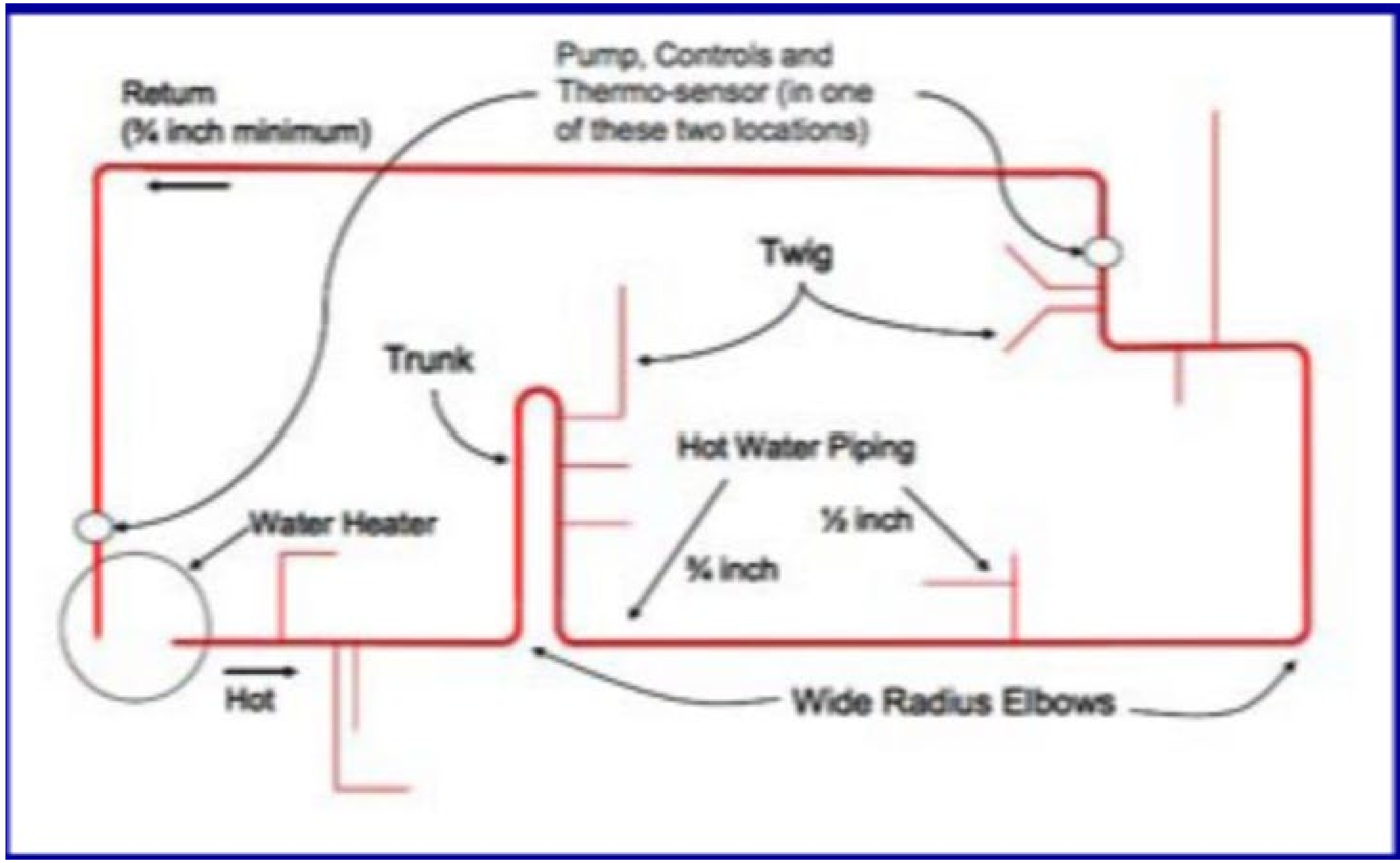
Figure 16. Measured DHW load profiles by month.

Florida Solar Energy Center

THREE – 199,000 BTU/HR GAS TANKLESS HW HEATERS
TOTAL CAPACITY: 597,000 BTU/HR
TOTAL HEATER COST: ~$6,000

FOUR – 15,000 BTU/HR HEAT PUMP HW HEATERS
TOTAL CAPACITY: 60,000 BTU/HR
TOTAL HEATER COST: ~$18,000

DHW Design and Layout



Water Demand Calculator (WDC v2.1)

PROJECT NAME : - - - - -

Click for Drop-down Menu → Multi-Family Building

Total Number of Apartments in the Building→ 95

Total Apartments in this Calculation→ 95

Monday, October 11, 2021

4:49 PM

FIXTURE GROUPS		FIXTURE	ENTER TOTAL NUMBER OF FIXTURES	PROBABILITY OF USE (%)	ENTER FIXTURE FLOW RATE (GPM)	MAXIMUM RECOMMENDED FIXTURE FLOW RATE (GPM)
Bathroom Fixtures	1	Bathtub (no Shower)	0	0.38	5.5	5.5
	2	Bidet	0	0.55	2.0	2.0
	3	Combination Bath/Shower	0	1.41	5.5	5.5
	4	Faucet, Lavatory	95	1.11	1.5	1.5
	5	Shower, per head (no Bathtub)	95	0.94	2.0	2.0
	6	Water Closet, 1.28 GPF Gravity Tank	95	0.55	3.0	3.0
Kitchen Fixtures	7	Dishwasher	0	0.32	1.3	1.3
	8	Faucet, Kitchen Sink	95	1.11	2.2	2.2
Laundry Room Fixtures	9	Clothes Washer	5	1.33	3.5	3.5
	10	Faucet, Laundry	0	1.11	2.0	2.0
Bar/Prep Fixtures	11	Faucet, Bar Sink	0	1.11	1.5	1.5
Other Fixtures	12	Fixture 1	0	0.00	0.0	6.0
	13	Fixture 2	0	0.00	0.0	6.0
	14	Fixture 3	0	0.00	0.0	6.0

COMPUTED RESULTS FOR PEAK PERIOD CONDITIONS

Total No. of Fixtures in Calculation
n = 385

99^{th} Percentile Demand Flow
Q = 17.0 GPM

Hunter Number
H(n,p) = 3.59

Stagnation Probability
Pr[Zero Demand] = 3%

DOWNLOAD RESULT | RESET WDC

↓ Select Units for Water Demand ↓

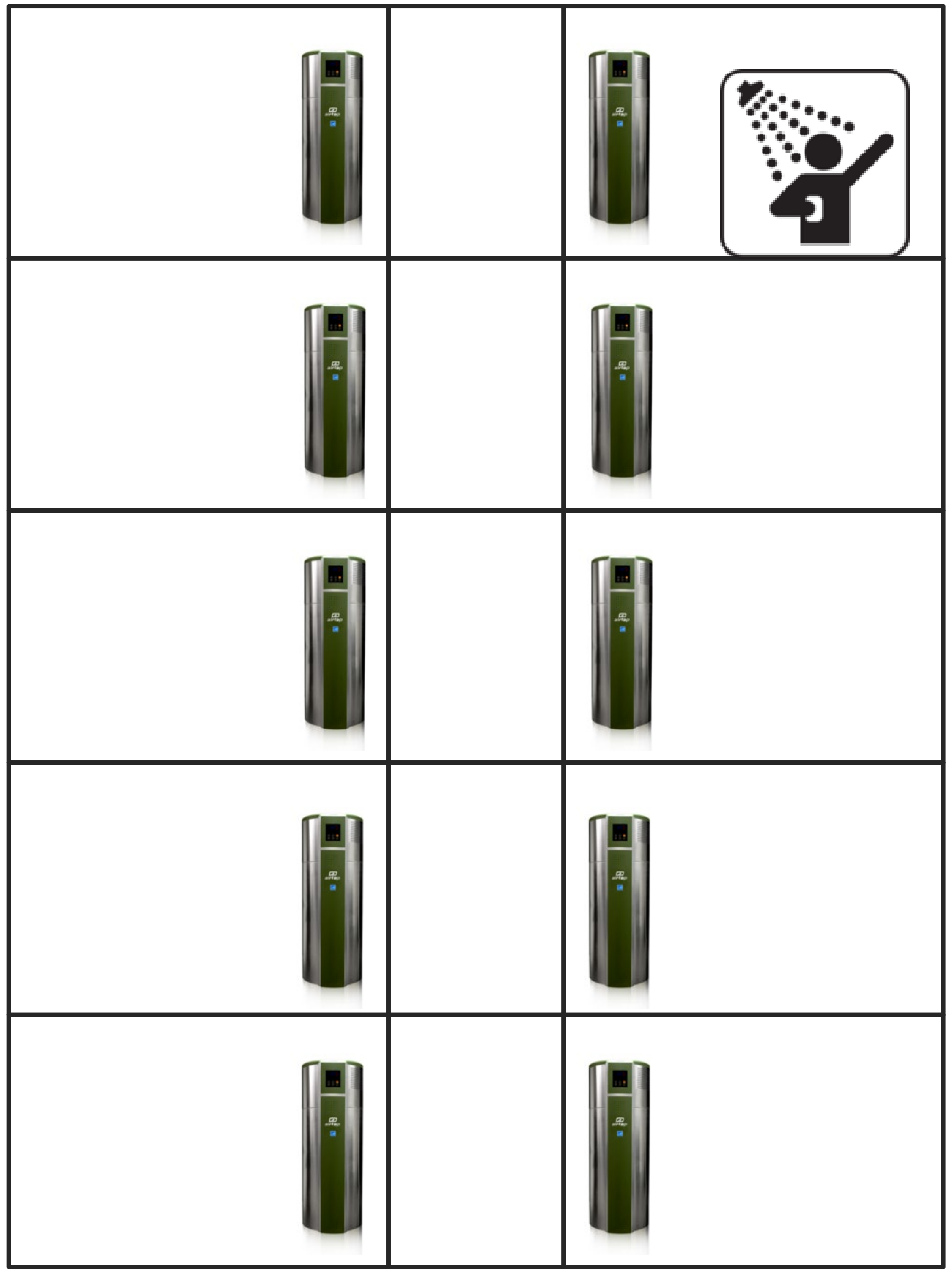
GPM | LPM | LPS

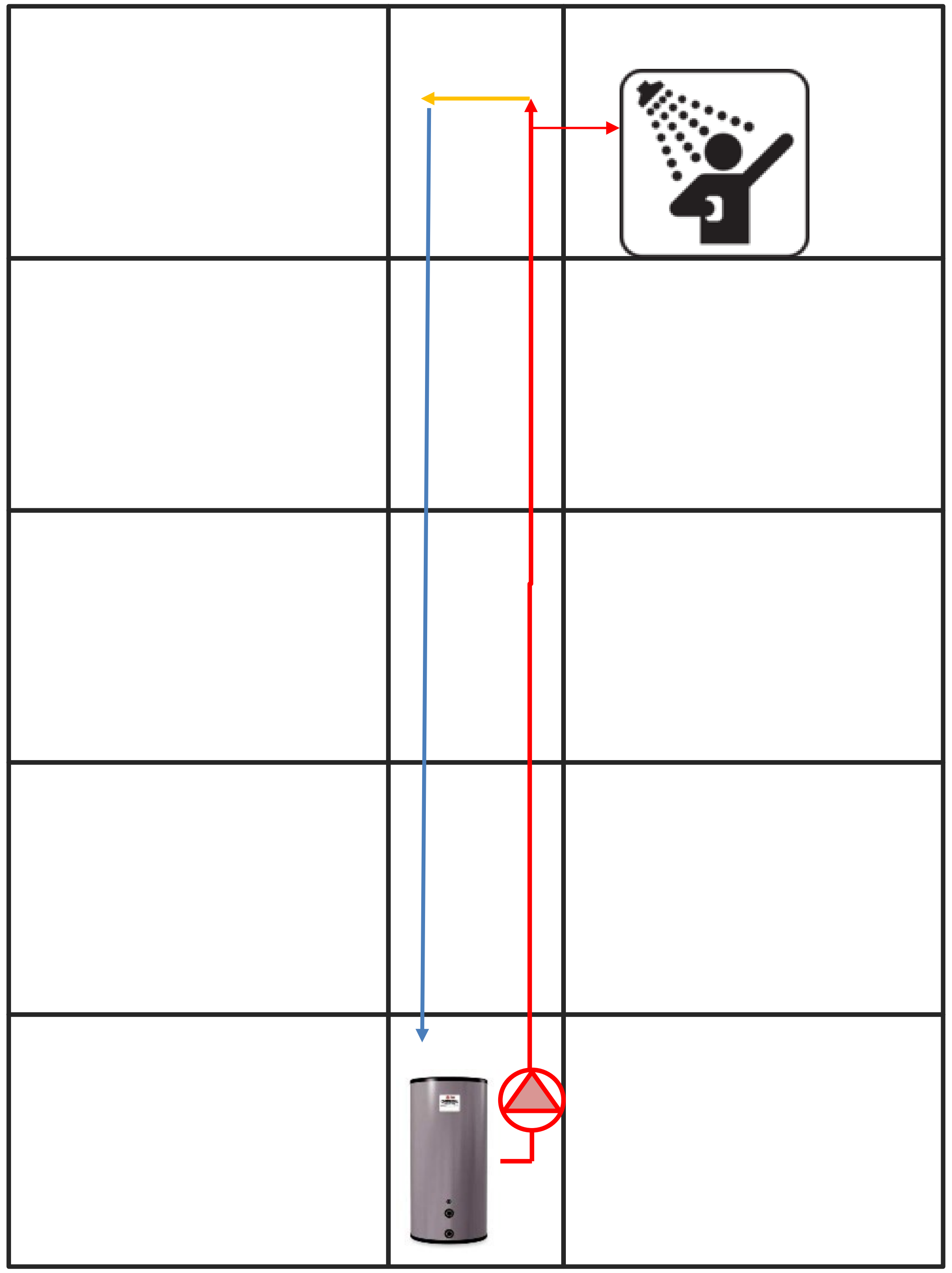
RUN WDC

IAPMO

System Types

Central vs. Distributed?

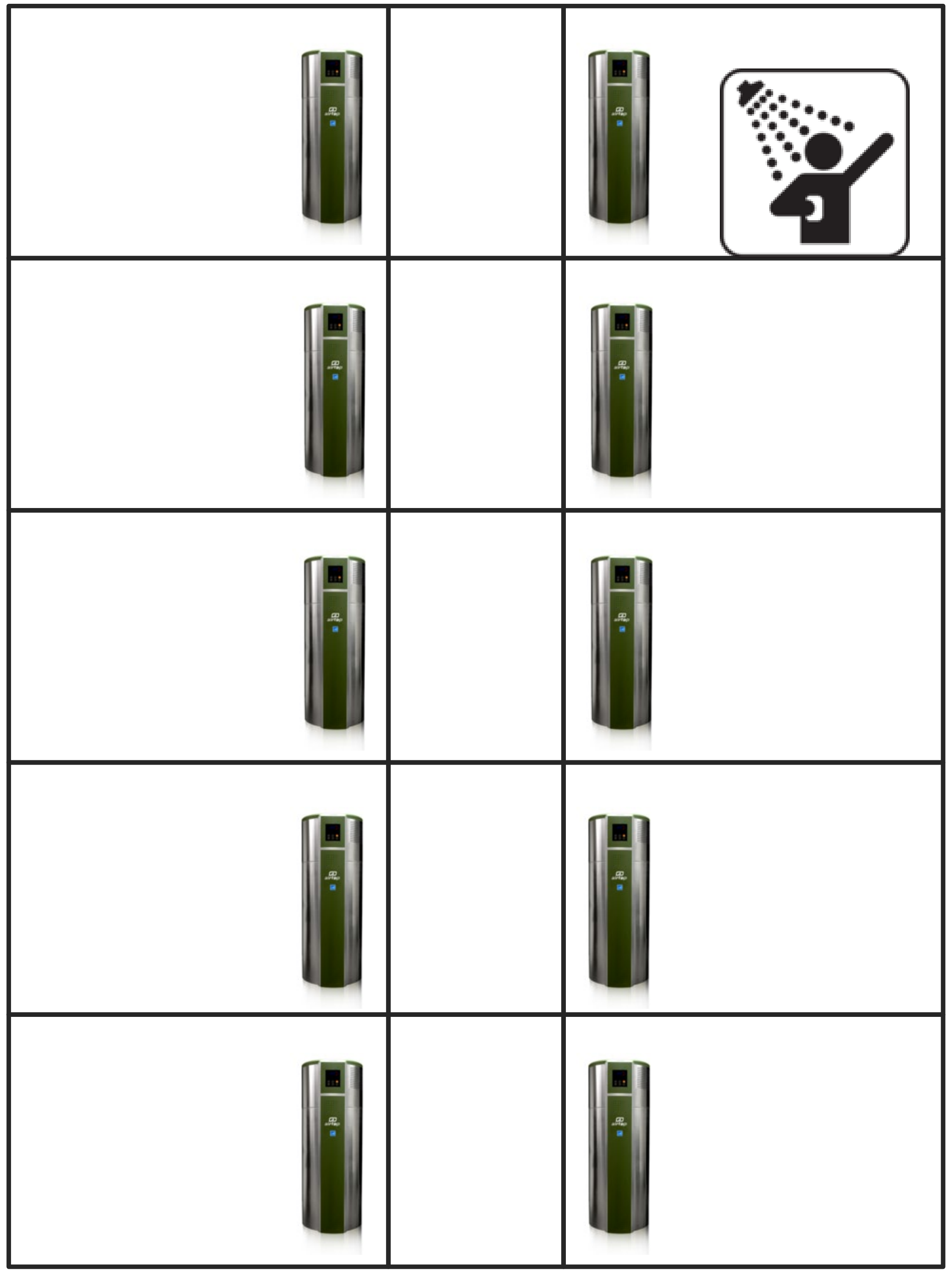




Distributed Heat Pumps

One heater per apartment

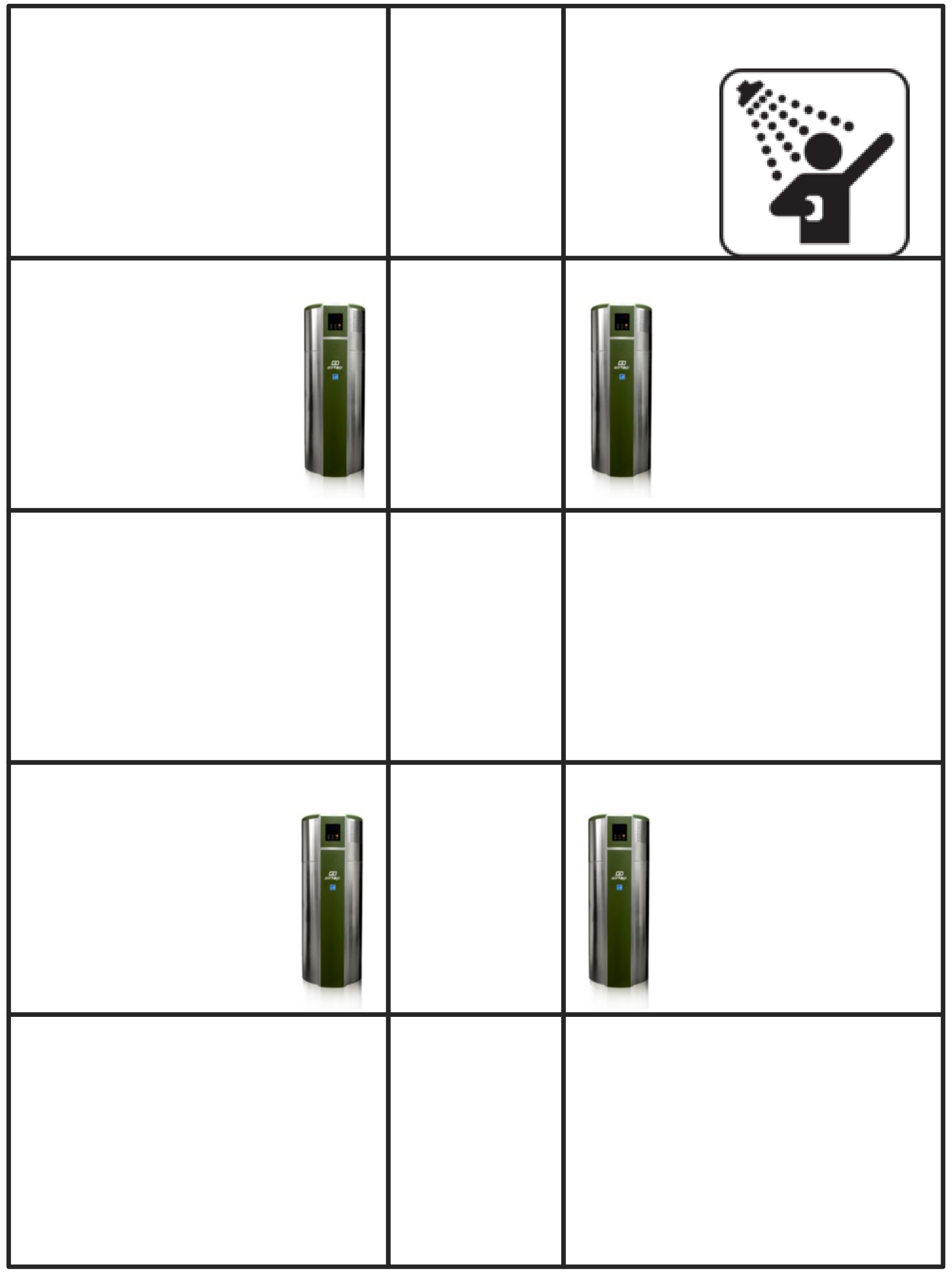
PROS	CONS
No Re-Circ Losses	Sound can be an Issue in Small Apartments
Lower Piping Cost	Expensive
May Work Well in Some Buildings	More Stand-by losses
	Heat load on apartment – Compressors in Series



Distributed Heat Pumps

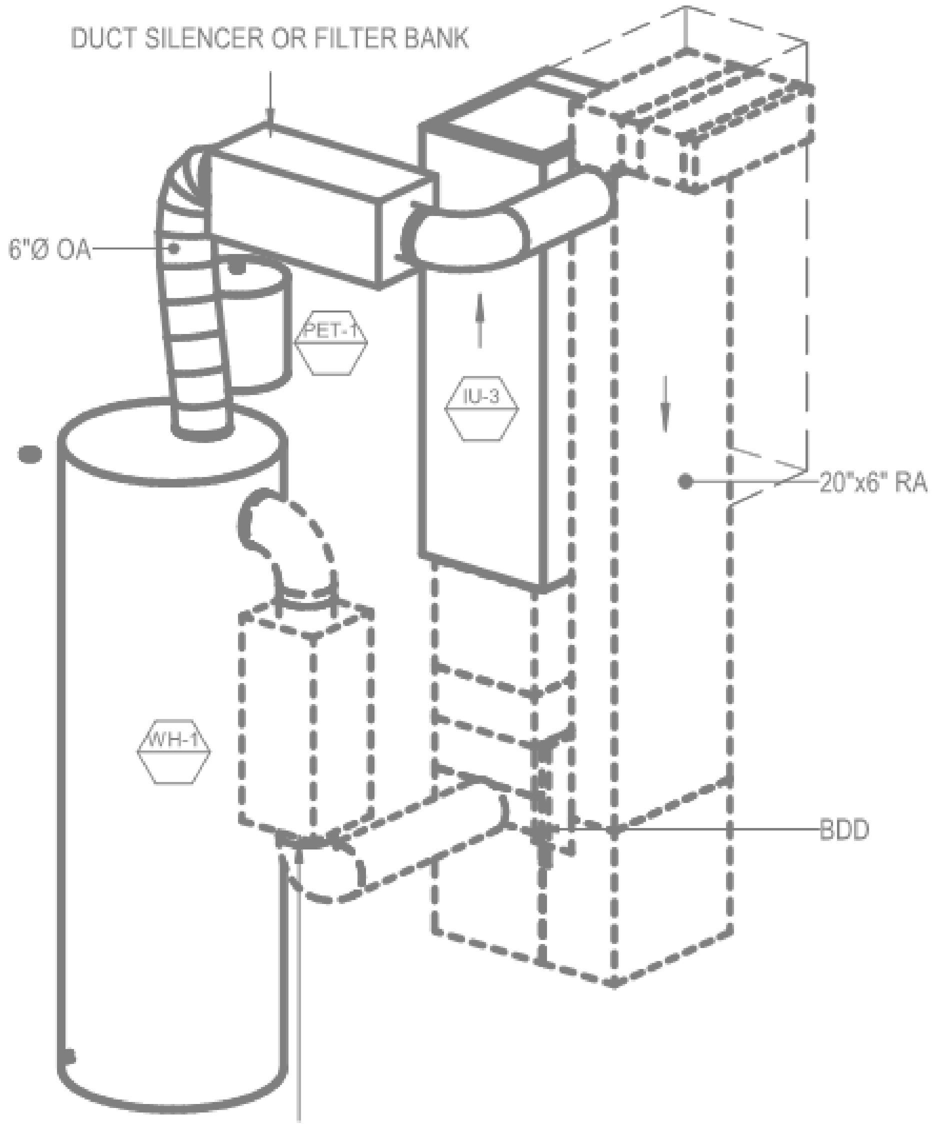
One heater serves multiple apartments

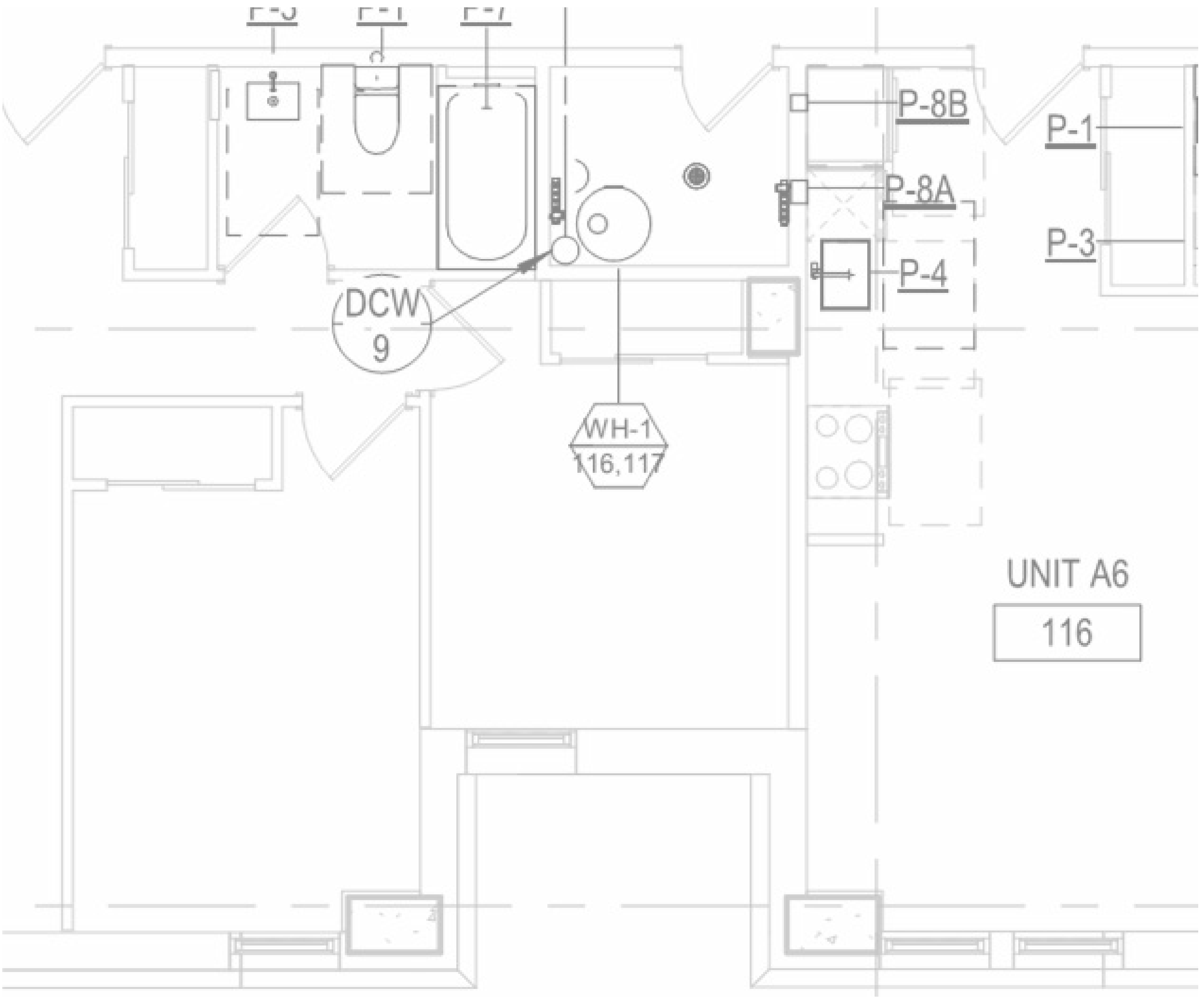
PROS	CONS
No Re-Circ Losses	Space for Heaters
Lower Piping Cost	More Equipment to Maintain
Easy heat recovery in the Cooling Season	Can be a challenge to manage heat pump air
Water Heating Redundancy - Resiliency	



Distributed Heat Pumps

One heater serves multiple apartments





Central Heat Pump Systems

PROS

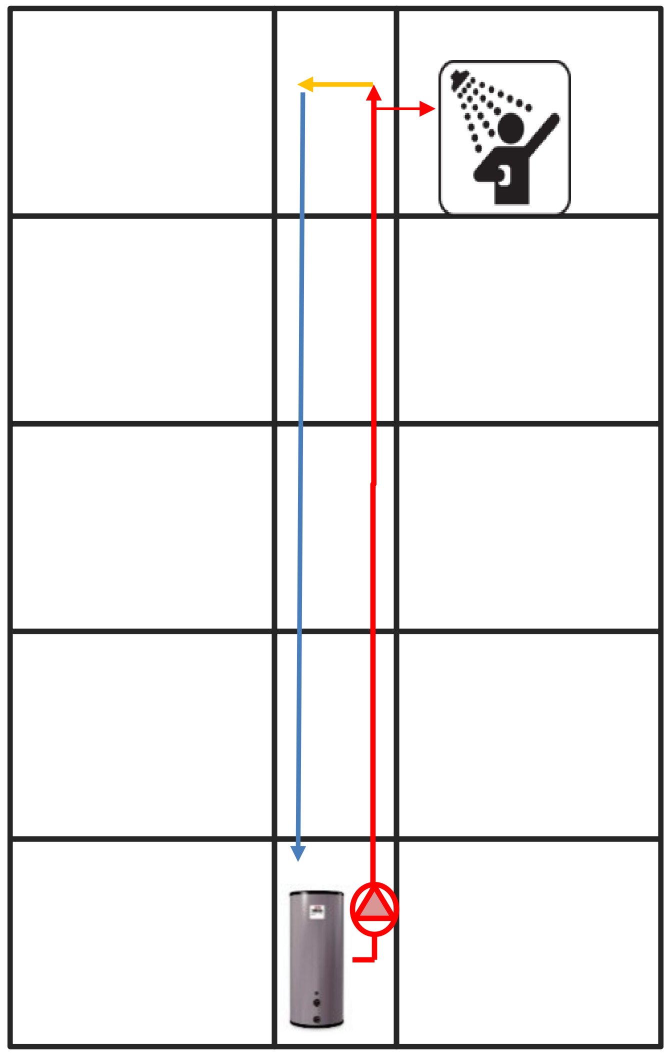
- Ease of Maintenance / Less EQ
- Heat Recovery Possible with Central HVAC
- CO2 Based EQ Available
- Takes up Less Space
- Doesn't add to Building Heating Load

CONS

- Re-Circ Losses
- Less Redundancy / Resiliency
- More Complex

Central System Design:

- Minimize time to service
- Don't over-size piping network
- Proper HW heater sizing

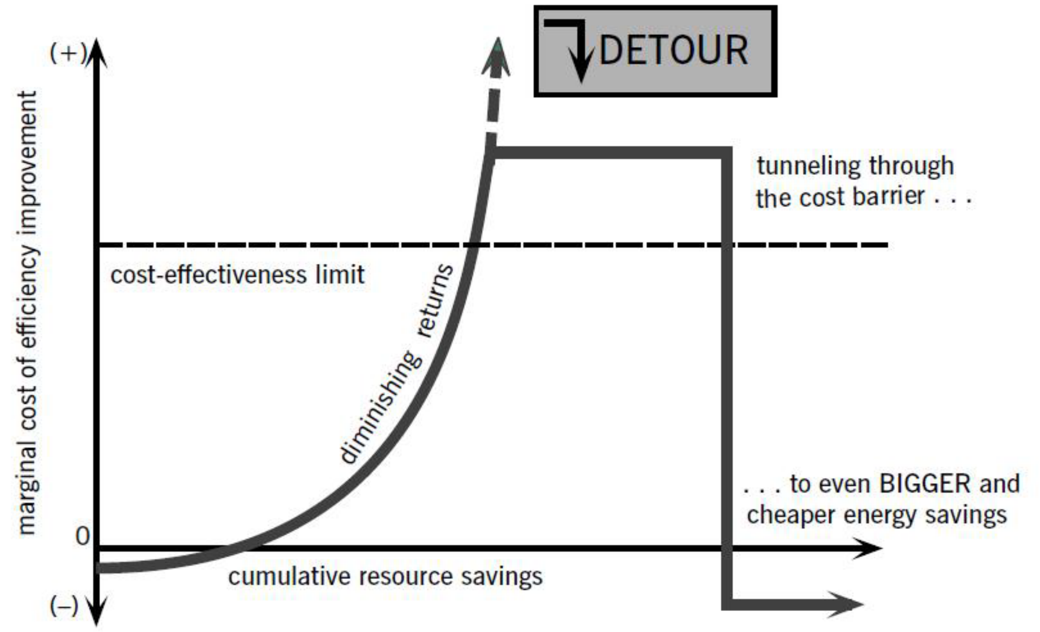


DISCUSSION/ QUESTIONS

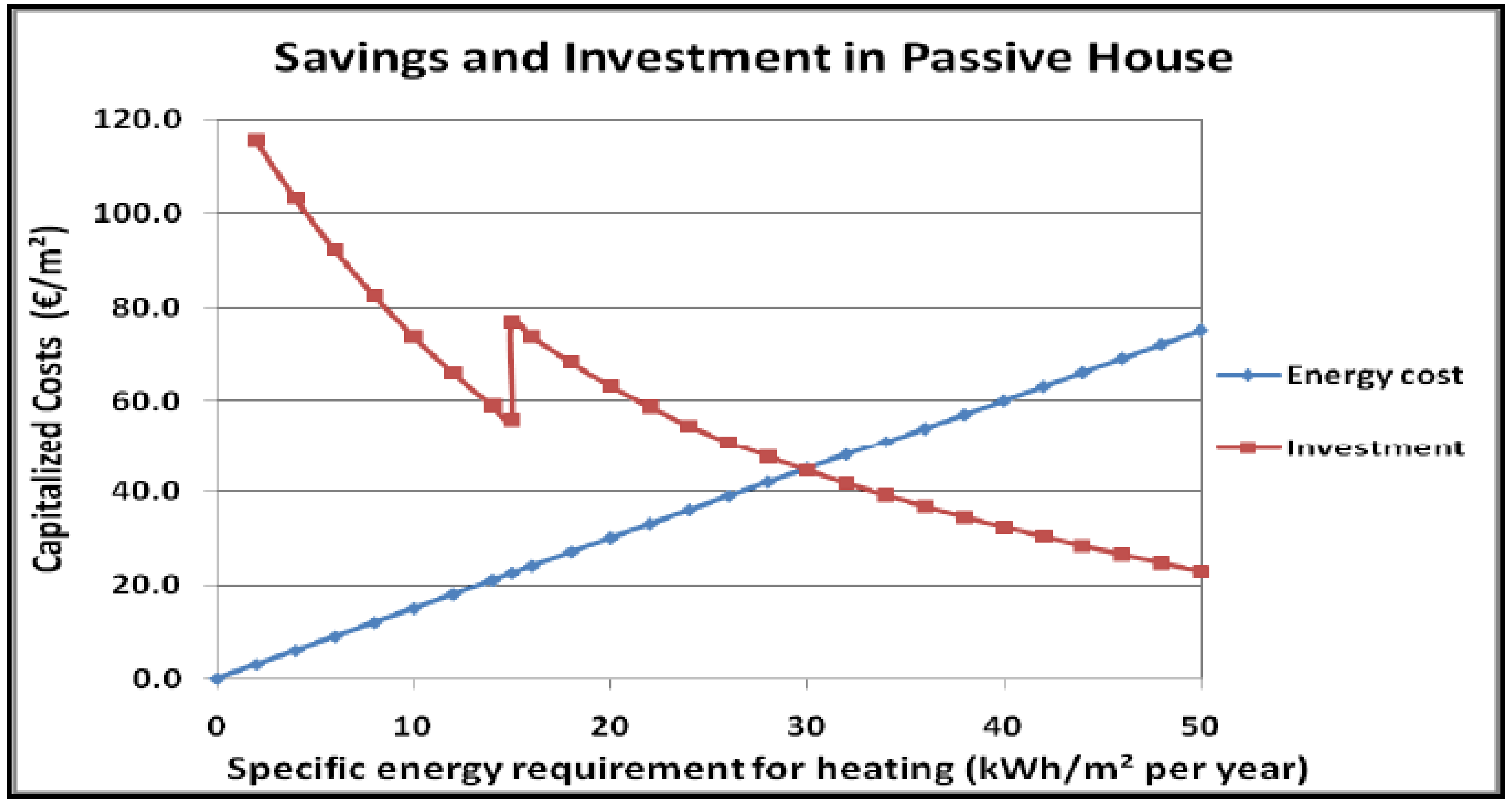
HVAC Loads and System Deep Dive-
Galen Lead, James make additions at the end

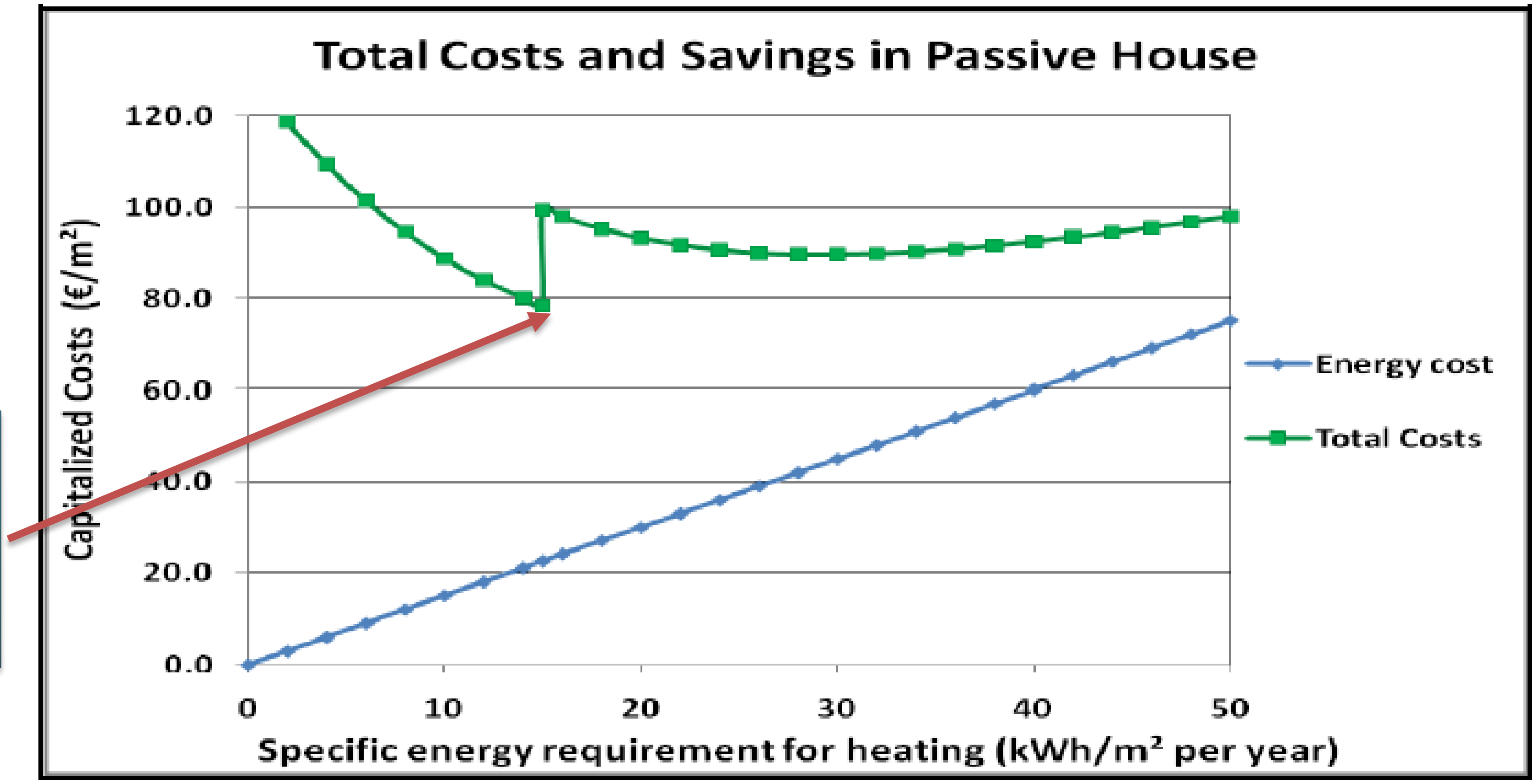
GALEN STAENGL, PE, CPHC, LEED AP

STAENGL ENGINEERING



Graph from 'Natural Capitalism' by Paul Hawkins, Amory Lovins, and L. Hunter Lovins

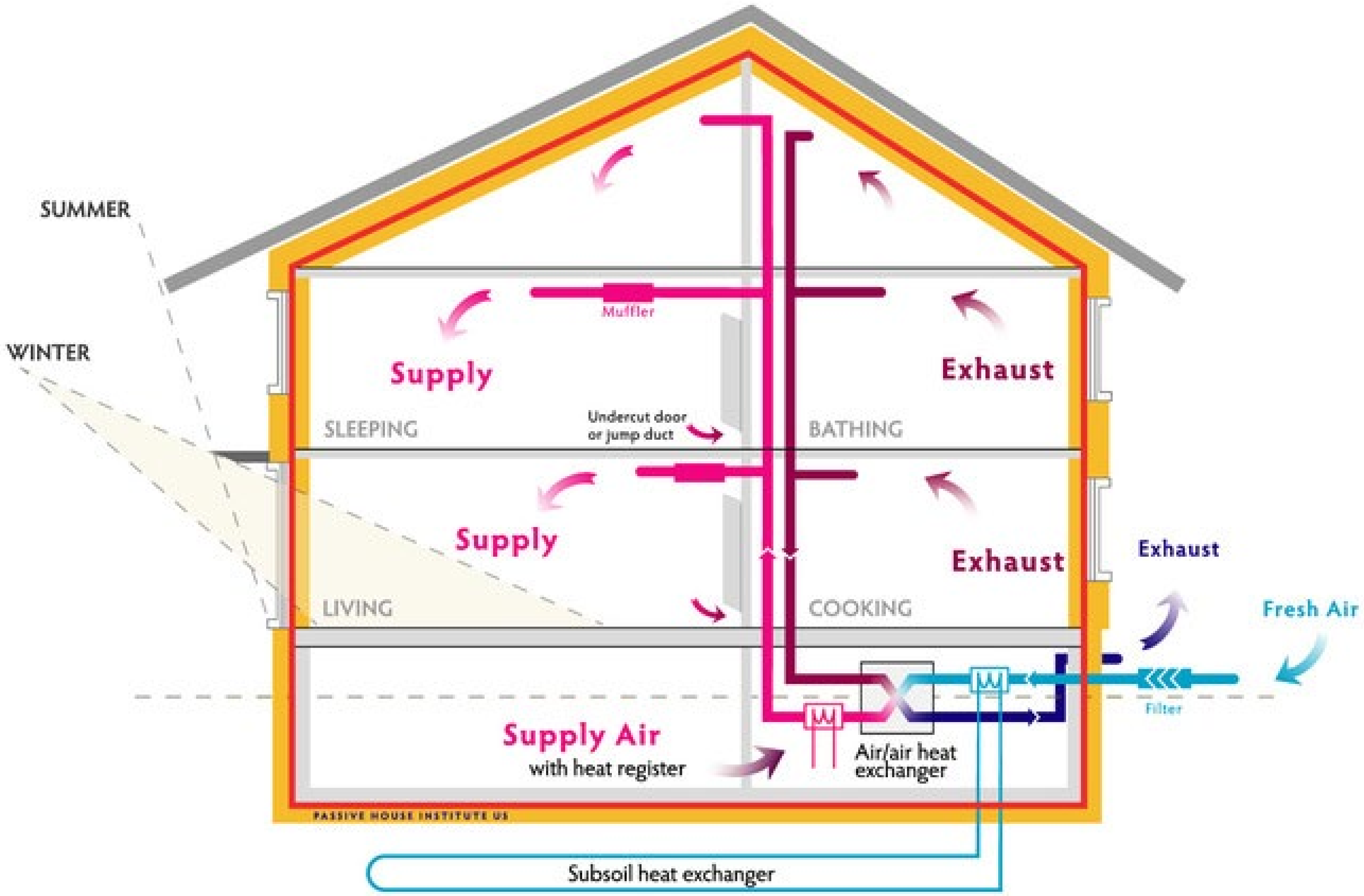




Life Cycle Cost Minimum

Source: IEA Information Paper: Energy Efficiency requirements in Building Codes, Jens Lausten

Can We Eliminate a System – Heating?

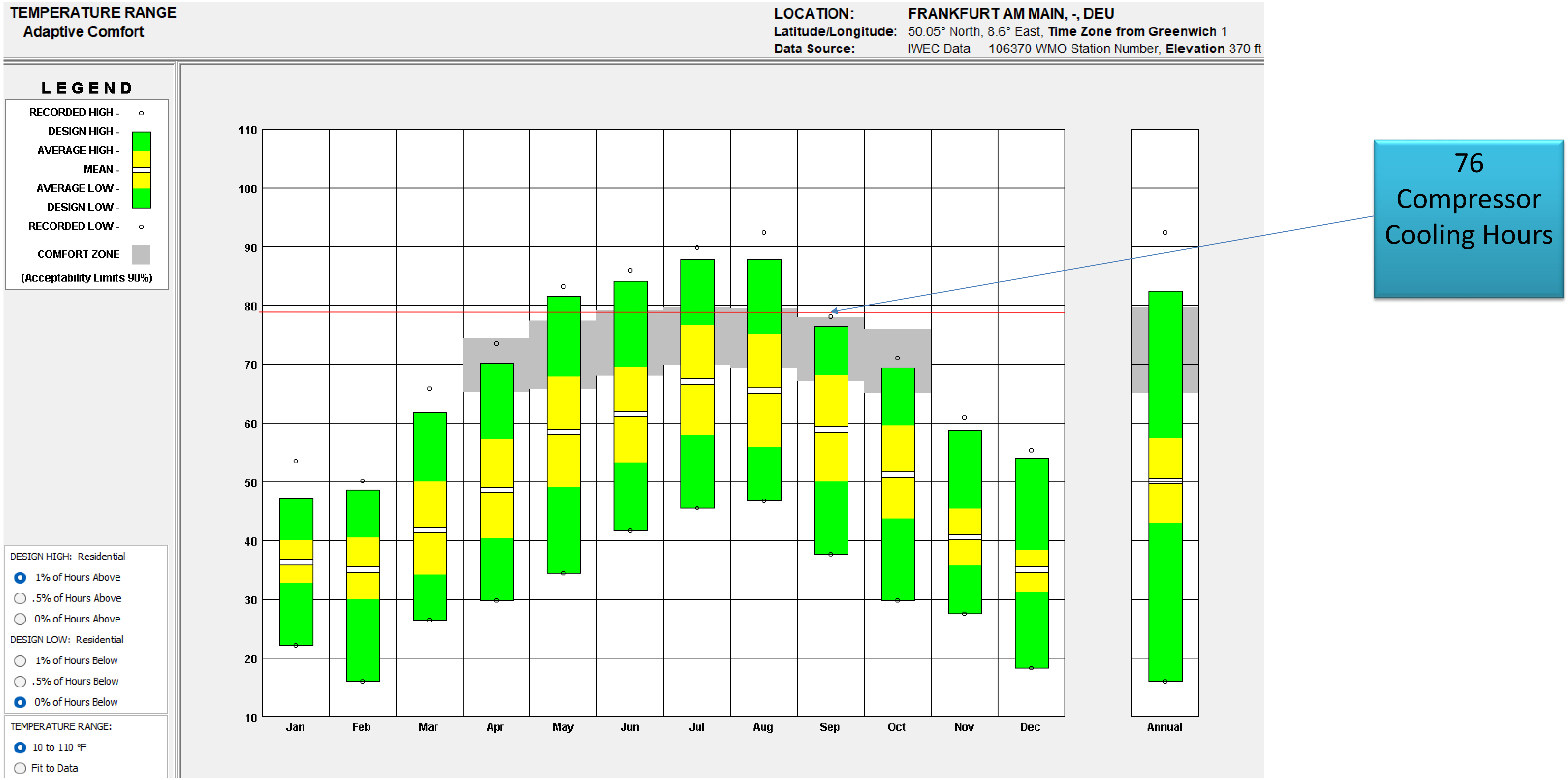


Can we heat it
with a hair dryer?

1200 sqft x 3.14 BTU/sqft h = 3,768 BTU/hr = 1,100 W -> YES!

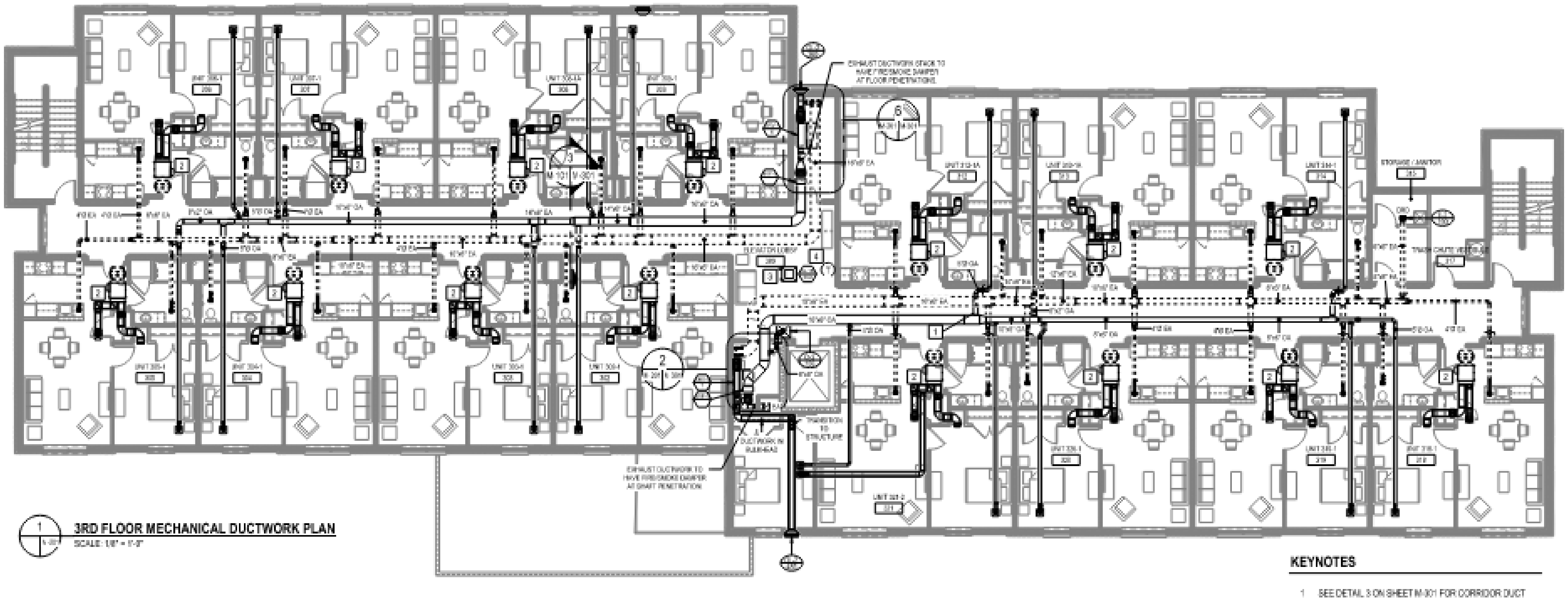
86 cfm * 1.08 * 40 = 3,715 BTU/hr

Climate in Germany

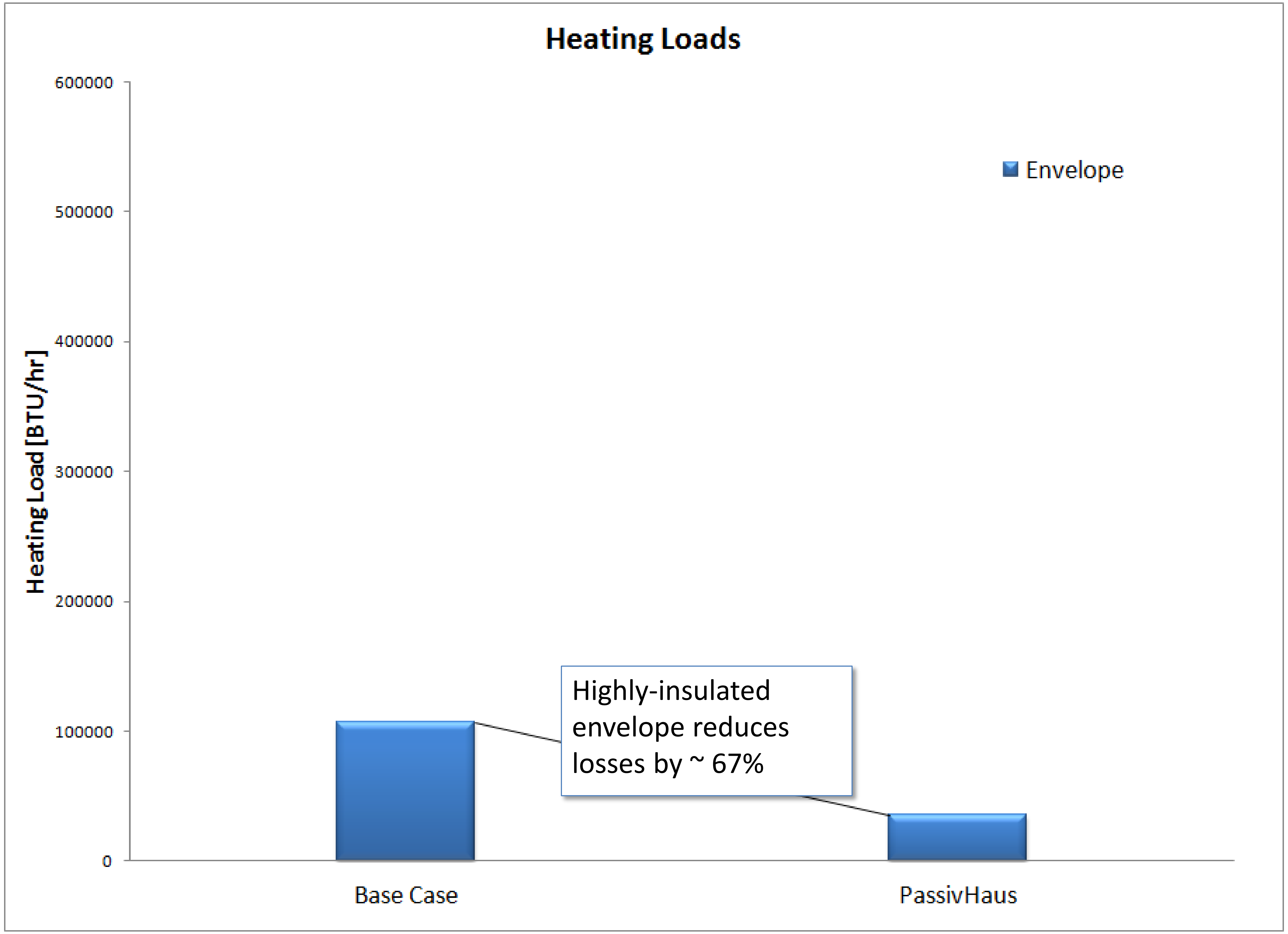


Can We Eliminate a System – Cooling?

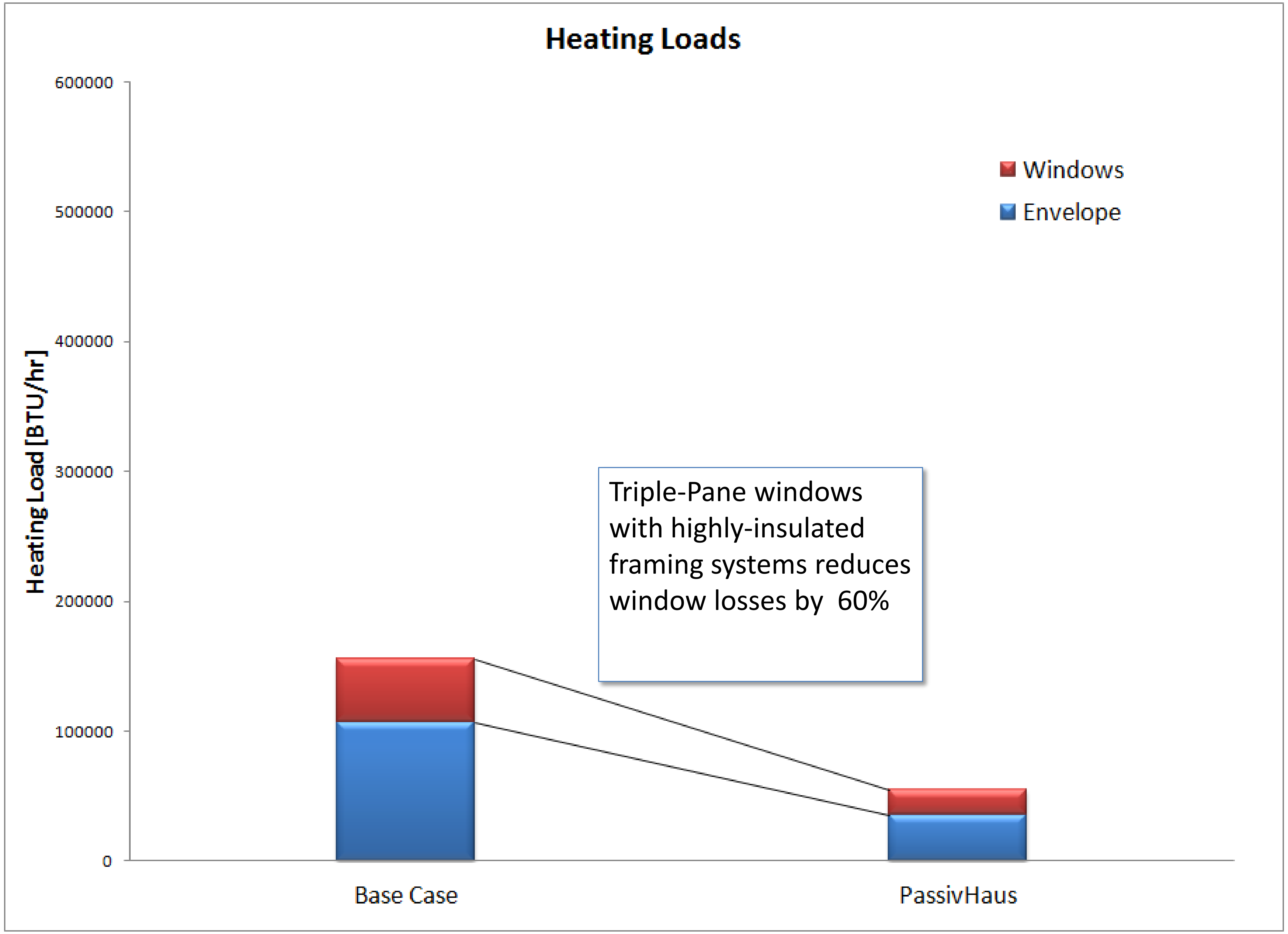
- Internal gains limit the cooling size reduction
- Latent loads must be treated
- Multi-family presents a special challenge



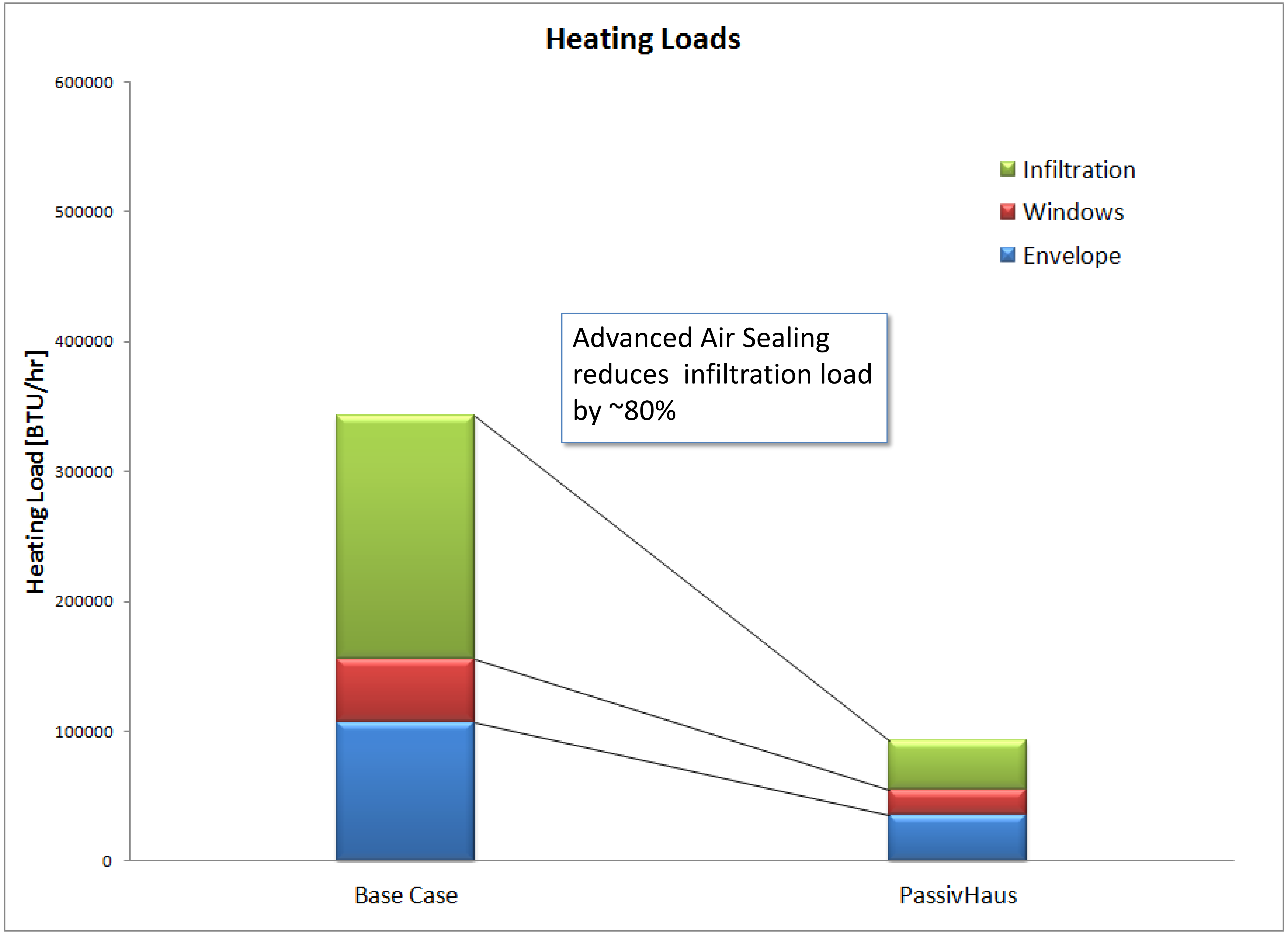
Loads for a Dorm in Virginia



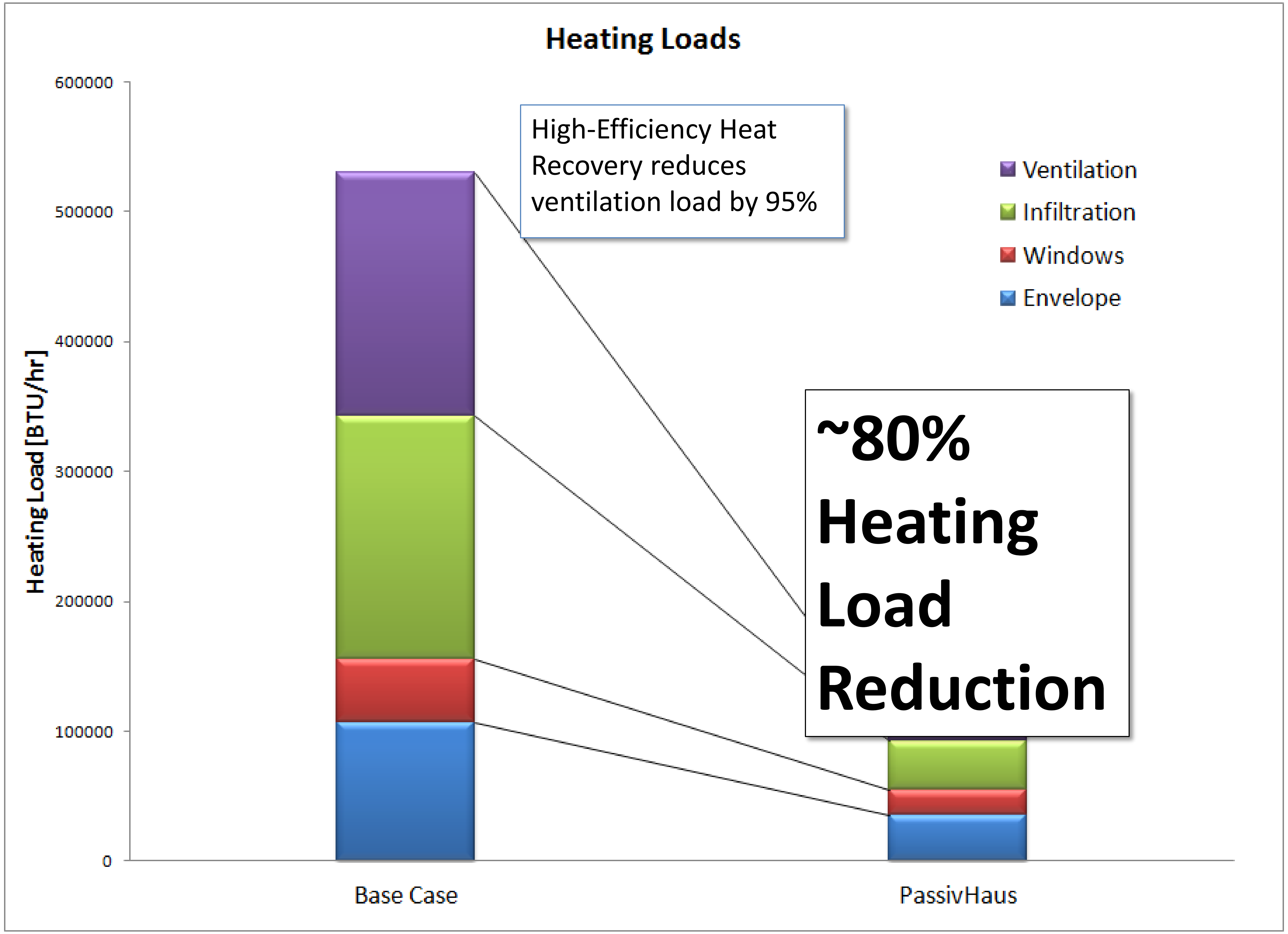
Loads for a Dorm in Virginia



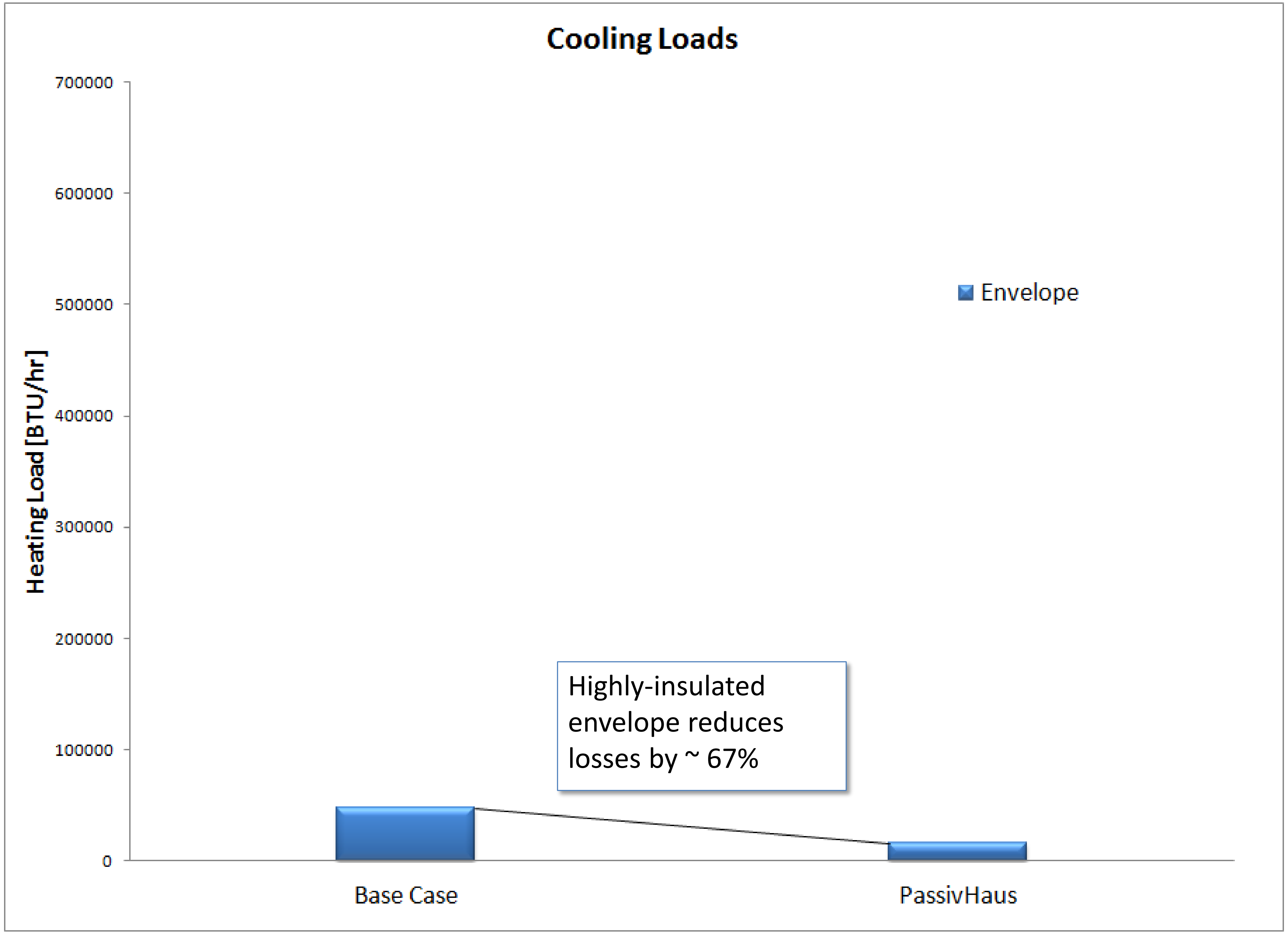
Loads for a Dorm in Virginia



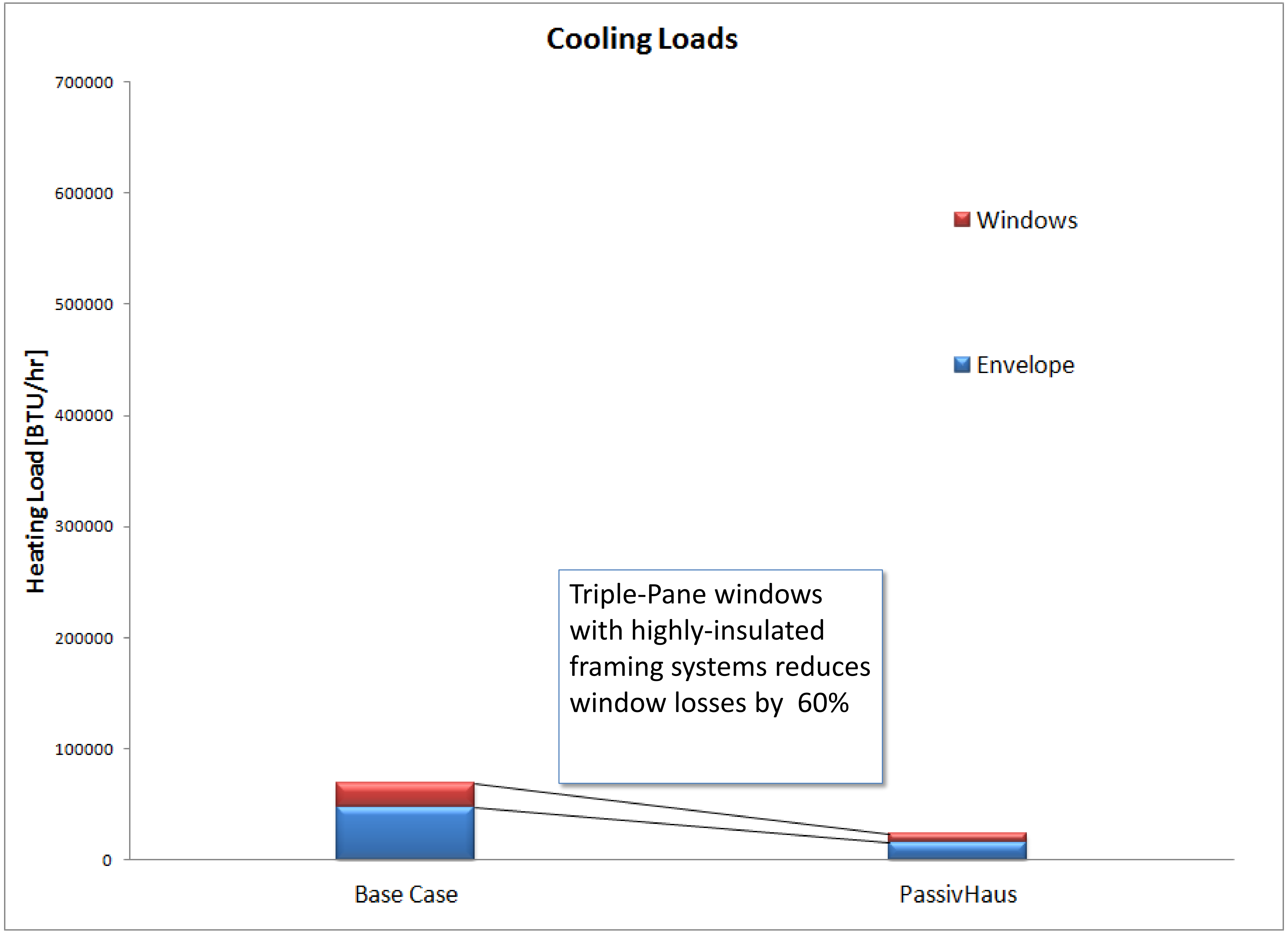
Loads for a Dorm in Virginia



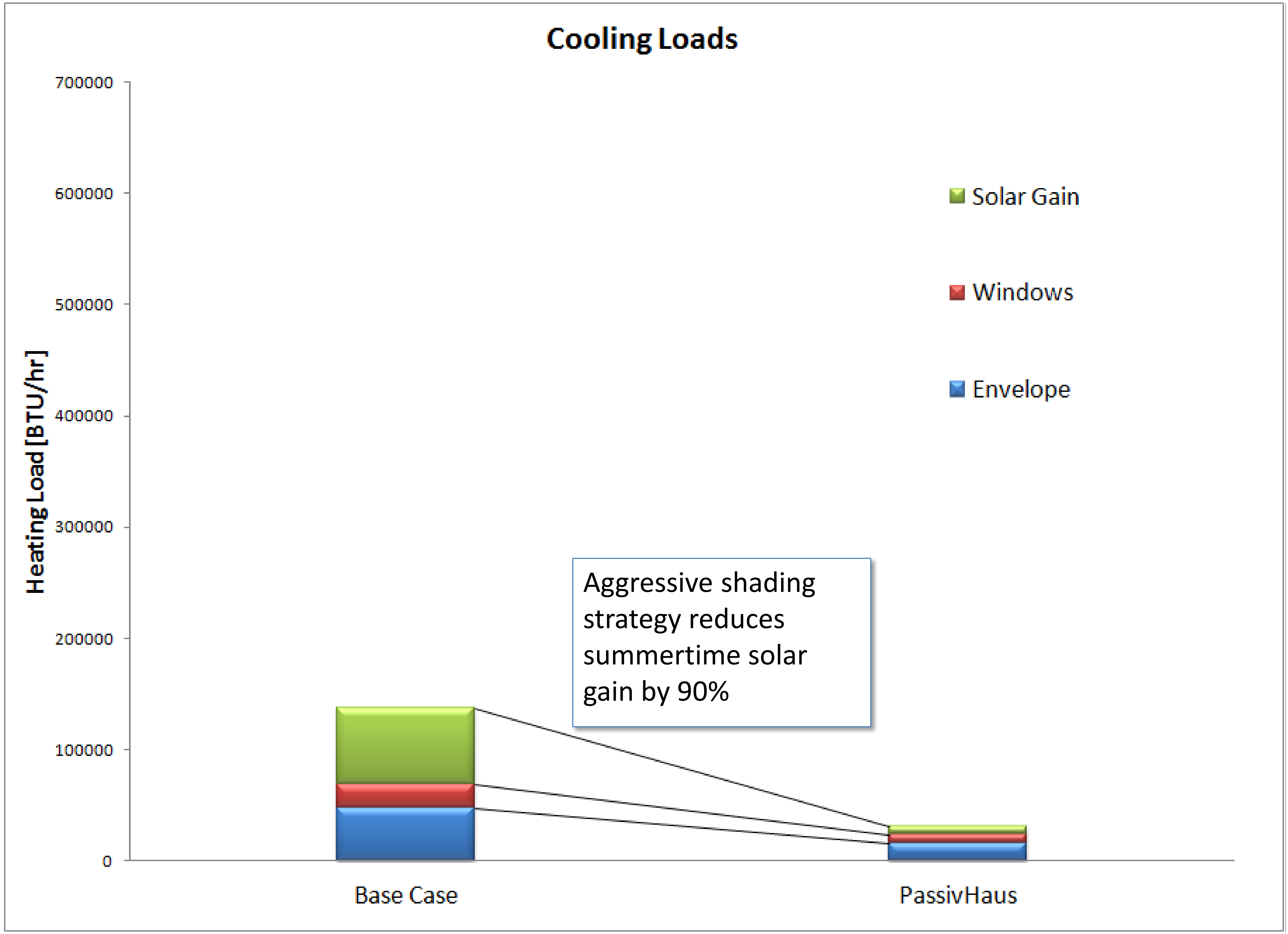
Loads for a Dorm in Virginia



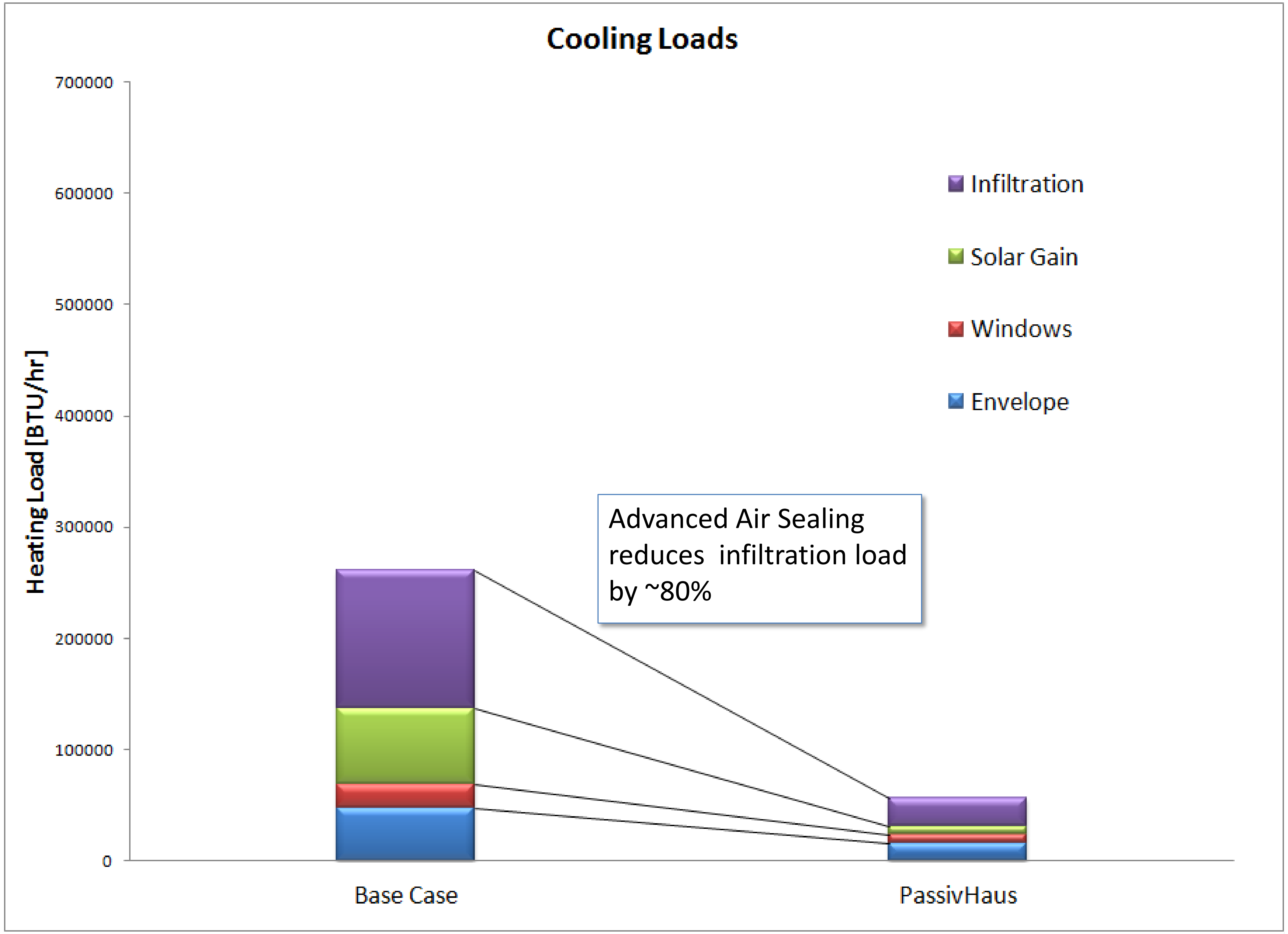
Loads for a Dorm in Virginia



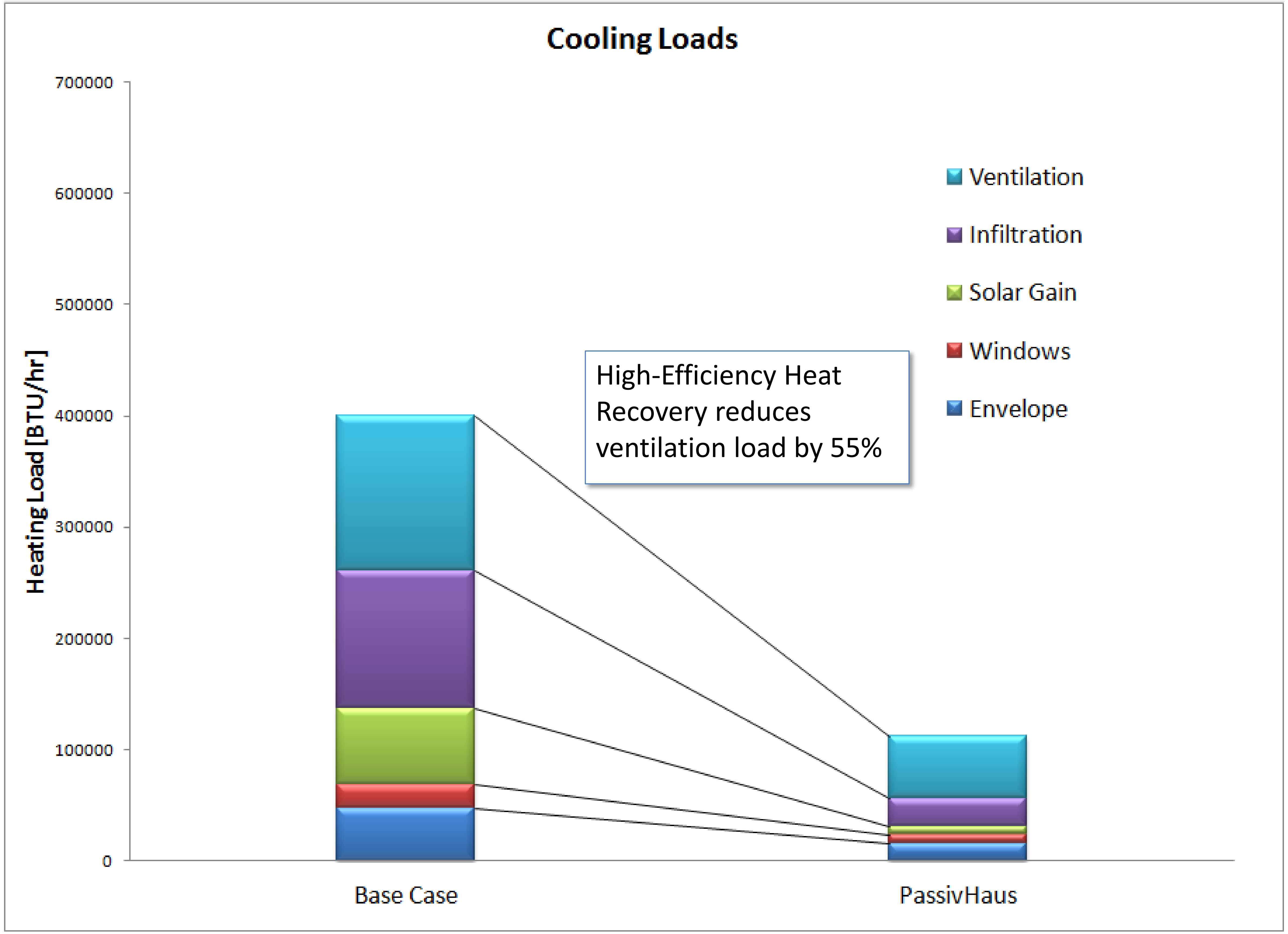
Loads for a Dorm in Virginia



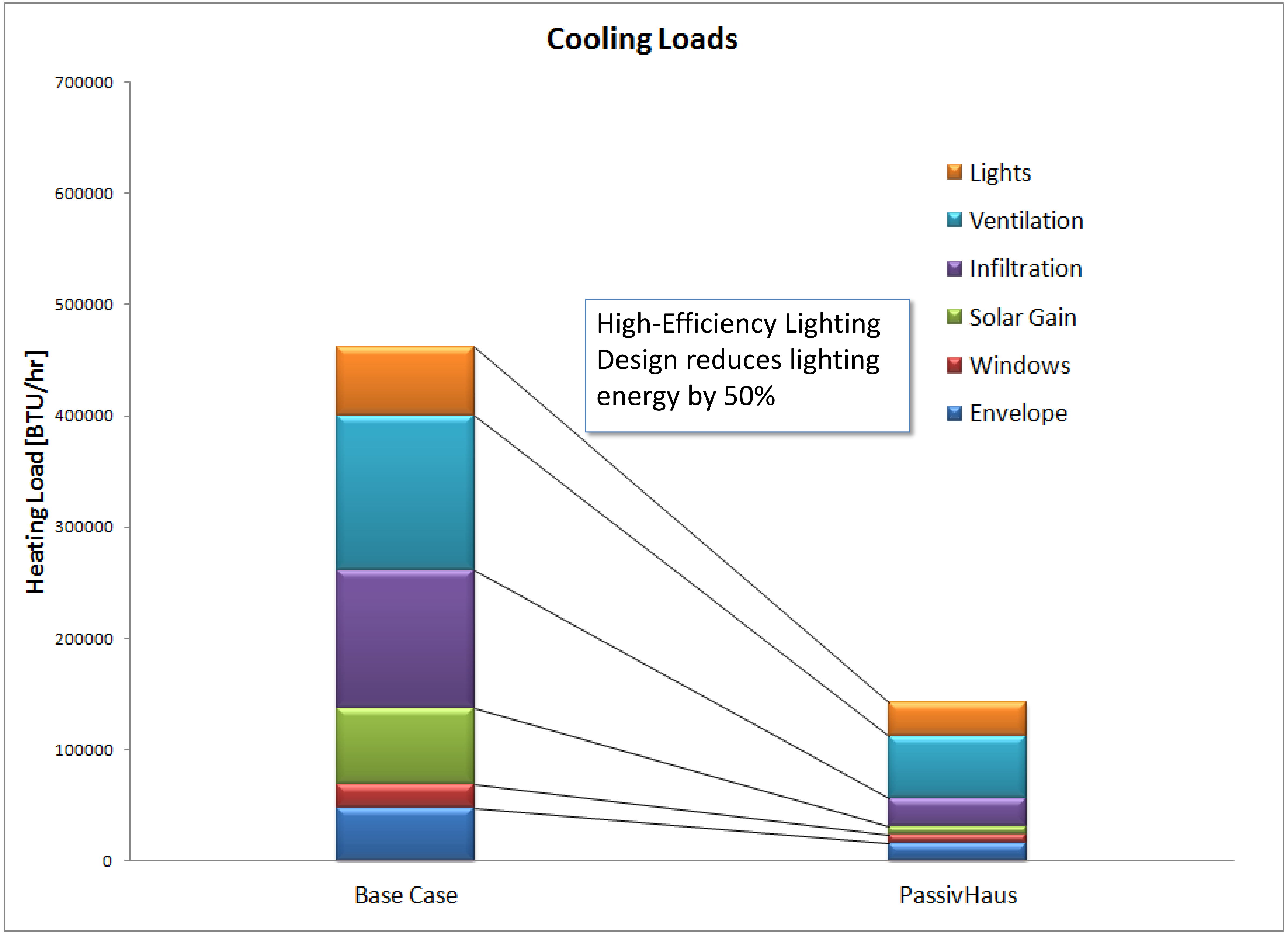
Loads for a Dorm in Virginia



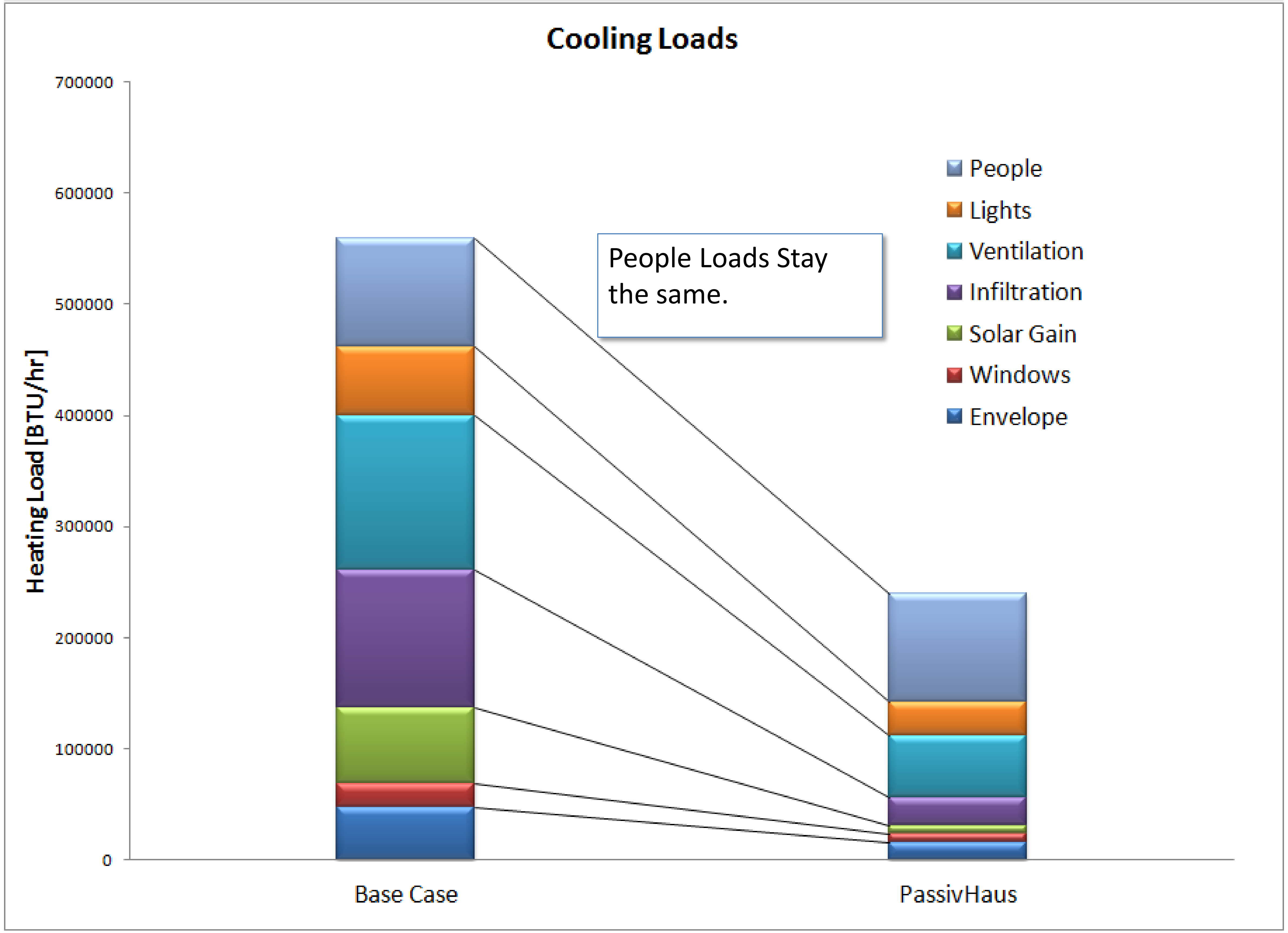
Loads for a Dorm in Virginia



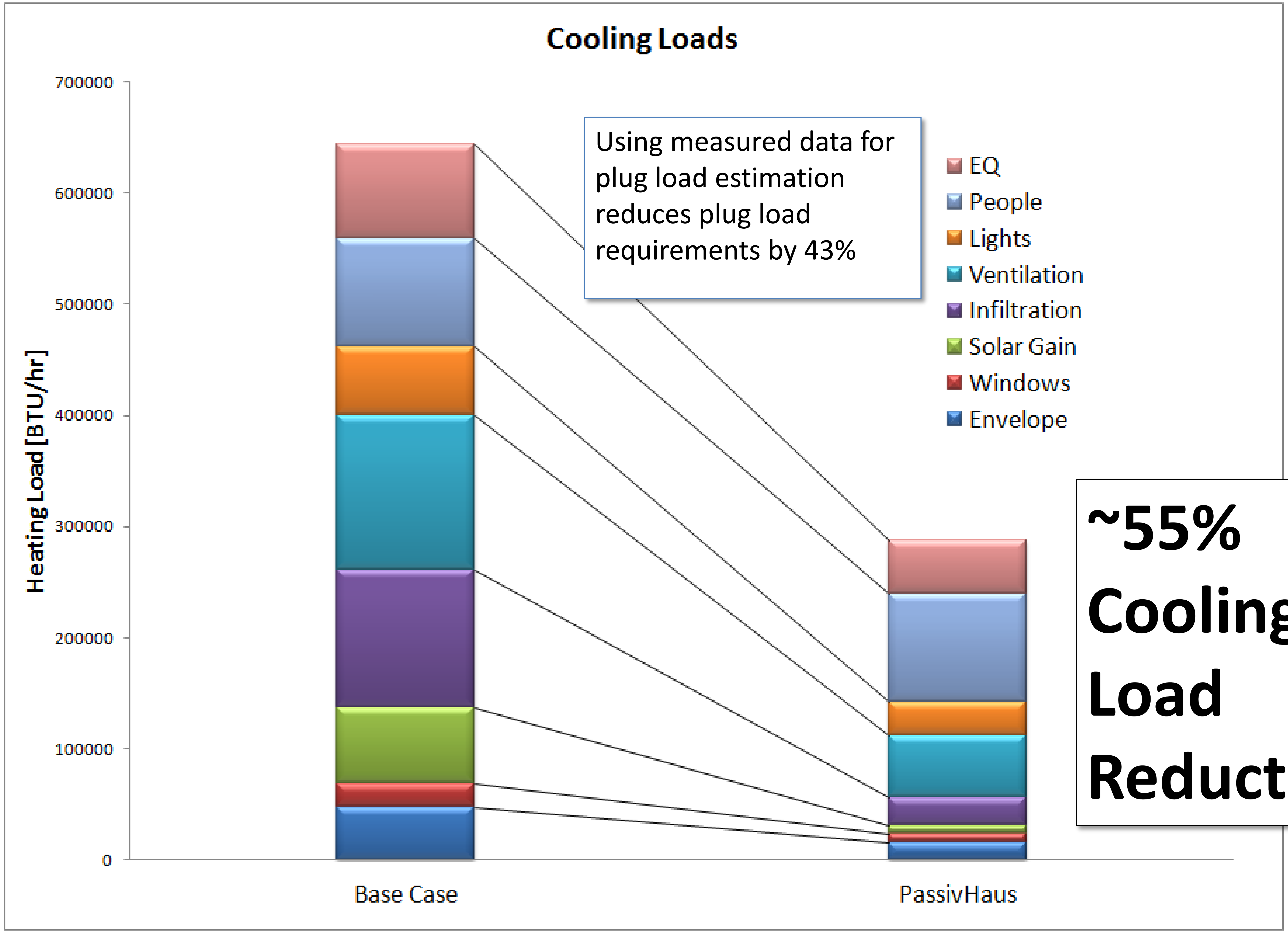
Loads for a Dorm in Virginia



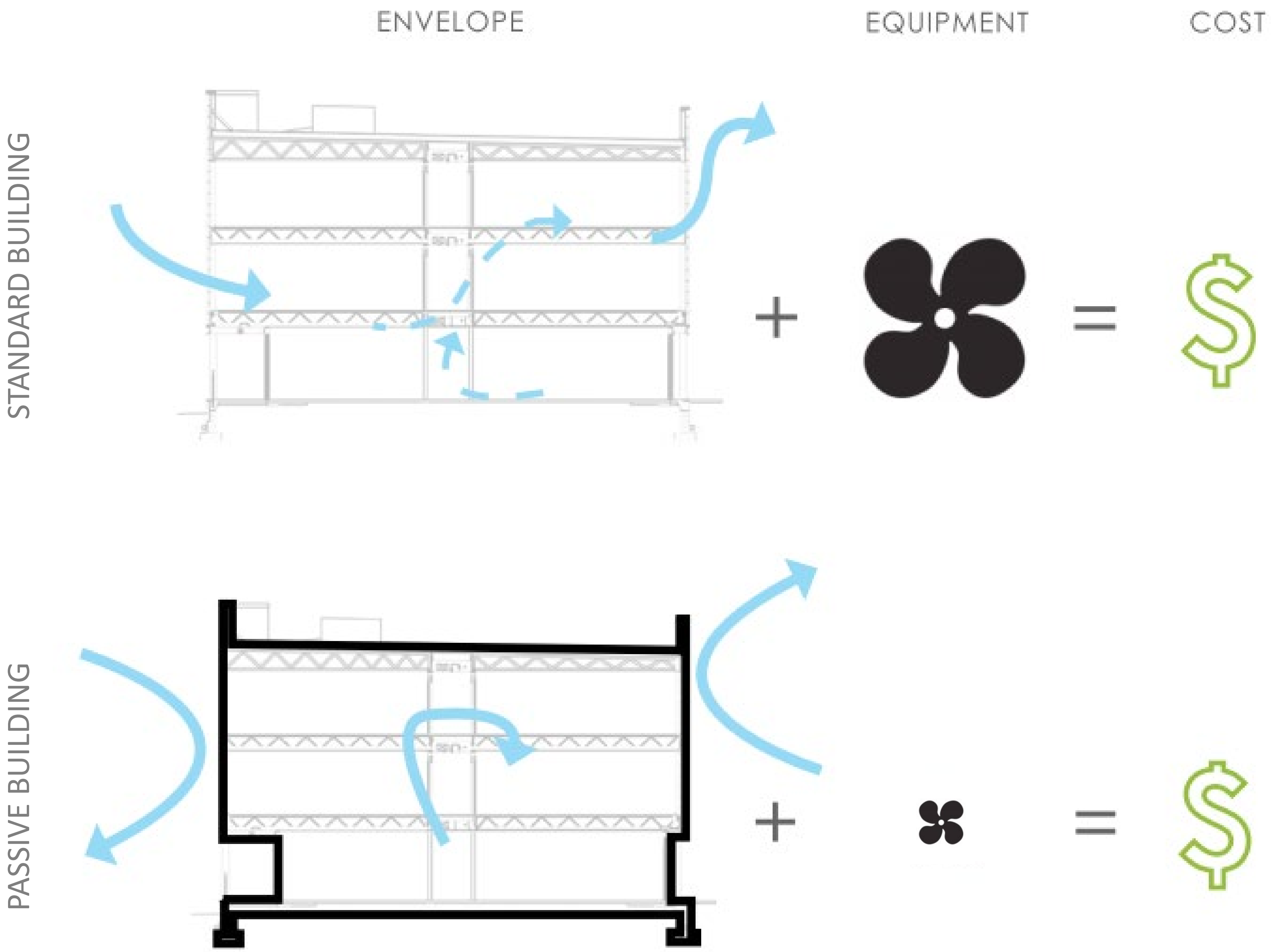
Loads for a Dorm in Virginia



Loads for a Dorm in Virginia



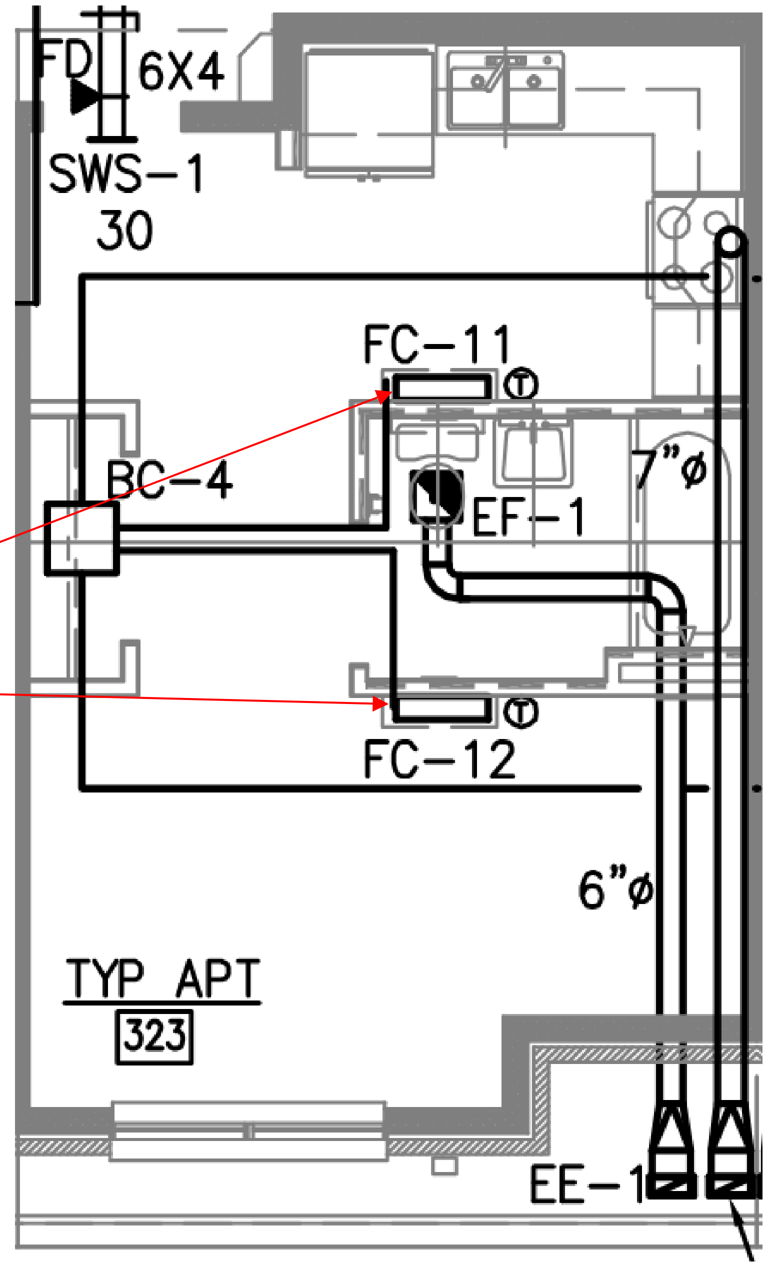
~55% Cooling Load Reduction


ENVELOPE
EQUIPMENT
COST
STANDARD BUILDING
PASSIVE BUILDING
+
=
+
=

Right-Sized Equipment

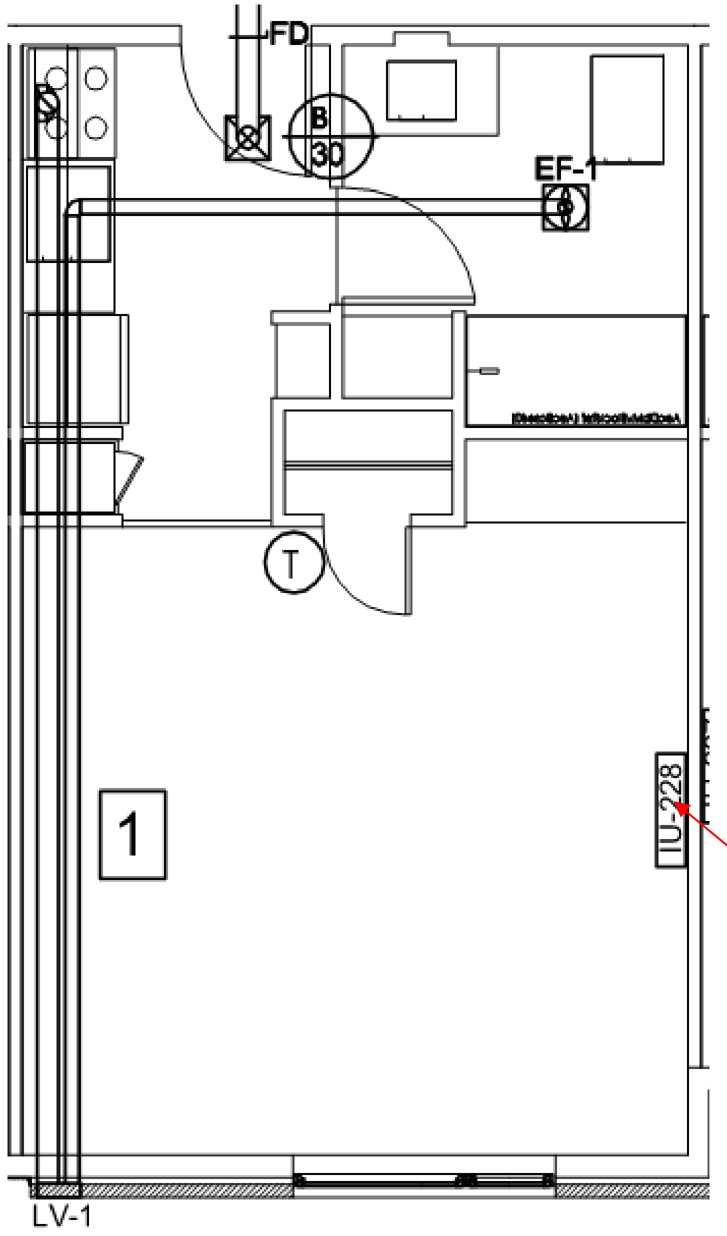
Lower First Cost - Lower Energy Cost - Better Humidity Control

2 Units, 17,100 BTU/hr unit serves 350 sqft ~ 245 sqft/ton



Standard

367 sqft/ton HVAC Cost: ~$20 / sqft



1,400 sqft/ton HVAC Cost: ~$11 / sqft

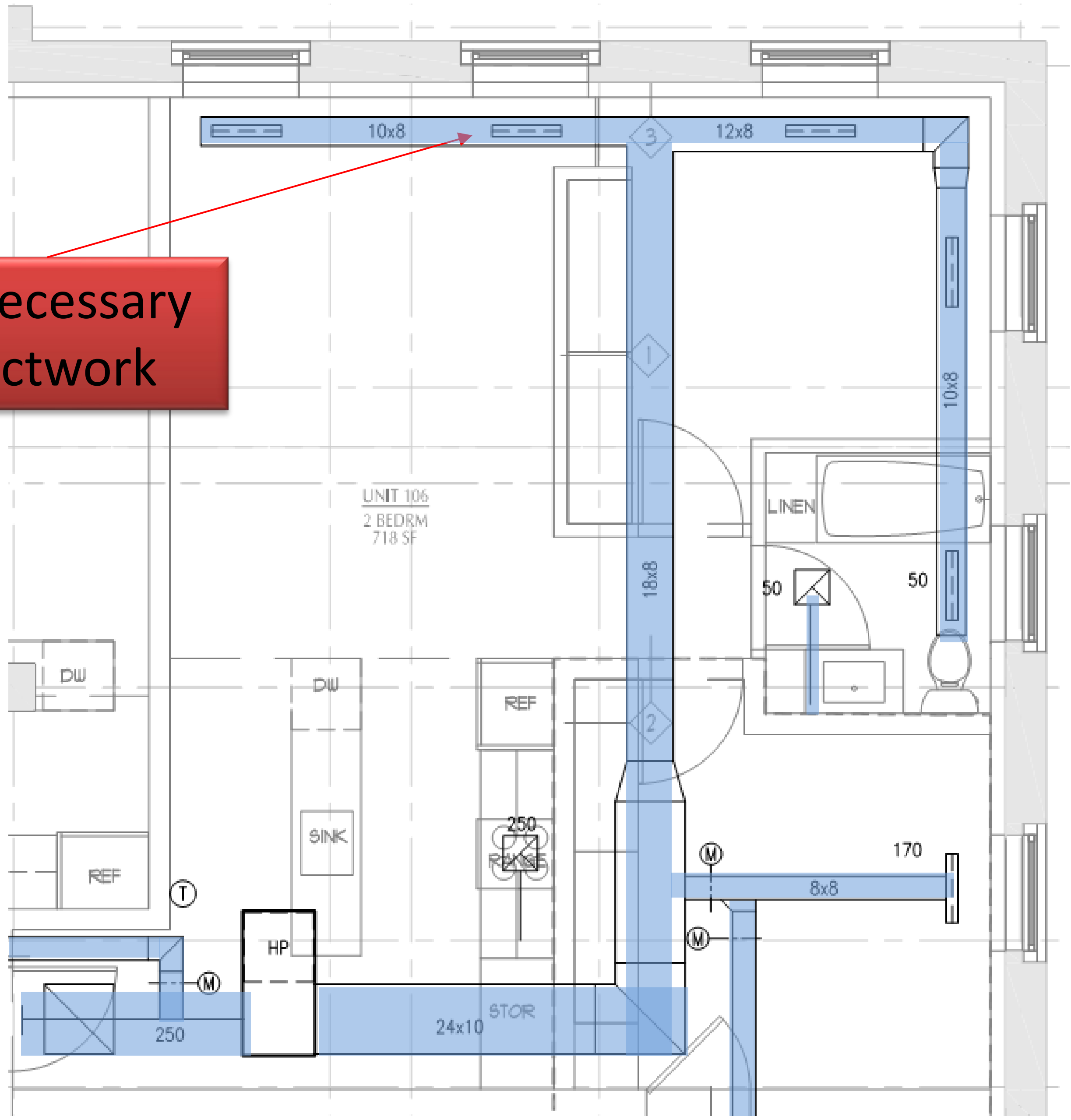
1 – 6,000 BTU/hr unit serves 350 sqft ~ 700 sqft/ton

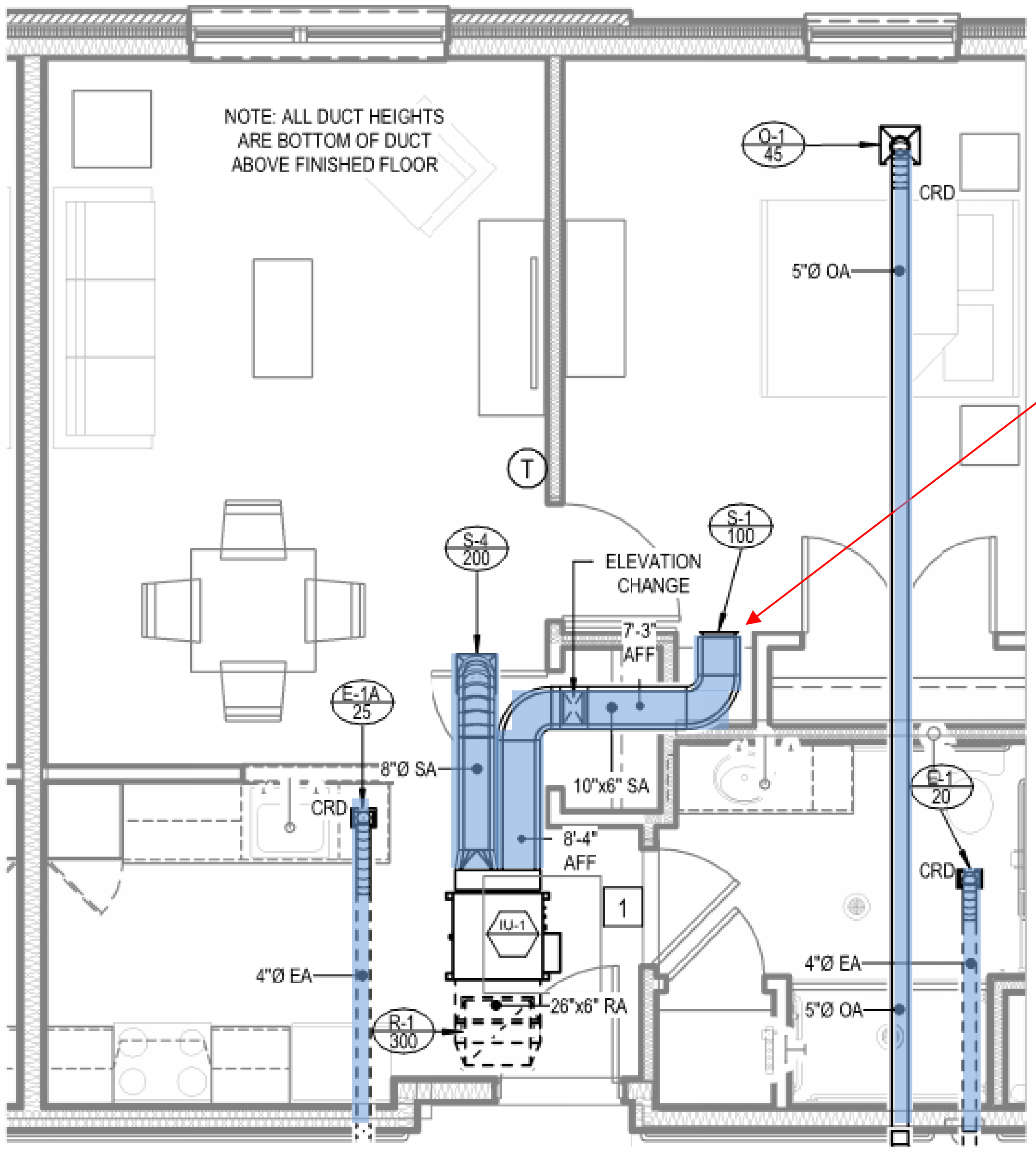
Passive House Building

Low Static Pressure Design

Less ductwork / low static pressure design. → **Lower First Cost - Lower Energy Cost**

Unnecessary Ductwork



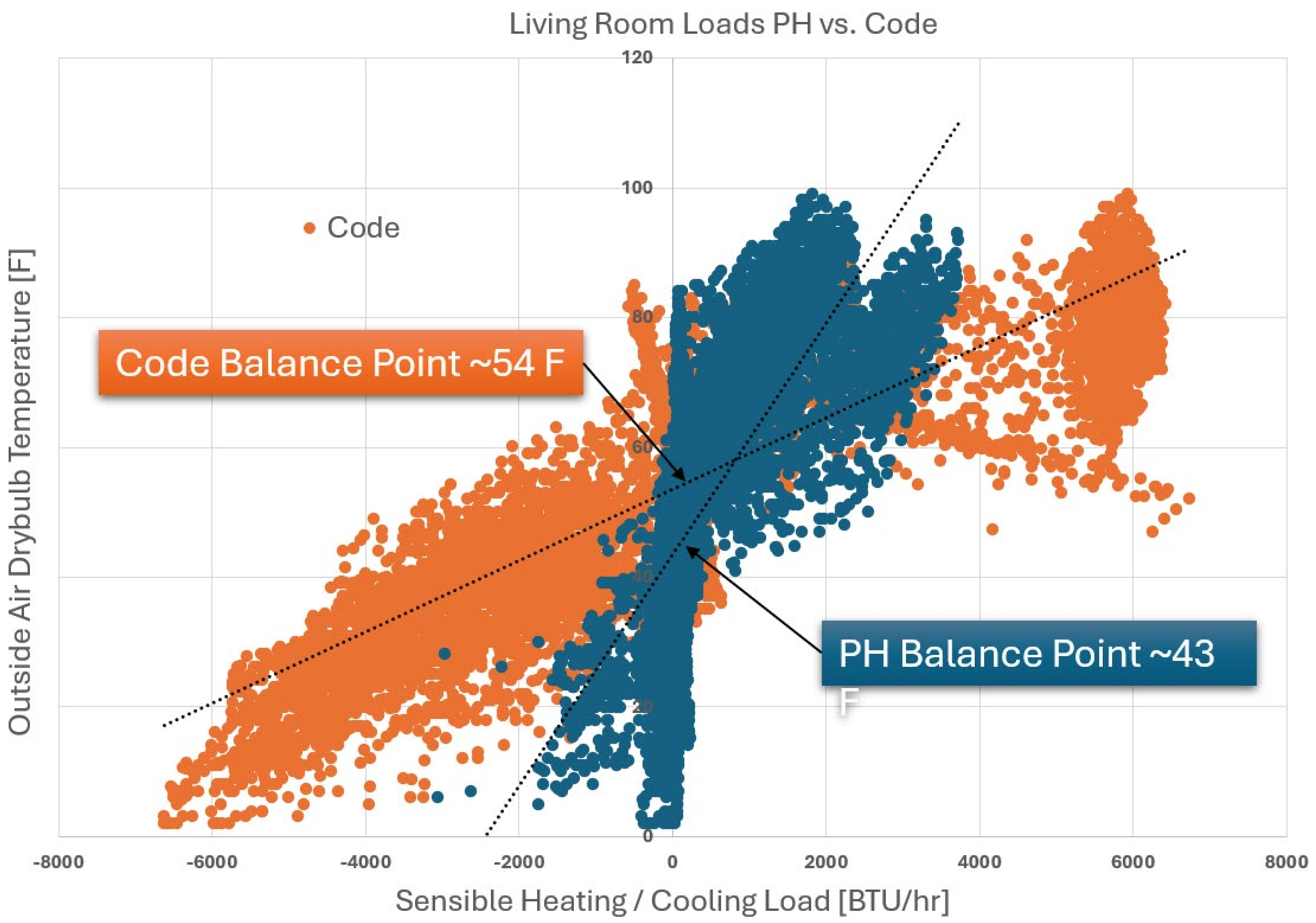


Passive Envelope eliminates need to heat at the perimeter

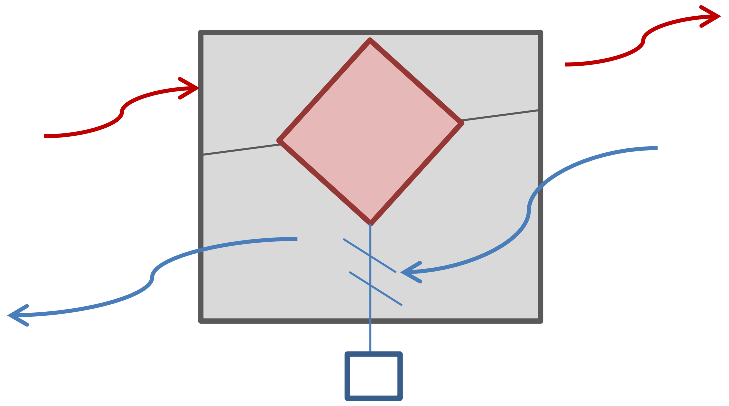
Standard

Passive House Building

The Load Shift

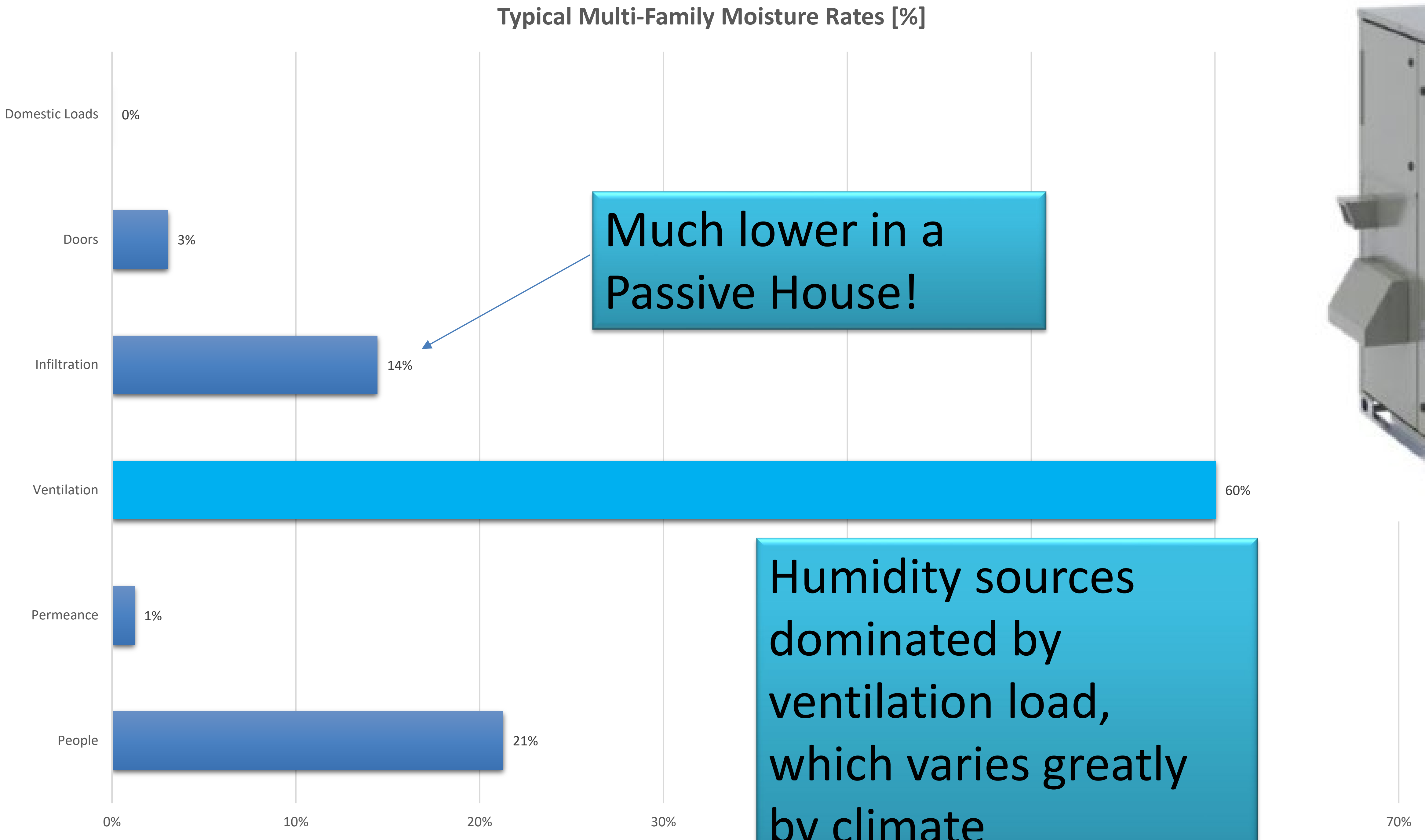


Advantageous for Ventilation System (Or Cooling System) to Economize!



ERV BYPASSES CORE TO ALLOW COOL FRESH AIR COOLS ROOMS DIRECTLY

Ventilation System
Climate Considerations



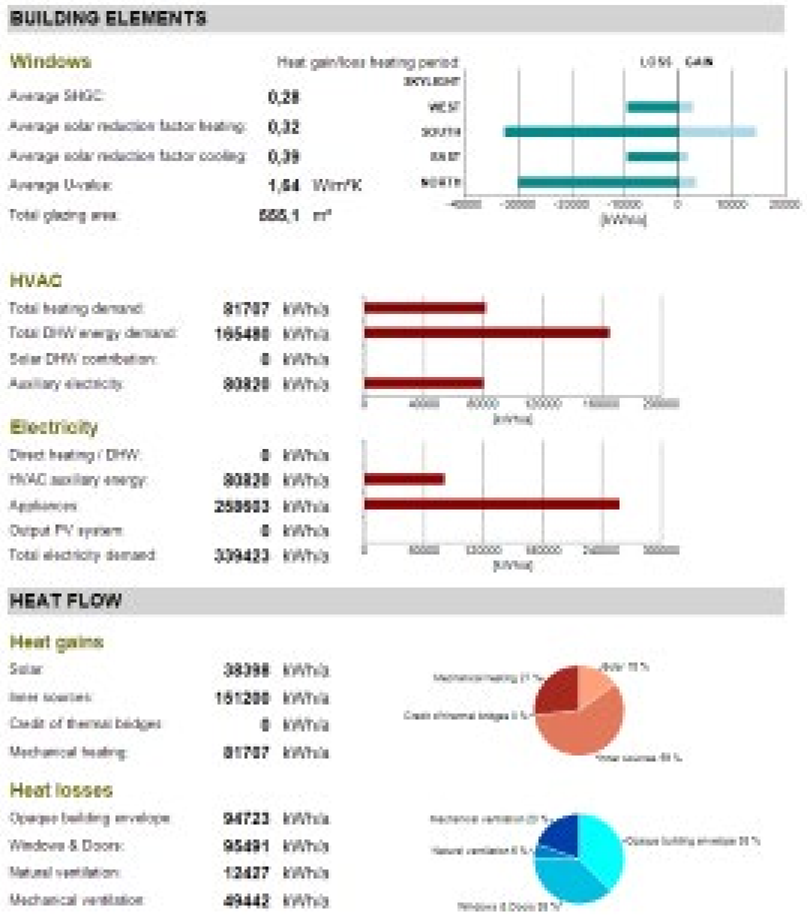
Much lower in a Passive House!

Humidity sources dominated by ventilation load, which varies greatly by climate

Define Loads – Envelope Loads

Energy Demands with Reference to the Treated Floor Area					
Treated Floor Area:	7243	ft^2			
	Applied:	Monthly Method	PH Certificate:		Fulfilled?
Specific Space Heat Demand:	**4.43**	**kBTU/(ft²yr)**	**4.75**	**kBTU/(ft²yr)**	**Yes**
Pressurization Test Result:	**0.60**	**ACH_{50}**	0.6	ACH_{50}	**Yes**
Specific Primary Energy Demand (DHW, Heating, Cooling, Auxiliary and Household Electricity):	**27.2**	**kBTU/(ft²yr)**	38.0	kBTU/(ft²yr)	**Yes**
Specific Primary Energy Demand (DHW, Heating and Auxiliary Electricity):	**7.0**	**kBTU/(ft²yr)**			
Specific Primary Energy Demand Energy Conservation by Solar Electricity:		**kBTU/(ft²yr)**			
Heating Load:	**4.30**	**BTU/(ft²hr)**			
Spec					

In Multi-Family Passive House, Cooling Loads are Dominated by Internal Gains!


BUILDING ELEMENTS

Windows

Heat gain/loss heating period

Average SHGC:	0,28	
Average solar reduction factor heating:	0,32	
Average solar reduction factor cooling:	0,39	
Average U-value:	1,64	W/m²K
Total glazing area:	555,1	m²

HVAC

Total heating demand:	81707	kWh/a
Total DHW energy demand:	165480	kWh/a
Solar DHW contribution:	0	kWh/a
Auxiliary electricity:	80820	kWh/a

Electricity

Direct heating / DHW:	0	kWh/a
HVAC auxiliary energy:	80820	kWh/a
Appliances:	258603	kWh/a
Output PV system:	0	kWh/a
Total electricity demand:	339423	kWh/a

HEAT FLOW

Heat gains

Solar:	38398	kWh/a
Inner sources:	151200	kWh/a
Credit of thermal bridges:	0	kWh/a
Mechanical heating:	81707	kWh/a

Heat losses

Opaque building envelope:	94723	kWh/a
Windows & Doors:	95491	kWh/a
Natural ventilation:	12427	kWh/a
Mechanical ventilation:	49442	kWh/a

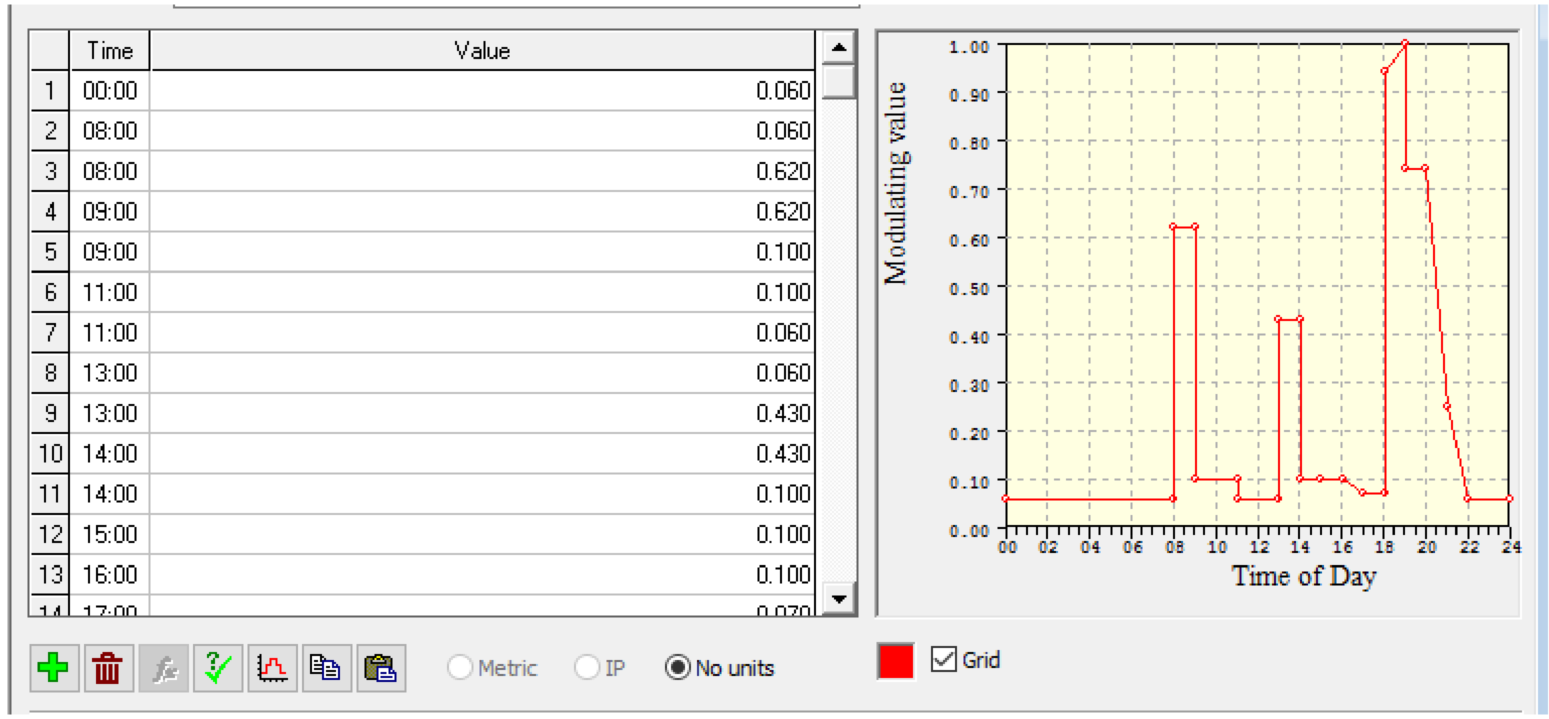
Define Loads – Internal Loads

- In Multi-Family Passive House in Cooling Climates, internal loads determine equipment sizing
- The same is true for higher density commercial building types
- In these buildings, only a small amount of solar gain is useful.

Define Loads – Occupancy Loads & Profiles

	2	3	4	5	6	7	8	9	10	11
	Utilization Pattern		Periods of Utilization and Operation	Begin Utilization [hr]	End Utilization [hr]	Daily Utilization Hours [hr/day]	Annual Utilization Days [day/yr]	Annual Utilization Hours [hr/yr]	Annual Utilization Hours During Daytime [hr/yr]	Annual Utilization Hours During Nighttime [hr/yr]
1	Sanctuary			18	22	4	55	220	1	219
2	Merkaz			5	22	17	300	5100	3604	1496
3	Office			7	18	11	300	3300	3171	129
4	Conference			8	10	2	65	130	130	0
5	WIC			8	10	2	65	130	130	0
6	Baths			8	10	2	365	730	730	0
7	Kitchen			16	20	4	55	220	111	109

- A good understanding of building use profiles allows proper estimation of diversity, and can help point to cost effective system strategies.



Define Loads
Detailed Equipment Loads

Define Loads
Detailed Equipment Loads

Room	Area (ft^2)	Loads	Load Consumption	UOM	ASHRAE Heat Gain (btuh)				
					Rated	Standby	1	2	3
Kitchen / LR	700	Refrigerator	295	watts/hr		1008	0.25	0.25	0.25
		Dishwasher	32	watts/hr	1302		0	0	0
		Electric Oven	55	watts/hr	8189		0	0	0
		Range - Induction	112	watts/hr	9167		0	0	0
		Microwave	67	watts/hr	10900		0	0	0
		Toaster	33	watts/hr	18080		0	0	0
		Coffee Maker	4	watts/hr	3413	0	0	0	0
		Range Hood Fan	4	watts/hr	341	0	0	0	0
		Computer	15	watts/hr	222	15	0	0	0
		Printer	4	watts/hr	61	14	0	0	0
		Monitor	5	watts/hr	92	3	0	0	0
		Modem\Router\DVR	40	watts/hr	0	136	1	1	1
		TV	8	watts/hr	92	10	0	0	0
		Max Load	**2.90**	**w/sqft**			**12**	**12**	**12**
		Max Load	**2.03**	**kW**	**Schedule %**		**0.6%**	**0.6%**	**0.6%**

Define Loads
Detailed Equipment Loads

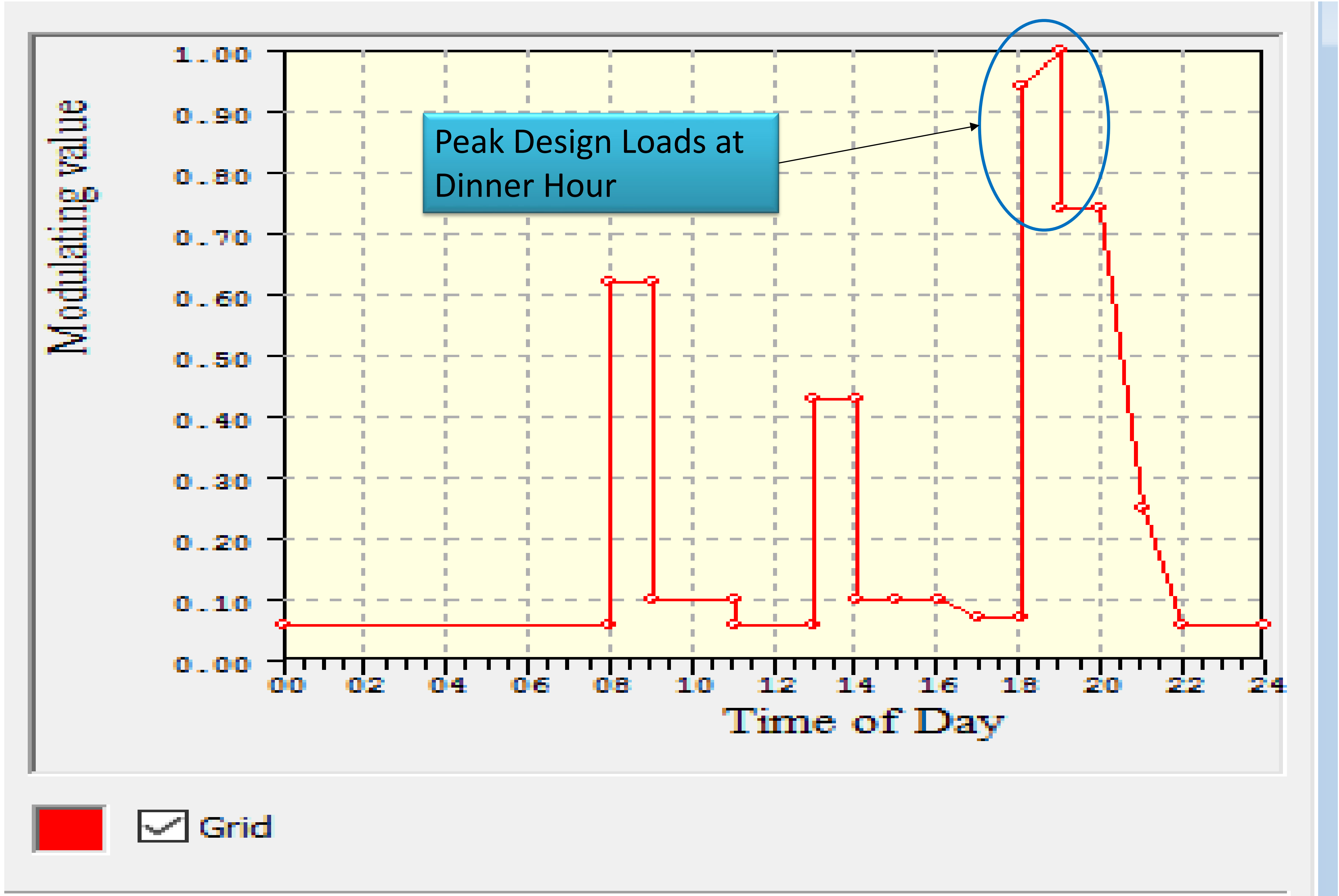
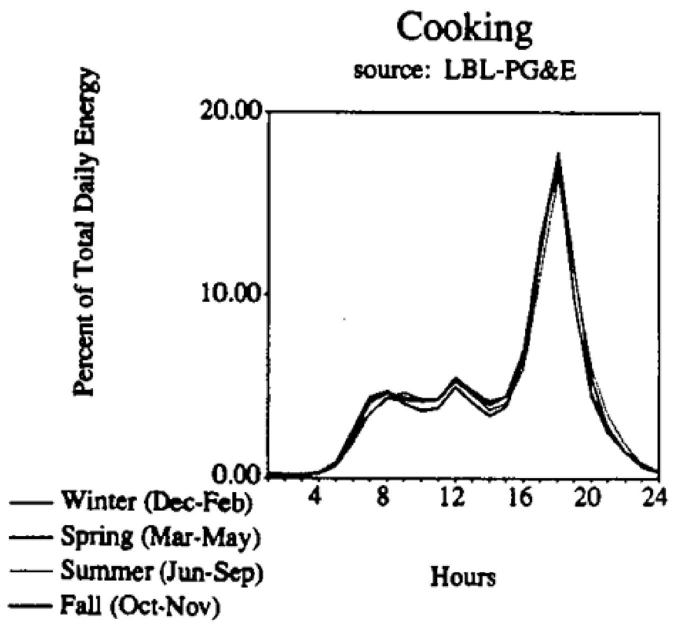
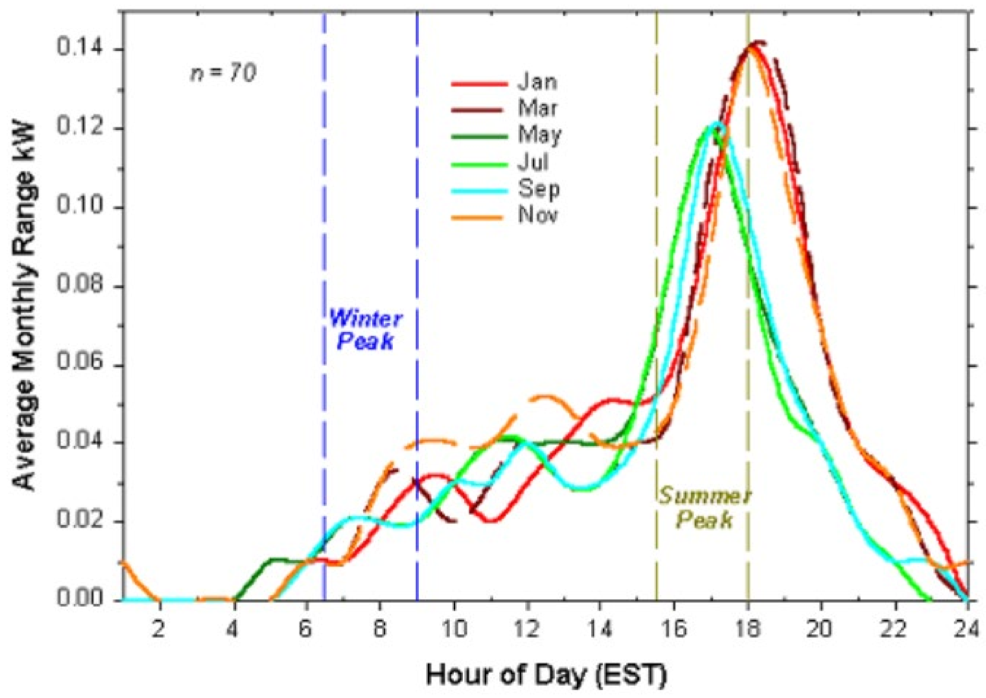
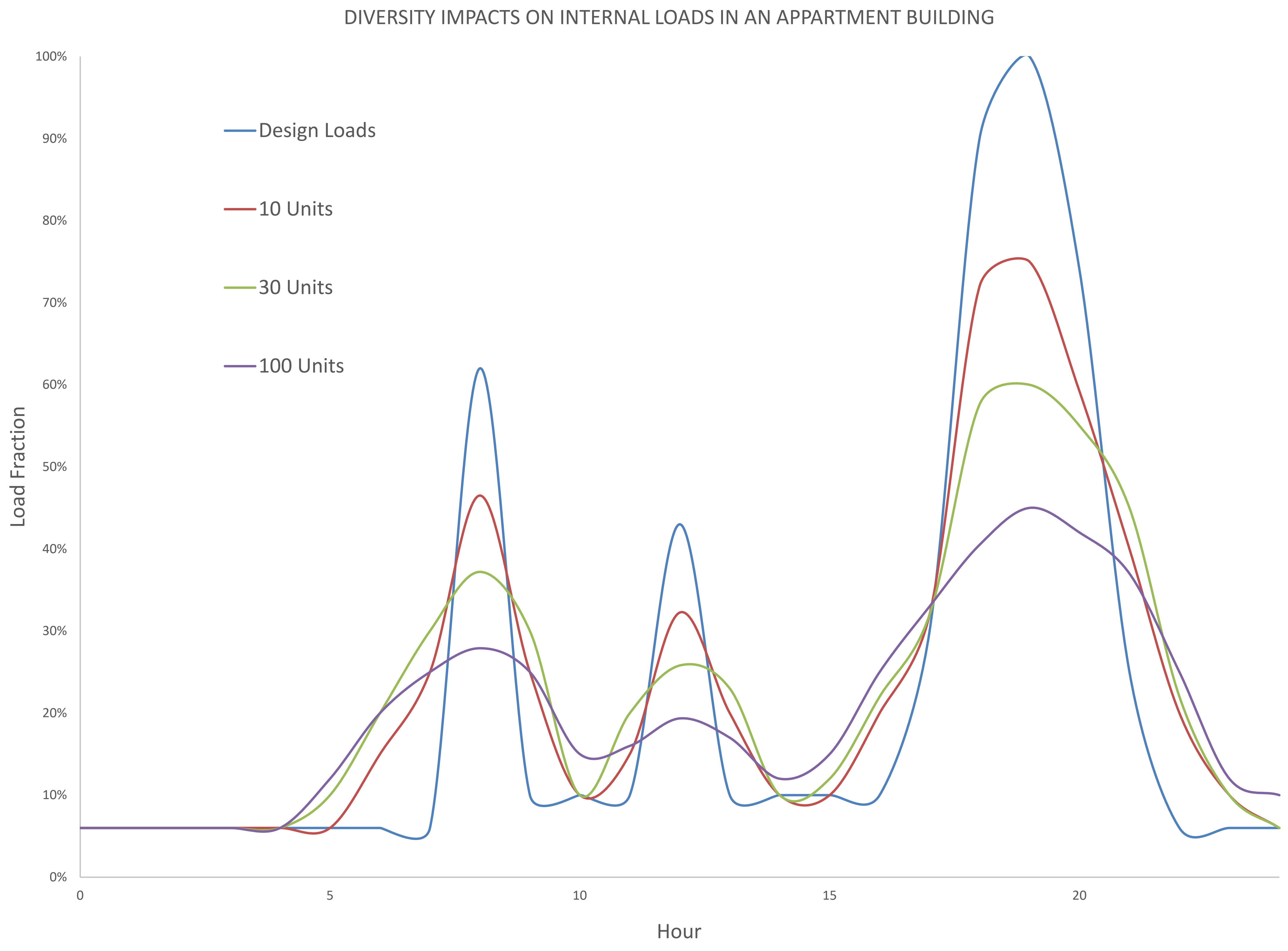


Figure 4. Daily Load Shape - Cooking
source: LBL-PG&E



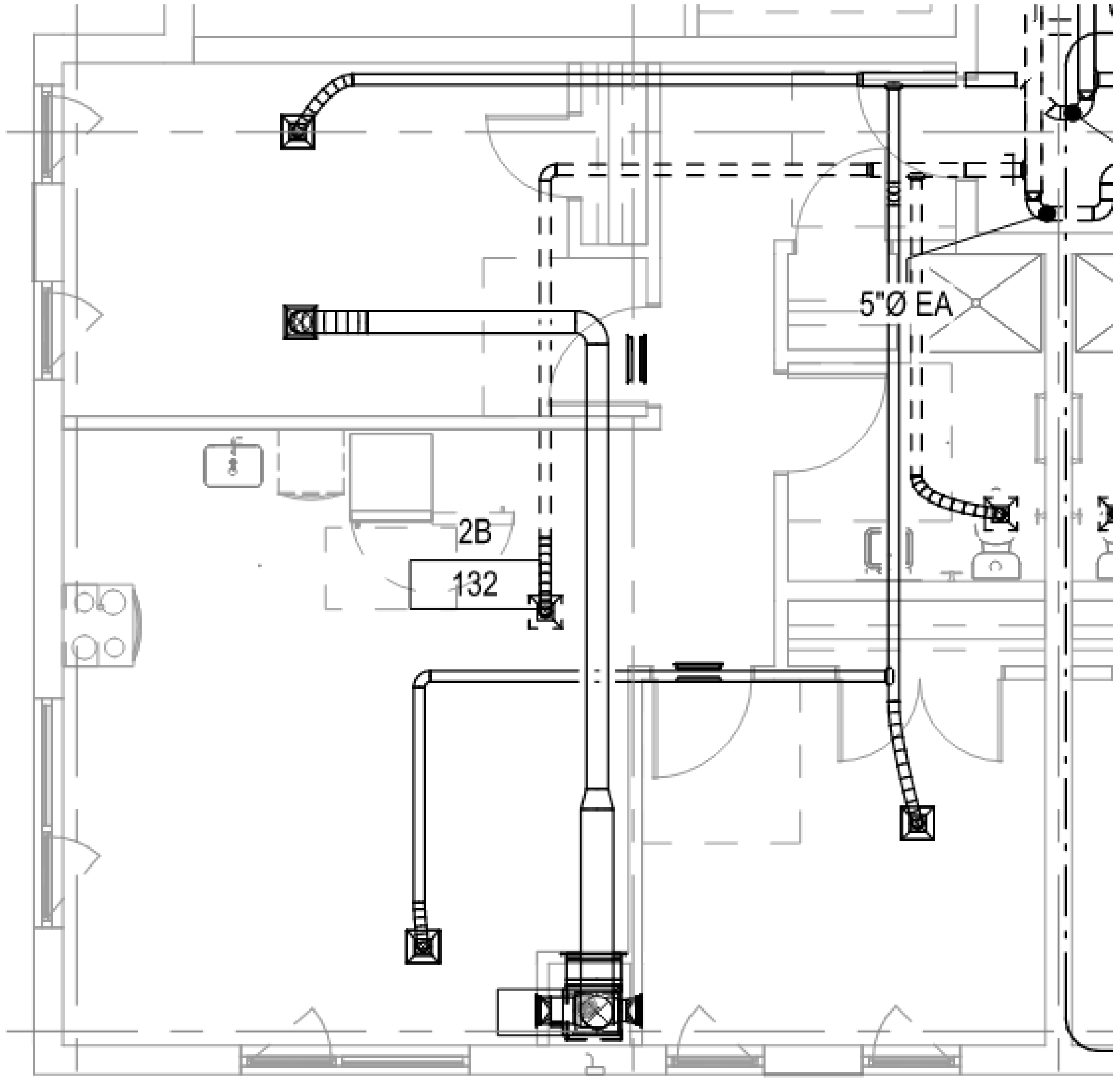


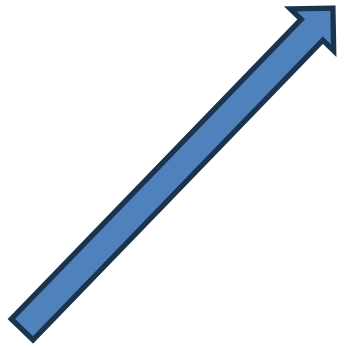
Load Diversity



MF Load Calculation Example

- 2 BR Apartment in Massachusetts – 937 Sq.Ft.
- Low Income – Family Housing
- SW/SE Exposure





Baseline Building Loads

COOLING

	Baseline	Unit	Load (BTU/hr) Sensible	Latent
Lighting	0.6	W/sqft	1,919	-
Appliances (Manual J)			1,200	240
People	3		735	465
Ventilation	45	cfm	713	576
Infiltration	86	cfm	1,358	1,097
Solar Gain			7,719	
Conduction Gain			1,729	
TOTAL COOLING			**15,373**	**2,378**

HEATING

	Baseline	Unit	Load (BTU/hr) Sensible	Latent
Lighting	0.6	W/sqft		
Appliances (Manual J)				
People	3			
Ventilation	45	cfm	3,262	
Infiltration	86	cfm	6,231	
Solar Gain				
Conduction Gain			9,874	
TOTAL HEATING			**19,367**	-

Looks like a 2 ton indoor unit! - Driven by heating loads.

Phius Building Loads

COOLING

	Phius	Unit	Load (BTU/hr) Sensible	Latent
Lighting	0.38	W/sqft	1,215	-
Appliances (Manual J)			1,200	240
People	3		735	465
Ventilation	45	cfm		
Infiltration	18	cfm	282	228
Solar Gain			5,428	
Conduction Gain			1,057	
TOTAL COOLING			**9,917**	**933**

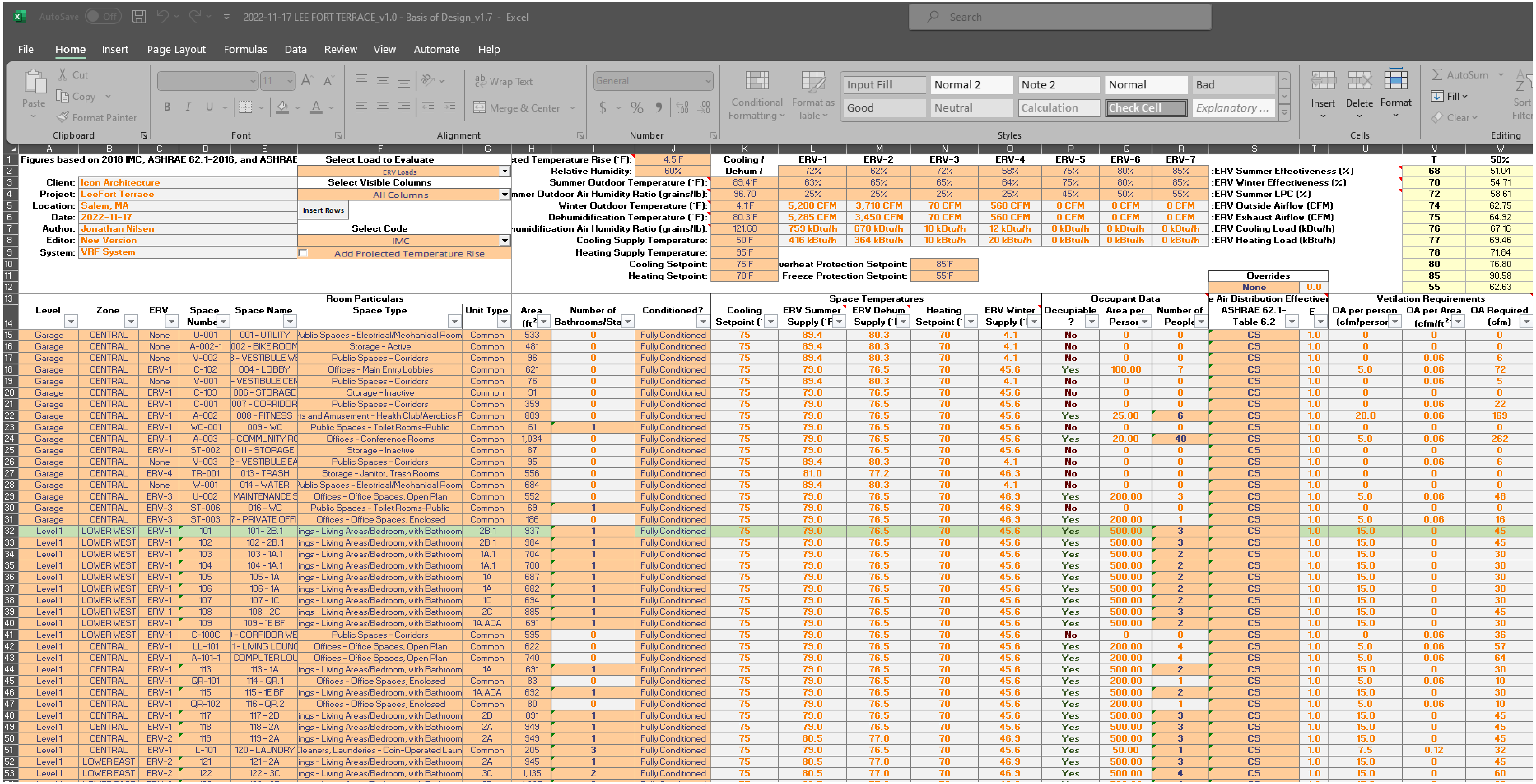
HEATING

	Phius	Unit	Load (BTU/hr) Sensible	Latent
Lighting	0.38	W/sqft		
Appliances (Manual J)				
People	3			
Ventilation	45	cfm		
Infiltration	18	cfm	1,246	
Solar Gain				
Conduction Gain			5,517	
TOTAL HEATING			**6,763**	**-**

1 ton indoor unit? - Cooling design capacity is 2x heating load.

Can we get to 9,000 BTU/hr?

Load Calculations



2022-11-17 LEE FORT TERRACE_v1.0 - Basis of Design_v1.7 - Excel

	A–E	F	H–I	J	K	L	M	N	O	P	Q	R	S	T	V	W
1	Figures based on 2018 IMC, ASHRAE 62.1-2016, and ASHRAE	Select Load to Evaluate	ted Temperature Rise (°F):	4.5°F	Cooling /	ERV-1	ERV-2	ERV-3	ERV-4	ERV-5	ERV-6	ERV-7			T	50%
2		ERV Loads	Relative Humidity:	60%	Dehum /	72%	62%	72%	58%	75%	80%	85%	:ERV Summer Effectiveness (%)		68	51.04
3	Client: Icon Architecture	Select Visible Columns	Summer Outdoor Temperature (°F):		89.4°F	63%	65%	65%	64%	75%	80%	85%	:ERV Winter Effectiveness (%)		70	54.71
4	Project: LeeFort Terrace	All Columns	mmer Outdoor Air Humidity Ratio (grains/lb):		96.70	25%	25%	25%	25%	45%	50%	55%	:ERV Summer LPC (%)		72	58.61
5	Location: Salem, MA	Insert Rows	Winter Outdoor Temperature (°F):		4.1°F	5,200 CFM	3,710 CFM	70 CFM	560 CFM	0 CFM	0 CFM	0 CFM	:ERV Outside Airflow (CFM)		74	62.75
6	Date: 2022-11-17		Dehumidification Temperature (°F):		80.3°F	5,285 CFM	3,450 CFM	70 CFM	560 CFM	0 CFM	0 CFM	0 CFM	:ERV Exhaust Airflow (CFM)		75	64.92
7	Author: Jonathan Nilsen	Select Code	umidification Air Humidity Ratio (grains/lb):		121.60	759 kBtu/h	670 kBtu/h	10 kBtu/h	12 kBtu/h	0 kBtu/h	0 kBtu/h	0 kBtu/h	:ERV Cooling Load (kBtu/h)		76	67.16
8	Editor: New Version	IMC	Cooling Supply Temperature:		50°F	416 kBtu/h	364 kBtu/h	10 kBtu/h	20 kBtu/h	0 kBtu/h	0 kBtu/h	0 kBtu/h	:ERV Heating Load (kBtu/h)		77	69.46
9	System: VRF System	Add Projected Temperature Rise	Heating Supply Temperature:		95°F										78	71.84
10			Cooling Setpoint:		75°F	verheat Protection Setpoint:		85°F							80	76.80
11			Heating Setpoint:		70°F	Freeze Protection Setpoint:		55°F					Overrides		85	90.58
12													None	0.0	55	62.63

Row	Level	Zone	ERV	Space Numbe	Space Name	Space Type	Unit Type	Area (ft²	Number of Bathrooms/Sta	Conditioned?	Cooling Setpoint (°	ERV Summer Supply (°F	ERV Dehum Supply (°	Heating Setpoint (°	ERV Winter Supply (°	Occupiable ?	Area per Persoı	Number of People	ASHRAE 62.1- Table 6.2	E	OA per person (cfm/persor	OA per Area (cfm/ft²	OA Required (cfm)
13						Room Particulars						Space Temperatures					Occupant Data		e Air Distribution Effective		Vetilation Requirements		
15	Garage	CENTRAL	None	U-001	001 - UTILITY	ublic Spaces - Electrical/Mechanical Room	Common	533	0	Fully Conditioned	75	89.4	80.3	70	4.1	No	0	0	CS	1.0	0	0	0
16	Garage	CENTRAL	None	A-002-1	002 - BIKE ROOM	Storage - Active	Common	481	0	Fully Conditioned	75	89.4	80.3	70	4.1	No	0	0	CS	1.0	0	0	0
17	Garage	CENTRAL	None	V-002	3 - VESTIBULE WE	Public Spaces - Corridors	Common	96	0	Fully Conditioned	75	89.4	80.3	70	4.1	No	0	0	CS	1.0	0	0.06	6
18	Garage	CENTRAL	ERV-1	C-102	004 - LOBBY	Offices - Main Entry Lobbies	Common	621	0	Fully Conditioned	75	79.0	76.5	70	45.6	Yes	100.00	7	CS	1.0	5.0	0.06	72
19	Garage	CENTRAL	None	V-001	- VESTIBULE CEN	Public Spaces - Corridors	Common	76	0	Fully Conditioned	75	89.4	80.3	70	4.1	No	0	0	CS	1.0	0	0.06	5
20	Garage	CENTRAL	ERV-1	C-103	006 - STORAGE	Storage - Inactive	Common	91	0	Fully Conditioned	75	79.0	76.5	70	45.6	No	0	0	CS	1.0	0	0	0
21	Garage	CENTRAL	ERV-1	C-001	007 - CORRIDOR	Public Spaces - Corridors	Common	359	0	Fully Conditioned	75	79.0	76.5	70	45.6	No	0	0	CS	1.0	0	0.06	22
22	Garage	CENTRAL	ERV-1	A-002	008 - FITNESS	ts and Amusement - Health Club/Aerobics F	Common	809	0	Fully Conditioned	75	79.0	76.5	70	45.6	Yes	25.00	6	CS	1.0	20.0	0.06	169
23	Garage	CENTRAL	ERV-1	WC-001	009 - WC	Public Spaces - Toilet Rooms-Public	Common	61	1	Fully Conditioned	75	79.0	76.5	70	45.6	No	0	0	CS	1.0	0	0	0
24	Garage	CENTRAL	ERV-1	A-003	- COMMUNITY RO	Offices - Conference Rooms	Common	1,034	0	Fully Conditioned	75	79.0	76.5	70	45.6	Yes	20.00	40	CS	1.0	5.0	0.06	262
25	Garage	CENTRAL	ERV-1	ST-002	011 - STORAGE	Storage - Inactive	Common	87	0	Fully Conditioned	75	79.0	76.5	70	45.6	No	0	0	CS	1.0	0	0	0
26	Garage	CENTRAL	None	V-003	2 - VESTIBULE EA	Public Spaces - Corridors	Common	95	0	Fully Conditioned	75	89.4	80.3	70	4.1	No	0	0	CS	1.0	0	0.06	6
27	Garage	CENTRAL	ERV-4	TR-001	013 - TRASH	Storage - Janitor, Trash Rooms	Common	556	0	Fully Conditioned	75	81.0	77.2	70	46.3	No	0	0	CS	1.0	0	0	0
28	Garage	CENTRAL	None	W-001	014 - WATER	ublic Spaces - Electrical/Mechanical Room	Common	684	0	Fully Conditioned	75	89.4	80.3	70	4.1	No	0	0	CS	1.0	0	0	0
29	Garage	CENTRAL	ERV-3	U-002	MAINTENANCE S	Offices - Office Spaces, Open Plan	Common	552	0	Fully Conditioned	75	79.0	76.5	70	46.9	Yes	200.00	3	CS	1.0	5.0	0.06	48
30	Garage	CENTRAL	ERV-3	ST-006	016 - WC	Public Spaces - Toilet Rooms-Public	Common	69	1	Fully Conditioned	75	79.0	76.5	70	46.9	No	0	0	CS	1.0	0	0	0
31	Garage	CENTRAL	ERV-3	ST-003	7 - PRIVATE OFFI	Offices - Office Spaces, Enclosed	Common	186	0	Fully Conditioned	75	79.0	76.5	70	46.9	Yes	200.00	1	CS	1.0	5.0	0.06	16
32	Level 1	LOWER WEST	ERV-1	101	101 - 2B.1	ings - Living Areas/Bedroom, with Bathroom	2B.1	937	1	Fully Conditioned	75	79.0	76.5	70	45.6	Yes	500.00	3	CS	1.0	15.0	0	45
33	Level 1	LOWER WEST	ERV-1	102	102 - 2B.1	ings - Living Areas/Bedroom, with Bathroom	2B.1	984	1	Fully Conditioned	75	79.0	76.5	70	45.6	Yes	500.00	3	CS	1.0	15.0	0	45
34	Level 1	LOWER WEST	ERV-1	103	103 - 1A.1	ings - Living Areas/Bedroom, with Bathroom	1A.1	704	1	Fully Conditioned	75	79.0	76.5	70	45.6	Yes	500.00	2	CS	1.0	15.0	0	30
35	Level 1	LOWER WEST	ERV-1	104	104 - 1A.1	ings - Living Areas/Bedroom, with Bathroom	1A.1	700	1	Fully Conditioned	75	79.0	76.5	70	45.6	Yes	500.00	2	CS	1.0	15.0	0	30
36	Level 1	LOWER WEST	ERV-1	105	105 - 1A	ings - Living Areas/Bedroom, with Bathroom	1A	687	1	Fully Conditioned	75	79.0	76.5	70	45.6	Yes	500.00	2	CS	1.0	15.0	0	30
37	Level 1	LOWER WEST	ERV-1	106	106 - 1A	ings - Living Areas/Bedroom, with Bathroom	1A	682	1	Fully Conditioned	75	79.0	76.5	70	45.6	Yes	500.00	2	CS	1.0	15.0	0	30
38	Level 1	LOWER WEST	ERV-1	107	107 - 1C	ings - Living Areas/Bedroom, with Bathroom	1C	694	1	Fully Conditioned	75	79.0	76.5	70	45.6	Yes	500.00	2	CS	1.0	15.0	0	30
39	Level 1	LOWER WEST	ERV-1	108	108 - 2C	ings - Living Areas/Bedroom, with Bathroom	2C	885	1	Fully Conditioned	75	79.0	76.5	70	45.6	Yes	500.00	3	CS	1.0	15.0	0	45
40	Level 1	LOWER WEST	ERV-1	109	109 - 1E BF	ings - Living Areas/Bedroom, with Bathroom	1A.ADA	691	1	Fully Conditioned	75	79.0	76.5	70	45.6	Yes	500.00	2	CS	1.0	15.0	0	30
41	Level 1	LOWER WEST	ERV-1	C-100C	I - CORRIDOR WE	Public Spaces - Corridors	Common	595	0	Fully Conditioned	75	79.0	76.5	70	45.6	No	0	0	CS	1.0	0	0.06	36
42	Level 1	CENTRAL	ERV-1	LL-101	1 - LIVING LOUNG	Offices - Office Spaces, Open Plan	Common	622	0	Fully Conditioned	75	79.0	76.5	70	45.6	Yes	200.00	4	CS	1.0	5.0	0.06	57
43	Level 1	CENTRAL	ERV-1	A-101-1	COMPUTER LOU	Offices - Office Spaces, Open Plan	Common	740	0	Fully Conditioned	75	79.0	76.5	70	45.6	Yes	200.00	4	CS	1.0	5.0	0.06	64
44	Level 1	CENTRAL	ERV-1	113	113 - 1A	ings - Living Areas/Bedroom, with Bathroom	1A	691	1	Fully Conditioned	75	79.0	76.5	70	45.6	Yes	500.00	2	CS	1.0	15.0	0	30
45	Level 1	CENTRAL	ERV-1	QR-101	114 - QR.1	Offices - Office Spaces, Enclosed	Common	83	0	Fully Conditioned	75	79.0	76.5	70	45.6	Yes	200.00	1	CS	1.0	5.0	0.06	10
46	Level 1	CENTRAL	ERV-1	115	115 - 1E BF	ings - Living Areas/Bedroom, with Bathroom	1A.ADA	692	1	Fully Conditioned	75	79.0	76.5	70	45.6	Yes	500.00	2	CS	1.0	15.0	0	30
47	Level 1	CENTRAL	ERV-1	QR-102	116 - QR.2	Offices - Office Spaces, Enclosed	Common	80	0	Fully Conditioned	75	79.0	76.5	70	45.6	Yes	200.00	1	CS	1.0	5.0	0.06	10
48	Level 1	CENTRAL	ERV-1	117	117 - 2D	ings - Living Areas/Bedroom, with Bathroom	2D	891	1	Fully Conditioned	75	79.0	76.5	70	45.6	Yes	500.00	3	CS	1.0	15.0	0	45
49	Level 1	CENTRAL	ERV-1	118	118 - 2A	ings - Living Areas/Bedroom, with Bathroom	2A	949	1	Fully Conditioned	75	79.0	76.5	70	45.6	Yes	500.00	3	CS	1.0	15.0	0	45
50	Level 1	CENTRAL	ERV-2	119	119 - 2A	ings - Living Areas/Bedroom, with Bathroom	2A	949	1	Fully Conditioned	75	80.5	77.0	70	46.9	Yes	500.00	3	CS	1.0	15.0	0	45
51	Level 1	CENTRAL	ERV-1	L-101	120 - LAUNDRY	Cleaners, Launderies - Coin-Operated Laun	Common	205	3	Fully Conditioned	75	79.0	76.5	70	45.6	Yes	50.00	1	CS	1.0	7.5	0.12	32
52	Level 1	LOWER EAST	ERV-2	121	121 - 2A	ings - Living Areas/Bedroom, with Bathroom	2A	945	1	Fully Conditioned	75	80.5	77.0	70	46.9	Yes	500.00	3	CS	1.0	15.0	0	45
53	Level 1	LOWER EAST	ERV-2	122	122 - 3C	ings - Living Areas/Bedroom, with Bathroom	3C	1,135	2	Fully Conditioned	75	80.5	77.0	70	46.9	Yes	500.00	4	CS	1.0	15.0	0	60

Electrification – Space Heat / Cool

Air-to-Air

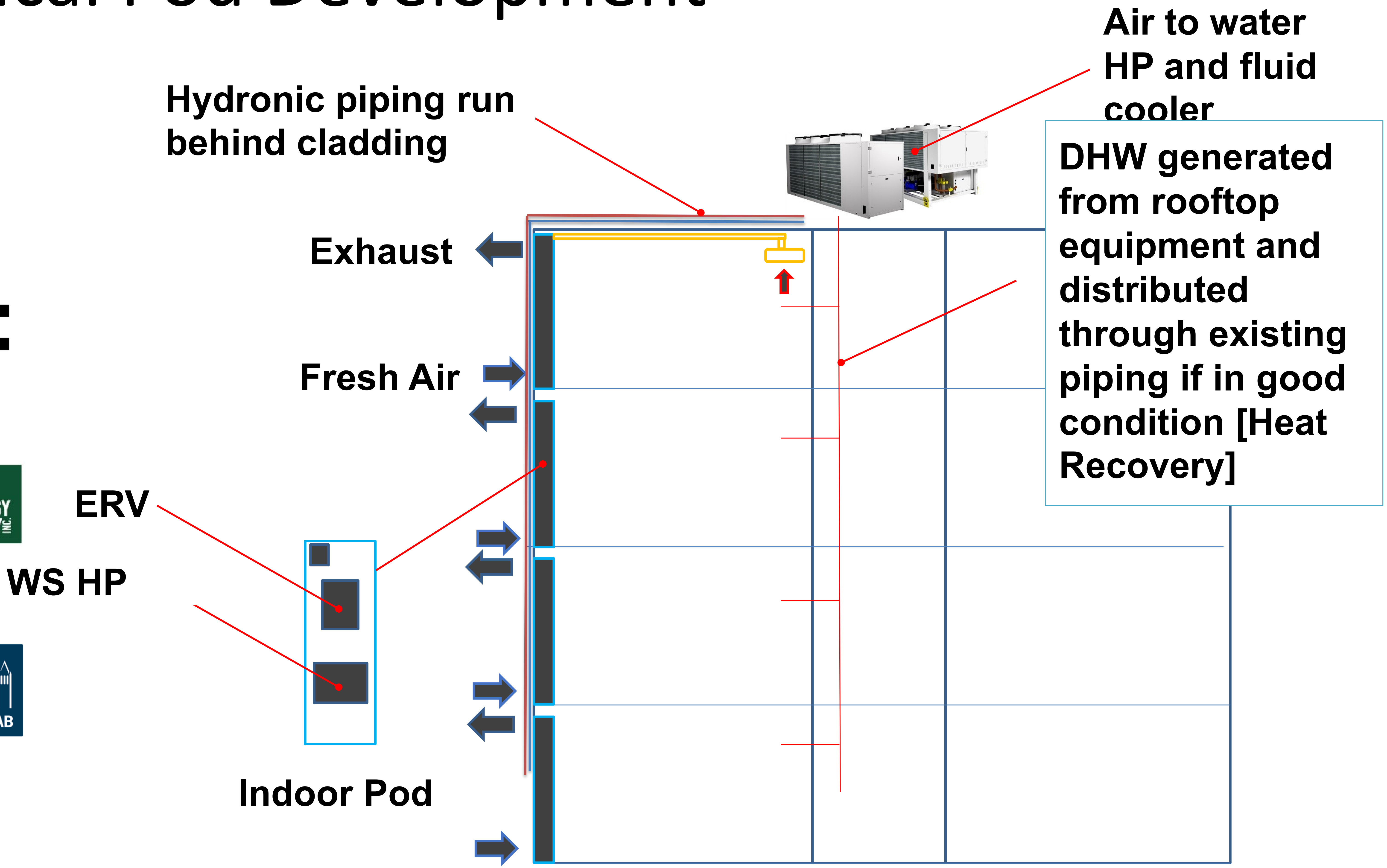
Air-to-Water

Water-to-

Water-to-Water

Electrification - DHW

Mechanical Pod Development



DISCUSSION/ QUESTIONS

DHW Deep Dive- James lead, Galen make additions at end

DHW is a tough nut to crack- here's what we know.

Cost of Energy

Electricity:

- Total cost in January: $5,060.29
- Total kWh use: 22200 kWh

$0.28/kWh

Gas:

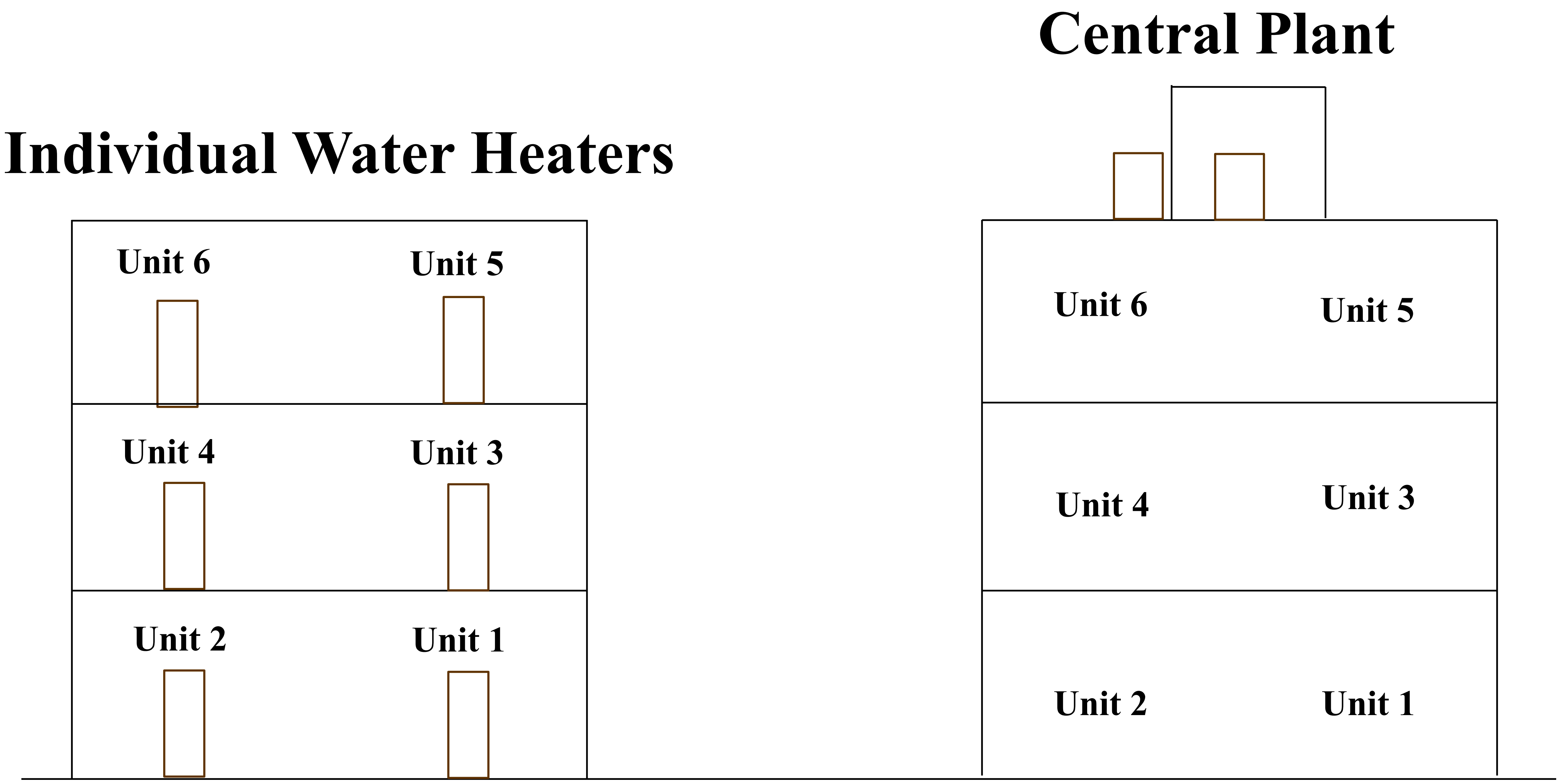
- Total cost in January: $5,542.46
- Total therm use: 3996 therms
  - $1.39/therm

$0.05/kWh

Electricity is 5.6 x more expensive than gas

Electric and Gas Cost for the Month of January 2024, Multi Family Building, New Bedford, MA

Individual Heaters vs Central Water Plant



Individual Heaters

Issues with local water heaters

- Take up space

Hybrid heat pump issues

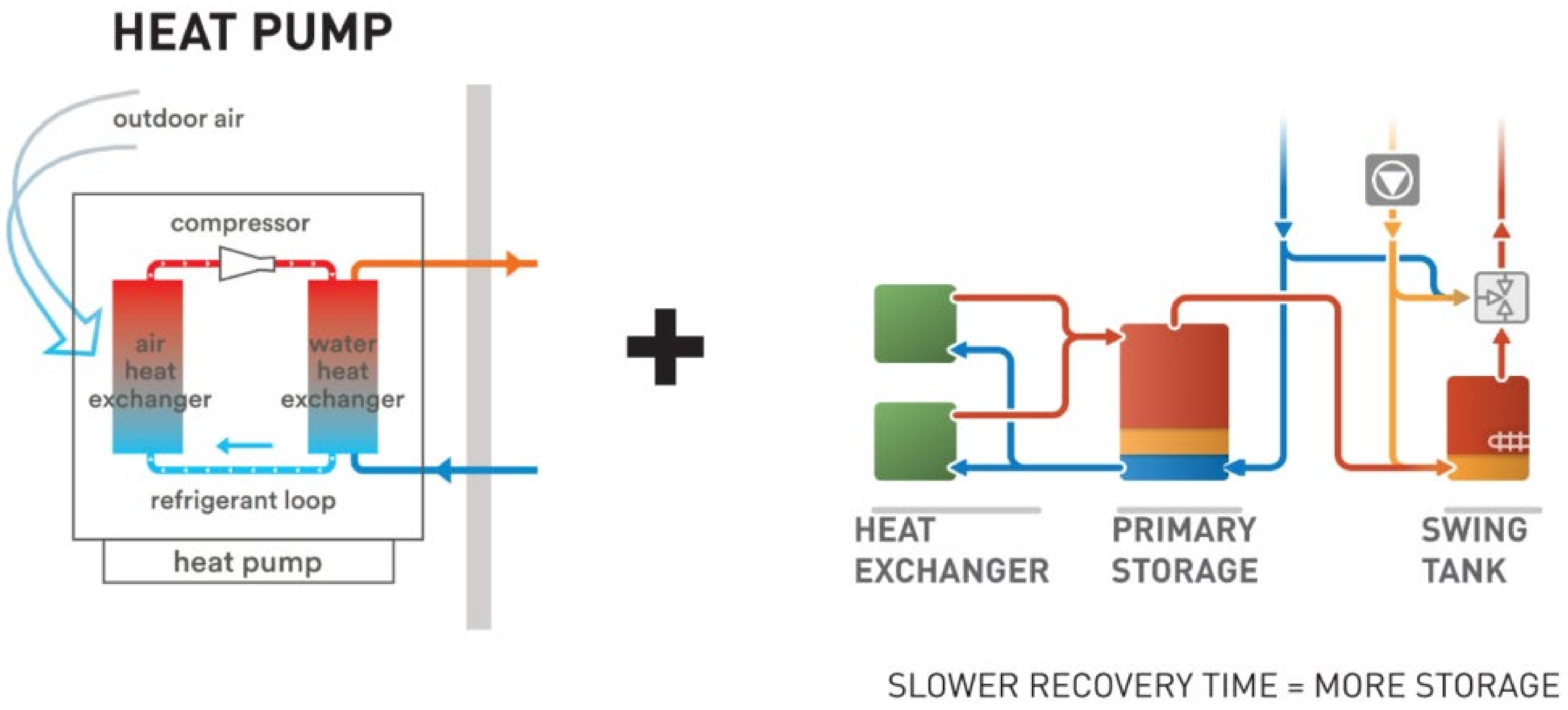
- Heat pumps in series
- Cold draft
- Better suited for commercial kitchens

There is no individual DHW solution that has a low operating cost.

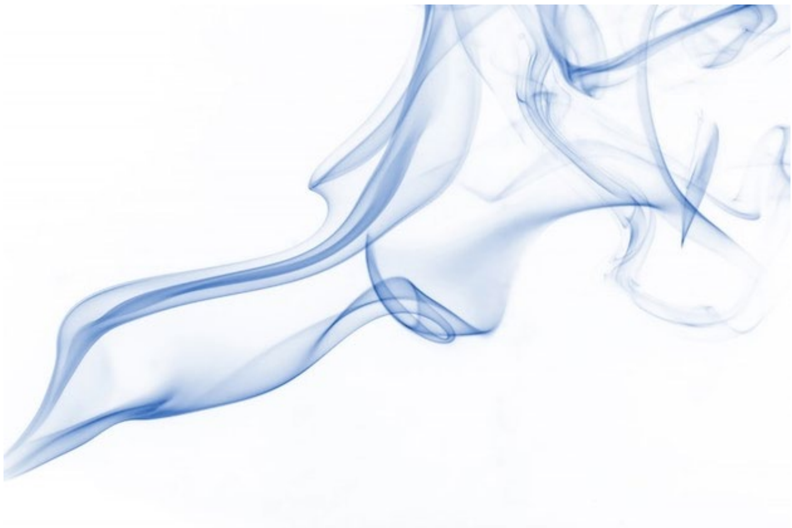
Central Plant

- CO_2 based
- **High upfront and operating cost compared to central gas plant**
- Chance for COP 2-3
- High temperature
- Low recovery/high storage
- New to market

Electric ASHP Domestic Hot Water Central System



Heat Capacity Water vs Air

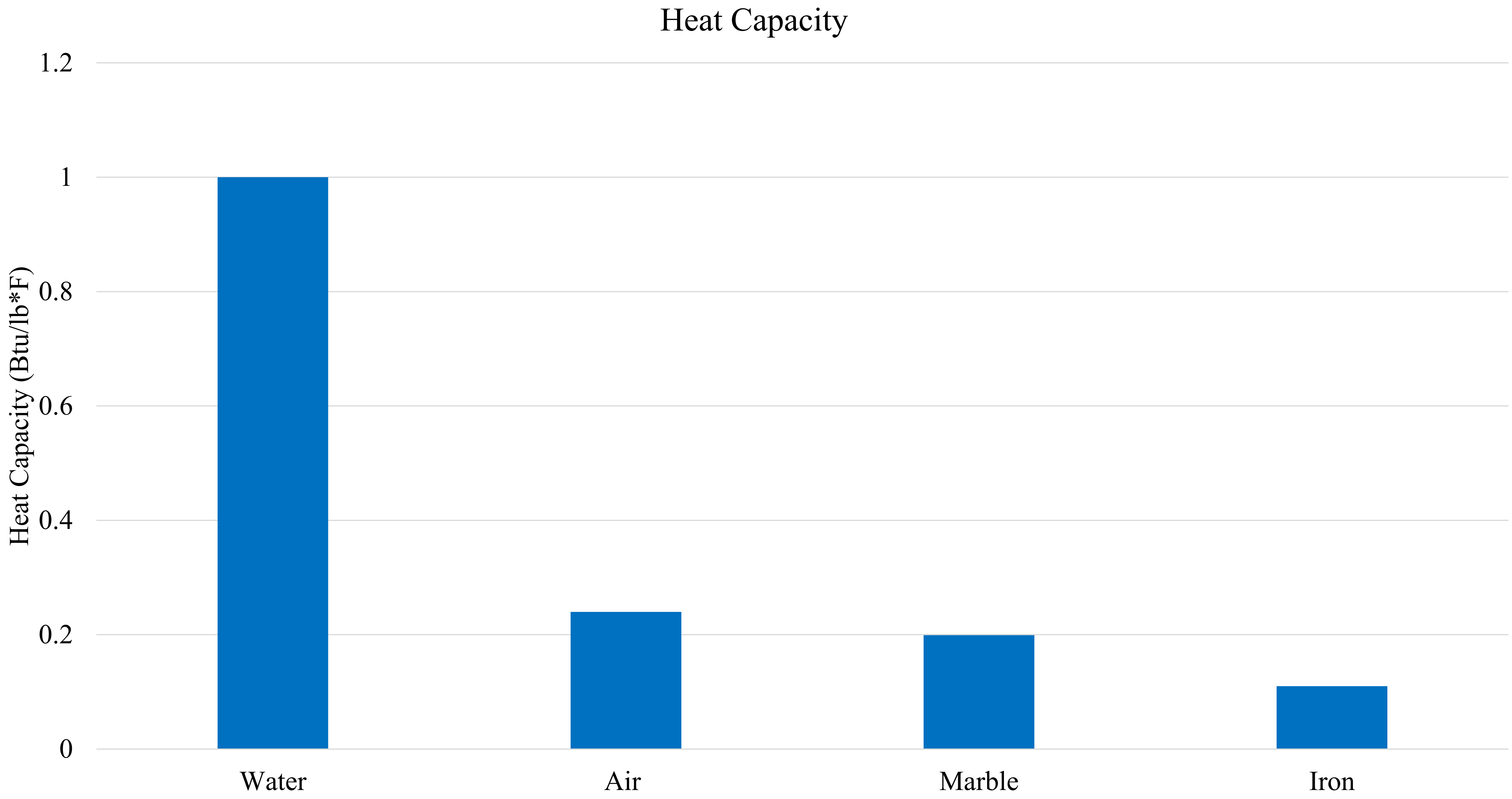


Heat capacity is the measure of energy required to raise a quantity of a substance by one temperature degree. Heat capacities for water and air:

Water: $\mathbf{\mathit{1}}\ \frac{BTU}{lb \cdot F}$ Air: $\mathbf{\mathit{0.24}}\ \frac{BTU}{lb \cdot F}$

The energy required to heat water is 4 x that of air! Therfore with a hybrid heat pump we need to move a lot of air.

Heat Capacity Comparison



Water has the highest heat capacity of any common substance!

Seasonal Water Temperature – MWRA

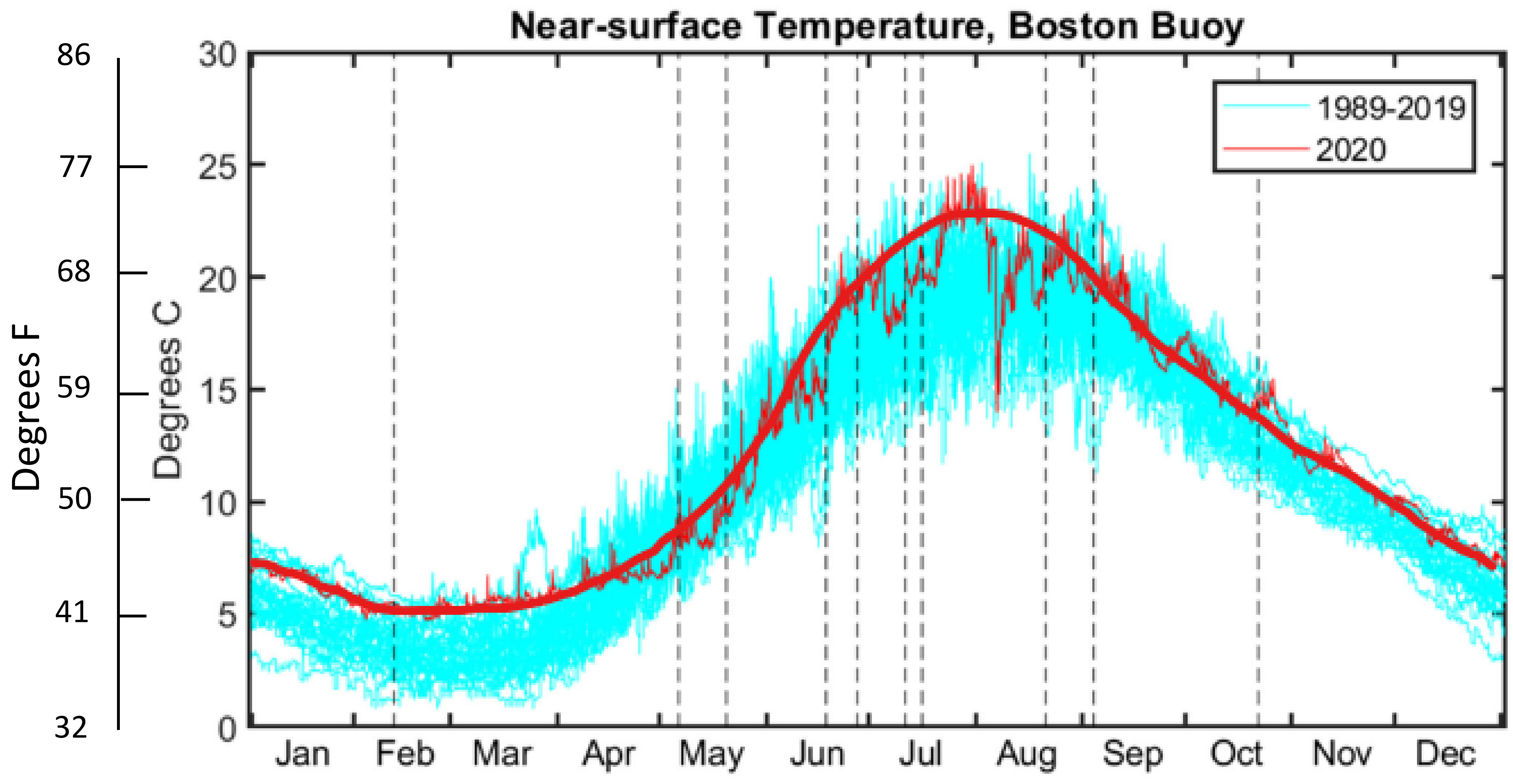
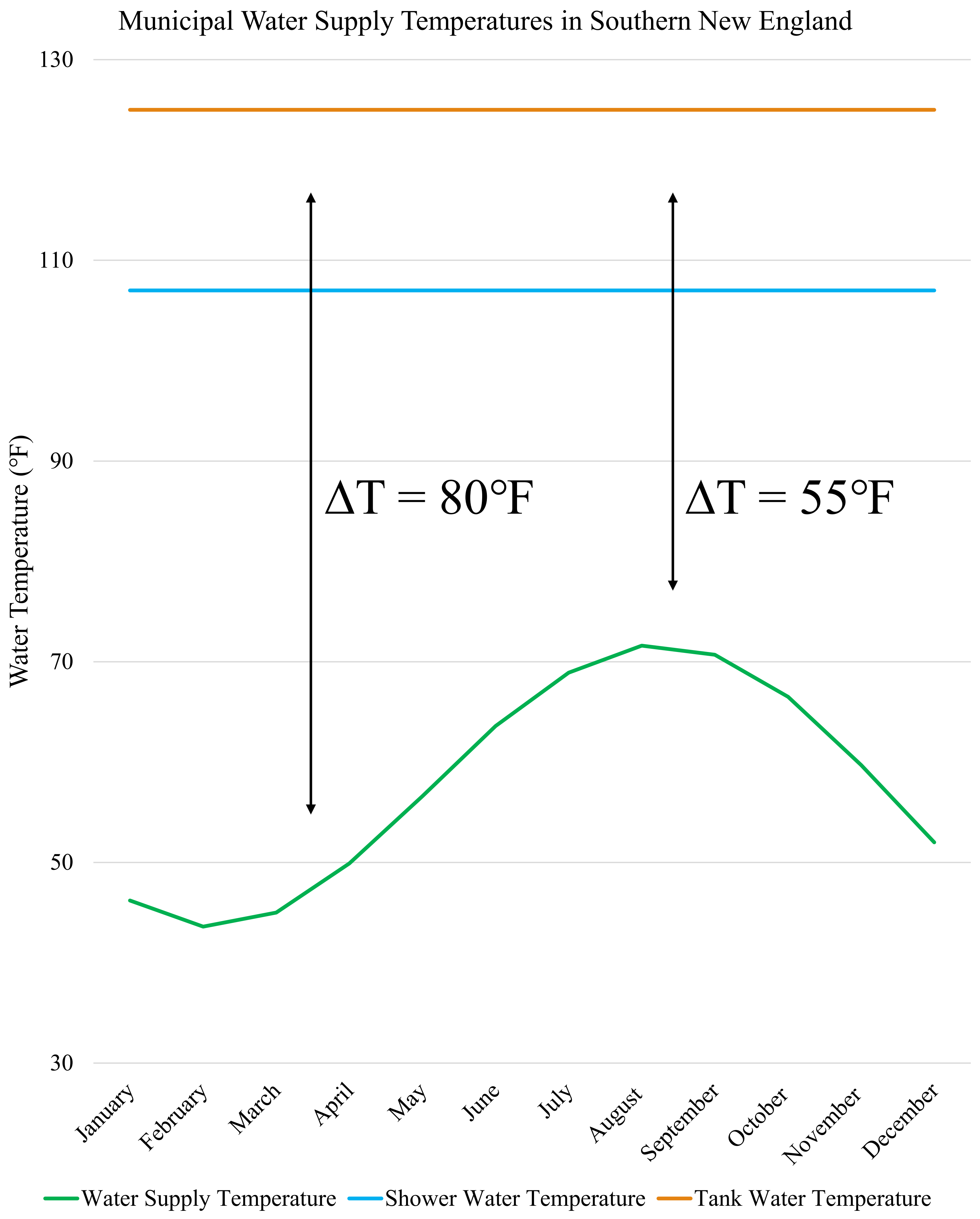


Figure 2-1. **Comparison of 2020 (solid red line) surface water temperature (°C) at Buoy 44013 ("Boston Buoy") in the vicinity of the nearfield with 1989-2019 (cyan lines).** The vertical dashed lines are when the 10 surveys were conducted in 2020.

Massachusetts Water Resources Authority Environmental Quality Department Report, October 2021

Seasonal Water Temperature – Mass Save Guidelines



Mass Save Hourly Simulation Guidelines: Version 2.4, January 2022

Hybrid Heat Pump Water Heaters = Cold Drafts

Summer Condition - What amount of energy is required to heat 20 gallons from 70°F to 125°F?

(Gallons) x (Temperature Difference) x (Specific Heat) x (Pounds/Gallon) = Energy

$$(20 \text{ gals}) \times (125°F - 70\ °F\ \Delta T) \times \left(1\ \frac{BTU}{lb \bullet F}\right) \times \left(8.33\ \frac{lb}{gal}\right) = 9,163\ BTUs$$

Summer Condition - What amount of energy is extracted from the apartment.

Total energy to heat the water: ***9,163 BTUs***

Portion of energy from electricity = ***(1/3) x 9,163 = 3,054 BTUs***

Portion of energy from apartment = ***(2/3) x 9,163 = 6,109 BTUs***

Assumes a COP of 3 water heater efficiency

Summer Condition - What is the HPWH run time when we heat 20 gallons from 70°F to 125 °F?

Assumptions:

1. 70 degrees F entering air temperature (EAT)
2. 55 degrees F leaving air temperature (LAT)
3. 9,163 BTUs moved from air to water
4. 200 CFM water heater fan volume

$$\frac{\text{Energy}}{[(\text{Volume/Time}) \times (\text{Temperature Difference}) \times (\text{Specific Heat}) \times (\text{Density})]} = \text{Time}$$

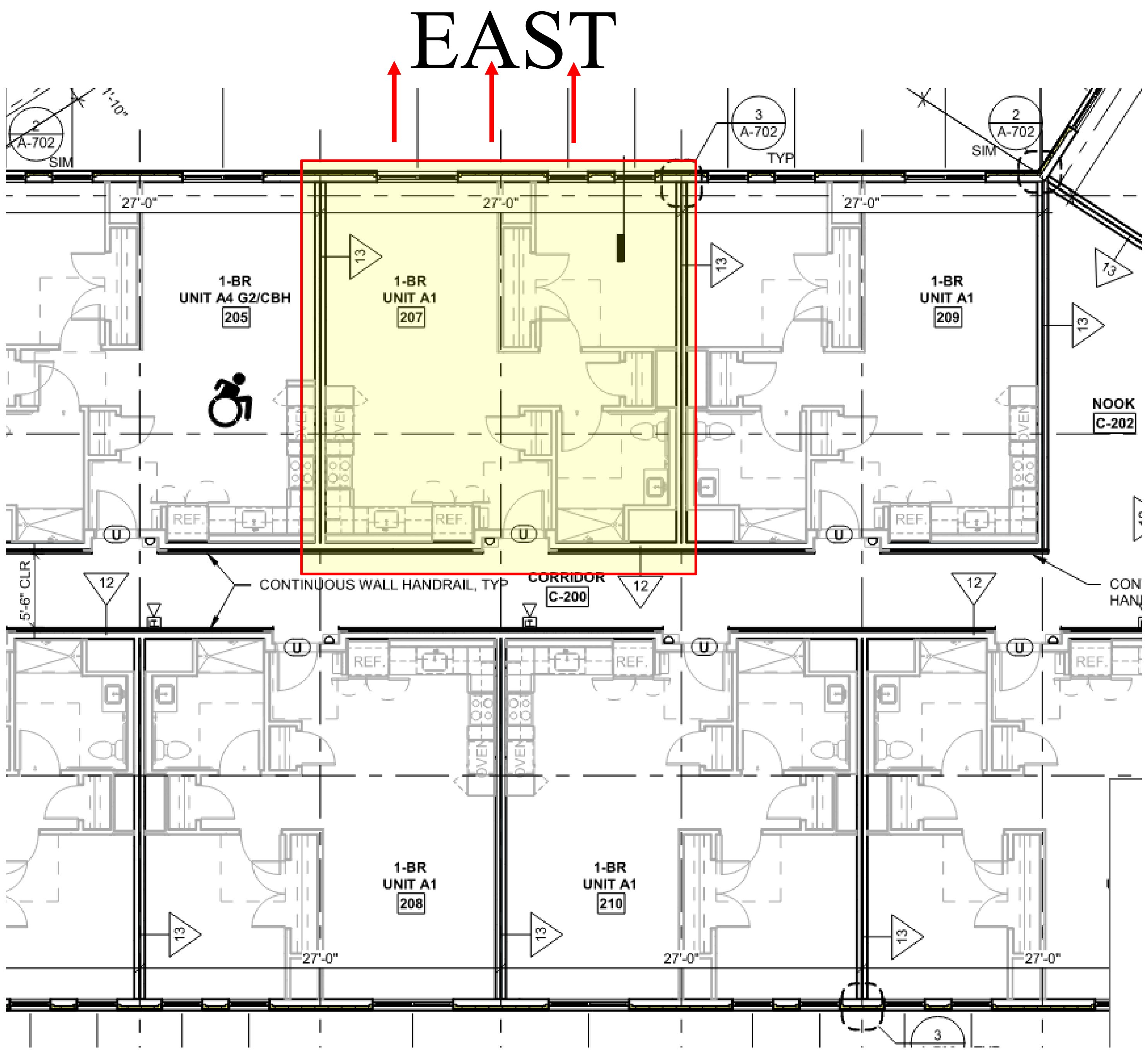
$$\frac{\mathit{9{,}163\ BTUs}}{(200\ \frac{ft^3}{min}) \times (70\ °F - 55\ °F) \times (0.24\ \frac{BTU}{lb \cdot F}) \times (0.075\ \frac{lb}{ft^3})} = \mathit{170\ minutes}$$

Almost 3 hours!

Conclusion: A significant cold draft of 200 CFM and 55°F is discharged into the apartment for 170 minutes. An uncontrolled source of cold air is likely to cause occupant comfort issues.

Cooling Load Study

- One bedroom, 700 SF, apartment with an Eastern exposure
- Peak cooling load with Boston design conditions: 7,000 Btu/hr
- Amount of cooling contributed by the water heater: 6,100 Btu/hr



$$\frac{6{,}100\ Btu/hr}{7{,}000\ Btu/hr} = 87\%$$

DHW cold draft is almost equal to summer time peak AC load!

Heat pump water heater will overcool even in the summer.

Winter Condition - Temperature Difference Water vs Air

The temperature difference for water is significantly greater than air

Water: 45°F → 125°F   Air: 70°F → 55°F

We are increasing water tempertures more than 5x more than we are decreasing the air temperature. 5-1/3 in this case.

Winter Condition - Quantity of Water vs Air

$$(200\ \frac{ft^3}{min})\ x\ (246\ mins^1)\ x\ (0.075\frac{lb}{ft^3})\ = 3{,}690\ lbs\ of\ air$$

$$(20\ gals^2)\ x\ (8.33\frac{lb}{gal})\ = 167\ lbs\ of\ water$$

Due to the 4x difference in heat capacity plus the 5.3x difference in temperature difference we need to move a lot of air to extract the heat needed for hot water production. And it's going to be cold (55°F).

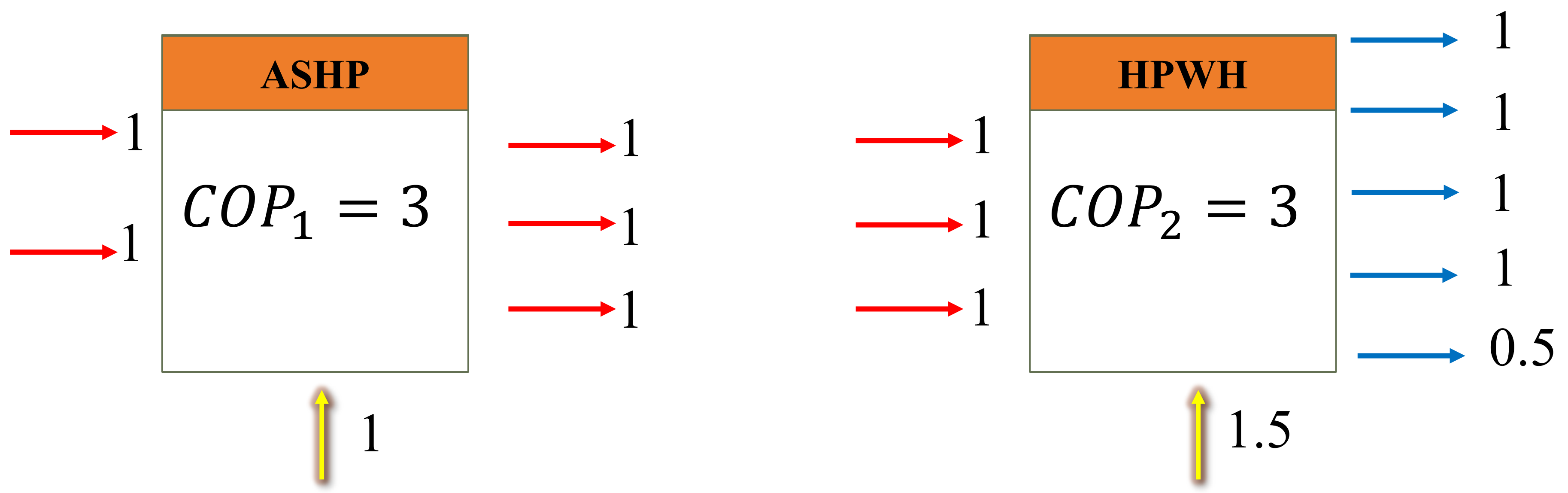
BTW 200 CFM is 2.1 air changes/hr for a 700 SF apartment.

Also, we are moving 49,200 cubic feet of cold air.

1: In the winter condition the temperature rise is from 45°F to 125 °F
2: 20 gallons of 125 °F water equates to approximately 30 gallons of hot water out of the faucet

Heat Pumps in Series

Two Heat Pumps in Series



COP is the ratio of useful heating provided to the energy required.

For a COP_1 of 3, the ASHP uses 1 unit of energy that is electricity powering the compressor to move 2 units of heat from the outdoors. This results in 3 units of heat delivered to the corridor.

For a HPWH with a COP_2 of 3, all 3 units of the heat moved by the ASHP are utilized by the HPWH.

The HPWH uses 1.5 units of energy that is electricity powering the compressor to move the 3 units of heat from the corridor. This results in 4.5 units of heat delivered to hot water.

The total COP for this system would be the heat output 4.5 divided by the energy input, 2.5, which equals 1.8.

Heat Pumps in Series Math Steps

$$O_x = E_x + I_x \quad (1)$$

Where, O = heat output of system, E = electricity used in the process, I = energy extracted from an outside medium.

$$COP_x = \frac{O_x}{E_x} \quad (2)$$

The entire output by heat pump 1 is used as input by heat pump 2, therefore:

$$O_1 = I_2 \quad (3)$$

The total COP of the system is defined as the heat output of the last heat pump in the series divided by the total electricity used by the system to achieve that output.

$$COP_{total} = \frac{O_3}{E_1+E_2} \quad (4)$$

Replace the numerator of Equation 4 by rearranging Equation 2.

$$COP_{total} = \frac{COP_2 E_2}{E_1+E_2} \quad (5)$$

Replace the first term in the denominator by rearranging Equation 2.

$$COP_{total} = \frac{COP_2 E_2}{\frac{O_1}{COP_1}+E_2} \quad (6)$$

Replace O_1 with Equation 3.

$$COP_{total} = \frac{COP_2 E_2}{\frac{I_2}{COP_1}+E_2} \quad (7)$$

Mathematical Derivation Courtesy of Hans Moritz Gunther and Lauren Gunther

In order to put the I term in terms of COP and E, insert Equation 1 into Equation 2 and rearrange to solve for I:

$$COP_x = \frac{E_x+I_x}{E_x} = 1 + \frac{I_x}{E_x} \tag{8}$$

$$I_x = E_x(COP_x - 1) \tag{9}$$

Insert Equation 8 in for the I terms in Equation 6.

$$COP_{total} = \frac{COP_2 E_2}{\frac{E_2(COP_2-1)}{COP_1}+E_2} \tag{10}$$

Cancel out E_2 from the equation

$$COP_{total} = \frac{COP_2}{\frac{(COP_2-1)}{COP_1}+1} \tag{11}$$

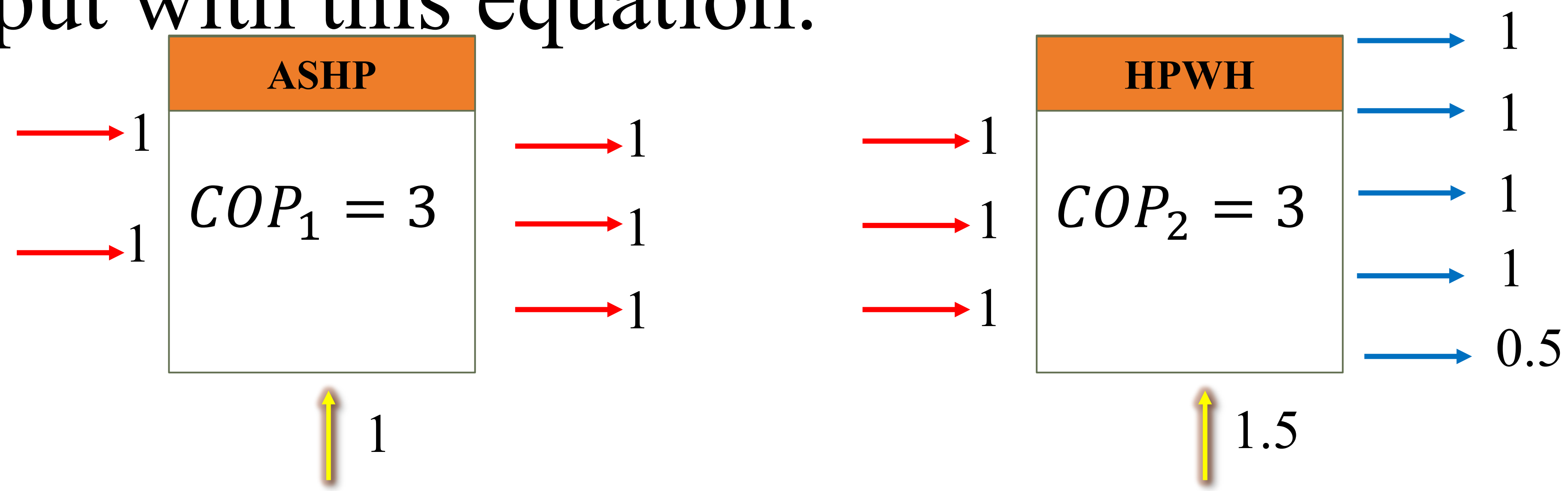
Multiply the numerator and denominator by COP_1

$$\boxed{COP_{total} = \frac{COP_1 COP_2}{COP_1+COP_2-1}} \tag{12}$$

Mathematical Derivation Courtesy of Hans Moritz Gunther and Lauren Gunther

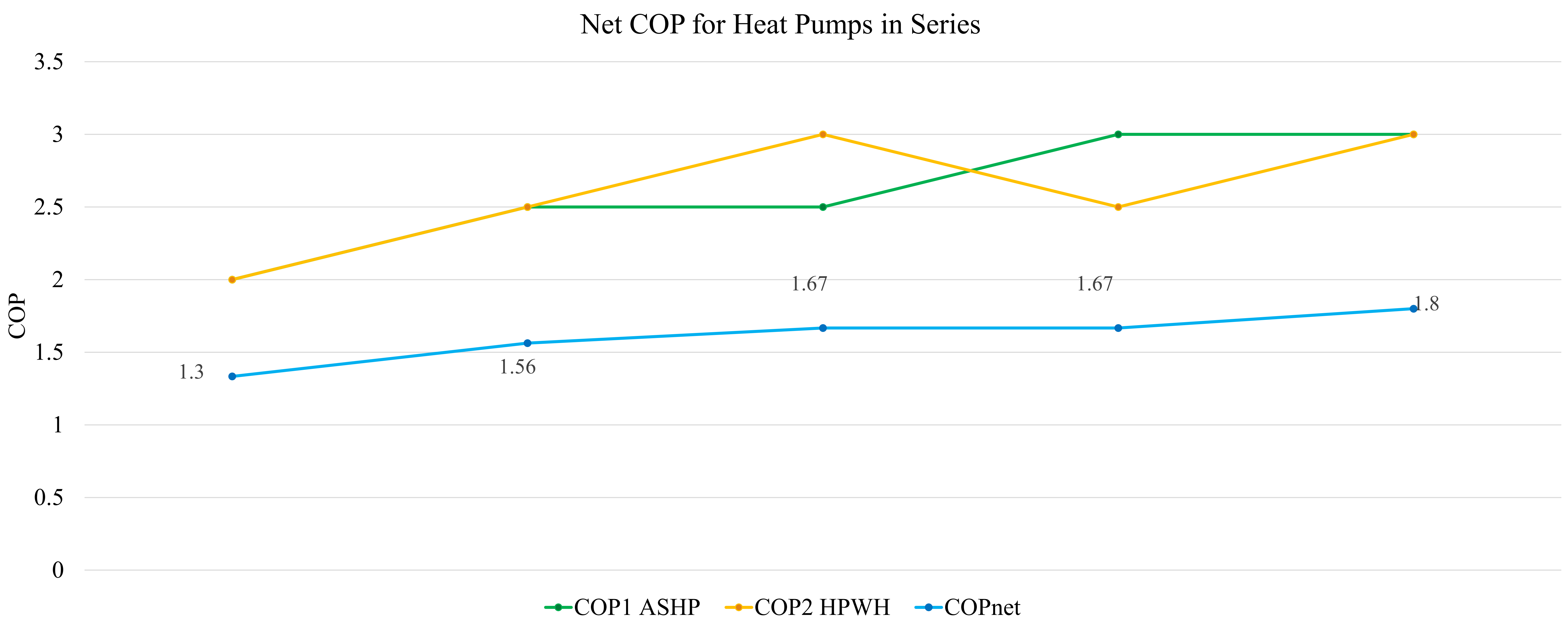
Plug and Chug

Looking at the original example, with a total COP of 1.8, we see the same output with this equation.

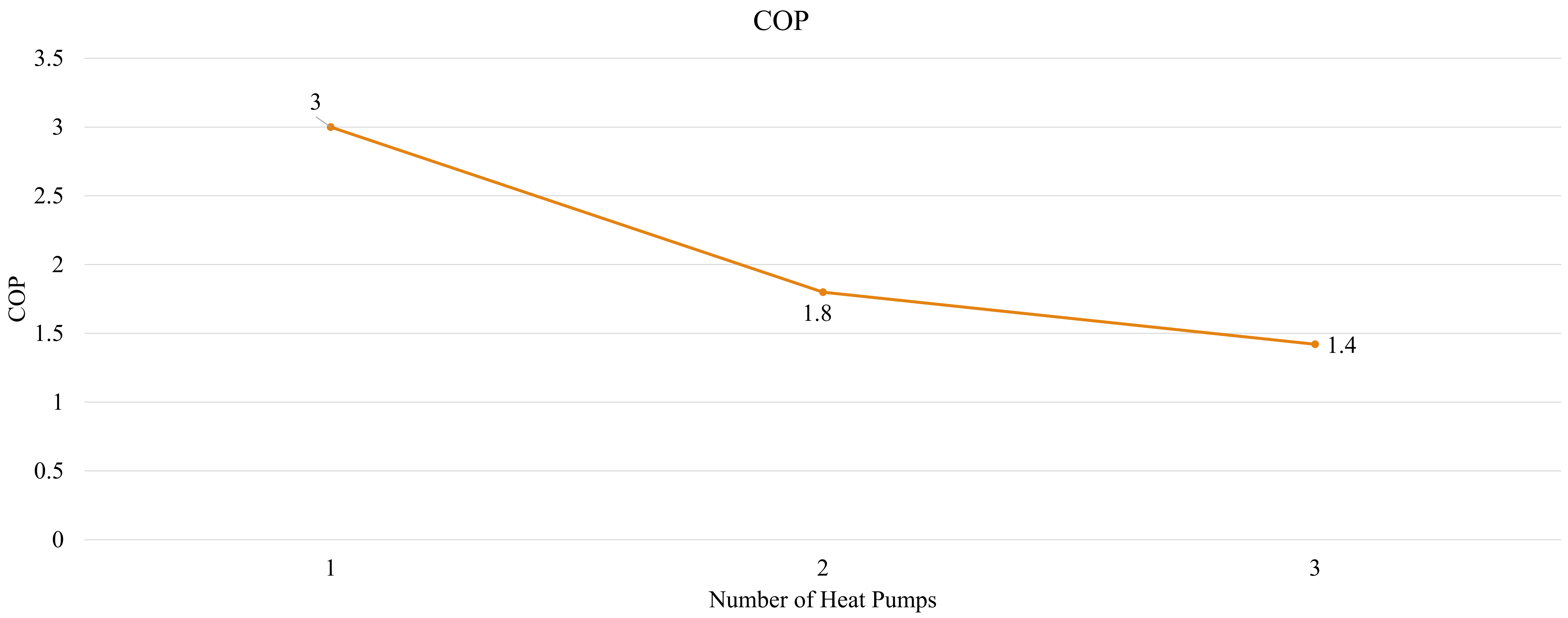


$$\frac{COP_1 COP_2}{COP_1 + COP_2 - 1} = \frac{3*3}{3+3-1} = 1.8$$

Graphical Representation



Number of Heat Pumps vs COP



How about some solutions?
How can we reduce electricity use in hot water heating?

Drain Water Heat Recovery

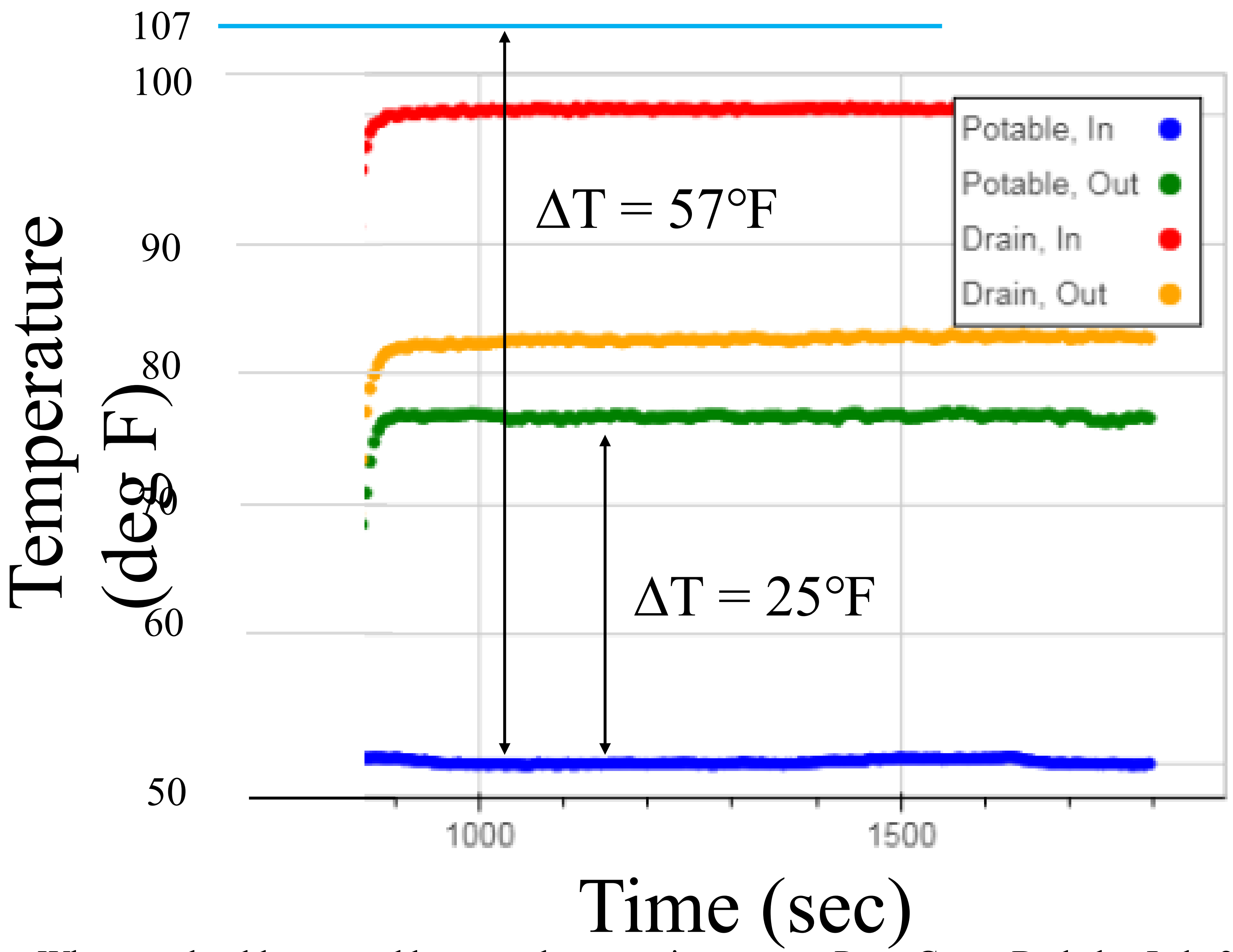
Drain Water Heat Recovery (DWHR) Definition

DWHR works by
using the outgoing
warm drain water
to pre-heat the incoming
cold fresh water

Fresh Inlet ~ 46°F   Drain Inlet ~ 101°F   Fresh Outlet ~ 75°F

Drain Water Heat Recovery Technologies Research Slides, Gerald Van Decker, Renewability Energy Inc.

Potable vs Drain Temperatures



$$\frac{\Delta T\ 25°F}{\Delta T\ 57°F} = 44\%\ \text{Reduction}$$

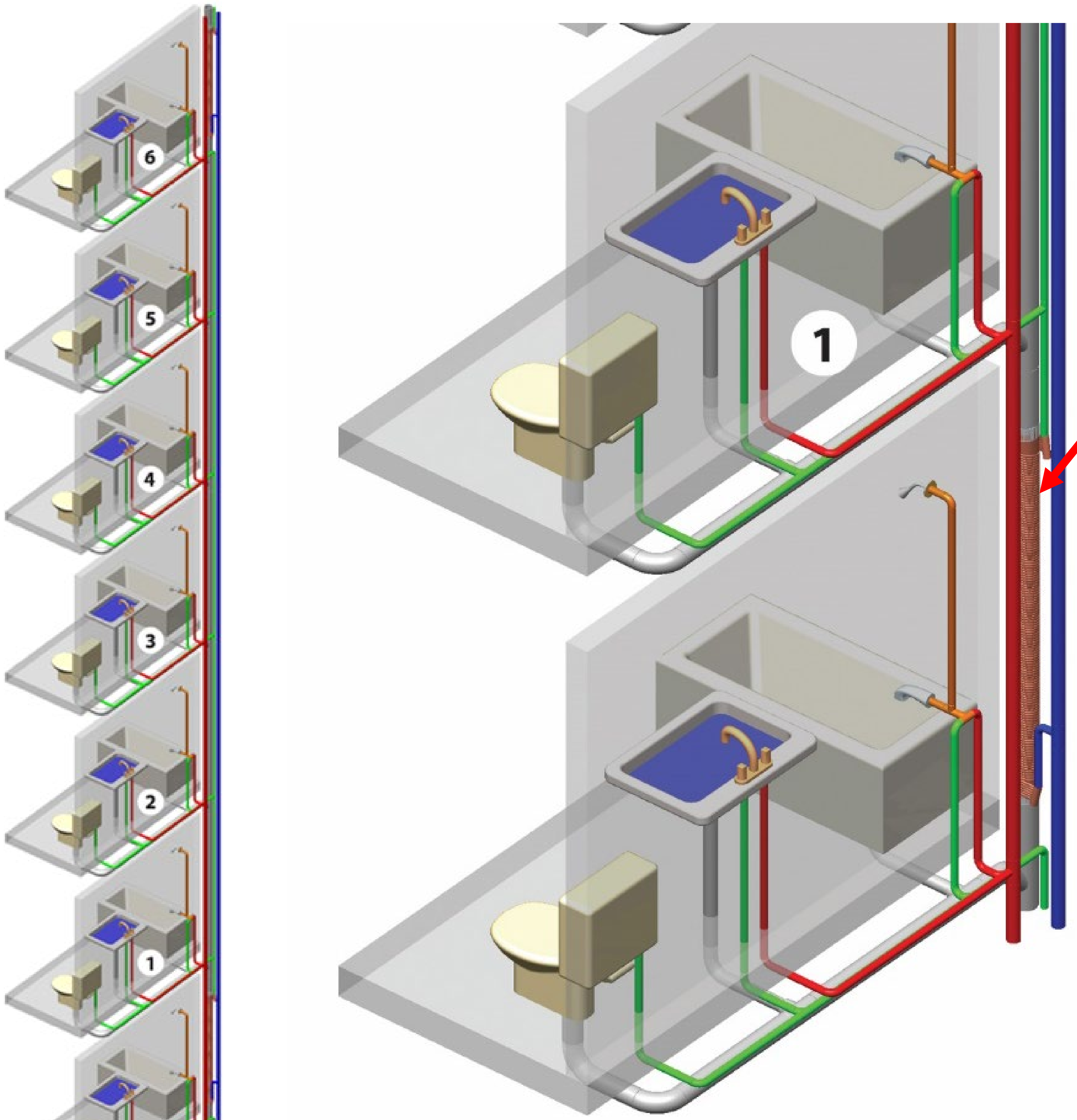
Drain water recovery reduces the temperature we need to raise the water by 44%!

Drain water heat recovery: Why you should care, and how much energy it can save, Peter Grant, Berkeley Lab, 2017

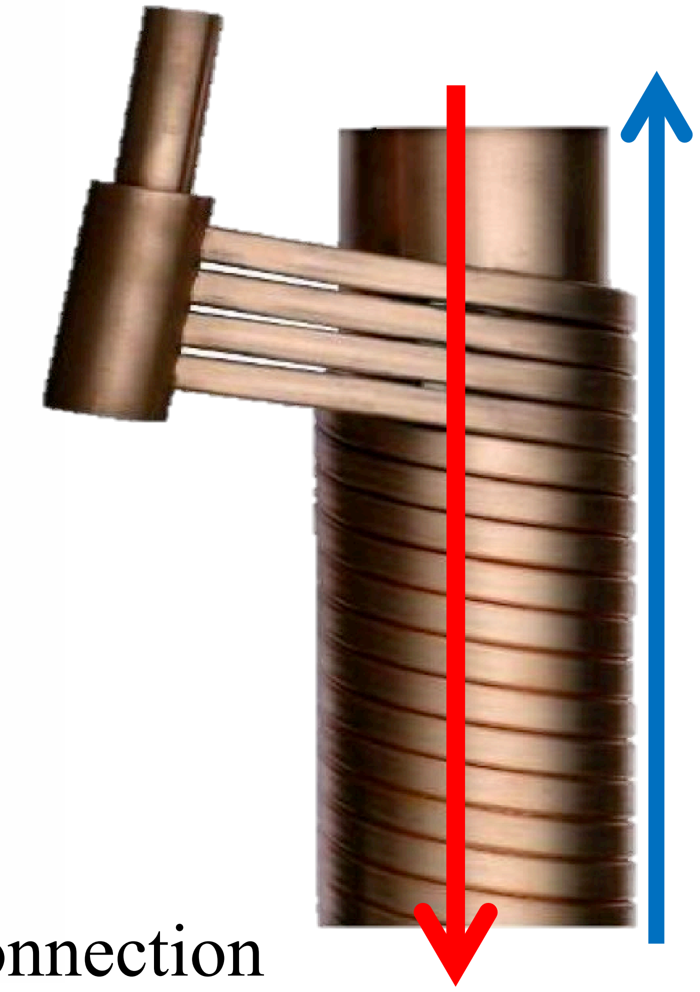
6 Story Midrise Stacked Bathrooms

Fresh water from DWHR to cold water supply at fixtures.

- Shower water is approximately 60% of hot water use in an apartment
- Heat required for shower water is reduced by approximately 50%
- Overall heat required for DHW is reduced by 30%



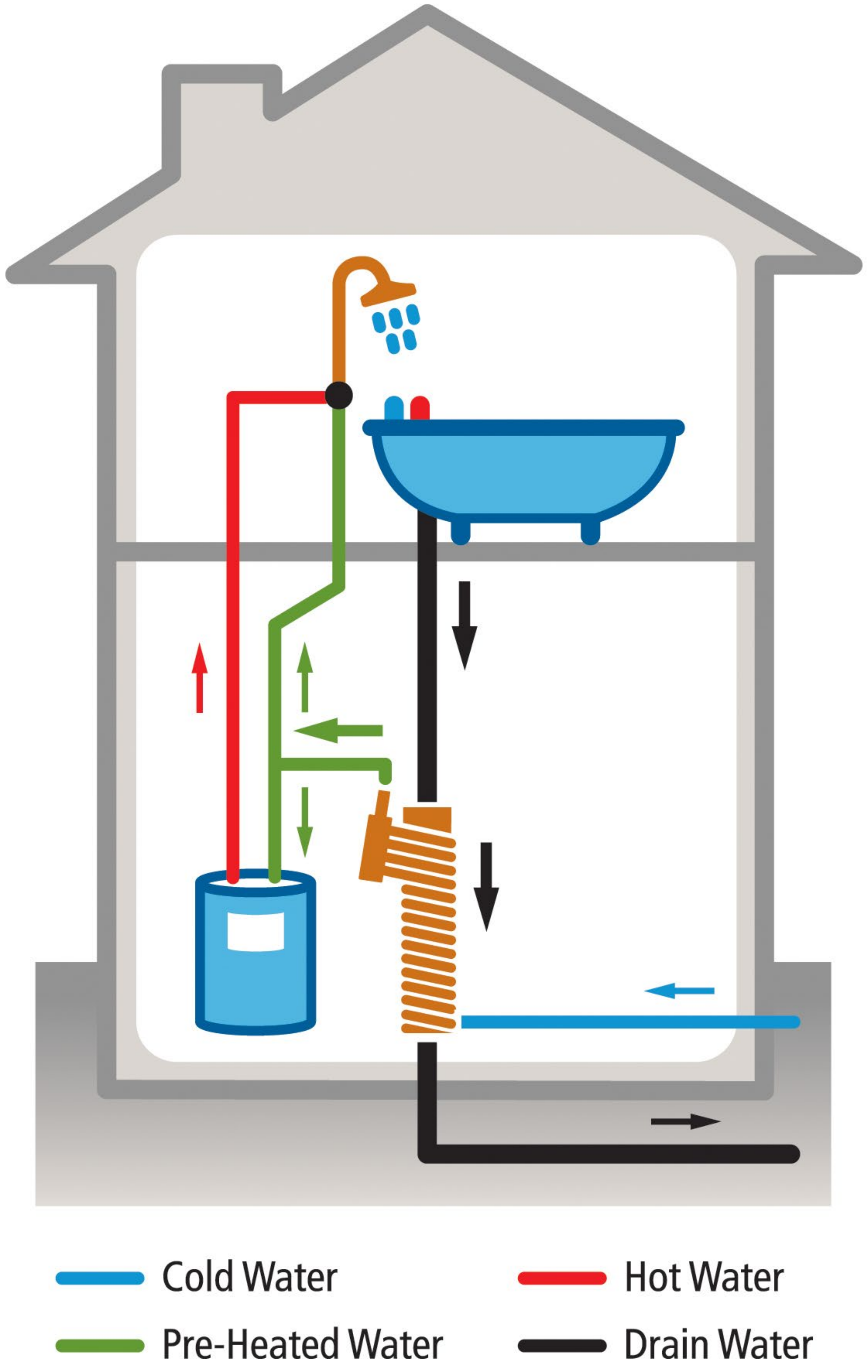
DWHR located at bottom of 6 story stack



4 in. diameter, 72 in. long, 1 in. pipe connection
Cost to contractor for DWHR qty-1: $819
For 100 unit multi-family likely need qty 8-10
Passive technology, zero electricity input, COP ∞!

Drain Water Heat Recovery Technologies Research Slides, Gerald Van Decker, Renewability Energy Inc.

DWHR Configuration When Water Heater is in Apartment



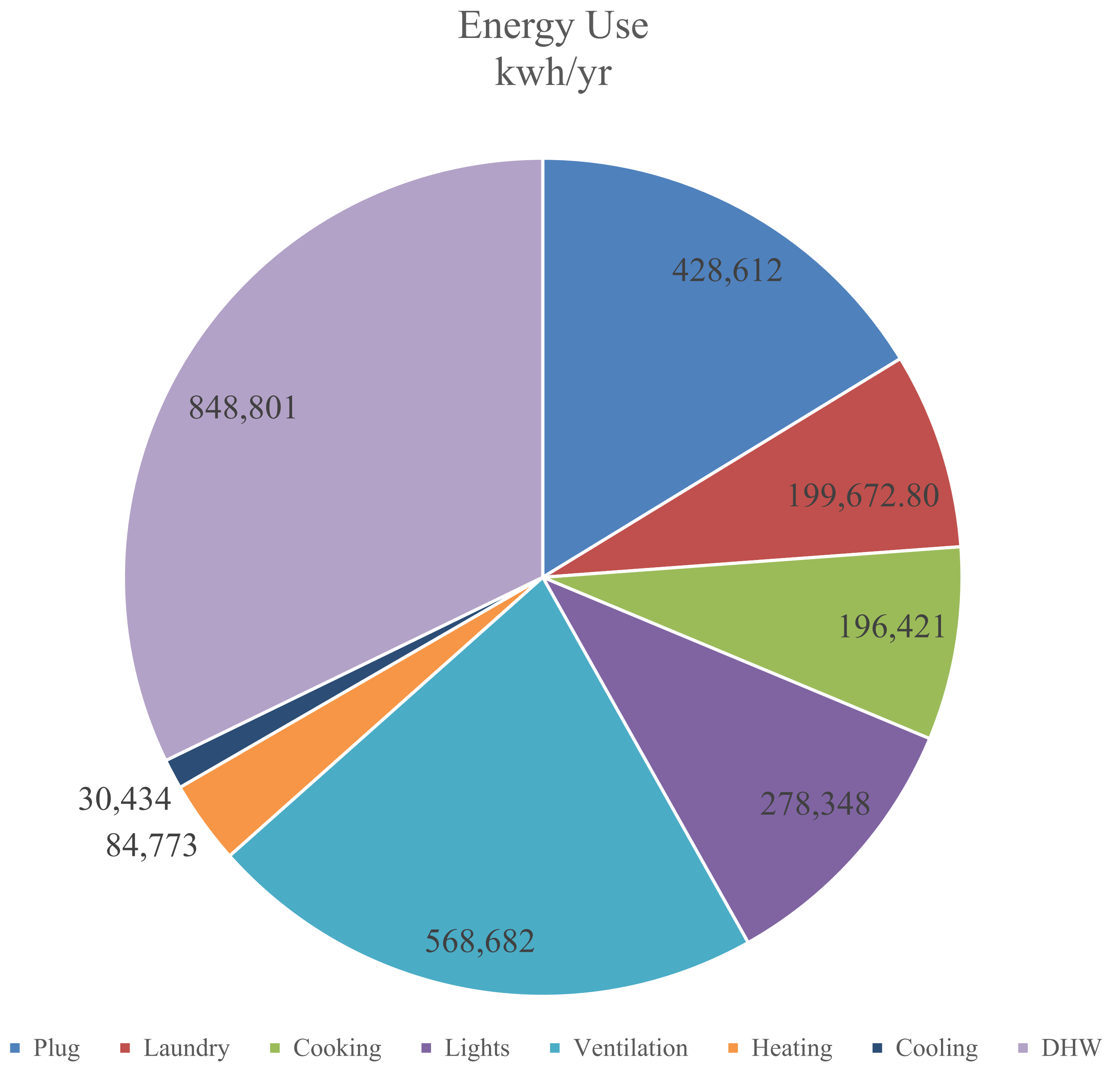
Power Pipe Flow Diagram

Drain Water Heat Recovery Technologies Research Slides, Gerald Van Decker, Renewability Energy Inc.

Distribution of Energy Use in PH Multi-Family

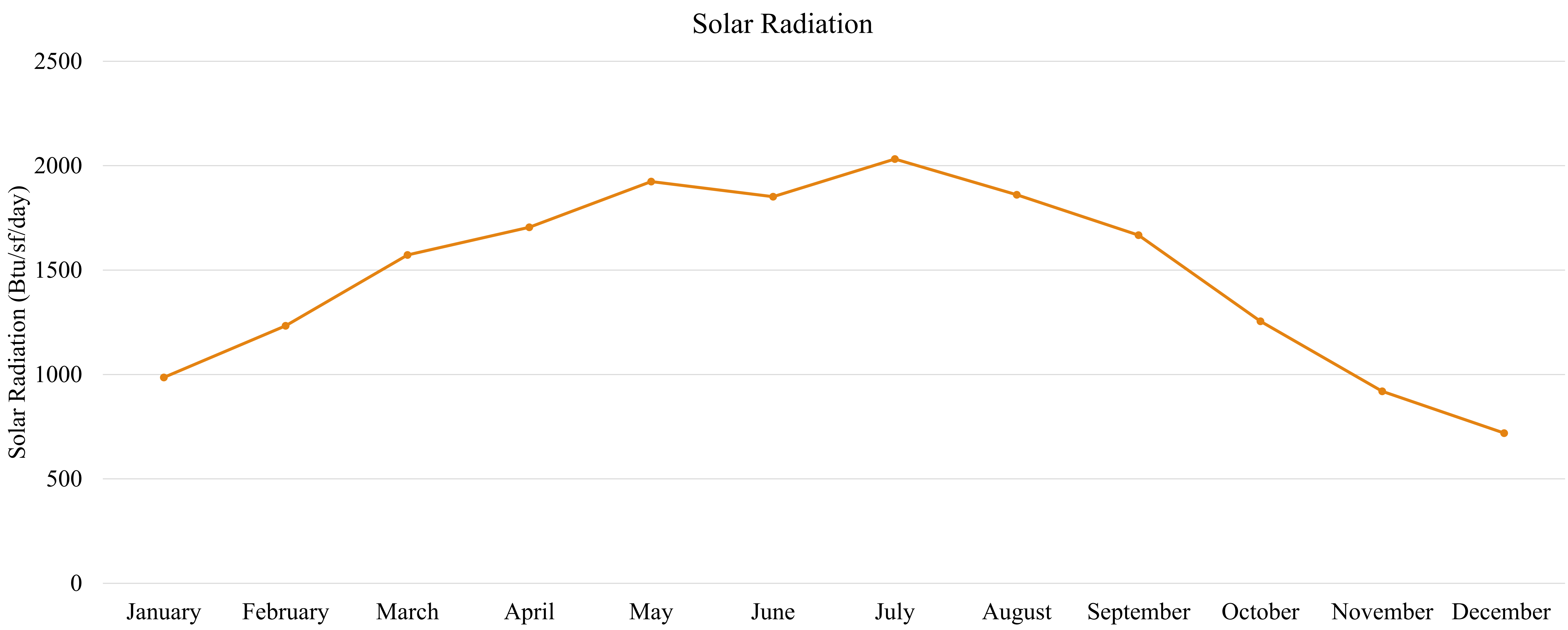
30% of DHW energy is eliminated by drain water recovery!

DWHR reduces size of ASHP DHW central plant and therefore saves first cost too!



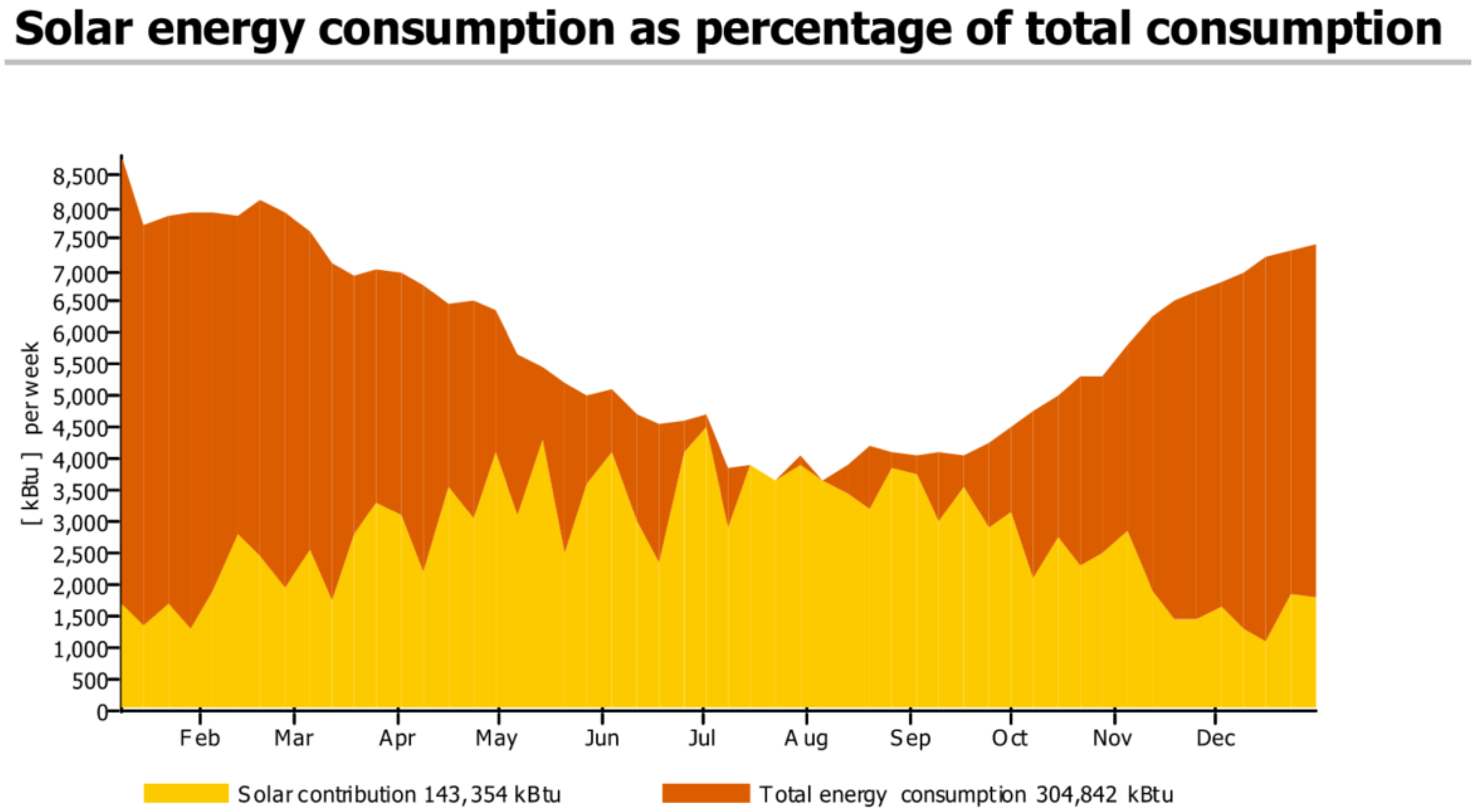
Solar Thermal

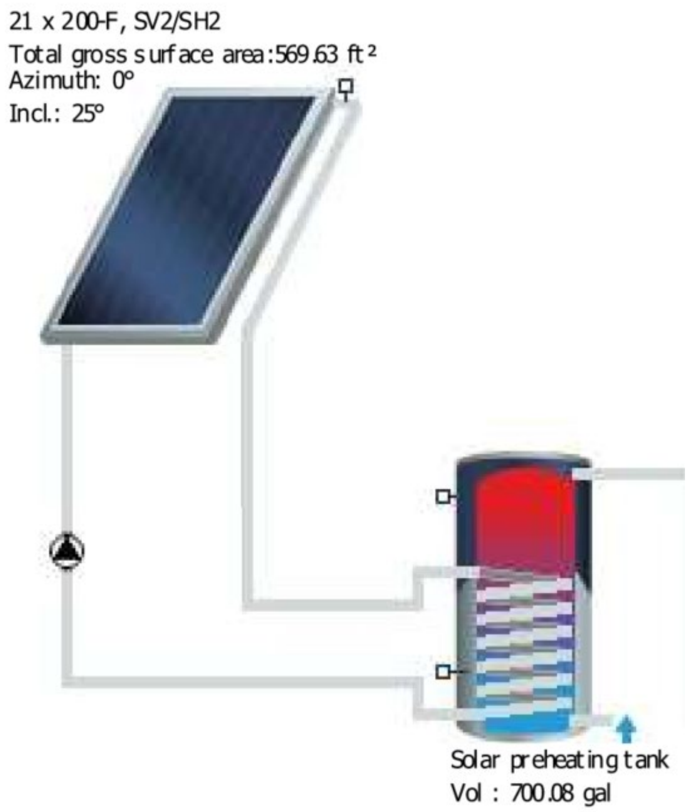
Solar Radiation in Boston



PVWatts Calculator – National Renewable Energy Laboratory

Solar Thermal Preheating





Assumptions:

- 100 unit building
- 1.5 people per unit
- 13 gallons/day/person

Outputs:

- Qty-21 panels
- Solar panel area: 570 SF
- DHW solar fraction: 47%
- Qty-1 variable speed pump, 125 Watts max power
- Cost: $140,000

Daniel Khait, Jody Samuell, Kevin Flynn- Viessmann, T*SOL Software

Results of Simulation

Installed collector power:		126.39 kBtu/hr
Installed solar surface area (gross):		569.63 ft²
Irradiation on to collector surface (active):	290.52 MMBtu	510.04 kBtu/ft²
Energy delivered by collectors:	144.72 MMBtu	254.07 kBtu/ft²
Energy delivered by collector loop:	143.62 MMBtu	252.15 kBtu/ft²
DHW heating energy supply:		296.11 MMBtu
Solar contribution to DHW:		142.83 MMBtu
Energy from auxiliary heating:		160.9 MMBtu
Natural gas (H) savings:		**2,165.5 therm**
CO2 emissions avoided:		**28,395.34 lbs**
DHW solar fraction:		**47.0 %**
Fractional energy savings (DIN CEN/TS 12977-2):		**47.6 %**
System efficiency:		**49.2 %**

$$COP = \frac{143{,}000\ kBtu\ (41{,}000\ kWh) output}{181\ kwh\ input}$$

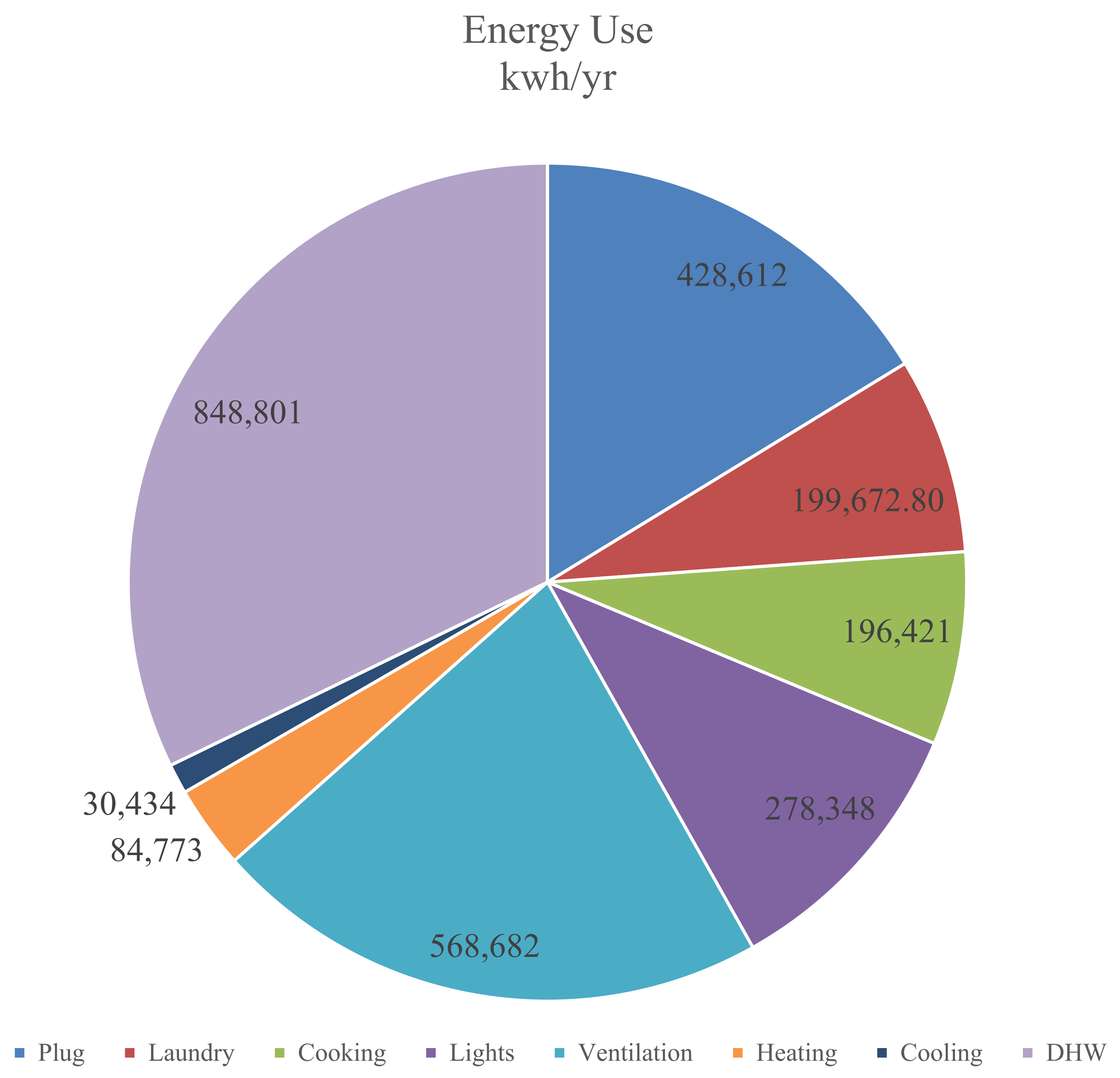
COP = 227

Assuming 0.125 kw pump, average 50% Watt draw, on 1/3 of the time annually

Distribution of Energy Use in PH Multi-Family

Electricity for annual DHW is reduced by 50%!

Central plant size is not reduced because some days we get zilch from the sun.



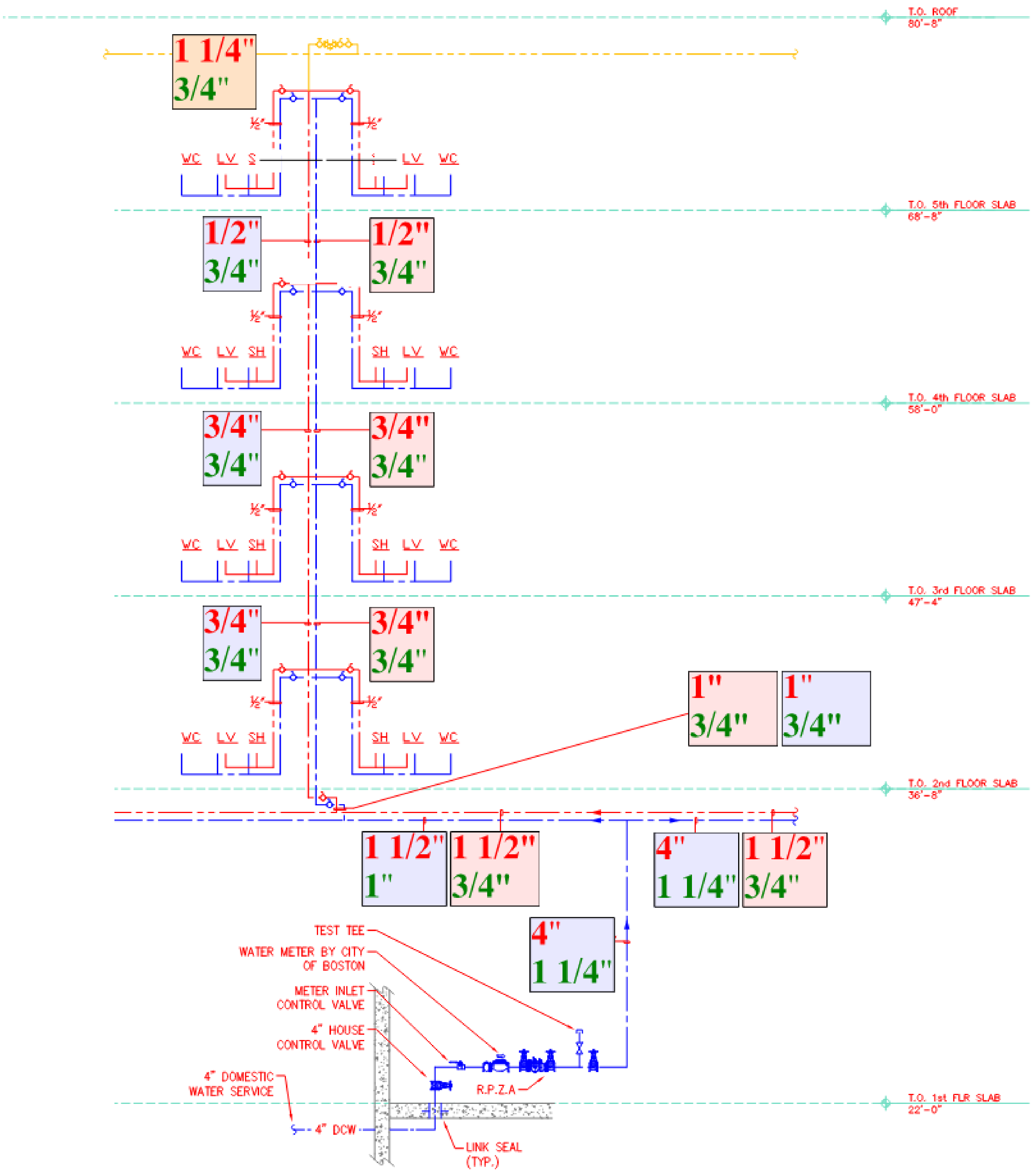
Downsizing Potable Water Piping

Case Study | Old Colony Phase 6 South Boston, MA

- •5 story multi family building
- •116,000 GSF
- •94 dwelling units

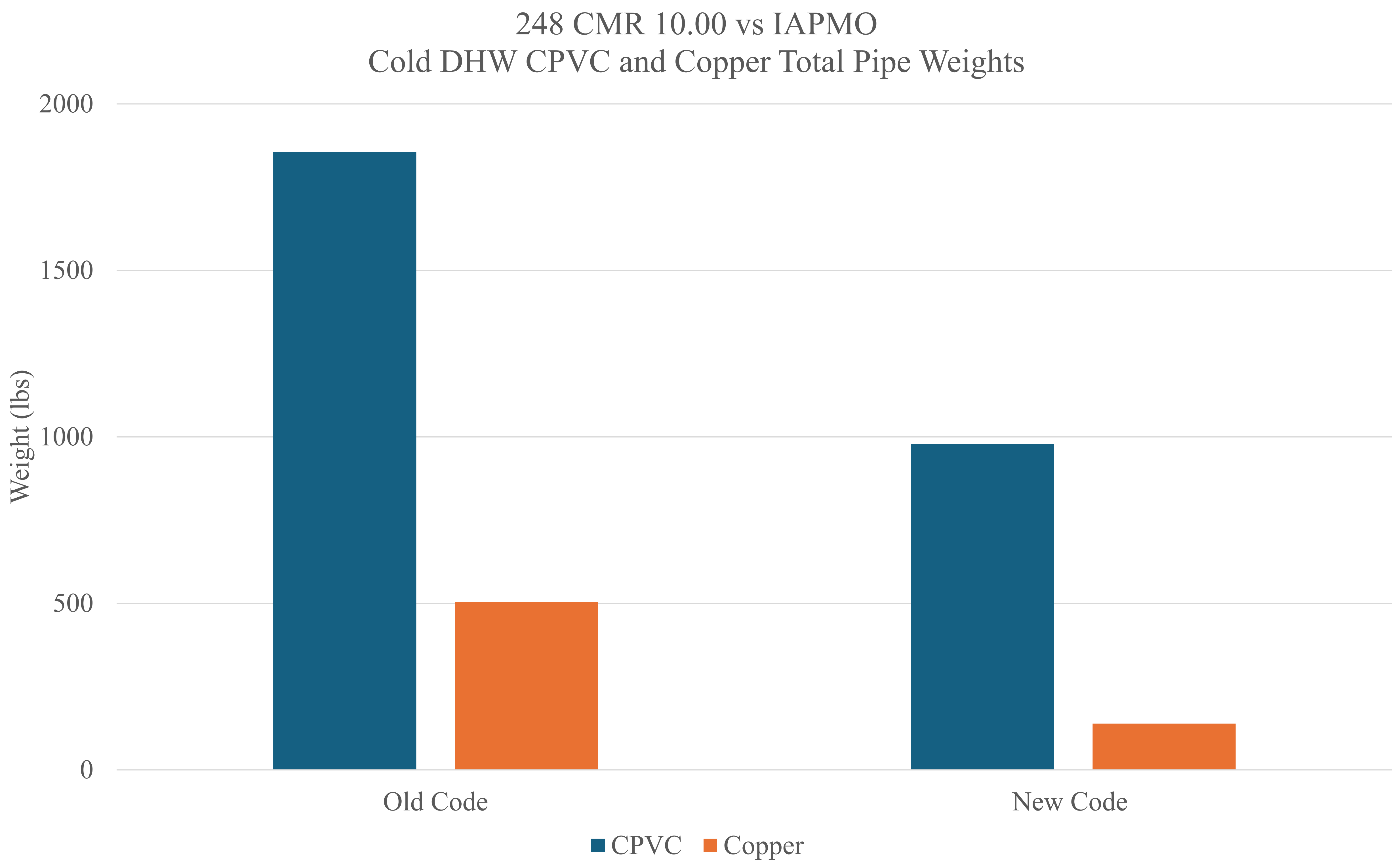
Boston Planning & Development Agency

Pipe Size Distribution – 248 CMR 10.00 vs IAPMO Water Demand Calculator



248 CMR 10.00 (12/23 edition) Sizing vs IAPMO Water Demand Calculator Sizing

Potable Water Distribution Downsizing



47% weight reduction in CPVC piping – pounds saved: 876 lbs

72% weight reduction in Copper piping – pounds saved: 366 lbs

Pipe densities from: Charlotte Pipe and Foundry Company

Potable Water Distribution Downsizing

GWP[1] Reduction Using IAPMO

Reduction	Copper	CPVC	Total
$kgCO_2e$	809	2,052	2,861
%	72%	44%	50%

[1]GWP (A1-A3) Data Sources: One Click LCA (Copper) & Manufacturer EPRs (CPVC)

DISCUSSION/ QUESTIONS

Multifamily MEP

Early Considerations

Layouts

HVAC

- Loads/Modeling
- Systems
  - Space-conditioning
  - Ventilation
- Ductwork

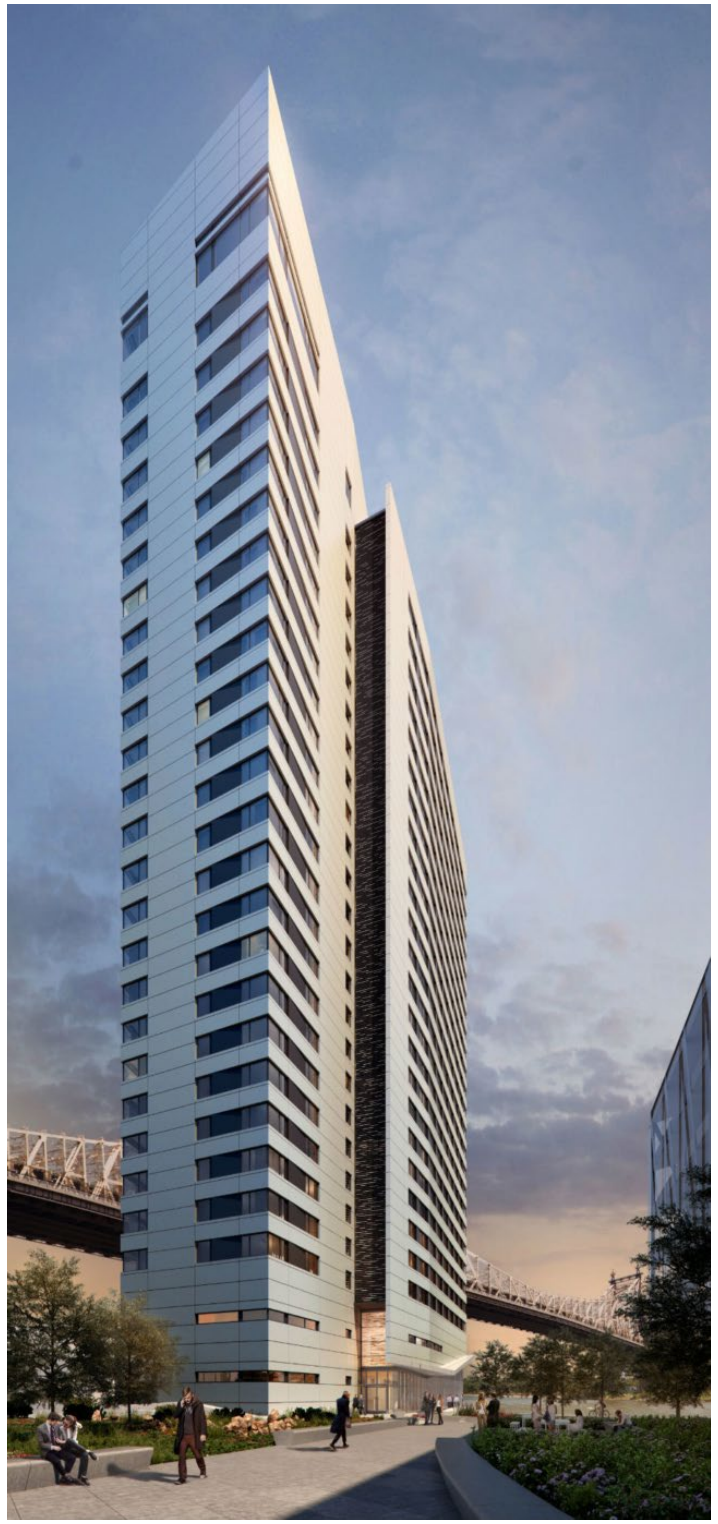
DHW

- Loads/Modeling
- Systems
- Distribution

Questions to Leave With

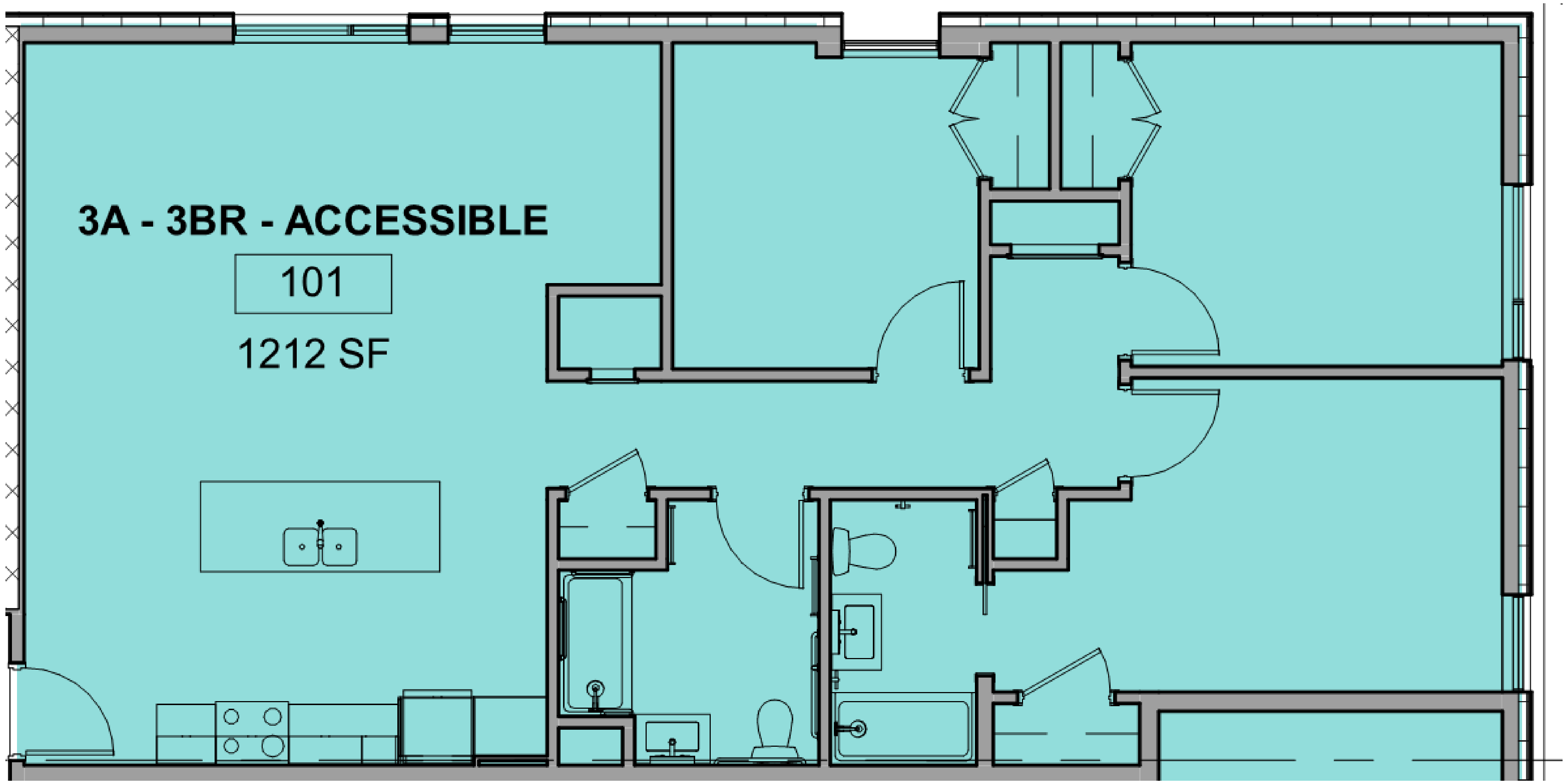
What is multi-family?

Building Size

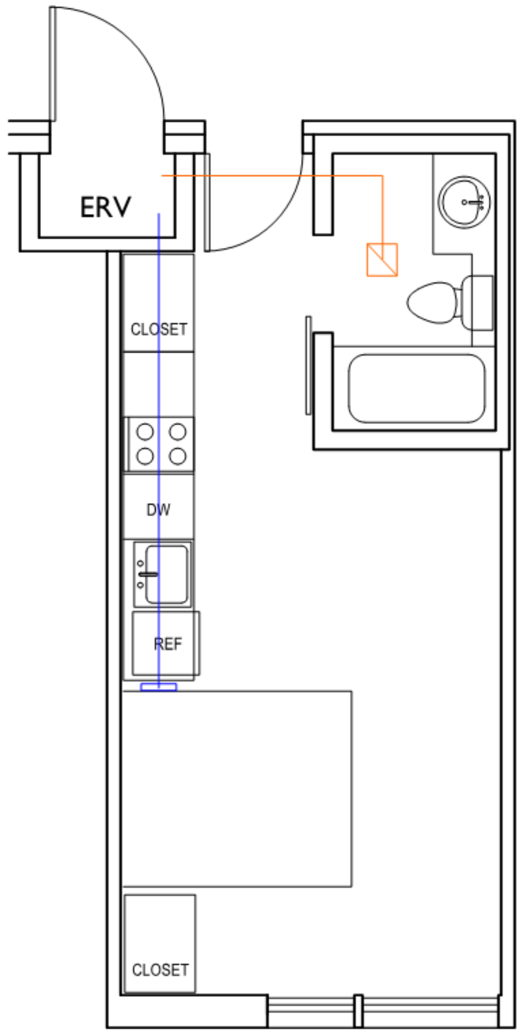


Handel Architects

What is multi-family?



3BR



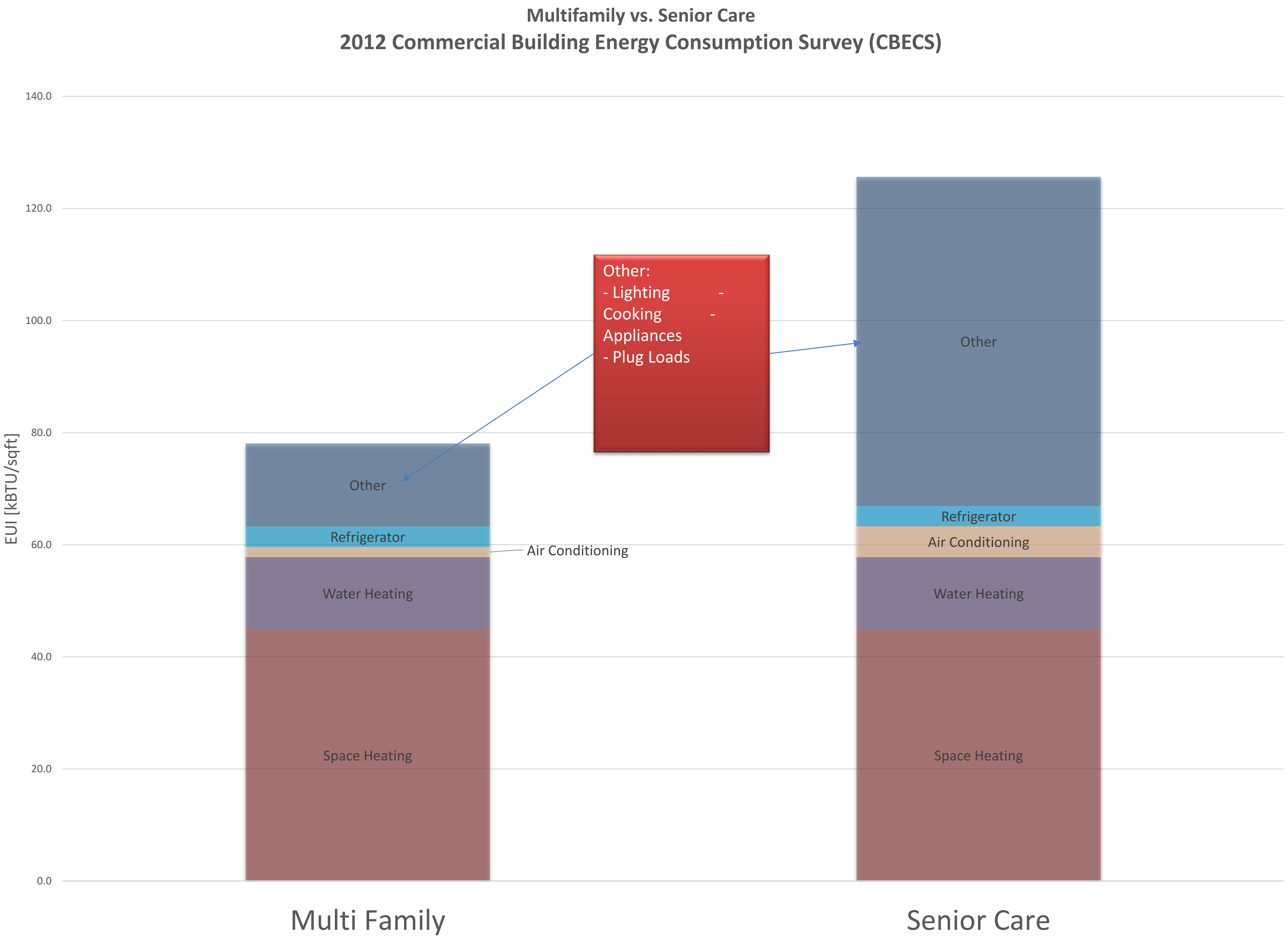
STUDIO

YOTEL

Apartment Size

What is multi-family?

Population


Multifamily vs. Senior Care
2012 Commercial Building Energy Consumption Survey (CBECS)
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
EUI [kBTU/sqft]
Other:
- Lighting -
Cooking -
Appliances
- Plug Loads
Other
Refrigerator
Air Conditioning
Water Heating
Space Heating
Other
Refrigerator
Air Conditioning
Water Heating
Space Heating
Multi Family
Senior Care

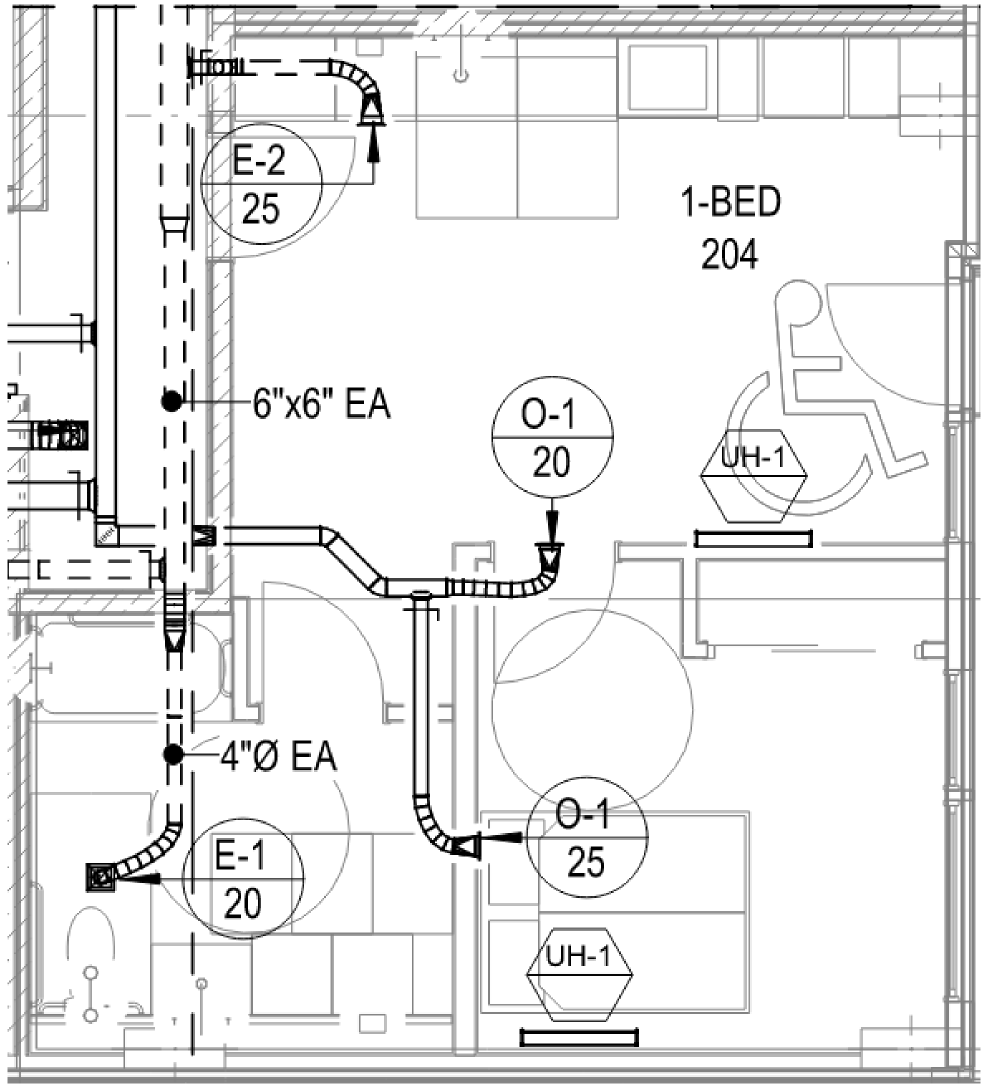
Madrone Passive House

b9 architects

CASCADE BUILT

STAENGL ENGINEERING

Heating

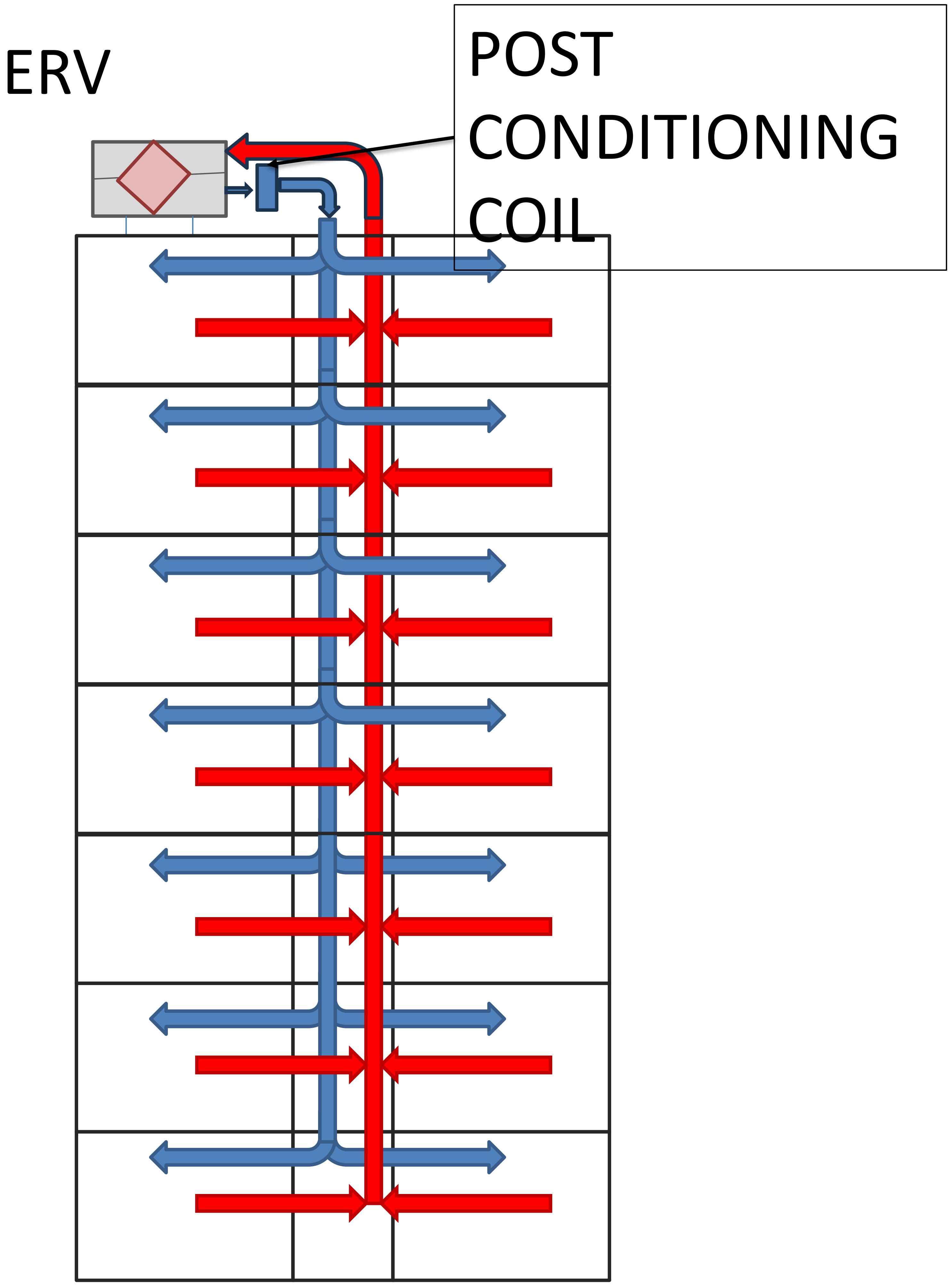


1 BR Apartment Size: 385 sqft

Code Exhaust Rate: 45 cfm

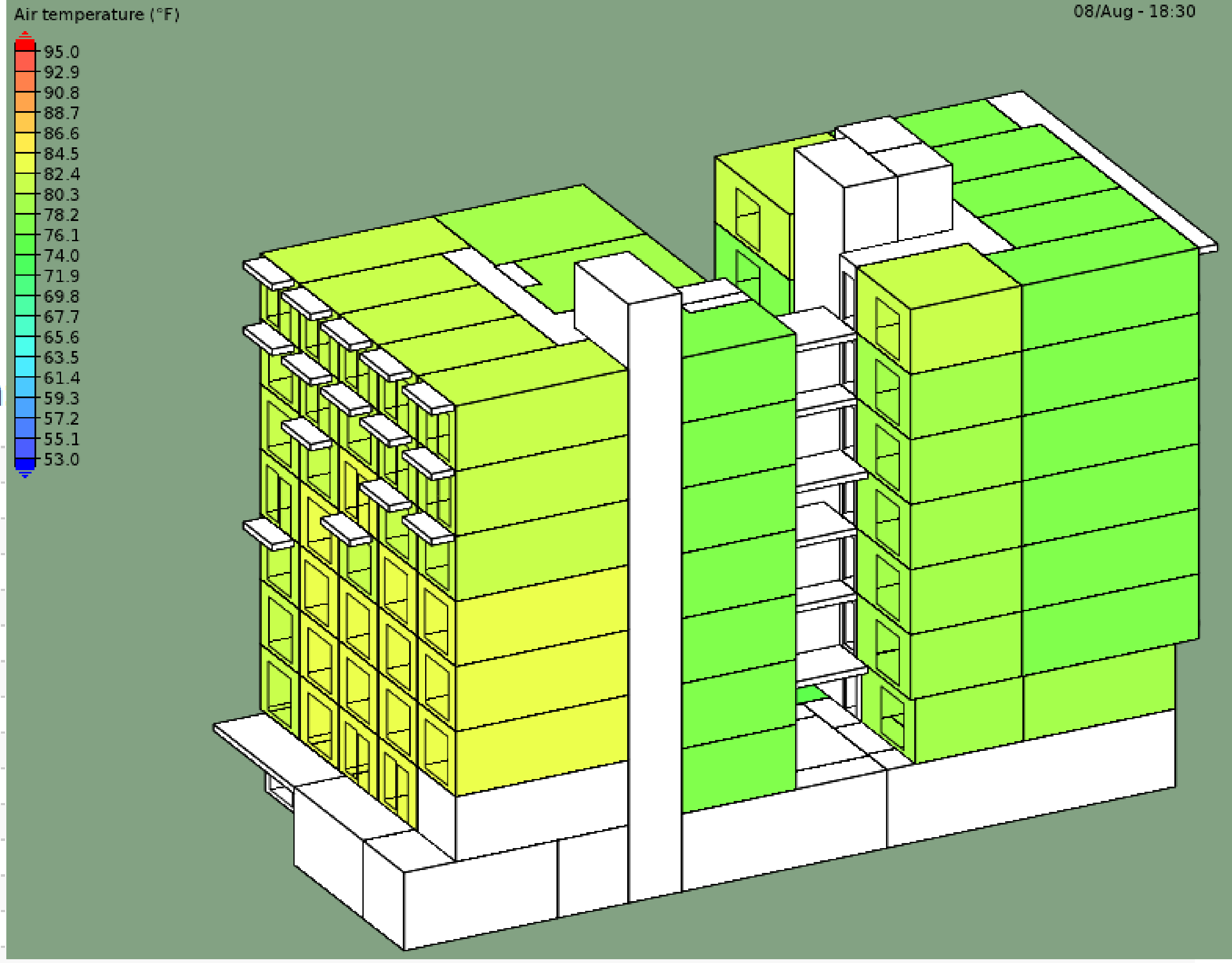
Heating Load: 1 BR – 1,000 - 1,500 BTU/hr

Ventilation Air Heat Rate (@95 F): 1,350 BTU/hr + 1 person = 1,550 BTU/hr

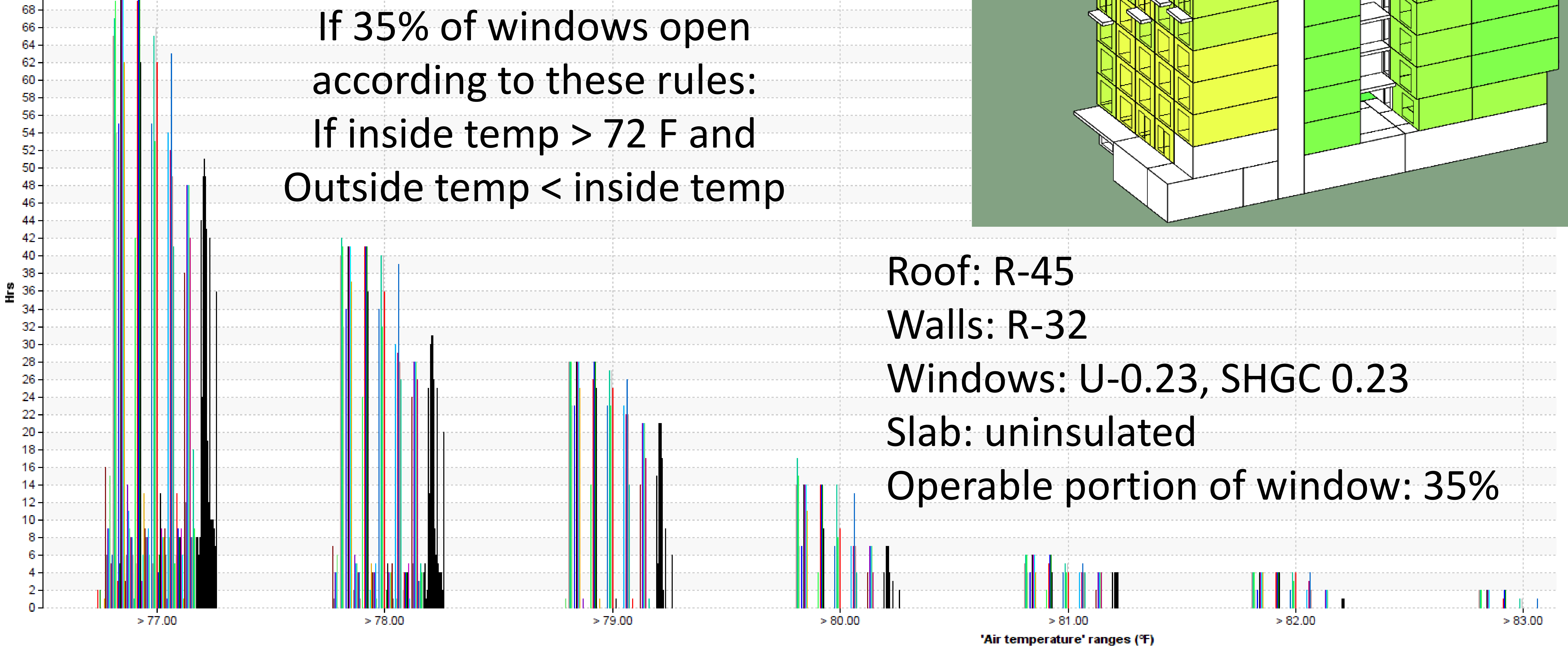


ERV
POST CONDITIONING COIL

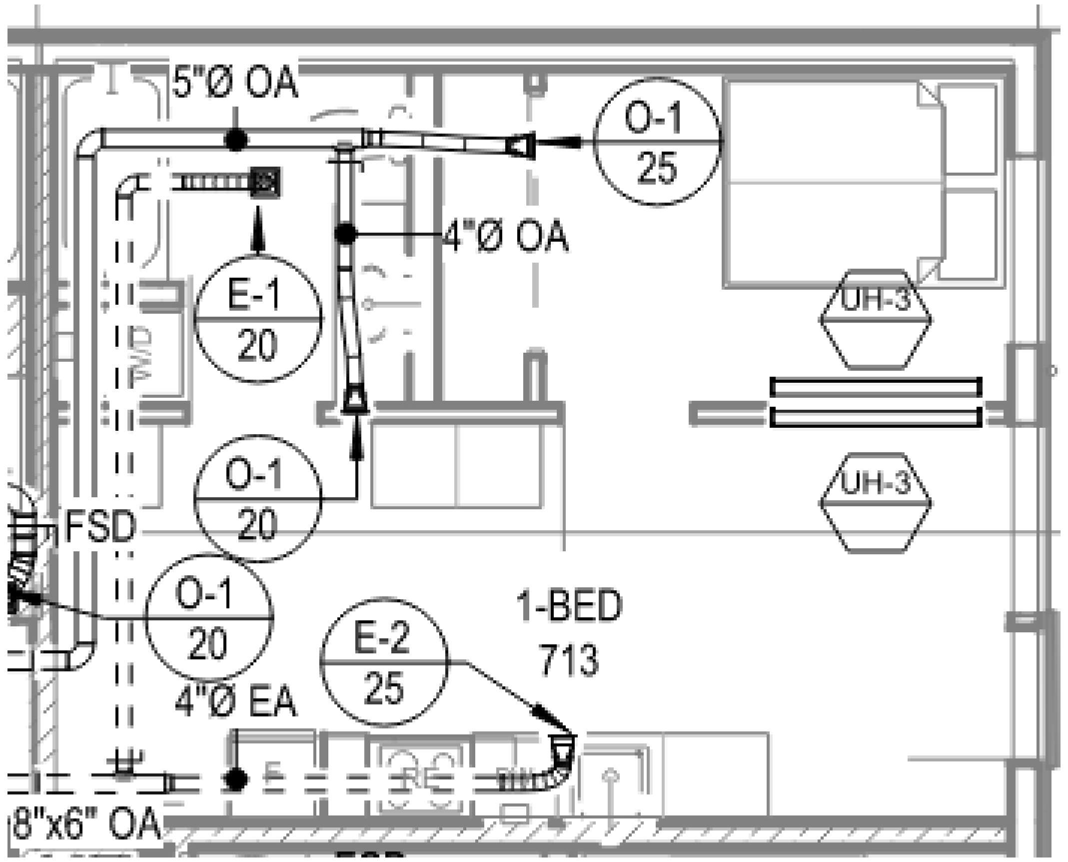
Cooling



If 35% of windows open according to these rules:
If inside temp > 72 F and
Outside temp < inside temp

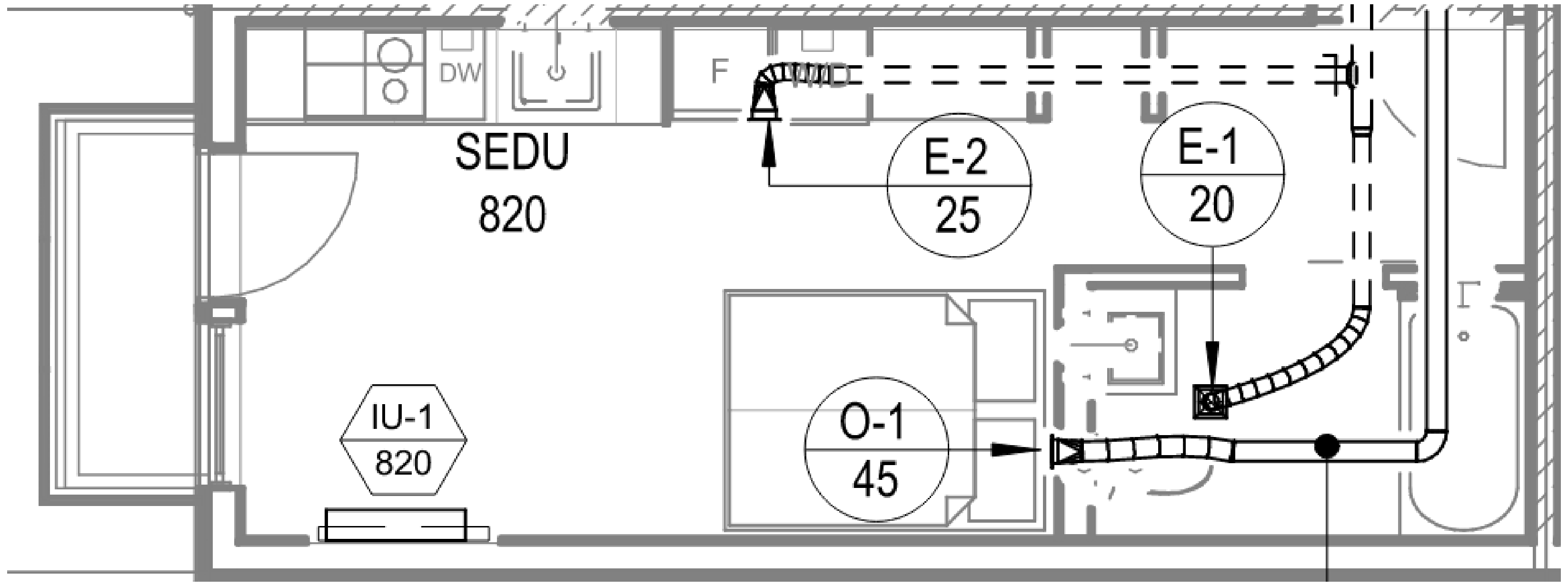


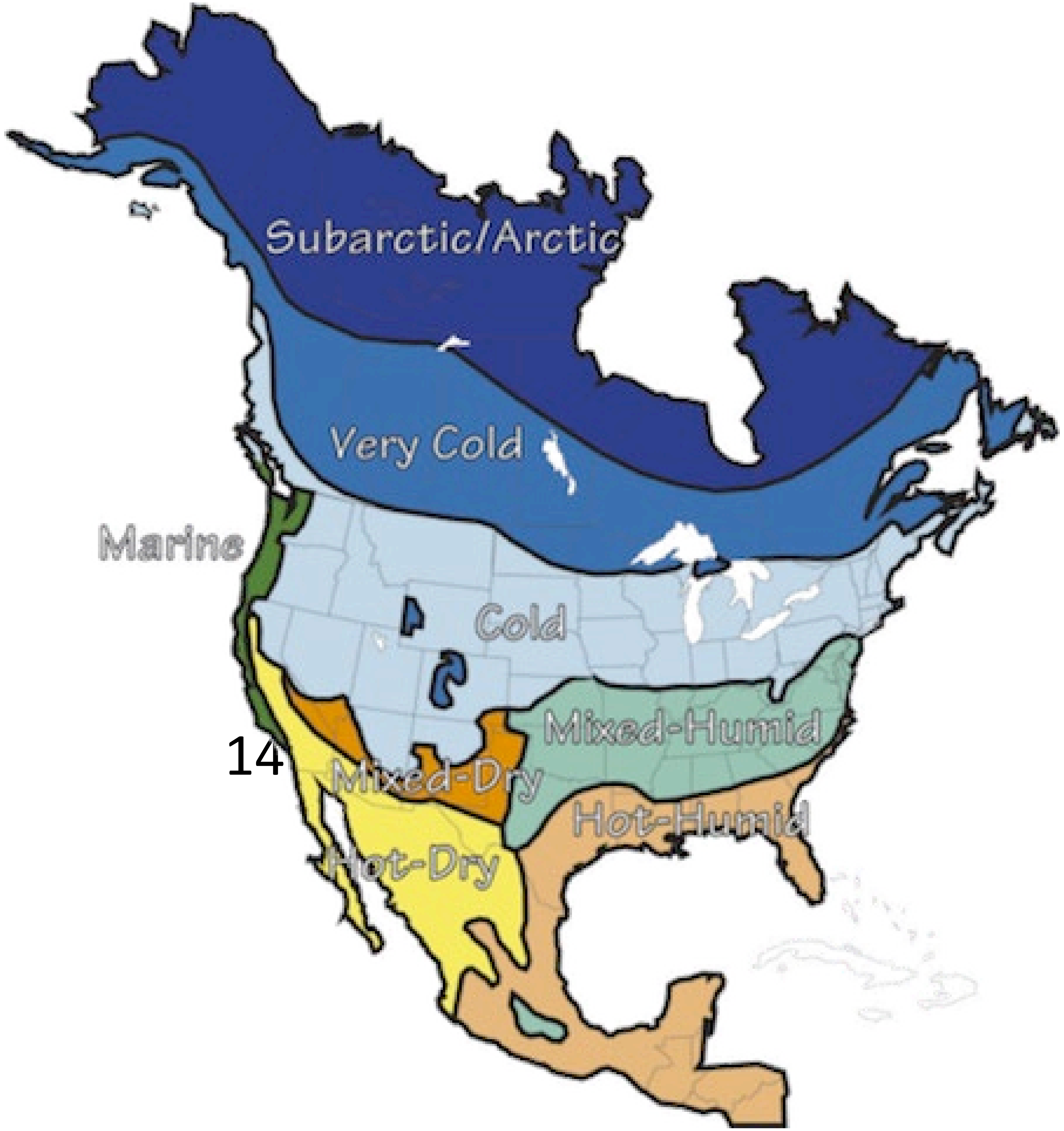
Roof: R-45
Walls: R-32
Windows: U-0.23, SHGC 0.23
Slab: uninsulated
Operable portion of window: 35%



COOLING THROUGH VENTILATION AIR:

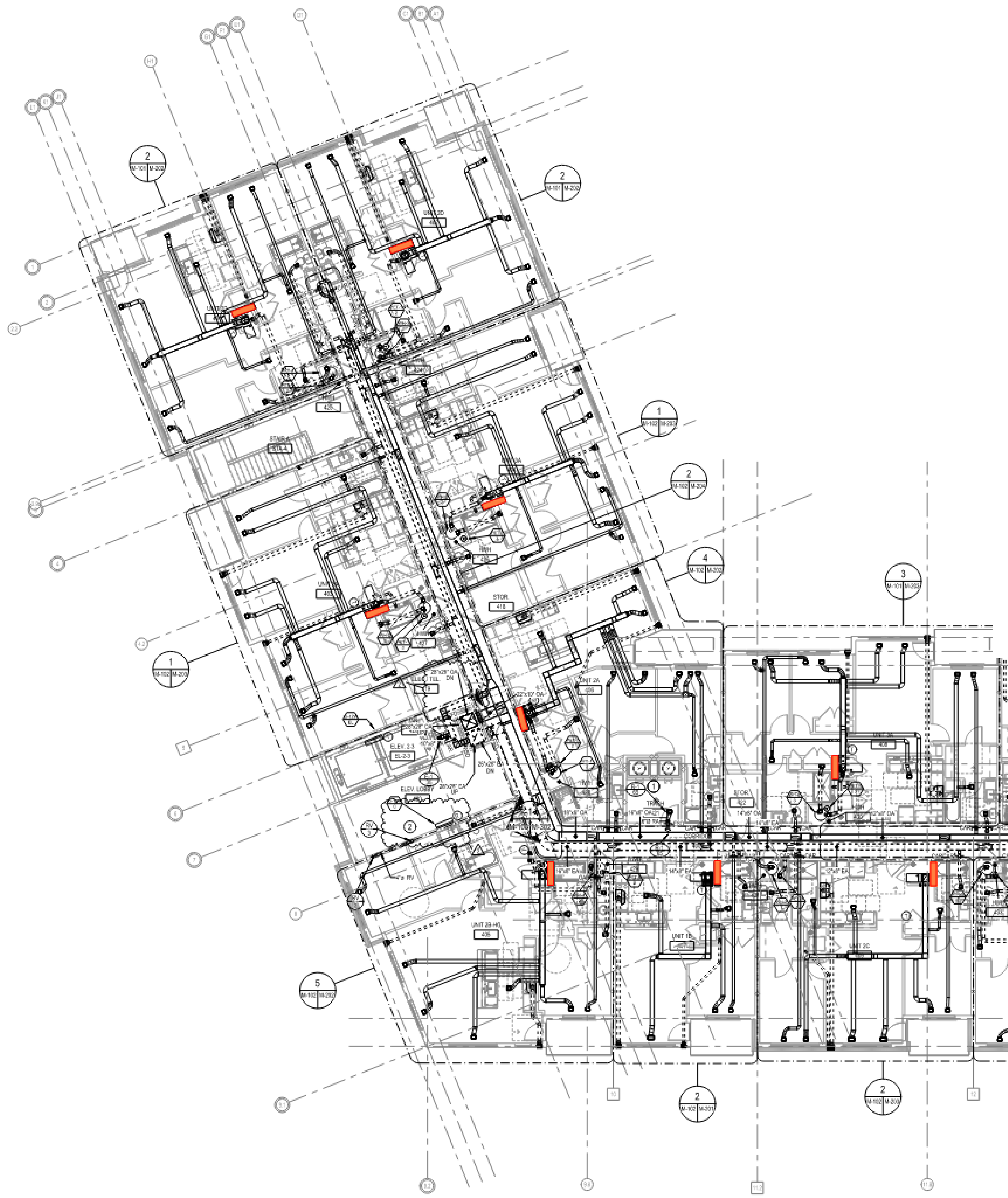
1.08 X 45 CFM X 20 F = ~1,000 BTU/HR





14

EnergyVanguard.com



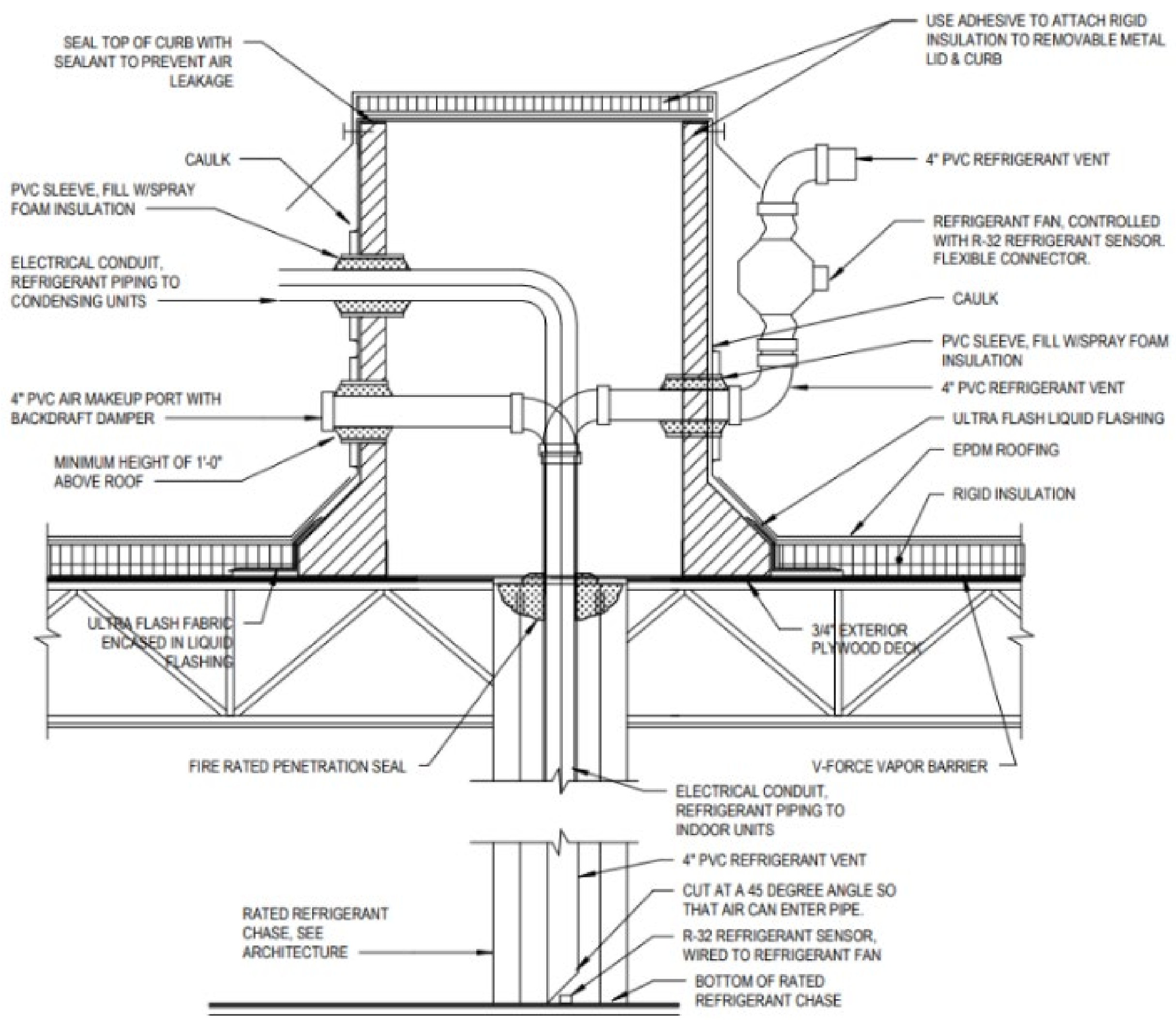
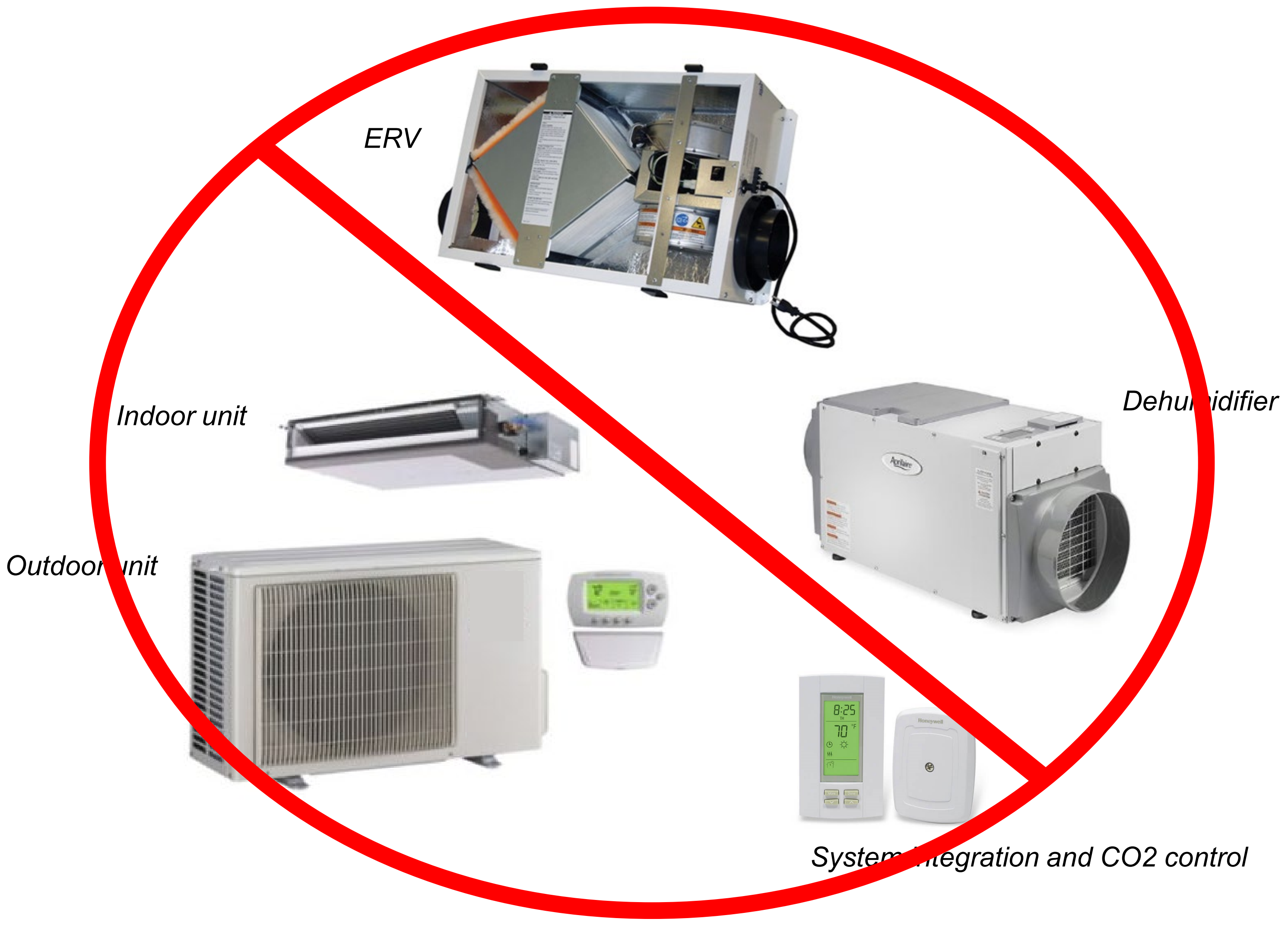


FIGURE 3: EXAMPLE REFRIGERANT SHAFT DETAIL

Self Contained

1. No outdoor units!
2. One piece of EQ replaces HP, ERV & Dehumidifier (maybe)
3. Low level of refrigerant
4. Integrated humidity control
5. Low installed cost
6. May need supplemental heating depending on loads and climate – electrical or additional heat pump
7. No Passive ERV core reduces energy performance



Multi-family Retrofit

Colonial II

A Net-Zero Energy Retrofit

mda

BEACON communities

BETTE | CRING CONSTRUCTION GROUP

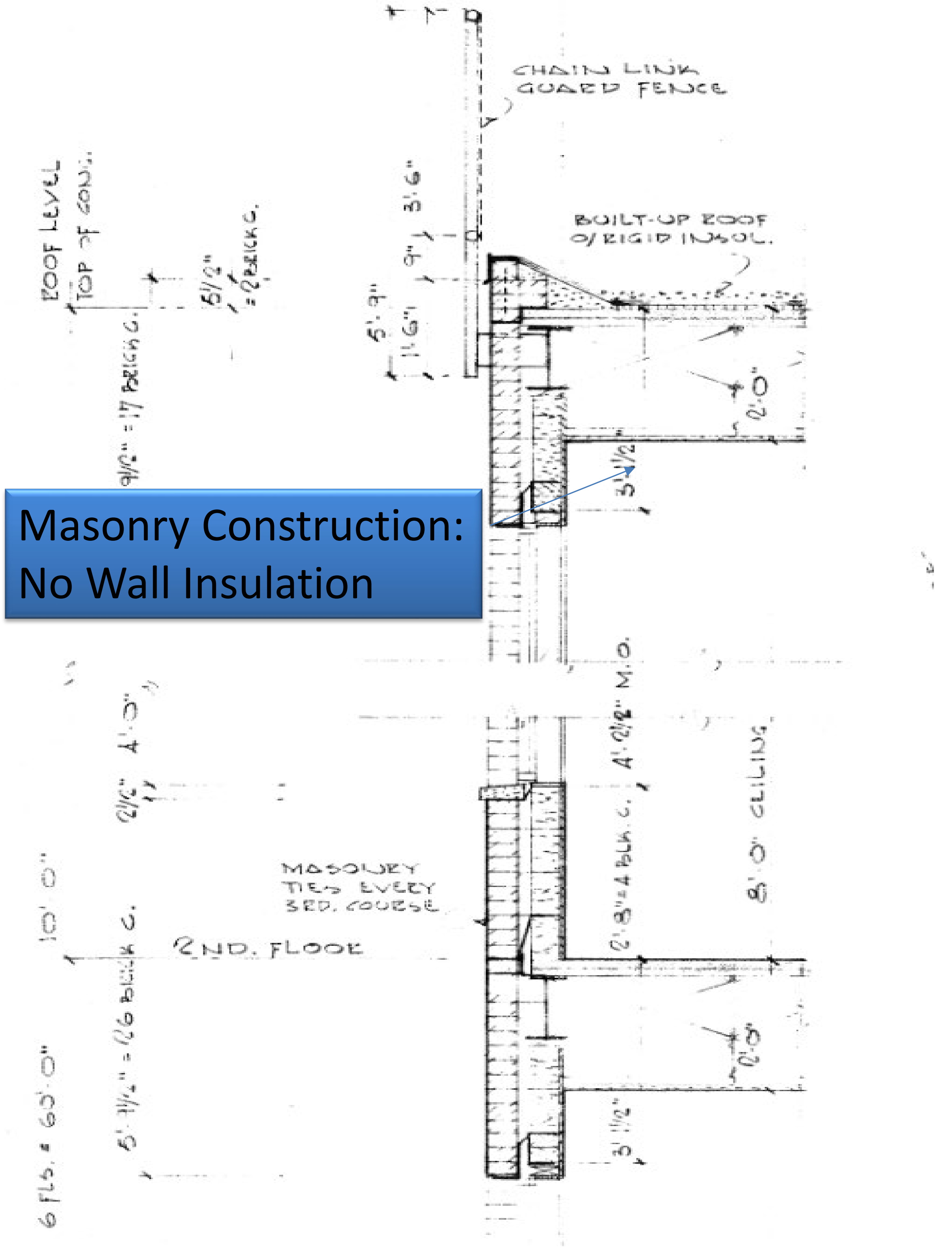
NEW ECOLOGY
Community-Based Sustainable Development

L&S ENERGY SERVICES

NGBC
Building in Nature's Image

Colonial II

Window Box A/C



Masonry Construction: No Wall Insulation

Pre- Retrofit EUI: 117 kBTU/sqft!

Colonial II

Ancient Gas Boilers:
2 x 2.6 MMBTU/hr

Gas HW Heaters:
2 x 300kBTU/hr

Colonial II

New Windows

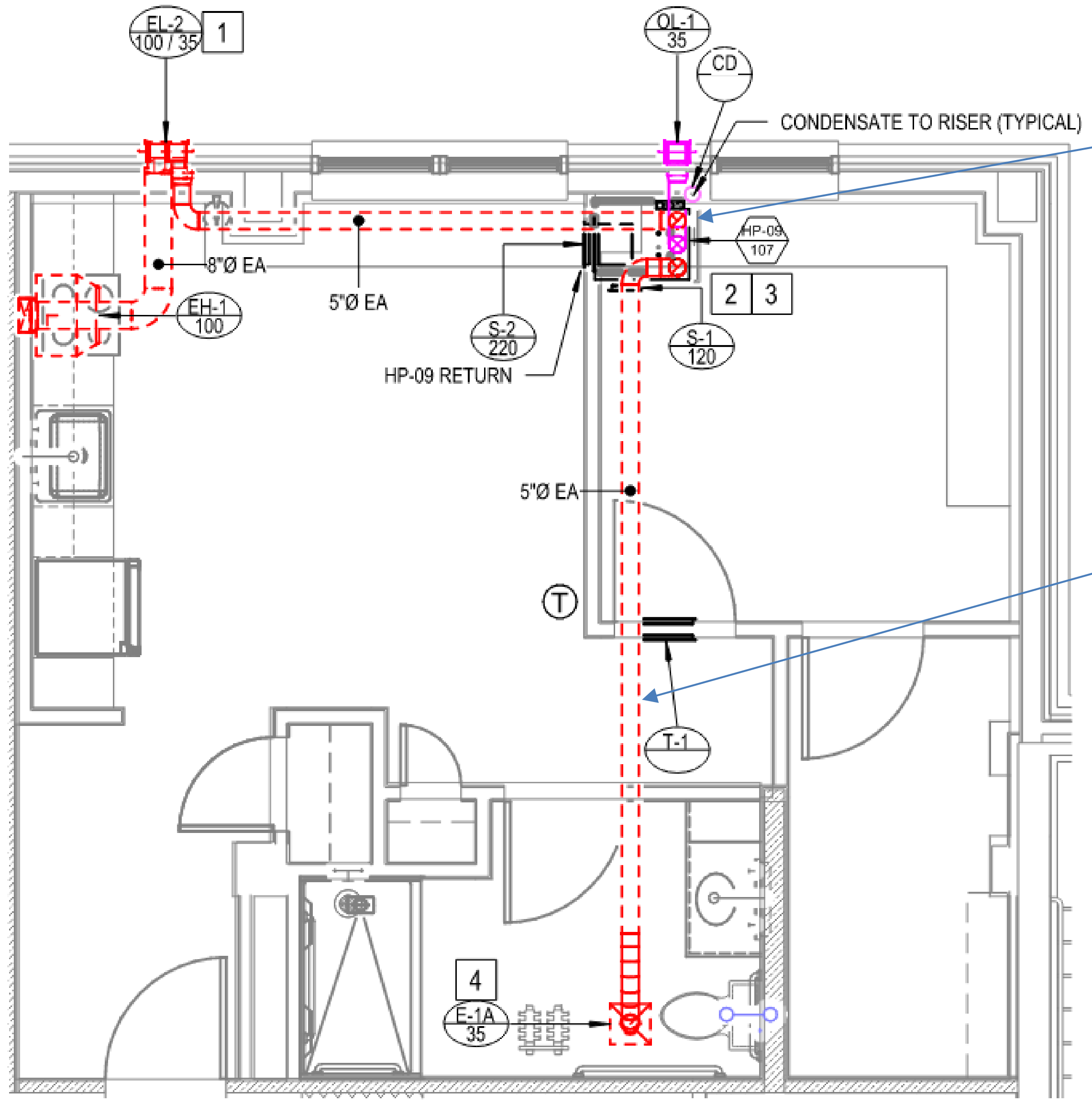
New Air Barrier

New Exterior Insulation

Colonial II

ERV

WATER-SOURCE HEAT PUMP



UNIT TYPE A MECHANICAL DUCTWORK PLAN

SCALE: 1/4" = 1'-0"

All-In One Heat Pump

Simple Ductwork

Interior Retrofit 99 to 74 Apartments

~1,000,000 BTU/HR OF HEAT PUMP INSTALLED

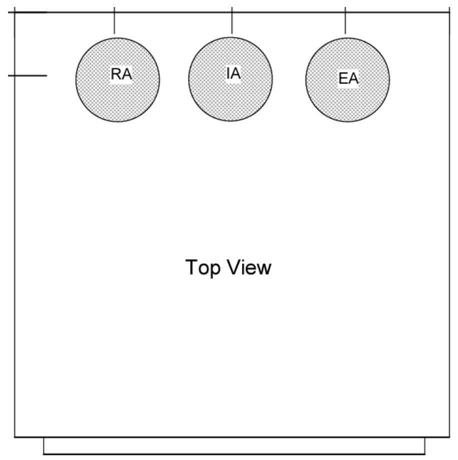
Colonial II

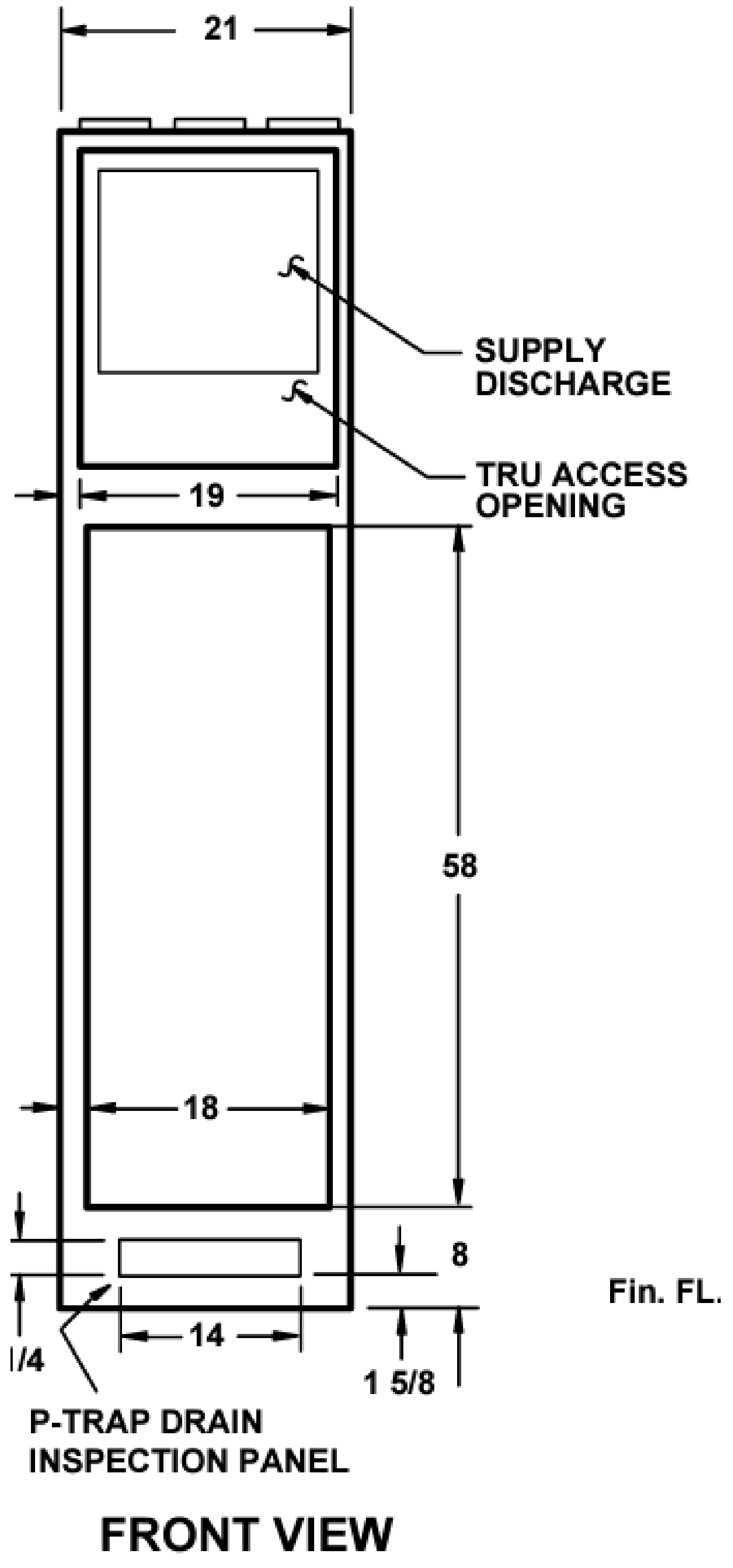
~0.9 W/SQFT

ASE 85%

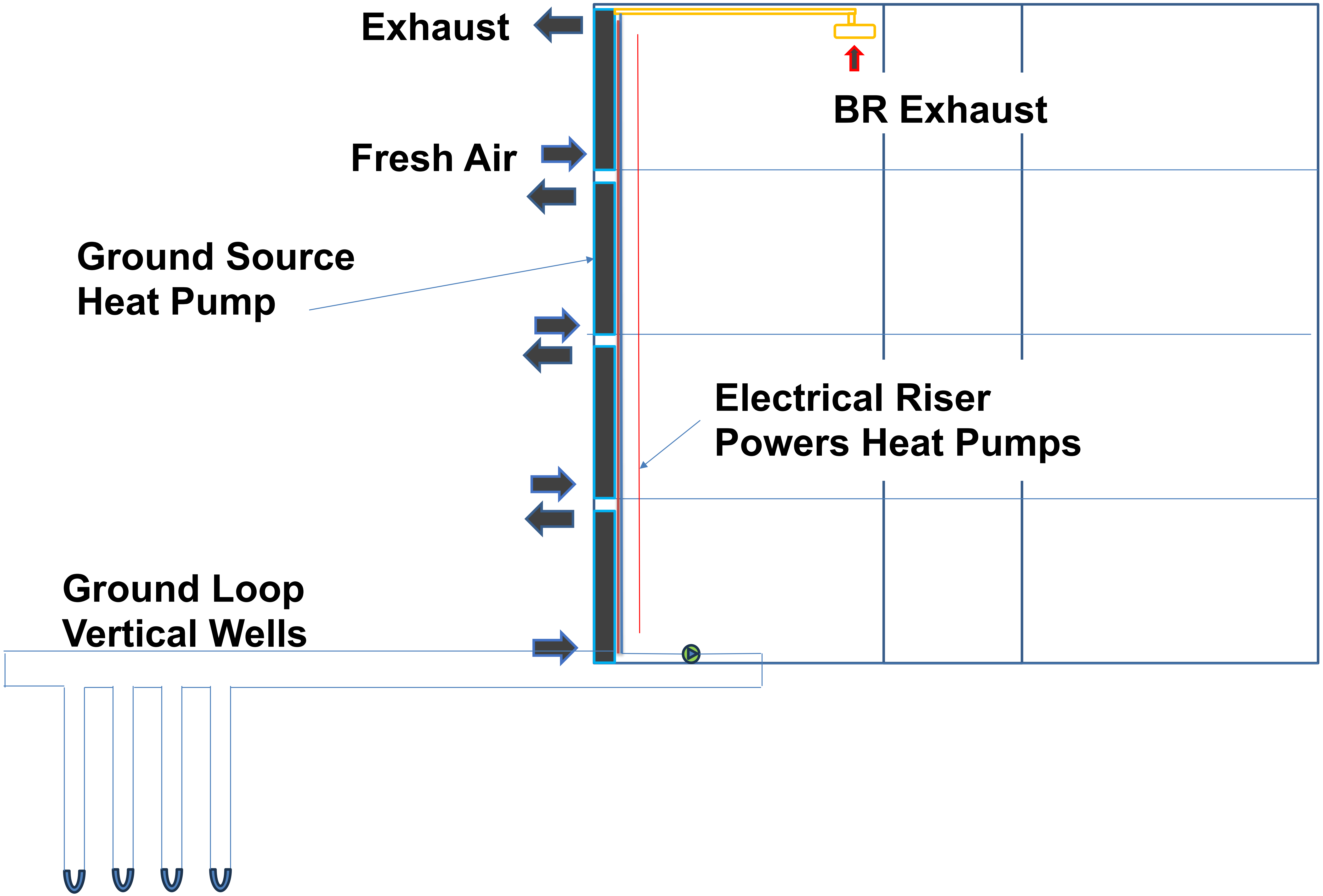
TRE 67%

INTEGRATED HEAT PUMP WITH ERV





Colonial II



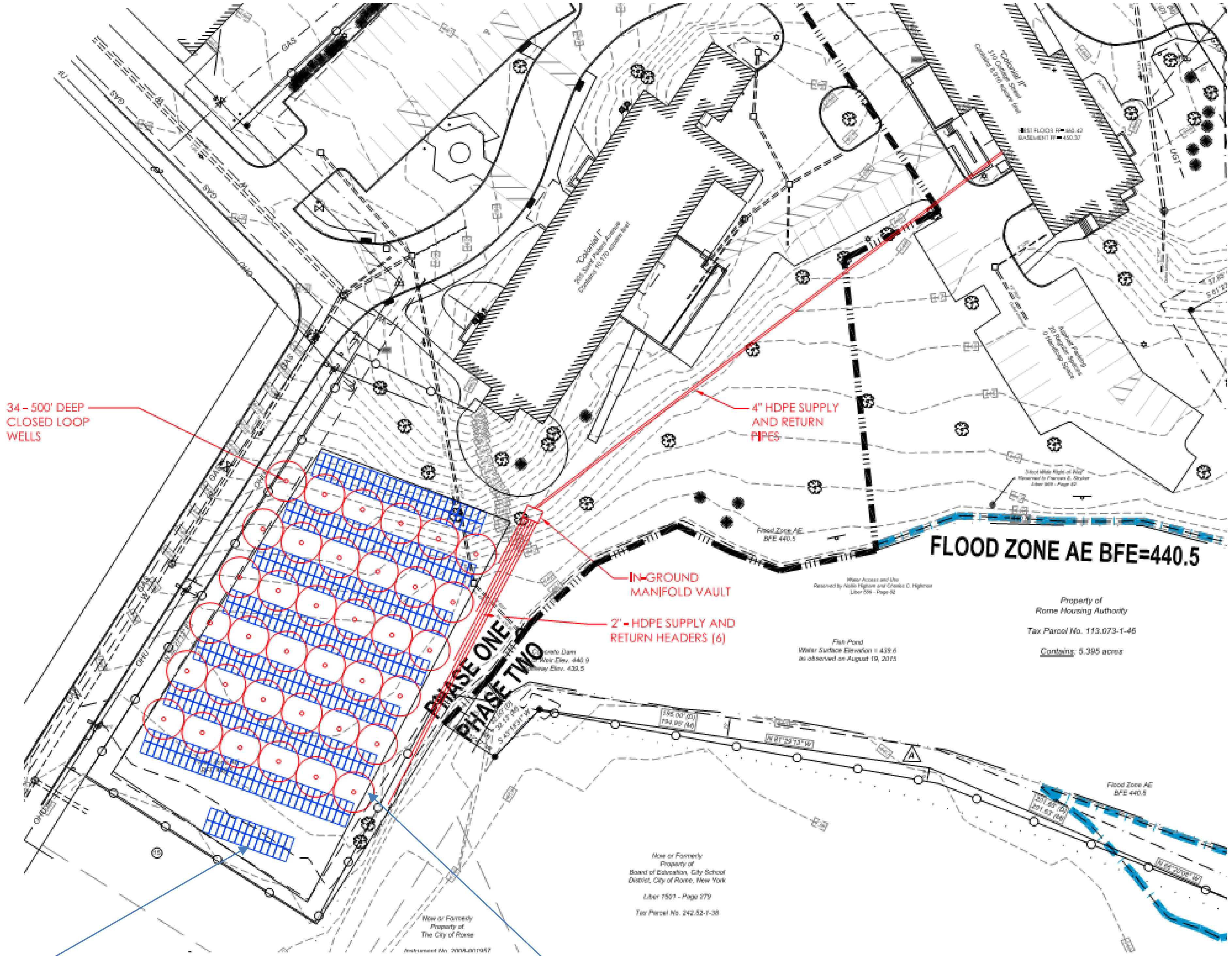
Exhaust
BR Exhaust
Fresh Air
Ground Source
Heat Pump
Electrical Riser
Powers Heat Pumps
Ground Loop
Vertical Wells

Colonial II

All-in One WS Heat Pump

Geothermal Manifold

Colonial II



Solar Field Above Well Field

Vertical Geothermal Well Field

Colonial II

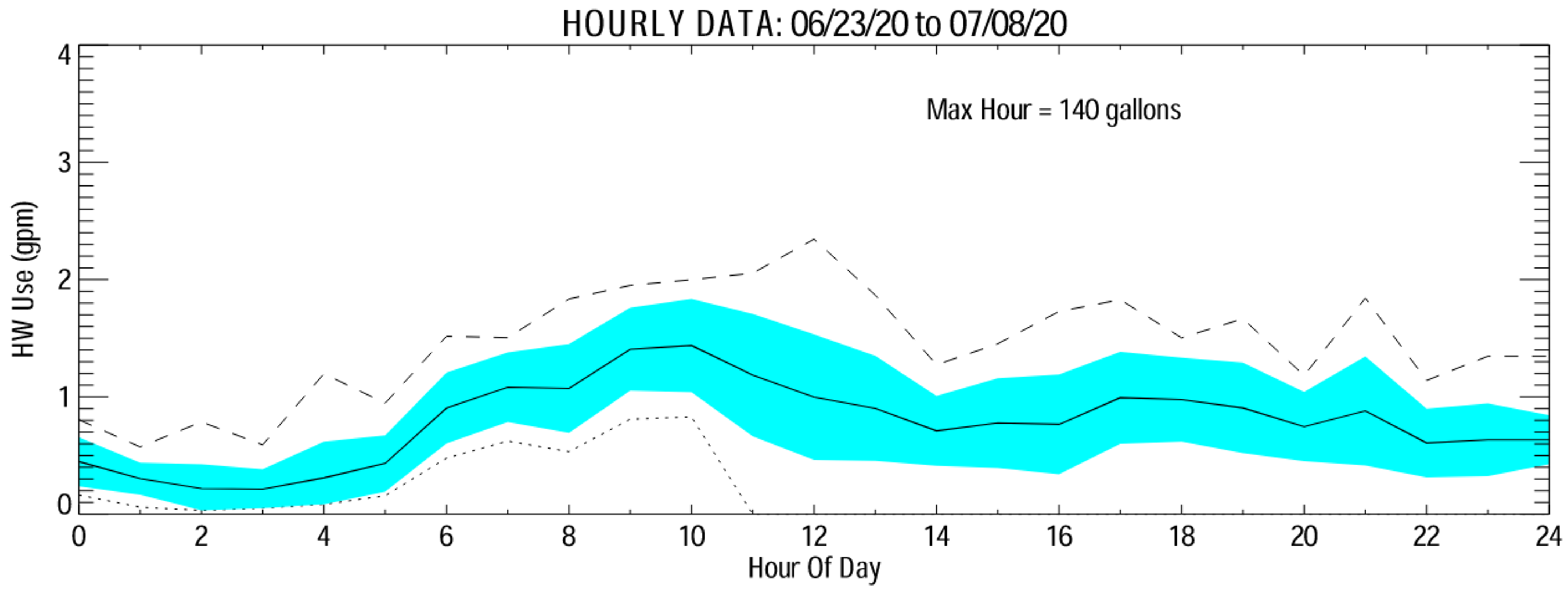
- New electrical service – 3000 A / 208 V / 3 Phase
- Old electrical service - 1400 A / 208 V / 3 Phase

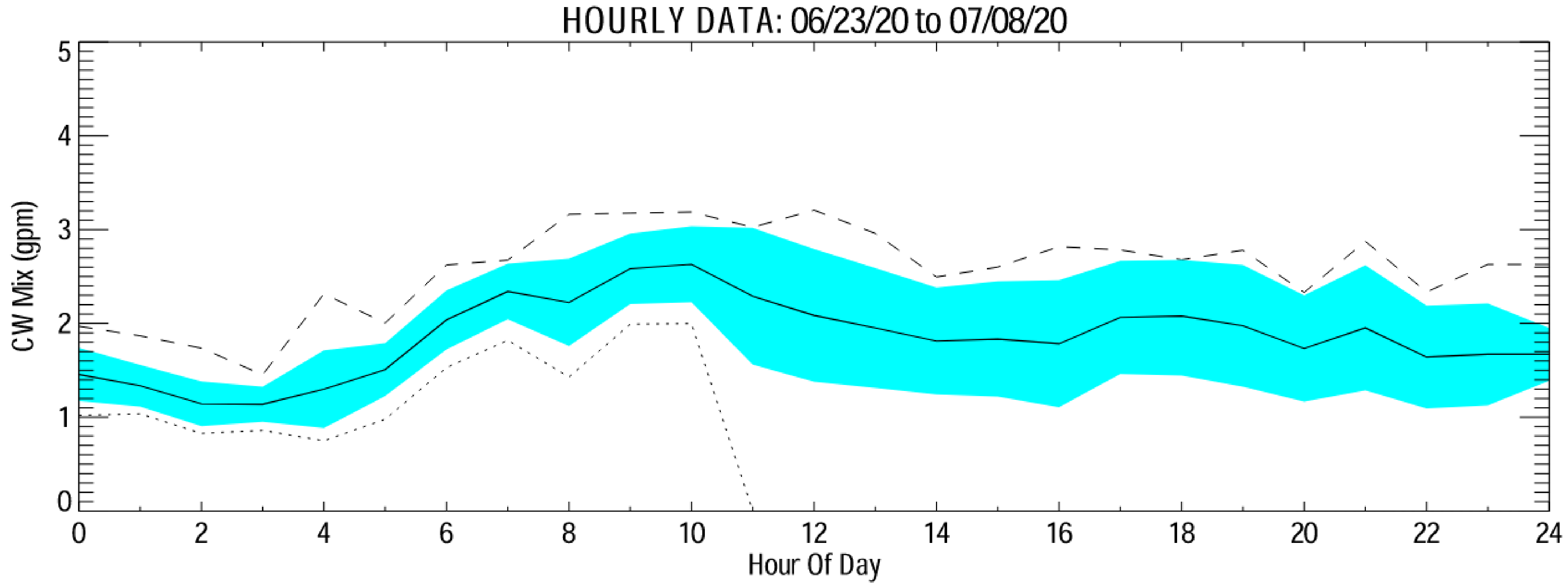
Required New Fire Pump, and Solar Field Required Electrical Service Upgrade

Colonial II

HW consumption of building population measured prior to retrofit
Pre-retrofit condition:

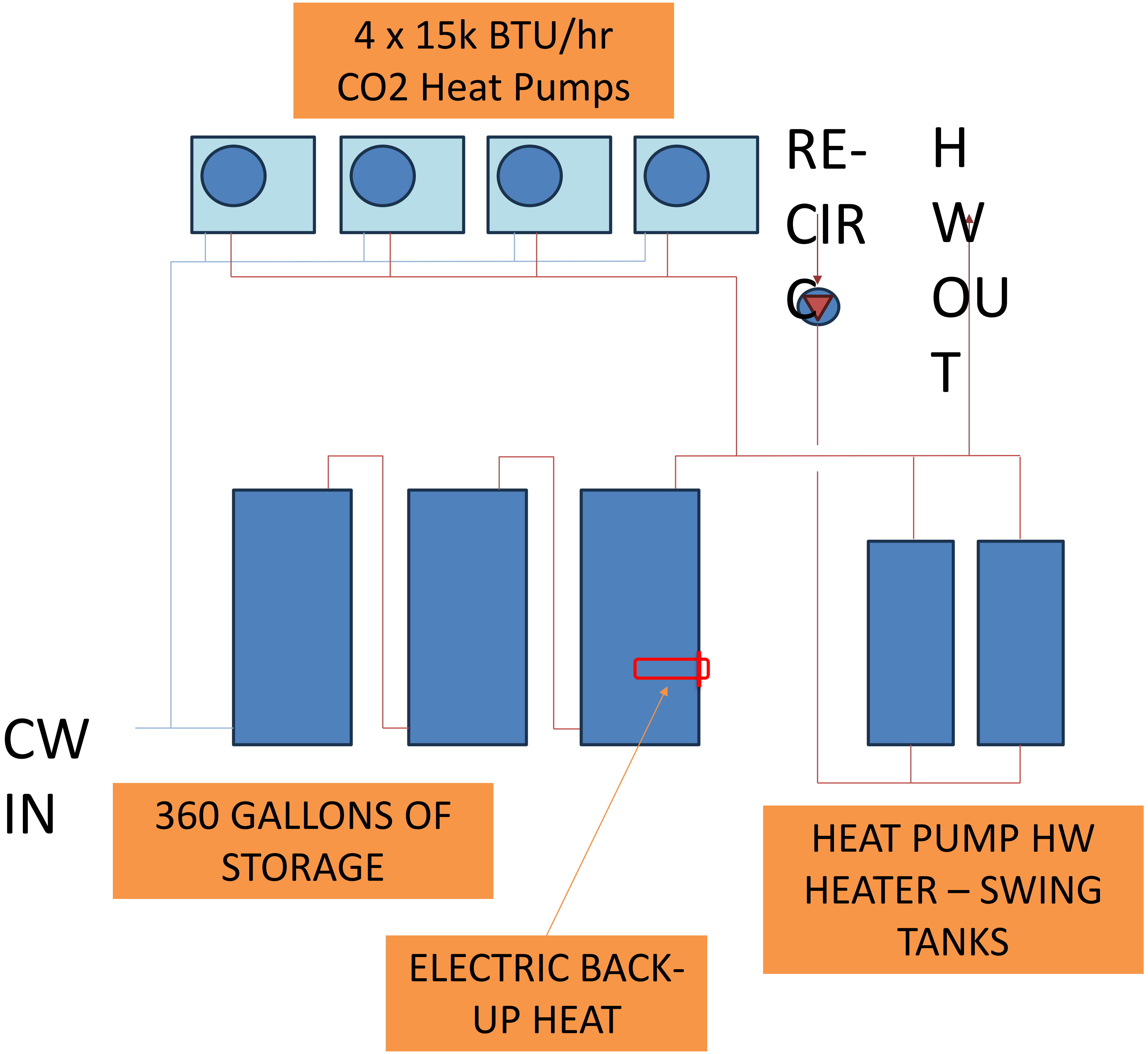
- 99 Apartments
- Low flow fixtures





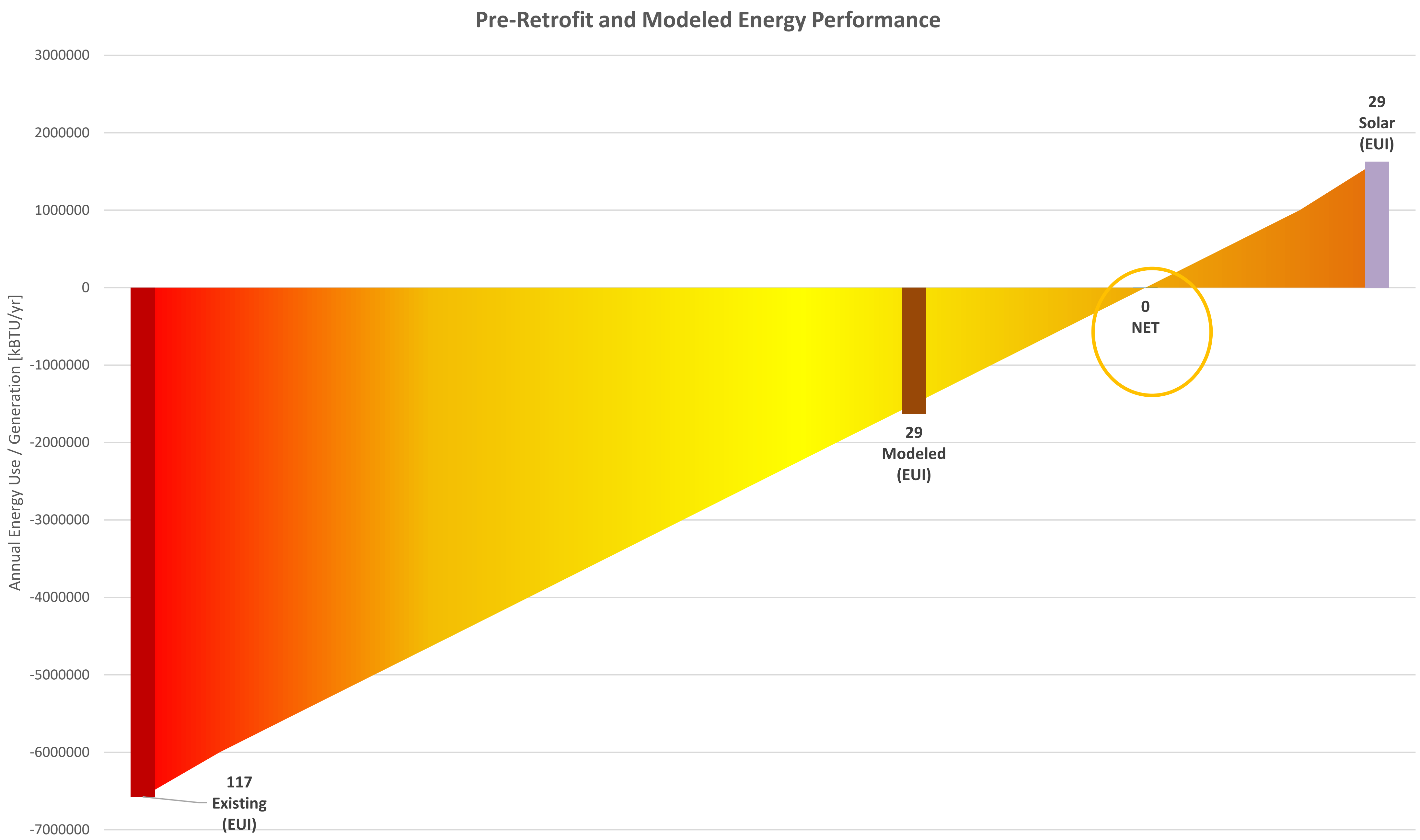
Measured HW Consumption: Courtesy of Klein and Skinner

Colonial II



HEAT PUMP CAPACITY ~12% OF ORIGINAL GAS CAPACITY!

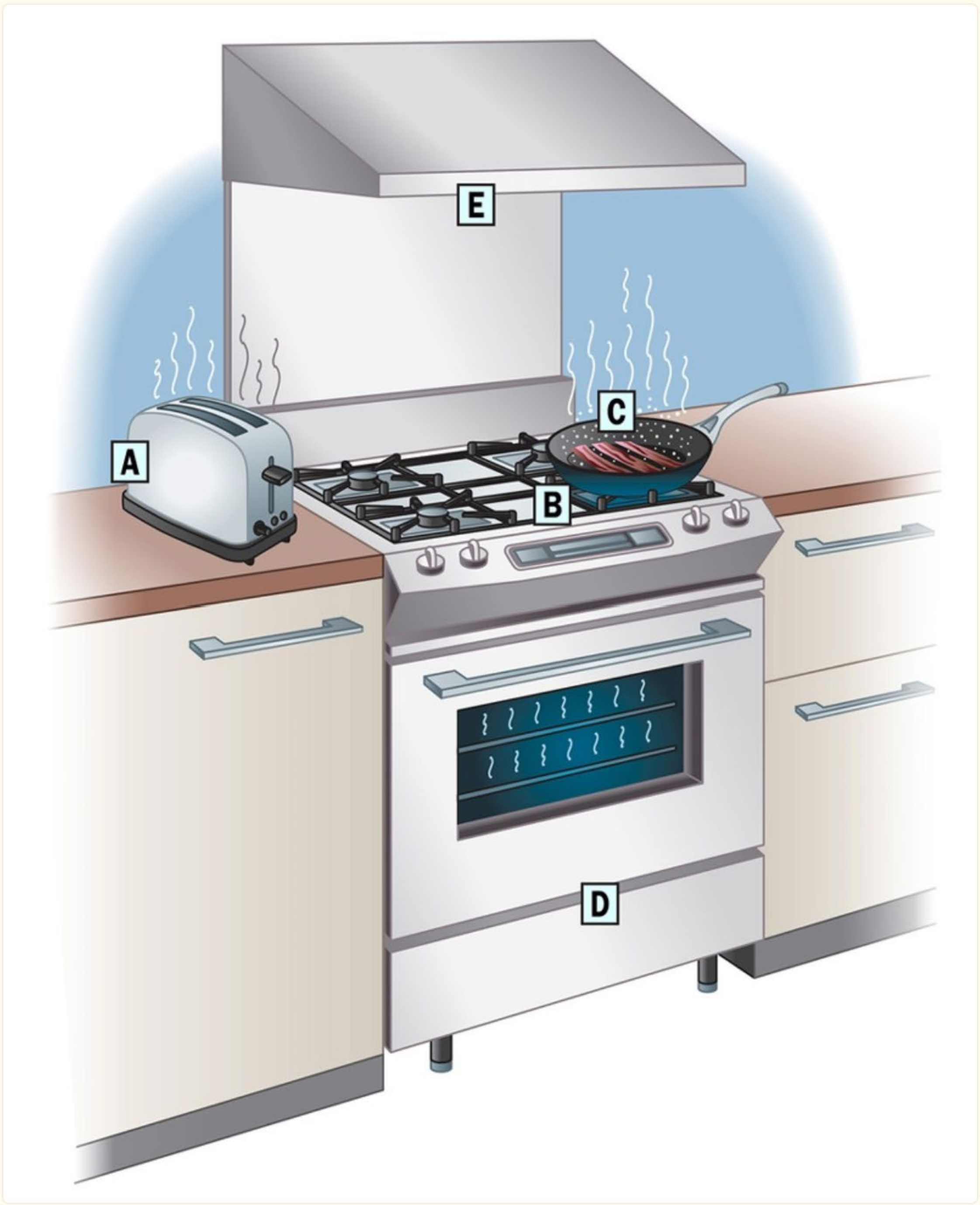
Colonial II



Pre-Retrofit and Modeled Energy Performance
Annual Energy Use / Generation [kBTU/yr]
3000000
2000000
1000000
0
-1000000
-2000000
-3000000
-4000000
-5000000
-6000000
-7000000
117
Existing
(EUI)
29
Modeled
(EUI)
0
NET
29
Solar
(EUI)

Ducted Range Hoods

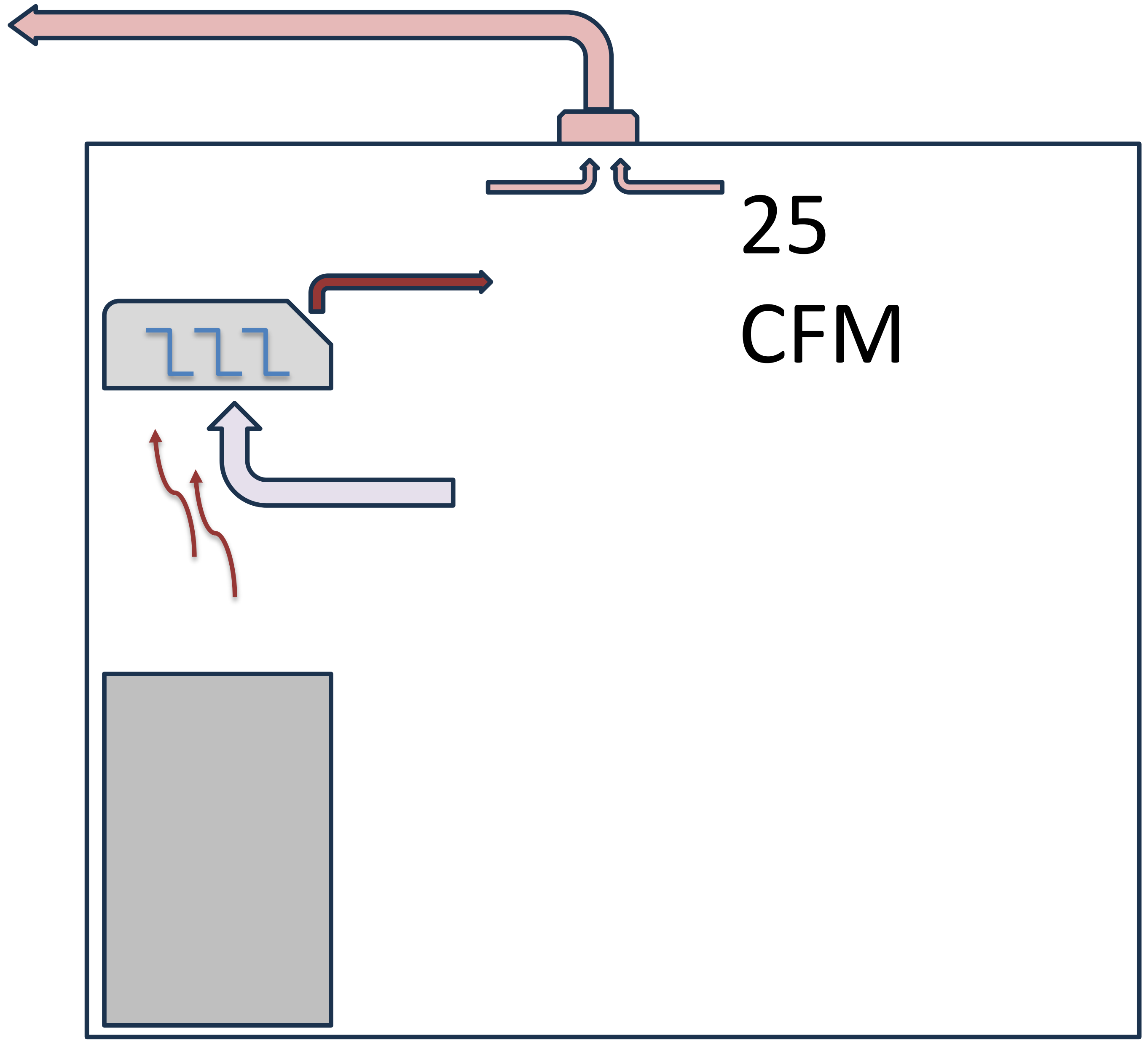
Kitchen Pollutants



Reproduced with permission from Environmental Health Perspectives

- Carbon Monoxide
- Nitrogen Oxides
- Particulates
- VOCs

Code Requirements



Recirculating Range Hood

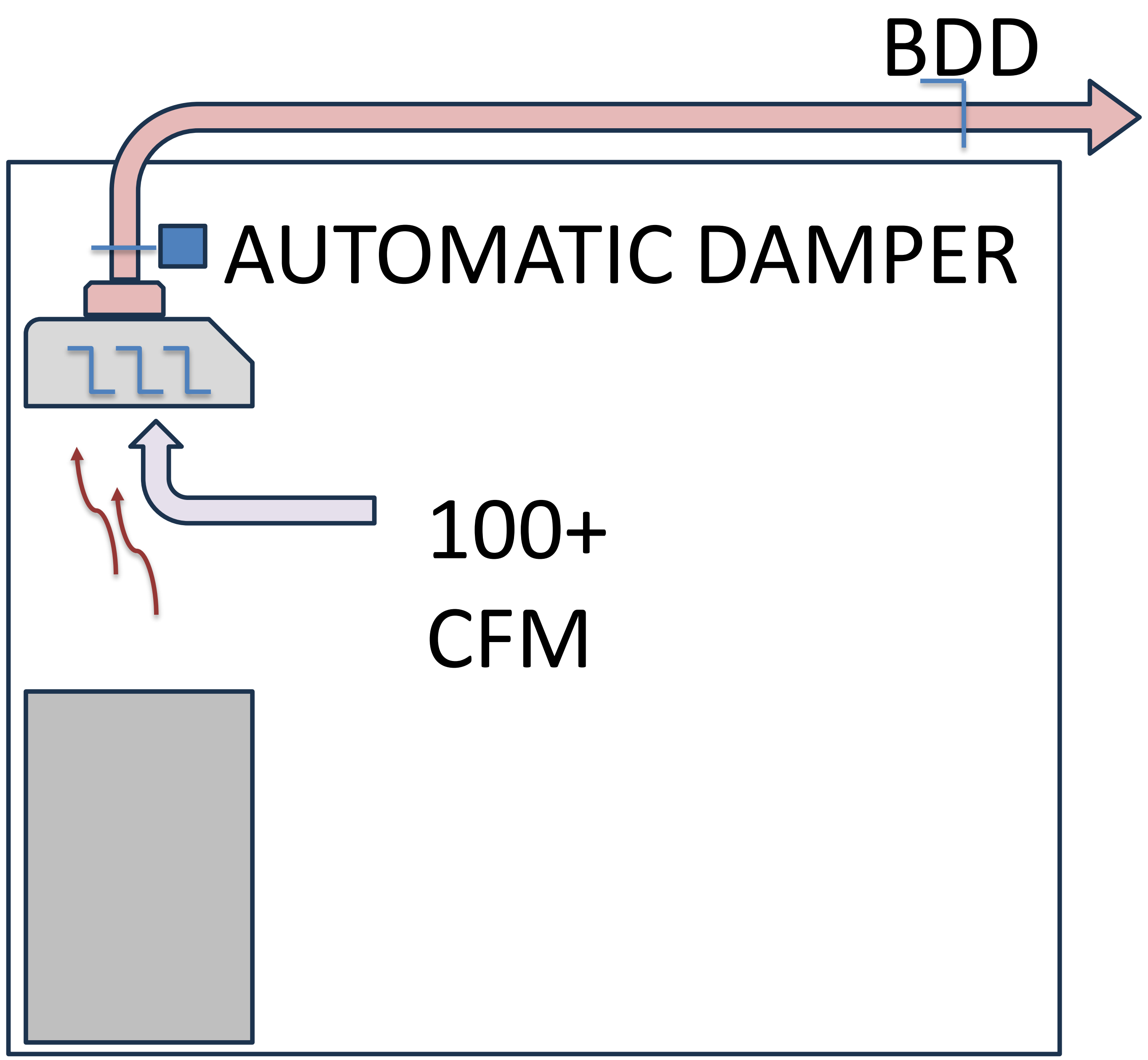
Most Mechanical Codes:

- 100 CFM intermittent or 25 cfm continuous

ASHRAE 62.2-2013

- 100 CFM intermittent (Vented Range Hood)

Vented Range Hoods in Passive House MF?



Recirculating Range Hood


PHIUS

TECH CORNER

Makeup Air Requirements for Direct Kitchen Hood Exhaust

Lisa White, September 18, 2019

- Building MUA must keep building pressurization below 5 Pa assuming 12% of hoods are operational.
- Recommend tight fitting backdraft damper or automatic damper in duct for pressure control

DISCUSSION/ QUESTIONS

Office Retrofit Case Study

4528 Freret Street

Phius REVIVE 2024

RETROFIT STANDARD FOR BUILDINGS v0.8

Good for the planet | Good for your buildings | Quality assured results

CRITICAL UPGRADES

ROOF

WATER MANAGEMENT DETAILING

HVAC

WINDOWS

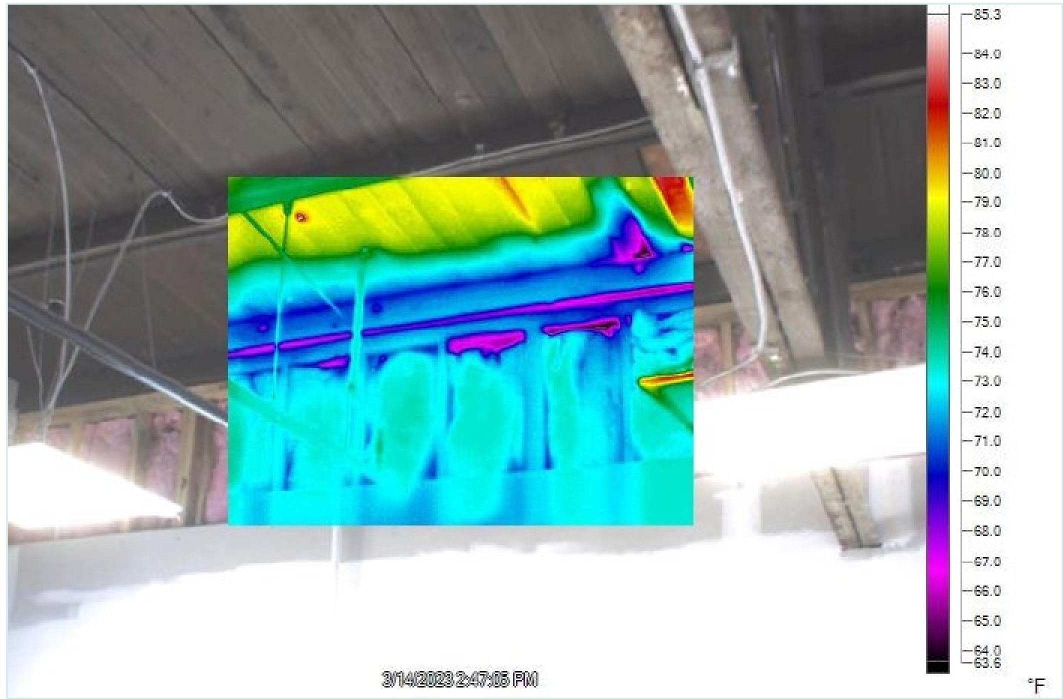
SITE DRAINAGE

Roof Replacement is the #1 Priority

Bulk Water Failure

KL site images
Standing water on roof at east parapet wall may be related to areas of high moisture content and may be related to wet batts noted in BSC Report: pg 18, Figure 40

Air Leakage Failure



LaGrange Report: pg 21, Image 11163
West wall/roof interface.
Air leakage from exterior to interior while building is depressurized for infiltration testing.

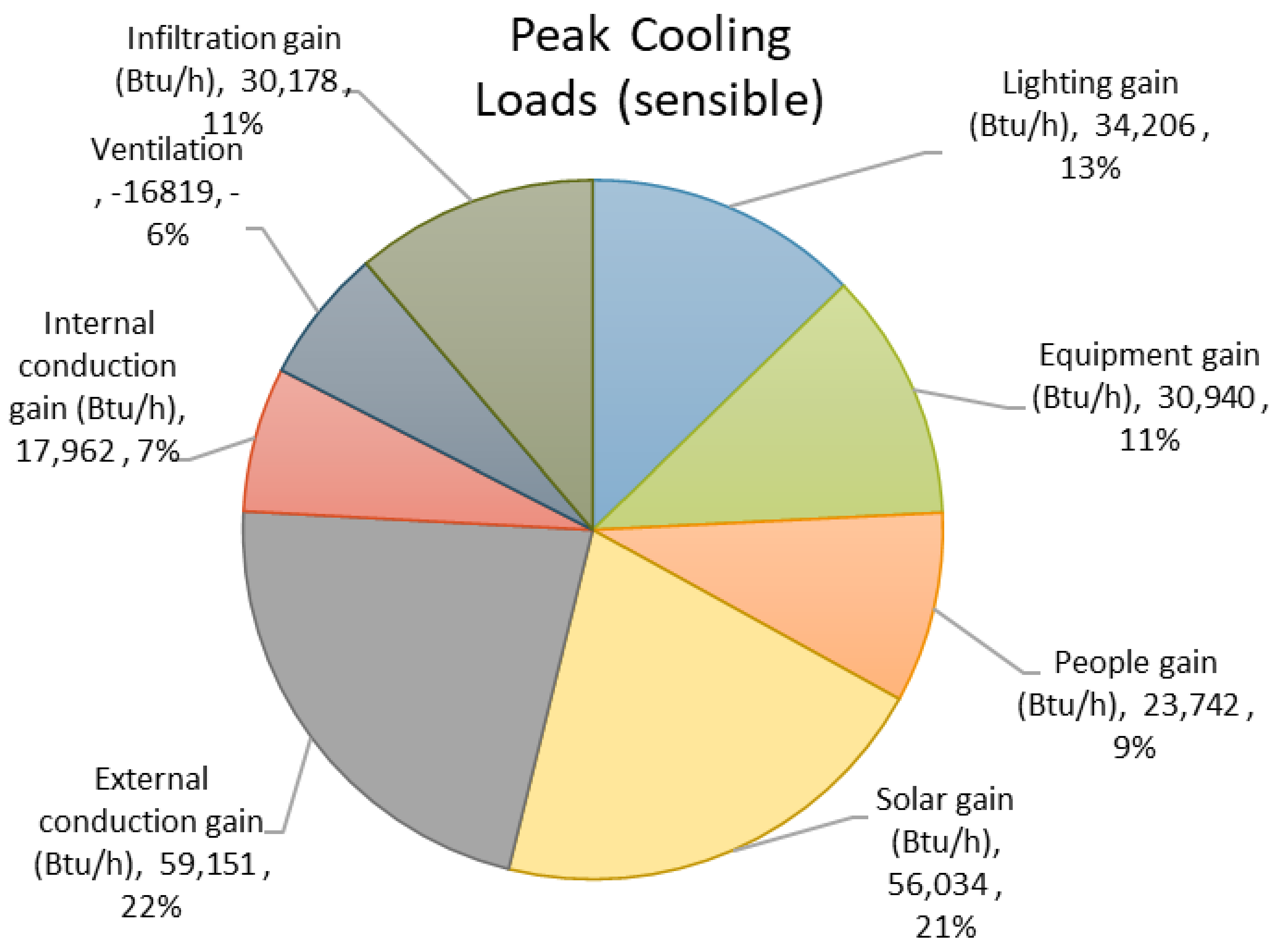
Thermal Failure

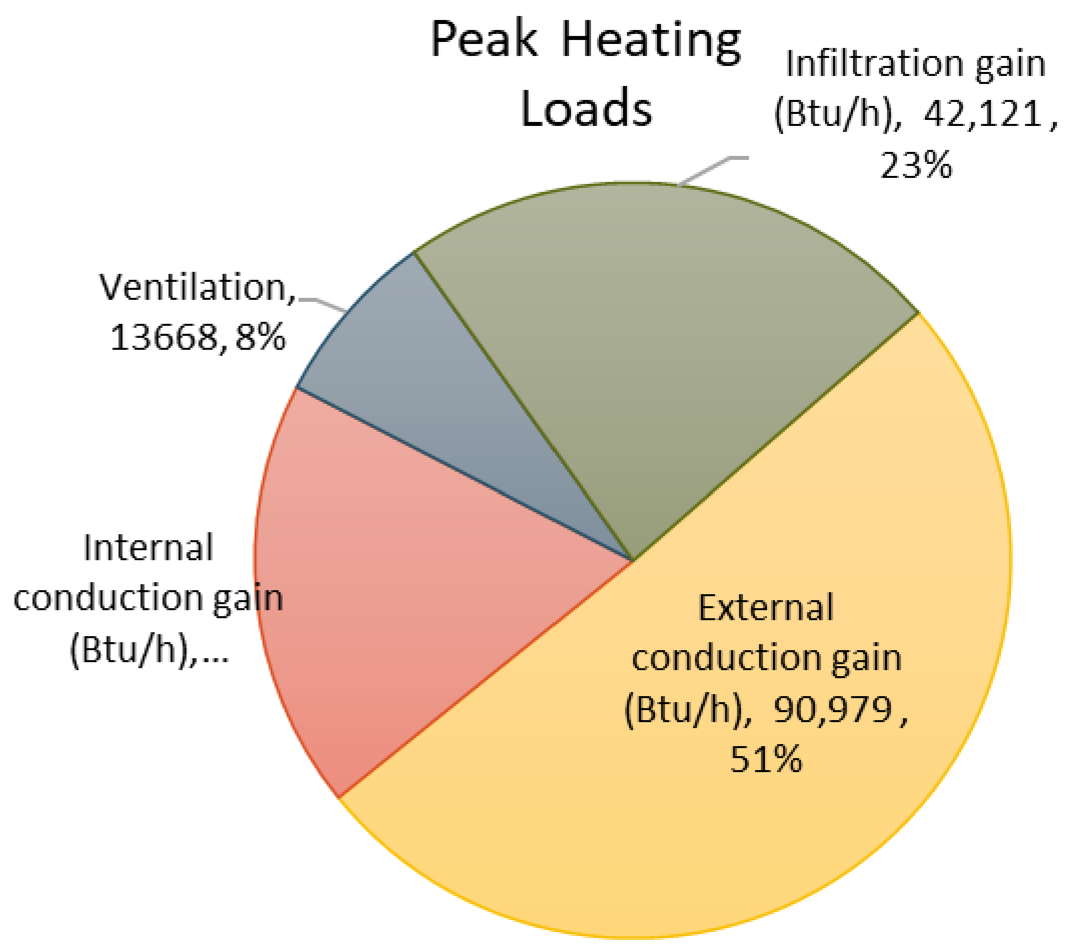
BSC Report: pg 37, Figure 111
Roof 2nd floor east.
Extreme heat transfer due to very poor thermal performance. This results from solar gain of roof. Outside temperature at the time of reading was 65F.

4528 Freret Street

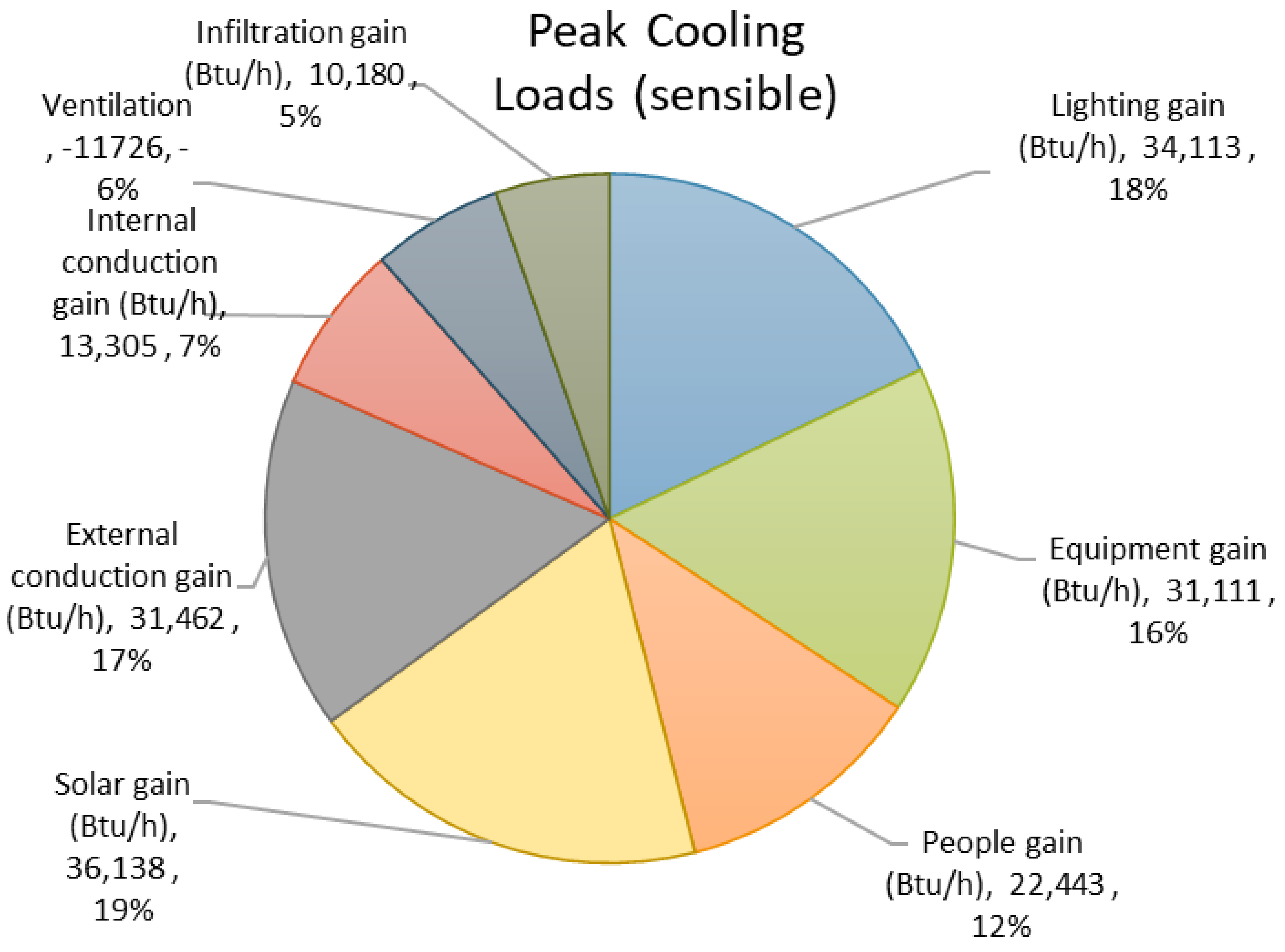
Kirksey
ARCHITECTURE

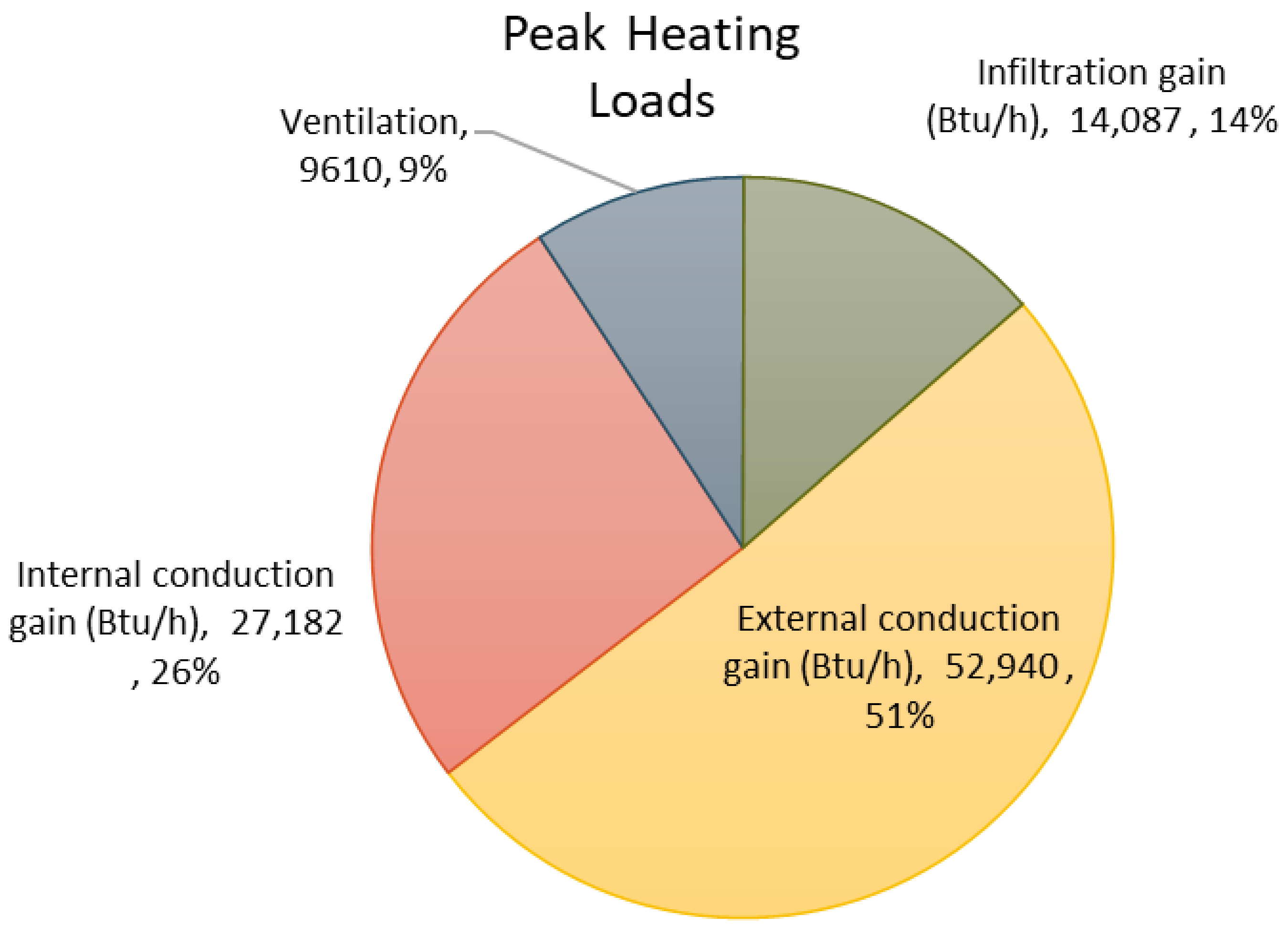
4528 Freret Street – Loads - IECC2021



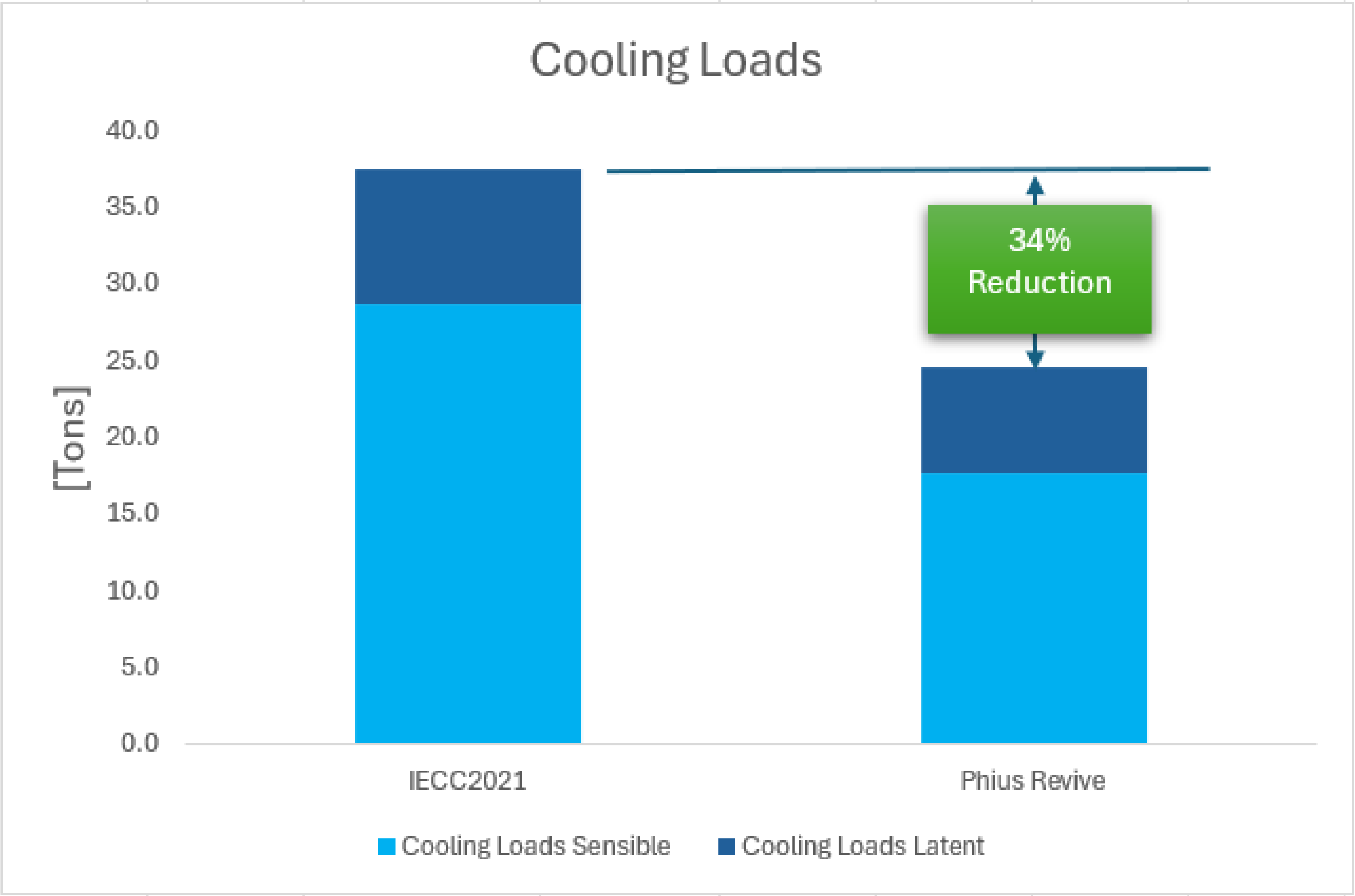


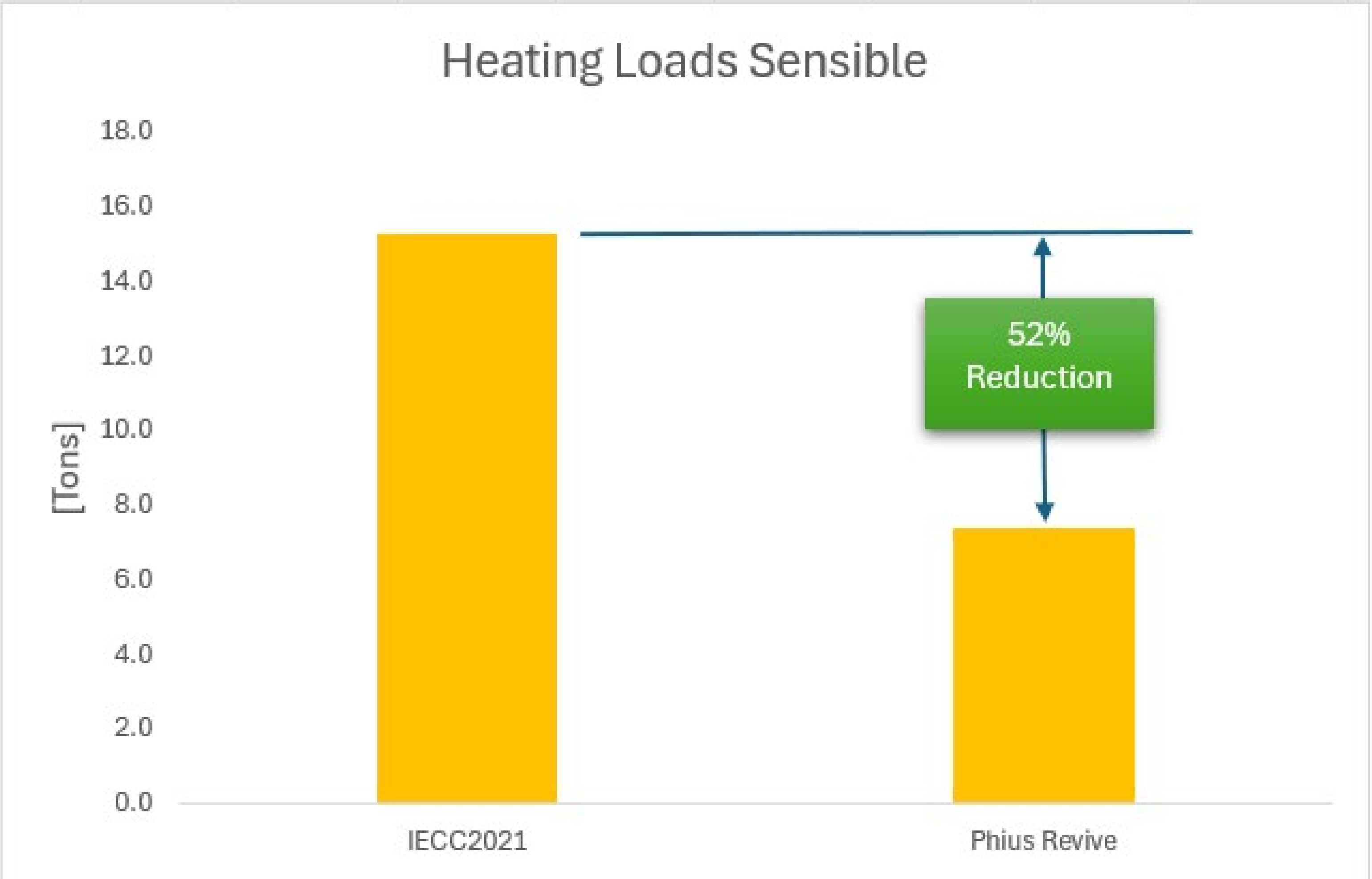
4528 Freret Street – Loads – Phius Revive



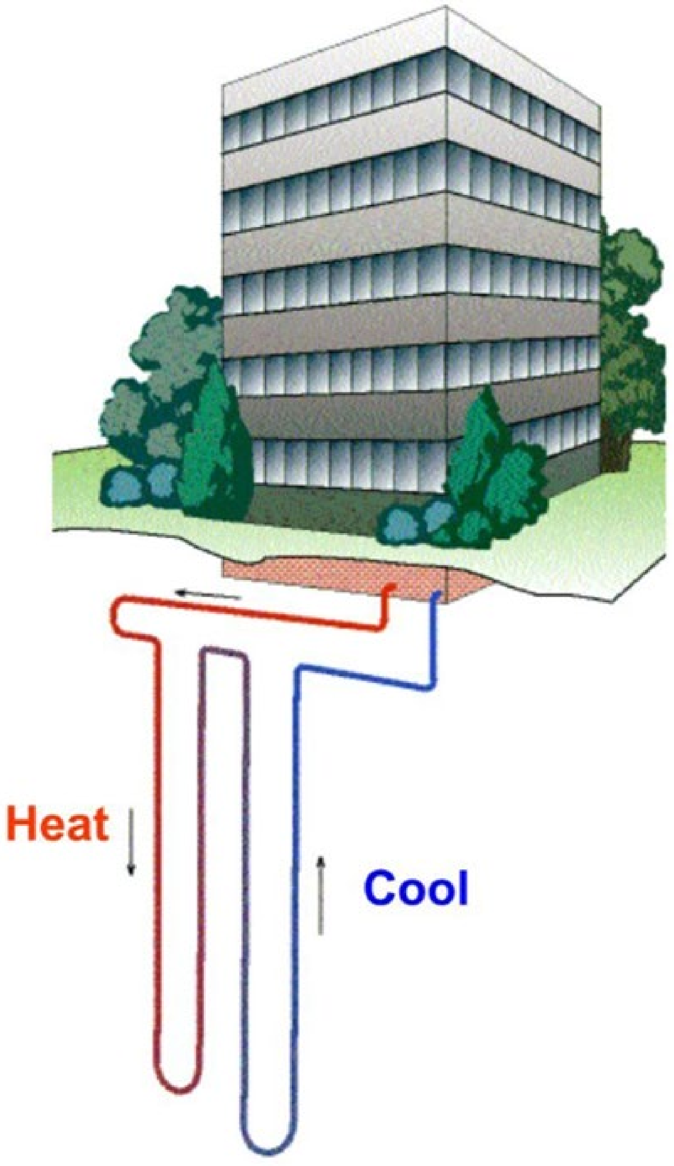


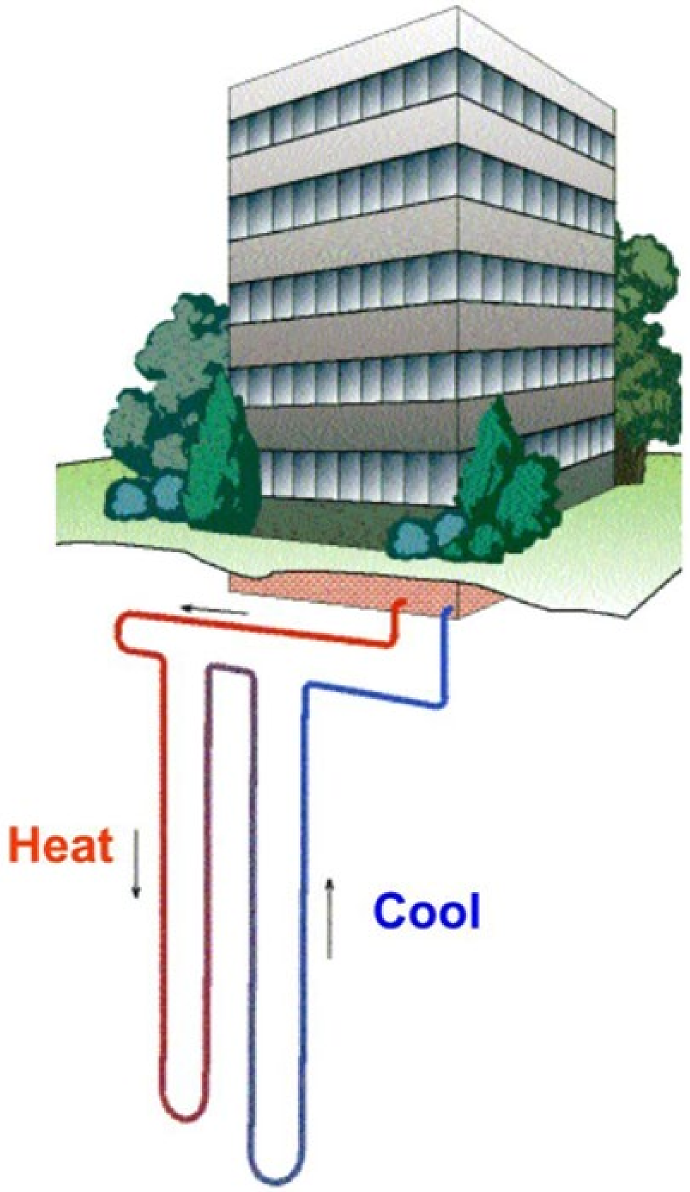
4528 Freret Street – Loads - Compared





SYSTEM OPTIONS





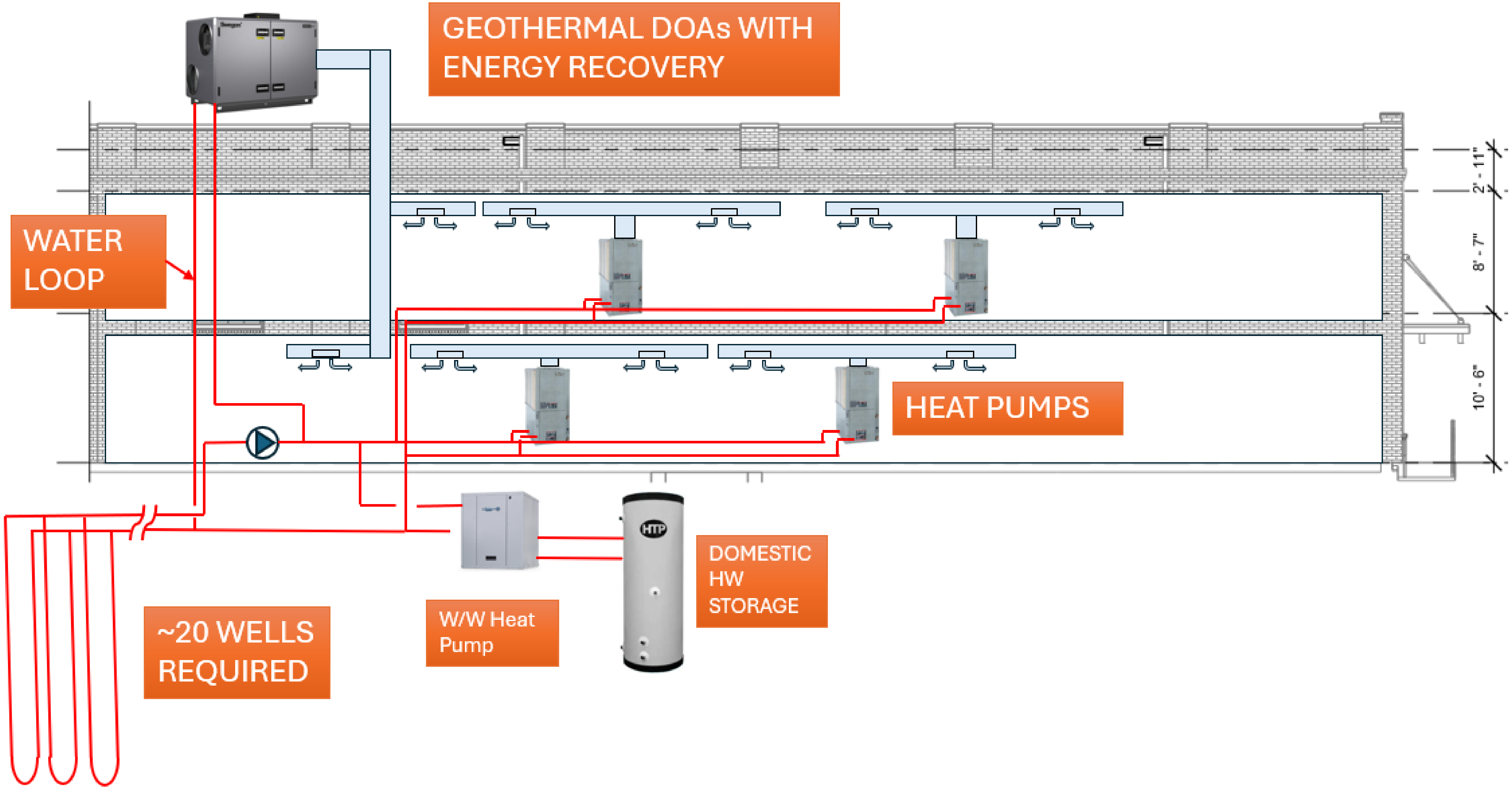
GEO

GEO + AS DOAs

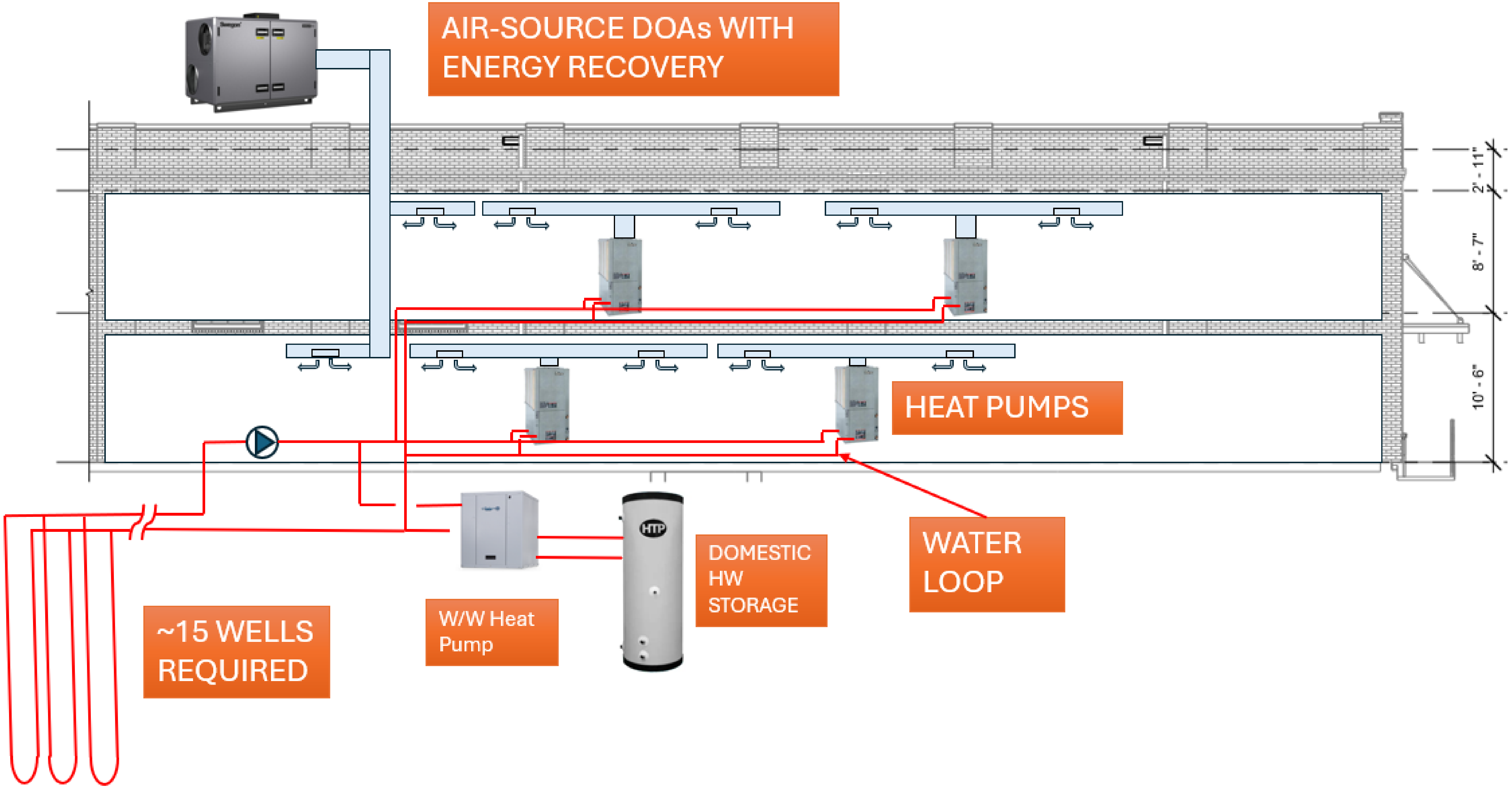
4-PIPE

VRF

GEOTHERMAL SYSTEM SCHEMATIC

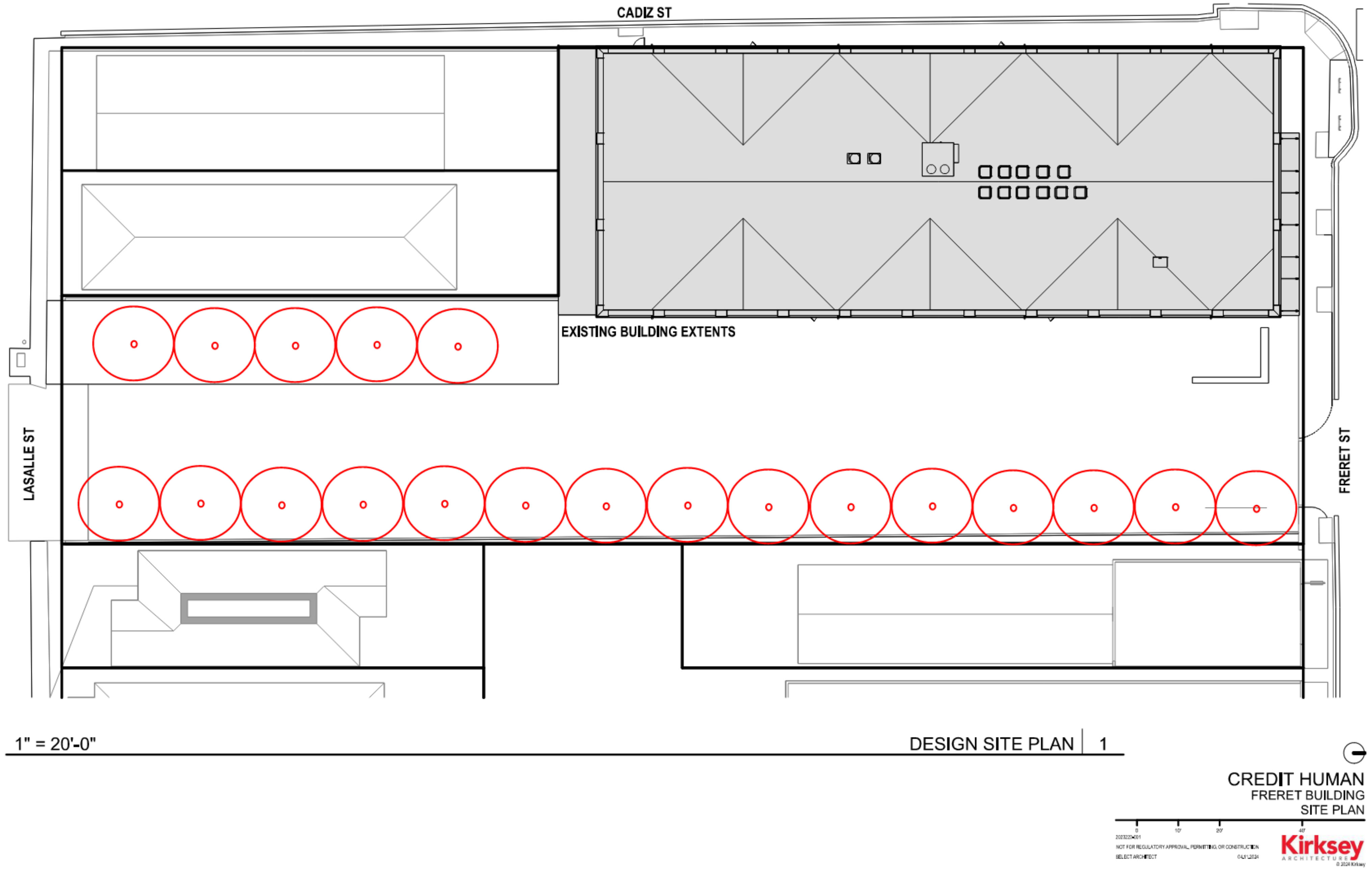


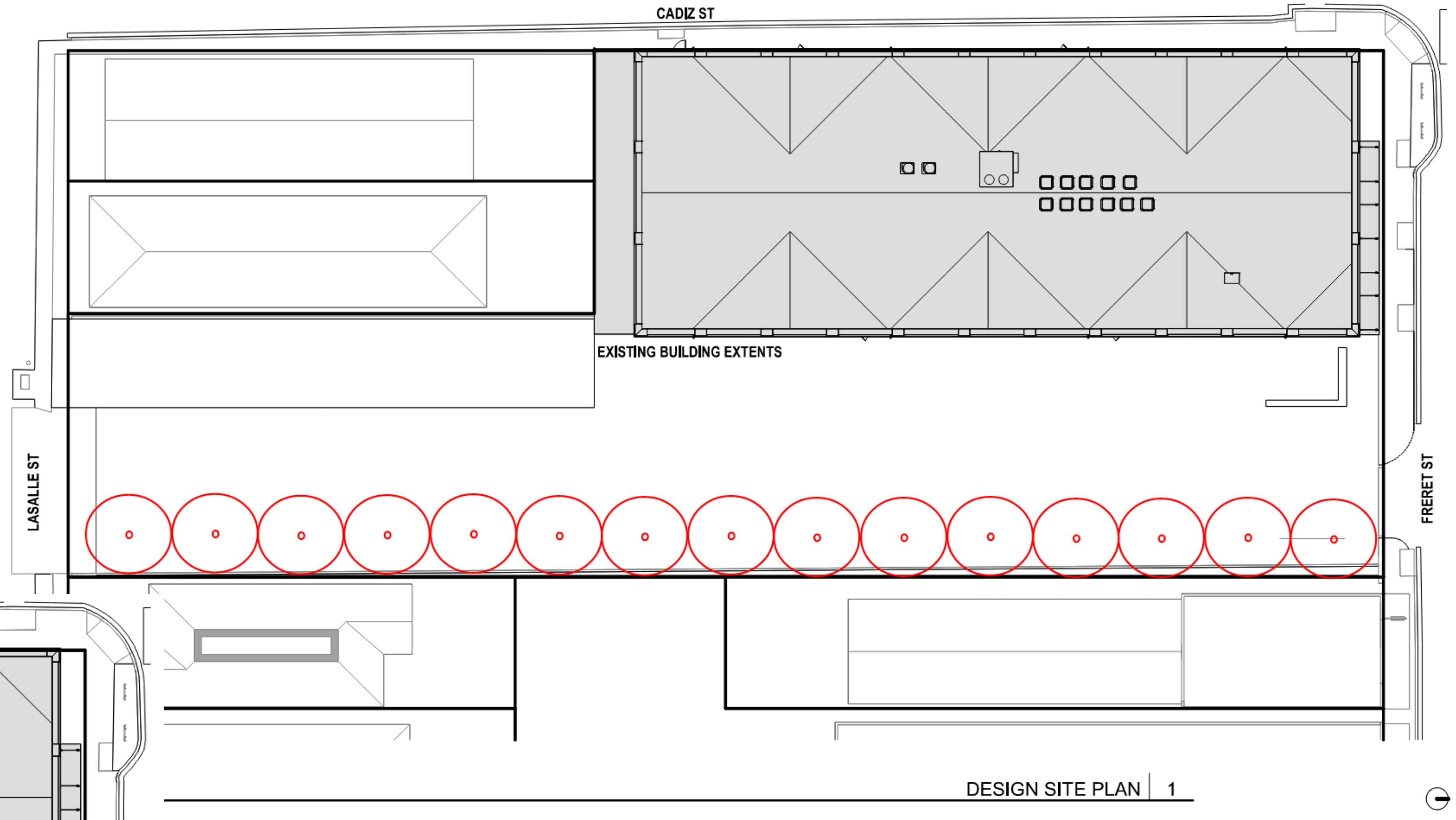
GEOTHERMAL SYSTEM w/ AIR SOURCE DOAs



GEOTHERMAL WELLS

All Geothermal System
20 Wells (300' deep)

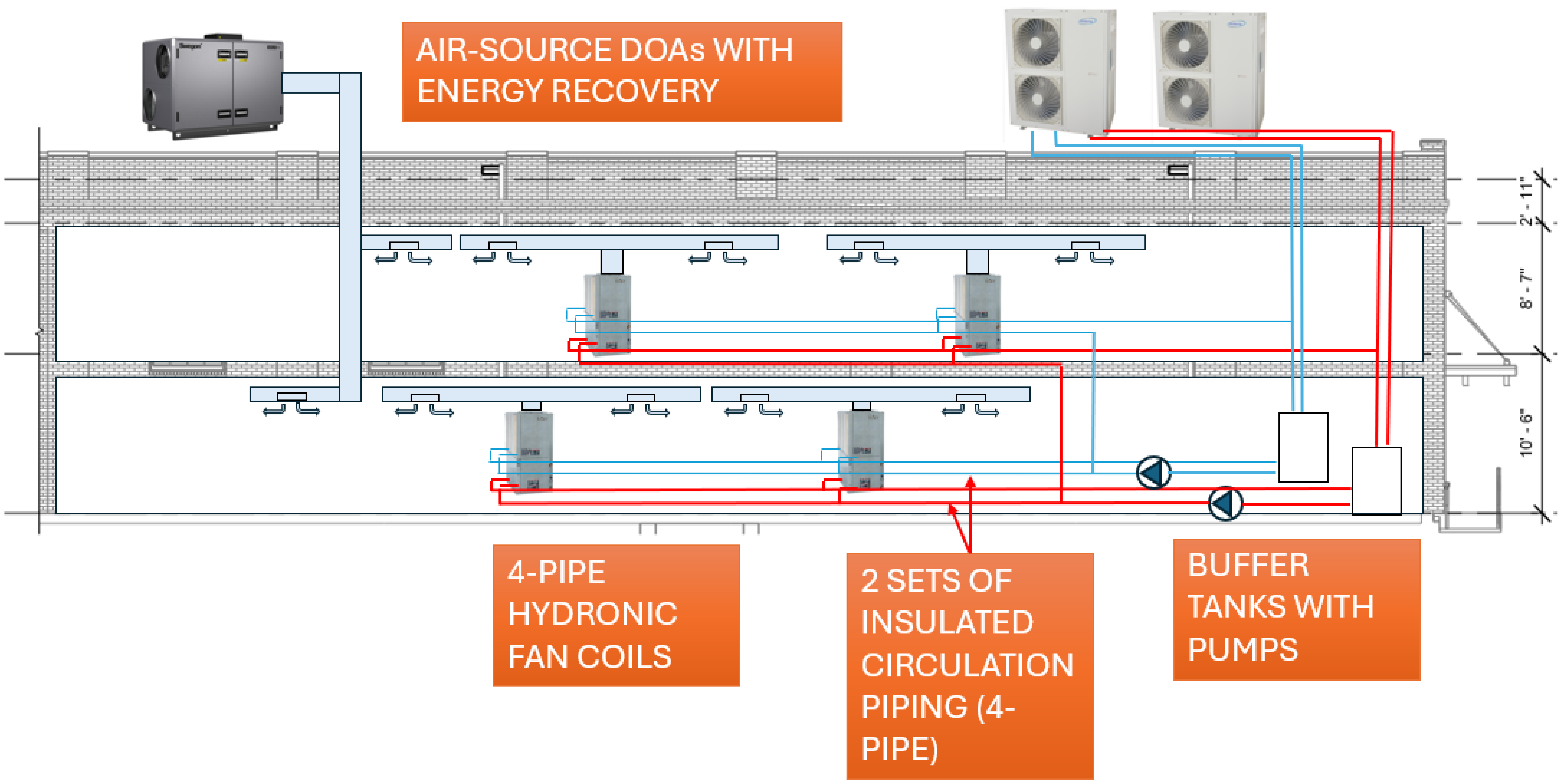




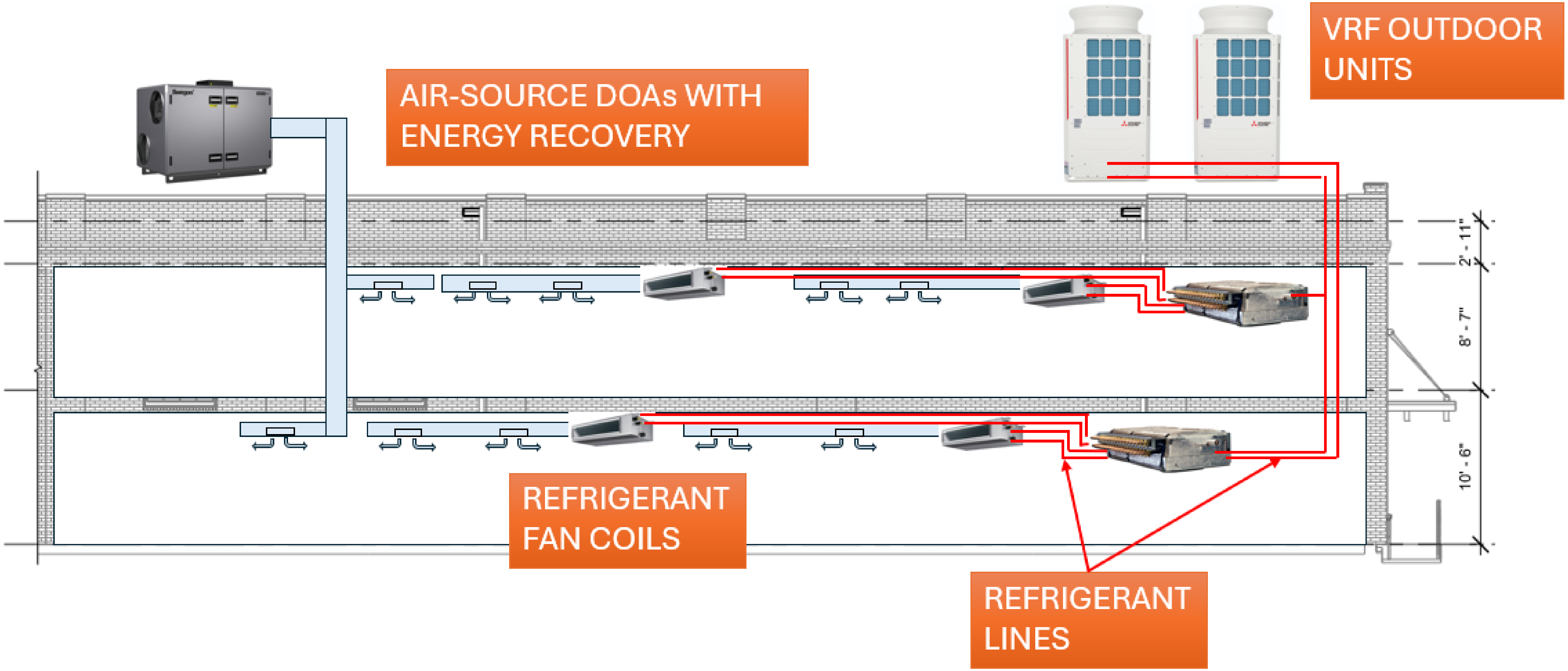
Geothermal plus air source
DOAs
15 wells (300' deep)

STAENGL ENGINEERING

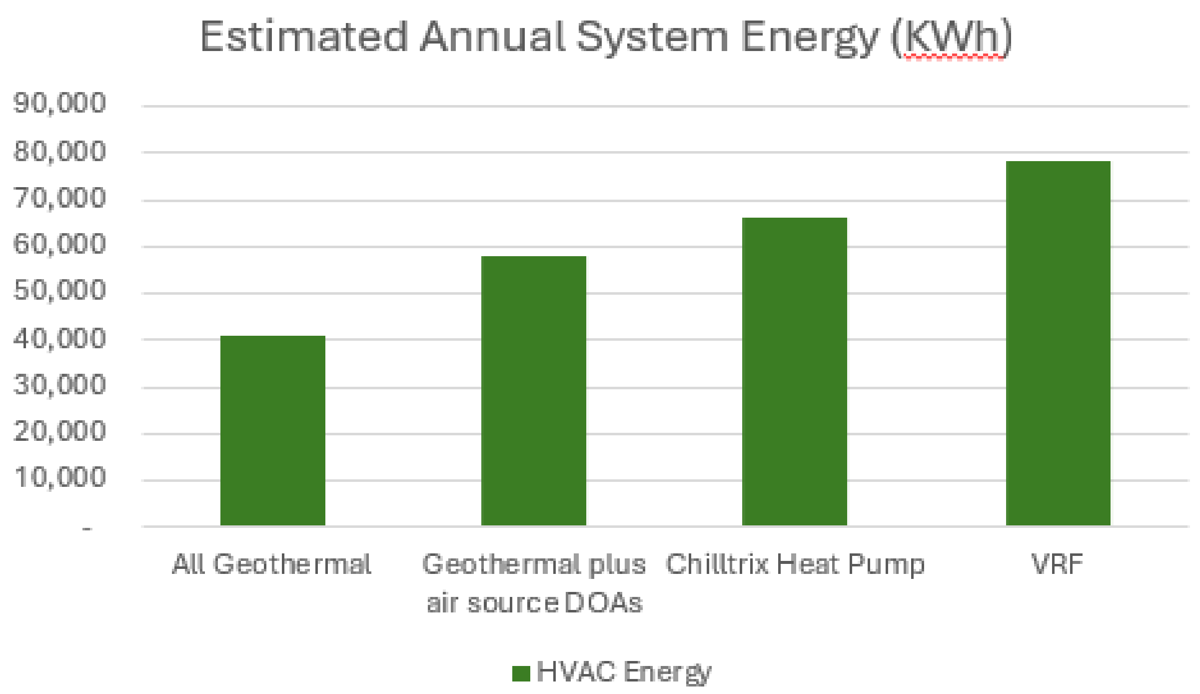
HYDRONIC SYSTEM w/ AIR SOURCE DOAs

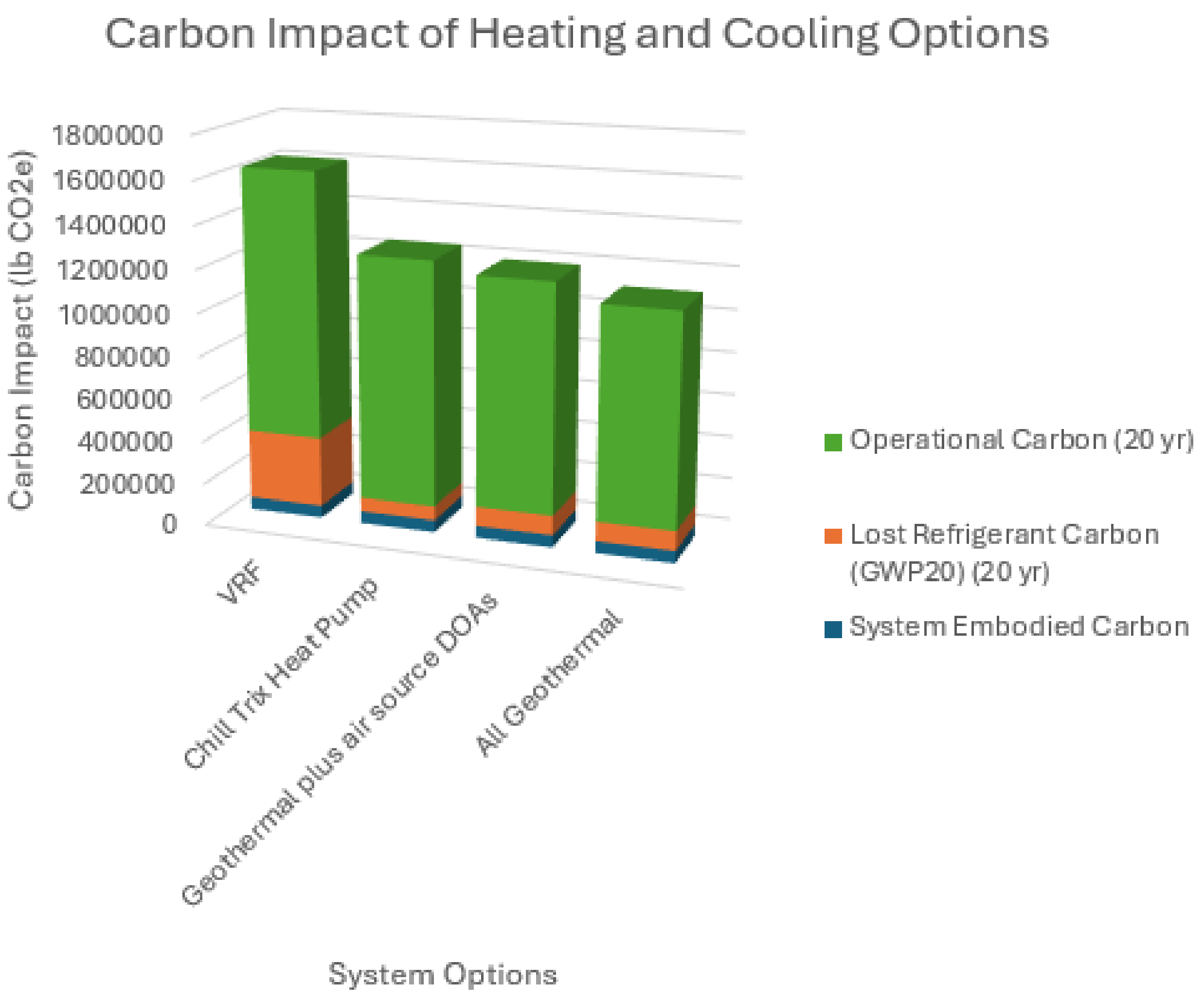


VRF SYSTEM w/ AIR SOURCE DOAs



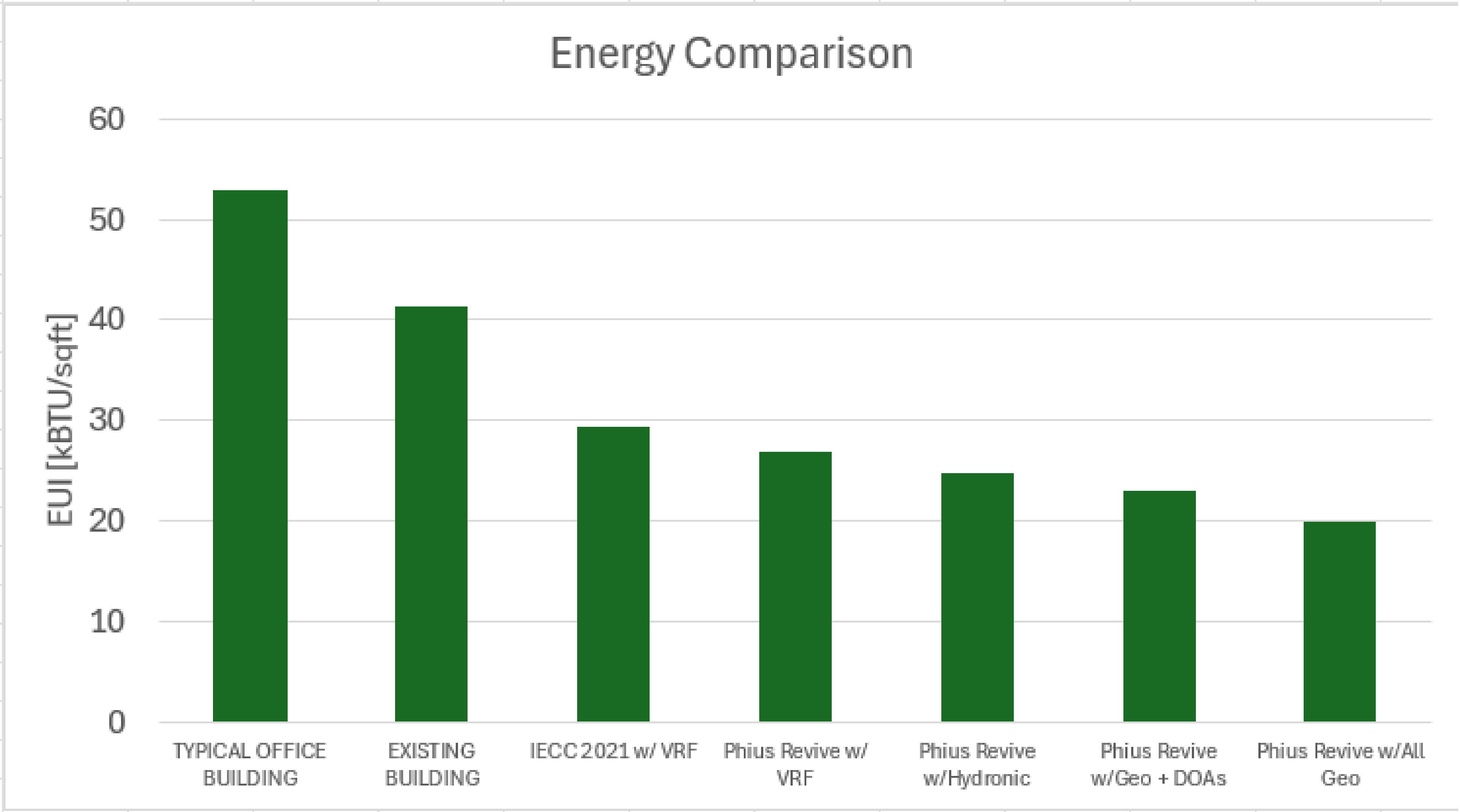
SYSTEM COMPARISON

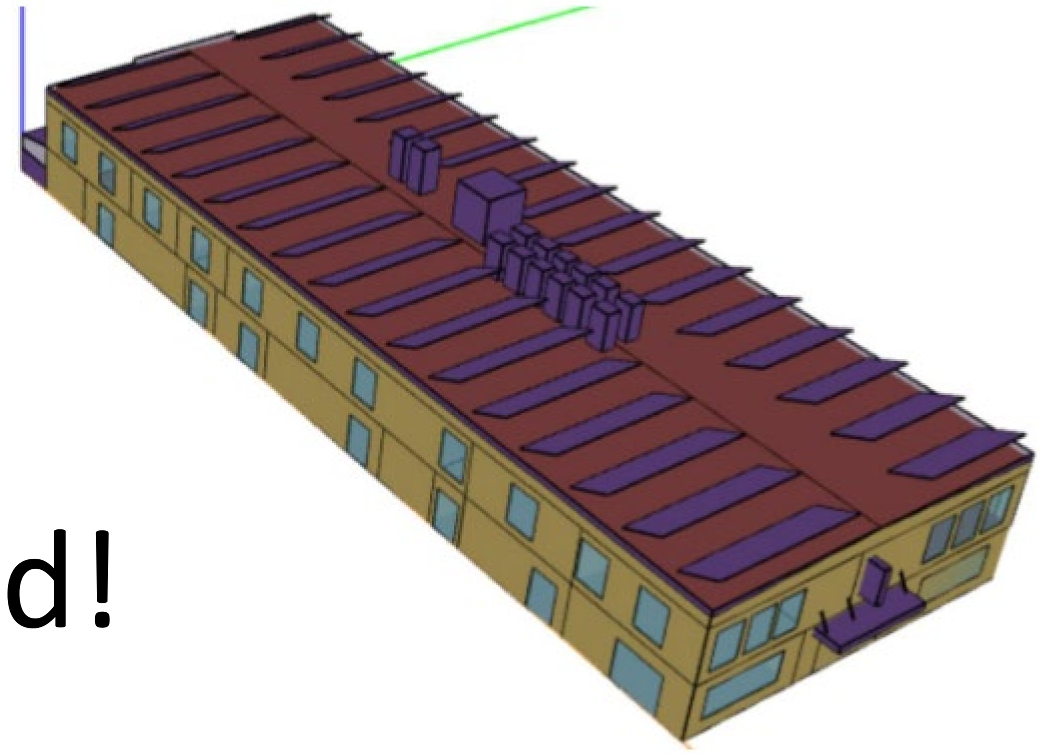




System	Carbon (lb Co2e/MWh Over 20 Years)	Energy	Maintenance	**Installation**
Geothermal plus air source DOAs	1,212,903	23.06	$	$$ ($ with tax credits)
All Geothermal	1,131,623	19.96	$	$$$ ($ with tax credits)
Chilltrix Heat Pump	1,263,624	24.72	$$	$$
VRF	1,623,994	26.85	$$$	$

NET ZERO





~100 kW Rooftop solar array required!

DISCUSSION/ QUESTIONS

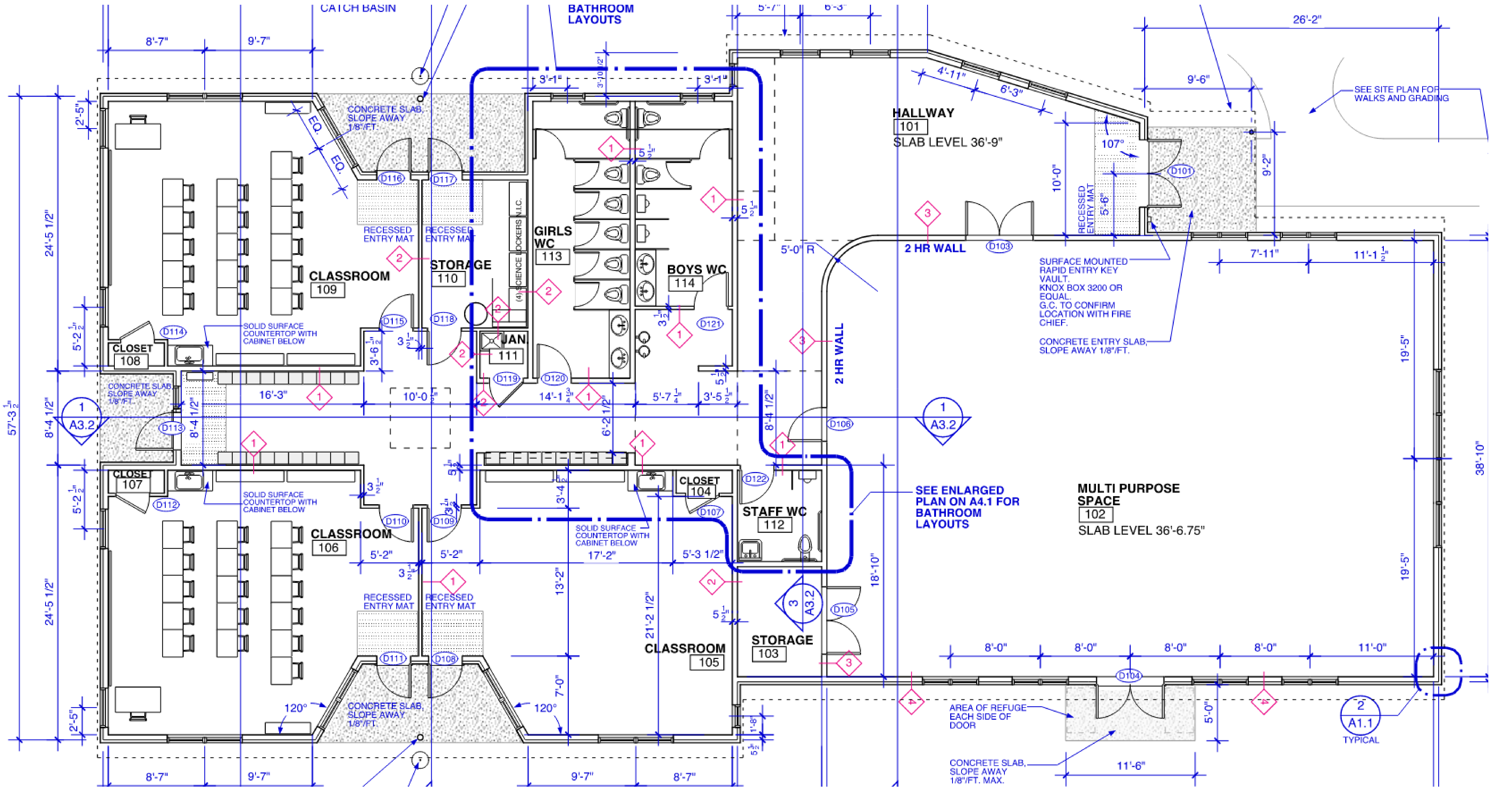
School Case Study

Seacoast Waldorf Middle School – Elliot, ME

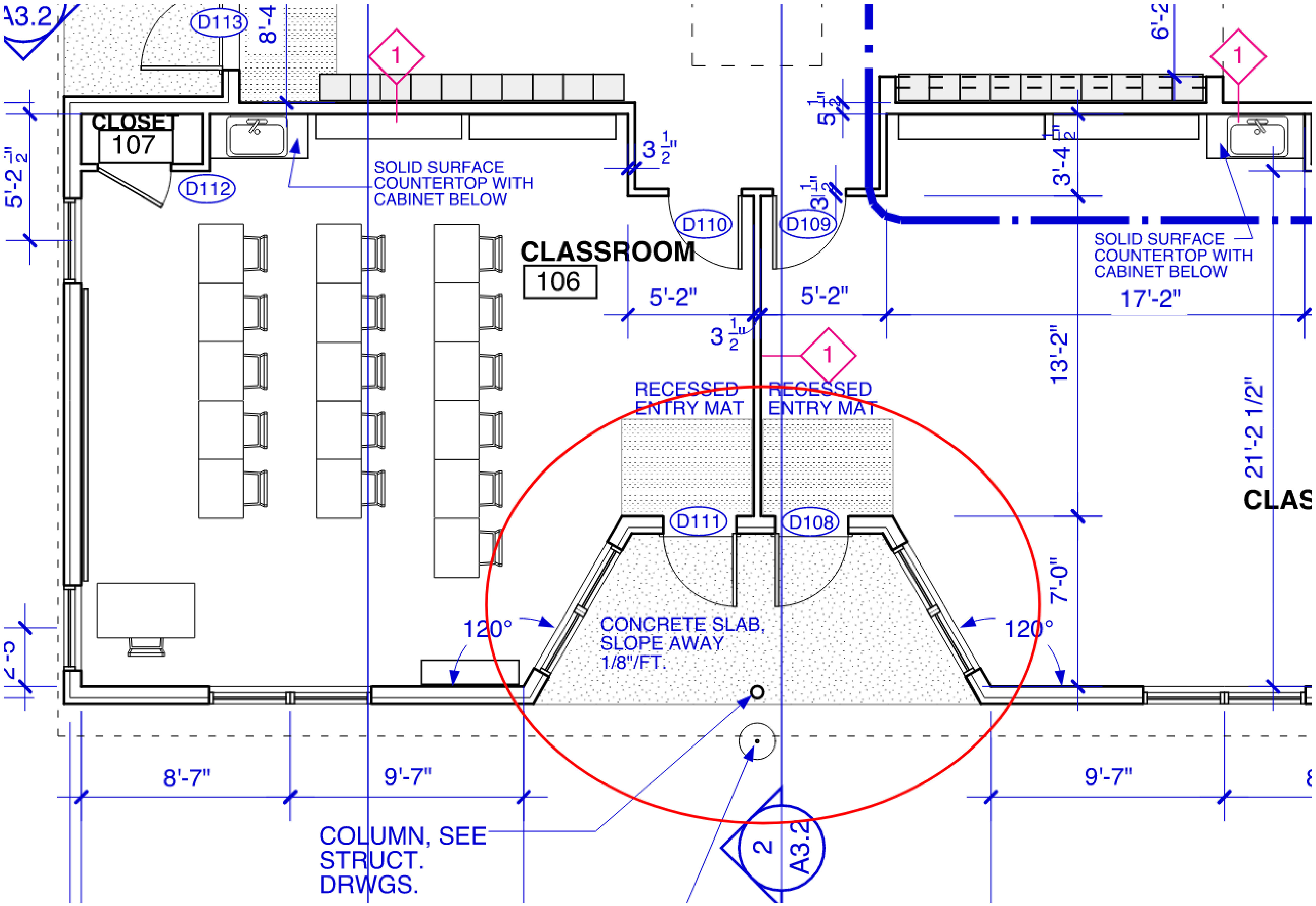
Multi-Purpose Room Heating & Cooling

Monday
Tuesday
Wednesday
Thursday
Friday
Math
Math
Math
German
ML
GR 8 BLOCKS
History I
Platonic Solids /Algebra
History II
Physics
History III /Short Story
Class Play
Anatomy & Chemistry
Demonstrations/Review

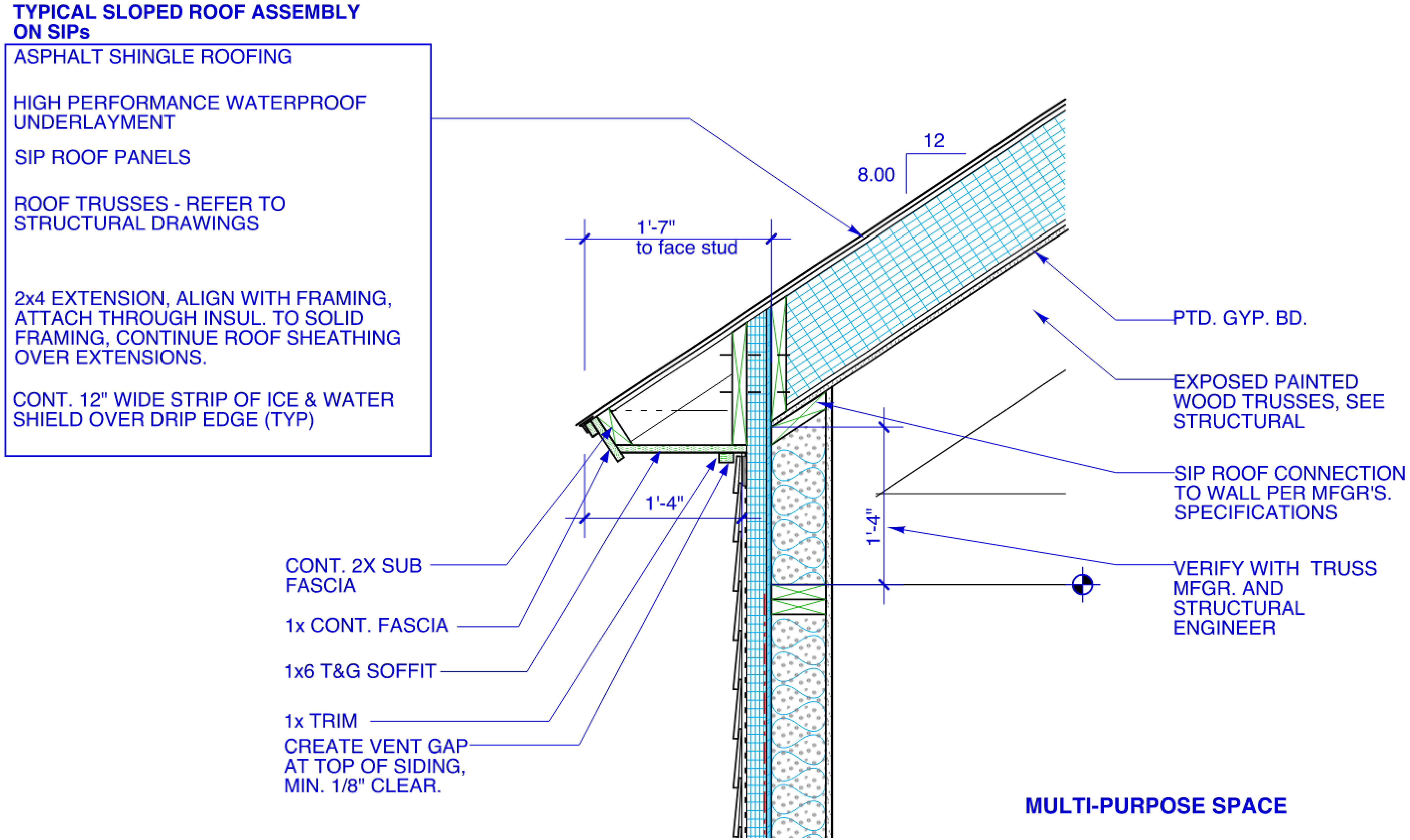
Architectural Floor Plan



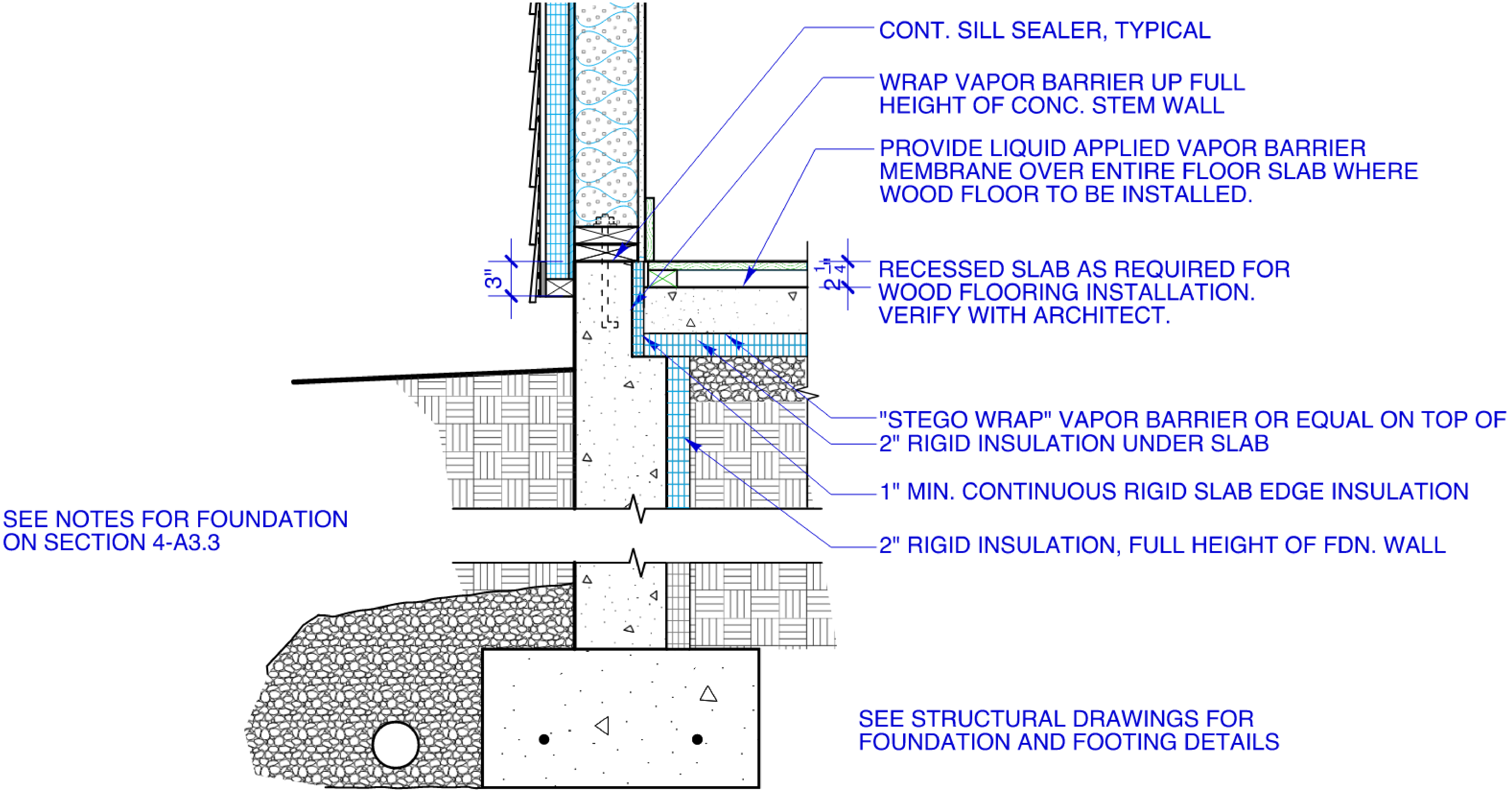
Classrooms with Three Exposures



Roof Assembly



Wall Assembly



Mechanical Systems

Outdoor Unit 1

- Spaces Unit Serves: 3 Classrooms & Corridor (2237 sf)
- Heating Capacity: 48,000 Btu/h
  - 21.5 Btu/h / sf
- Cooling Capacity: 42,000 Btu/h
  - 640 sf/ton

Outdoor Unit 2

- Spaces Unit Serves: Multi-Purpose Room, Hallway & 2 Bathrooms (3133 sf)
- Heating Capacity: 80,000 Btu/h
  - 25.5 Btu/h / sf
- Cooling Capacity: 72,000 Btu/h
  - 522 sf/ton

Project Cost: $2 Million - $329/sf

DISCUSSION/ QUESTIONS

Multifamily Case Studies

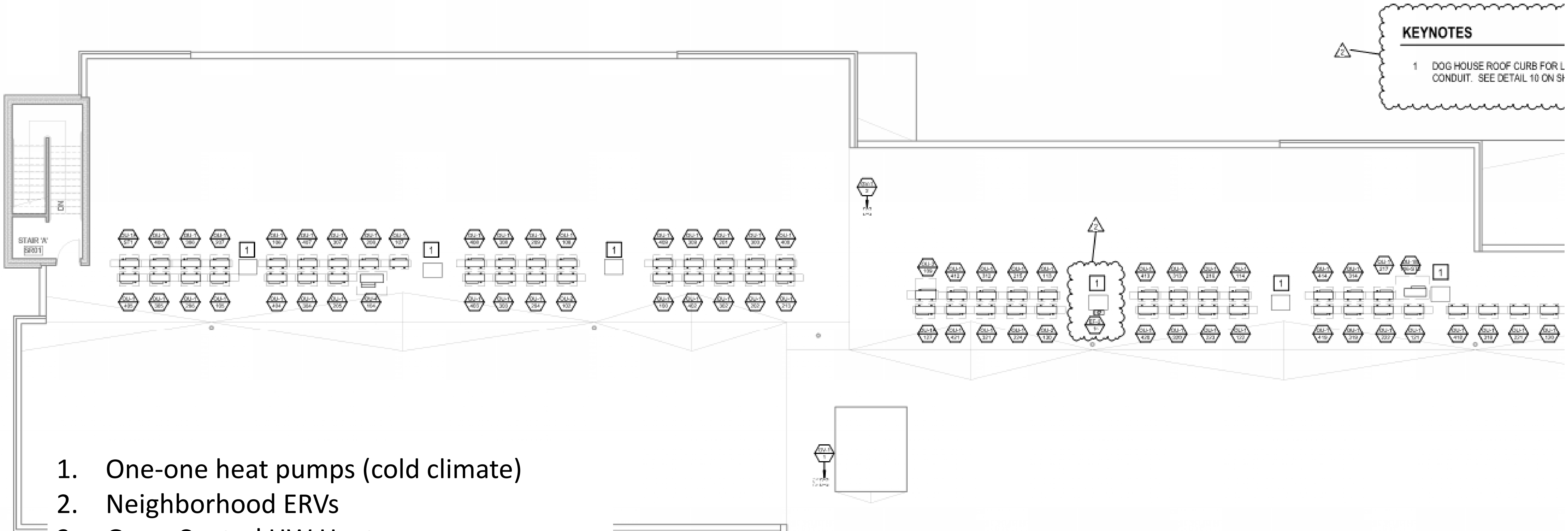
Simple Systems – Emerald Hills

AVON DESIGN GROUP

STAENGL ENGINEERING

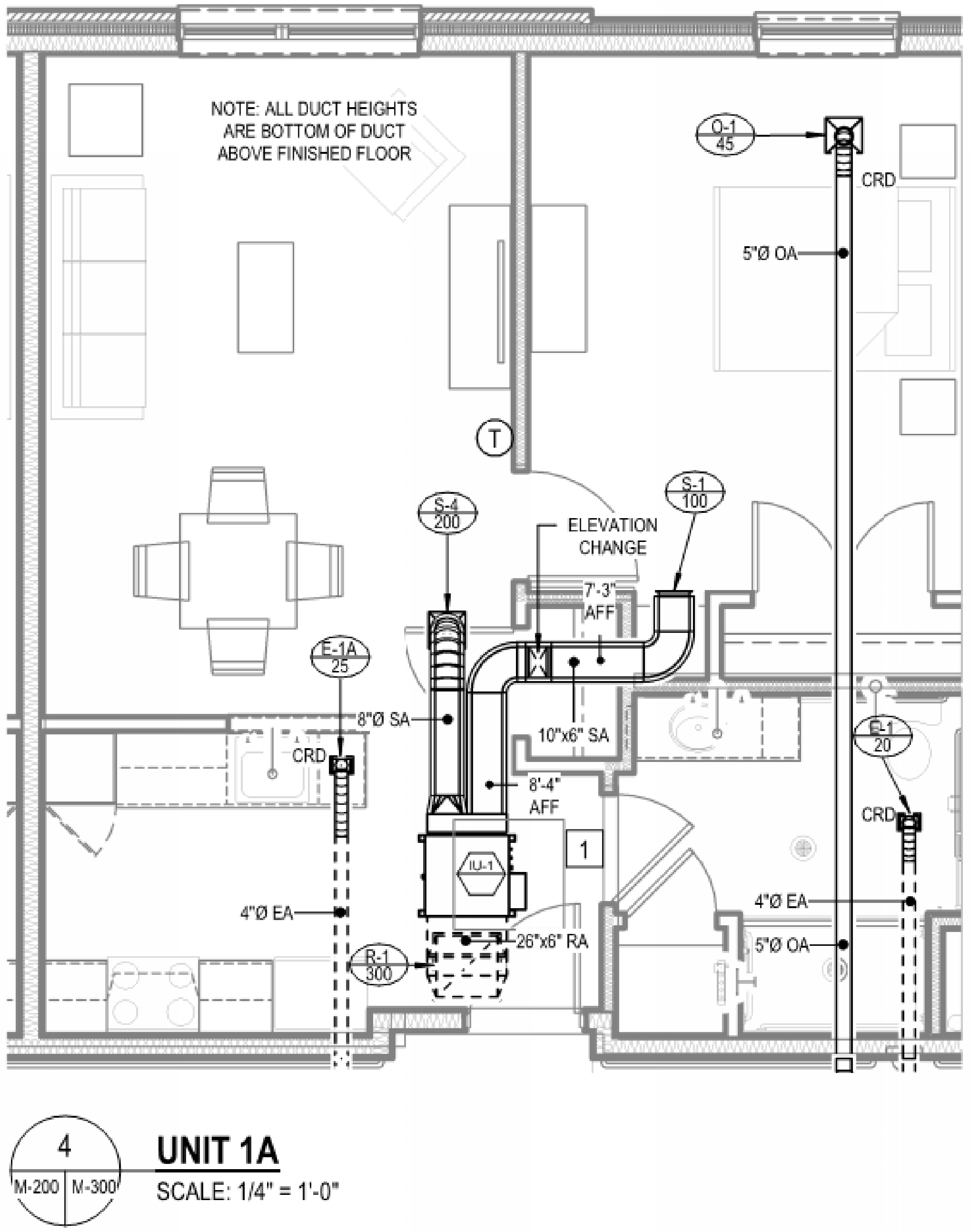
SoTA CONSTRUCTION SERVICES, INC.

Location	Size	Population	Envelope	HVAC	Ventilation	HW System
Pittsburgh	55 Apartments	Senior Housing	Walls: R37 Roof: R53 Windows: 3-pane	Ducted - Split Heat Pumps	Semi-Central ERVs	Condensing Gas

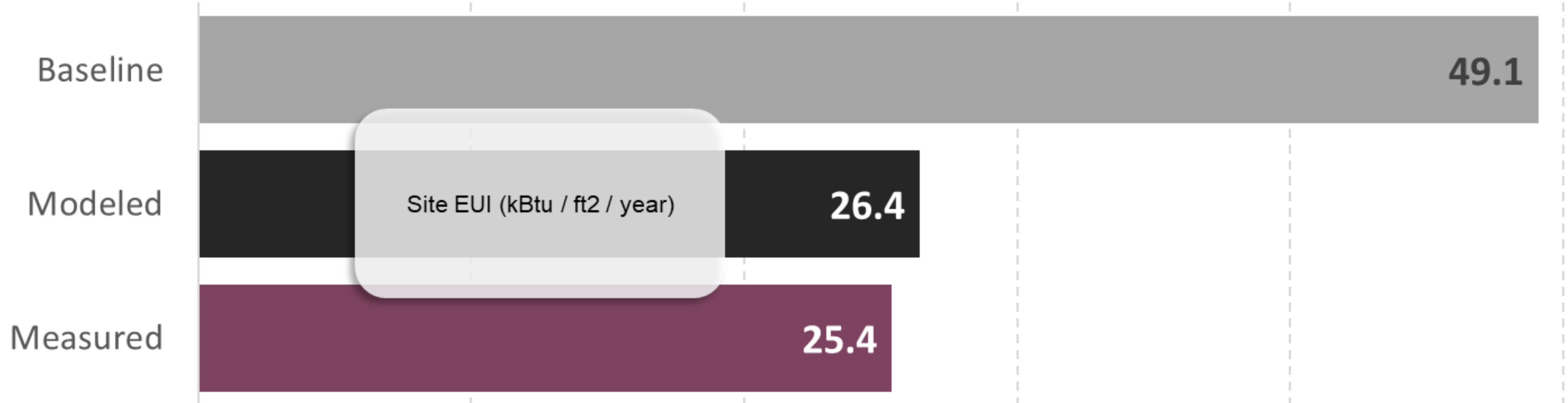


1. One-one heat pumps (cold climate)
2. Neighborhood ERVs
3. Gas – Central HW Heaters

Emerald Hills



Energy Performance



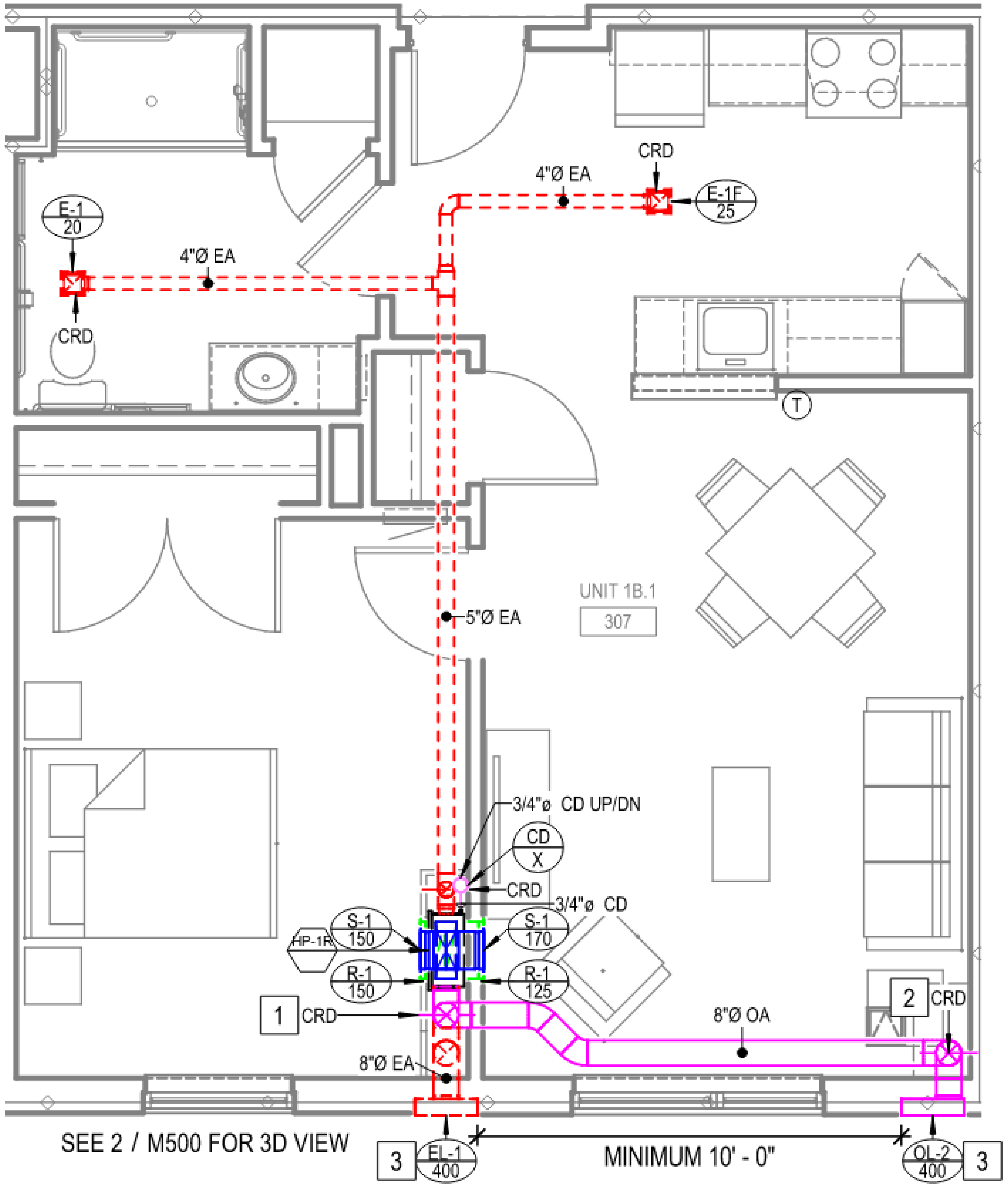
Emerald Hills - DHW

Domestic HW generated by condensing gas HW heaters. Three 199,000 BTU/hr sealed combustion heaters.

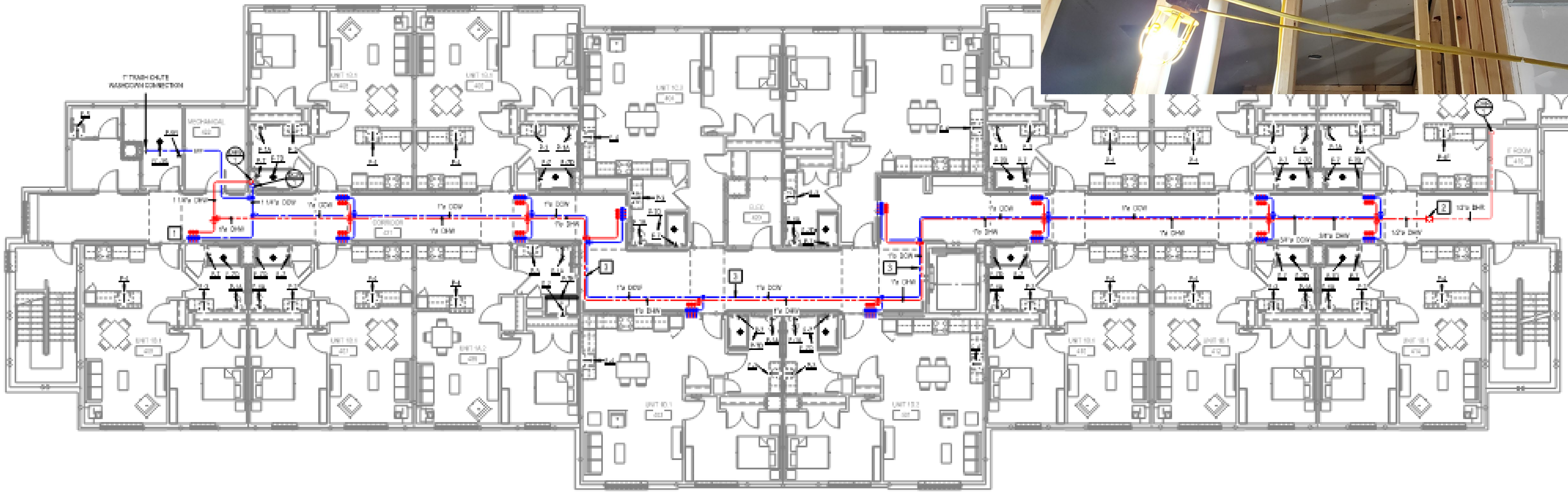
Edgewood

Location	Size	Population	Envelope	HVAC	Ventilation	HW System
Pittsburgh	55 Apartments	Senior Housing	Walls: R37 Roof: R53 Windows: 2-pane	EPHOCA All-In-One units	EPHOCA All-In-One units	CO2 Heat Pumps

Edgewood


CRD
4"Ø EA
E-1F
25
E-1
20
4"Ø EA
CRD
T
UNIT 1B.1
307
5"Ø EA
3/4"ø CD UP/DN
CD
X
CRD
3/4"ø CD
S-1
150
HP-1R
S-1
170
R-1
150
R-1
125
1
CRD
8"Ø OA
2
CRD
8"Ø EA
SEE 2 / M500 FOR 3D VIEW
3
EL-1
400
MINIMUM 10' - 0"
OL-2
400
3

Edgewood



Old Colony | Boston

- ~1,000,000 SF
- 830 Units
- 23 Buildings
- 10 Phases
- 4 Passive House Buildings

Phase 3C


Old Colony Phase 4 & 5

Anne M. Lynch Homes at Old Colony

Boston Housing Authority - Boston, MA | October 16, 2024 | 18177 | © The Architectural Team, Inc.

Old Colony | Boston, MA

BEACON communities

Copley Wolff Design Group Landscape Architects & Planners

tat

Glossary

- **HRV:** Heat Recovery Ventilator – recovers heat from the exhaust air leaving a building and transfers it to the incoming fresh outdoor air, without exchanging moisture.

- **ERV:** Energy Recovery Ventilator – recovers energy from the exhaust air of a building and uses it to condition incoming fresh outdoor air.

- **DOAS:** Dedicated Outside Air System – supplies fresh outdoor air to a building's interior independently of the heating and cooling system. This system delivers the necessary ventilation to maintain indoor air quality.

- **CAR:** Constant Airflow Regulator – used to maintain a consistent airflow rate in duct systems, regardless of changes in pressure.

- **DX:** Direct Expansion – refrigerant directly absorbs heat from the air or another medium as it expands or evaporates within the evaporator coil.

- **VRF:** Variable Refrigerant Flow – provides efficient heating and cooling by varying the flow of refrigerant to multiple indoor units.

- **ASHP:** Air Source Heat Pump – transfers heat between the indoor and outdoor air.

Old Colony Project Timeline – Heating & Cooling

Phase 1
2010

- 2-pipe changeover
- Gas boiler
- AC chiller
- Vertical fan coils

Phase 2A, 2B & 2C
2011

- Same as Phase 1

Phase 3A & 3B
2018-2019

- Central gas
- Hydronic heating with DX cooling – cooling bill is on tenant

Phase 3C - PH
2019

- Central VRF
- 55+ housing – funding differed from other phases

Phase 4 & 5 - PH
2020-2021

- Individual ASHP – heating and cooling bill is on tenant

Phase 6 - PH
2022

- Central VRF

Old Colony Project Timeline - Ventilation

Phase 1 — 2010

- Central penthouse DOAS
- Hydronic heating and cooling supply to living room only with CAR
- Ducted range hoods – DHCD required

Phase 2A, 2B & 2C — 2011

Midrise:

- Central rooftop DOAS ERV with packaged DX
- Gas heating
- Otherwise, same as Phase 1

Midrise Flats:

- Individual HRVs ducted to living room

Phase 3A & 3B — 2018-2019

- Same as Phase 2A, 2B, & 2C

Phase 3C - PH — 2019

- Central rooftop DOAS ERV with packaged DX
- Gas heating
- Ducted to living room and bedrooms with CAR
- Recric range hoods

Phase 4 & 5 - PH — 2020-2021

- Central rooftop DOAS ERV with remote heat pump
- Otherwise, same as Phase 3C

Phase 6 - PH — 2022

- Same as Phase 4 & 5

Old Colony Project Timeline – Domestic Hot Water

Phase 1
2010

- Indirect storage tanks off space heating boiler plant

Phase 2A, 2B & 2C
2011

- Same as Phase 1

Phase 3A & 3B
2018-2019

- Gas water heater with storage tanks

Phase 3C - PH
2019

- Same as Phase 3A & 3B

Phase 4 & 5 - PH
2020-2021

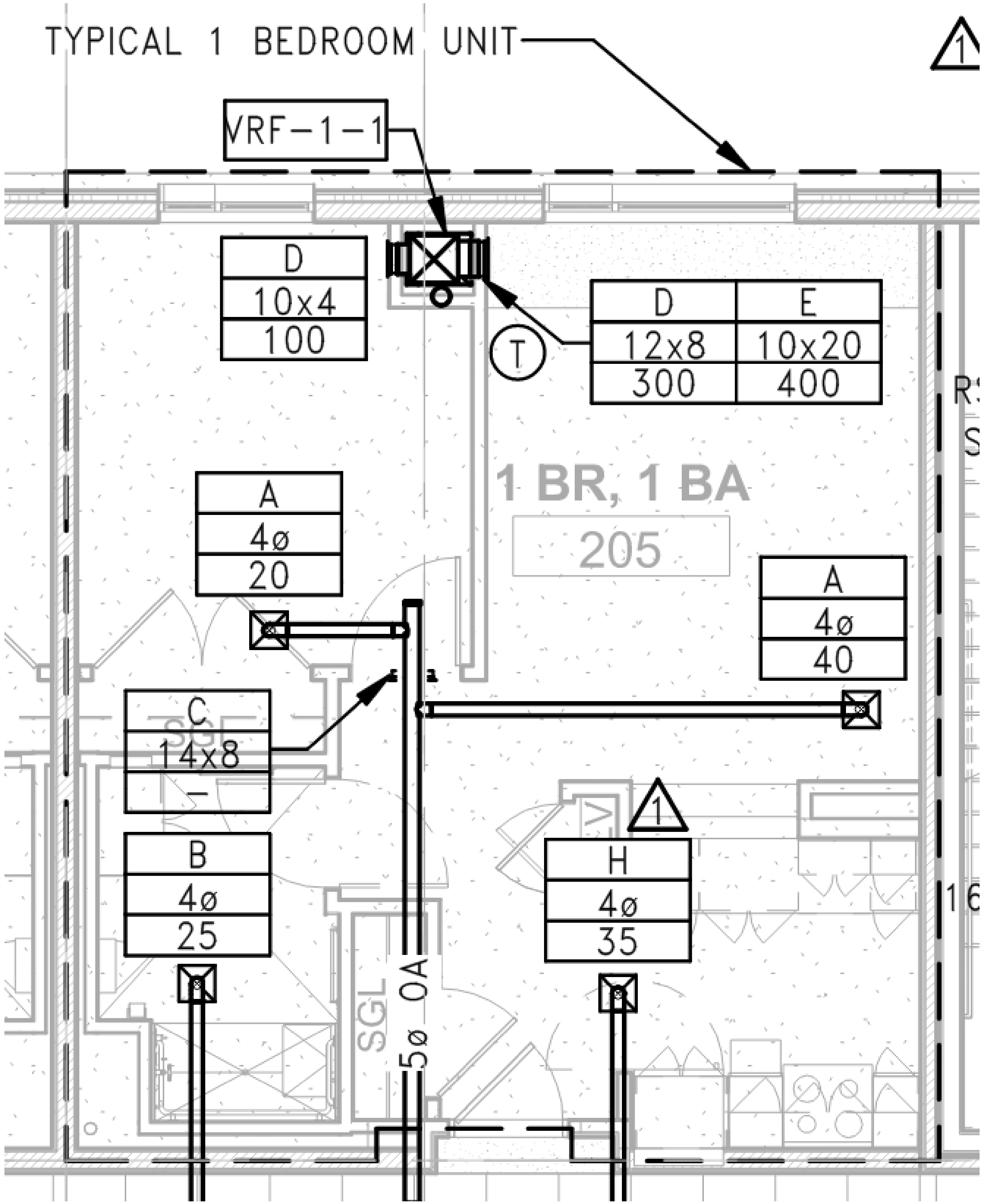
- Same as Phase 3A & 3B

Phase 6 - PH
2022

- Central ASHP water heaters

Old Colony Phase 6 – Case Study

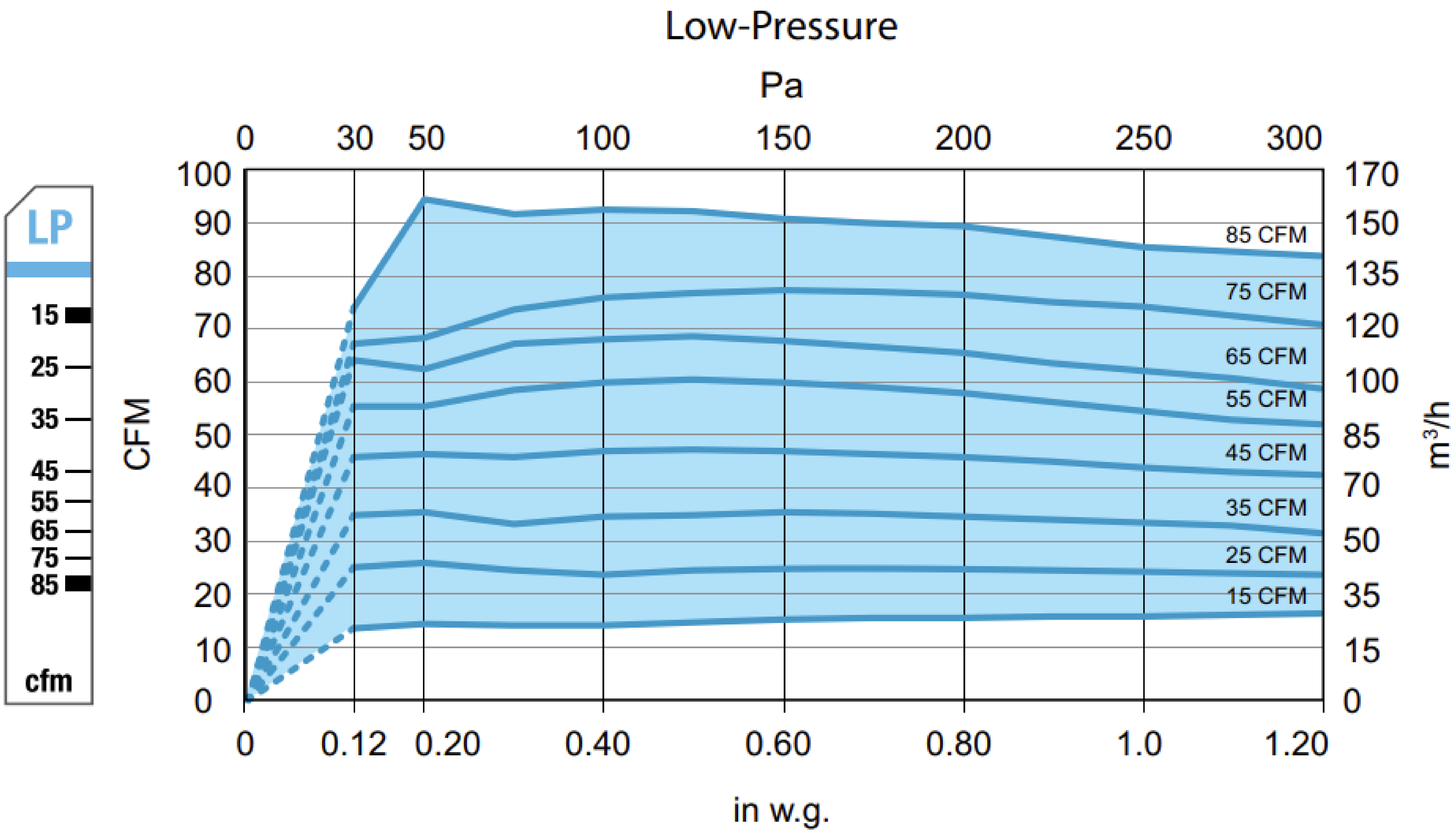
1 Bedroom Typical Duct Layout



CAR Damper Drama

American Aldes CAR3

CAR3 4” Diameter



Petersen Engineering

STANDARD OPERATING PROCEDURE

For Internal Use Only

CAR DAMPER TESTING

6/04/2024 by Sarah Carter, P.E.

General Requirements

1. Constant Air Regulator (CAR) dampers, particularly within the ceiling box/grille/damper assembly, are difficult to reliably test in the field with traditional flow hood due to turbulence at the air outlet.
2. All fan systems shall have an external static pressure calculation prepared by the engineer of record. The purpose of the calculation is to ensure that there is appropriate static pressure at all points in the ductwork.
3. CAR dampers are factory set and tested, they should work properly if the inlet pressure is within range, typically 0.12 to 1.2 IN WG.
4. Provide a sample of the CAR damper to EOR as part of submittal process.

CAR DAMPER TESTING

6/04/2024 by Sarah Carter, P.E.

Base Measuring/Verification Requirements

1. Measure the inlet pressure at CAR damper with a manometer at most remote location and nearest to ERV and verify that all duct static pressures fall within the CAR damper manufacturer's published pressure range.
    a. In lieu of measuring static pressure at the inlet of the damper, static pressure may also be measured at the main in the corridor. This represents the maximum available static pressure to the car damper. Note however that it doesn't include branch duct losses between the duct main and the damper.
2. Perform visual check to make sure the damper is operating freely (not at its maximum or minimum position but somewhere in between).

CAR DAMPER TESTING

6/04/2024 by Sarah Carter, P.E.

Audit Measures

1. Bag Inflation Device per RESNET 380 Standard is an acceptable method for verifying proper operation of CAR damper for supply application. This can be done as a sampling method.
2. Provide a traverse at ERV and halfway down main duct within a straight piece of duct, for both outdoor air and exhaust air ducts.

ANSI/RESNET/ICC 380-2022

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).

6.3.1. Powered flow hood. To measure airflow at an outlet terminal using a powered flow hood, Section 6.2.1 shall be followed except with all occurrences of the phrase "inlet terminal" replaced with "outlet terminal."

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.

6.3.2.2. Procedure to conduct airflow test.

ANSI/RESNET/ICC 380-2022

6.3.2.2.1. The bag shall be completely emptied of air, and the shutter shall be closed to prevent airflow into the bag.

6.3.2.2.2. The bag inflation device shall be placed over the outlet terminal.

6.3.2.2.3. The shutter shall be removed rapidly, and the stopwatch started.

6.3.2.2.4. The stopwatch shall be stopped when the bag is completely filled with air from the outlet terminal, and the elapsed time is recorded.

6.3.2.2.5. The airflow shall be calculated using Equation 6.3-1a or 6.3-1b

$$Airflow\ (CFM) = \frac{8 \times Volume}{Elapsed\ Time} \qquad \textbf{(Equation 6.3-1a)}$$

$$Airflow\ (L/s) = \frac{4 \times Volume}{Elapsed\ Time} \qquad \textbf{(Equation 6.3-1b)}$$

where: Volume = The volume of the plastic bag, in gallons.
Elapsed Time = The time that elapsed until the bag was filled, in seconds.

6.3.3 Vane anemometer with hood. To measure airflow at an outlet terminal using a vane anemometer with hood, Section 6.2.4 shall be followed except with all occurrences of the phrase “inlet terminal” replaced with “outlet terminal.”

Duct Tightness Requirements

DUCT LEAK CLASS AND SEALING SCHEDULE							
TYPE	DUCT PRESSURE CLASS	SEAL CLASS	SEALING APPLICABLE	AEROSEAL REQUIRED	SMACNA LEAKAGE CLASS	RECOMMENDED TEST PRESSURE	NOTES
CENTRAL VENTILATION ERV ROUND DUCT	3”	A	JOINTS, SEAMS AND ALL WALL PENETRATION	YES	3	1”	1, 2
CENTRAL VENTILATION ERV RECTANGULAR DUCT	3”	A	JOINTS, SEAMS AND ALL WALL PENETRATION	YES	6	1”	1, 2
APARTMENT FAN COIL SUPPLY AND RETURN ROUND DUCT	2”	A	JOINTS, SEAMS AND ALL WALL PENETRATION	NO	3	1”	1, 2
APARTMENT FAN COIL SUPPLY AND RETURN RECTANGULAR DUCT	2”	A	JOINTS, SEAMS AND ALL WALL PENETRATION	NO	6	1”	1, 2

1. REFER TO SMACNA HVAC AIR DUCT LEAK TEST MANUAL, FIGURE 4-1 FOR ALLOWABLE LEAKAGE RATES AT DIFFERENT TEST PRESSURES.
2. DO NOT EXCEED DUCT PRESSURE CLASS WHEN LEAK TESTING.

Hot Water Use Data

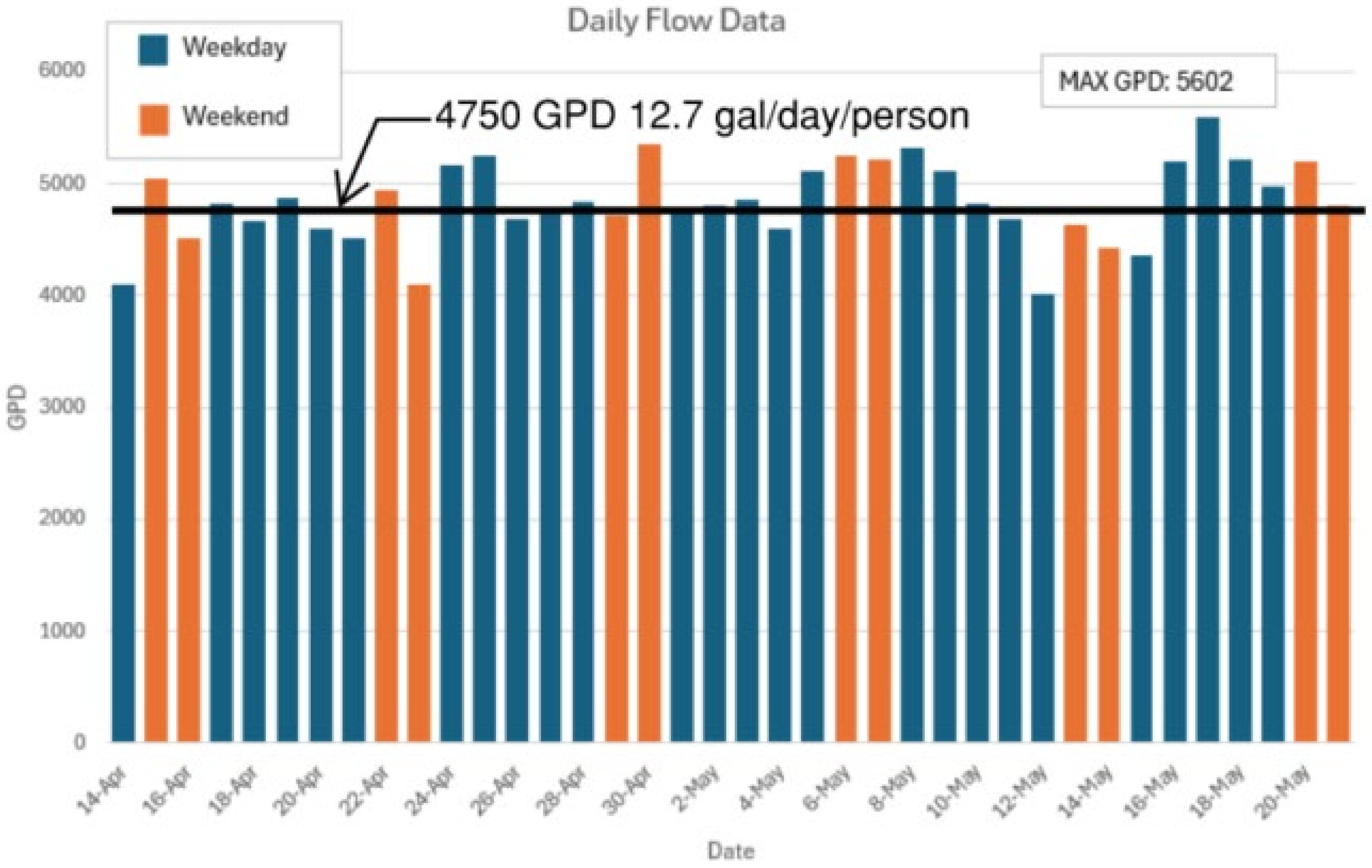
Old Colony Phase 3 - Domestic Hot Water Use

Domestic Water Use in Building 3A1 and 3C 99th Percentile (Max) - Peak Flow Rates		
Building	Date	Hot GPM
Building 3A1 (multifamily)	5/10/2023	12.0 (16.7)
Building 3A1 (multifamily)	5/25/2023	11.9 (21.0)
Building 3C (55 + 1-bdrm)	6/6/2023	1.0 (4.0)
Building 3C (55 + 1-bdrm)	7/12/2023	0.9 (4.0)

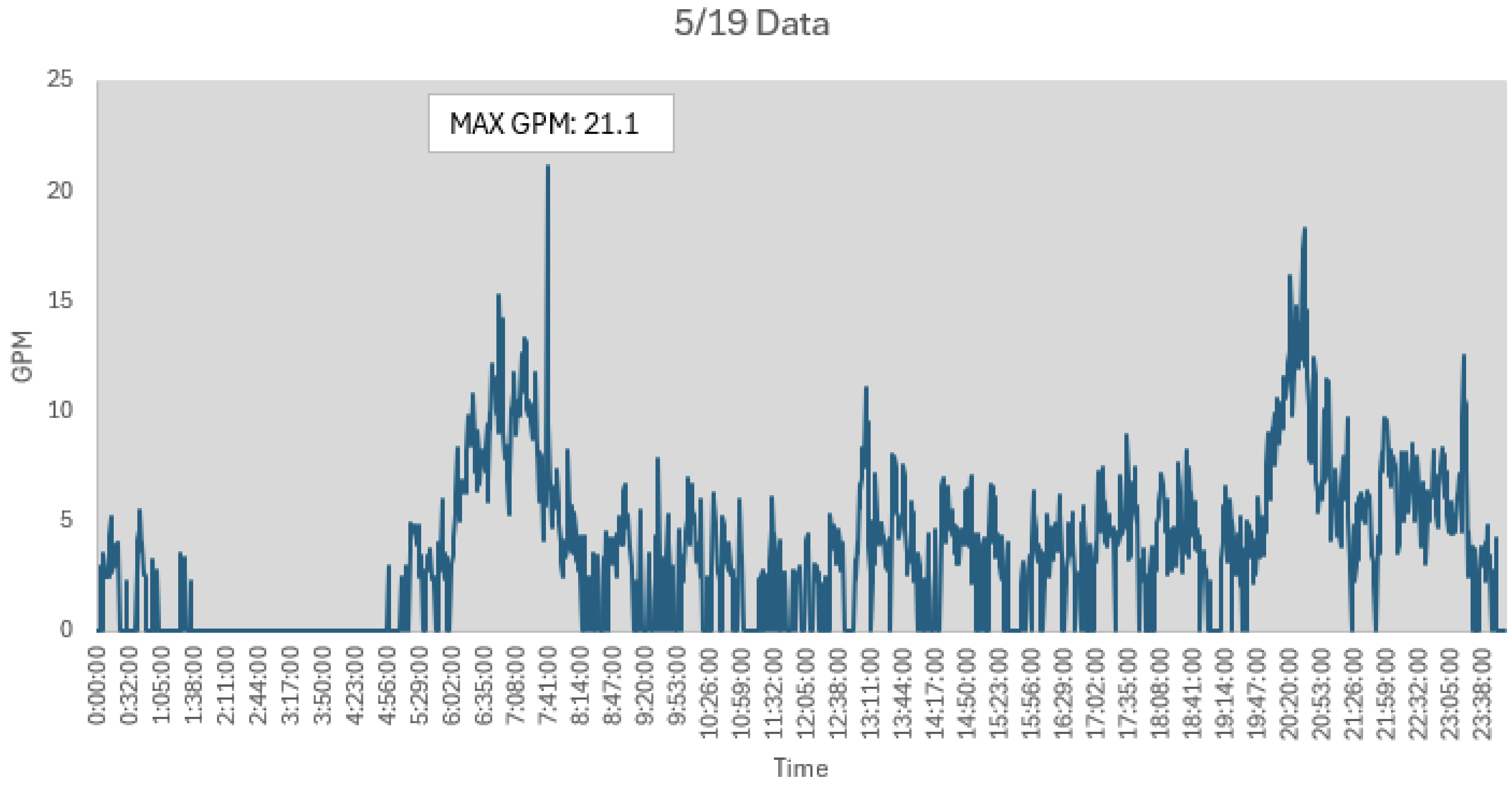
Domestic Hot Water Use Per Person				
Building	Total Hot GPD	# bedrooms	# people	DHW gal/person/day
Building 3A1 (multifamily)	4,832	187	374	13
Building 3A1 (multifamily)	4,840	187	374	13
Building 3C (55 + 1-bdrm)	1,017	55	110	9
Building 3C (55 + 1-bdrm)	1,038	55	110	9

We had one data point of measured hot water from OCA at time of issuance of OC6 permit set which was 13 gal/person/day. Based on optimizing the equipment size availability for the air source heat pumps and storage tanks that are all provided as a packaged system from the vendor, we landed on DHW plant capable of 20 gal/person/day

Old Colony Phase 3A - Domestic Hot Water Use - GPD



Old Colony Phase 3A - Domestic Hot Water Use - GPM



Design Exercise and Discussion

Outdoor DHW Heat Pumps

Image Courtesy of Sanden

Image Courtesy of Mitsubishi

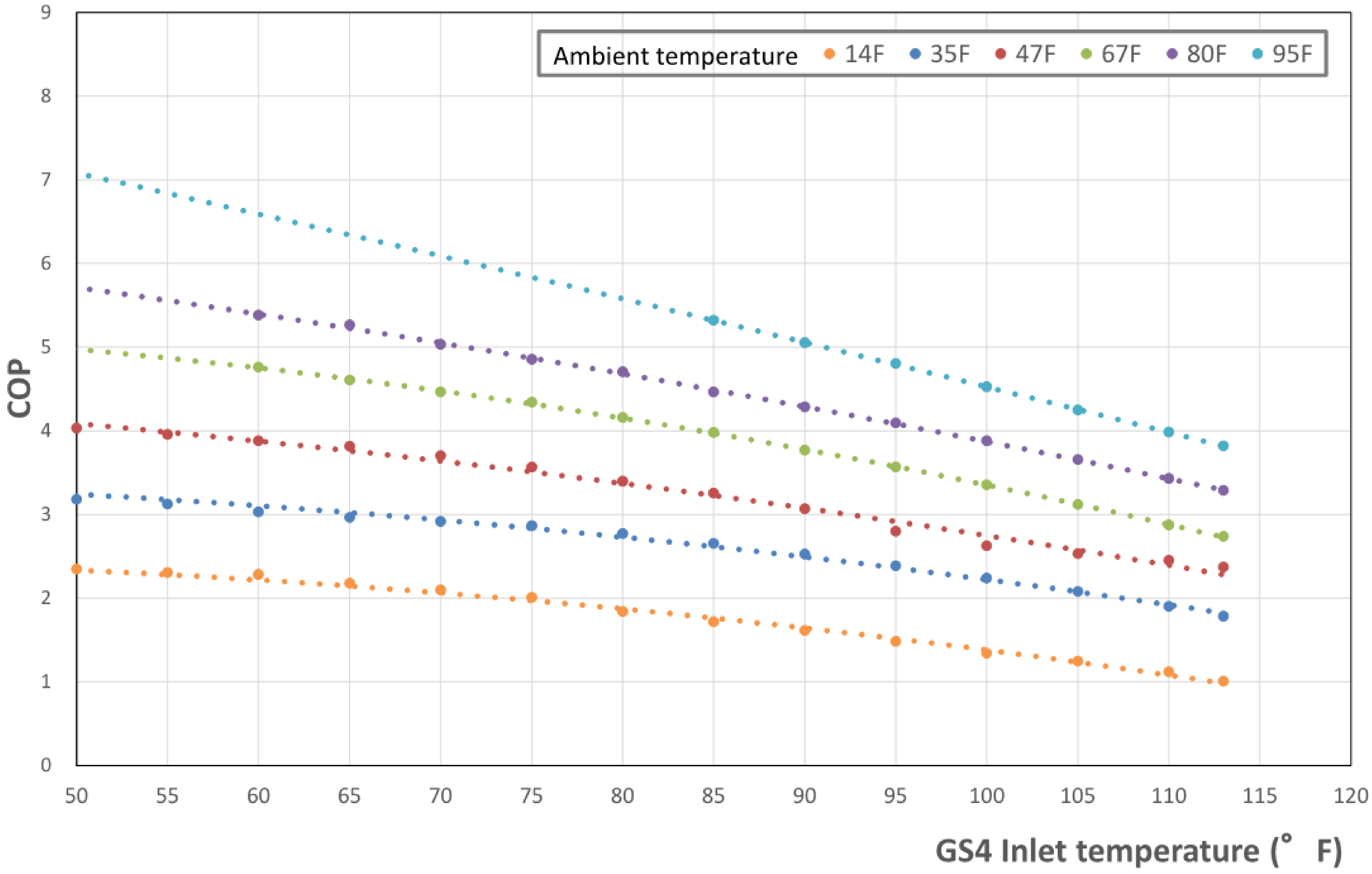
Image Courtesy of Lync

C02 Refrigerant Heat Pumps

1. Operate down to very low ambient temperatures
2. Can generate very hot water (160-180 degrees F)
3. High COPs!
4. Low greenhouse gas content

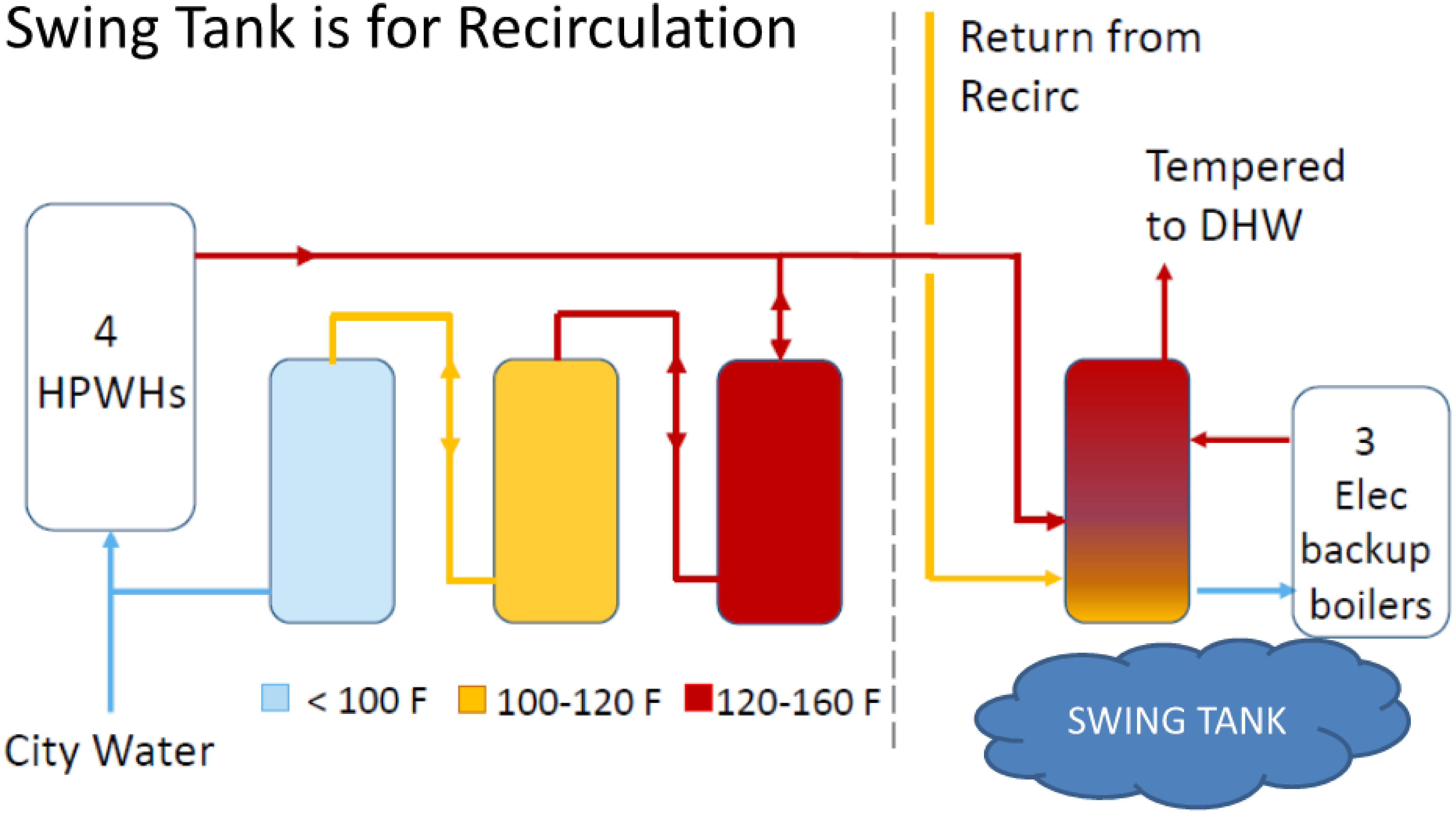
GS4-45HPC COP Values

COP is defined as the ratio of Capacity/Power Input



Central System Design

- Swing Tank is for Recirculation



From: SanC02 Multi-Family Design Strategy

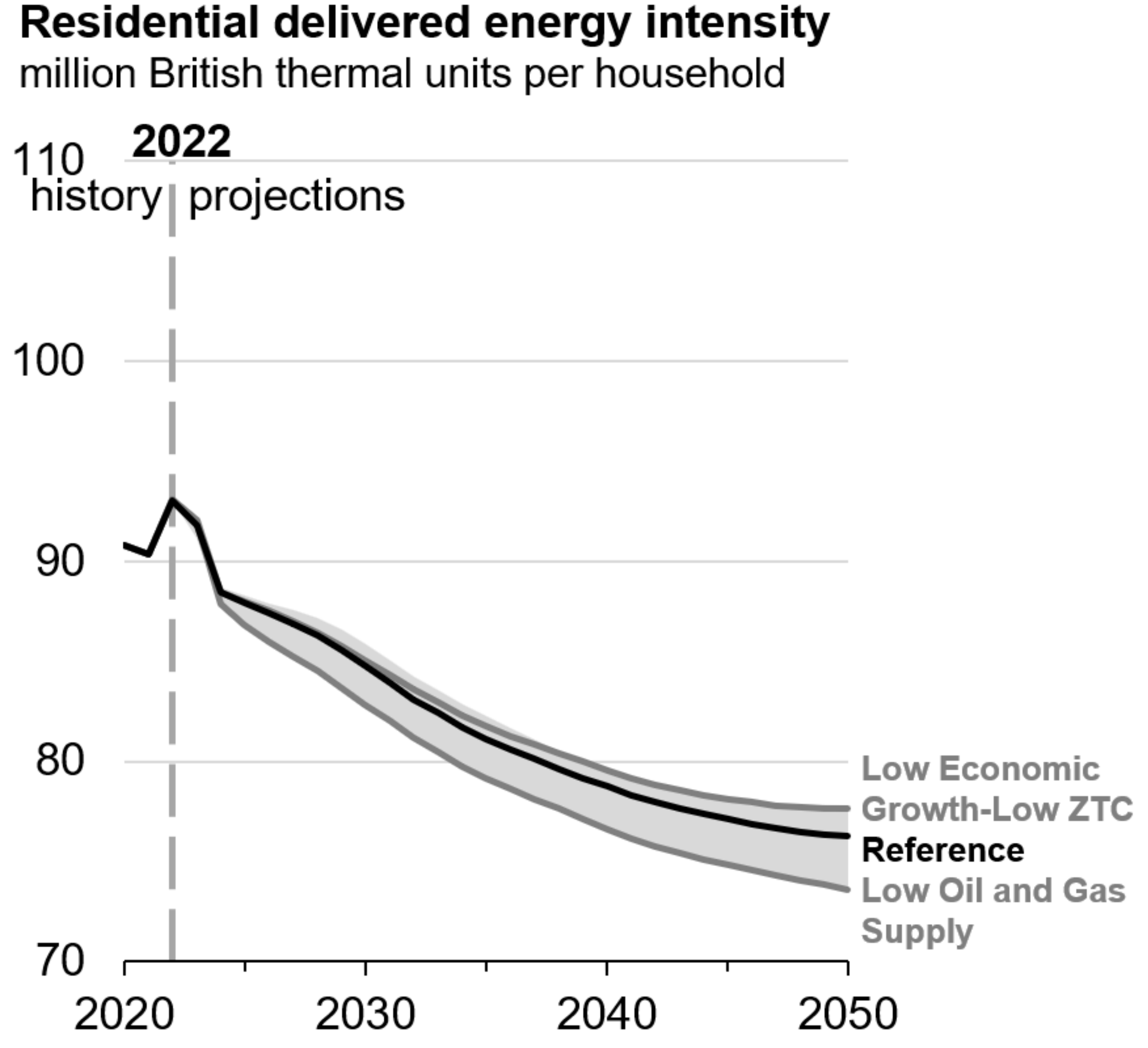
Mechanical Systems for Multifamily Deep Energy Retrofits

- Retrofit relevance
- The problem
- Electrification - reinventing fire?
- The big idea (solution approach)
- System approaches
- Case Study (Colonial II)
- Mechanical Pod Development

Galen Staengl, PE, LEED BD+C CHPC

STAENGL ENGINEERING

The Importance of Deep Energy Retrofits



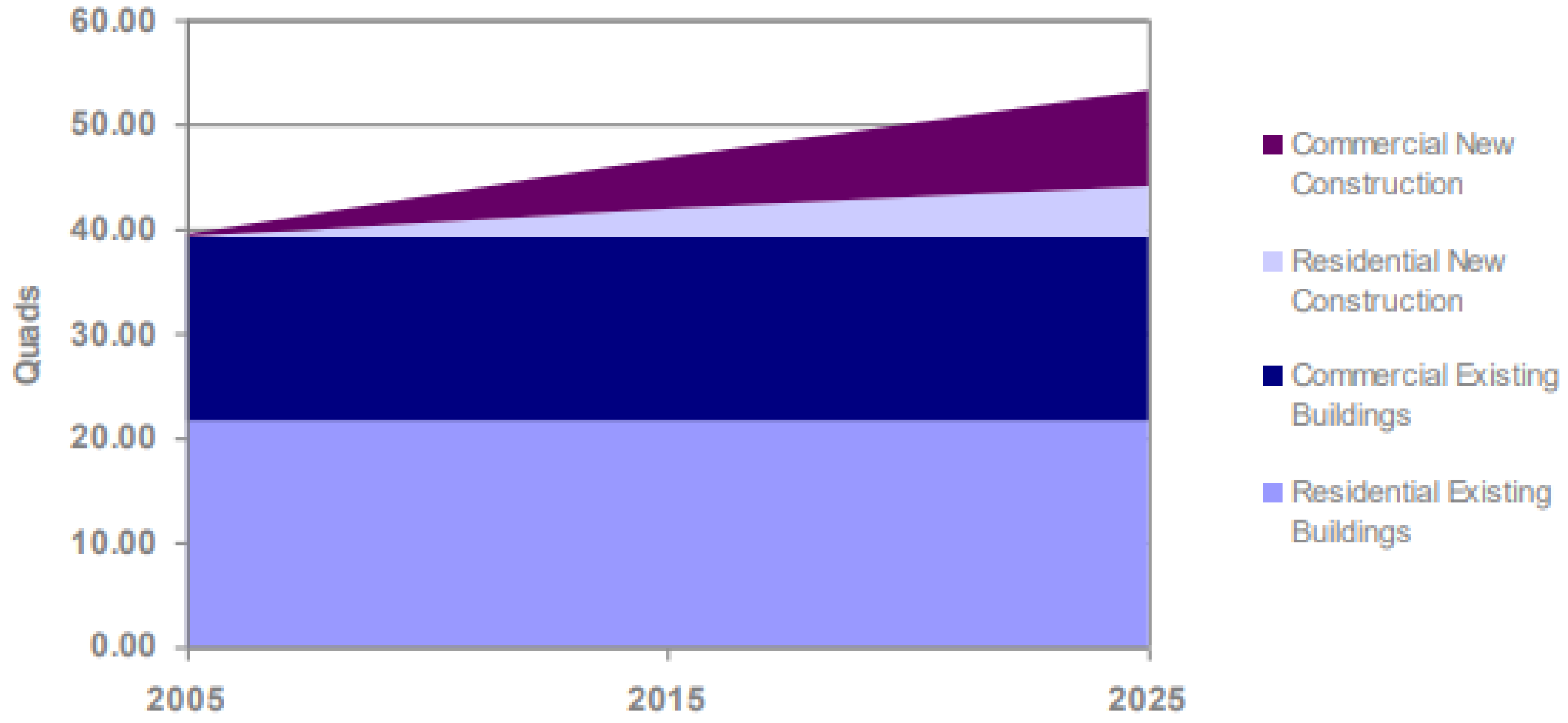
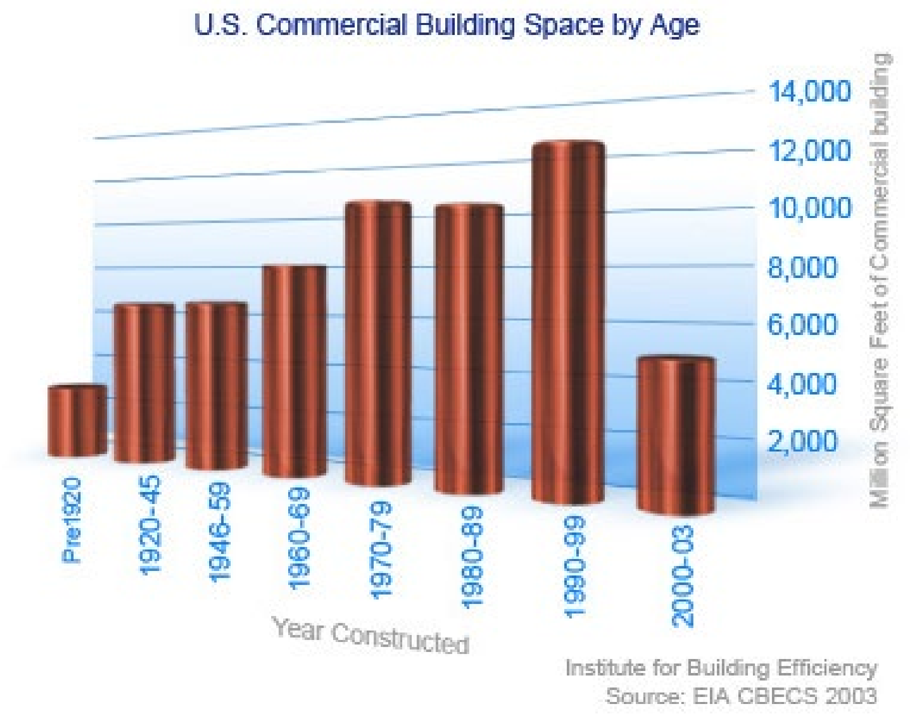


Figure ES3. Base Case Energy Use



U.S. Energy Information Administration

The Opportunity

- Total Housing Units in the US: ~ 145,000,000
- New Housing Units: ~ 1%/year

Deep Energy Retrofits are key to reducing the carbon intensity of the housing sector.

U.S. Building Stock Characterization Study

A National Typology for Decarbonizing U.S. Buildings

Janet Reyna,[1] Eric Wilson,[1] Andrew Parker,[1] Aven Satre-Meloy,[2] Amy Egerter,[3] Carlo Bianchi,[1] Marlena Praprost,[1] Andrew Speake,[1] Lixi Liu,[1] Ry Horsey,[1] Matthew Dahlhausen,[1] Christopher CaraDonna,[1] and Stacey Rothgeb[1]

1 National Renewable Energy Laboratory
2 Lawrence Berkeley National Laboratory
3 Rocky Mountain Institute

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Contract No. DE-AC36-08GO28308

Technical Report
NREL/TP-5500-83063
Revised July 2022

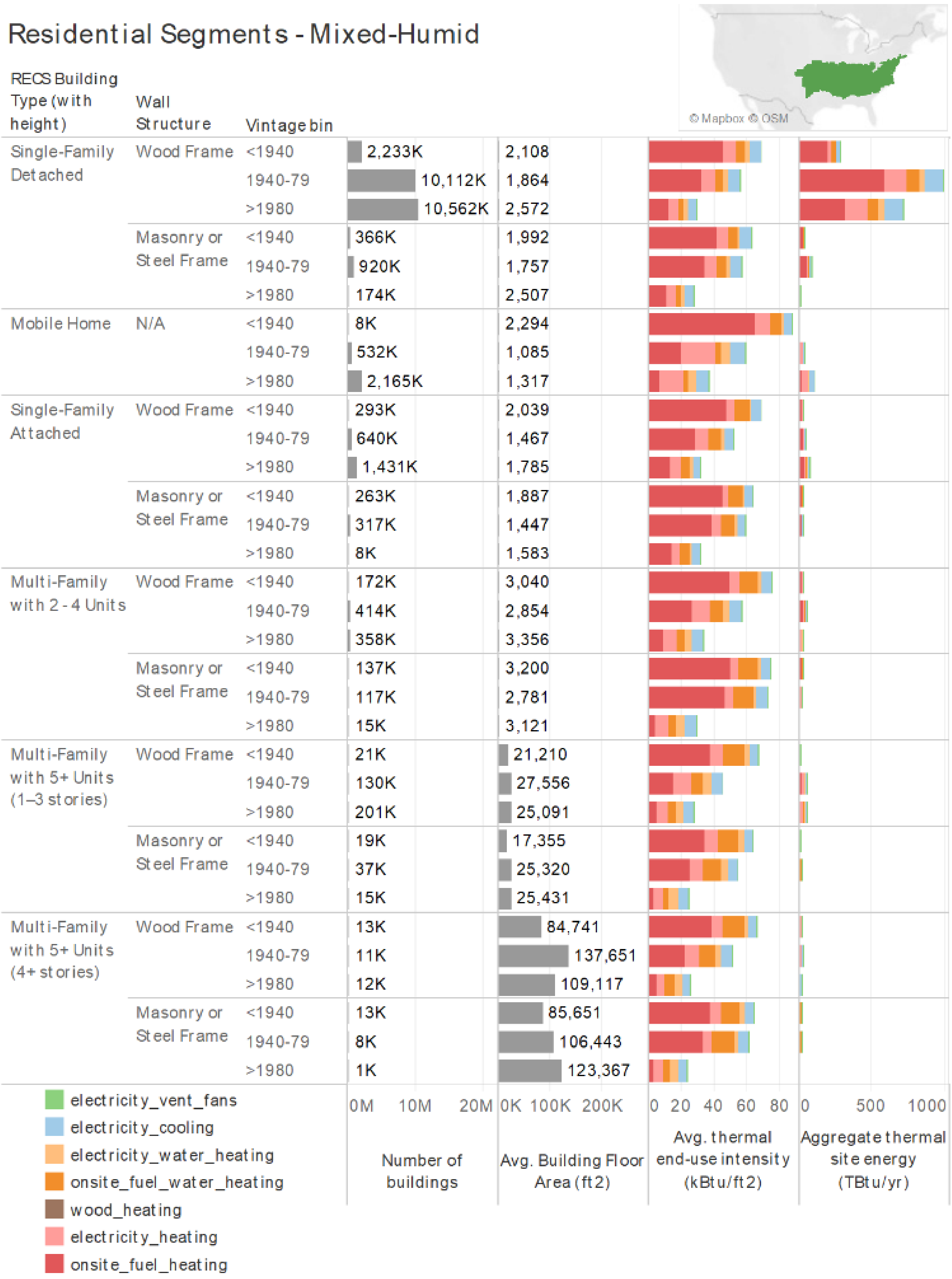


Figure 10. Residential Mixed-Humid typology segments

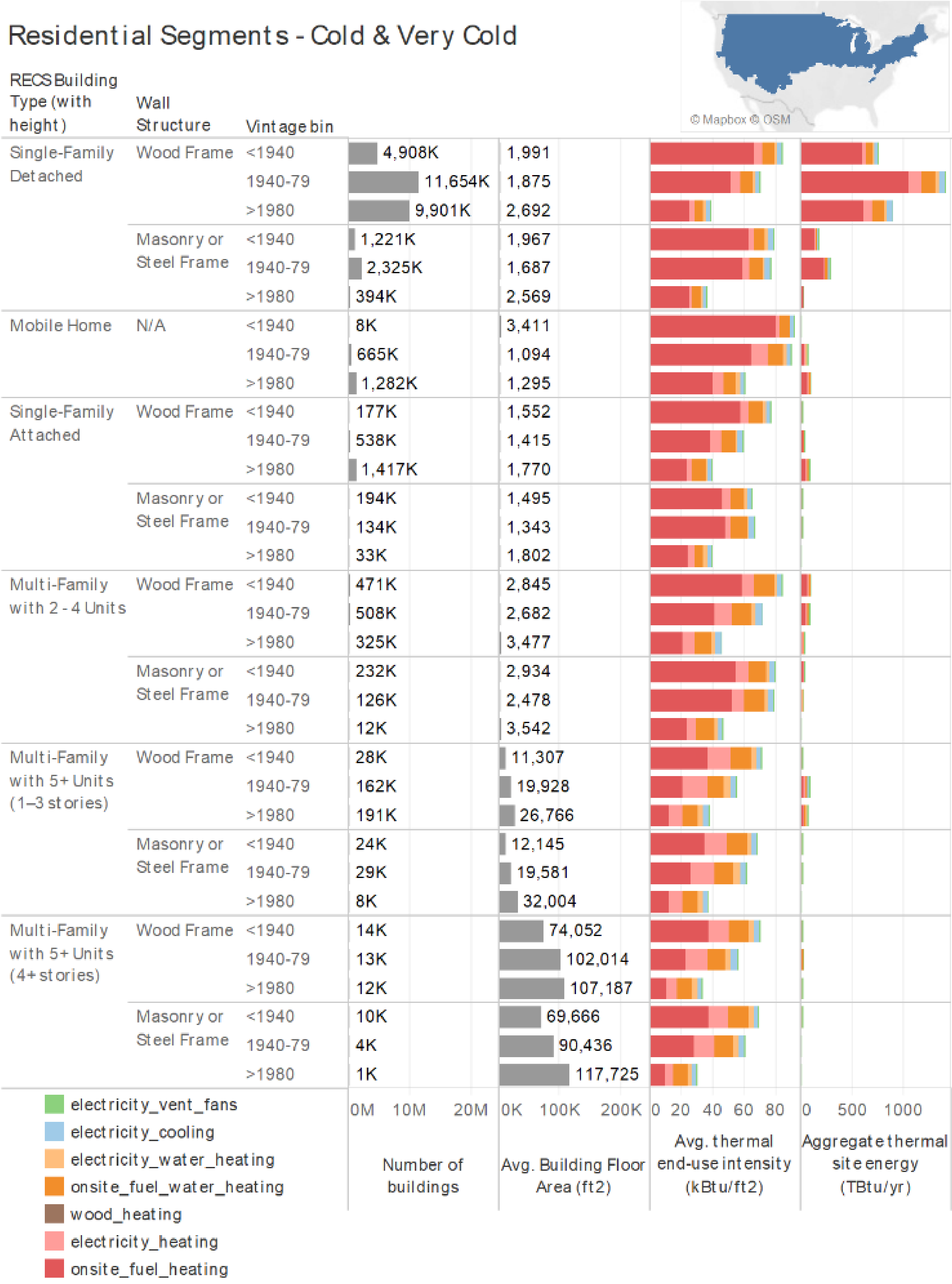


Figure 7. Residential Cold/Very-Cold typology segments

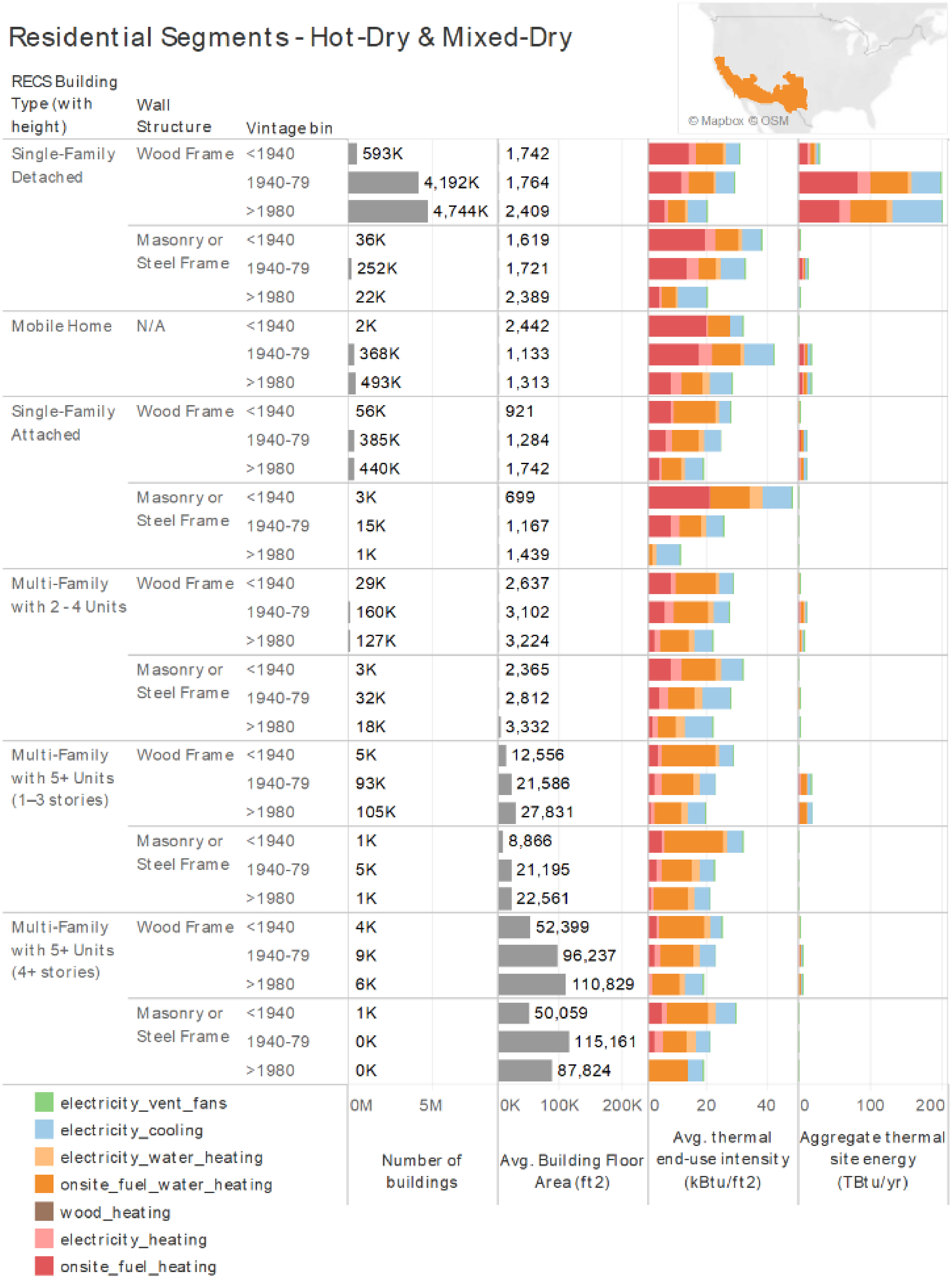


Figure 16. Residential Hot-Dry/Mixed-Dry typology segments

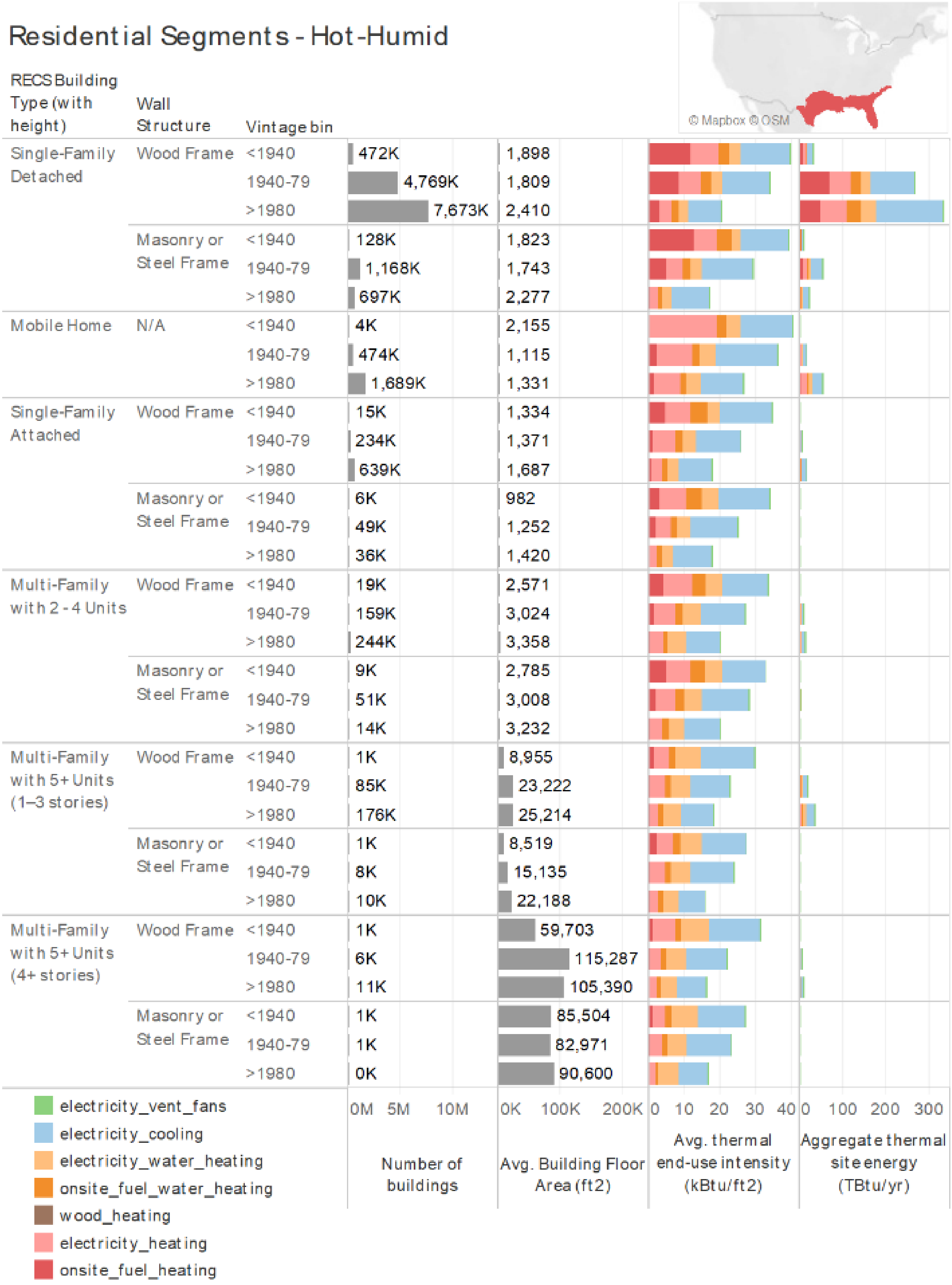


Figure 19. Residential Hot-Humid typology segments



Objectives:

- Dramatic Building Energy Savings (>50%)
- Retrofit-in-place
- Electrification

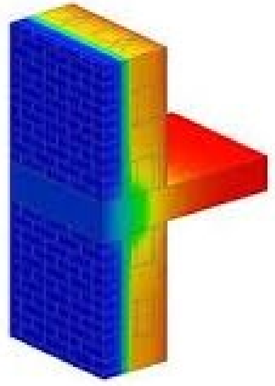
Challenges:

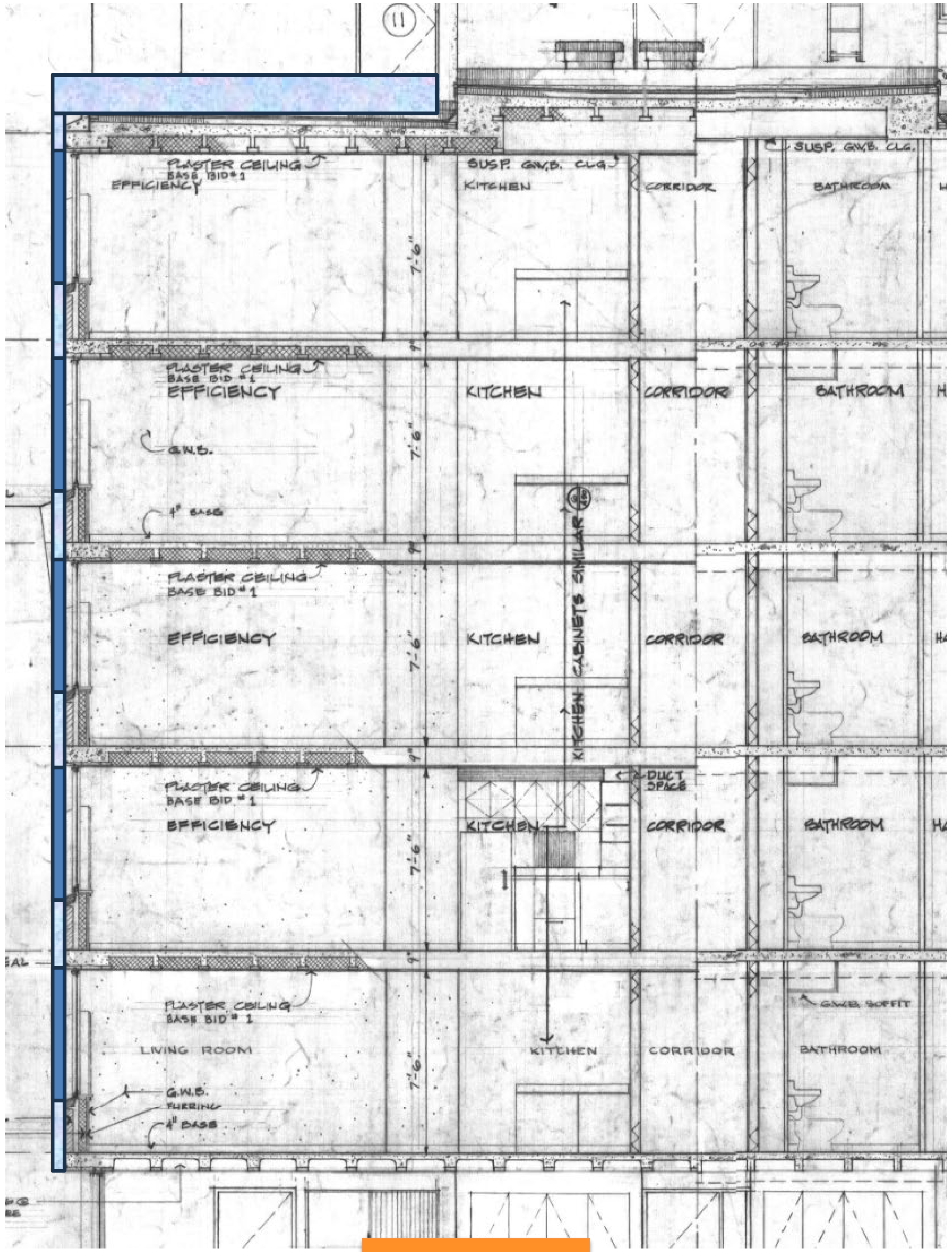
- Limitations on exterior insulation
- Electrical service capacity
- Equipment availability
- COST

Electrification

- Benefits
  - Carbon reduction
  - Safety
  - IAQ
  - Local Air Quality
- Barriers
  - Heating loads
  - Electrical Infrastructure
  - Relative cost of Gas / Electricity
  - Immature heat pump market in the US
  - Outside design temperature?

Insulate the Envelope





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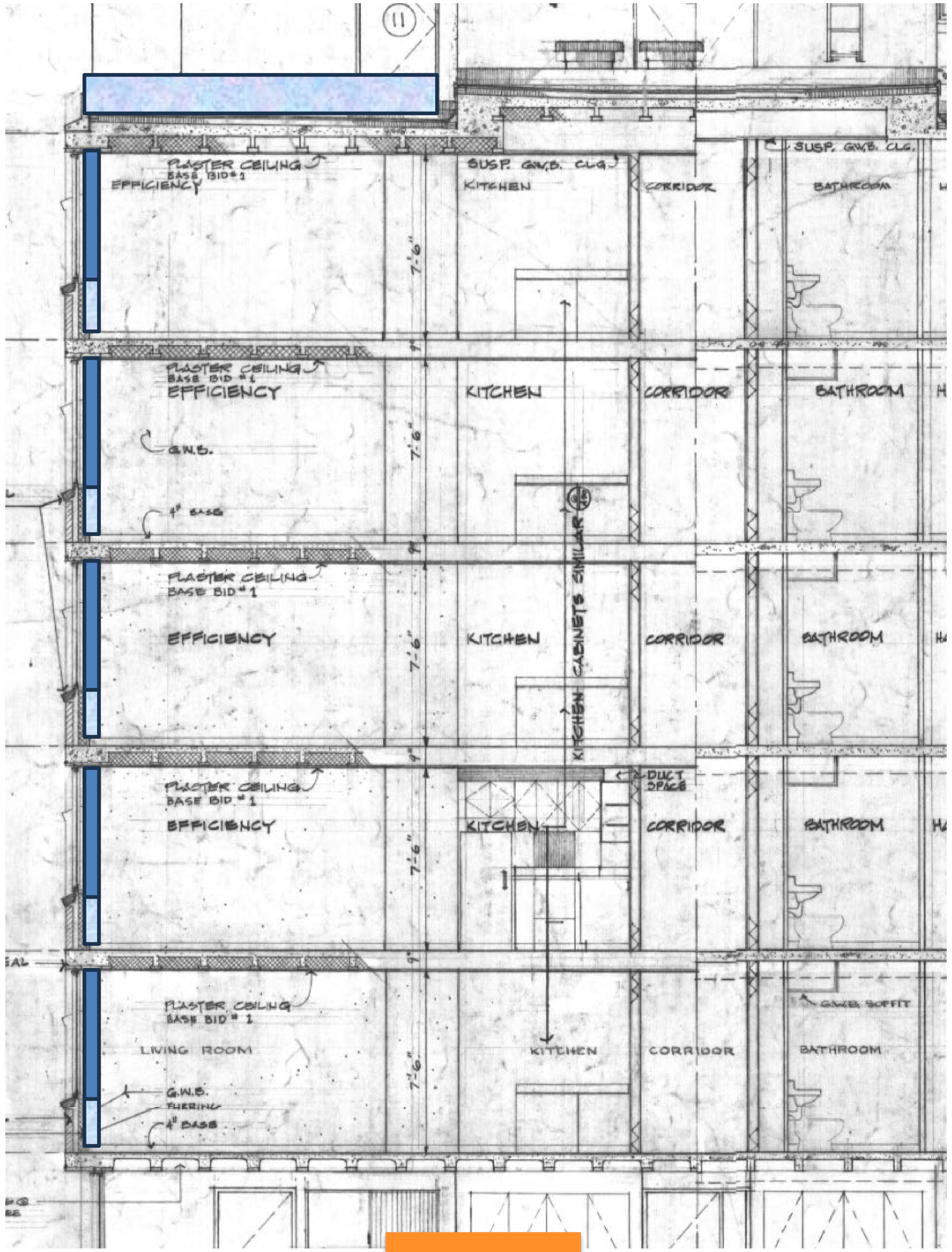
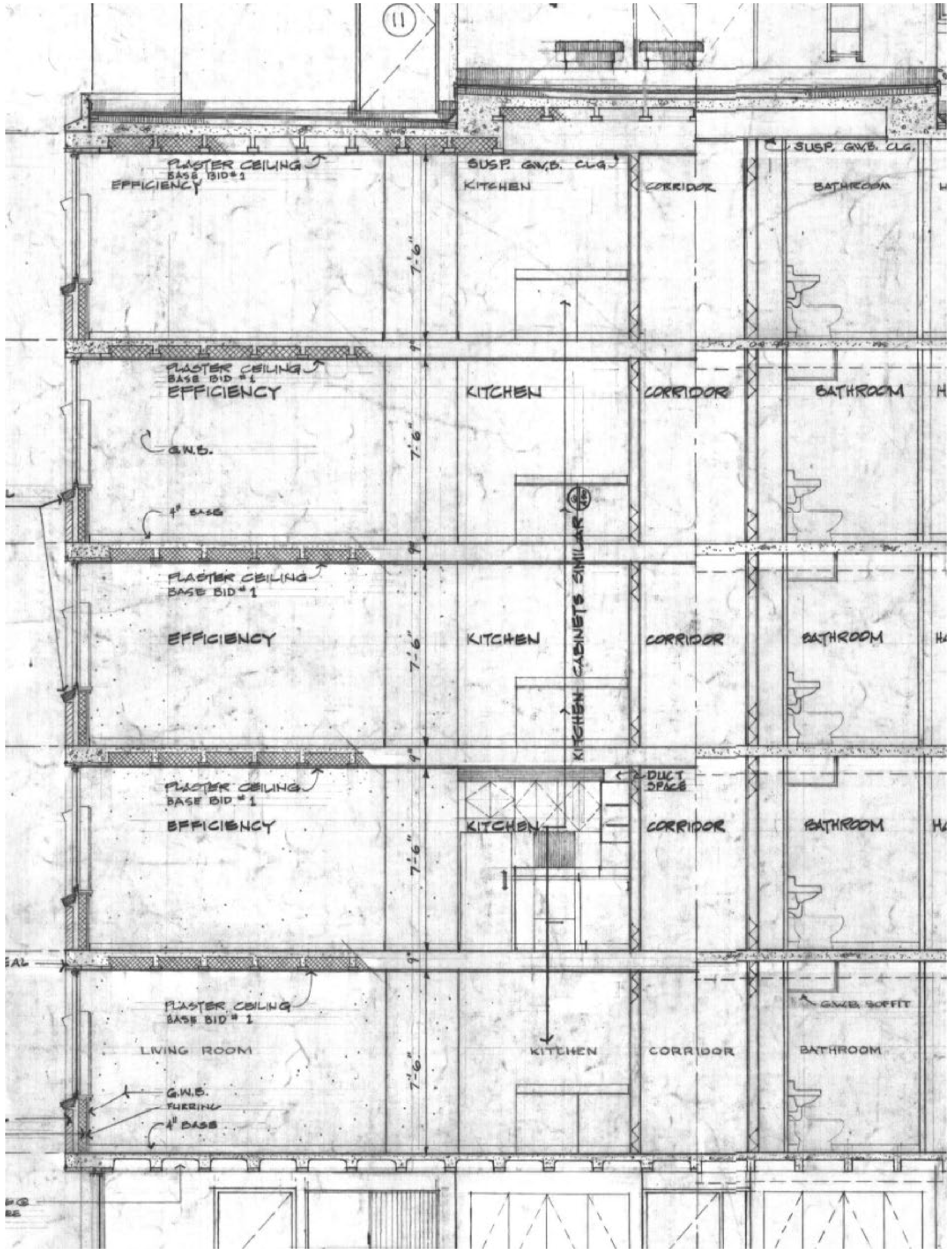


Interi

System Approach

Can we penetrate the exterior envelope?

- Historic Envelope?
- Lot Line Issues?



System Approach

Can we penetrate the exterior envelope?

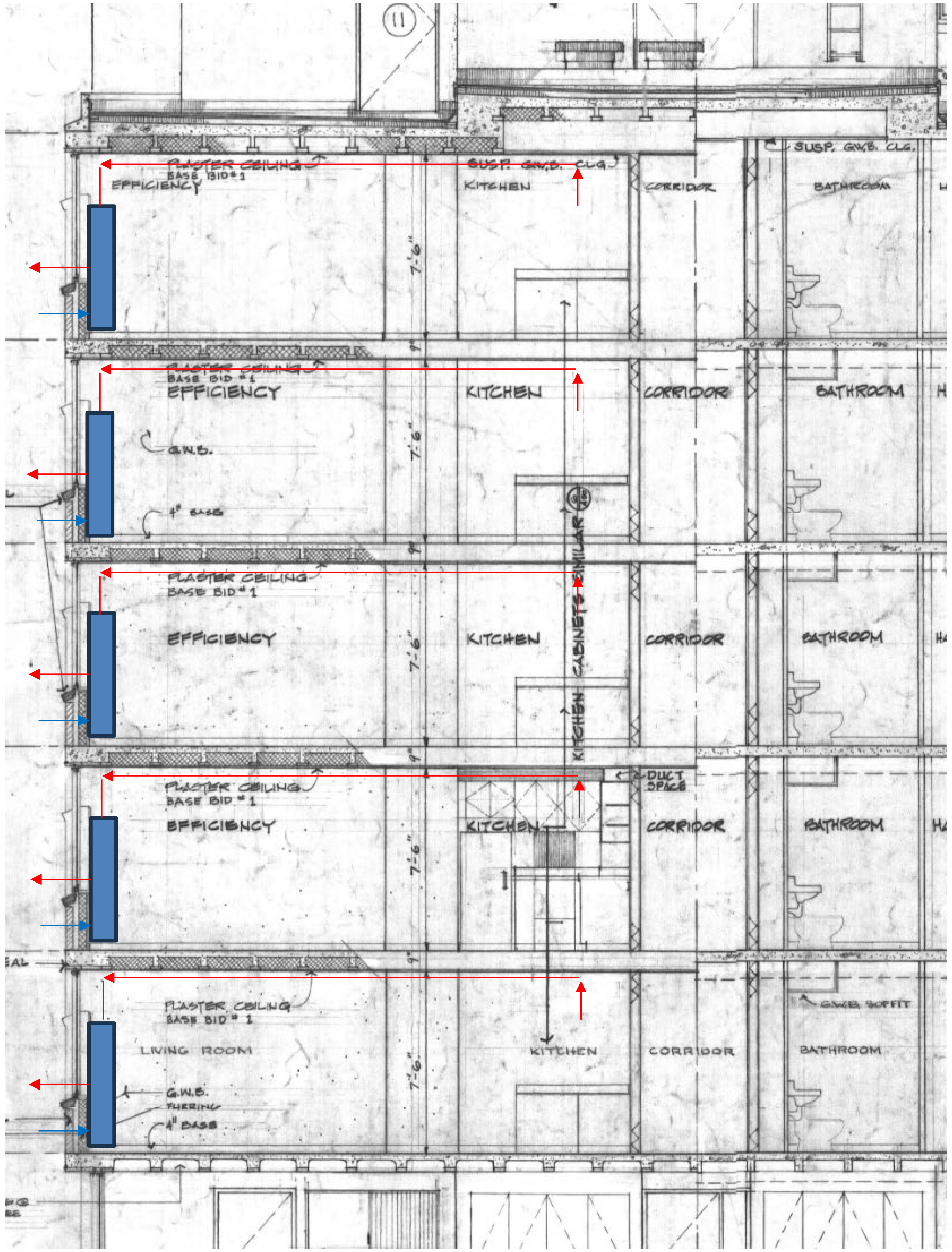
YES – Apartment Level Solutions

- Ventilation and Condenser Air F

e

nical Pod

?

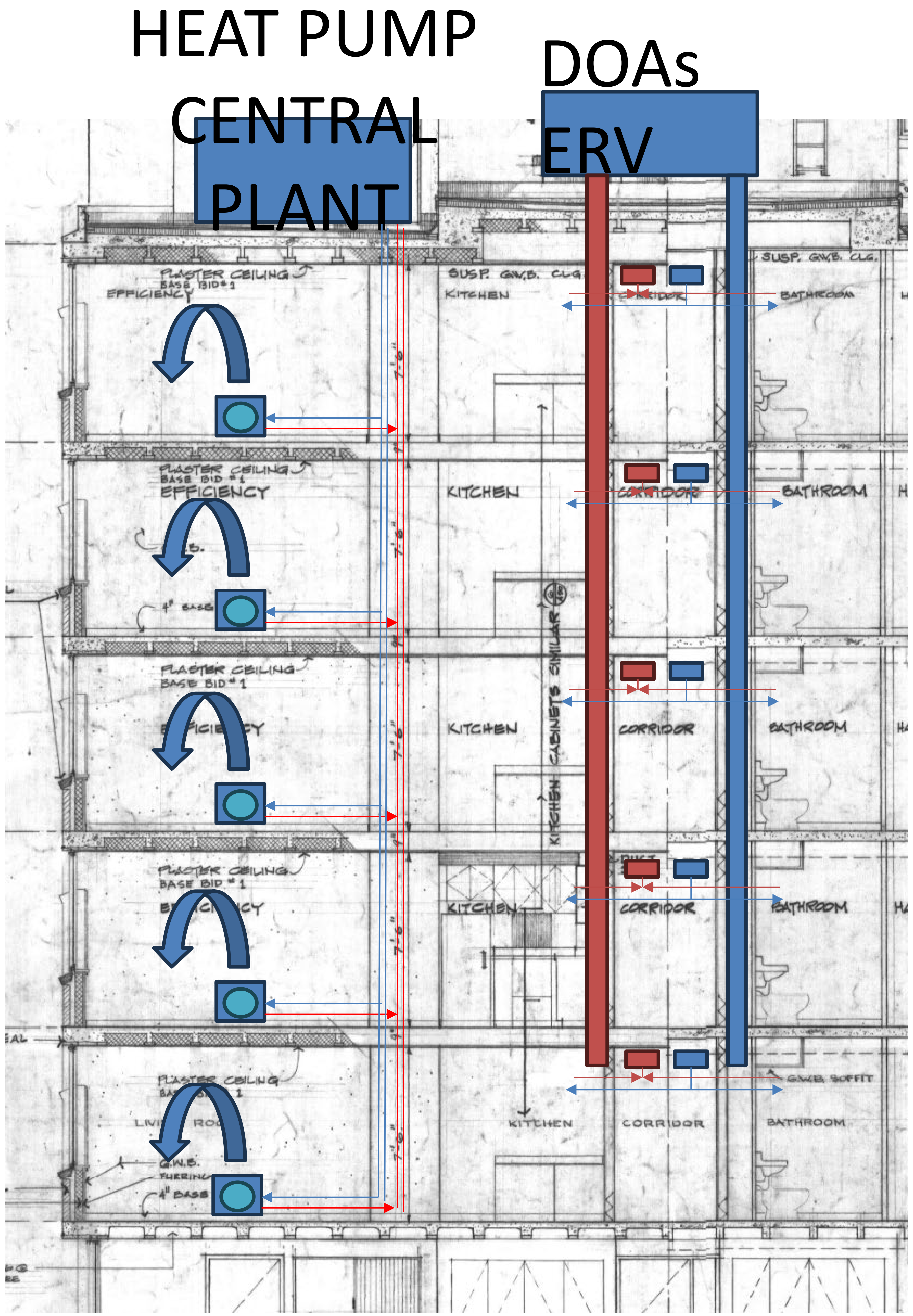


System Approach

If we can't penetrate the exterior: Can we fit ductwork in the corridor?

YES

- Ventilation Air from Rooftop DOAS/ERV
- Space Conditioning:
  - Water source heat pumps?
  - Hydronic fan coils?
  - VRF?
- Heat Pump Based Central Plant:
  - Air Source Heat Pumps?
  - Geothermal?
  - Solar HW?
  - VRF?



System Approach

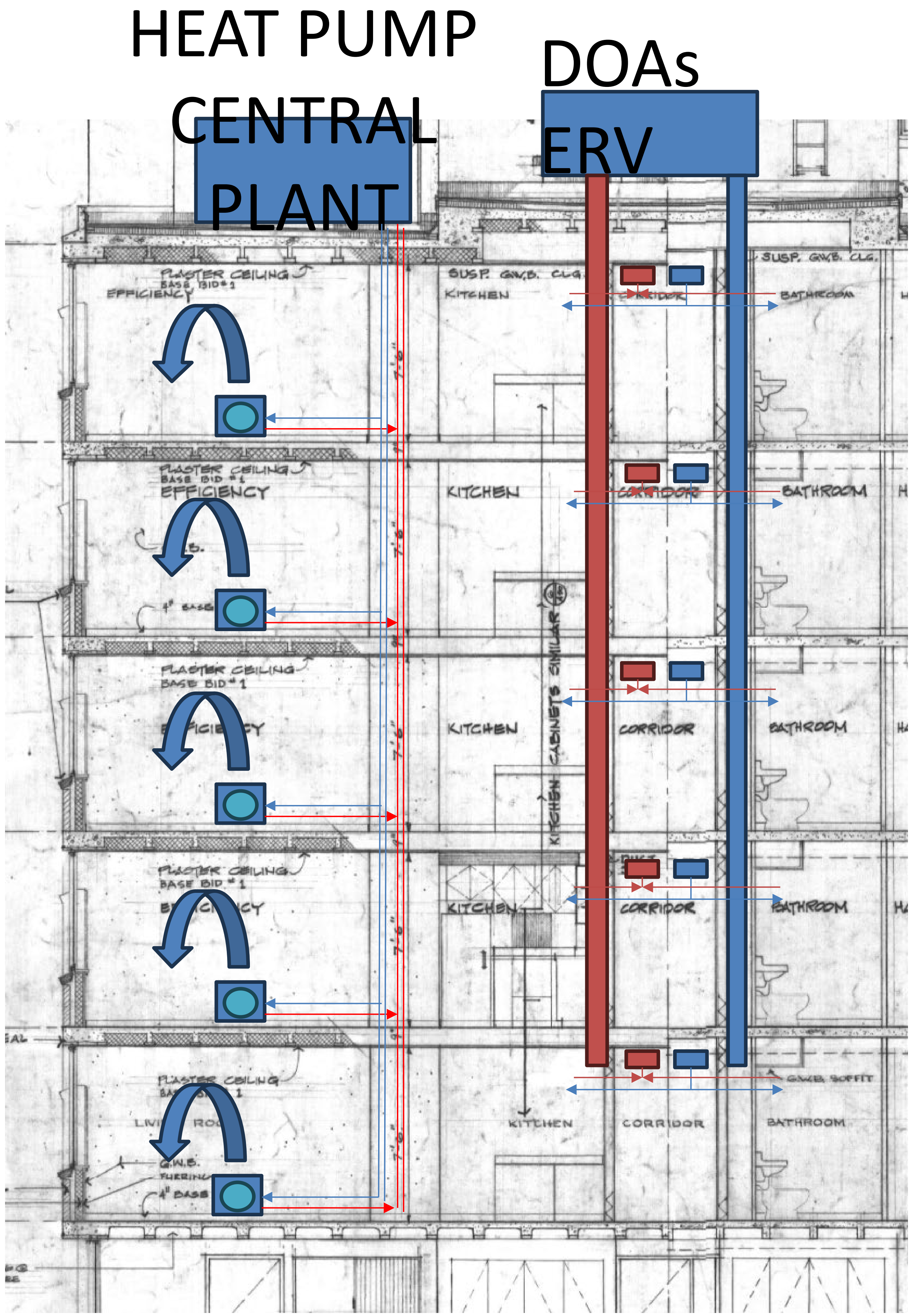
4-pipe or 2-pipe hydronic system

Advantages

- High Efficiency
- Opportunities for heat recovery to domestic hot water in central DHW system

Disadvantages

- Cost of piping is high if not already there



System Approach

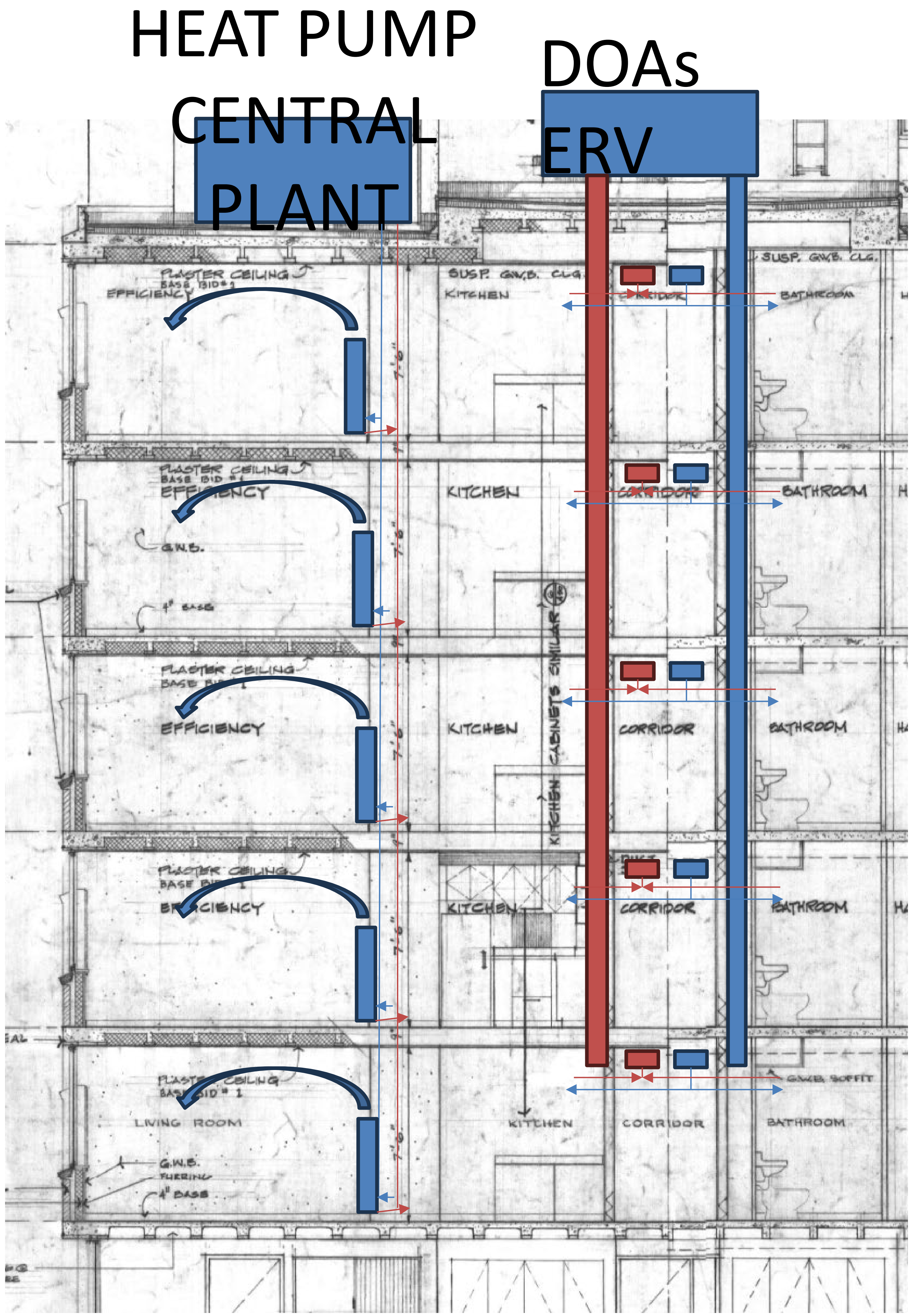
Water-source heat pumps

Advantages

- Neutral water piped through the building. Can re-use existing heating water piping
- Can capture waste heat for domestic hot water heating in a central DHW plant

Disadvantages

- Compressor in every apartment



System Approach

Ground / Solar-source heat pumps

Advantages

- Very low energy use
- Can be integrated with solar
- Lower maintenance costs
- Heat recovery to DHW possible

Disadvantages

- Requires real estate for geothermal wells
- High cost, but lower now with tax credits available,

Ground Loop
Vertical Wells

System Approach

VRF

Advantages

- Less costly than hydronic

Disadvantages

- Requires refrigerant line-sets to be run throughout the building
- High potential refrigerant loss, with high global warming potential
- High embodied carbon content of refrigerant
- High maintenance costs