BUILDINGENERGY BOSTON

Heat Pump Design Challenges in Larger Buildings: Air-to-Air VRF or Air-to-Water

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Northeast Sustainable Energy Association (NESEA)
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Westin Boston Seaport District

Overcoming VRF Design Obstacles for High Rise Buildings

David Glickman PE LEED AP
GEA Consulting Engineers, NYC

SUMMARY

- This course will provide the practical knowledge that everyone involved with high rise buildings requires to decide if a VRF system is right for their building and to guide and assist the engineer with the actual design. You will learn the options regarding heat pump and heat recovery, how to zone the equipment and how to control them. You will learn the optimum locations for the outdoor condensing units, how to pipe them and how to tell if there is adequate clearance and airflow. You will also learn optimum piping practices, how to properly hang refrigeration piping, and how to prevent refrigeration leaks.

- A case study will be reviewed to discuss owner decisions and interactions with regard to condenser metering, location and acoustics. We will discuss CFD (computational fluid dynamics) analysis and the ways it can be used to optimize condenser spacing, proper access and adequate airflow to allow for proper condenser performance.

INSTRUCTOR BIO

David Glickman PE, LEED AP is the managing partner of GEA Consulting Engineers, which he founded in his attic more than 25 years ago. Mr. Glickman is a born and bred New Yorker with a mechanical engineering degree from Columbia University. He has performed hundreds of building condition reports, both pre-purchase and forensic, for all types of buildings throughout the country. He has provided mechanical, electrical, plumbing and fire protection design services for upscale retail, residential, commercial and institutional clients. Projects have included the design of new office buildings, new manufacturing plants, commercial tenant space, kitchen/restaurant facilities, parking facilities, institutional design and commercial to residential building conversions.

OUTLINE AND LEARNING OBJECTIVES

- Basics of VRF Systems
- Ideal conditions for designing VRF
- Options for location of outdoor units
- Permitted piping lengths and heights
- Causes of refrigeration leaks
- Potential problems with piping installations
- Case study showcasing acoustical issues, excessive cost and condenser farm layouts
- CFD analysis of condenser farm layouts

REFRIGERATION CYCLE

Figure 2b: Components of an Air-source Heat Pump (Cooling Cycle)

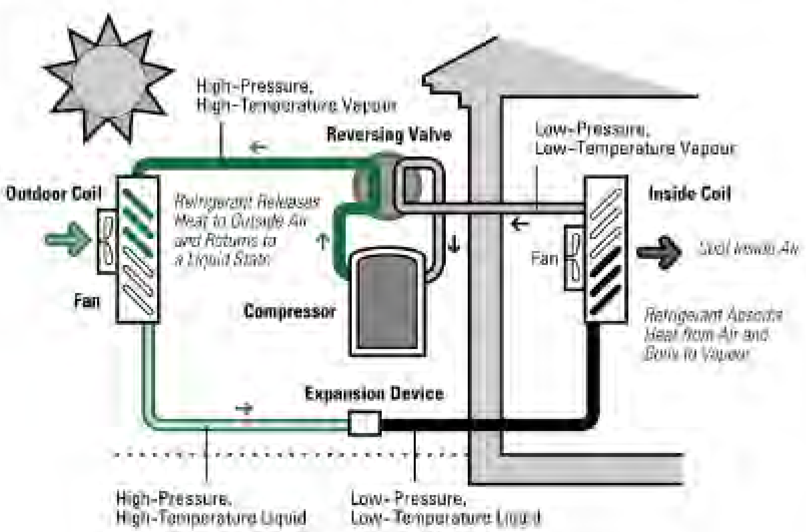
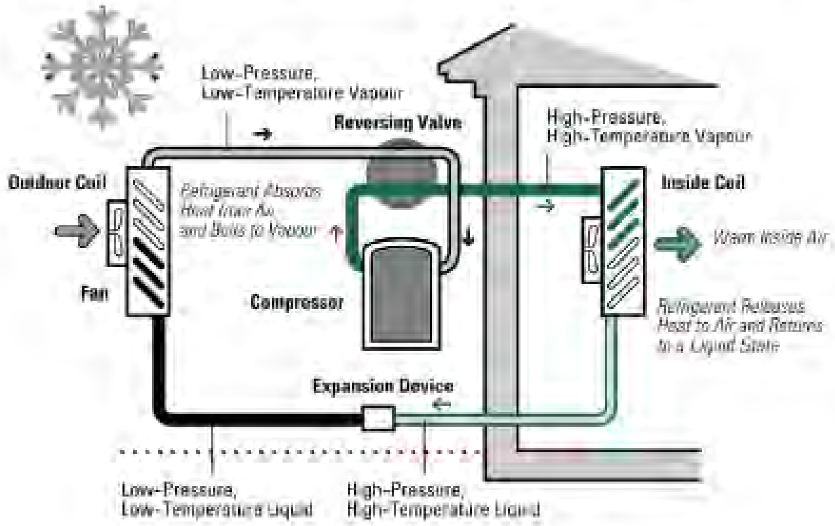
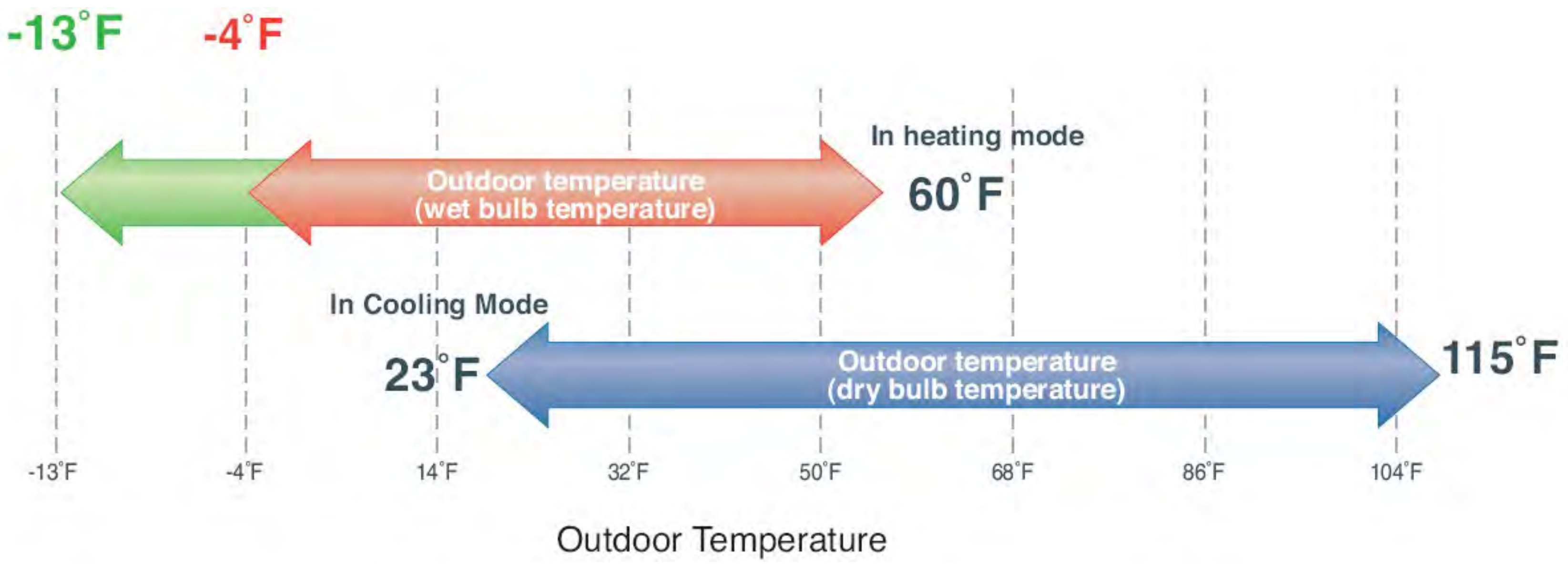


Figure 2a: Components of an Air-source Heat Pump (Heating Cycle)



VARIABLE REFRIGERANT FLOW (VRF)



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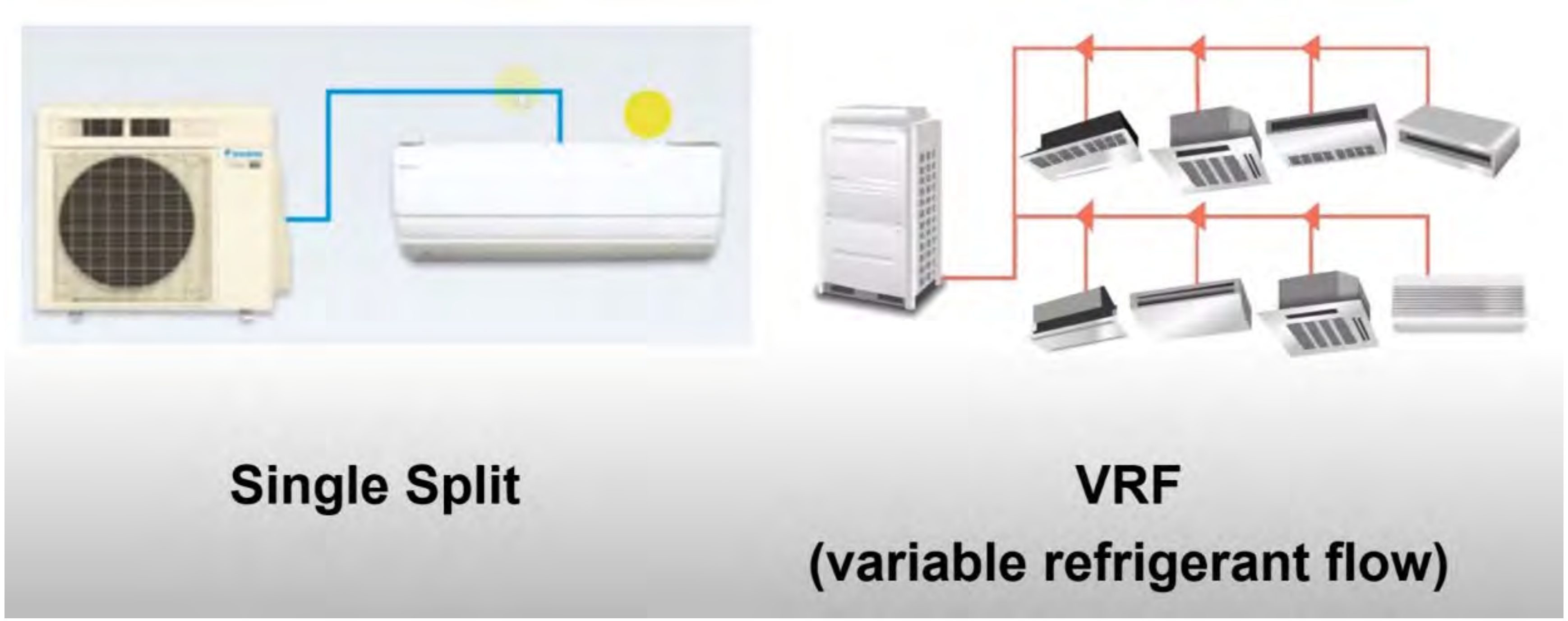
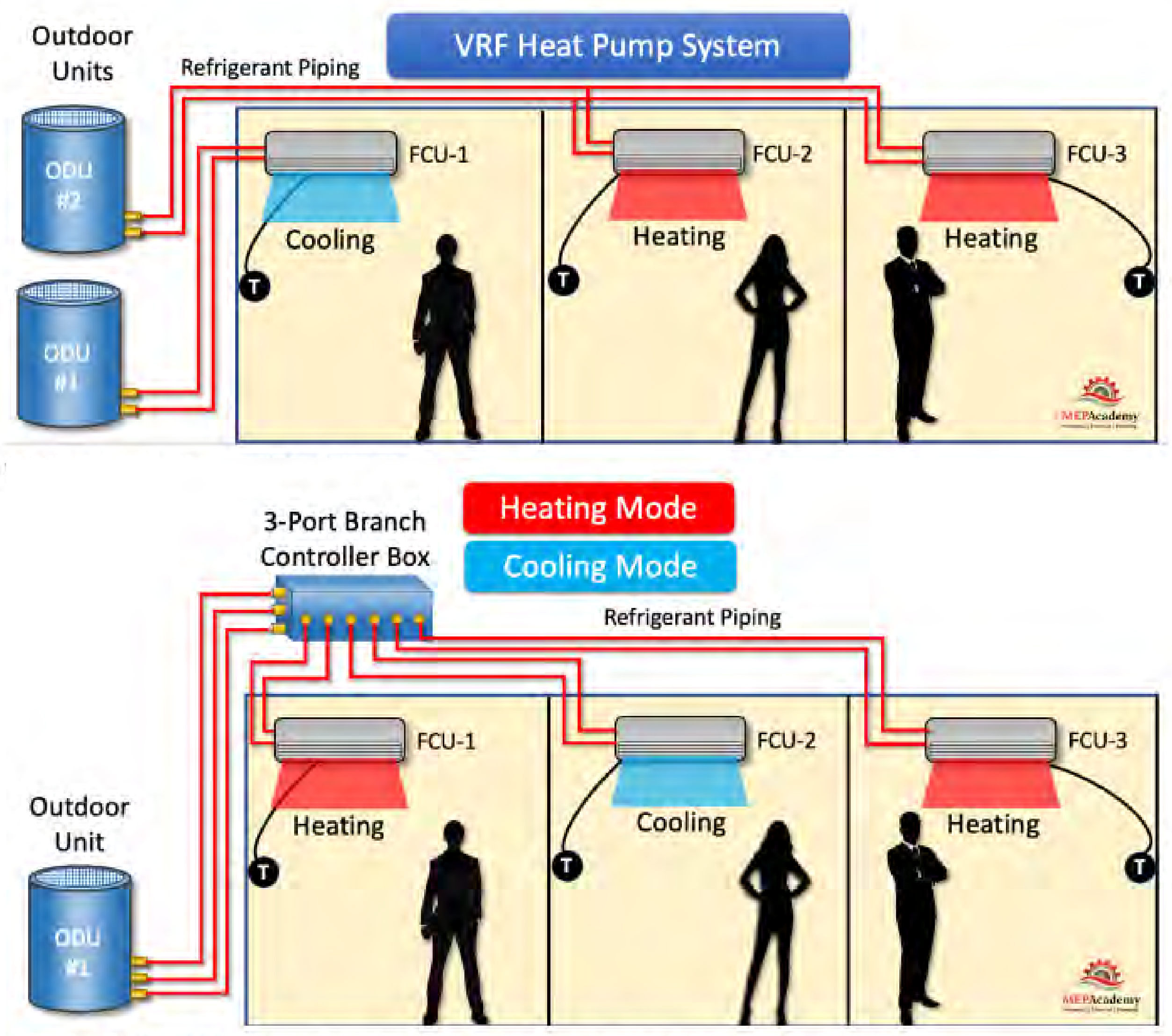


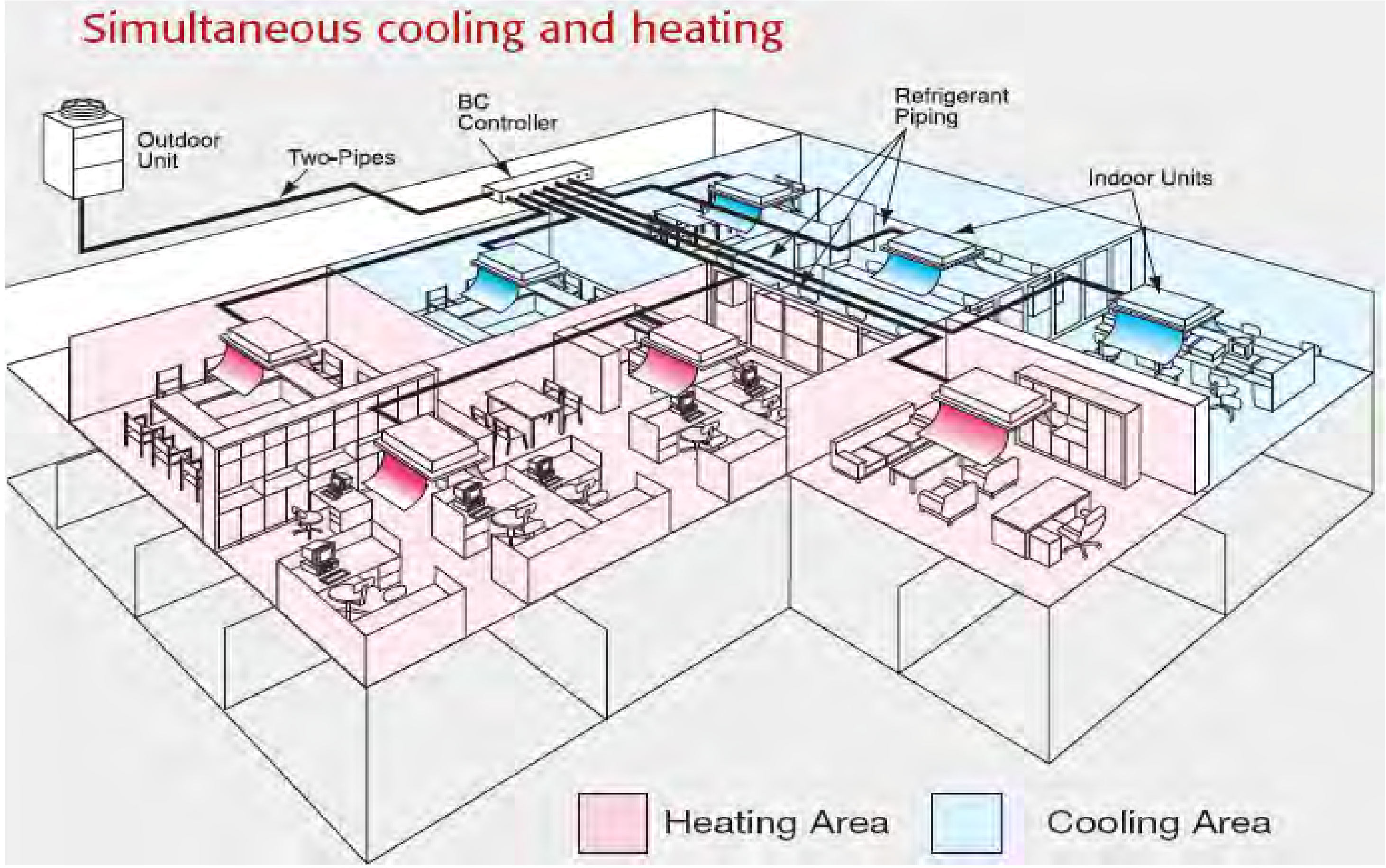
HEAT PUMP VS HEAT RECOVERY



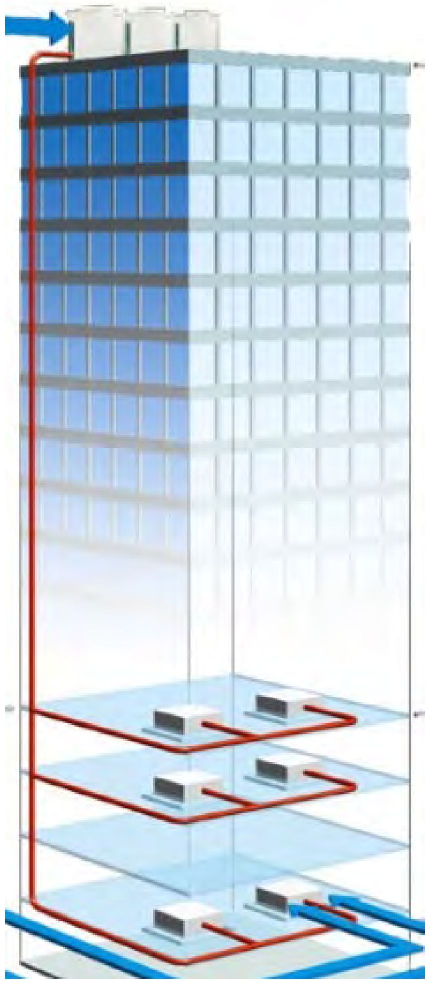
VRF Heat Recovery vs VRF Heat Pump (Heat Recovery System with 3-Port Branch Controller)

VRF DESIGN CONSIDERATIONS

Refrigerant Piping Layout



VARIABLE REFRIGERANT FLOW (VRF)



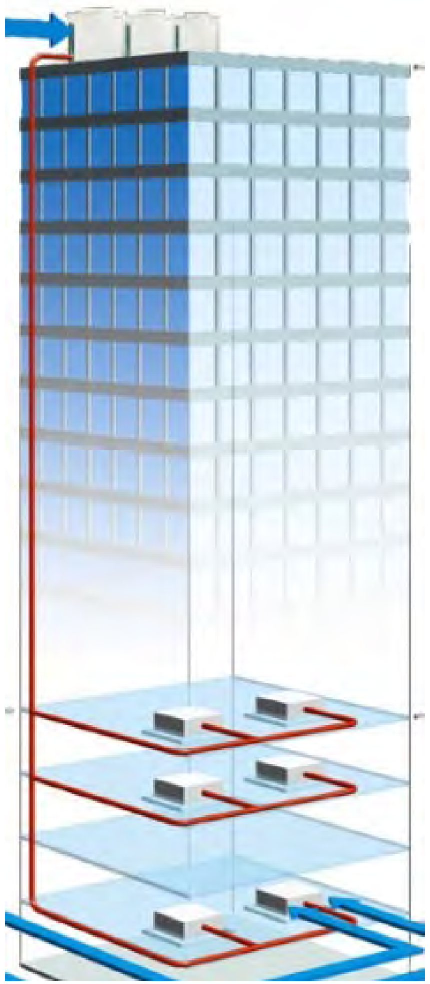
ADVANTAGES

- No need for a Central Plant.
- No fossil fuel usage for cooling or heating.
- Will contribute to avoid fines due to Local Law 97 of 2019.
- Very quiet operation (compressor is located outdoors).
- Multiple options for indoor units and very small.
- Very High Efficiency System.
- Very easy sub-metering of energy use.

DISADVANTAGES

- Requires a large amount of refrigerant piping (shaft space).
- Maximum vertical distance between outdoor and indoor unit is 295'-0" (depending on manufacturer).
- It requires sub-metering of the energy consumption if the VRF system is using larger condensing units. Tenant will receive two (2) utility bills **IF** the entire building is directly metered. One bill by the utility company and one by the building management.

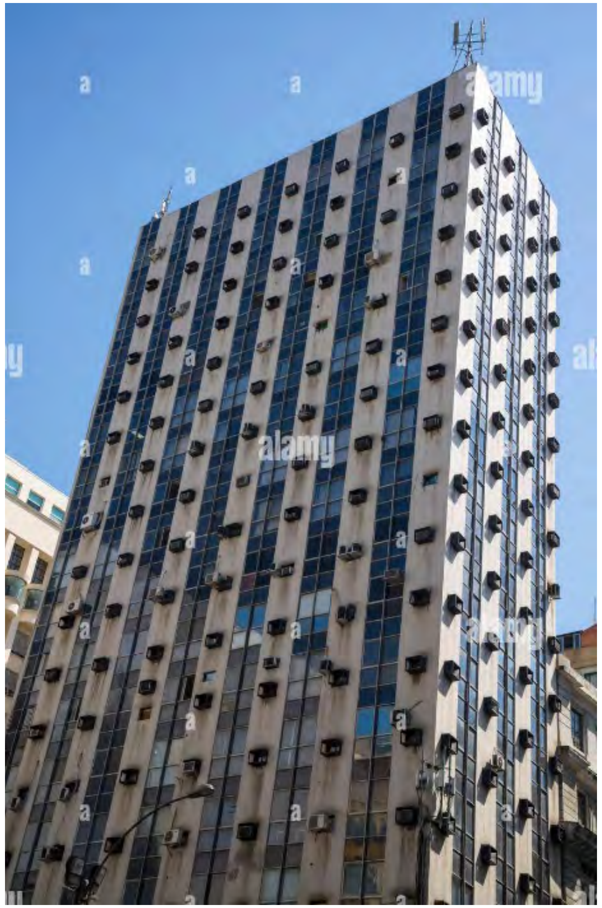
VARIABLE REFRIGERANT FLOW (VRF)

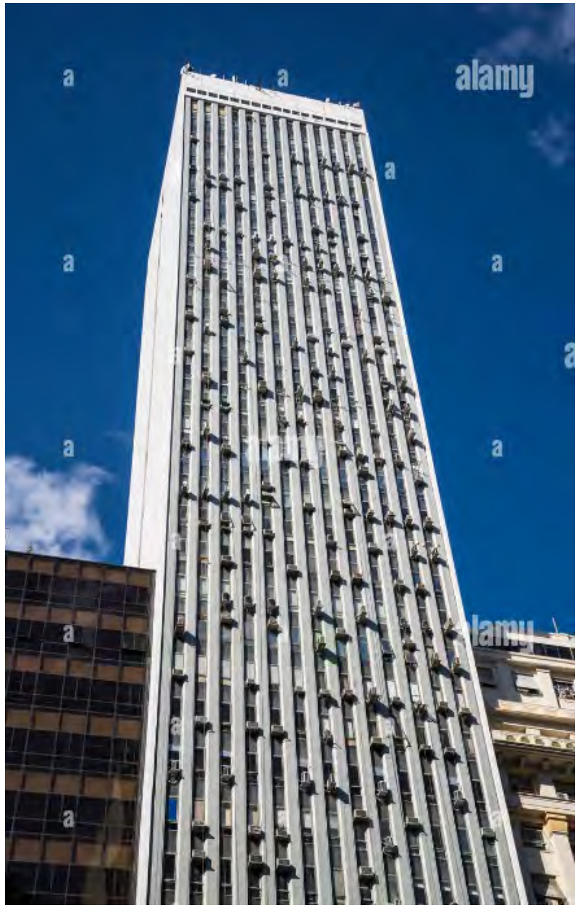


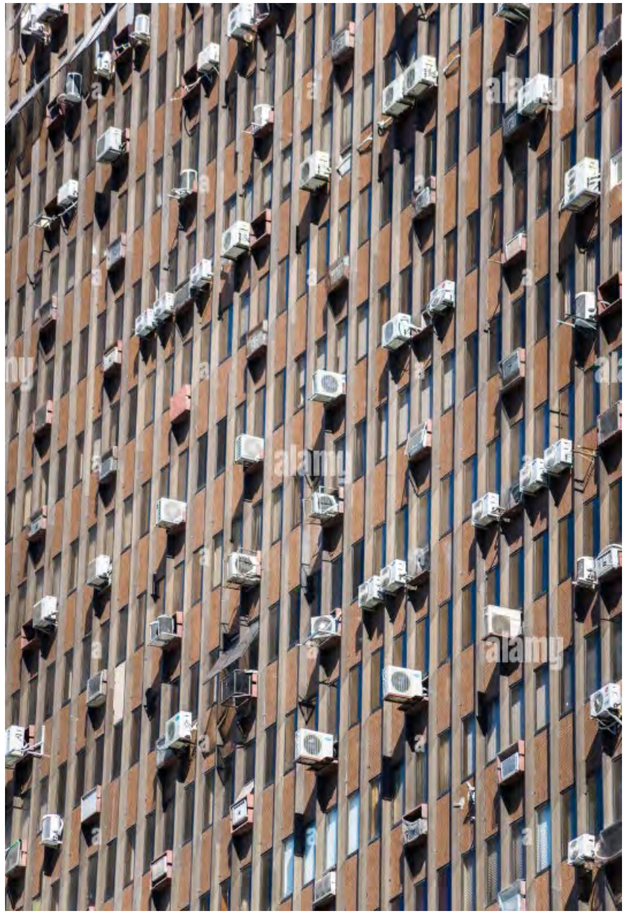
Refrigerant piping lengths	Maximum feet
Total length	1,804 - 2,624
- Maximum total length is dependent on the outdoor unit model and distance between BC controller.	
Farthest Indoor from Outdoor	541 (623 equivalent)
Maximum length between outdoor and single/main BC controller	360
Maximum length between single/main BC controller and indoor	131-196
Vertical differentials between units	**Maximum feet**
Indoor/outdoor (outdoor higher)	164*
Indoor/outdoor (outdoor lower)	131
Indoor/BC controller (single/main)	49
- Maximum length between single/main BC controller and indoor is dependent upon the vertical differential between the single/main BC controller and the indoor unit.	
Indoor/indoor	49

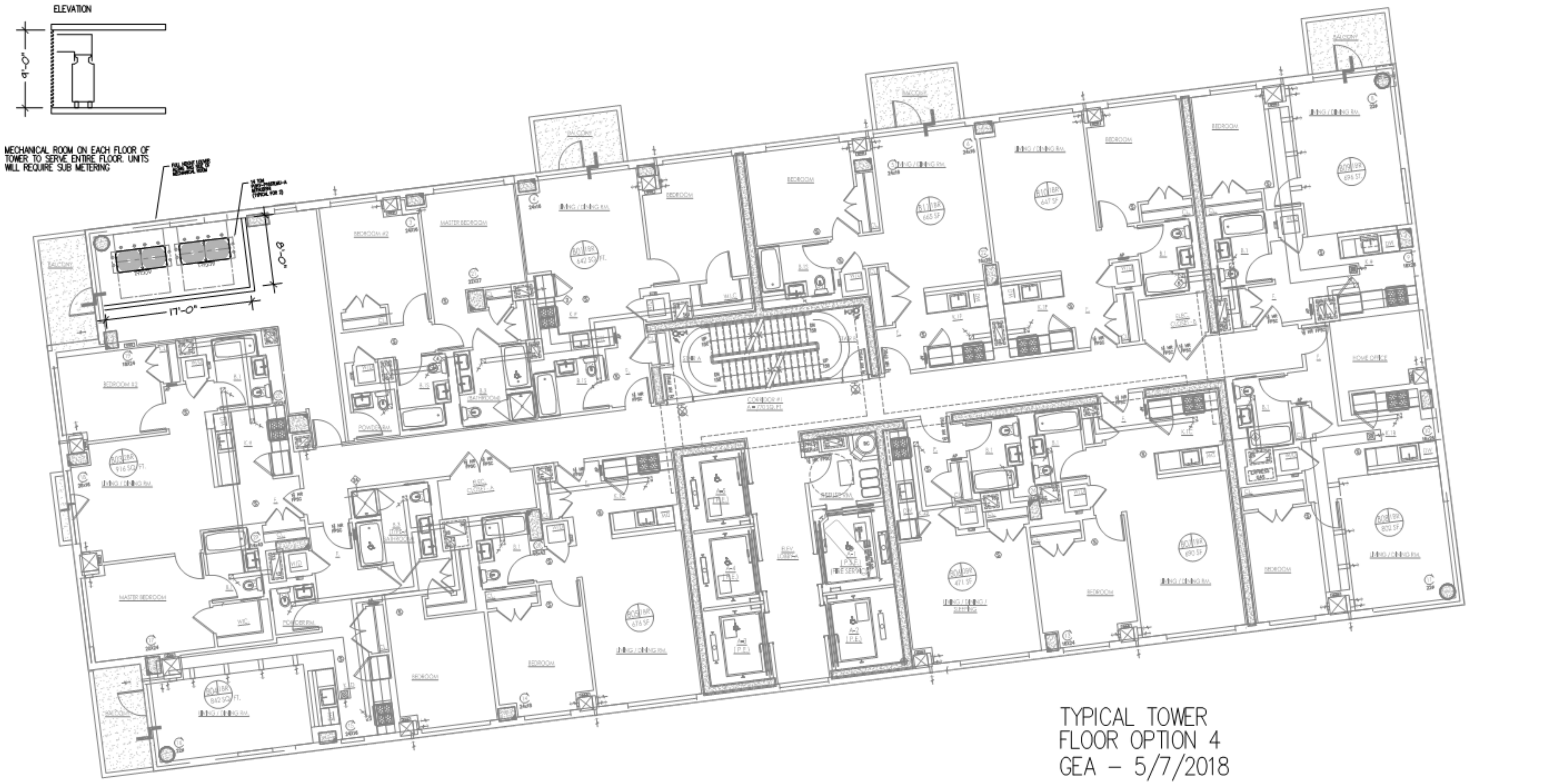
TYPICAL CONDENSER SETUP I HAVE SEEN IN THE FAR EAST/EUROPE

TYPICAL CONDENSER SETUP I HAVE SEEN IN THE FAR EAST/EUROPE

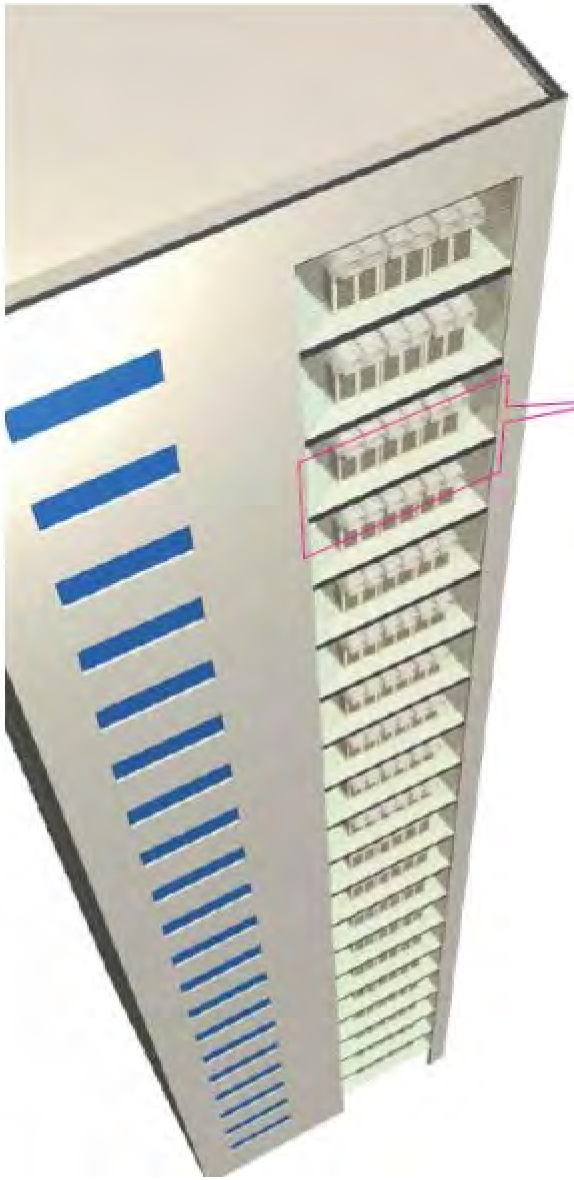




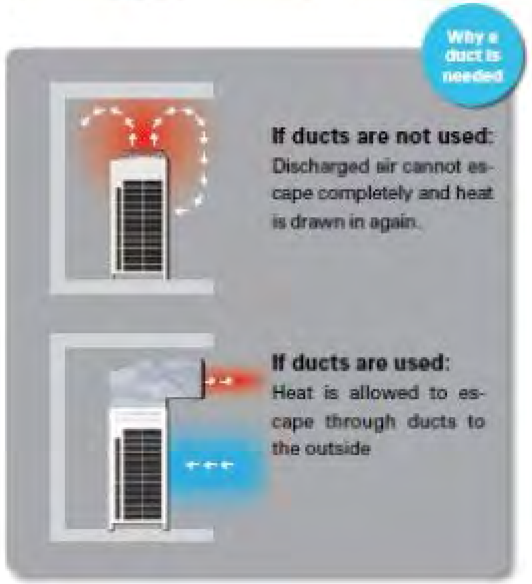




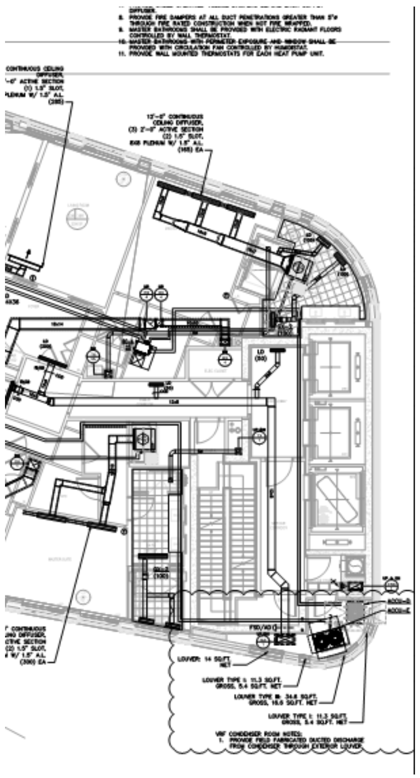
TYPICAL TOWER
FLOOR OPTION 4
GEA – 5/7/2018

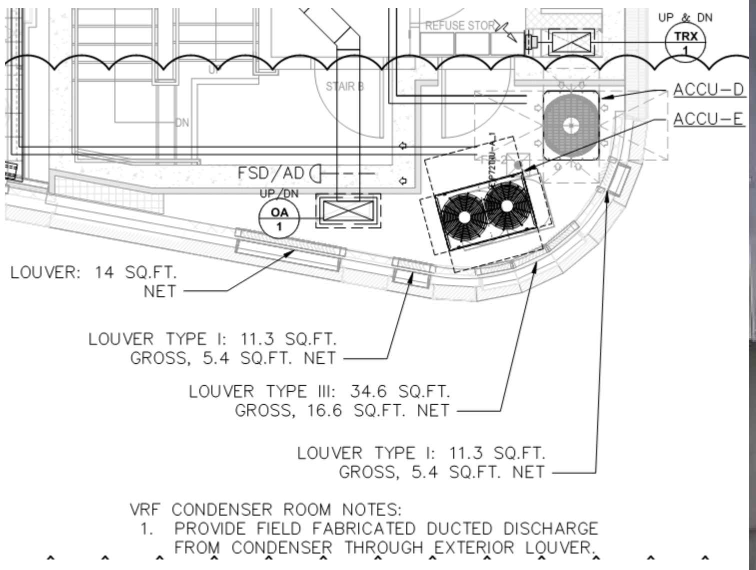


Quantity of VRF units per Floor
2 - 3

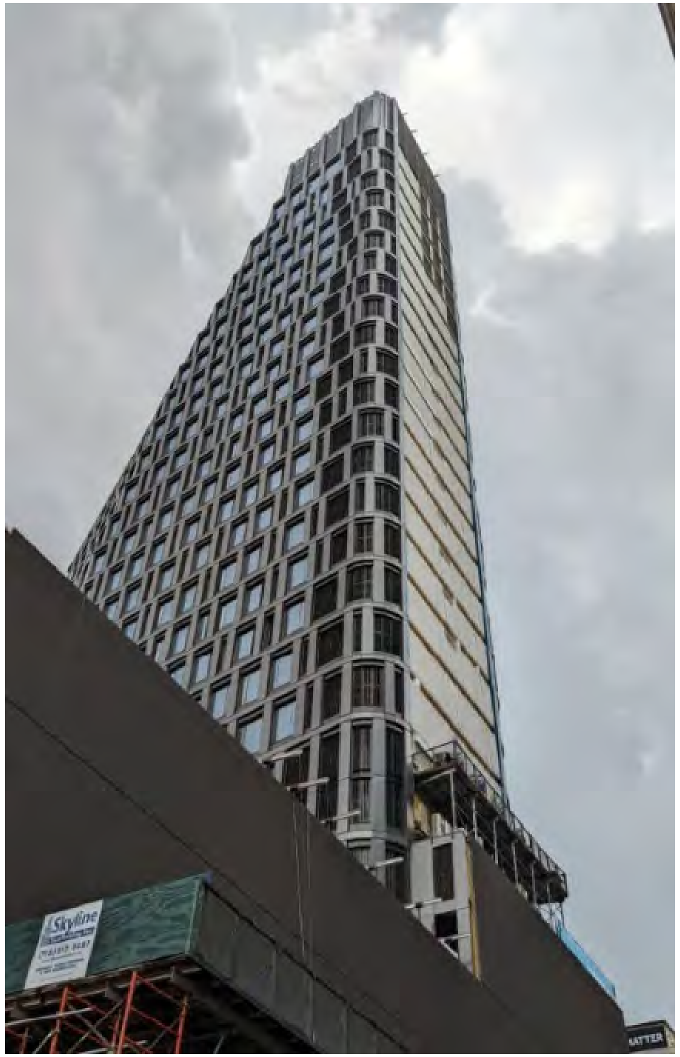


RECENT SIDE CORE PROJECT

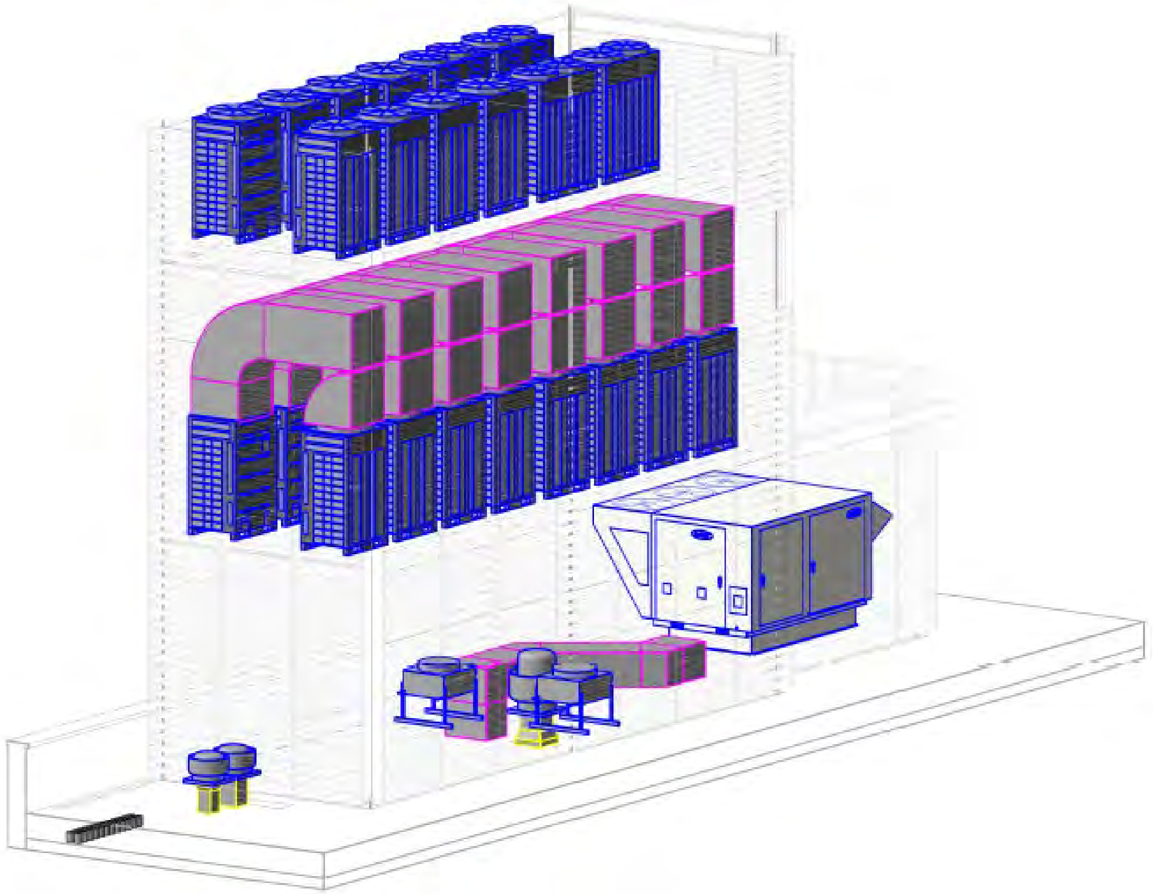




RECENT SIDE CORE PROJECT



VARIABLE REFRIGERANT FLOW (VRF)



STACKED ROOF MECHANICAL EQUIPMENT TO MAXIMIZE RECREATIONAL ROOF SPACE

STACKED ROOF MECHANICAL EQUIPMENT TO MAXIMIZE RECREATIONAL ROOF SPACE

VARIABLE REFRIGERANT FLOW (VRF)

CONDENSER "FARM" ON ROOF

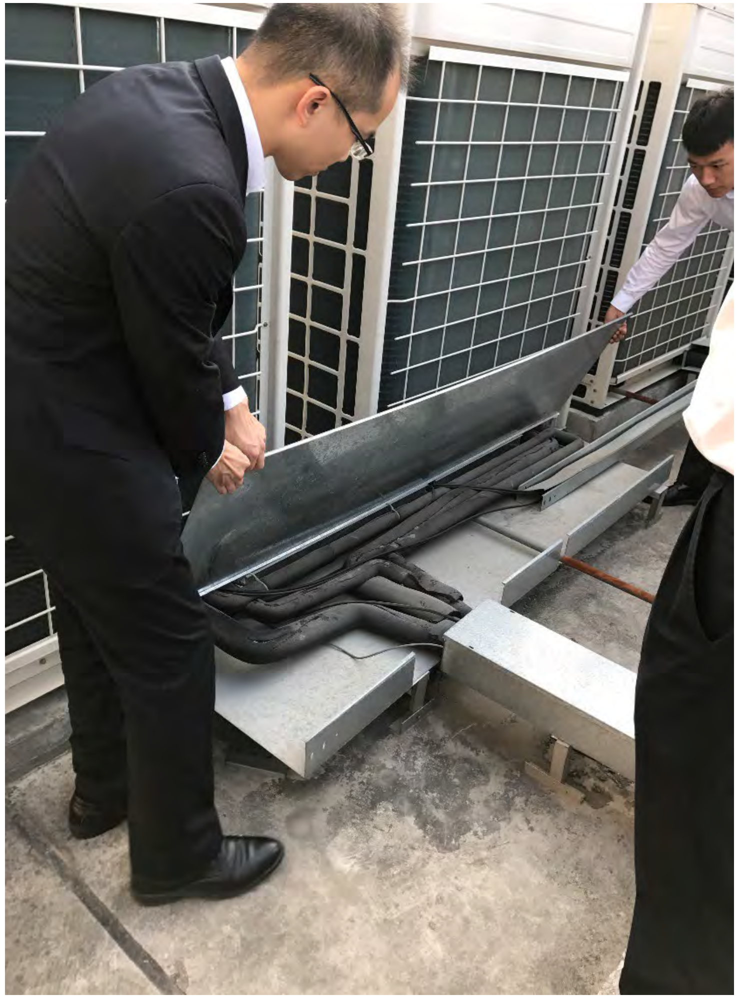
REFRIGERANT PIPING ON ROOF

REFRIGERANT PIPING ON ROOF

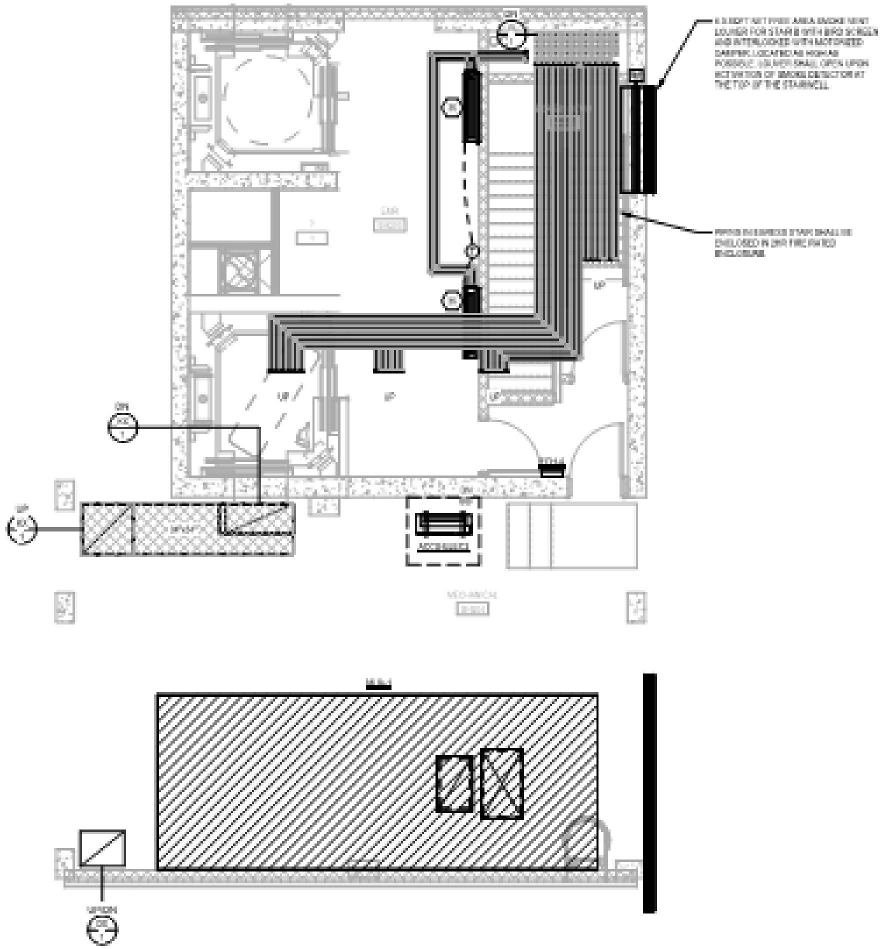
CONDENSER FARMS

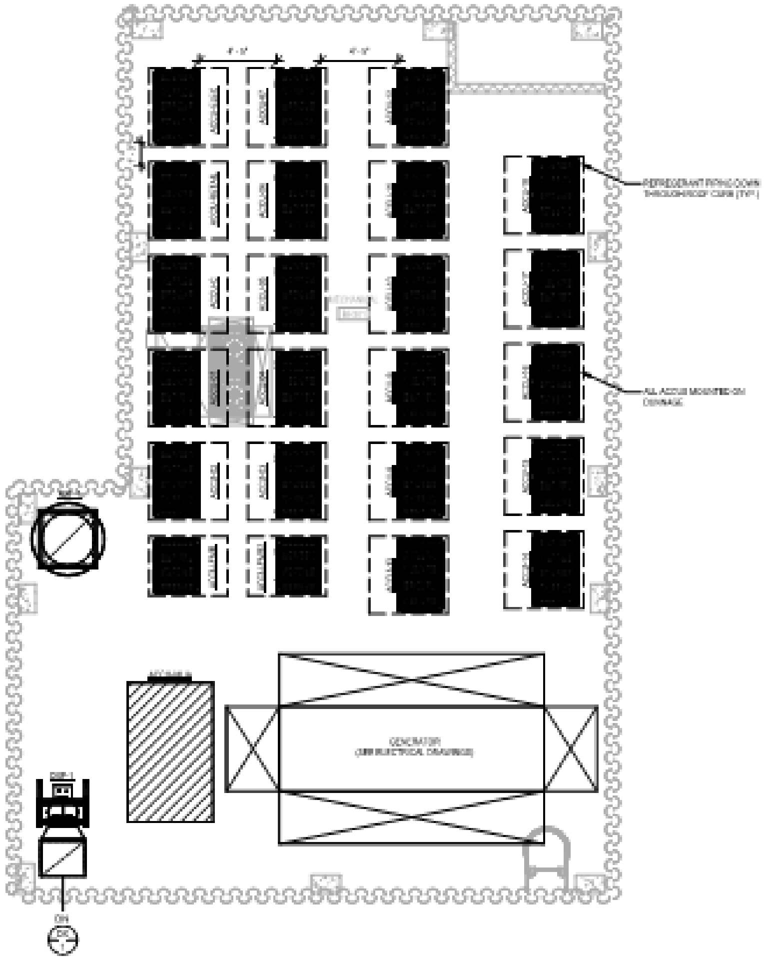
REFRIGERANT PIPING AND ELECTRICAL
CONDUITS UNDER STEEL GRATING

CONDENSER SUPPORT AND PIPING



REFRIGERANT PIPING AND ELECTRICAL CONDUITS INSIDE PROTECTIVE COVERS


LOUVER FOR STAIR B WITH BIRD SCREEN AND INTERLOCKED WITH MOTORIZED DAMPER, LOCATED AS HIGH AS POSSIBLE. LOUVER SHALL OPEN UPON ACTIVATION OF SMOKE DETECTOR AT THE TOP OF THE STAIRWELL.
PIPING IN EGRESS STAIR SHALL BE ENCLOSED IN 2HR FIRE RATED ENCLOSURE.
MECHANICAL


REFRIGERANT PIPING DOWN THROUGH ROOF CURB (TYP.)
ALL ACCUS MOUNTED ON DUNNAGE
GENERATOR (SEE ELECTRICAL DRAWINGS)

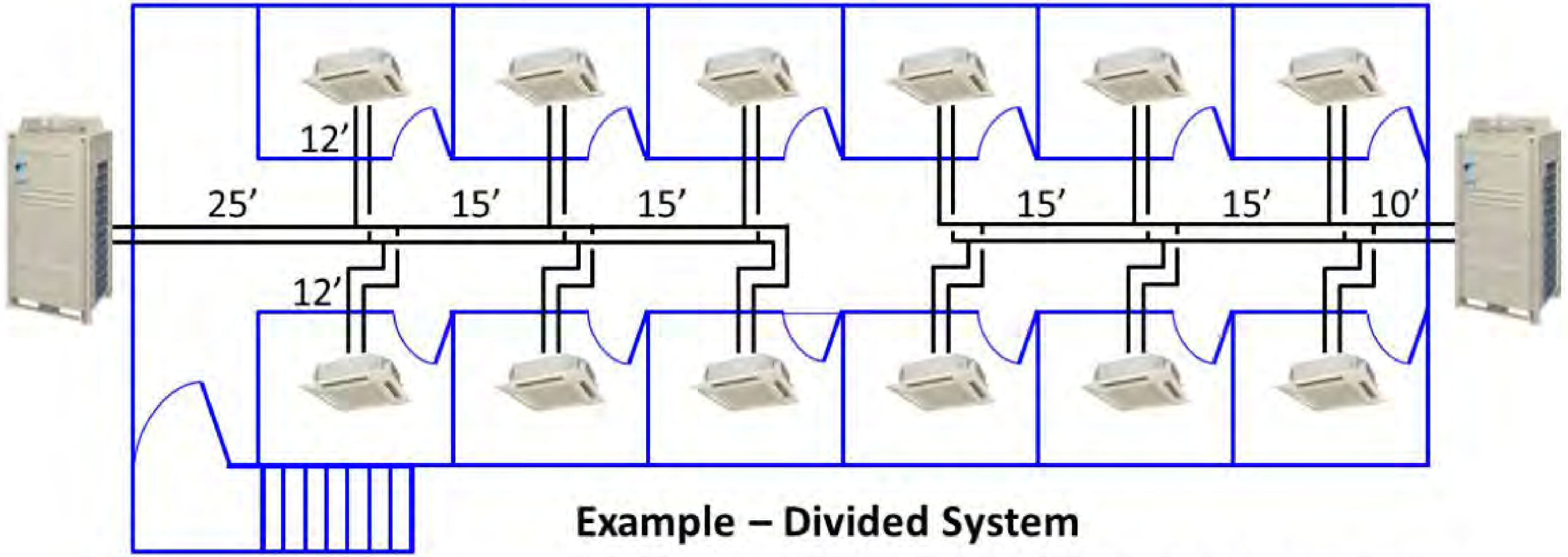
VARIABLE REFRIGERANT FLOW (VRF)

REFRIGERANT PIPING ABOVE CORRIDOR CEILINGS

VRF DESIGN CONSIDERATIONS

Potential Solutions addressing RCL.

2. **Divide refrigerant circuit into multiple smaller systems.**



Example – Divided System

(**40%** of the refrigerant charge for the *Initial Piping Layout)*
(**48%** of the refrigerant charge for the *Revised Piping Layout)*

REFRIGERANT PIPING BEST
ES

- Maintain system capacity & efficiency. Avoid heat gains or losses.
- Prevent condensation on piping or insulation.
- Prevent piping system corrosion
- Prevent mold growth from occurring on construction materials.
- Avoid costly lawsuits.
- Avoid property damage from condensation.

REFRIGERATION LEAKS

MAJOR CAUSES:

- IMPROPER INSTALLATION
- FACTORY FAULT: EQUIPMENT OR LINE SETS
- CORROSION / PINHOLE LEAKS
- SYSTEM VIBRATION

ORIGINS OF REFRIGERANT LEAK

Condenser: 3%

Coil and evaporator: 48%

Mechanical room: 36%

Piping installation: 13%

PREVENTING REFRIGERATION LEAKS

PRECAUTIONS

- PRESSURE TESTING
- SHAFT DESIGNATION TO AVOID PENETRATIONS
- PREINSULATED PIPING SETS
- SPARE PIPING
- LEAK DETECTION

PRESSURE TESTING

2. **Stop Valves securely closed & field refrigerant piping pressure tested to 550 psi (450psi FXTQ) for 24 hours min. Include Pressure Equalization pipe on manifolded Heat Recovery systems (PB)**
3. **Triple evacuate to 500 microns or less; Include Pressure Equalization pipe on HR**
4. **All liquid lines are measured, "Additional Refrigerant Charge" is calculated and weighed into the system, breaking the final vacuum**

Alternate: 50% (trim charge) of the calculated charge weighed in for "*Auto Charge*" operation

Calculation A

Total length (ft) of 1/4" liquid line 254 X .015 lbs/ft = 3.81
+
Total length (ft) of 3/8" liquid line 173 X .040 lbs/ft = 6.92
+
Total length (ft) of 1/2" liquid line 78 X .081 lbs/ft = 6.31
+
Total length (ft) of 5/8" liquid line 52 X .121 lbs/ft = 6.29
+
Total length (ft) of 3/4" liquid line 0 X .175 lbs/ft = 0.00
+
Total length (ft) of 7/8" liquid line 0 X .249 lbs/ft = 0.00

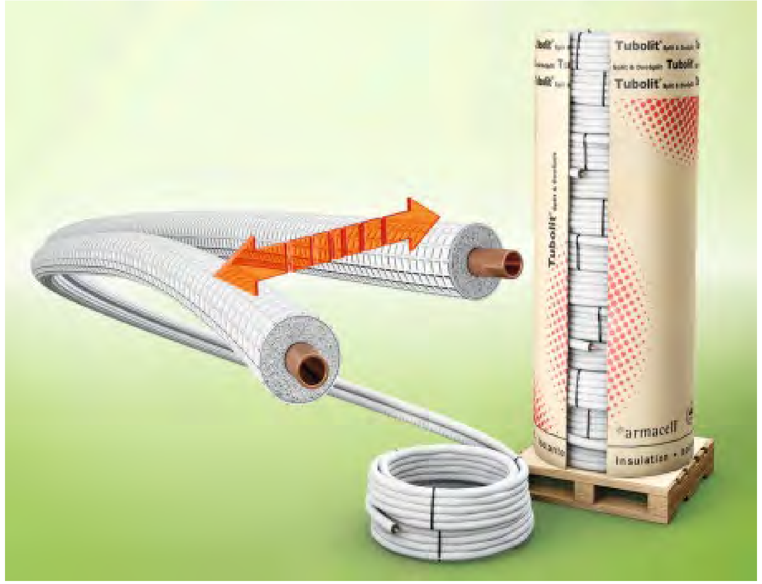
Liquid Line Example Total: 23.33 Lbs

Heat Pump RXYQ - Add total amount from **Calculation A** to **Calculation B**

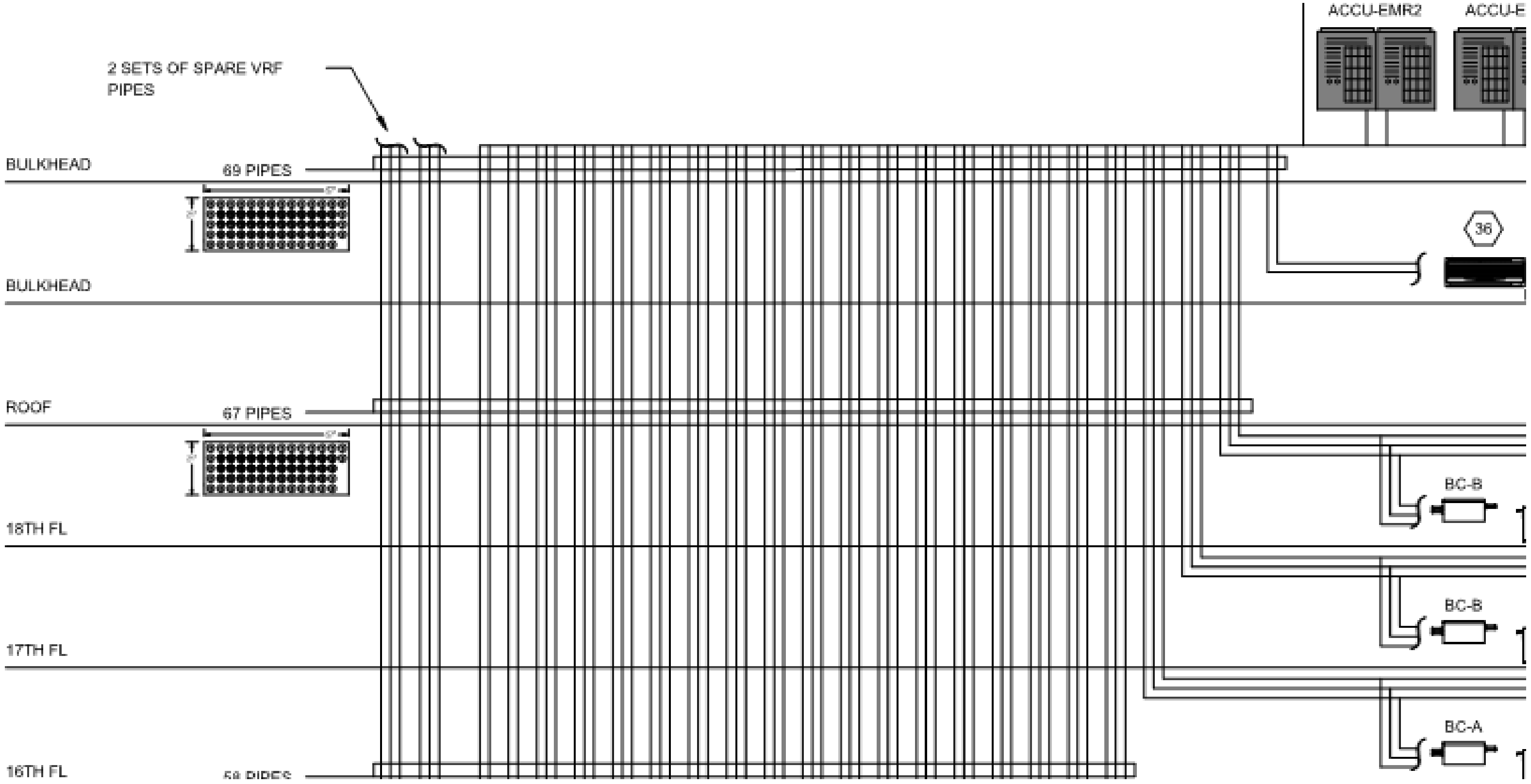
OR

If Heat Recovery REYQ_ Multiply **Calculation A Total** by: **1.02** and add amount to **Calculation B**

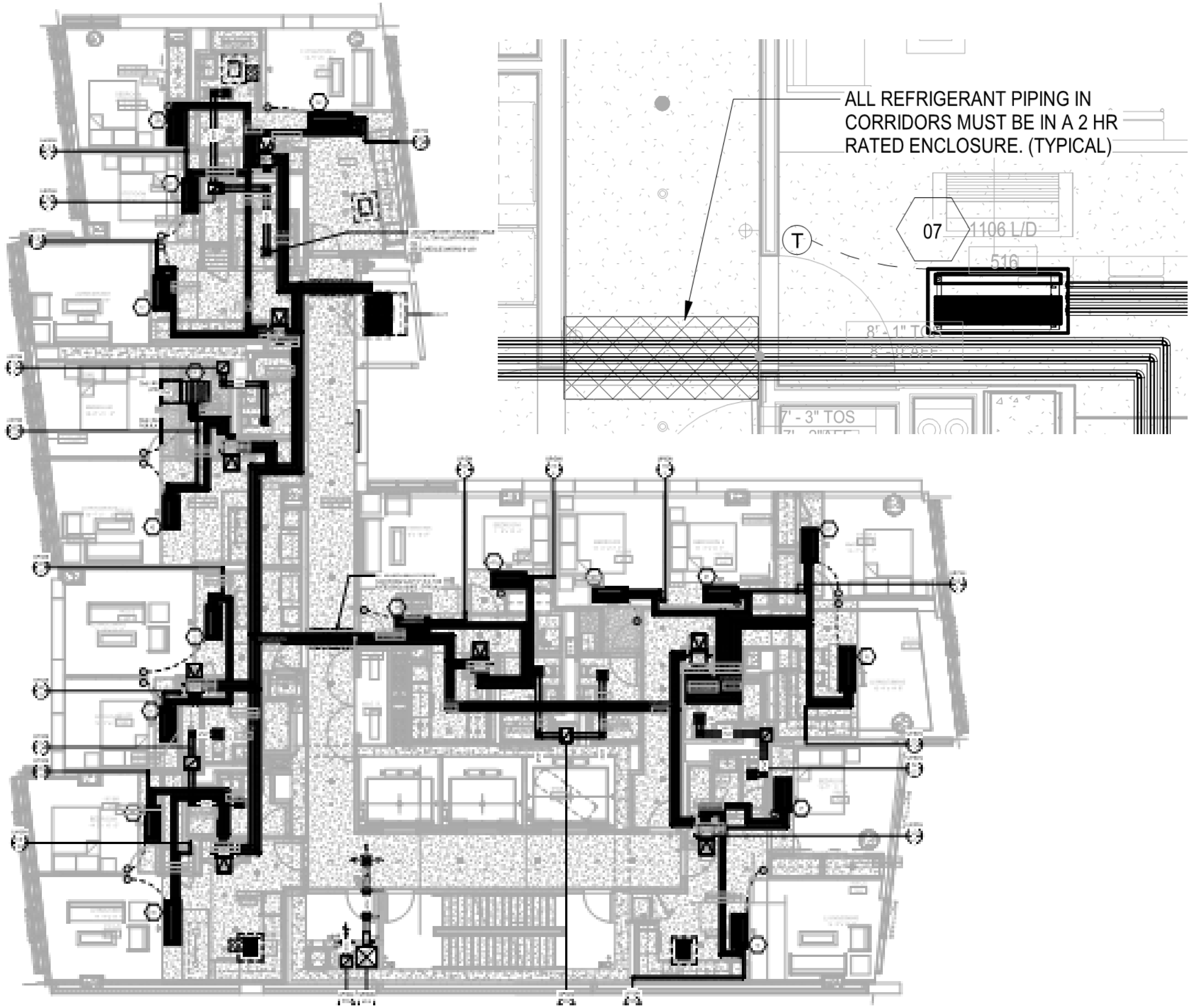
ROLLED PIPING



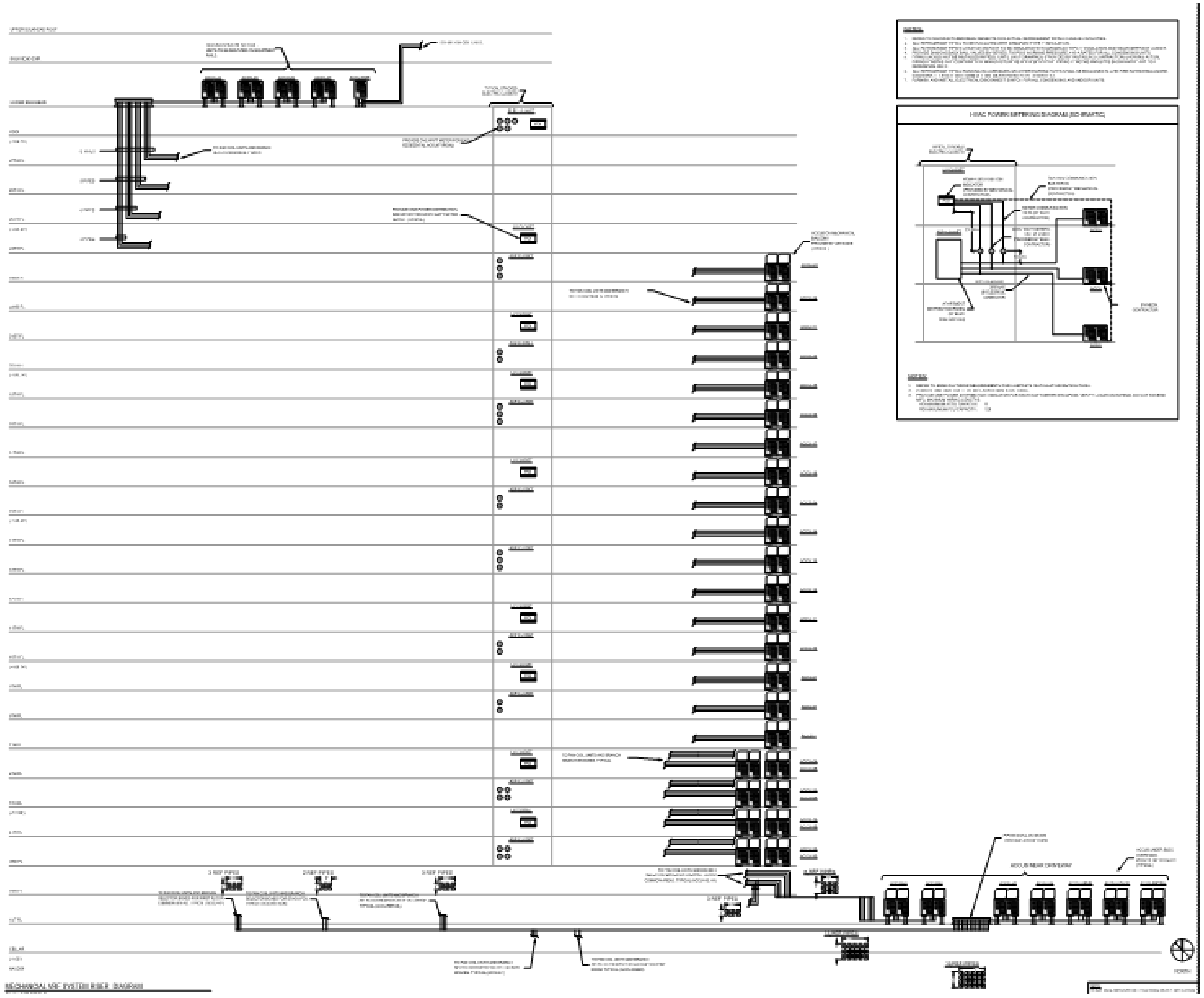
SPARE REFRIGERATION PIPING



SAMPLE PIPING LAYOUT

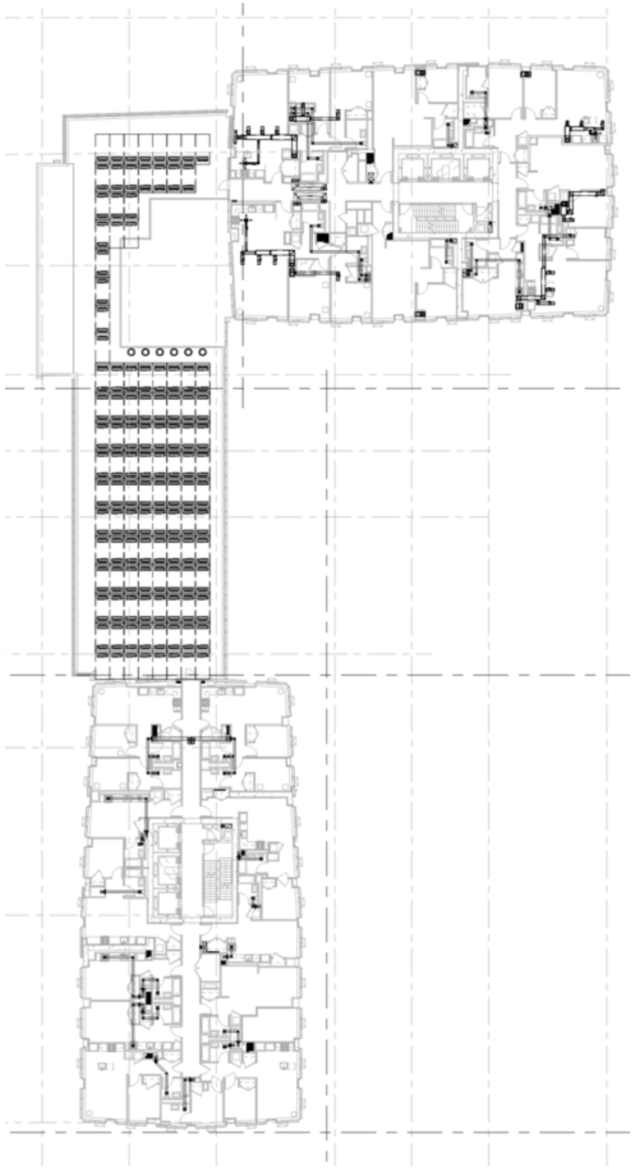


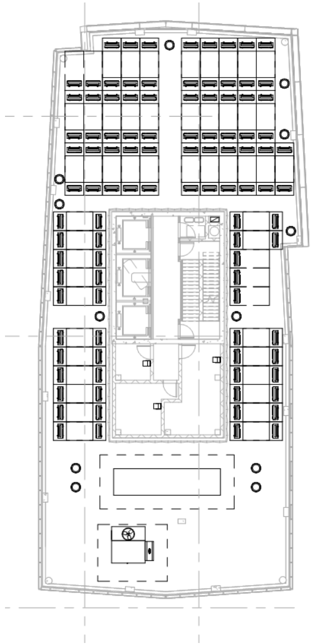
SAMPLE PIPING RISER DIAGRAM

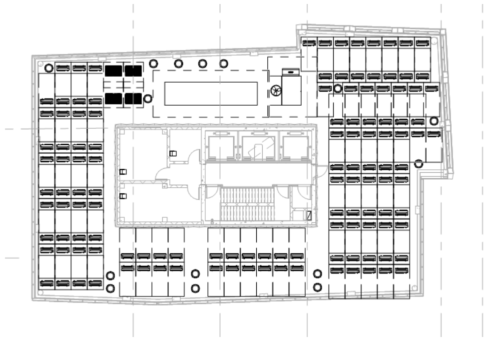


Initial Ownership Direction

Every apartment in the residential towers to be provided with a dedicated VRV-S condenser unit to avoid sub-metering. This required careful study of maximum piping lengths.







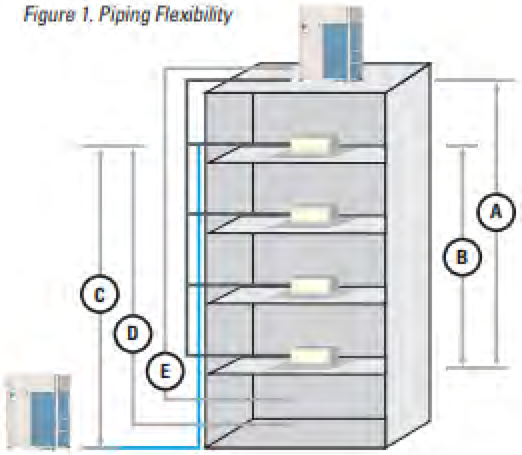
PIPING LENGTH LIMITATIONS

Piping Flexibility

The VRV IV provides very flexible piping possibilities. Generous allowances outlined below facilitate an extensive variety of system designs.

- 100 ft. maximum vertical difference between indoor units provides greater flexibility for riser type piping layouts.
- Allows up to 12 floors served from a single VRV System.
- Ideal for mid to high rise chiller or WSHP replacement projects.

Figure 1. Piping Flexibility



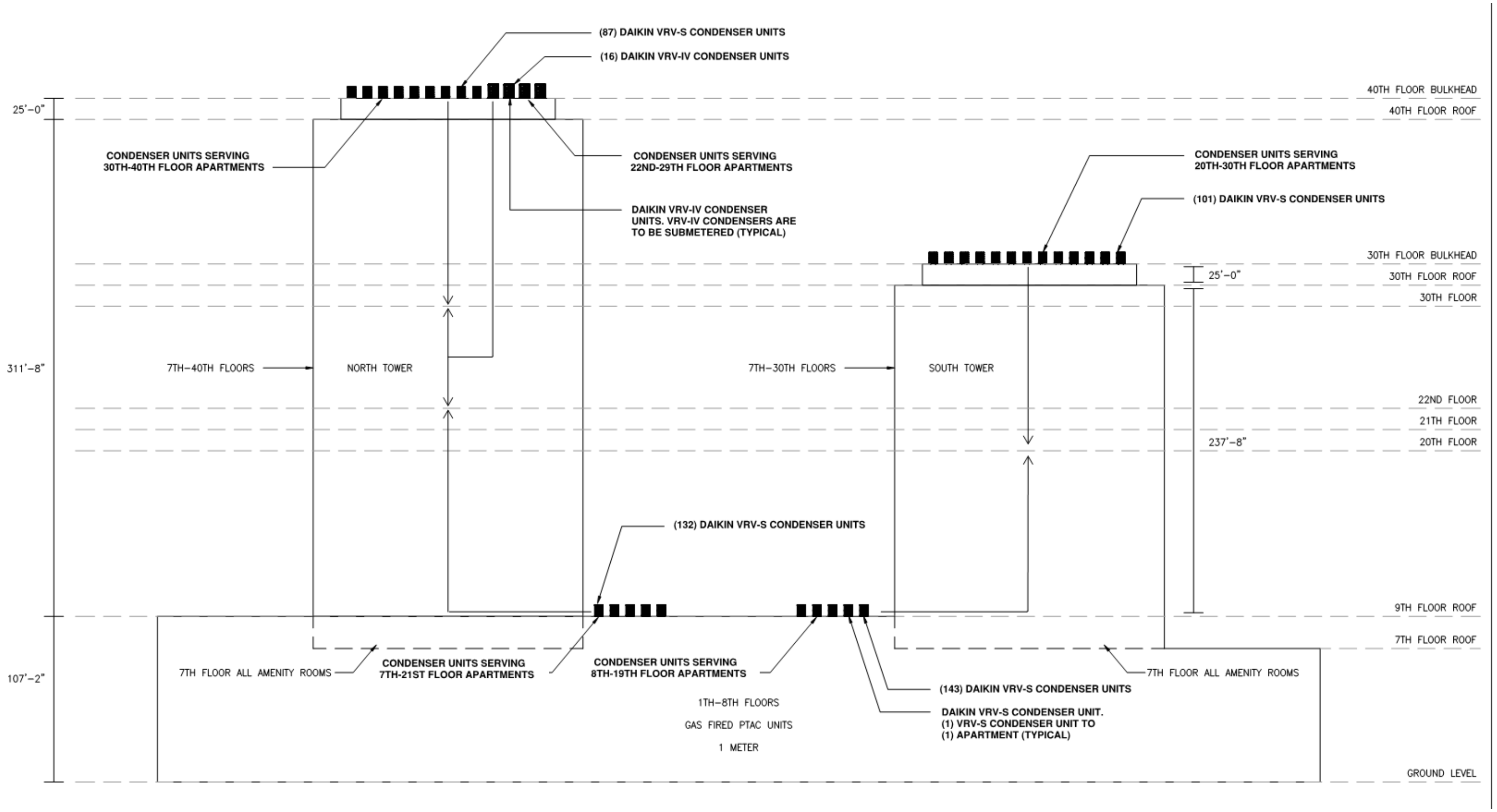
Daikin VRV IV Piping		Distance	Corresponds to Figure 1 (above)
Maximum total one-way piping length		3282 ft.	
Maximum piping length between outdoor unit and indoor unit		541 ft.	E
Maximum piping length between 1st branch connection and indoor unit (with application rules)		131 ft. (295 ft.**)	D
Maximum piping length between indoor unit and closest branch connection		131 ft.	
Maximum vertical difference between outdoor unit and indoor unit (with application rules)	OU above IUs	164 ft. (295 ft.***)	A
	OU below IUs	131 ft. (195 ft.)	C
Maximum vertical difference between indoor units		100 ft.	B

** Fan Coil distance differentials need to be met.

*** Or other symbol — setting adjustment on condensing unit required.

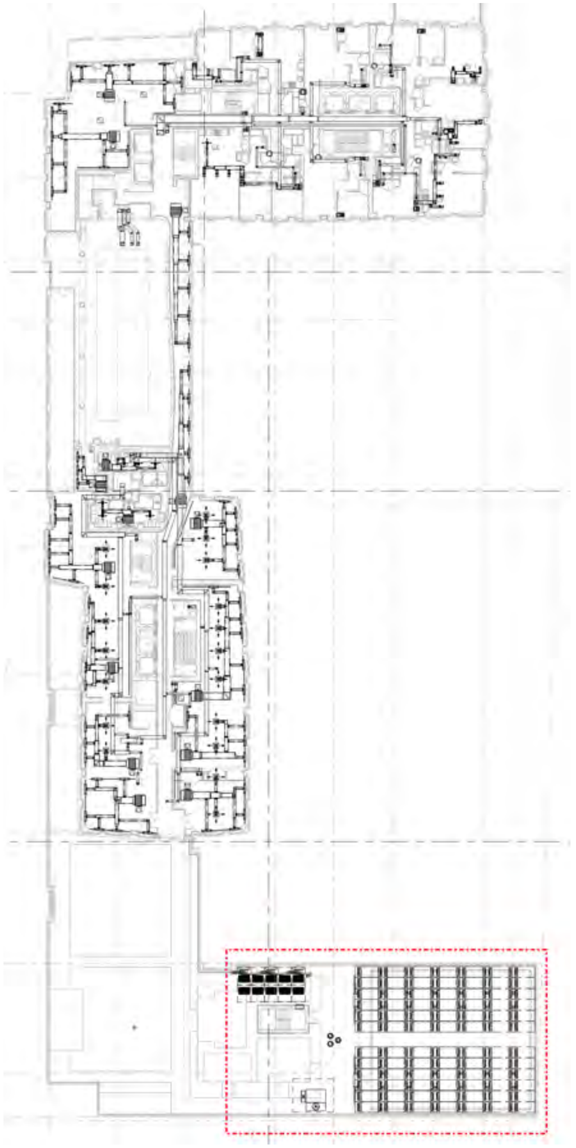
DAIKIN AIR INTELLIGENCE™

WORKING WTIHIN PIPING LENGTH LIMITATIONS



Second Design Iteration

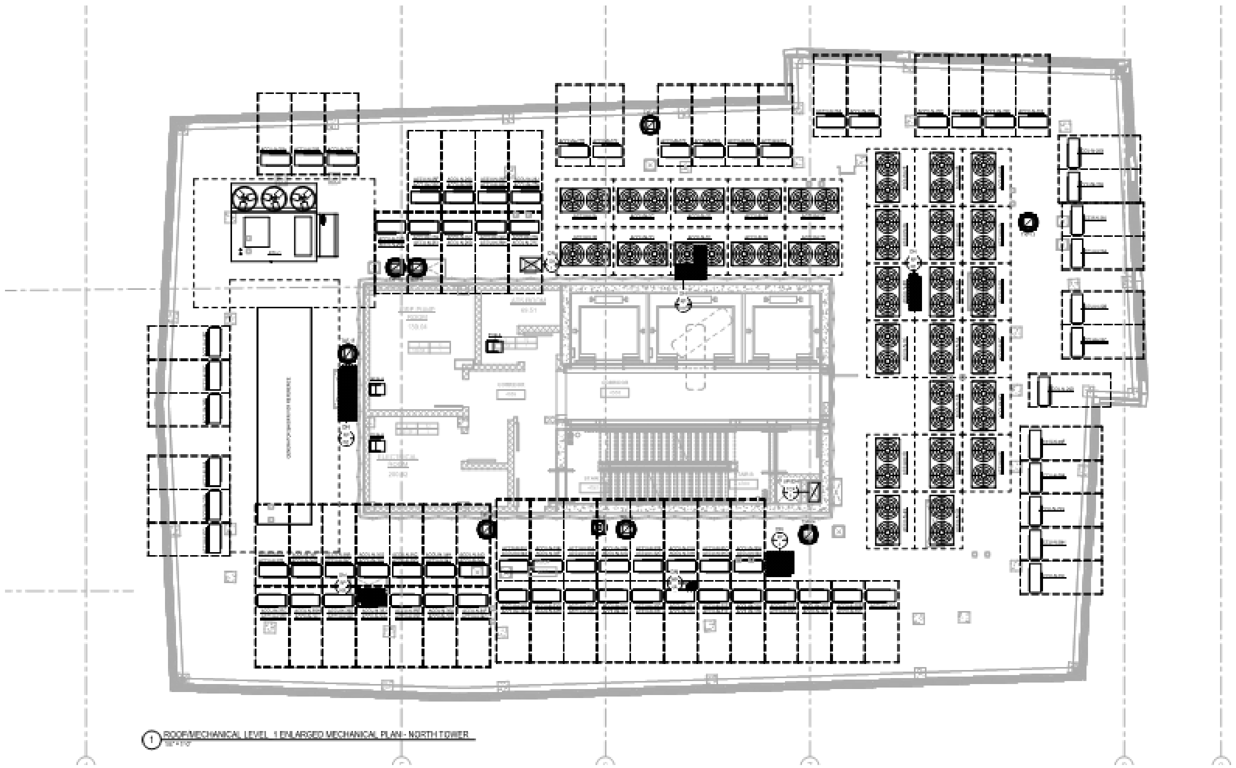
Due to acoustical code compliance the condenser farm at the lower roof needed to be relocated. This added approximately 100 feet of horizontal refrigerant run per system to the South Tower, and 200 feet of additional run to the North Tower.

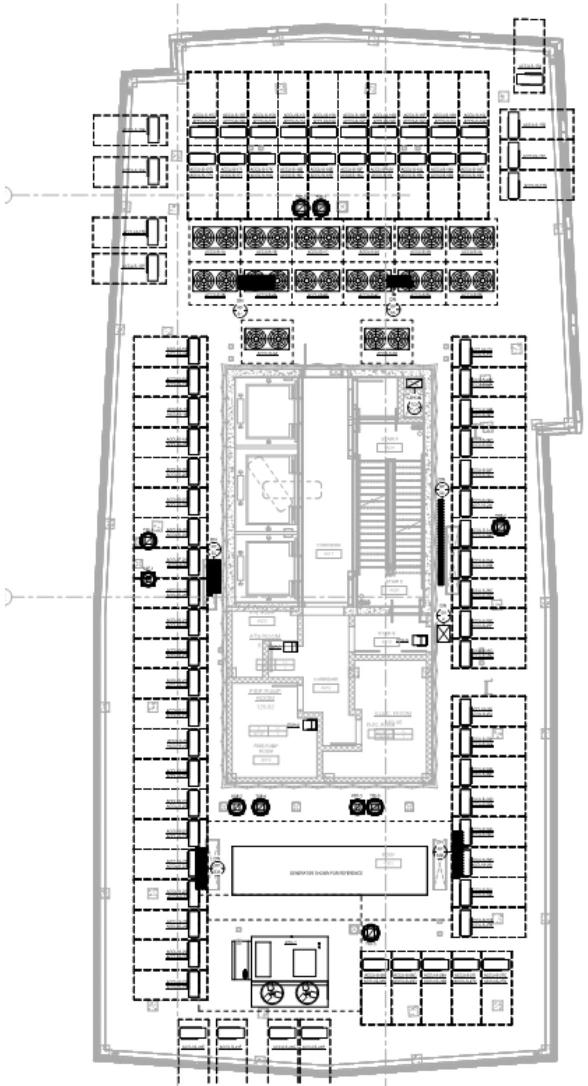



GEA

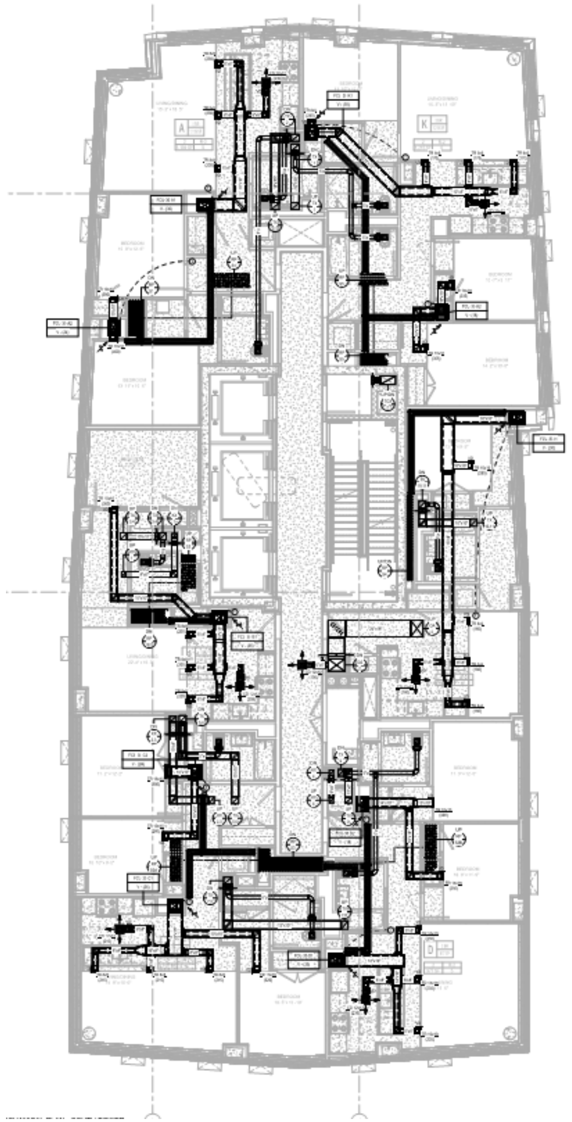
Final Design Iteration

Revised roof equipment layout based on savings from electrical and refrigerant piping routing.

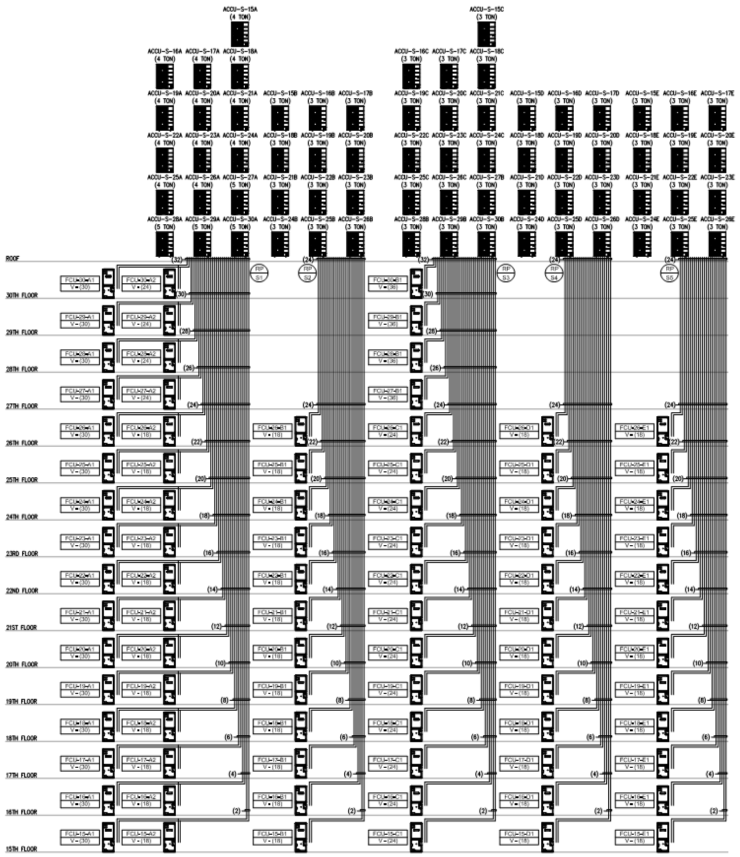


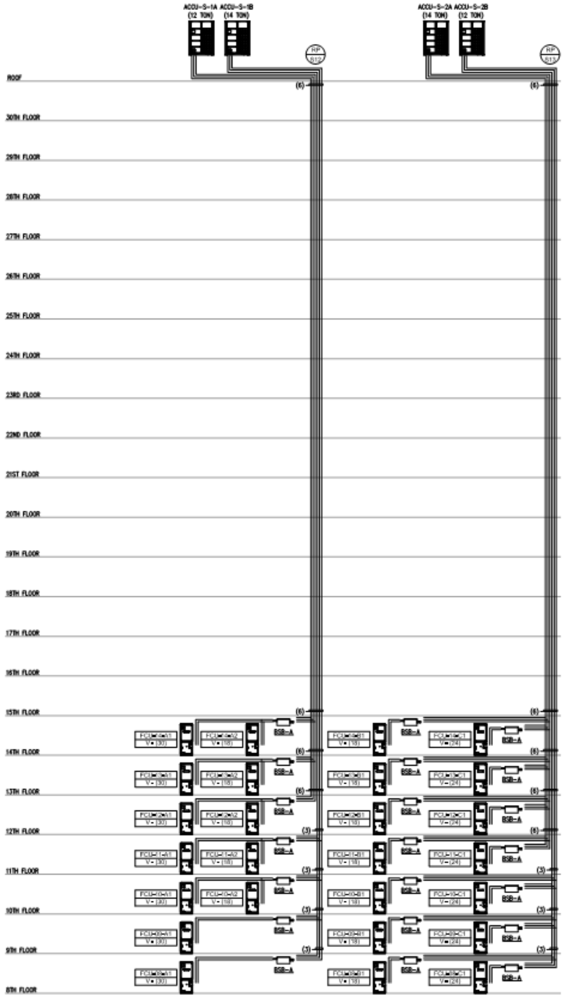


1 ROOF/MECHANICAL LEVEL 1 ENLARGED MECHANICAL PLAN - SOUTH TOWER

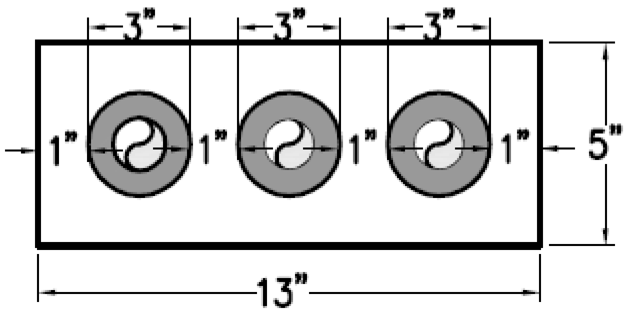


PIPING LIMITATIONS AND SHAFT SIZES





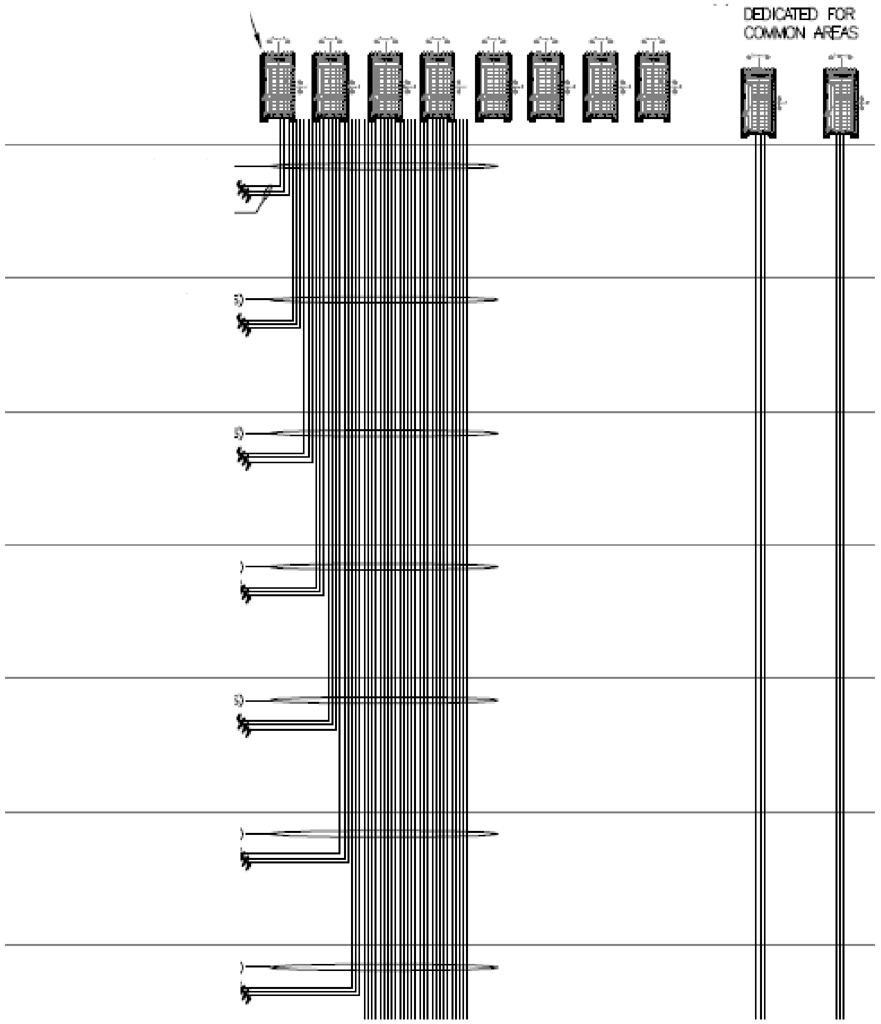
VARIABLE REFRIGERANT FLOW (VRF)



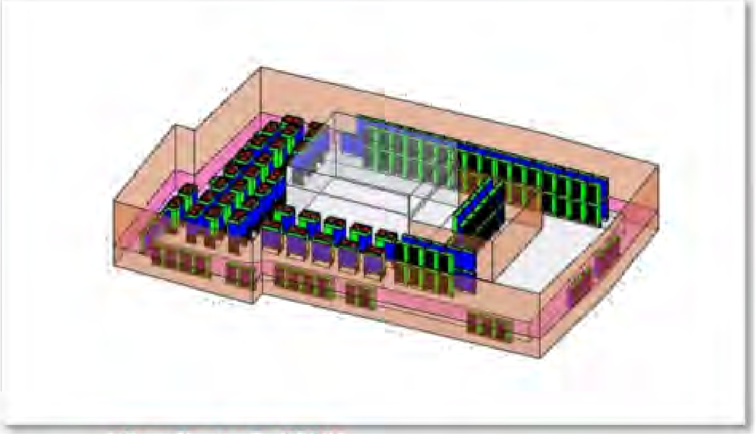
REFRIGERANT PIPING REQUIREMENTS

PER CONDENSING UNIT

Quantity of Refrigerant Pipes
60 x 3 = 180



CFD ANALYSIS



1. Purpose
 -. Review the normal operation and improvement through CFD analysis

2. PJT : CFD Analysis Report for 77 Commercial St. Brooklyn in USA

3. Product type

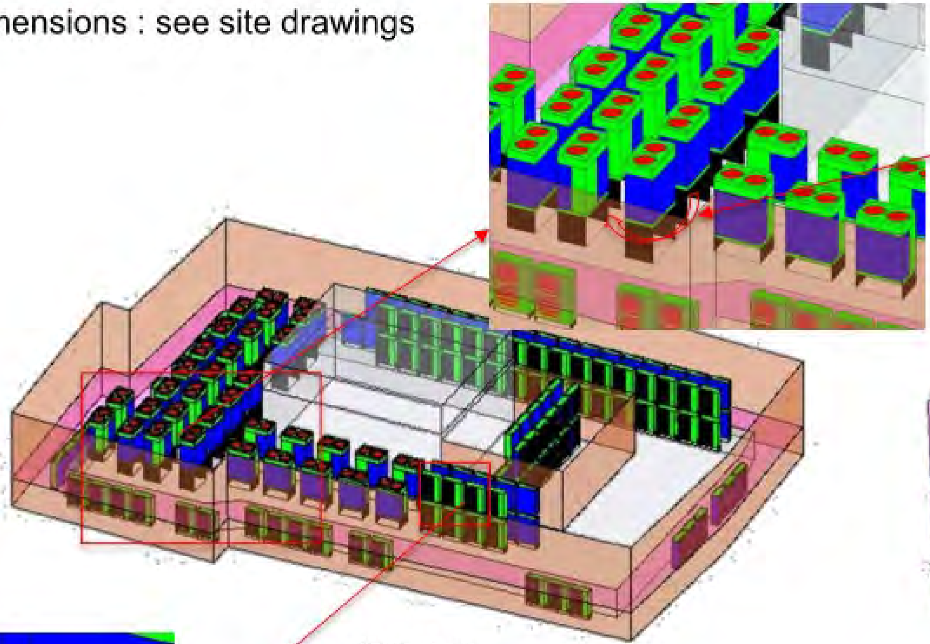
4. Analysis program
 -. Pre-Process : ANSYS R19
 -. Analysis & Post Process : ANSYS R19
 -. Viscous model : Realizable k-ε, Standard Wall Function

5. Boundary conditions
 -. Ambient temp. : 90 ˚F
 -. Operating ratio : 100%
 -. Side wall 11`- 4`` and 10`- 6``
 -. Issues : Too many ODUs are installed on the rooftop

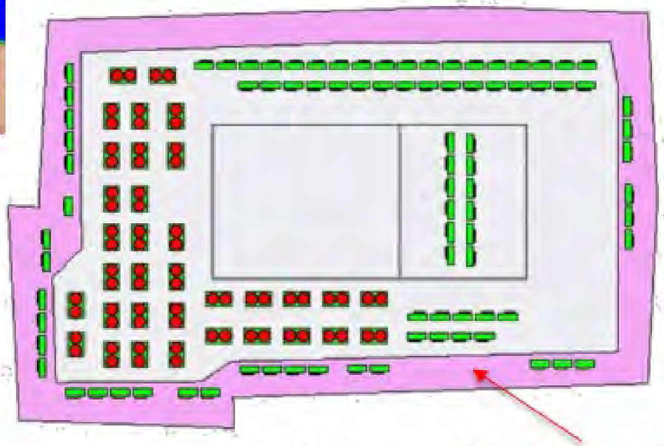
6. Analysis cases
 -. As drawings

3D Modeling

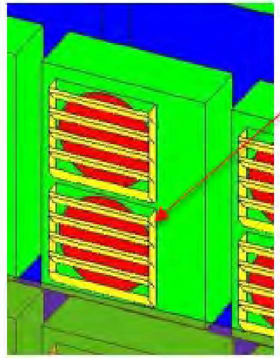
-. Dimensions : see site drawings



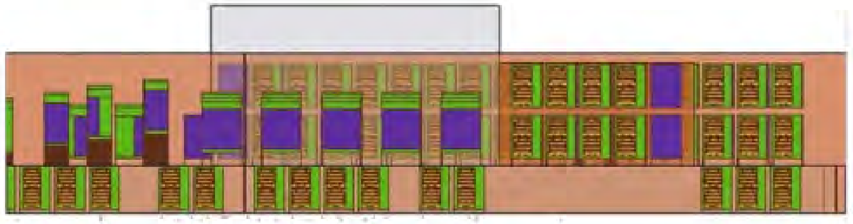
ISO view



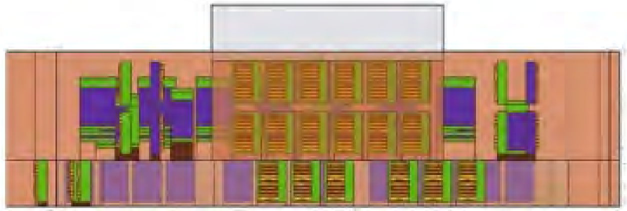
Top view



Discharge air-guide



Front view



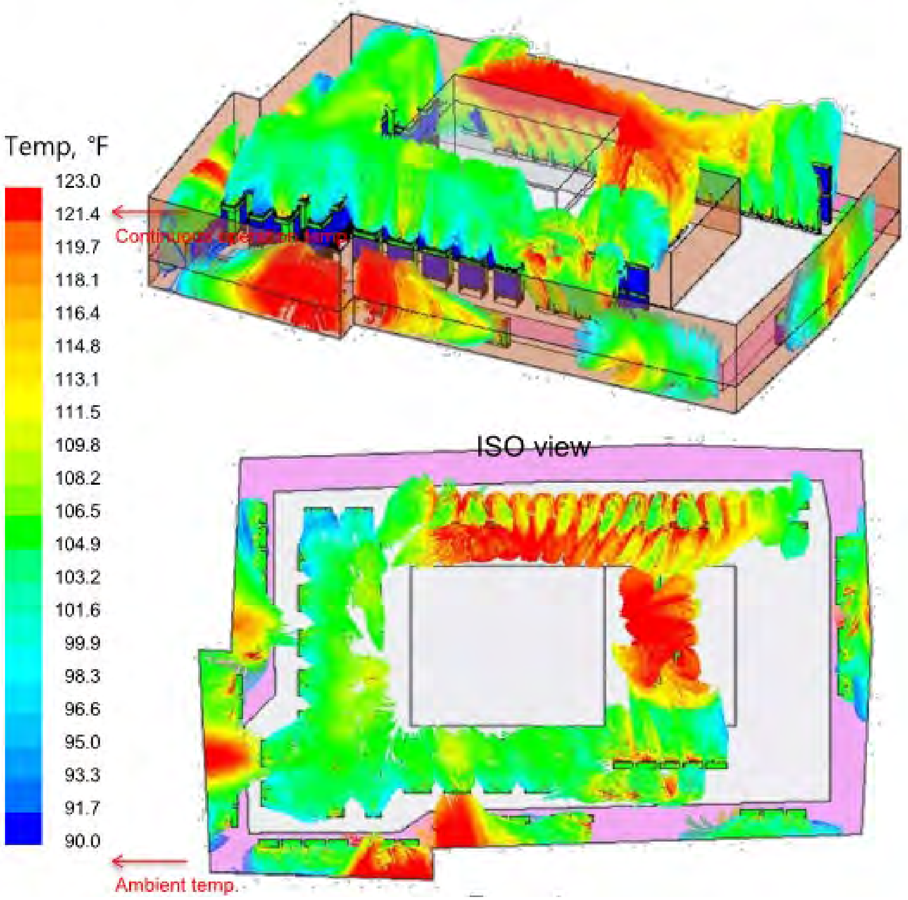
Side view

Result

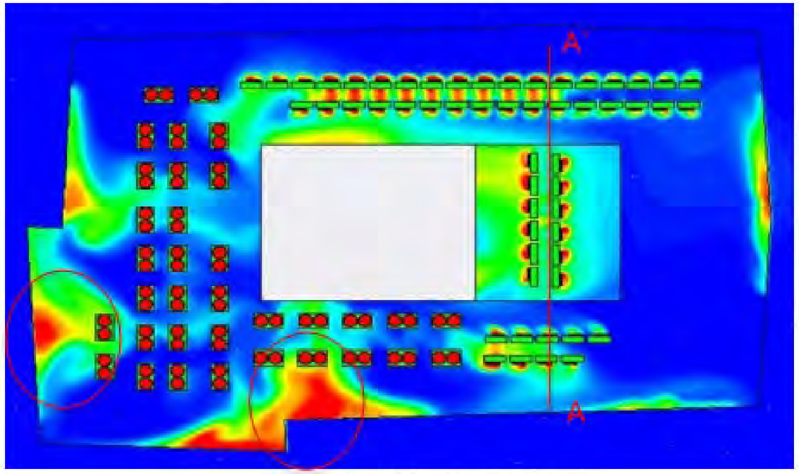
-. Ambient temp. : Cooling 90 °F, Operating ratio : 100%

- -Suction the units in the upper floor where the air from the units in the lower floor is exhausted.

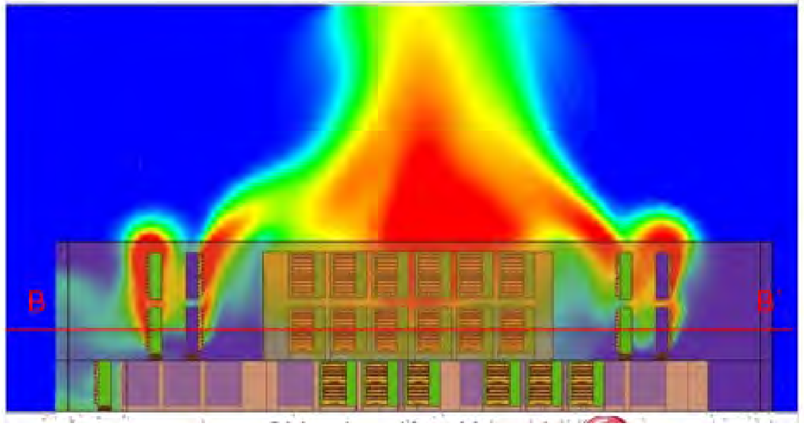
-. Max inlet air temp. of heat exchanger is 131 °F (Cooling operating range : 5-122 °F) - It would be in out of operation range.



ISO view



Top view (B – B` section)



CONCLUSION

1. SYSTEM SELECTION IS CRUCIAL
   - HEAT PUMP VS HEAT RECOVERY
   - MANUFACTURER
2. LOCATION OF CONDENSING UNITS
   - ACOUSTICS
   - LENGTH/DISTANCE OF PIPING
   - METERING CONSIDERATIONS
3. REFRIGERATION PIPING MANAGEMENT
4. SUPPORT OF CONDENSING UNITS
5. SPACING AND AIRFLOW AROUND CONDENSING UNITS

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THANK YOU!

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Air-to-Water Heat Pumps for Large Commercial Buildings

Ari Greenberg, PE
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617. 925.8298

BR+A Today

500+ | 10
Dedicated company staff | offices nationwide

47
Years in business

76
Employee Shareholders

1
Ranked No. 1 Commercial Net Zero Engineer in MA

3
Core markets: research, higher education, & healthcare

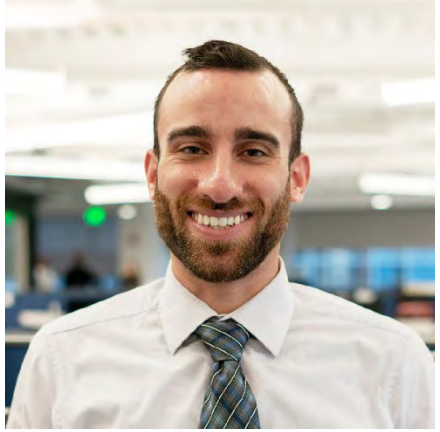
17
Ranked 17th Largest *Consulting-Specifying Engineer MEP Giants 2021*

100+
Certified sustainable projects, including LEED Platinum, Gold + Zero Net Energy Certified

16M+
Square feet of Net Zero Energy project experience, built and currently in design

AGENDA

1. Air-to-water basics
2. Equipment configurations
3. Temperature, capacity, and efficiency (COP)
4. Large building applications



ARI GREENBERG
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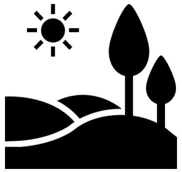
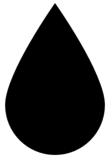
HEAT PUMPS MOVE HEAT

HEAT PUMPS MOVE HEAT

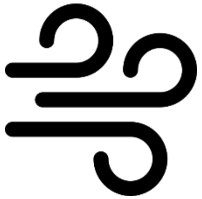
SOURCE



GROUND

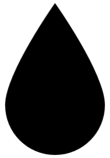


WATER

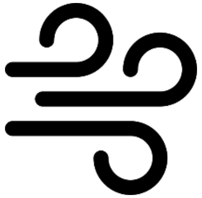


AIR

SINK

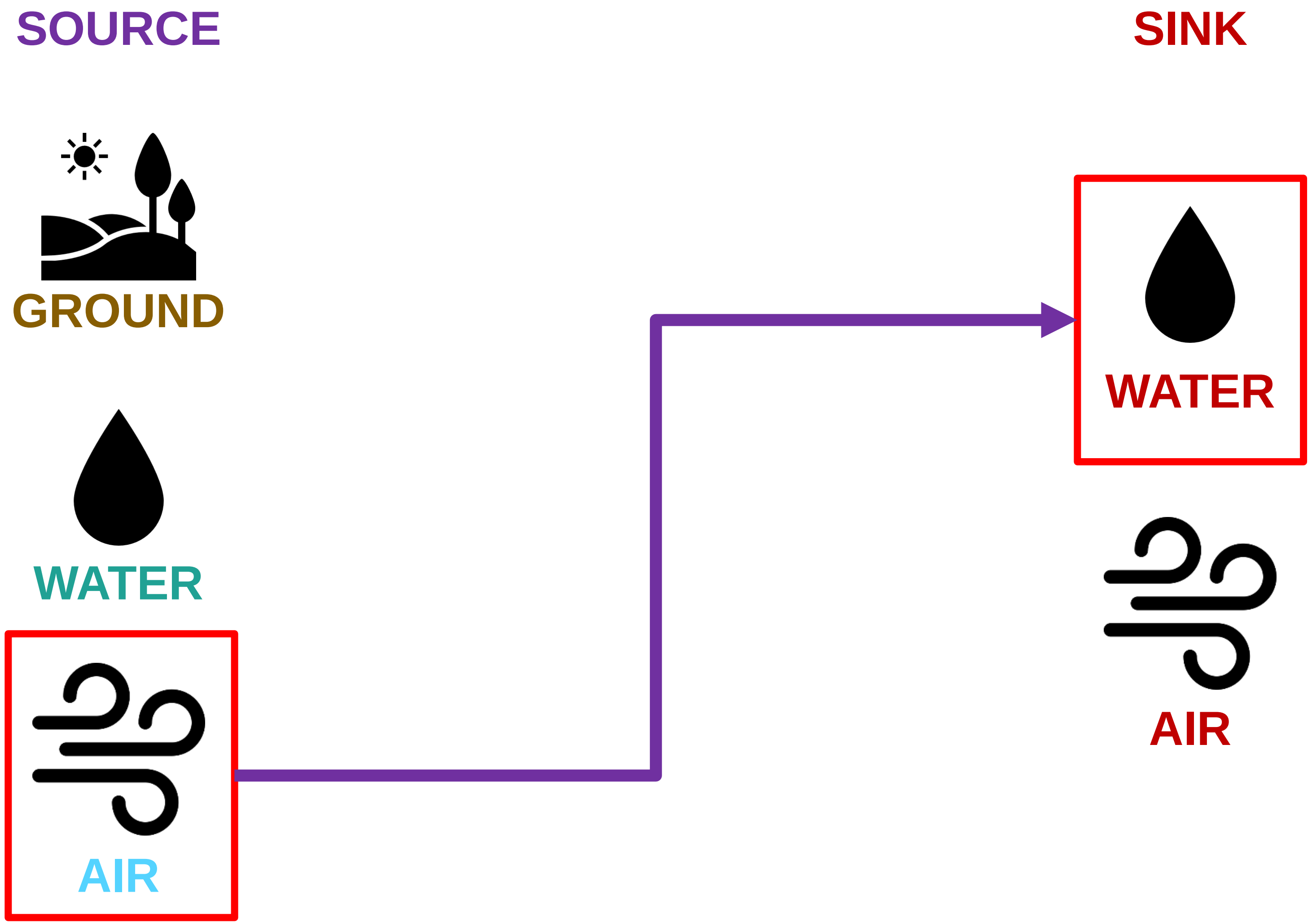


WATER



AIR

HEAT PUMPS MOVE HEAT



AIR TO WATER HEAT PUMPS

Modular

Unitary / Packaged

2-PIPE OR NOT 2-PIPE

2-Pipe

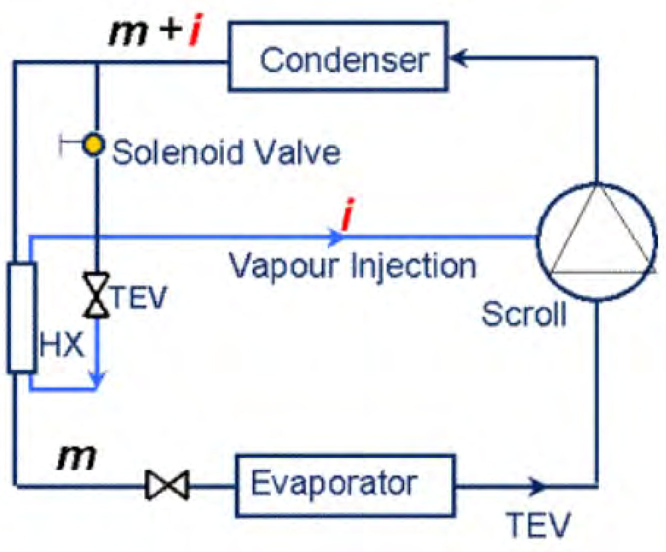
HW or CHW

4-Pipe

HW and CHW

COMPRESSORS

- Positive displacement
- Standard vs. low ambient (vapor injection)
- Fixed vs. variable speed (inverter)
- Multiple compressors / circuits
- R410A… for now

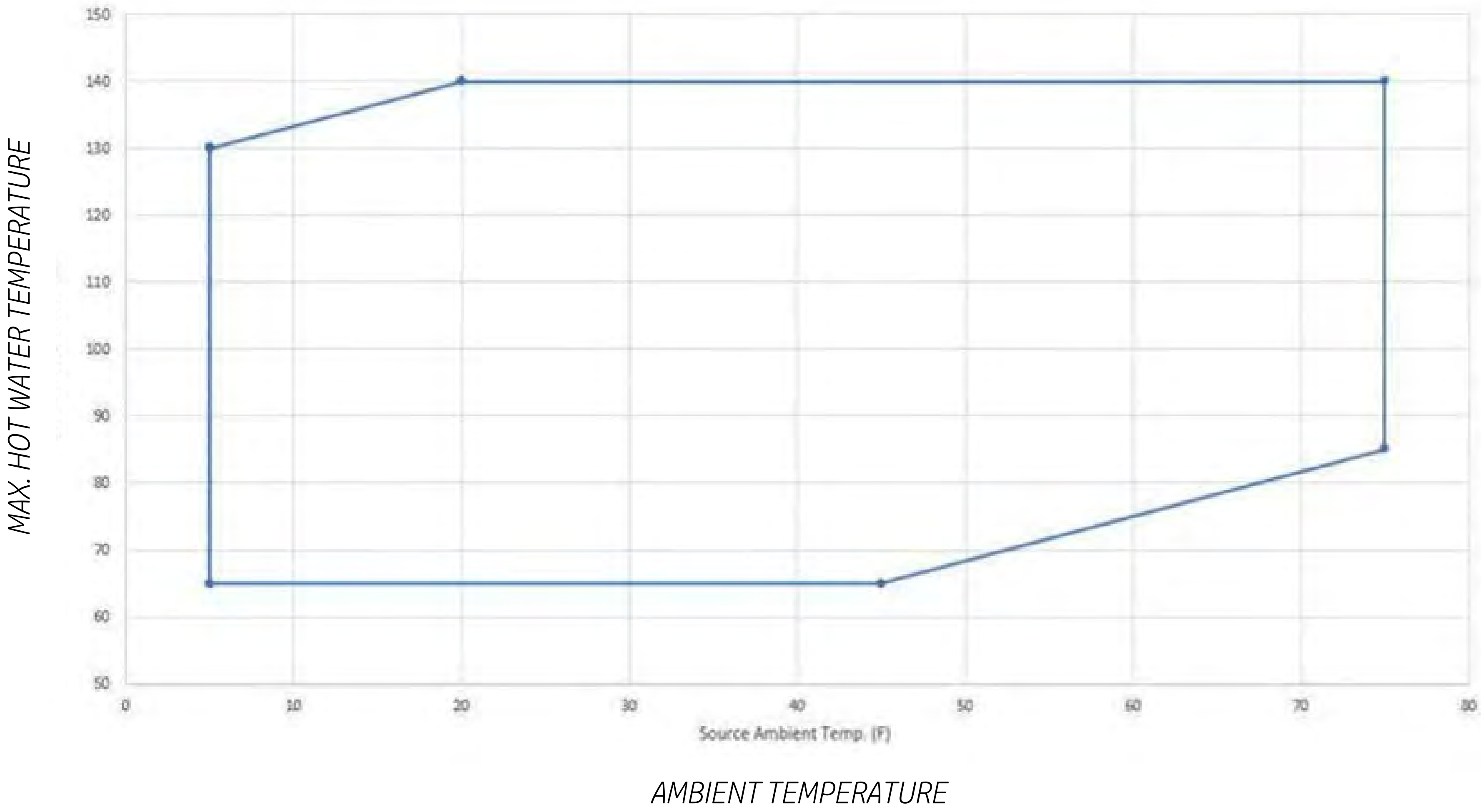


TEMPERATURE, CAPACITY, EFFICIENCY (COP)

↓ Ambient temperature ↓ COP ↓ CAPACITY

Load	Heating (MBH)	Input kW	Heating COP	Ambient °F
100%	1863	311.5	1.750	0.0000
100%	2111	318.1	1.940	10.00
100%	2387	324.5	2.160	20.00
100%	2682	330.6	2.380	30.00
100%	3008	336.6	2.620	40.00
100%	3399	343.2	2.900	50.00
100%	3738	348.9	3.140	60.00
100%	4166	355.5	3.430	70.00
100%	4832	365.1	3.880	80.00

TEMPERATURE, CAPACITY, EFFICIENCY (COP)



TEMPERATURE, CAPACITY, EFFICIENCY (COP)

Hot Water Temperature

COP

Heating Mode Performance

Ambient Temp (°F)	**HW Supply Temp** (°F)	**Output Capacity** MBH	**Efficiency** COP
-10	170	355	1.85
0	**170**	**450**	**1.87**
10	170	450	2.02
30	170	450	2.2
50	170	450	2.27
-10	145	338	1.87
0	**145**	**400**	**2**
10	145	400	2.11
30	145	400	2.39
50	145	400	2.75
-10	120	292	2.3
0	**120**	**364**	**2.31**
10	120	364	2.62
30	120	364	2.99
50	120	364	3.28
-10	100	275	2.41
0	**100**	**339**	**2.56**
10	100	339	2.88
30	100	339	3.37
50	100	339	3.67

DESIGNING FOR LOW TEMP HOT WATER

Coil Selection

Water-to-Water Booster

JACK OF ALL TRADES, MASTER OF NONE

30 Ton Modular

COOLING PERFORMANCE DATA									
Load	Capacity (tons)	Input kW	kW/Ton	EER	COP	Load Flow (GPM)	Load Leaving °F	ΔP (ft H2O)	Ambient °F
100%	243.0	311.4	1.282	9.362	2.740	612.2	39.00	13.50	95.00
75%	182.2	178.3	0.9788	12.26	3.590	612.2	39.00	13.50	80.00
50%	121.5	90.71	0.7468	16.07	4.710	612.2	39.00	13.50	65.00
25%	60.74	42.79	0.7045	17.03	4.990	612.2	39.00	13.50	55.00

		kW/Ton	EER (Btu/Wh)	COP (kW/kW)
With Ambient Relief (per AHRI 550/590)	NPLV.IP	0.8265	14.52	4.259

IECC 2021

EQUIPMENT TYPE	SIZE CATEGORY	UNITS	PATH A	PATH B	TEST PROCEDURE[c]
Air cooled chillers	< 150 tons	EER (Btu/Wh)	≥ 10.100 FL	≥ 9.700 FL	AHRI 550/590
			≥ 13.700 IPLV.IP	≥ 15.800 IPLV.IP	
	≥ 150 tons		≥ 10.100 FL	≥ 9.700FL	
			≥ 14.000 IPLV.IP	≥ 16.100 IPLV.IP	

JACK OF ALL TRADES, MASTER OF NONE

30 Ton Modular

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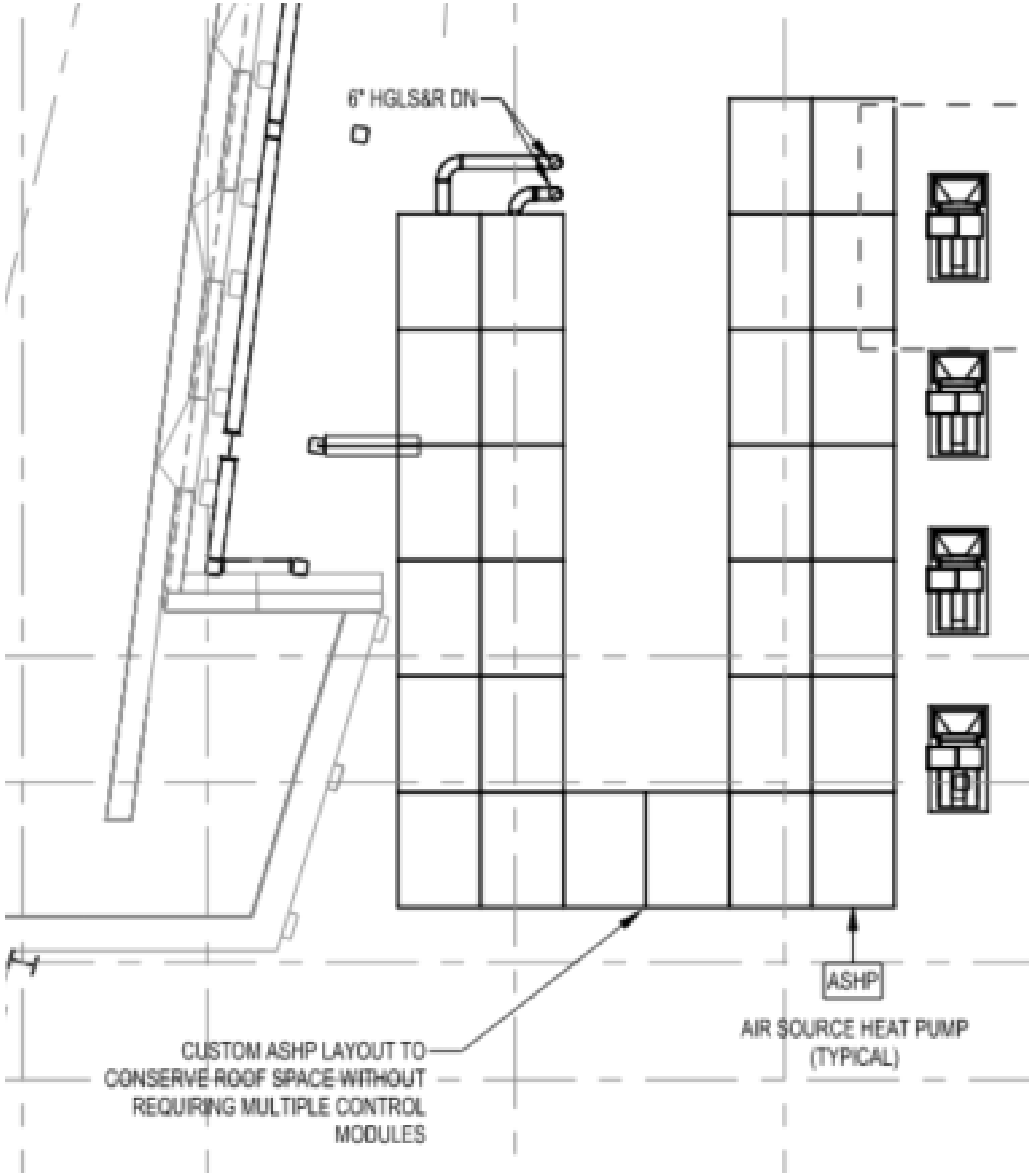
	≥ 150 tons		≥ 10.100 FL	≥ 9.700FL	
			≥ 14.000 IPLV.IP	≥ 16.100 IPLV.IP	

DEFROST

- Capacity and efficiency de-rate
  - Not all manufacturers account for it in ratings
  - Defrost typically not coincident with peak heating in cold climates
- Compressors per circuit
- Buffer tanks and system volume provide stability
- Drainage

LAYOUT + LOCATION

- Avoid cold re-entrainment
  - Proximity to walls/screens
  - Dunnage
  - Overhead obstructions
  - Ducted discharge?
- Noise
  - Fan attenuation
  - Compressor insulation
- Drainage



DESIGN CONSIDERATIONS

1. Sizing/Capacity
2. Back-up boilers?
3. Glycol
4. Pumps
5. Buffer tanks

OPERATIONAL CONSIDERATIONS

- Equipment life
- Maintenance
- Cost
- Outdoor location

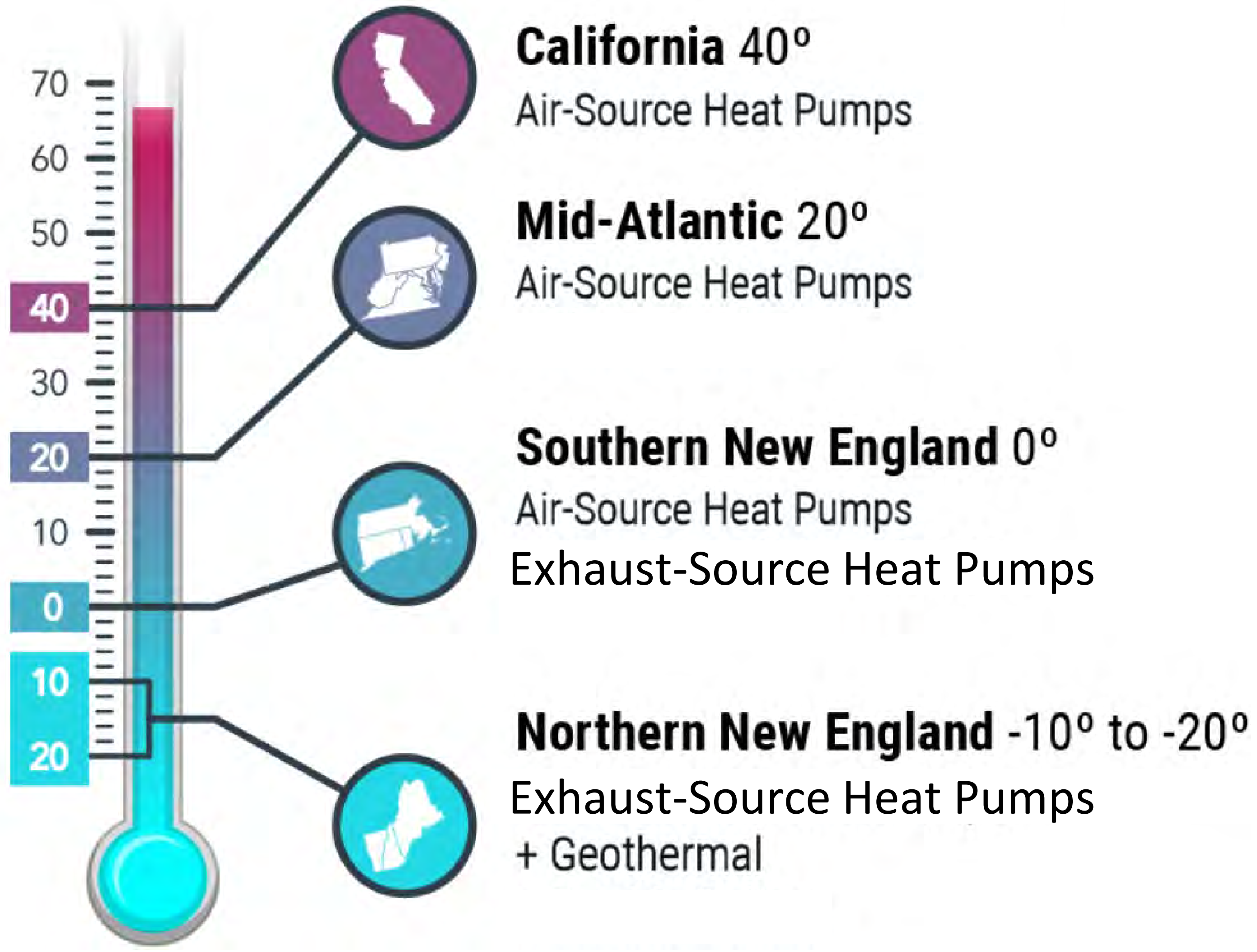
BUILDING EFFICIENCY

- Step 1: make your building energy efficient
- Step 2: reduce hot water temperature
- Step 3: simultaneous heating and cooling
- **Step 4: air-source heat pump**

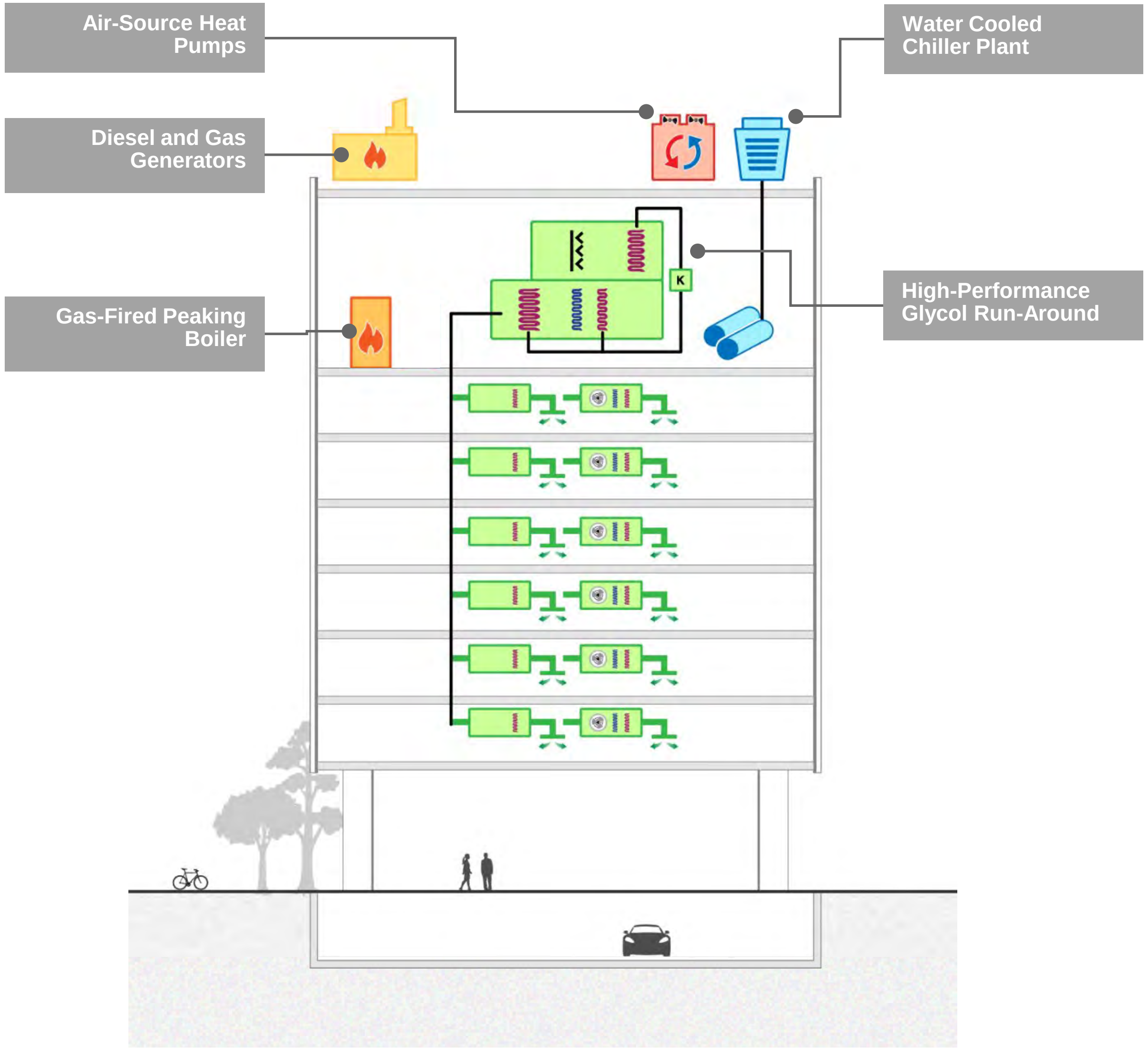
APPLICATIONS

- 2-pipe and 4-pipe hydronic
- Hybrid / mixed-fuel
- Tempered water-source loop
- Geothermal heat balance
- Cascading systems

ELECTRIFYING LARGE BUILDINGS

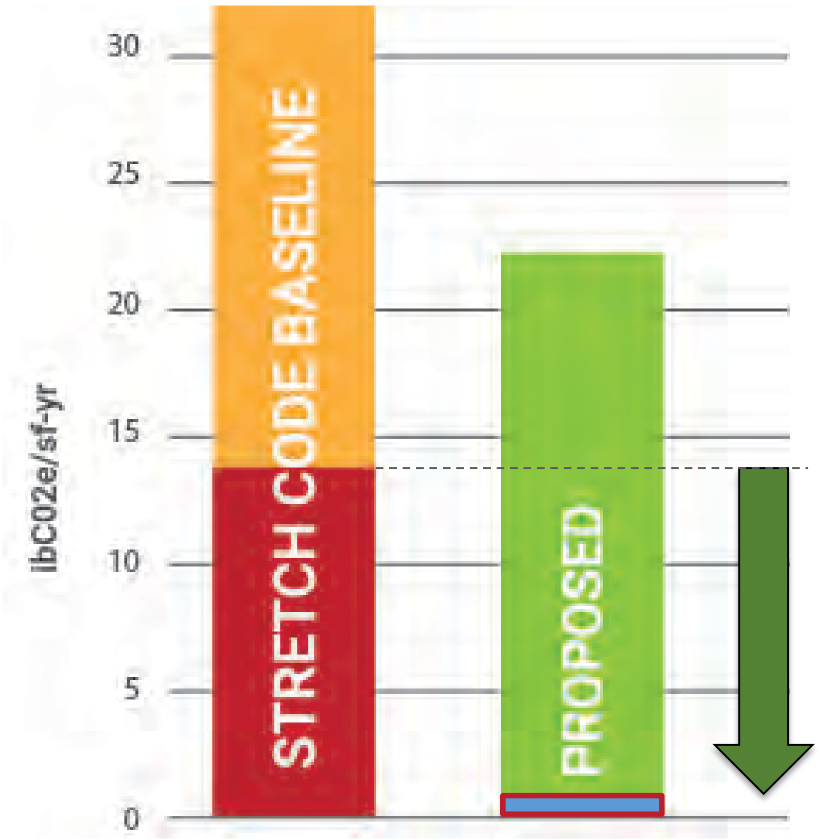


HYBRID SYSTEMS



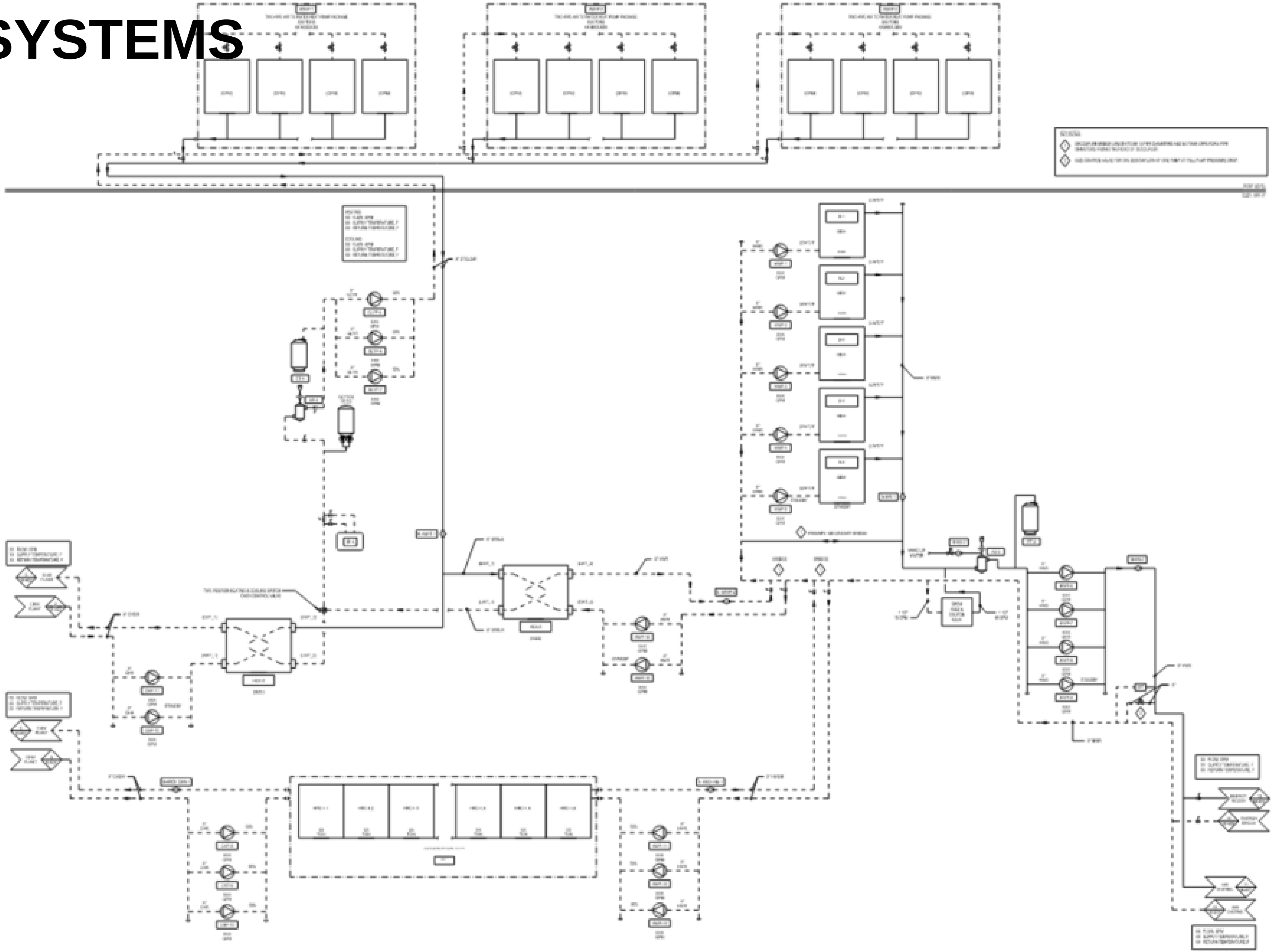
HYBRID SYSTEMS

Air to Water Heat Pumps



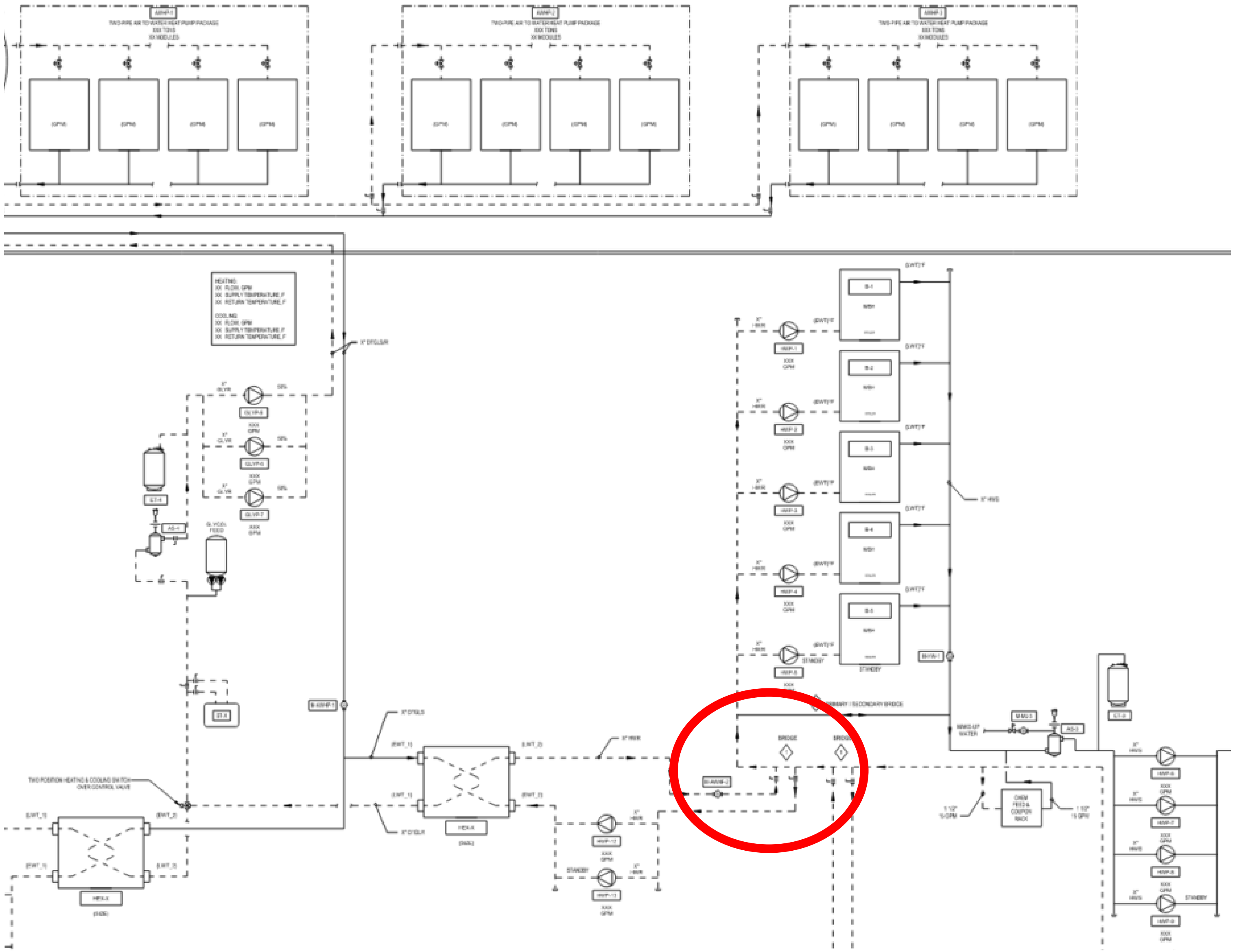
93% Fossil Fuel Reduction

HYBRID SYSTEMS



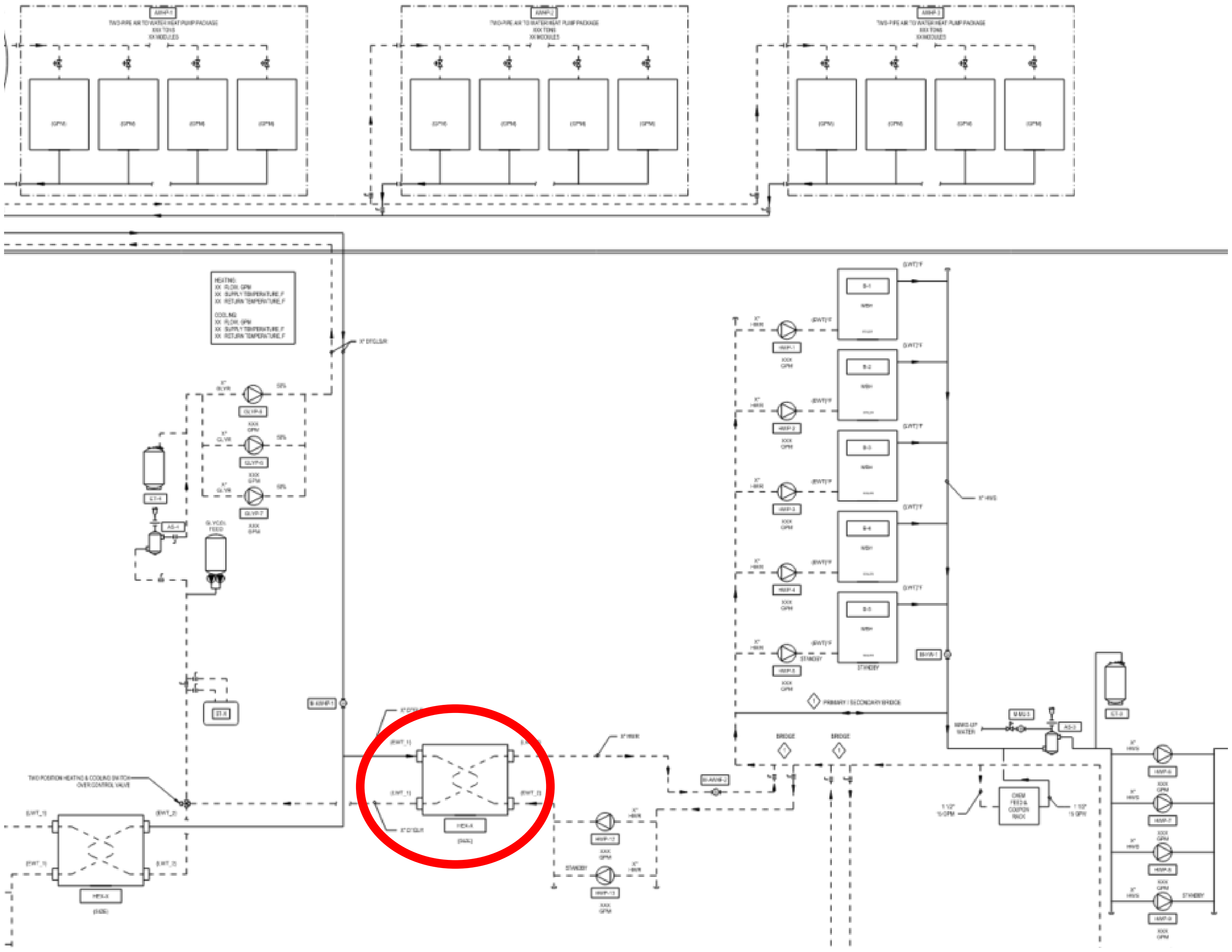
HYBRID SYSTEM

- Sidecar pumping
- Hydraulic separation
- Buffer tank
- Cooling mode



HYBRID SYSTEM

- Sidecar pumping
- **Hydraulic separation**
- Buffer tank
- Cooling mode



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- Sidecar pumping
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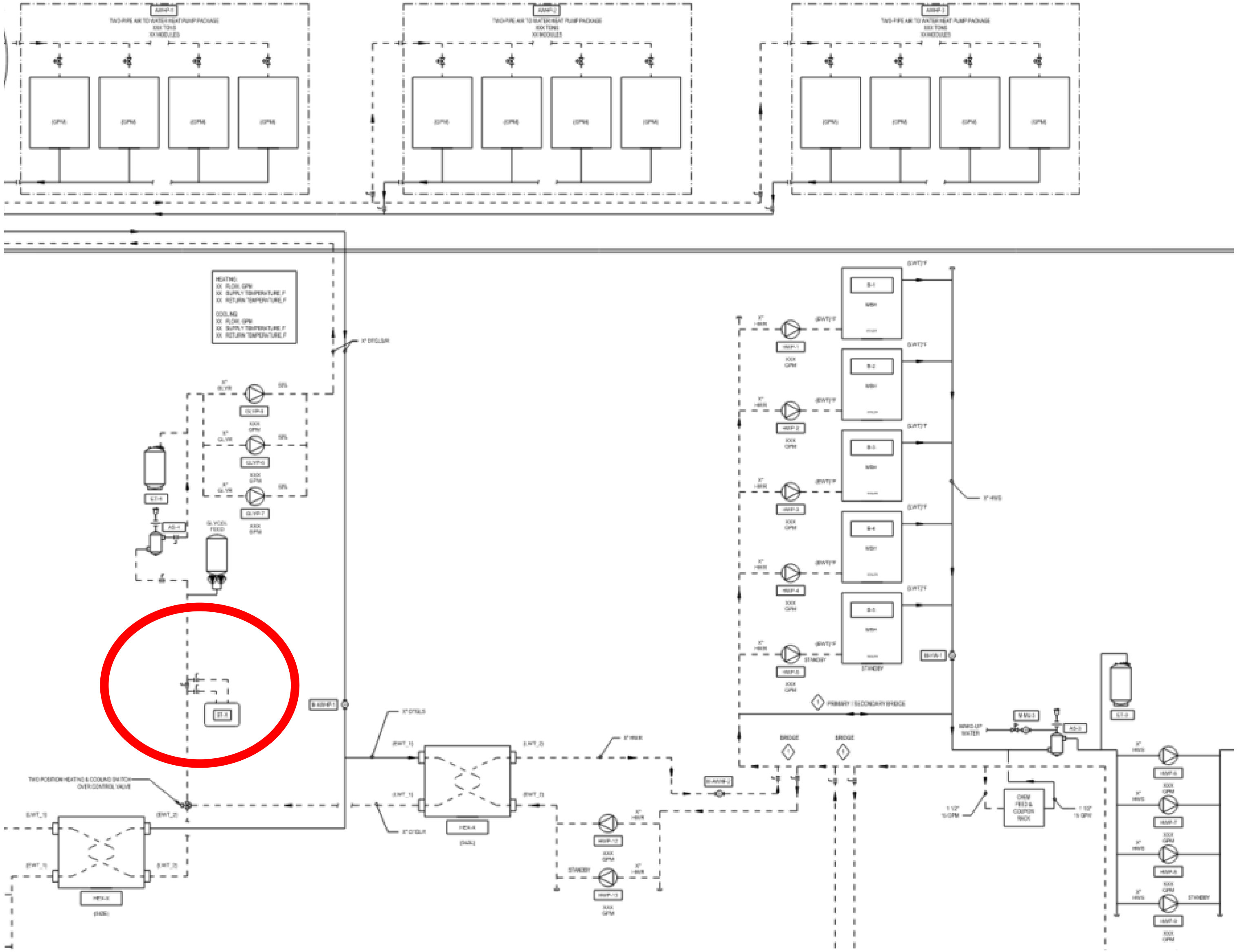

HYBRID SYSTEM

- Sidecar pumping
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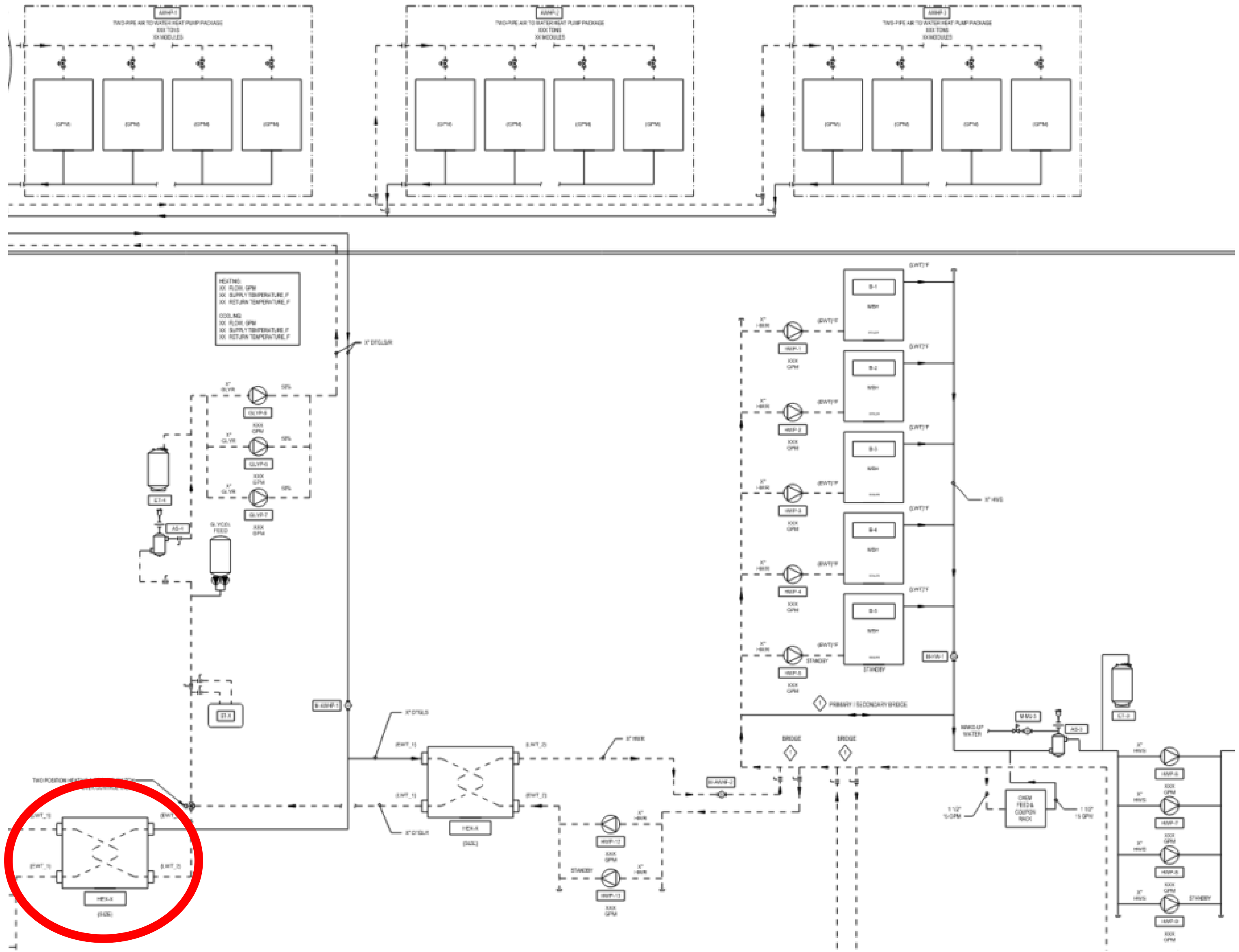
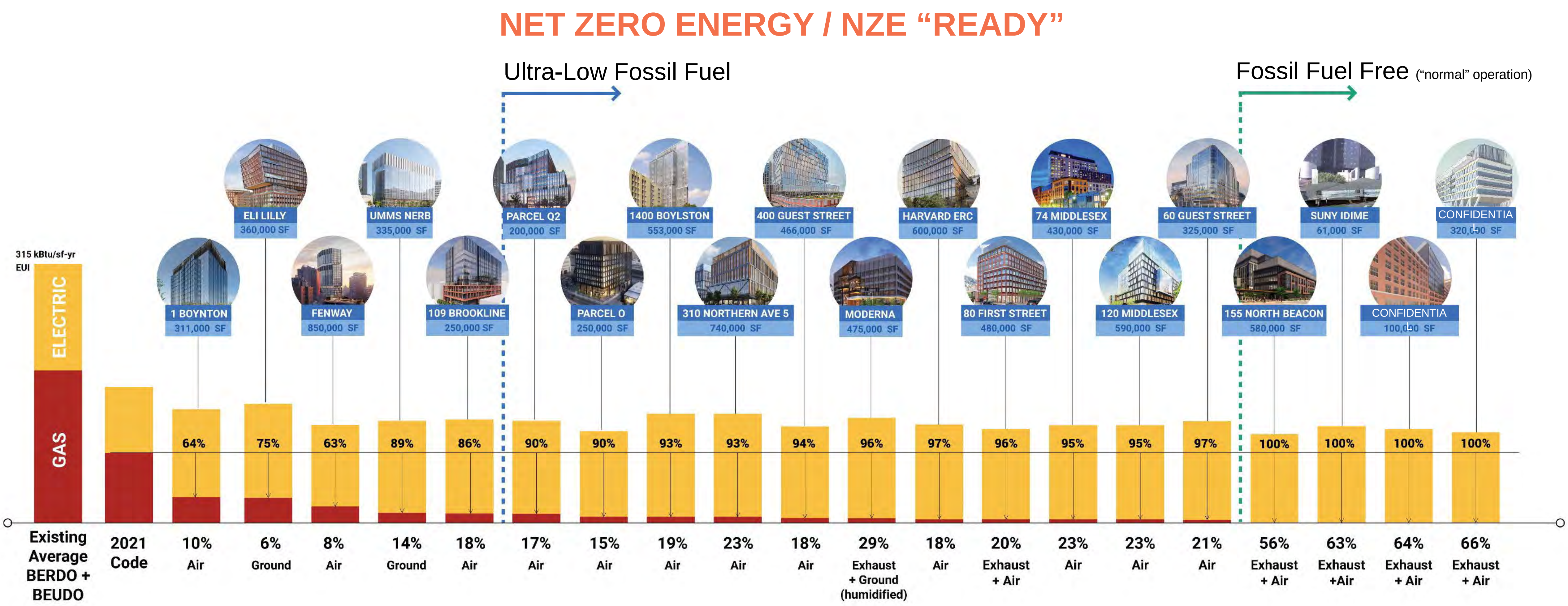
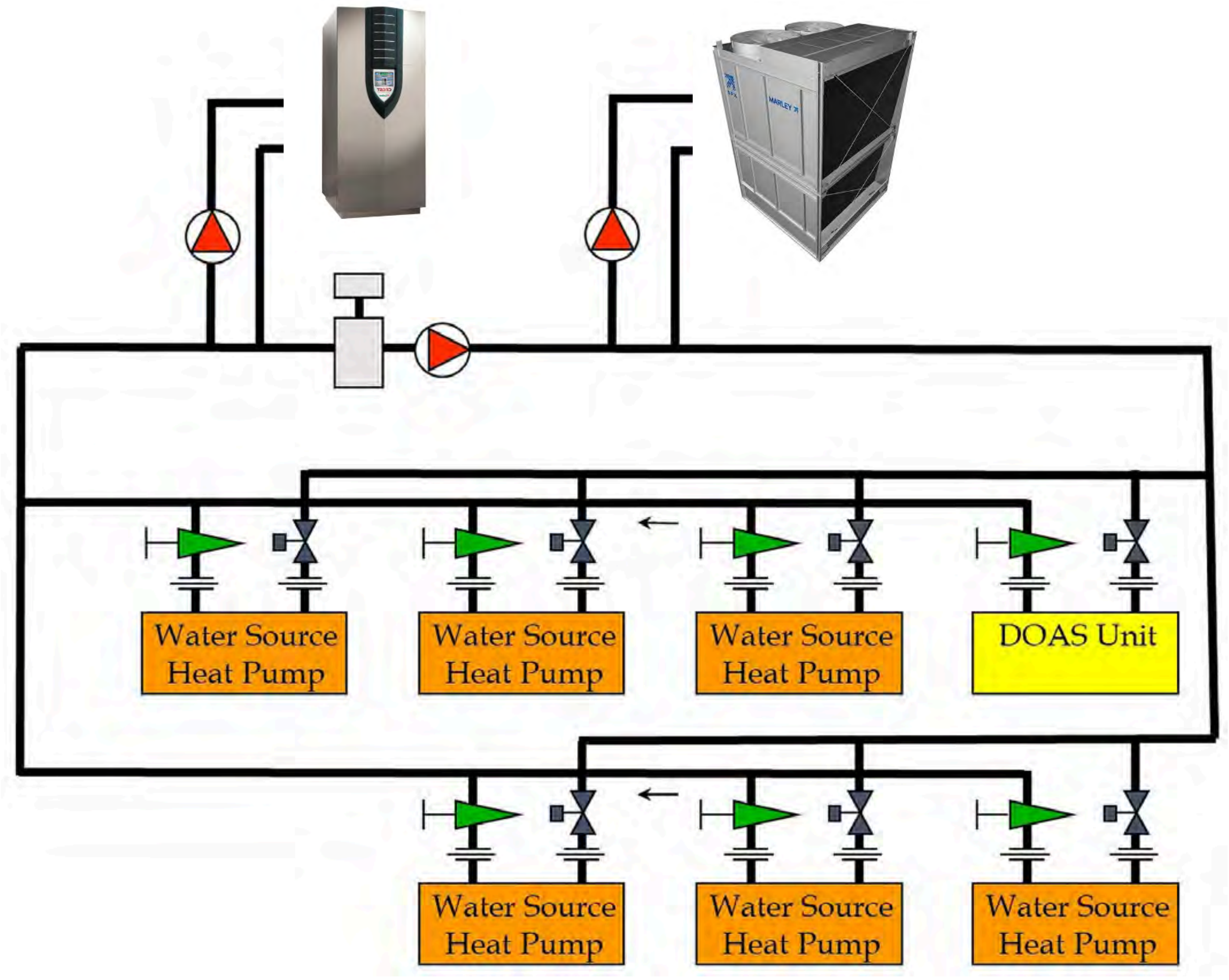
- Buffer tank
- **Cooling mode**



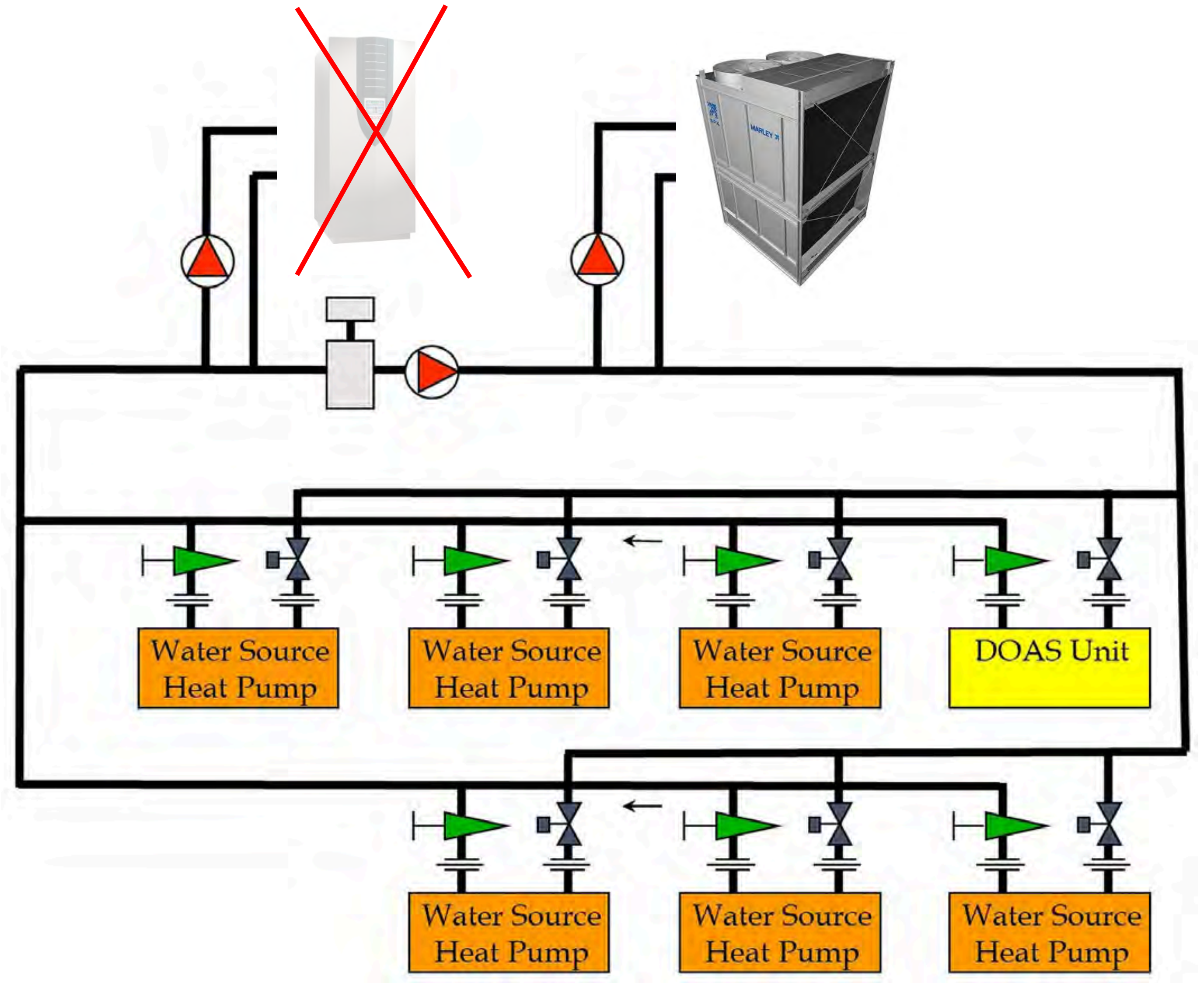
HYBRID SYSTEMS - LABS



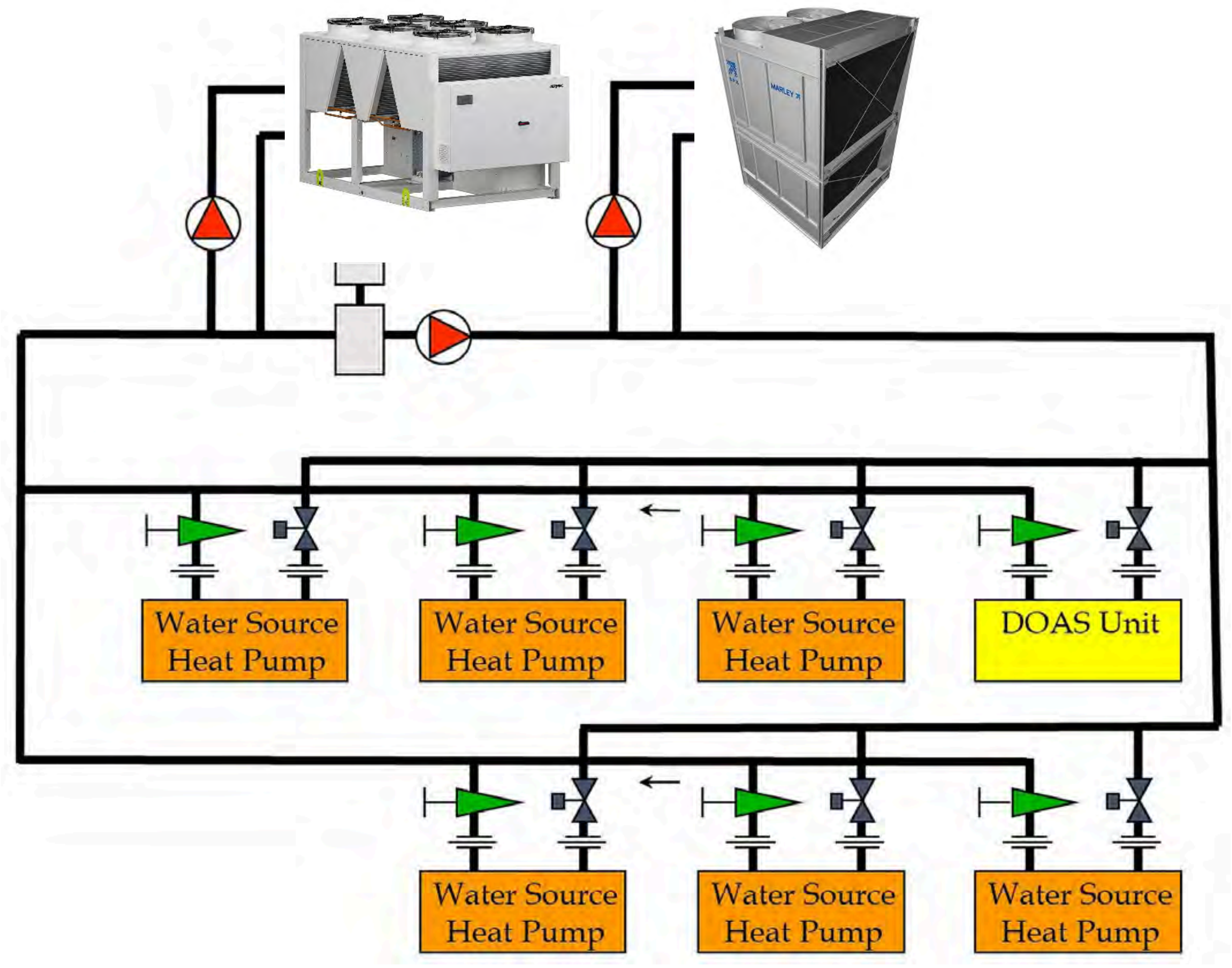
WATER-SOURCE HEAT PUMPS



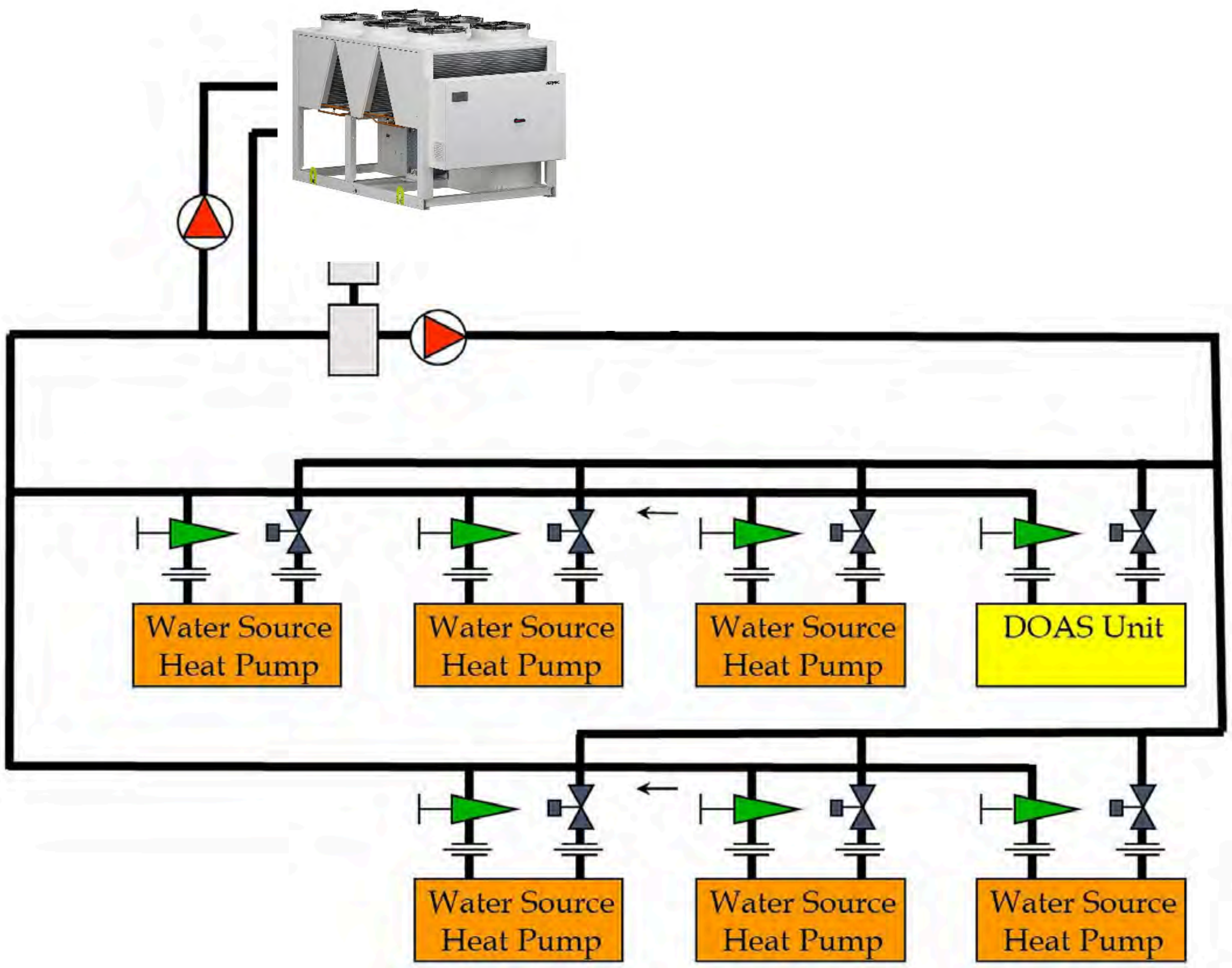
WATER-SOURCE HEAT PUMPS



WATER-SOURCE HEAT PUMPS

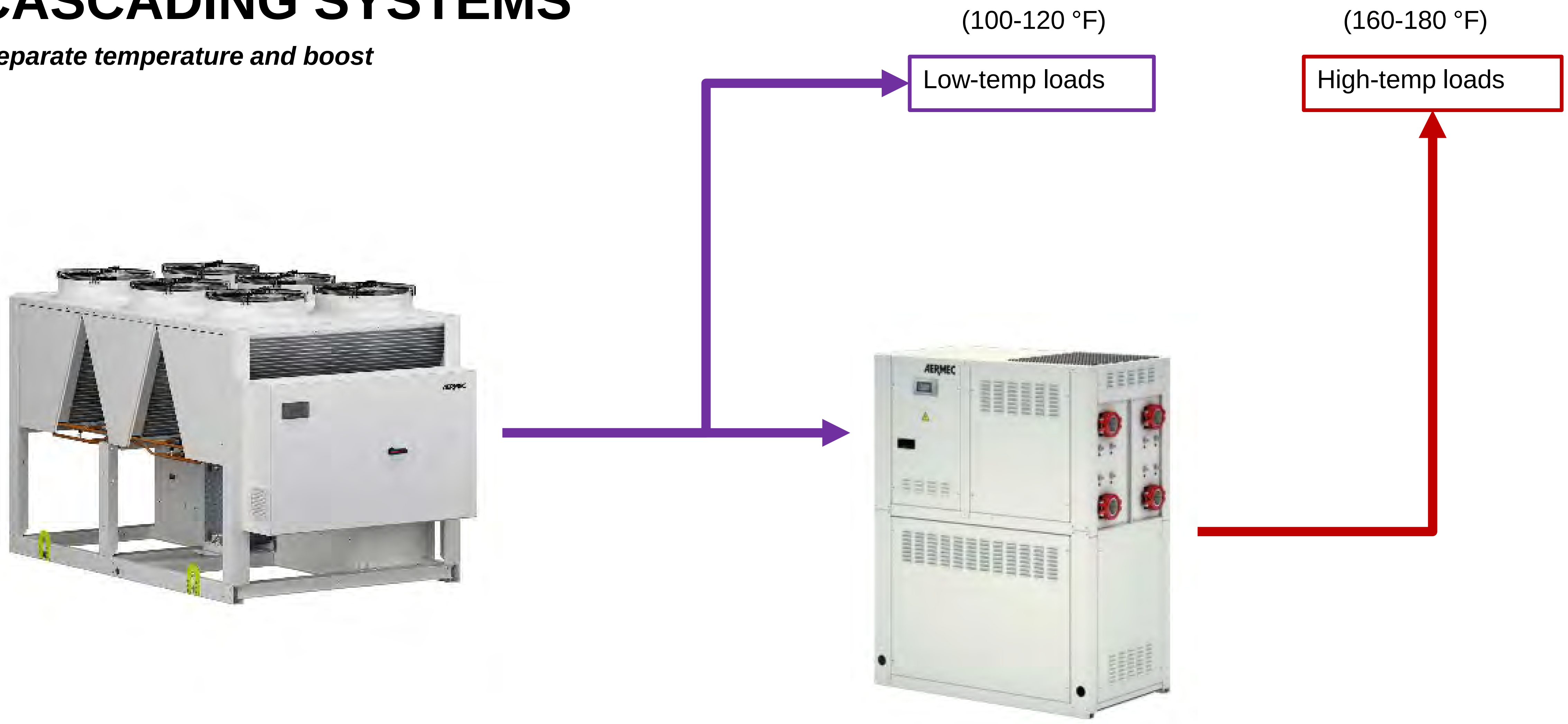


WATER-SOURCE HEAT PUMPS



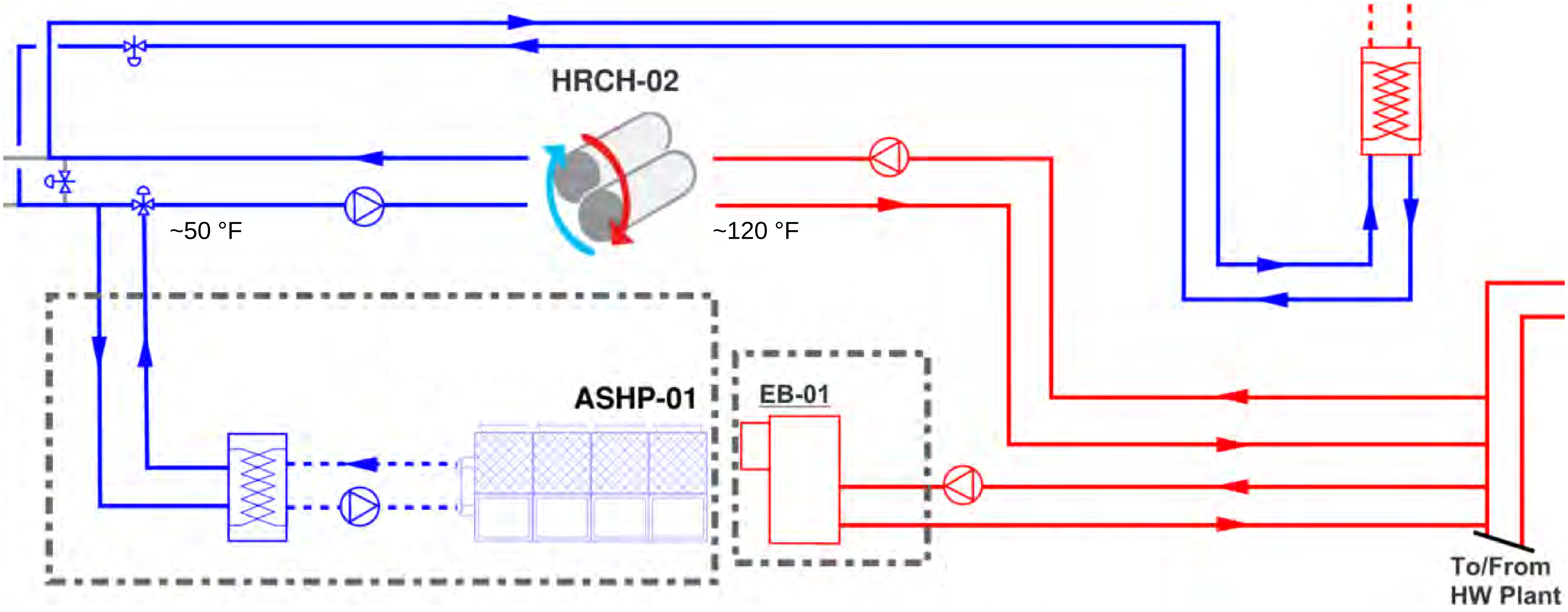
CASCADING SYSTEMS

Separate temperature and boost

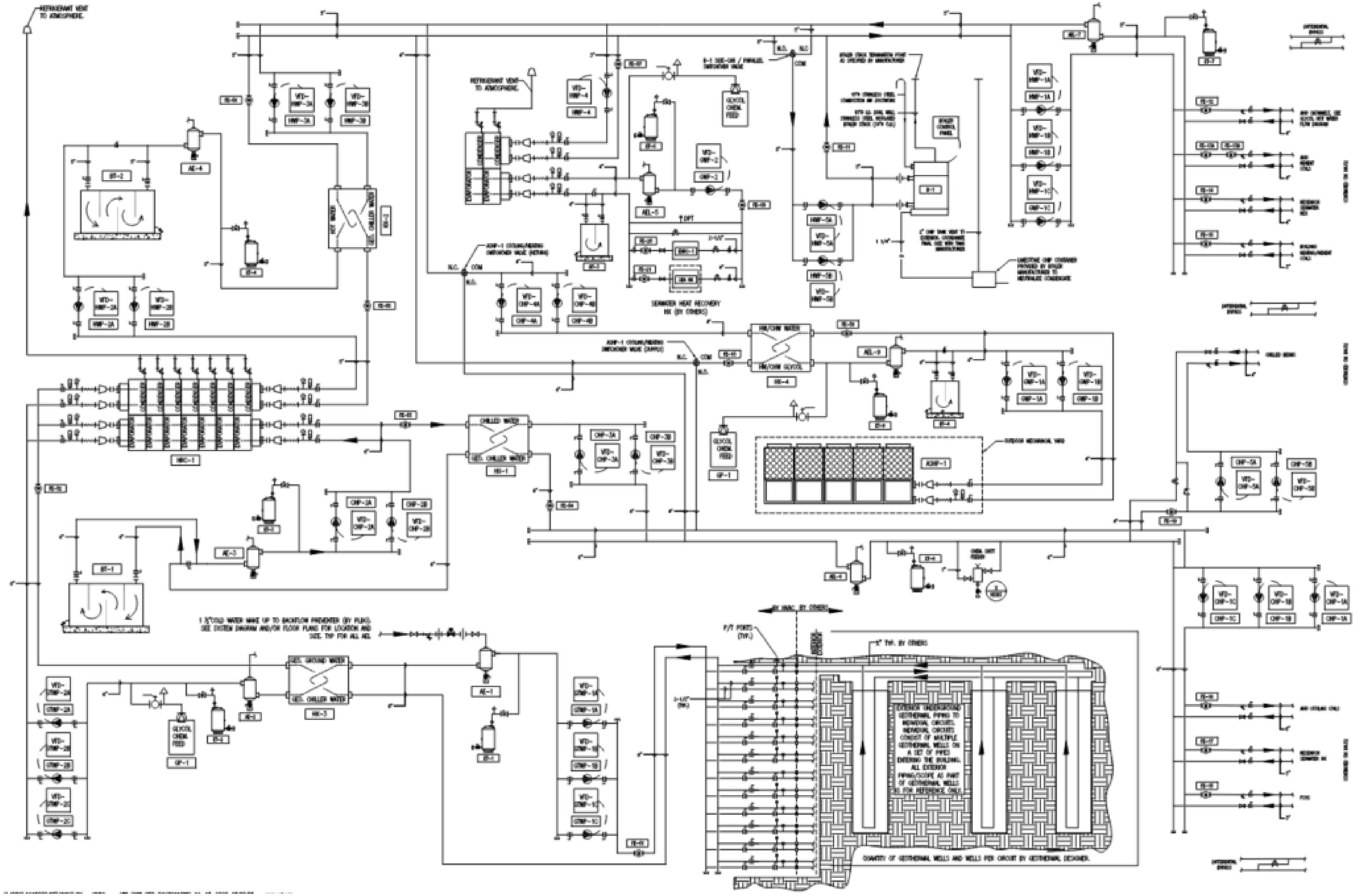


CASCADING SYSTEMS

Low-temperature heat injection



GEOTHERMAL HEAT BALANCE



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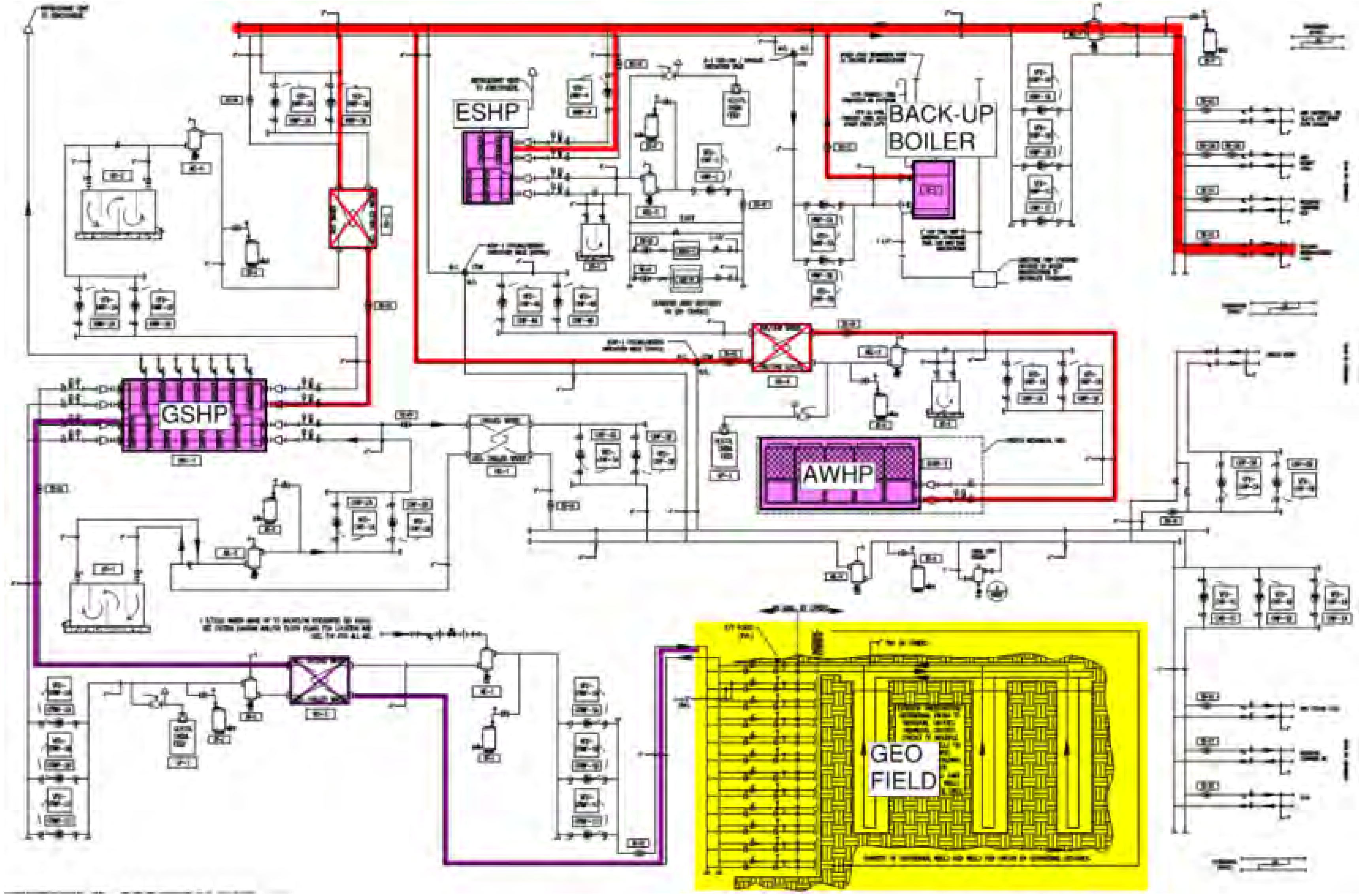

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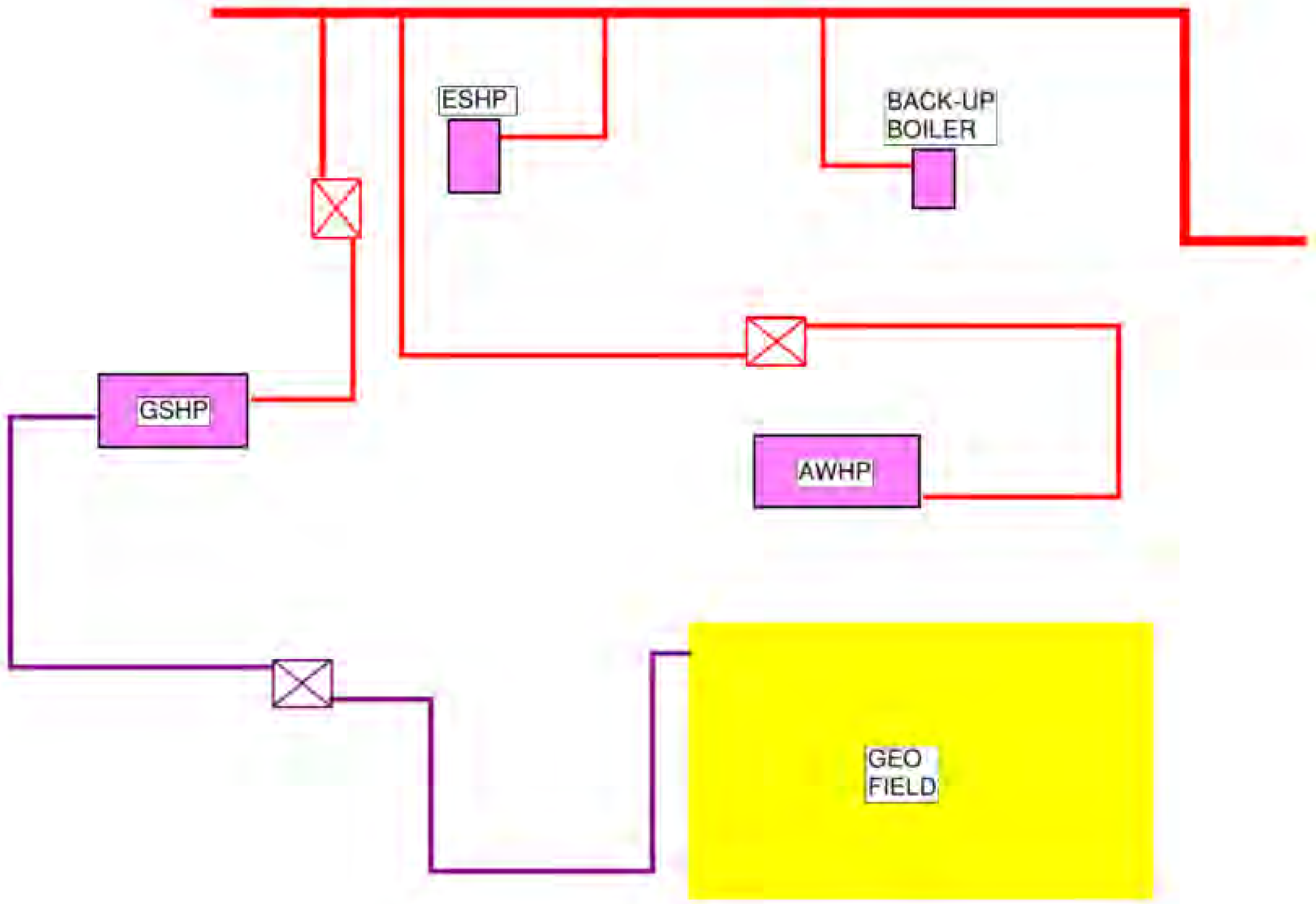

Thank you

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