

# PLANT CONTROLS IN ELECTRIFIED COLD-CLIMATE LABORATORIES

# LEARNING OBJECTIVES

After attending this session, the attendees will be able to...

- Identify challenges associated with electrifying lab buildings in cold climates
- Describe physical and control system design strategies intended to mitigate cold climate electrification challenges
- Define multi-nodal plants and explain their advantages
- Understand design considerations in the application of heat pump technologies, sewage waste energy recovery, and geothermal exchange

# AGENDA

- 1** PROJECT OVERVIEWS
- 2** COLD-CLIMATE CHALLENGES
- 3** CASE STUDY: VT ICAB
- 4** CASE STUDY: PPPL PPIC
- 5** Q&A



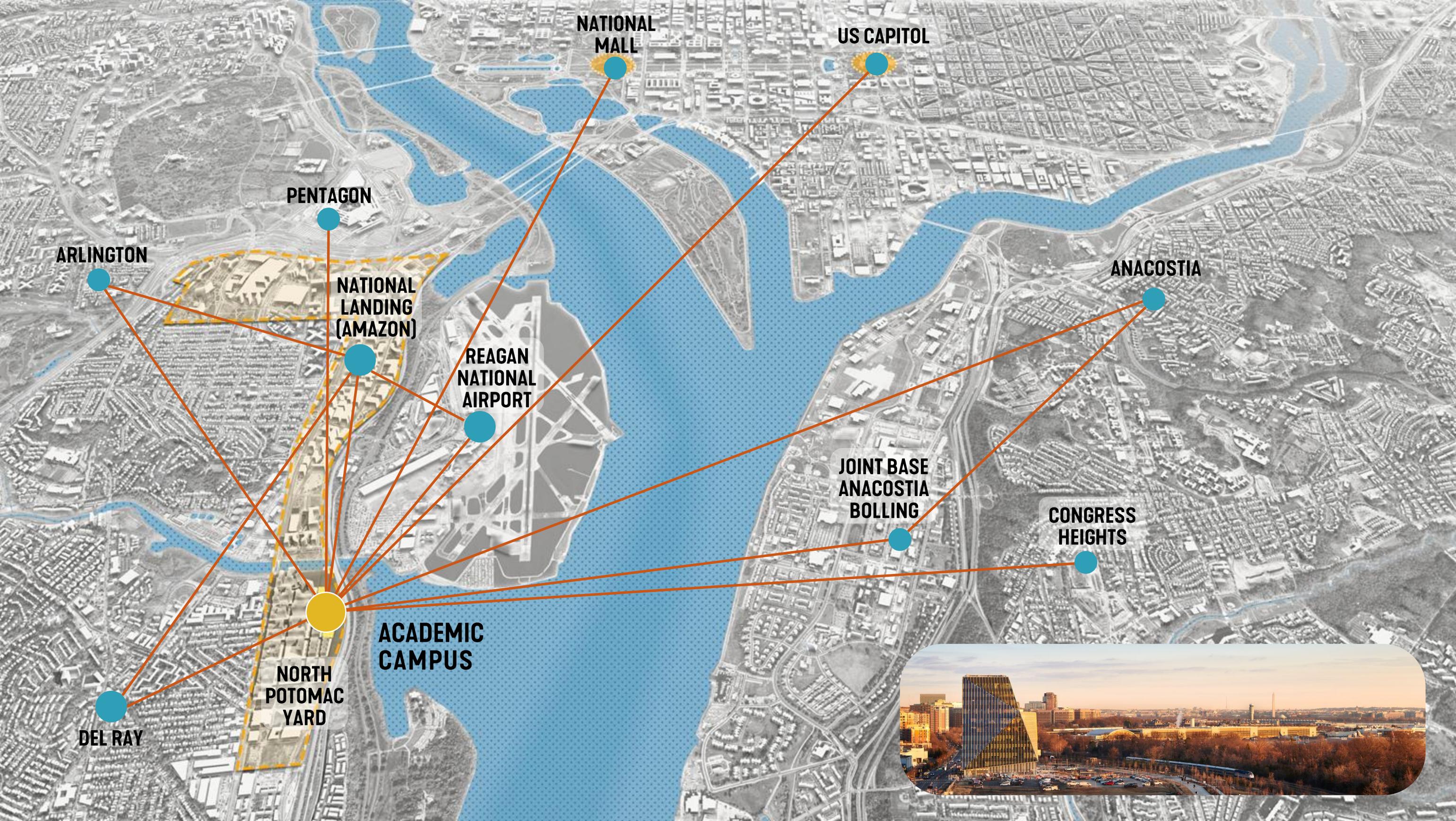


# PROJECT OVERVIEWS

# VIRGINIA TECH ACADEMIC BUILDING ONE

ALEXANDRIA, VIRGINIA





**NATIONAL MALL**

**US CAPITOL**

**PENTAGON**

**ARLINGTON**

**ANACOSTIA**

**NATIONAL LANDING (AMAZON)**

**REAGAN NATIONAL AIRPORT**

**JOINT BASE ANACOSTIA BOLLING**

**CONGRESS HEIGHTS**

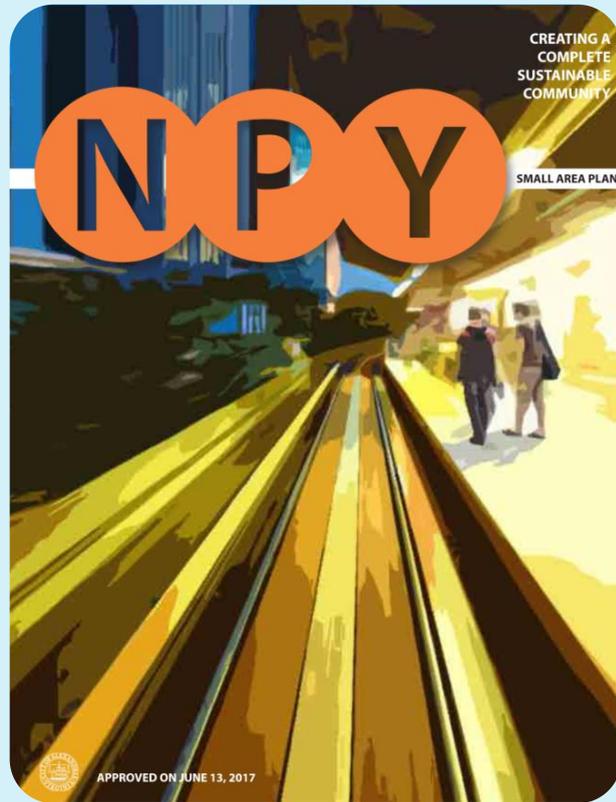
**DEL RAY**

**NORTH POTOMAC YARD**

**ACADEMIC CAMPUS**



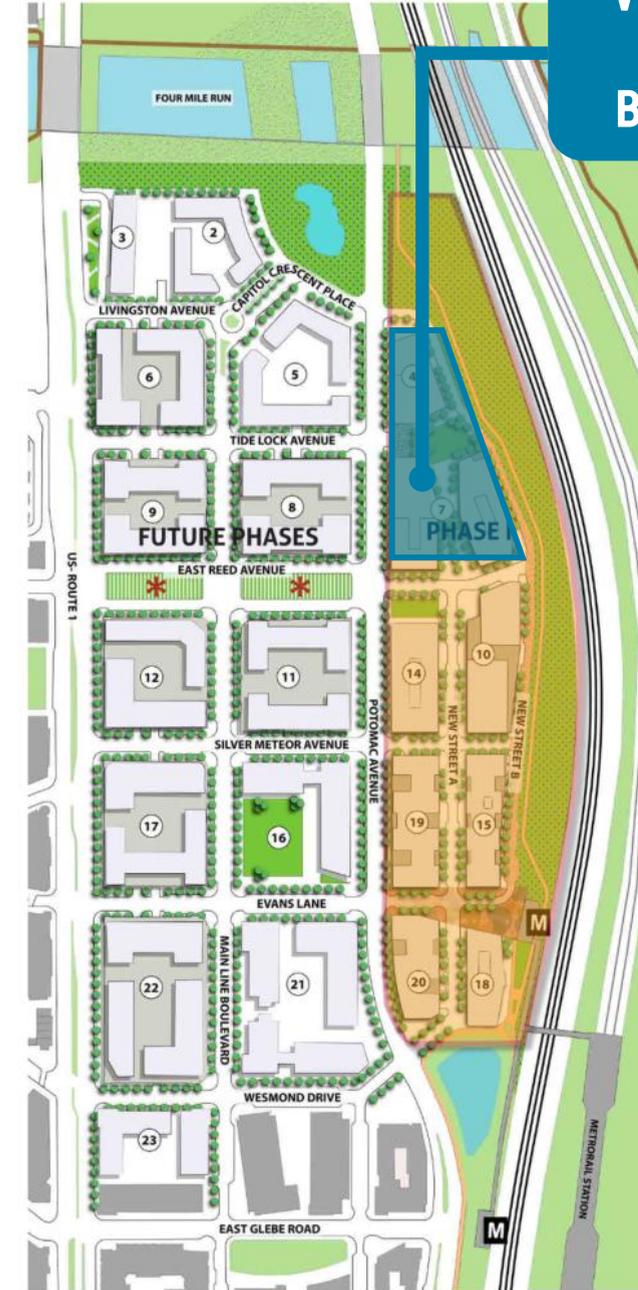
# NORTH POTOMAC YARD



*The intent of the Plan is to encourage district-wide sustainability measures that will be integrated in a coordinated and comprehensive manner...*



**EXISTING**



**VIRGINIA TECH  
ACADEMIC  
BUILDING ONE**

**PHASE 1**

# VT GUIDING PRINCIPLES

*The VT Experience and Identity*

*Universal Design*

*East of Movement*

*Health and Wellness*

*Green and Social Spaces*

*Connectivity*

*Flexibility*

*Visual Connectivity and*

*Transparency*

*Integrated Technology*

*Sustainability and Resilience*

# PRINCETON PLASMA INNOVATION CENTER

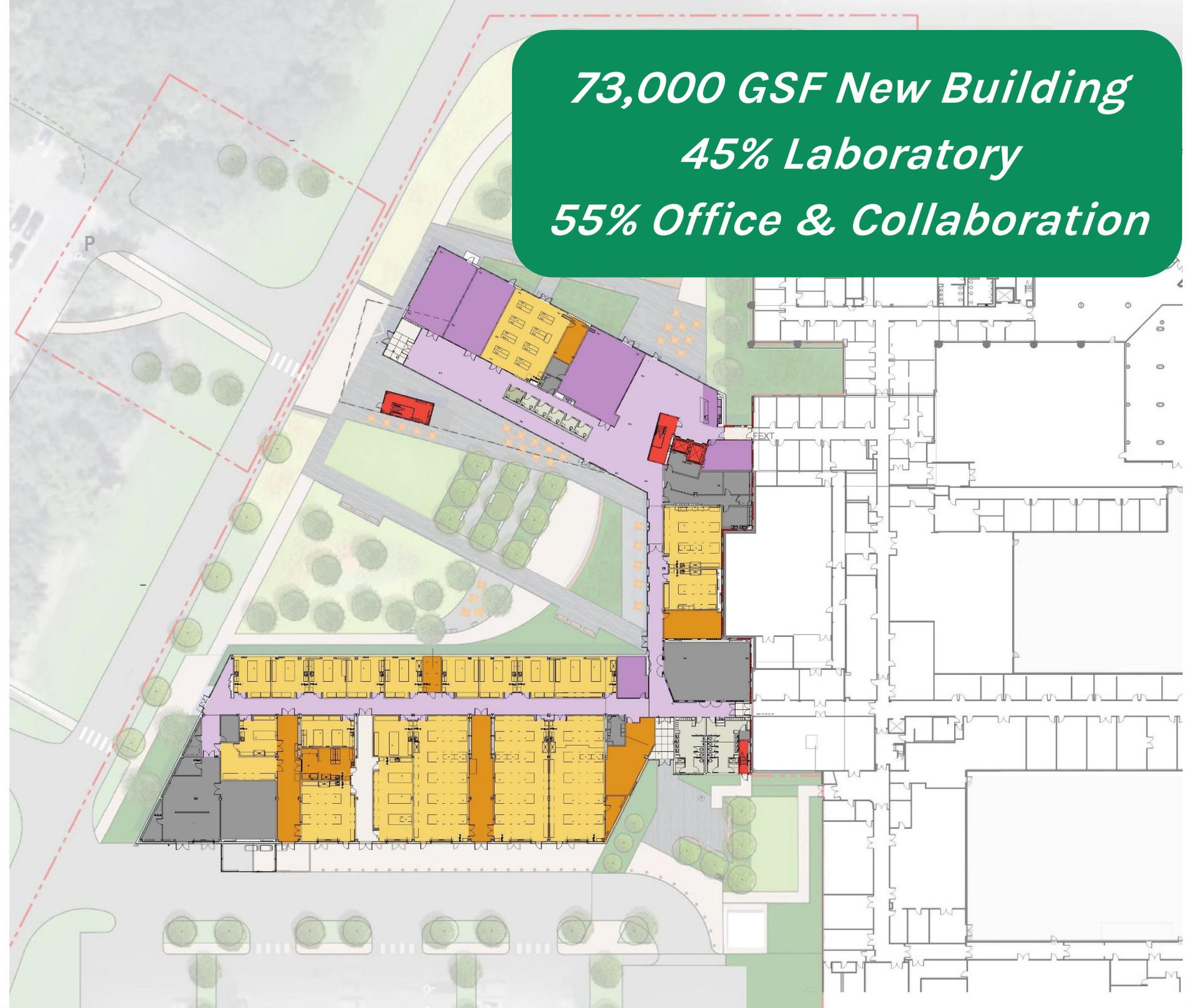
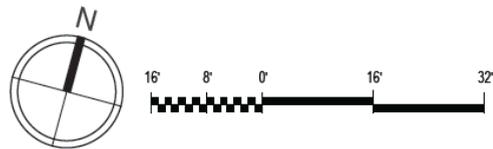
PRINCETON, NEW JERSEY



# BUILDING DESCRIPTION

*73,000 GSF New Building*  
*45% Laboratory*  
*55% Office & Collaboration*

- COLLABORATION CIRCULATION
- COLLABORATION
- LABORATORY
- LABORATORY SUPPORT
- ENCLOSED OFFICE
- OPEN OFFICE
- OFFICE CIRCULATION
- EXTERIOR SPACE
- MEP
- HORIZONTAL CIRCULATION
- VERTICAL CIRCULATION



# BUILDING DESCRIPTION

*“Dry” Laboratories  
Hazardous Exhaust  
Hydronic Process Cooling  
High Sensible Loads  
Flexible Pressurization*

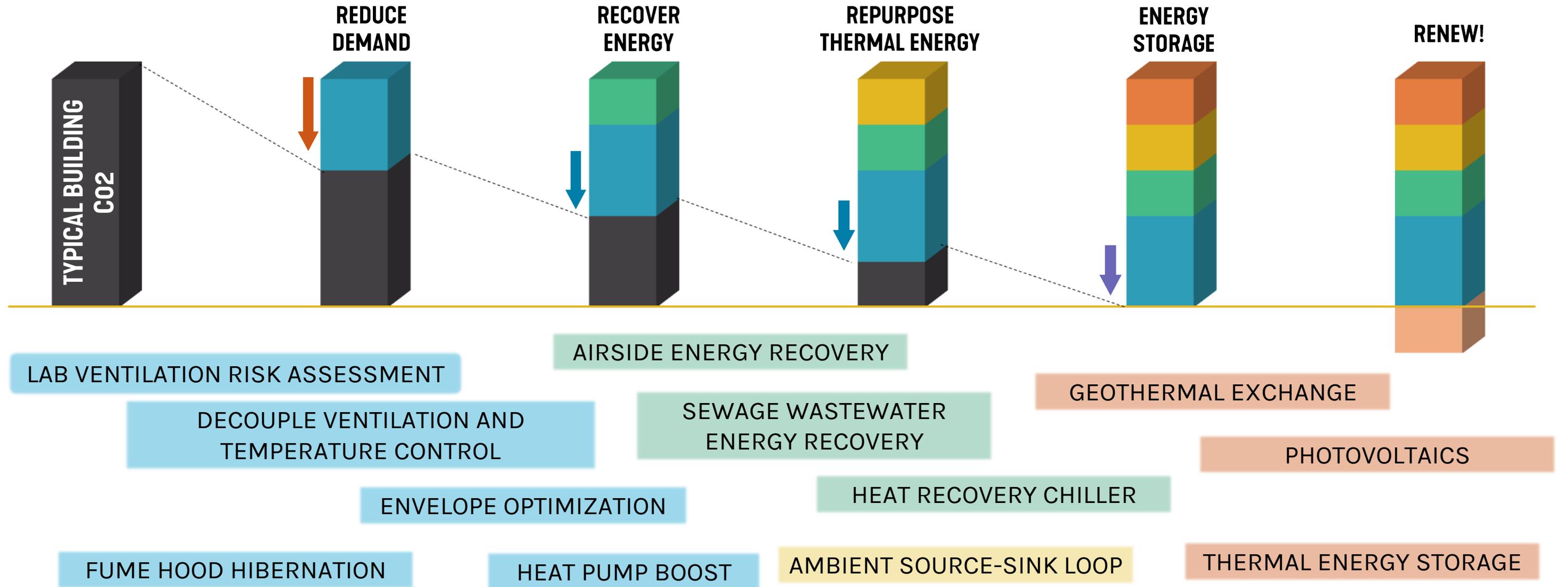




# **CHALLENGES OF COLD-CLIMATE ELECTRIFICATION**

# ELECTRIFICATION STRATEGIES

ZERO CO2 EMISSIONS



# CHALLENGES OF COLD-CLIMATE ELECTRIFICATION

**HIGH  
HEATING  
LOAD**

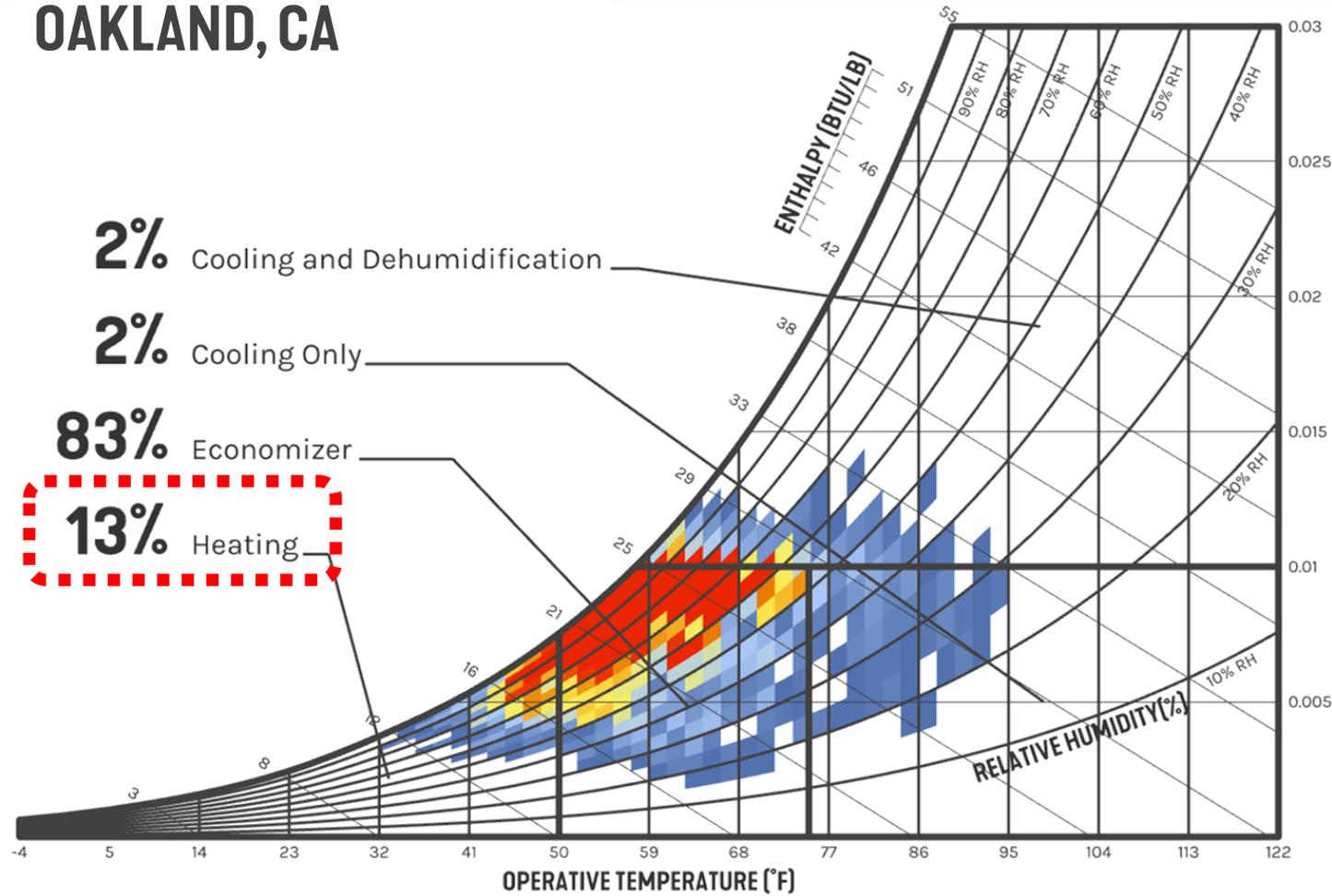
**ELECTRICAL  
INFRASTRUCTURE**

**ELECTRIC  
UTILITY RATES**

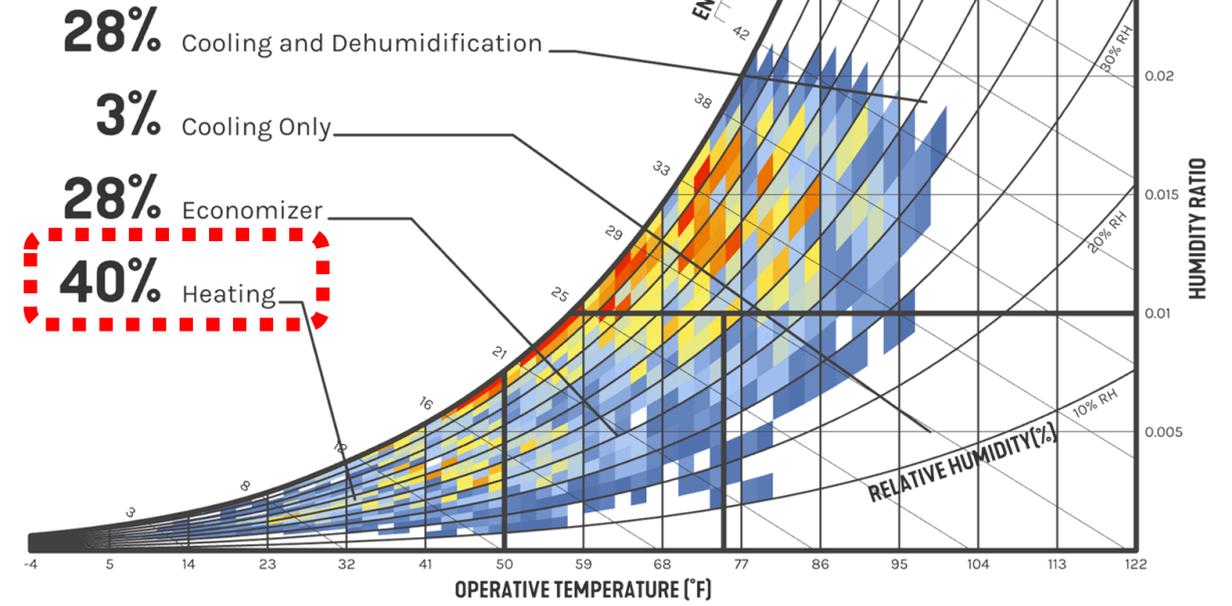
# CLIMATE DATA BY REGION

## ANNUAL LOAD

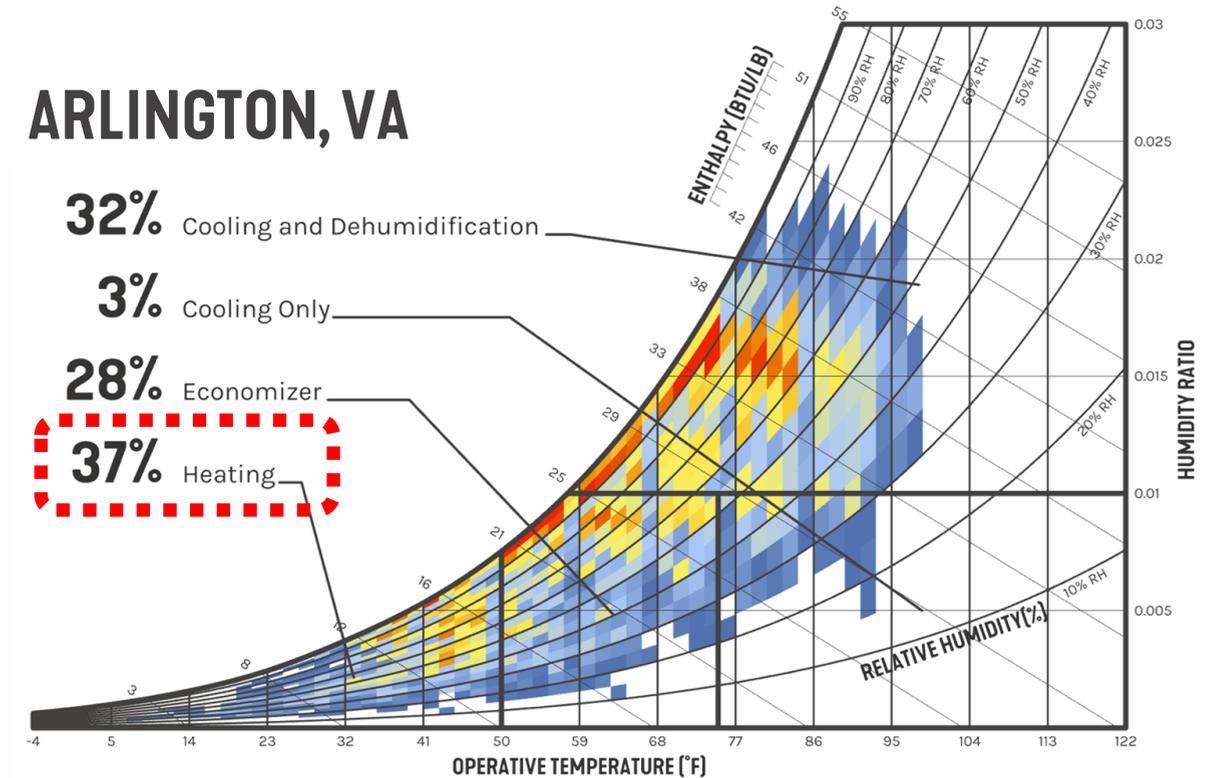
### OAKLAND, CA



### TRENTON-MERCER, NJ

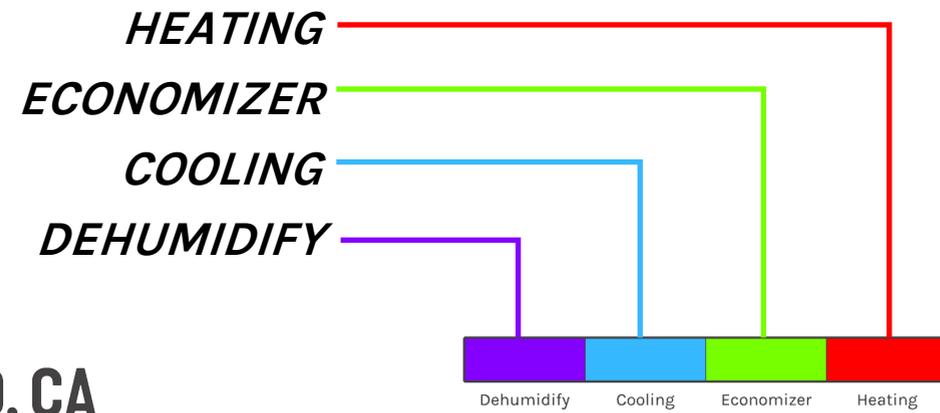


### ARLINGTON, VA

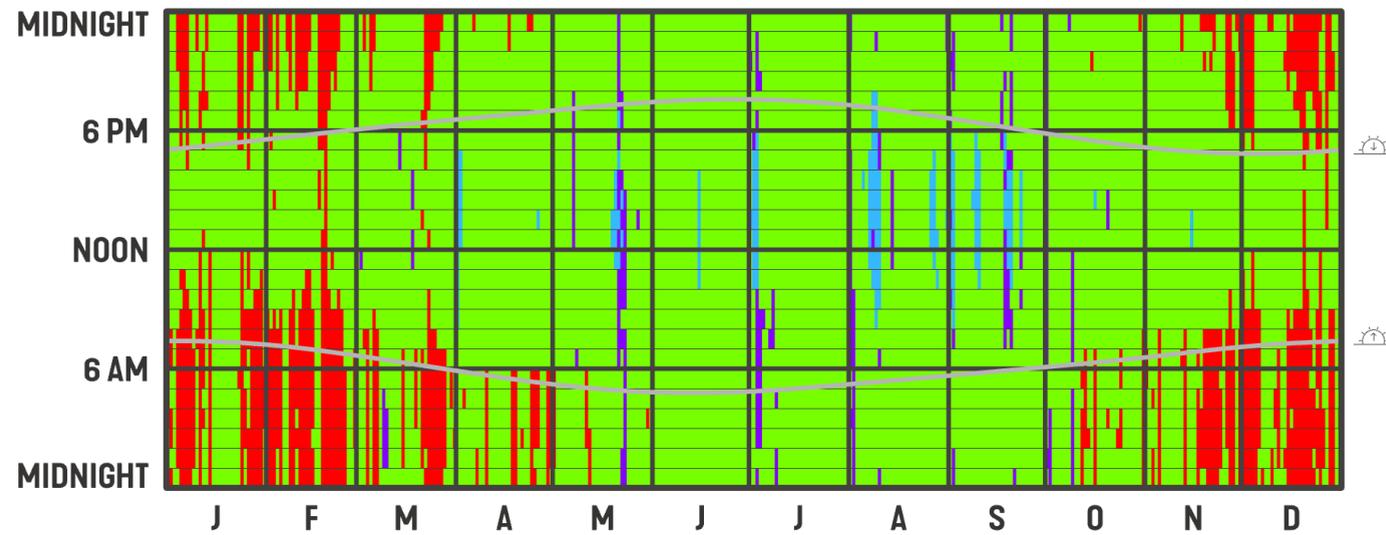


# CLIMATE DATA BY REGION

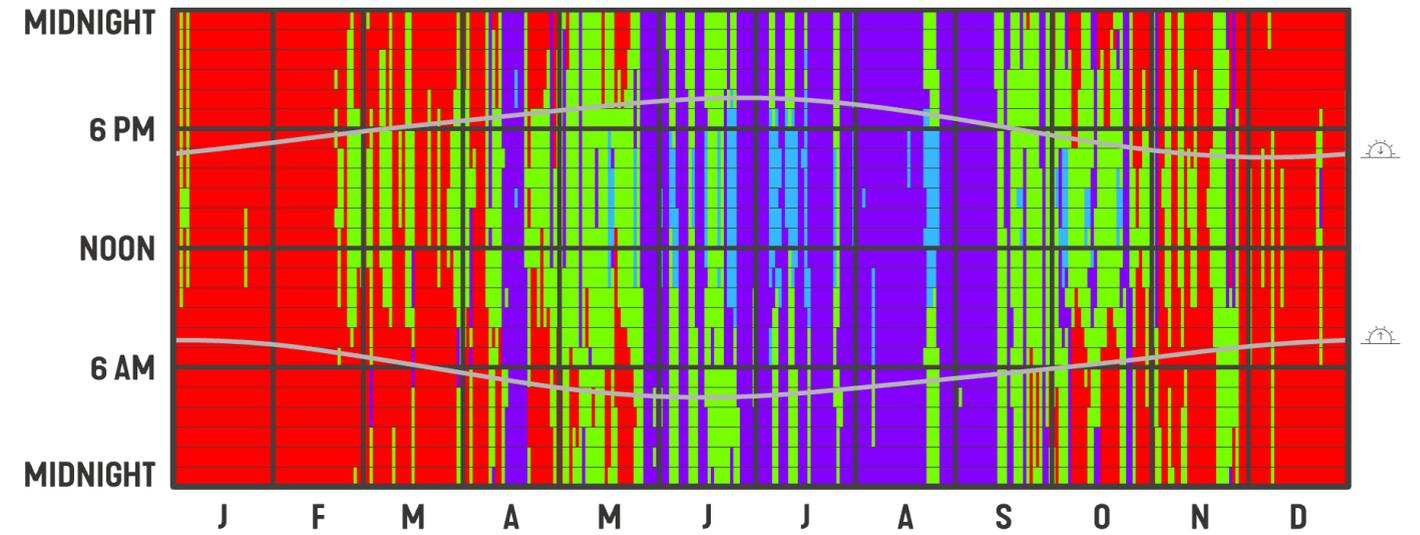
## PREDICTED HVAC MODE



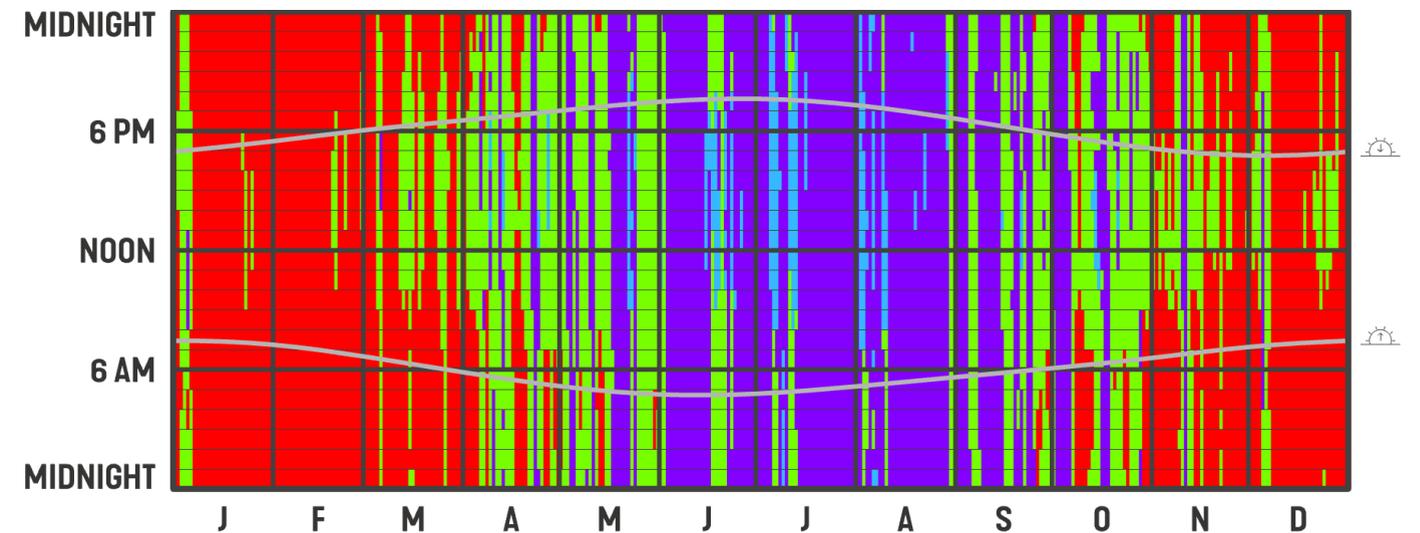
### OAKLAND, CA



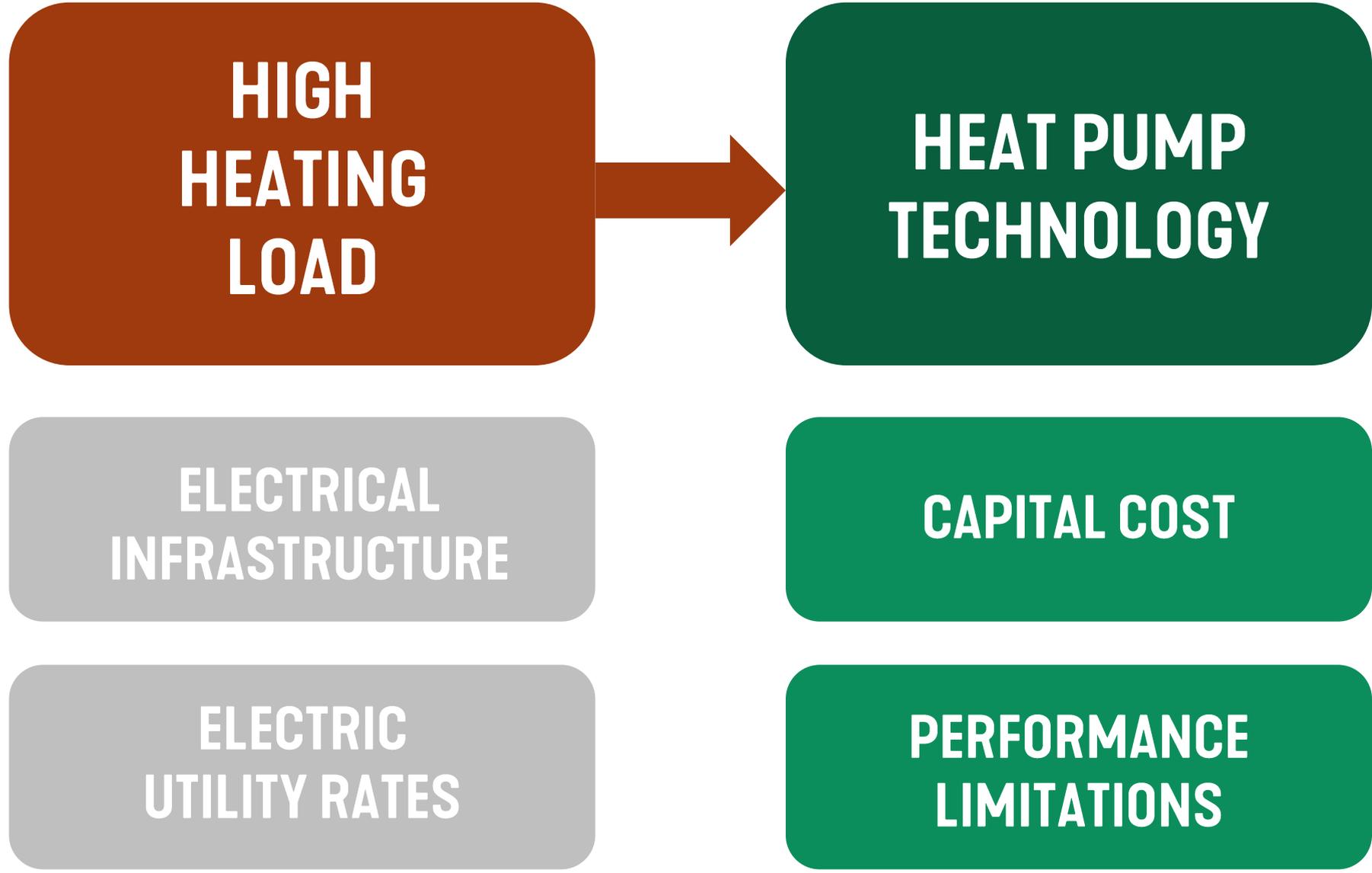
### TRENTON-MERCER, NJ



### ARLINGTON, VA



# CHALLENGES OF COLD-CLIMATE ELECTRIFICATION



# HEAT PUMP TECHNOLOGY CHALLENGES

## CAPITAL COST

CENTRIFUGAL CHILLER	MODULAR CHILLER-HEATER ARRAY
~\$600 / ton	~\$1,900 / ton

# HEAT PUMP TECHNOLOGY CHALLENGES

**CAPITAL COST**

**PERFORMANCE LIMITATIONS**

**CENTRIFUGAL CHILLER**

**MODULAR  
CHILLER-HEATER ARRAY**

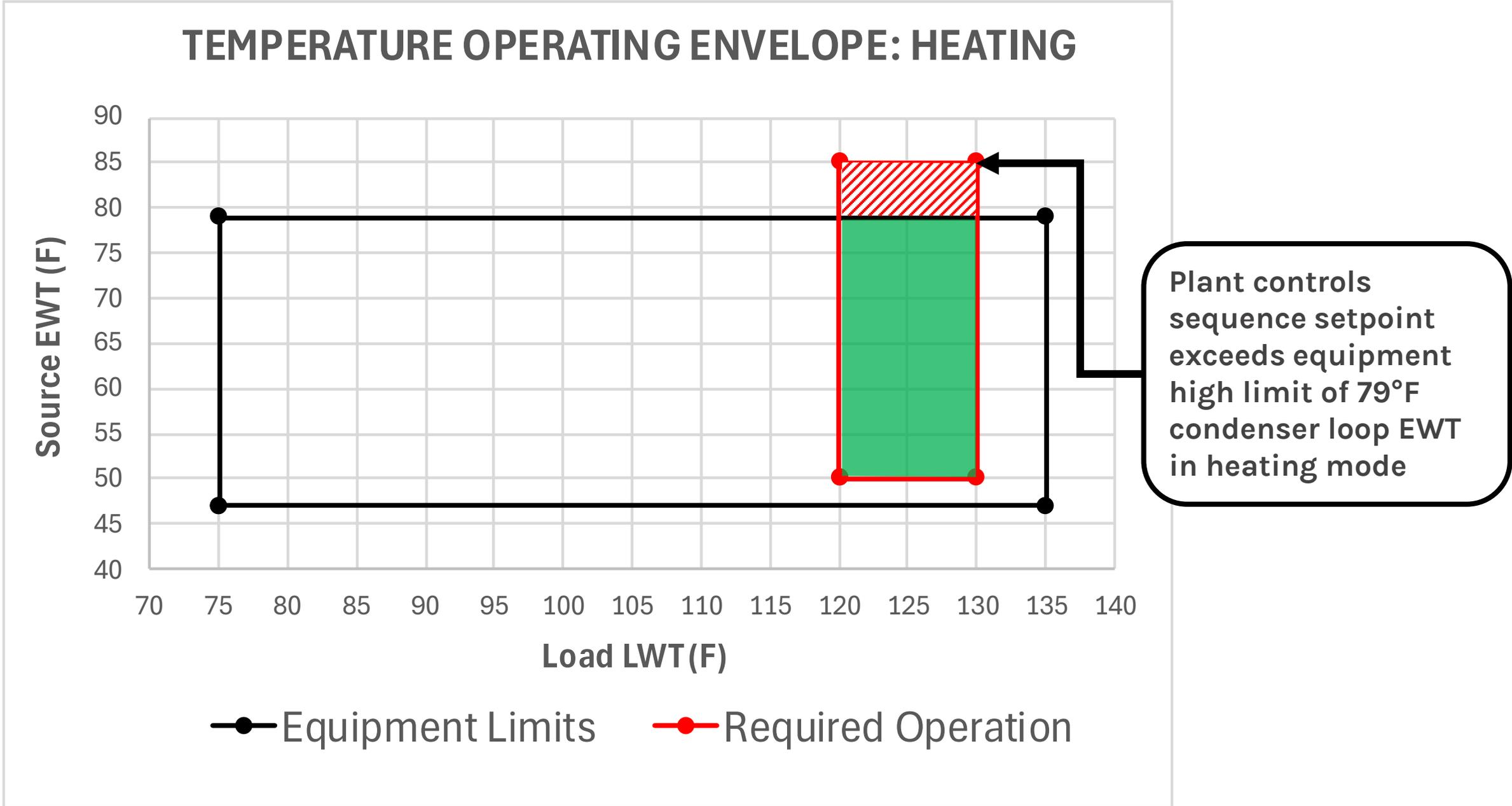
**~\$600 / ton**

**~\$1,900 / ton**

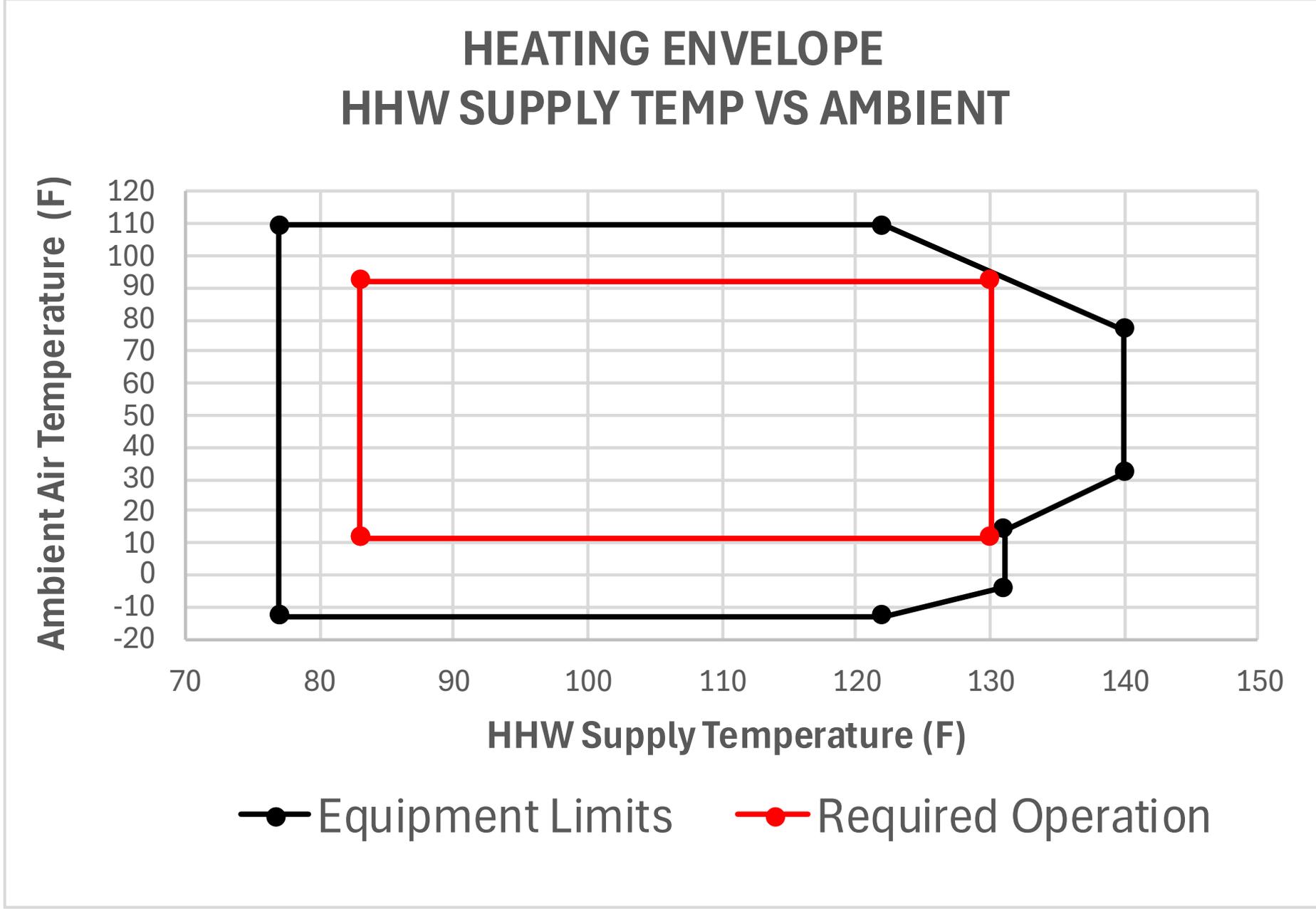
**OPERATING  
ENVELOPE**

**LOW  
AMBIENT**

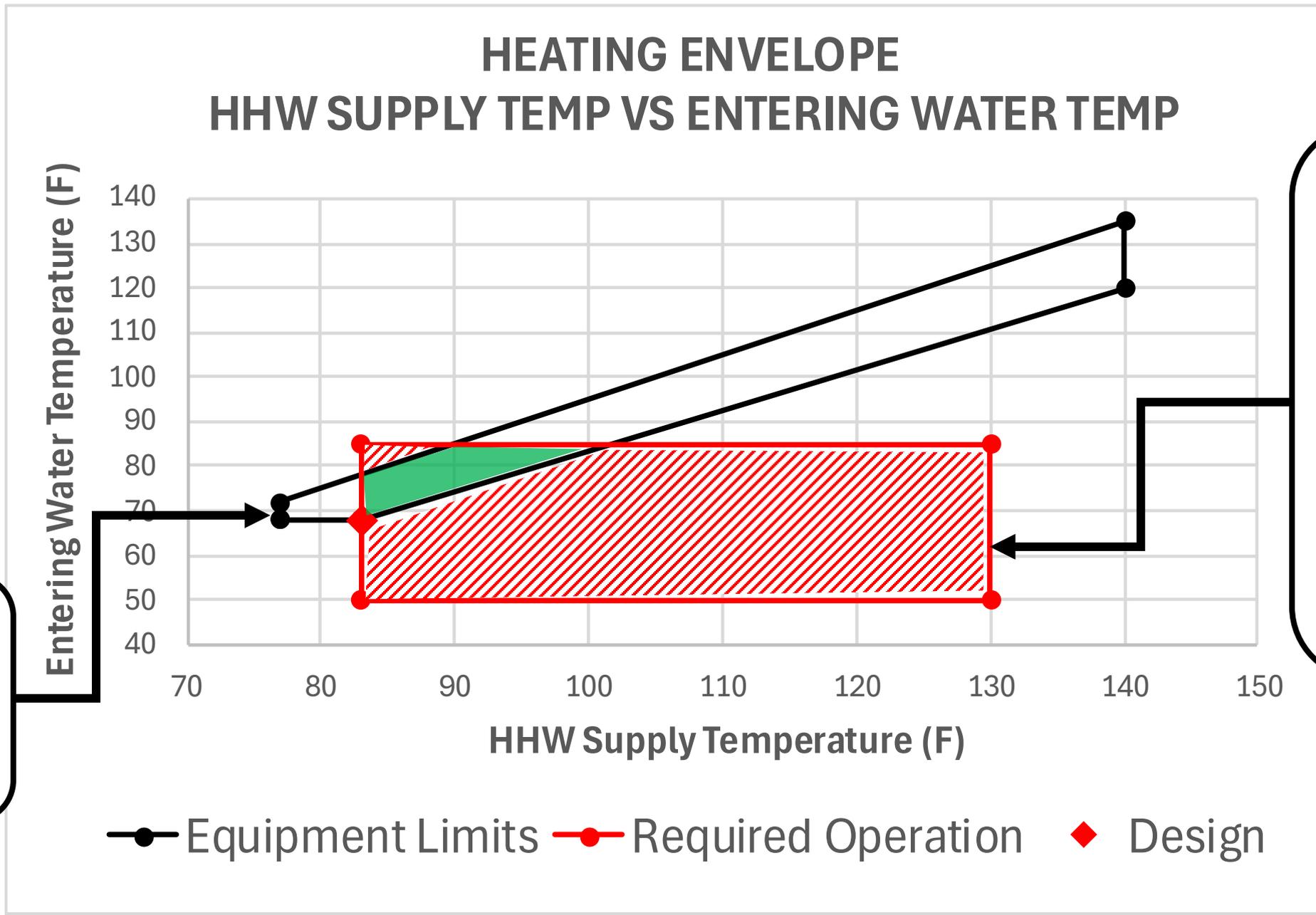
# PERFORMANCE LIMITS: WATER-SOURCE CHILLER-HEATER



# PERFORMANCE LIMITS: AIR-SOURCE CHILLER-HEATER



# PERFORMANCE LIMITS: AIR-SOURCE CHILLER-HEATER



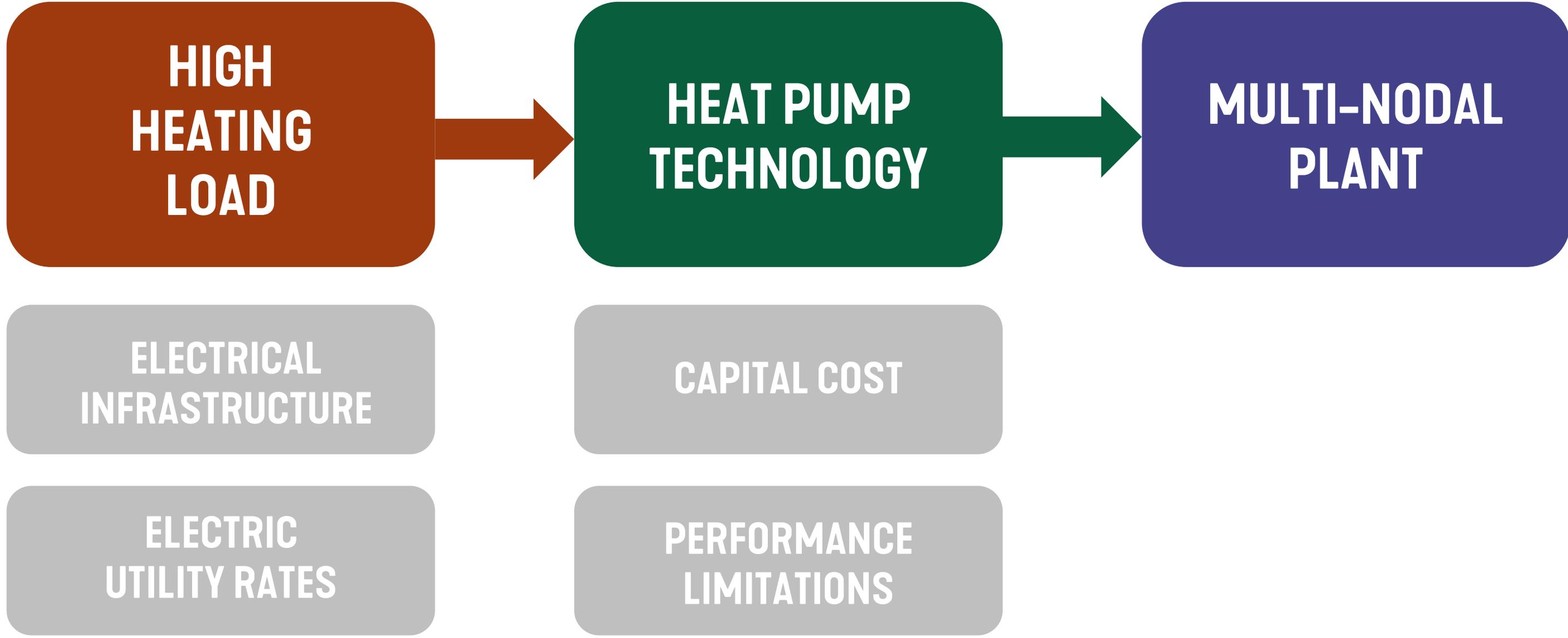
Plant controls sequence setpoint falls below equipment condenser loop low limit of 68°F

*How does equipment handle start up condition or other large  $\Delta T$  conditions?*

*How will it react to a cold source loop such as a geothermal system EWT (45-50°F)?*

*How will it generate 70-90°F HHWS?*

# CHALLENGES OF COLD-CLIMATE ELECTRIFICATION



# ADVANTAGES OF A MULTI-NODAL PLANT

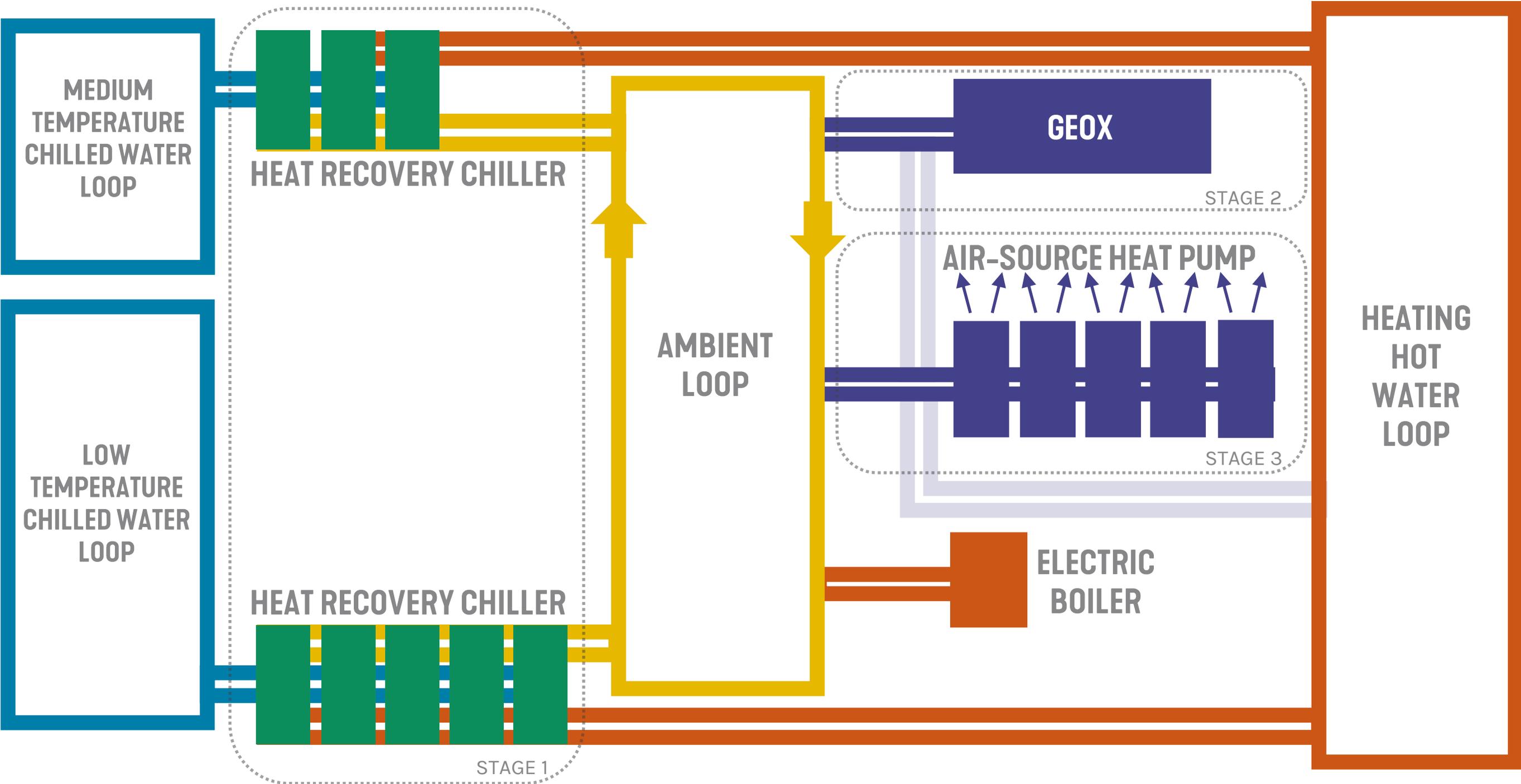
*A plant comprised of multiple energy-generating nodes that work together to meet demand*

*Resilience through diversification of system types*

*System types tailored to project and site features*

*Plant control modes tuned for resilience and COP optimization*

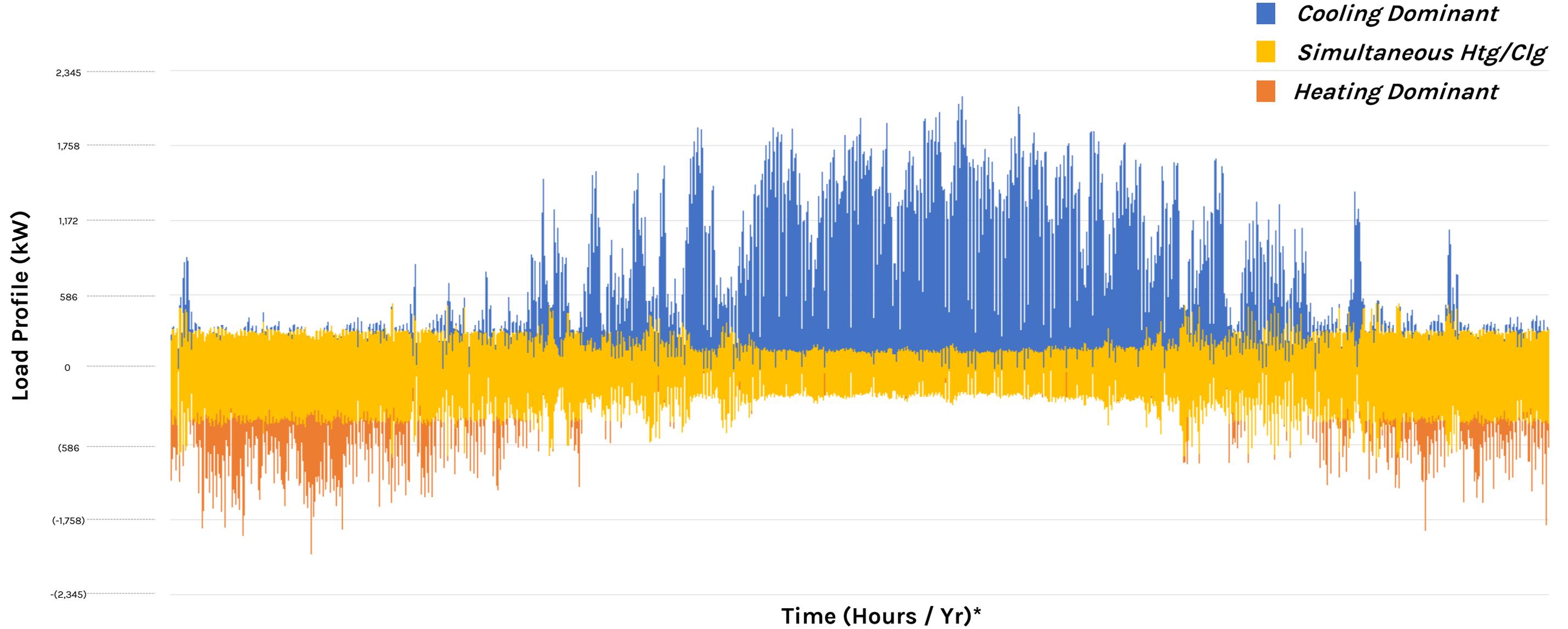
# MULTI-NODAL PLANT



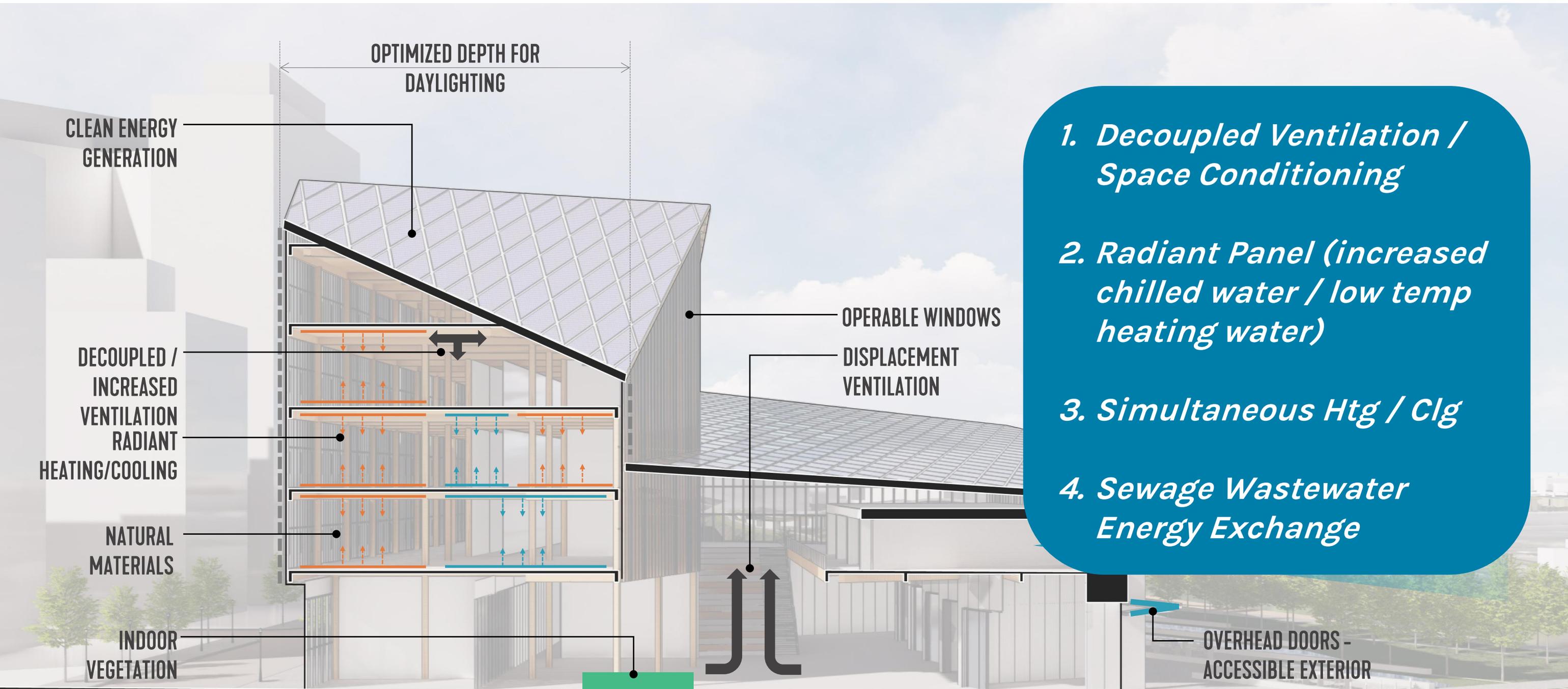


**CASE STUDY:  
VIRGINIA TECH ACADEMIC BUILDING ONE**

# BUILDING LOADS



# SYSTEM STRATEGIES



- 1. *Decoupled Ventilation / Space Conditioning*
- 2. *Radiant Panel (increased chilled water / low temp heating water)*
- 3. *Simultaneous Htg / Clg*
- 4. *Sewage Wastewater Energy Exchange*

# THERMAL ENERGY EXCHANGE

## HIGH-PERFORMANCE BLDG

- ① DOAS w/parallel conditioning (radiant, ACB, chilled box)

## PRIME THERMAL GENERATION

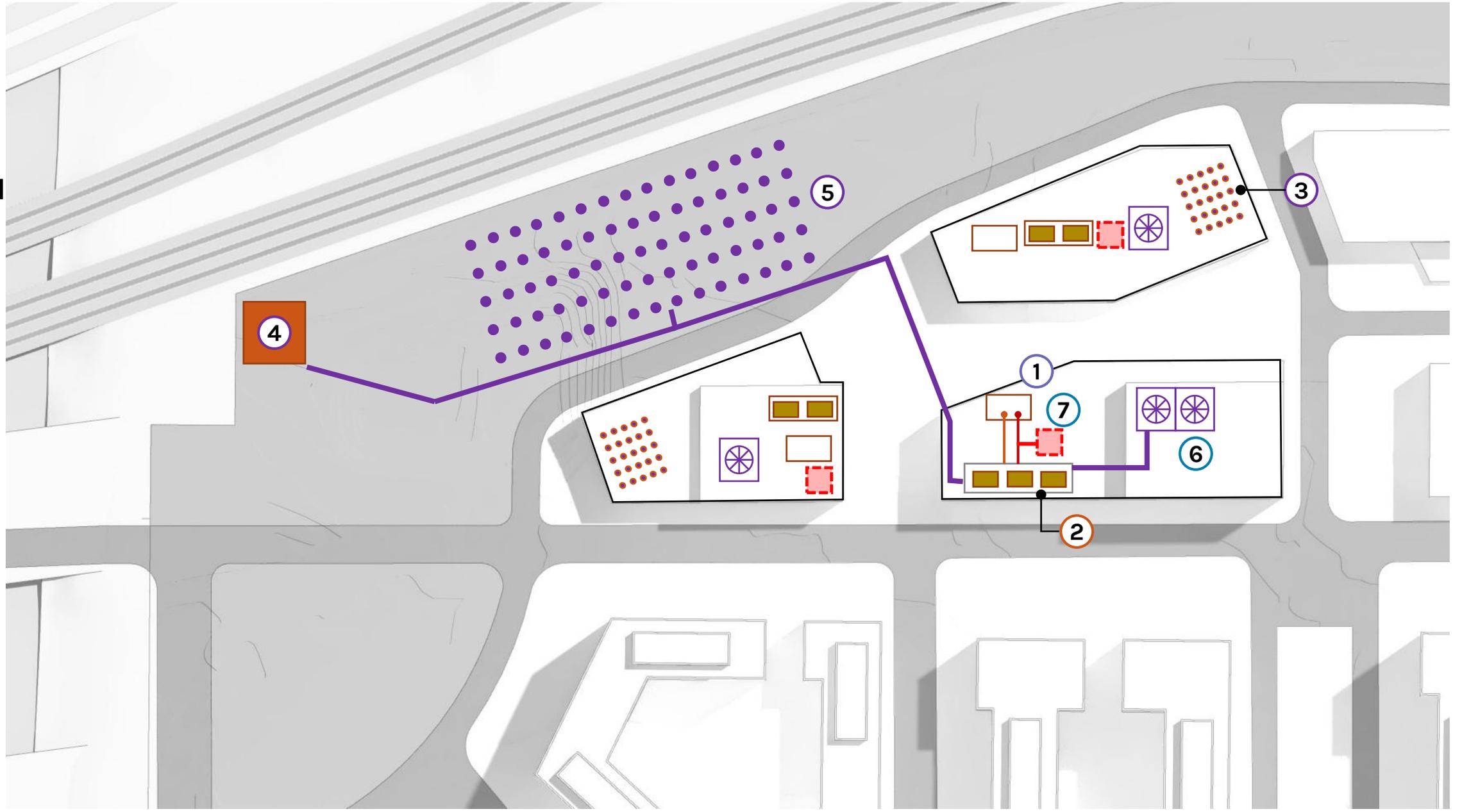
- ② Heat-recovery chillers

## MULTI-SOURCE ENERGY EXCHANGE

- ③ Deep foundation energy piles
- ④ Municipal pump station
- ⑤ Vertical borefield (70-100#)

## AUXILIARY HEATING, COOLING, HEAT REJECTION

- ⑥ CT, AC chiller, evaporative fluid cooler, dry cooler
- ⑦ ASHP, solar thermal



# THERMAL ENERGY ANALYSIS: WASTE WATER FLOWS

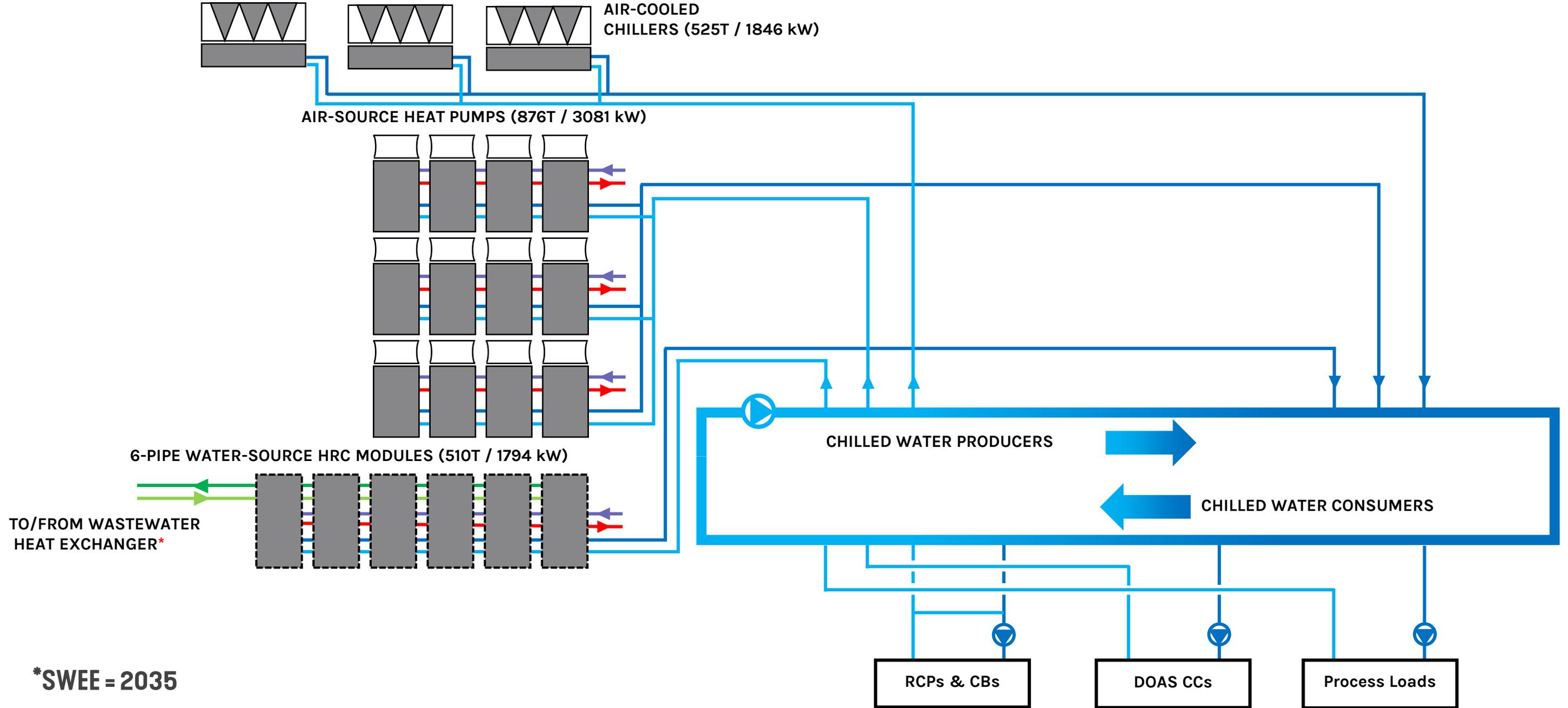
- ① NPY Phase I (ICAB I only)
- ② NPY Phase I (ICAB I, II, III)
- ③ 50% NPY Phase I & II
- ④ NPY Phase I & II



# SEWAGE WASTEWATER ENERGY EXCHANGE

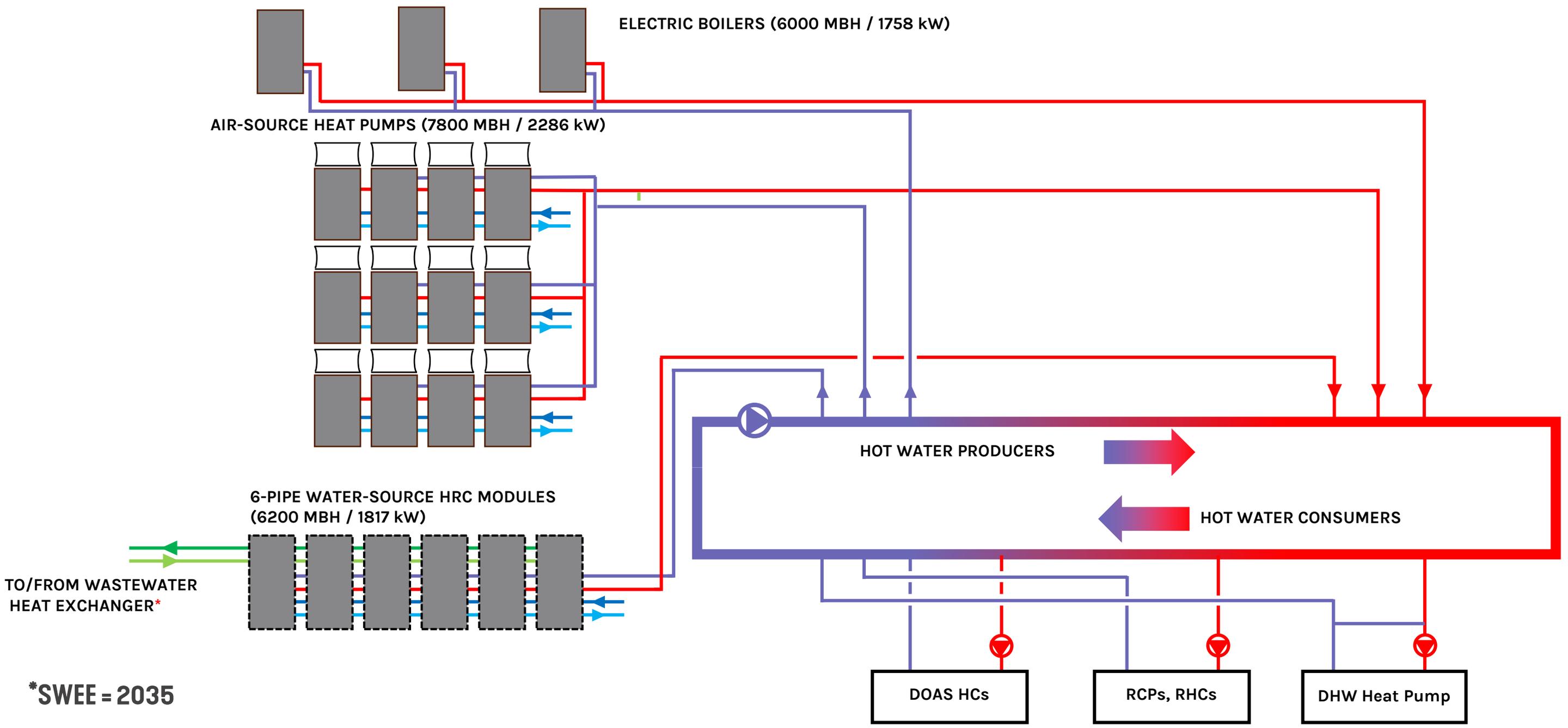


# CHILLED WATER FLOW DIAGRAM



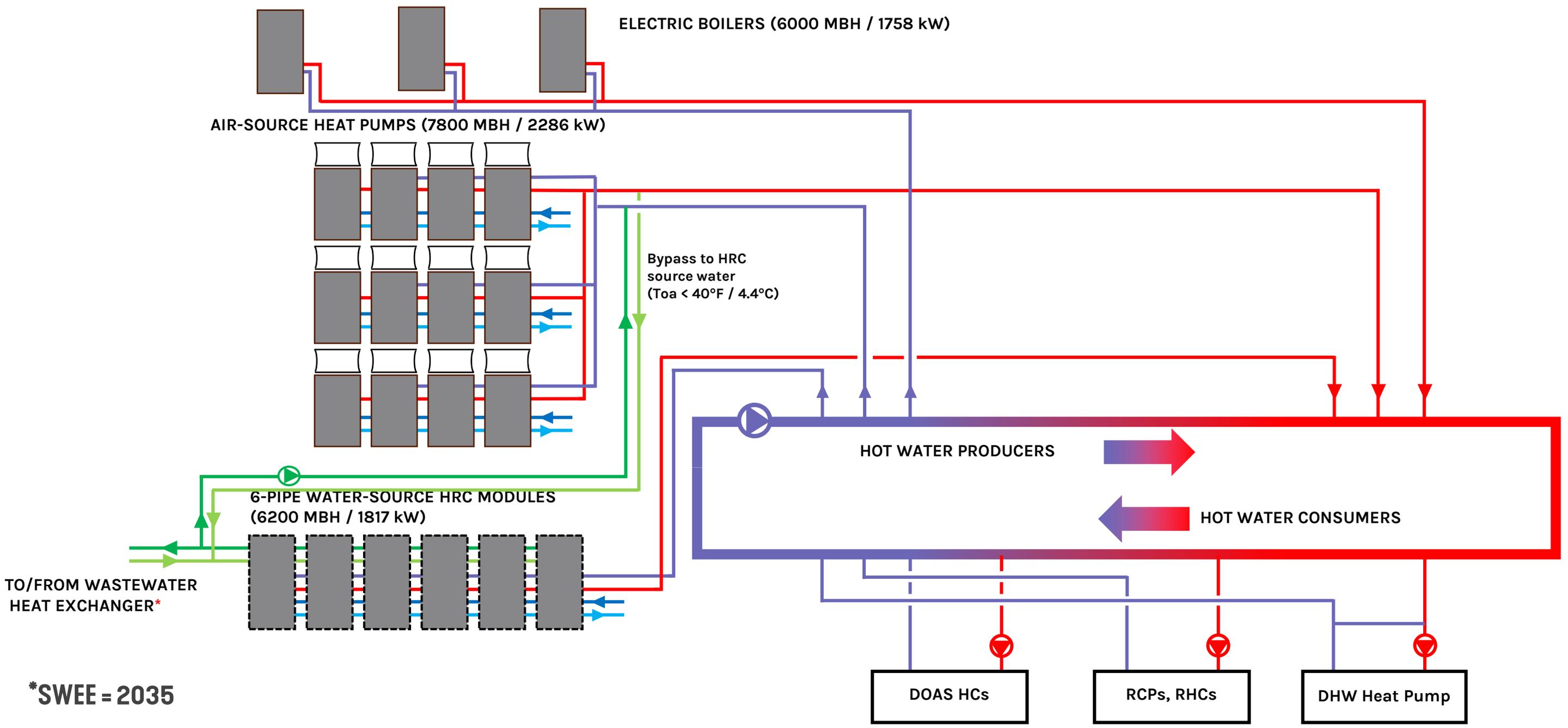
\*SWEE = 2035

# HEATING HOT WATER FLOW DIAGRAM



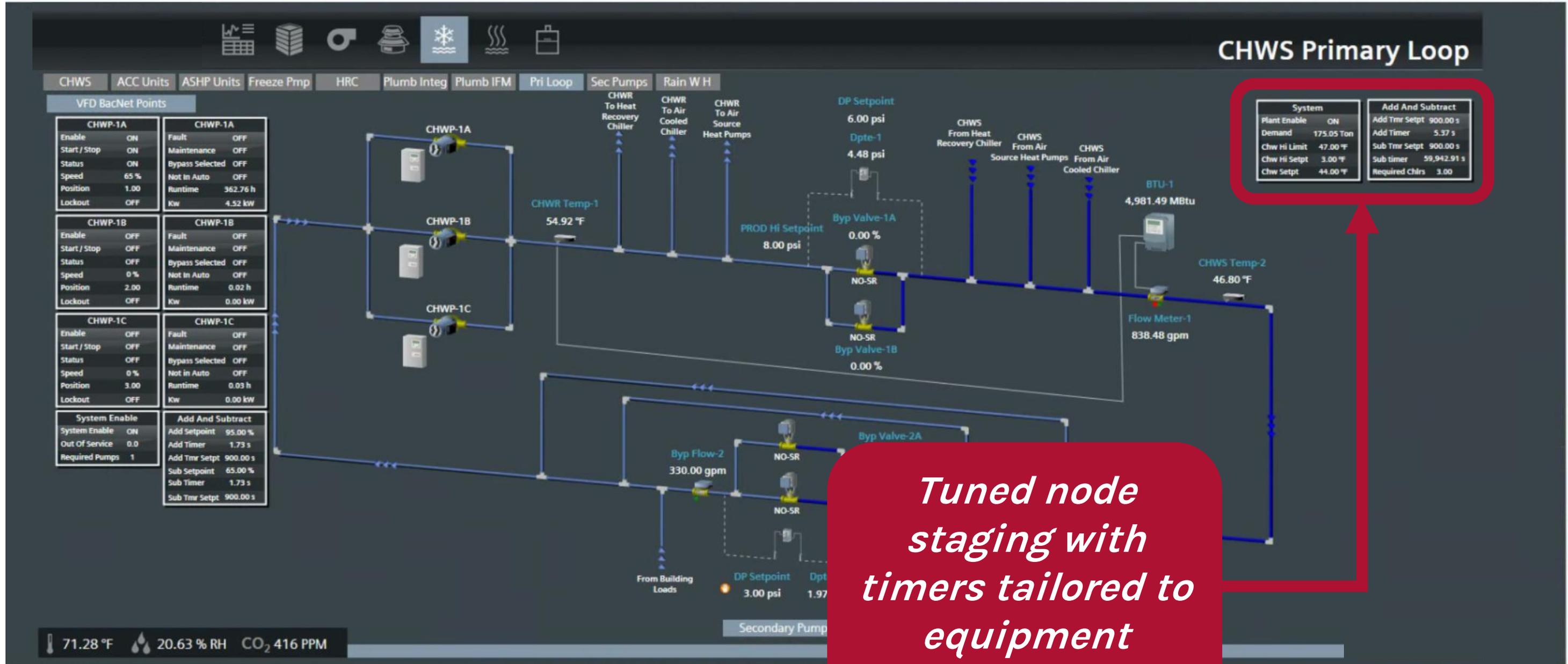
\*SWEE = 2035

# HEATING HOT WATER FLOW DIAGRAM



\*SWEE = 2035

# SYSTEM CONTROLS



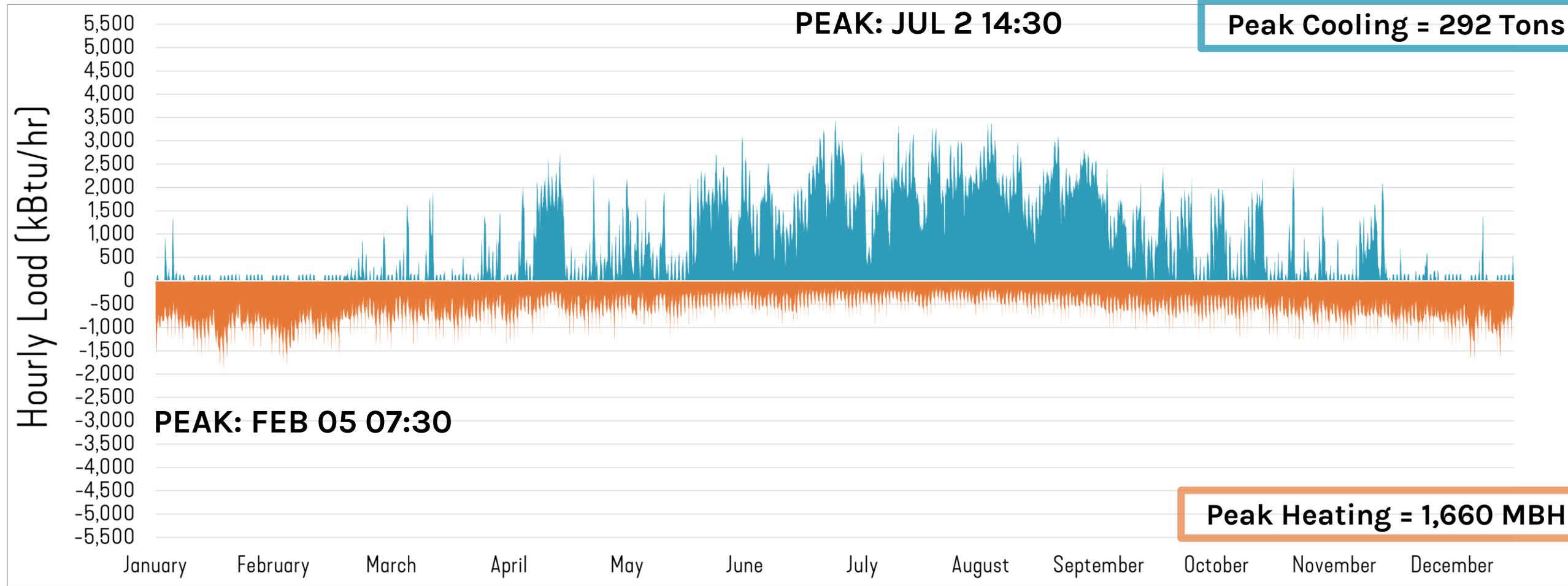
*Tuned node staging with timers tailored to equipment controllers*



**CASE STUDY:  
PRINCETON PLASMA INNOVATION CENTER**

# BUILDING LOADS: "DAY 1"

■ Cooling Load (kBtu/h) ■ Heating Load (kBtu/h)



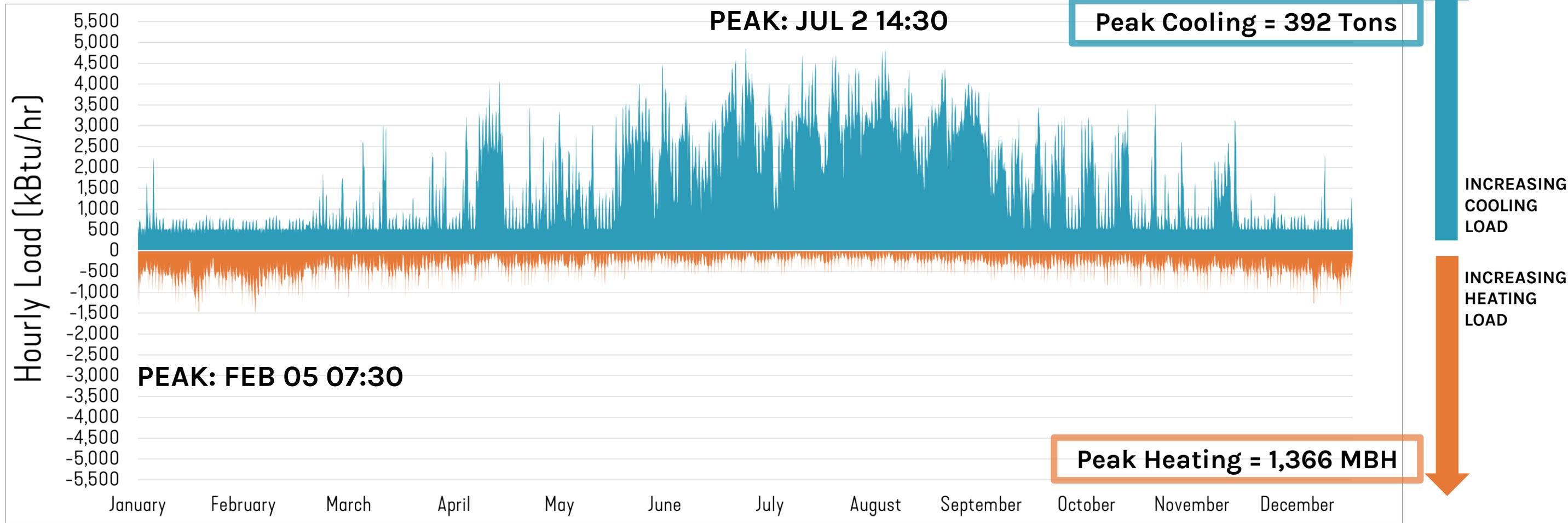
INCREASING COOLING LOAD

INCREASING HEATING LOAD

**HEATING TO COOLING RATIO: 73%**  
**COOLING DOMINANT**

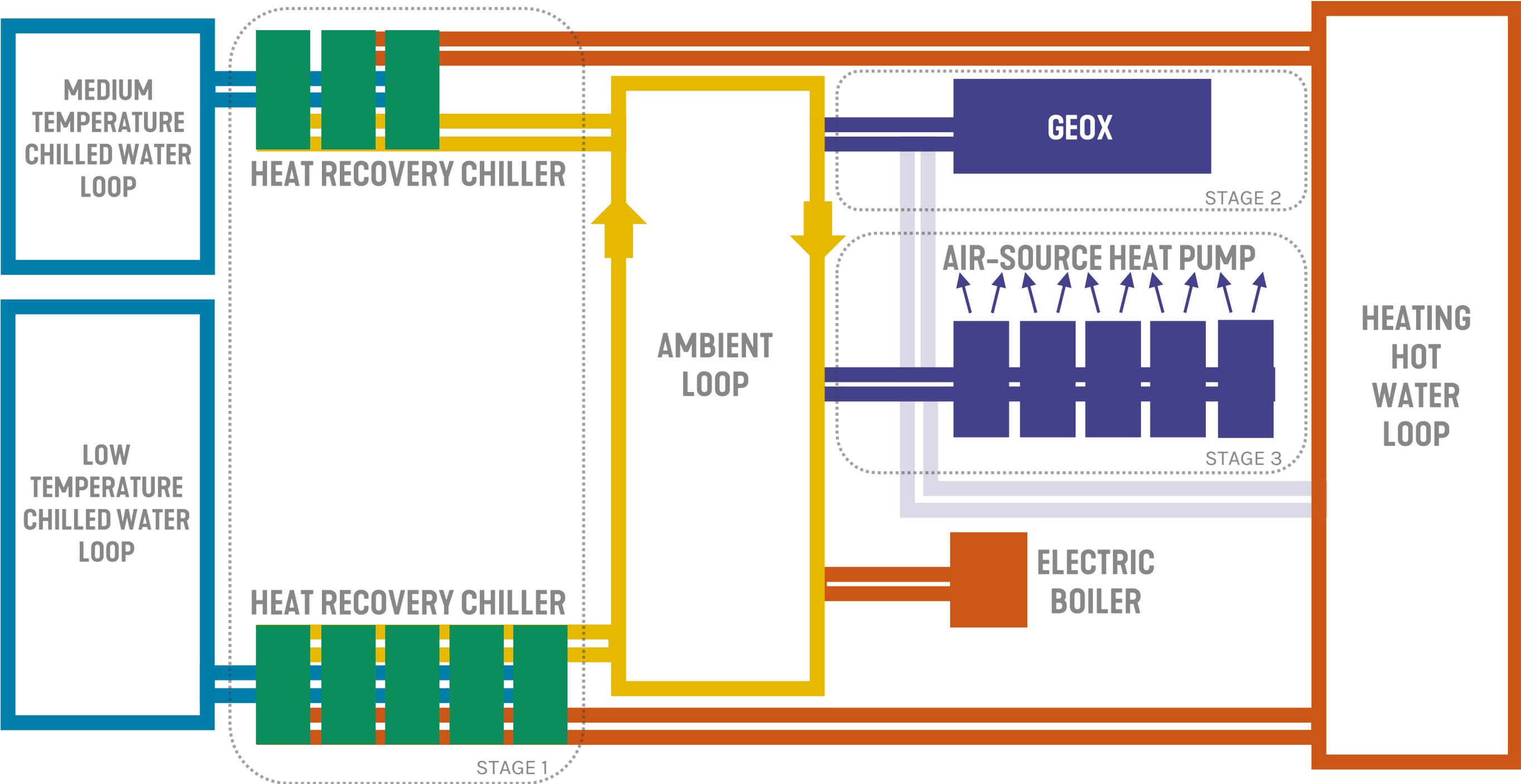
# BUILDING LOADS: "FUTURE"

■ Cooling Load (kBtu/h) ■ Heating Load (kBtu/h)



**HEATING TO COOLING RATIO: 19%**  
**COOLING DOMINANT**

# MULTI-NODAL PLANT

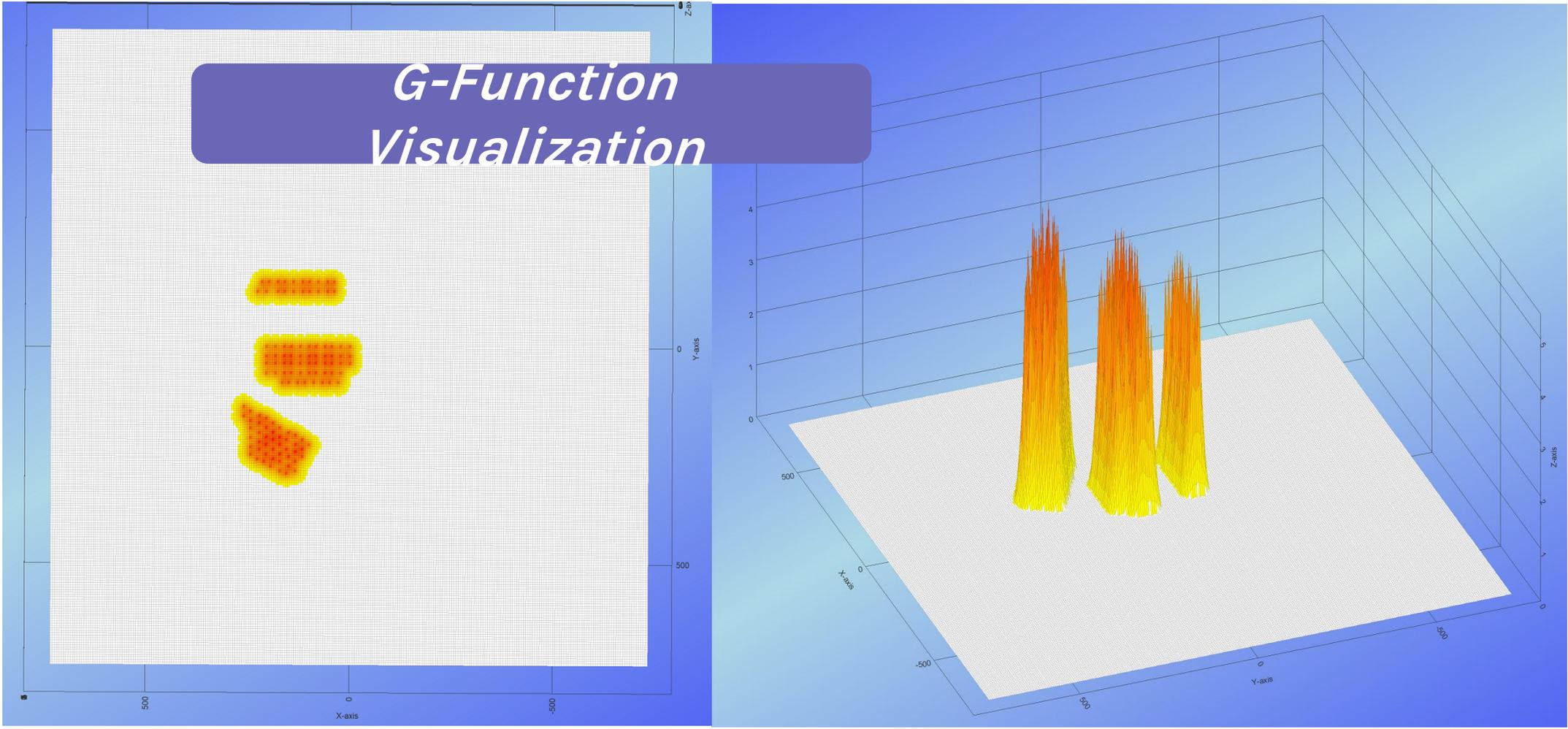


# SYSTEM CONSIDERATIONS

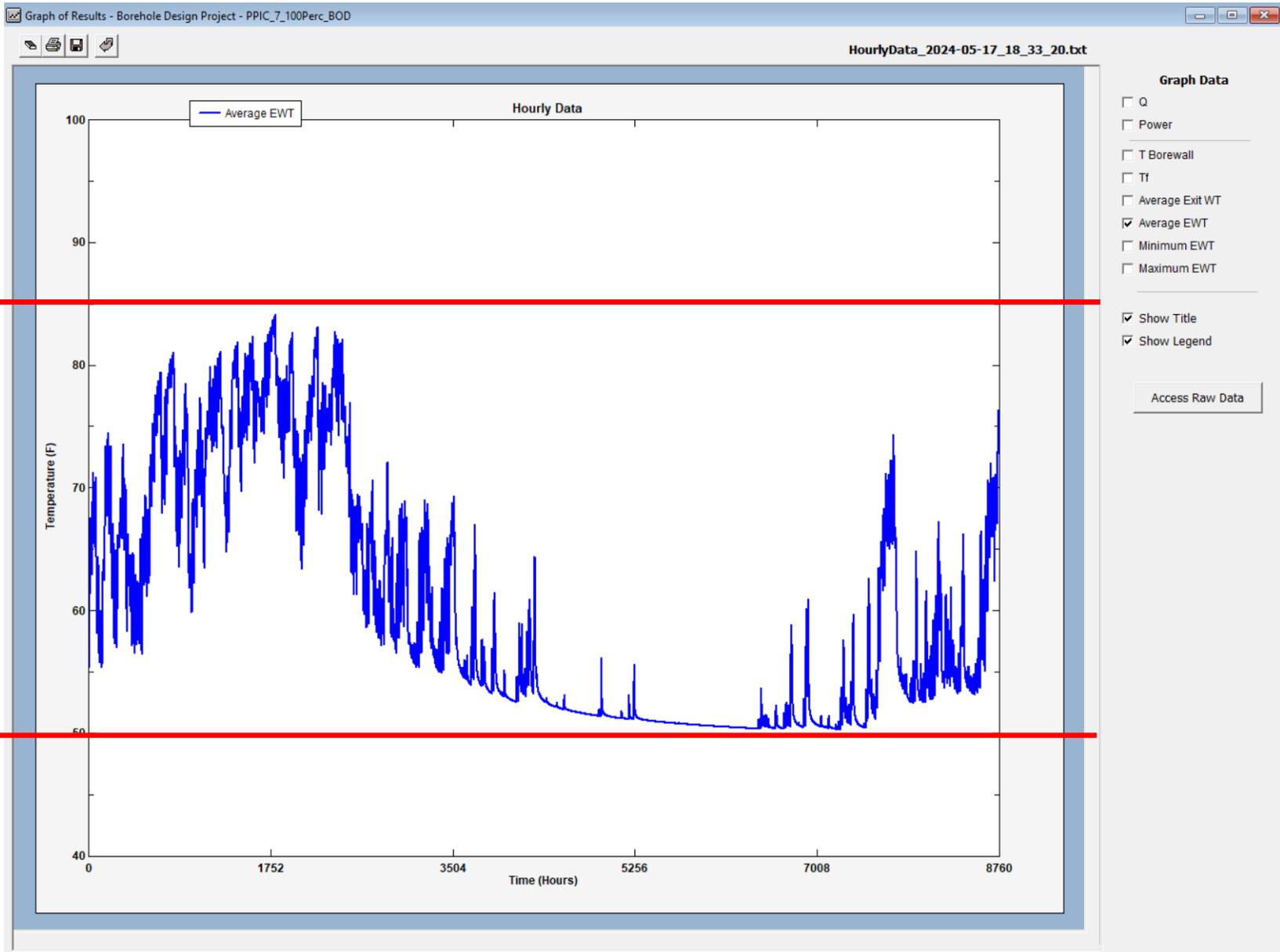
*118 Geothermal Bores  
500-Foot Depth*



# SYSTEM CONSIDERATIONS



# GEOEXCHANGE SYSTEM SIZING



85 F

CHILLER-HEATER EWT RANGE

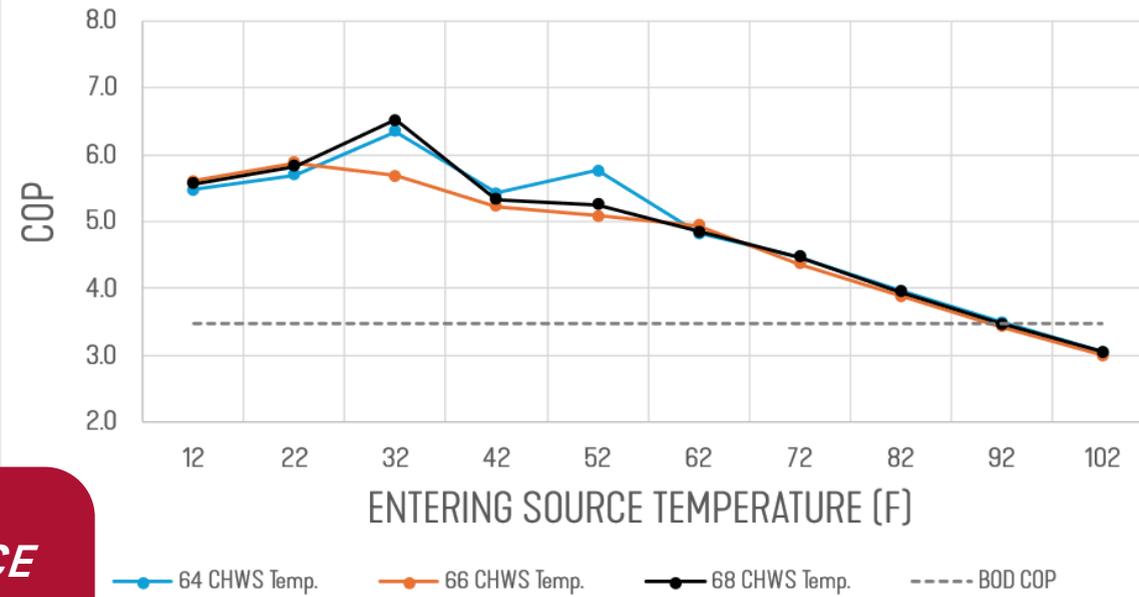
50 F

INPUTS	
Design Method	Hourly
Load Profile	Day 1_Htg2x_Clg1.15x
Prediction Time (yr)	1
Borefield Name	102 Bores
Borehole Count (#)	102
Borehole Depth (ft)	500
Total Bore Length (ft)	51,000
Ground Temp (F)	55.3
Ground Thermal Conductivity (Btu/(h-ft-F))	1.55
Ground Thermal Diffusivity (ft <sup>2</sup> /day)	0.97
RESULTS	
Max Heat Pump Inlet - EWT (F)	84.1
Min Heat Pump Inlet - EWT (F)	50.3
System Flow Rate (gpm)	630
Nominal Flow / Bore (gpm)	6.2
Geo - Peak Load Clg (kBtu/hr)	<b>2,495</b>
Geo - Peak Load Clg (Tons)	208
Geo - Peak Load Htg (kBtu/hr)	<b>786</b>
Geo - Peak Clg Load (% of Total)	72%
Geo - Total Annual Clg Load (% of Total)	98%
Geo - Peak Htg Load (% of Total)	21%
Geo - Total Annual Htg Load (% of Total)	52%

- Notes**
1. System flow rate assumes 3 gpm/ton
  2. GHX load input is the non-simultaneous load, which subtracts simultaneous load from total load
  3. RUN#2\_Day 1\_Htg2x\_Clg1.15x\_1YR\_#102,500FT\_72%GeoPkClg\_21%GeoPkHtg\_Water
  4. Source: HourlyData\_2024-05-17\_18\_33\_20.txt

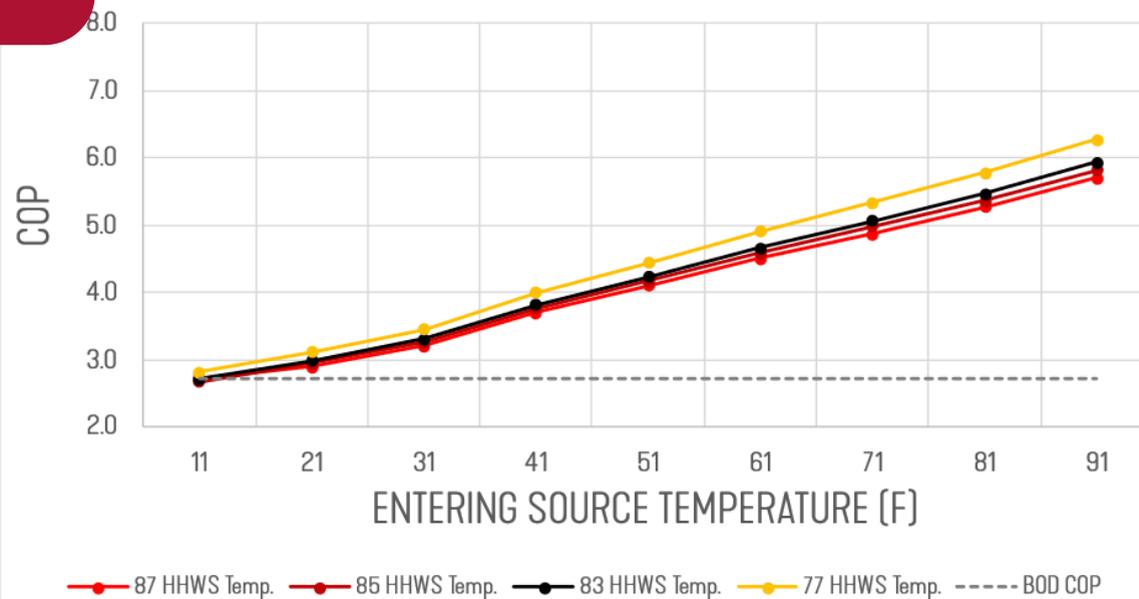
# COEFFICIENT OF PERFORMANCE

Cooling COP vs Entering Source Temperature

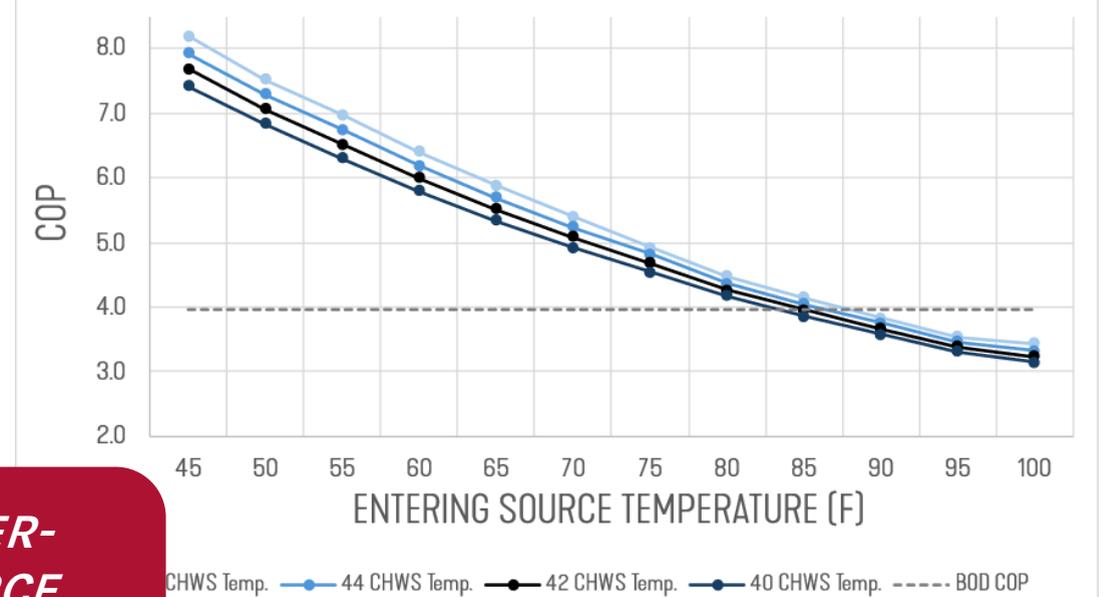


**AIR-SOURCE  
CHILLER  
HEATER**

Heating COP vs Entering Source Temperature

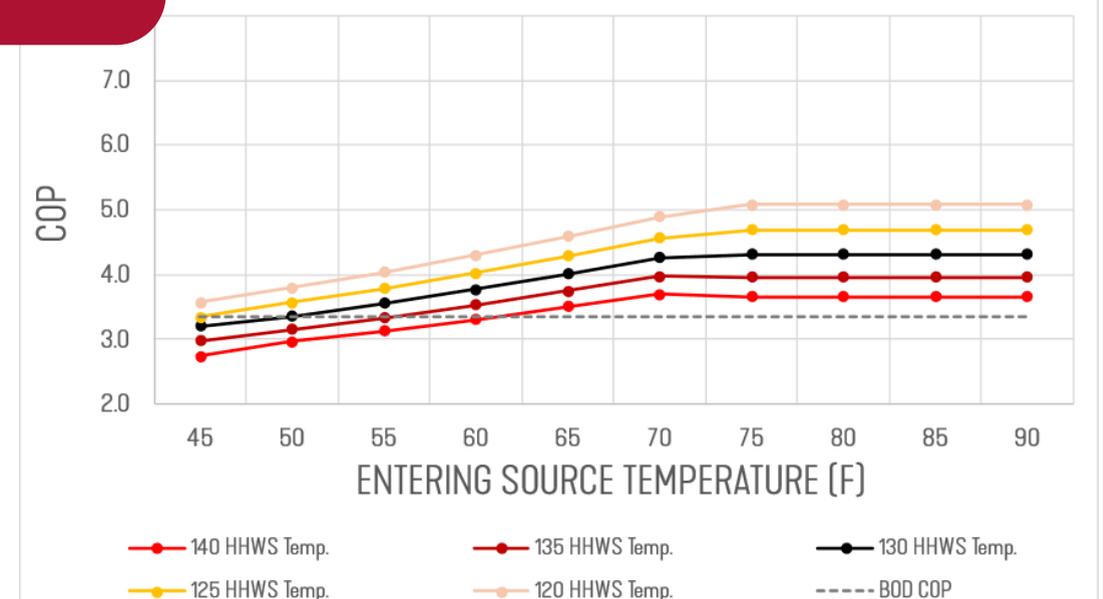


Cooling COP vs Entering Source Temperature



**WATER-SOURCE  
CHILLER  
HEATER**

Heating COP vs Entering Source Temperature



# PLANT CONTROL MODES

## BALANCED

*Mode is enabled when building HVAC load is balanced and source-sink loop temperature is steady.*

*Building heating and cooling is achieved through simultaneous heating and cooling internal to User Equipment and through the geexchange loop.*

## HIGH COOLING

*Building is heavily cooling dominant, geexchange loop temperature is warm, and plant requires auxiliary equipment to meet cooling load.*

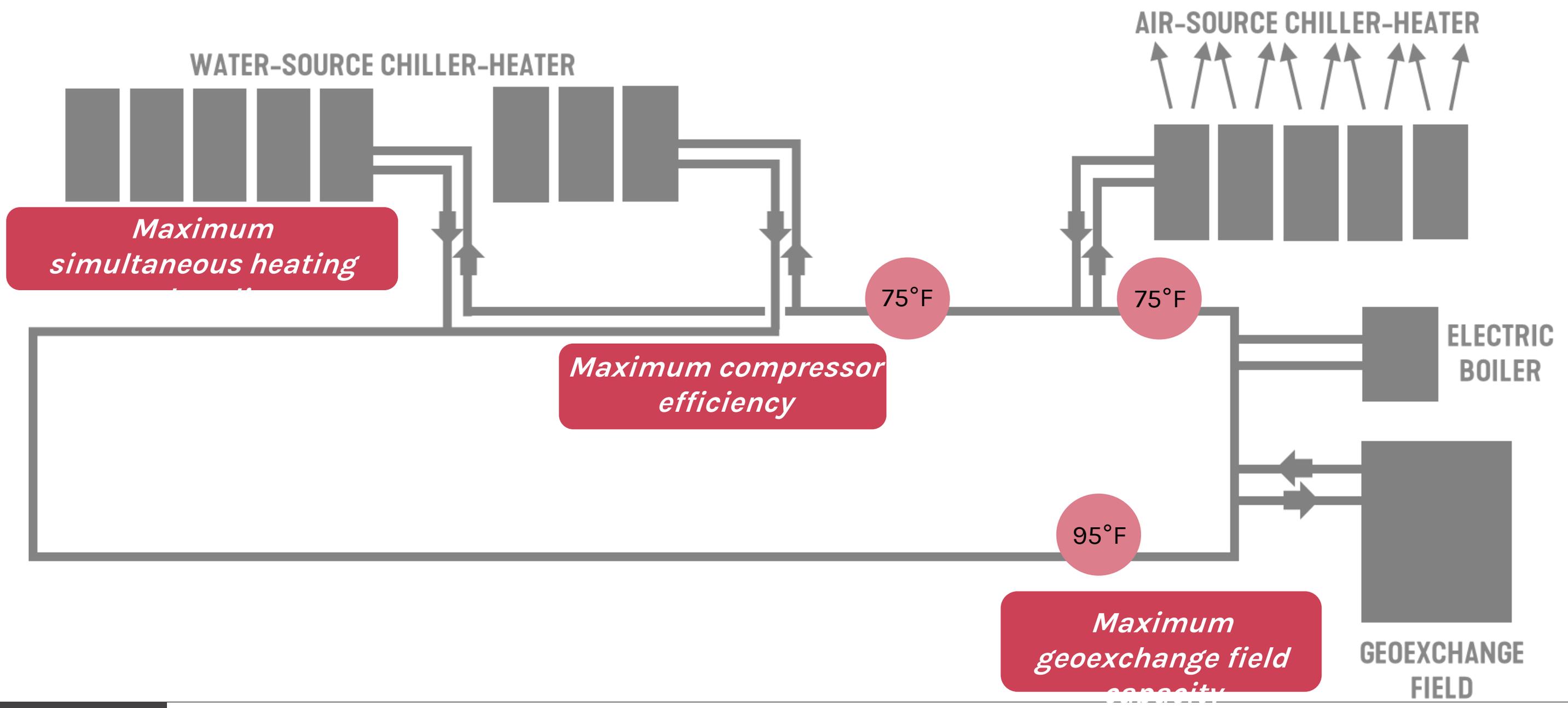
*Mode is enabled when User Equipment entering water temperature is greater than or equal to 85 F, and source-sink loop return temperature is increasing.*

## HIGH HEATING

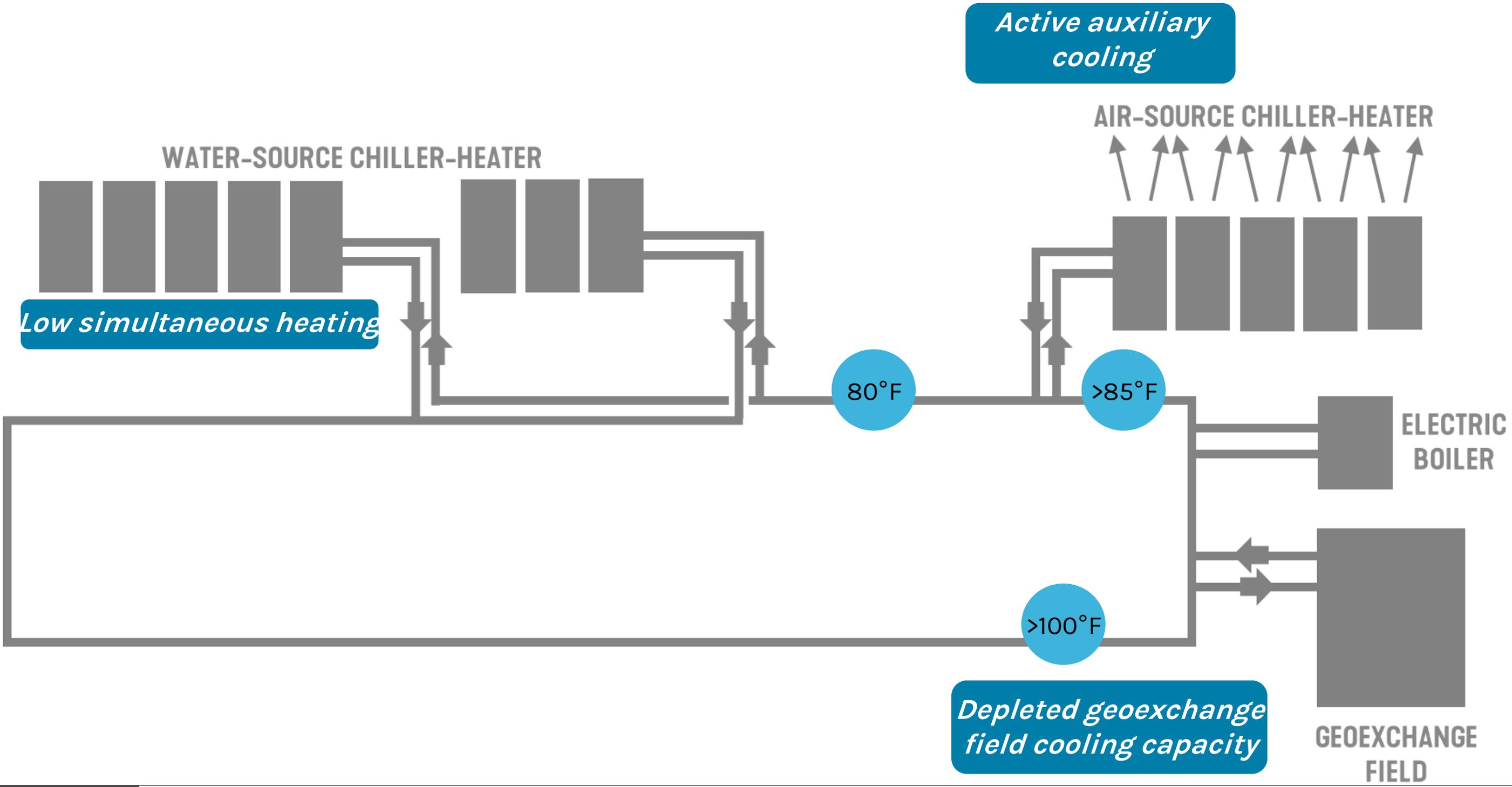
*Building is heavily heating dominant, geexchange loop temperature is cold, and plant requires auxiliary equipment to meet heating load.*

*Mode is enabled when User Equipment entering water temperature is less than or equal to 65 F and source-sink loop return temperature is decreasing.*

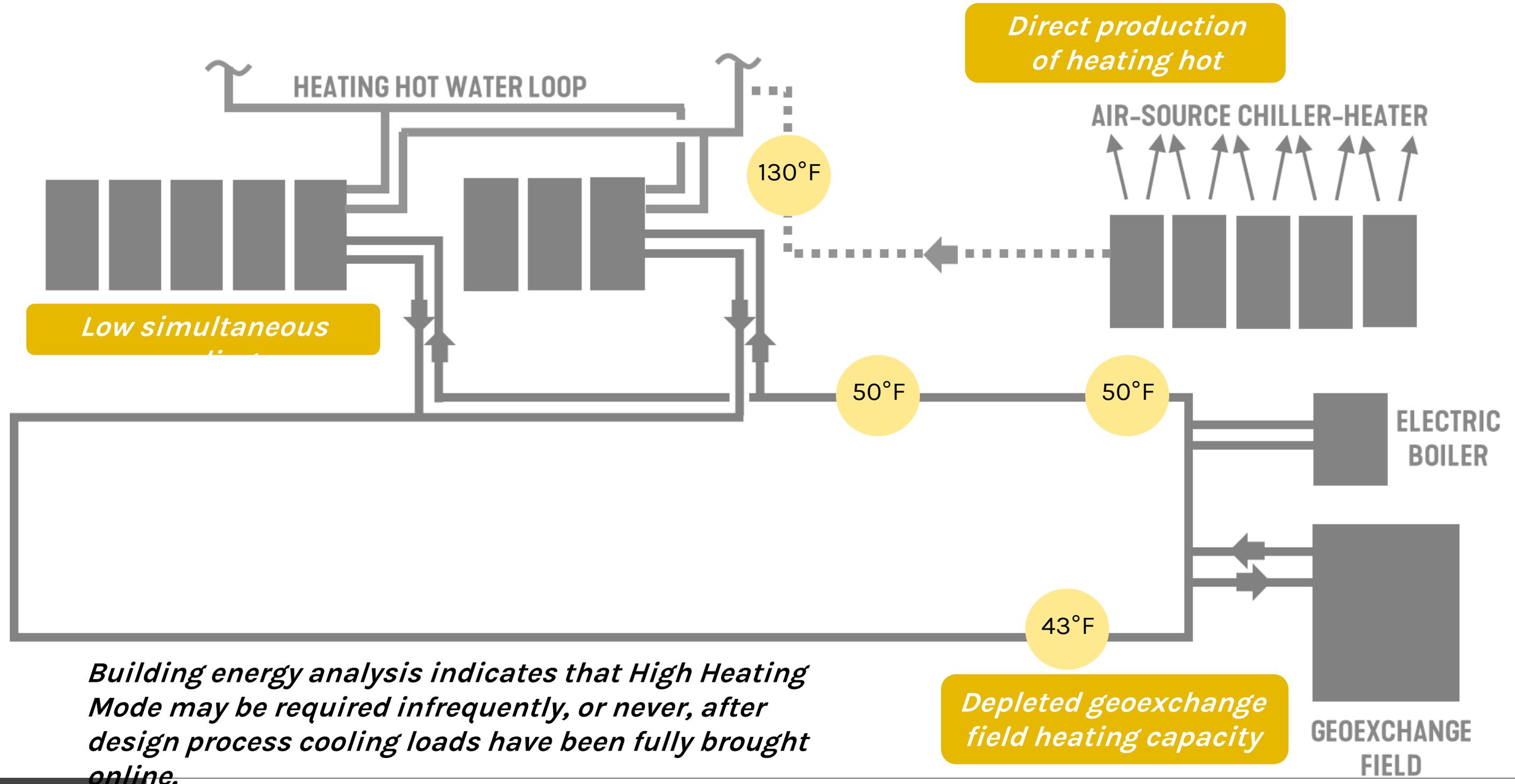
# CONTROL MODE: BALANCED



# CONTROL MODE: HIGH COOLING



# CONTROL MODE: HIGH HEATING



# CONTROLS STRATEGIES

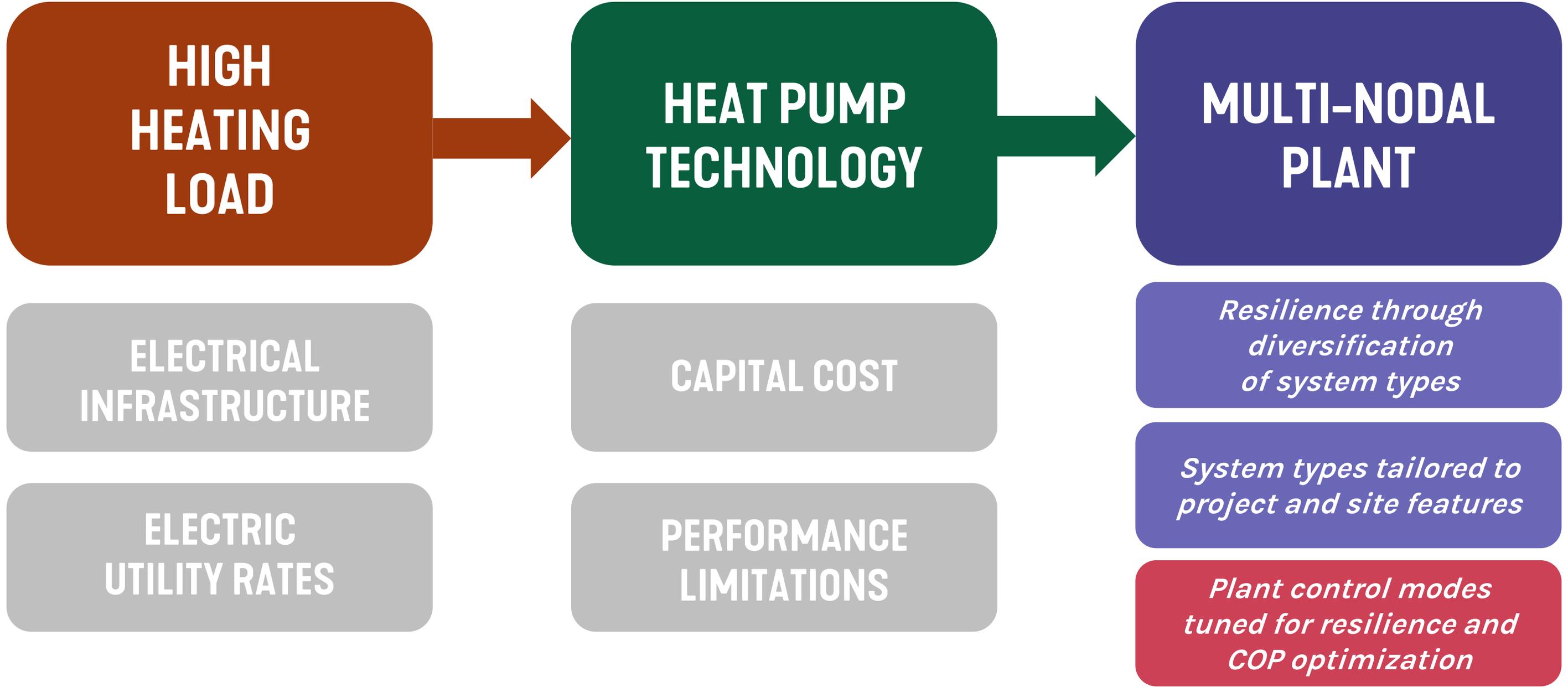
*Be responsive to seasonal  
geoexchange field capacity  
fluctuations*

*Maintain system redundancy  
for each anticipated load  
condition*

*Accommodate equipment  
operating envelopes bounded  
by entering water temperature  
and ambient air conditions*

*Operate central plant  
equipment at highest  
coefficient of performance*

# SUMMARY



**QUESTIONS?**

