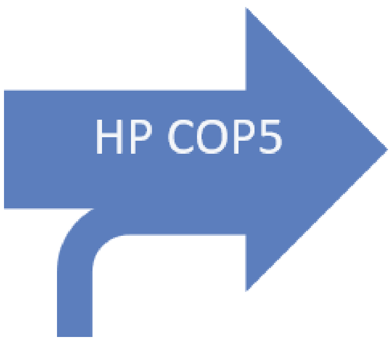
Electrification 101

COP AND HEAT PUMP EFFICIENCY

COP (Coefficient of Performance) = energy out / energy in

The higher the COP, the more heat can be produced for the same amount of electricity.

CHW
0.8 kW in
-\$0.014 – -\$0.023/kWh
-0.0724 lbs CO_2/kWh



Heating
1 kW out
\$0.01 – \$0.017 /kWh
0.0546 lbs CO_2/kWh

Electric
0.2 kW in
\$0.024 – \$0.04 /kWh
0.127 lbs CO_2/kWh

CHW
0.5 kW in
-\$0.009 – -\$0.014/kWh
-0.0453 lbs CO_2/kWh

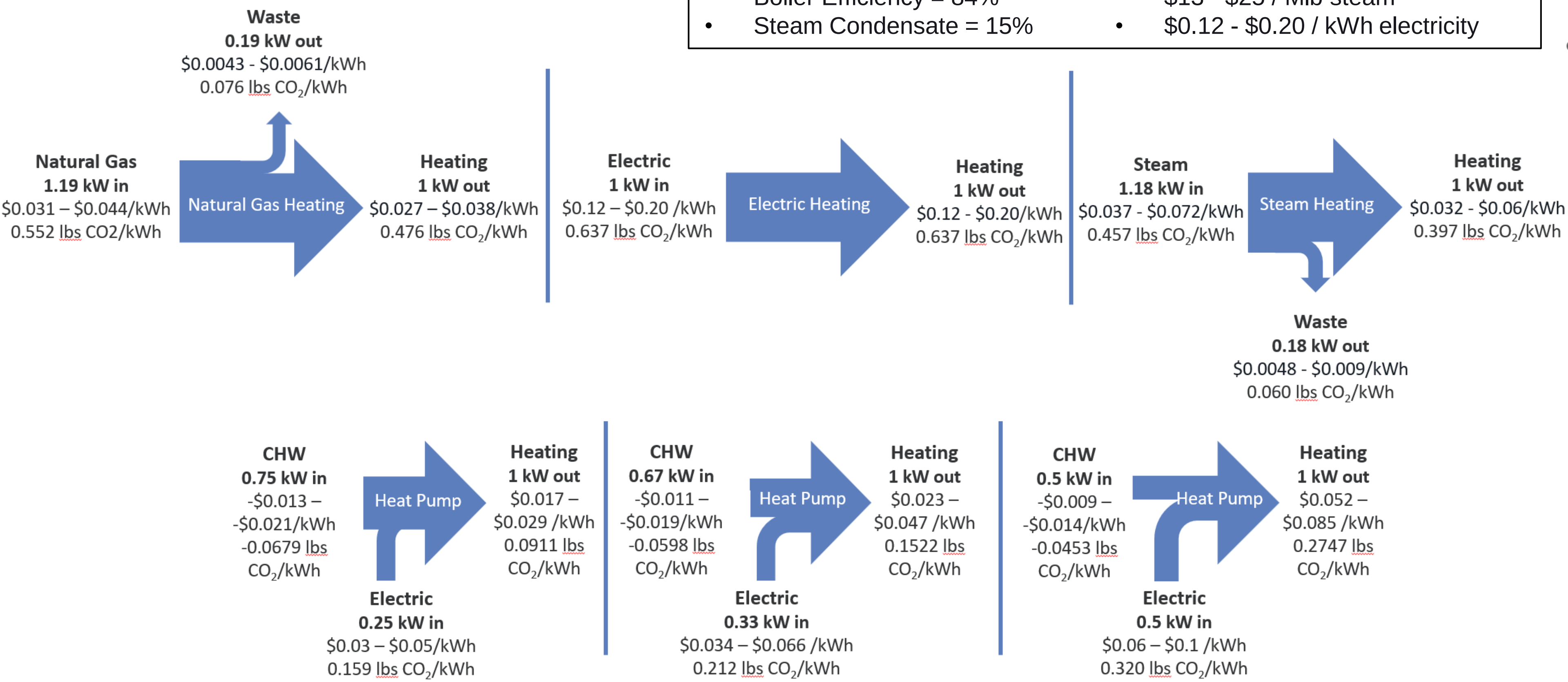
Heating
1 kW out
\$0.052 – \$0.085 /kWh
0.2747 lbs CO_2/kWh

Electric
0.5 kW in
\$0.06 – \$0.1 /kWh
0.320 lbs CO_2/kWh

PRODUCTION OF 1 KW OF HEAT BY FUEL TYPE

Assumptions:

- CHW Plant = 0.5 kW/ton
- Boiler Efficiency = 84%
- Steam Condensate = 15%
- $0.80 - $1.20 / therm natural gas
- $13 - $25 / Mlb steam
- $0.12 - $0.20 / kWh electricity



Heating COP = 1 / 0.25 = 4

Cooling COP = 0.75 / 0.25 = 3

Combined COP = (1 + 0.75) / 0.25 = 7

Heating COP = 1 / 0.33 = 3

Cooling COP = 0.67 / 0.33 = 2

Combined COP = (1 + 0.67) / 0.33 = 5

Heating COP = 1 / 0.5 = 2

Cooling COP = 0.5 / 0.5 = 1

Combined COP = (1 + 0.5) / 0.5 = 3

SMITH ENGINEERING

Heat Pumps 101

TYPES OF HEAT SOURCES

First Question. “What is my heat source(s)?”

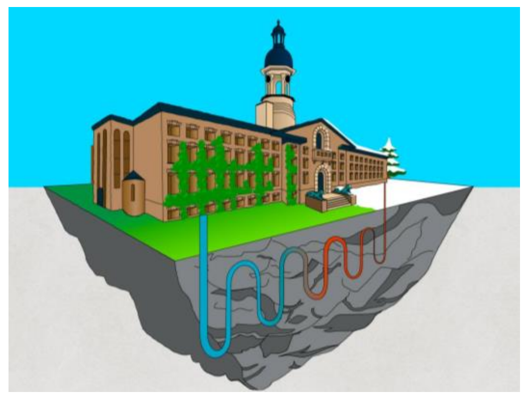
Air-Source

COP: <1 to 3.5

Outside Air
Exhaust Air
Electrical RM Air
MER Air
Process Air (React)

Ground-Source

COP: 3 to 5



Geo-Exchange
Lake Water
River Water
Ground Water
Ocean Water

Simultaneous Heating and Cooling

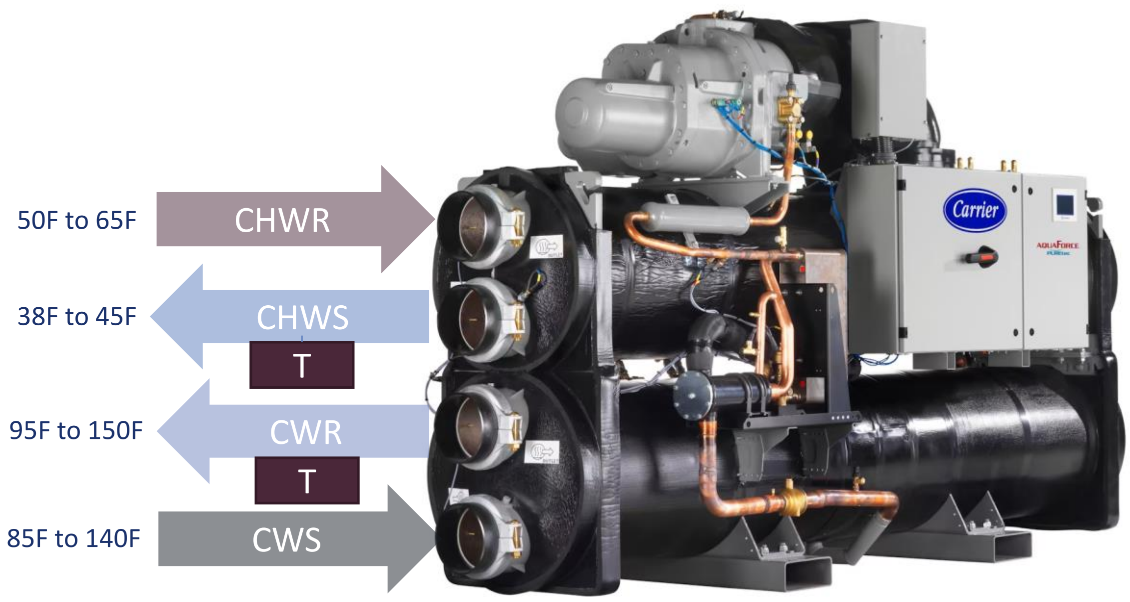
COP: 4 to 8

Process CHW/CW
CHW (Econ Off)
Water Cooled Air Comp
Freezers/Icemakers
Computer Rooms

SMITH ENGINEERING

HEAT PUMP VS HEAT RECOVERY

Heat Recovery Chiller
Control to LCHWT



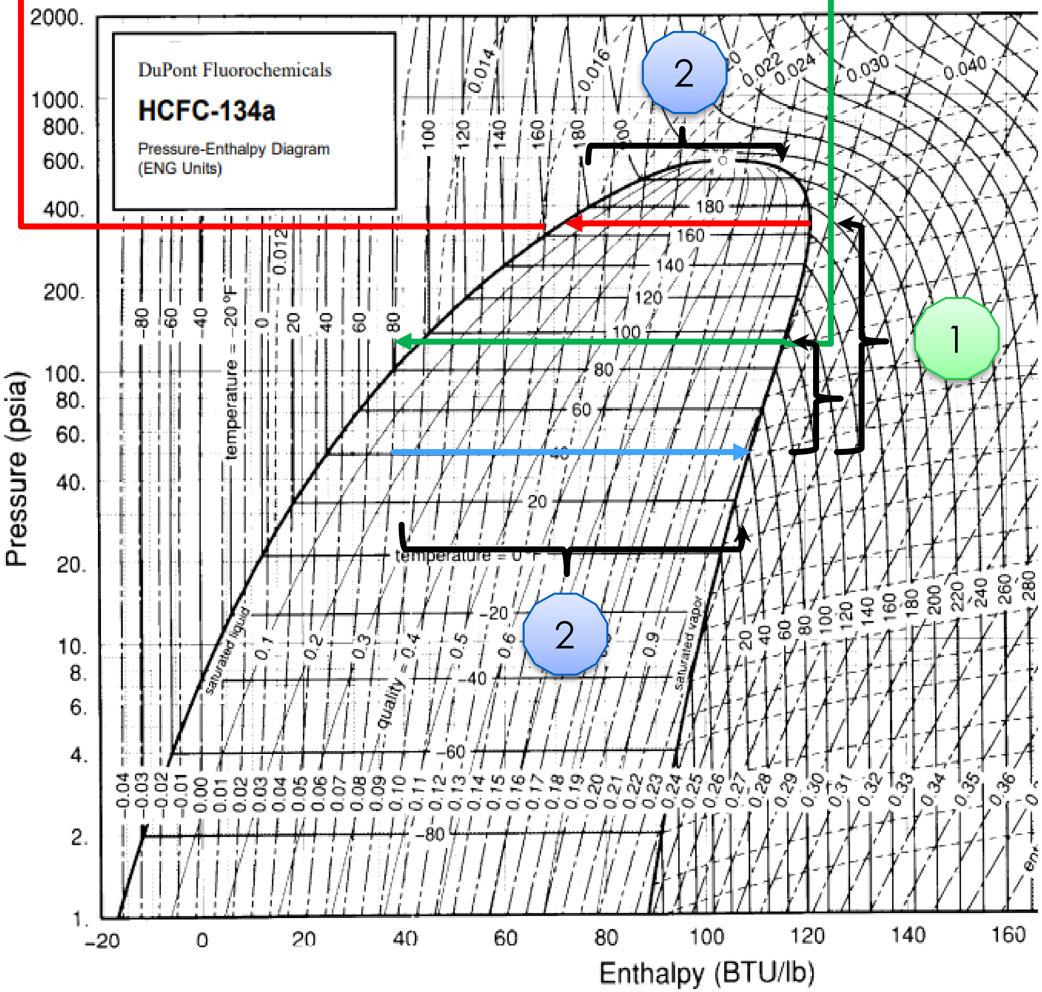
Heat Pump Chiller
Control to LCHWT or LCWT

SMITH ENGINEERING

CHALLENGES – HEAT PUMP CONSTRUCTION/OPERATION

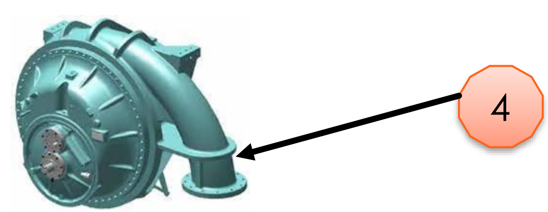
Heat Pump Chiller
165F (73.9C)
318 PSI (21.97 Bar)

Normal Chiller
95F (35.0 C)
113.3 PSIA (7.817 Bar)



Four Major Challenges:

1. Increase lift
   - Overcome by multiple stages
2. Decreased Δh – Vapor dome narrows at high pressure/temperature.
   - Improved with improved subcooling and/or flash interstage economizer
3. High Lift Surge – Centrifugal compressors do not like to unload at high lift. Turndown is limited.
4. Pressure
   - Overcome by special compressor castings.

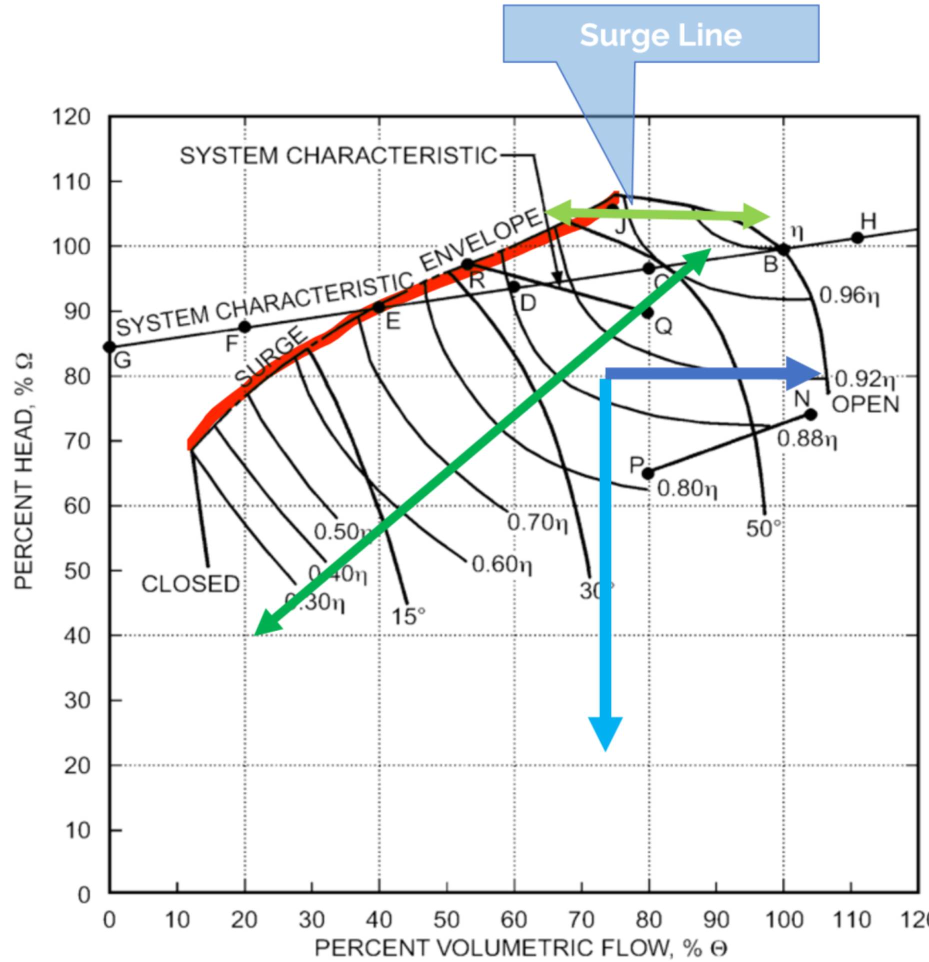


SMITH ENGINEERING

CHALLENGES - Equipment Selection and Sizing

Chiller/Heat Pump operation can be moved away surge line by:

1. Increasing mass flow
   - Increase load
   - Hot gas bypass
2. Reducing the refrigerant lift
   - Drop HHW supply temp – HHW Supply Temp Reset



Traditional Refrigeration — lift can be reduced at reduced loads

Heat Pump Chiller — Sustained high lift even at low loads (Especially at low evap loads)

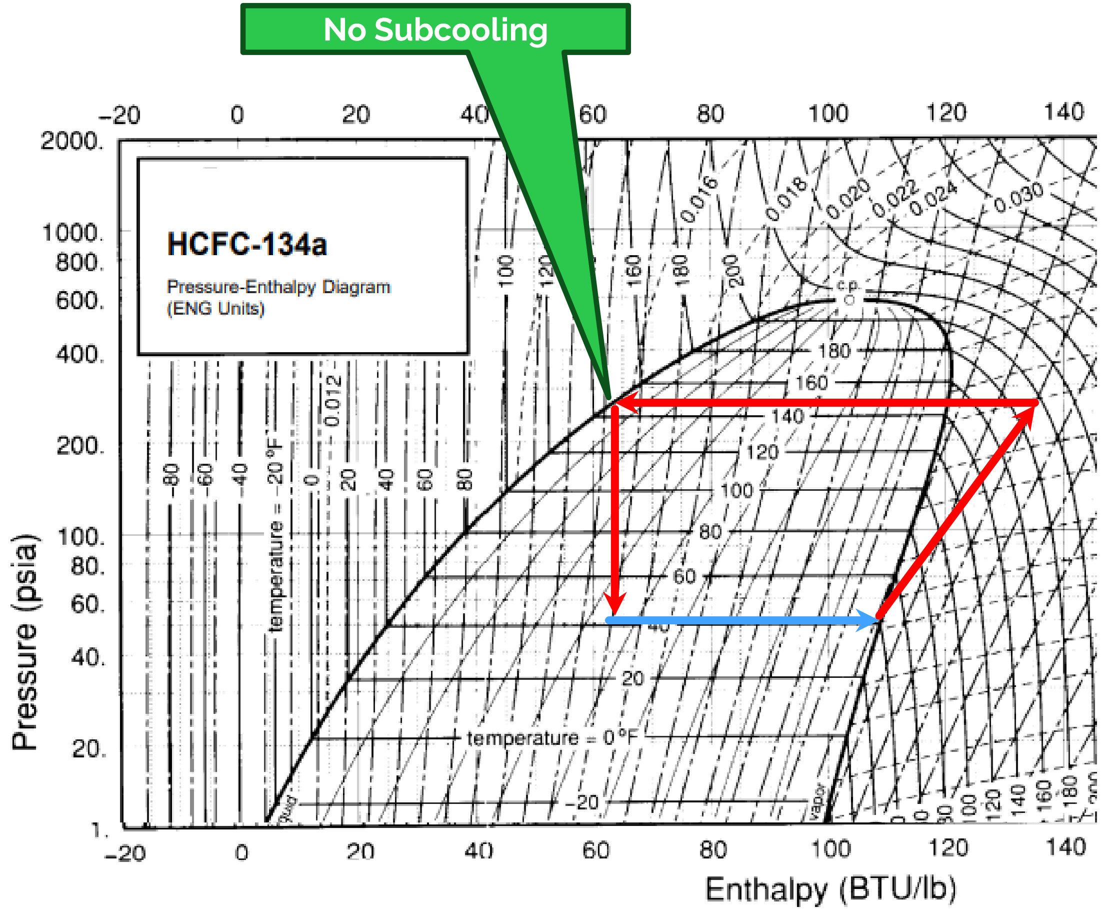
SMITH ENGINEERING

Public

Solution – Economizer: Liquid Subcooling vs Flash Gas Removal

No Subcooling No Flash Gas Recovery

1. High lift applications are very inefficient.
2. Low Δh per pound of refrigerant.
3. 45% of the refrigerant flashes prior to use in the evaporator. Only 55% of the mass flow is used in the evaporator for cooling.



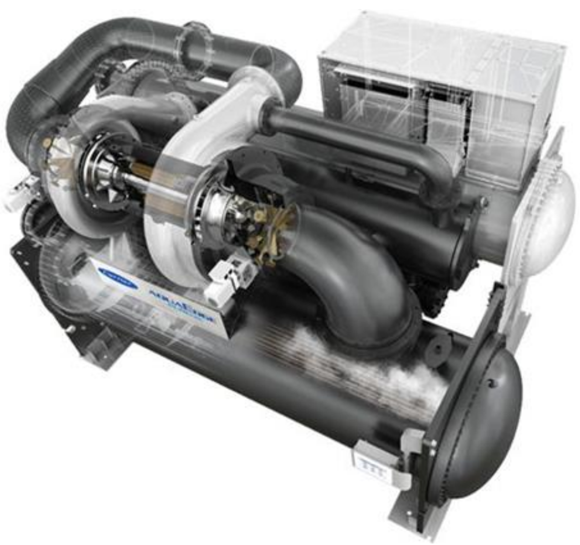
SMITH ENGINEERING

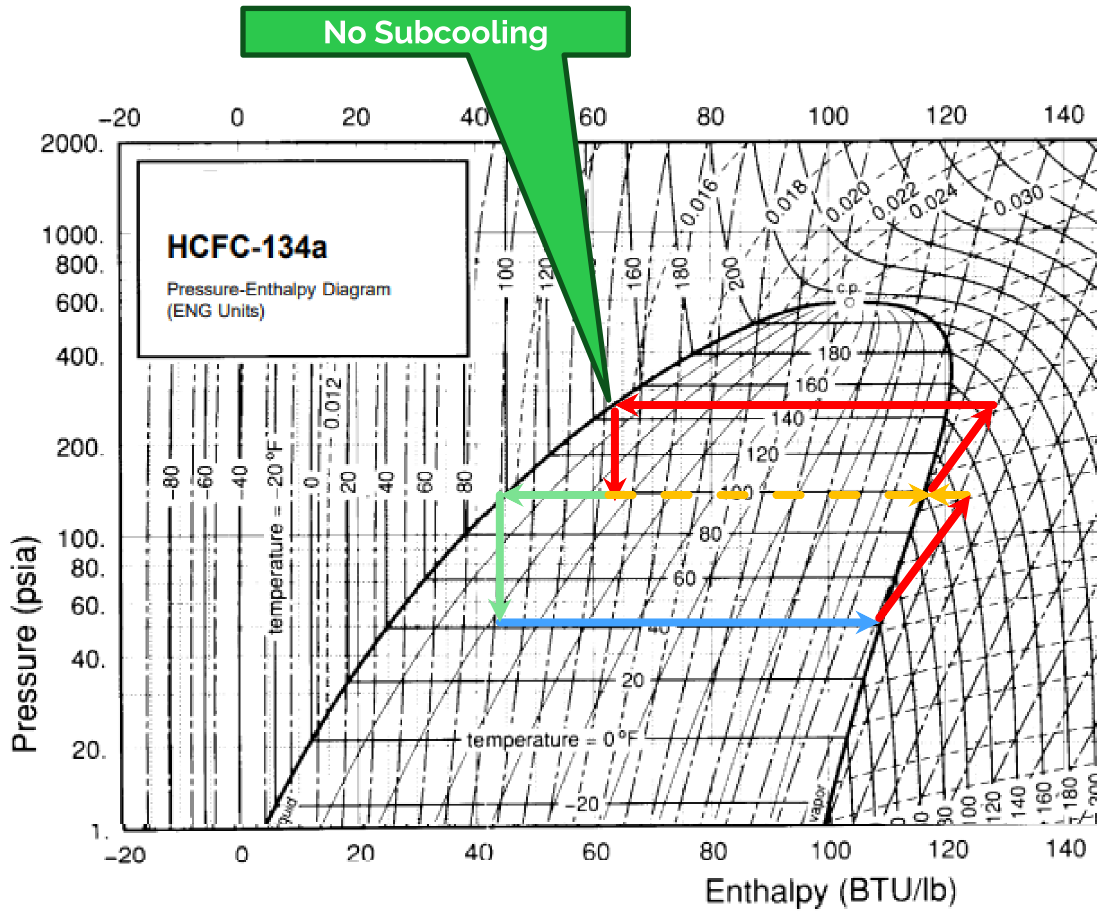
Public

Solution – Economizer: Liquid Subcooling vs Flash Gas Removal

No Subcooling w/ Flash Gas Recovery

1. Less critical with Flash Gas Recovery
2. Δh in Evap closer to traditional
3. More burden on the flash economizer. 25% of the refrigerant flashes in the economizer. 75% of the mass flow proceeds to the evaporator as liquid.



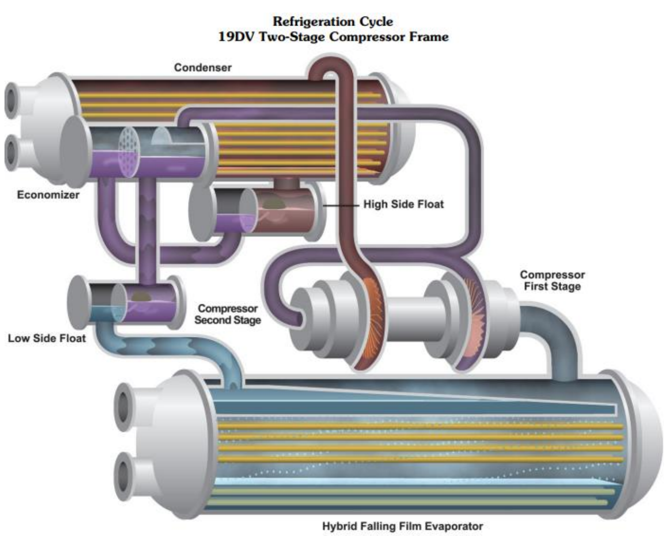


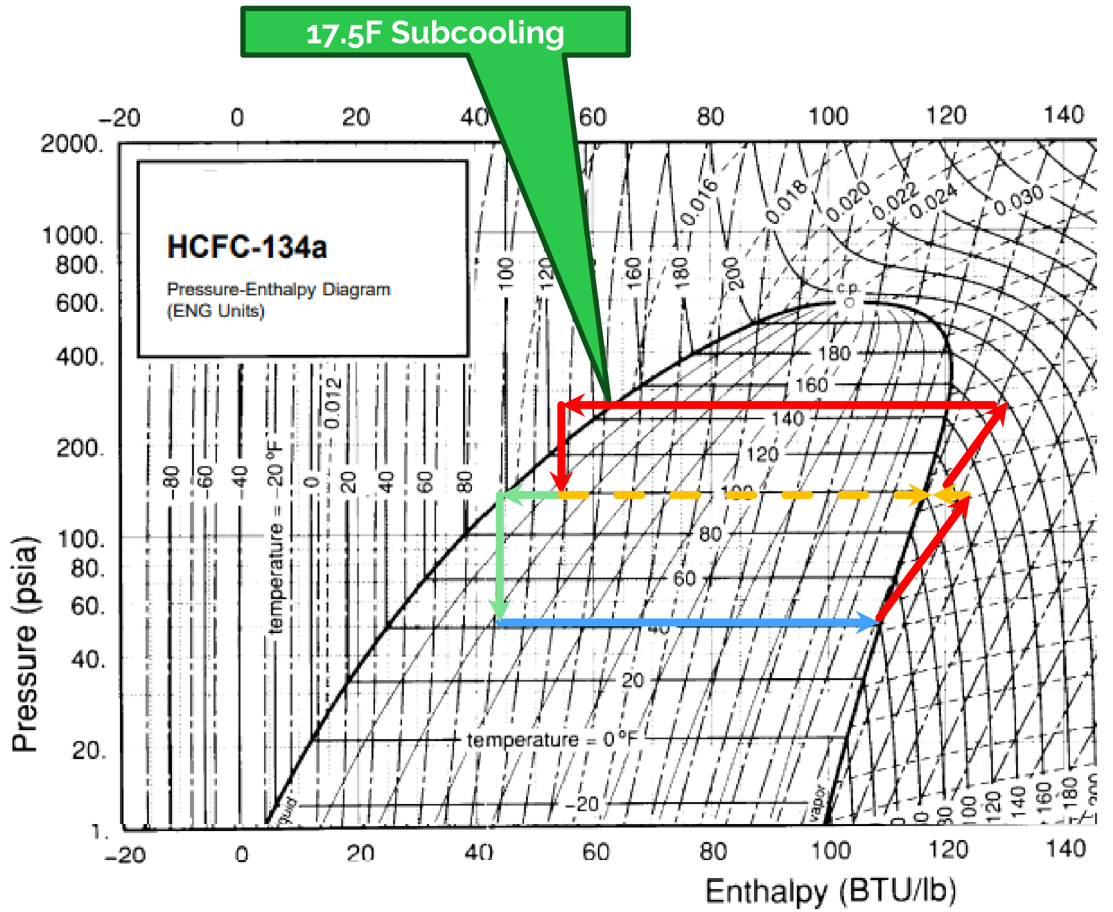
SMITH ENGINEERING

Solution – Economizer: Liquid Subcooling vs Flash Gas Removal

Subcooling w/ Flash Gas Recovery

1. Less critical with Flash Gas Removal
2. Less burden on the flash economizer. 12% of the refrigerant flashes in the economizer. 88% of the mass flow proceeds to the evaporator as liquid.
3. Subcooling is critical
   - More stable operation of flash economizer
   - Increased efficiency





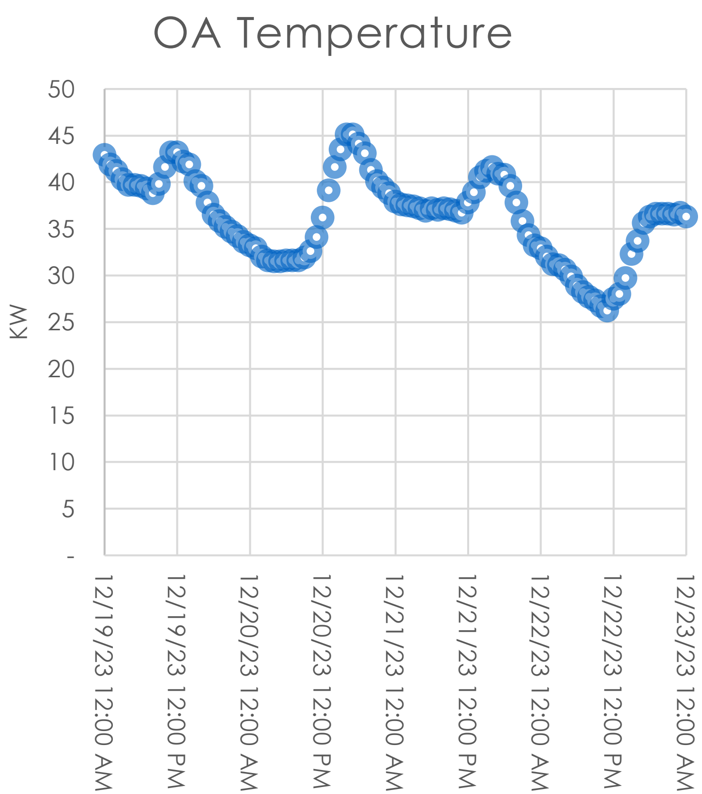
SMITH ENGINEERING

Public

Heat Recovery

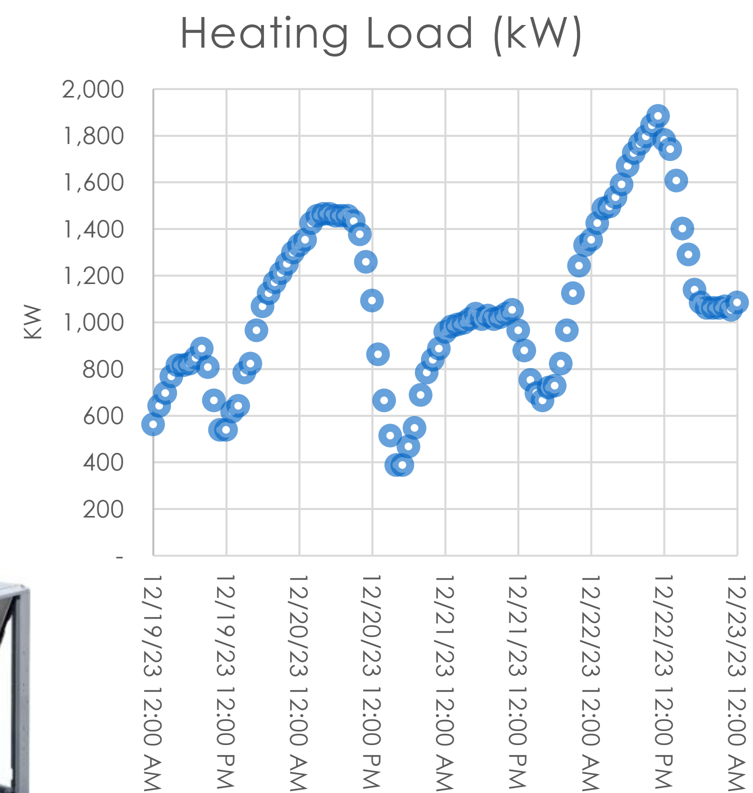
APPLICATION – AIR SOURCE

Heat Source: Air
Heat Sink: HHW
Special Consecration: Lower COP at Lower OAT



Heat

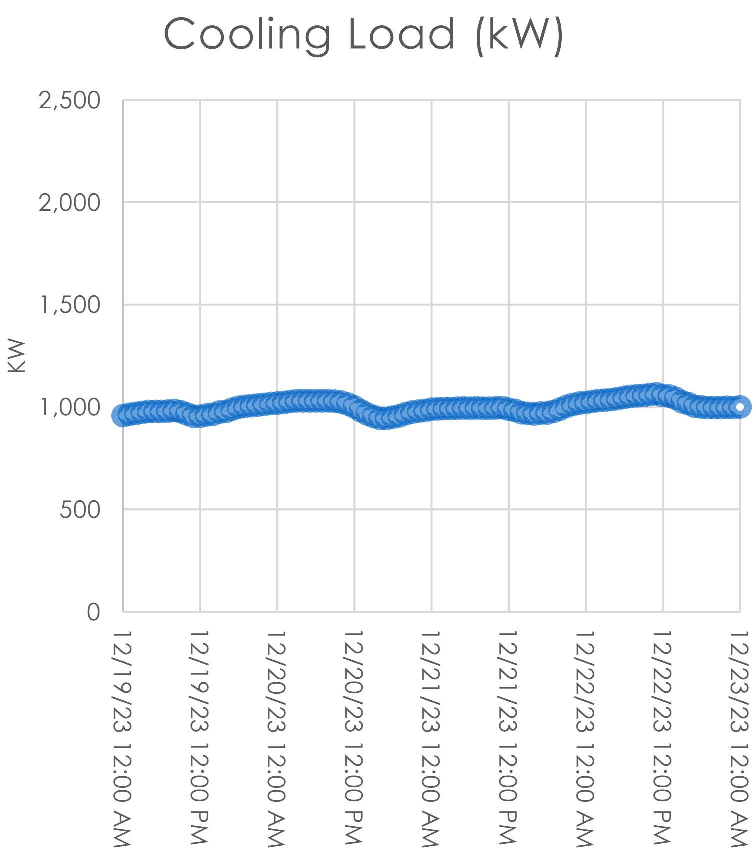
COP: <1 to 3.5

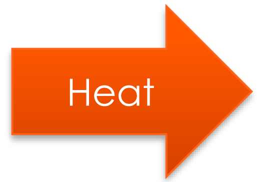


SMITH ENGINEERING

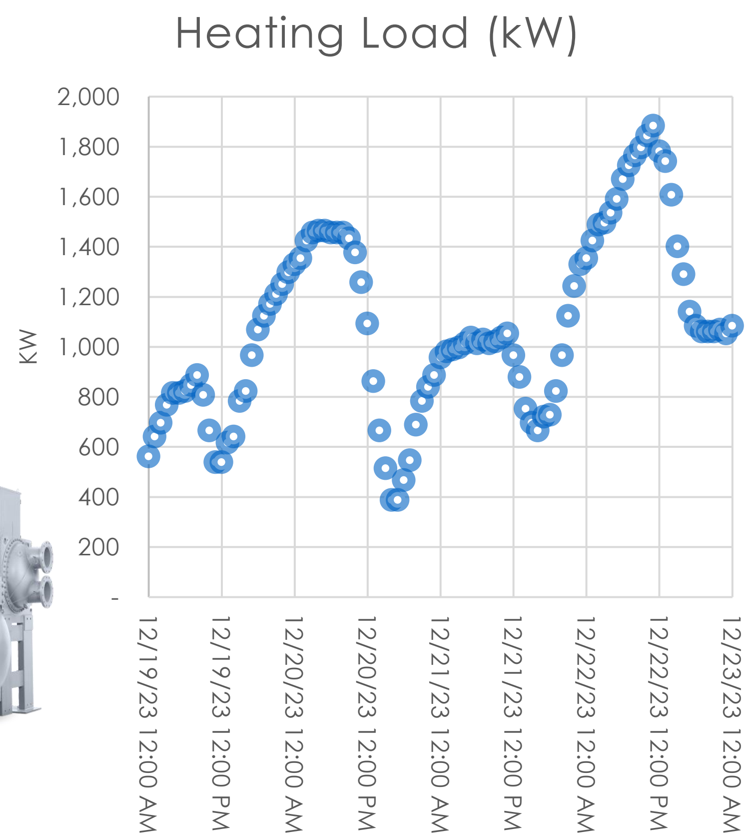
APPLICATION – CHW TO HHW

Heat Source: CHW (Data center / Data closets)
Heat Sink: HHW
Special Consecration: Thermal Storage or undersize the heat pump





COP: 4 to 7

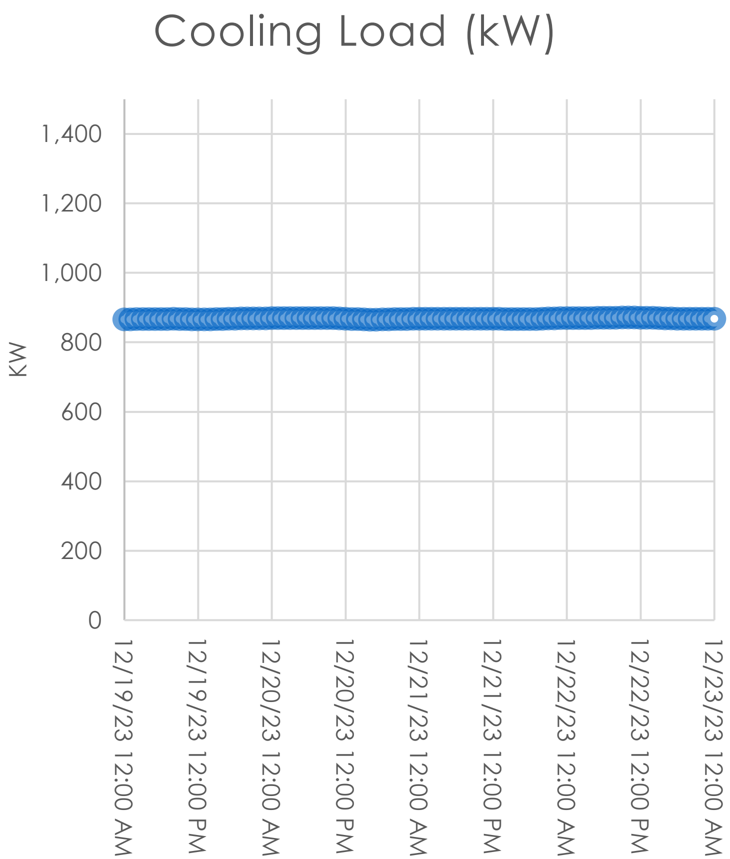


SMITH ENGINEERING

Public

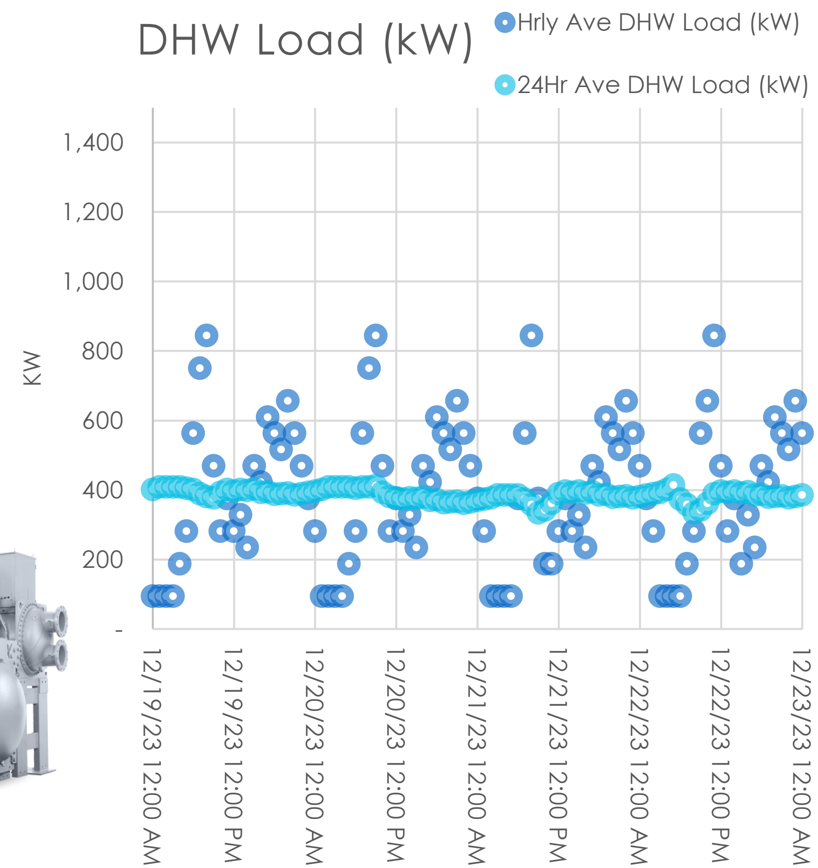
APPLICATION – CHW TO DHW

Heat Source: CHW (Data center / closets)
Heat Sink: HHW
Special Consecration: Thermal Storage



Heat

COP: 4 to 8



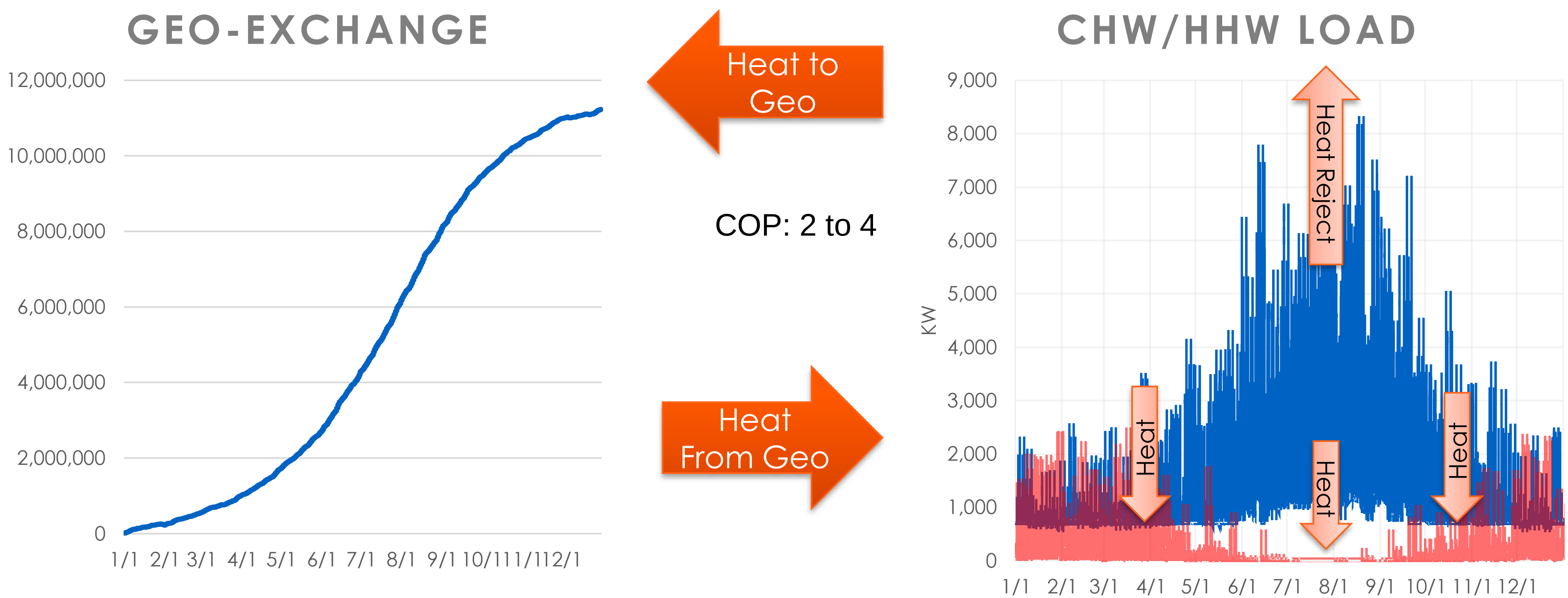
SMITH ENGINEERING

APPLICATION – GEO EXCHANGE / CHW AND HHW

Heat Source: CHW / Geo-Exchange
Heat Sink: HHW / Geo-Exchange
Special Consecration: Thermal Storage and Summer Heat Rejection
– Geo may not make sense

Geo-Exchange

Site heating and cooling load Profile

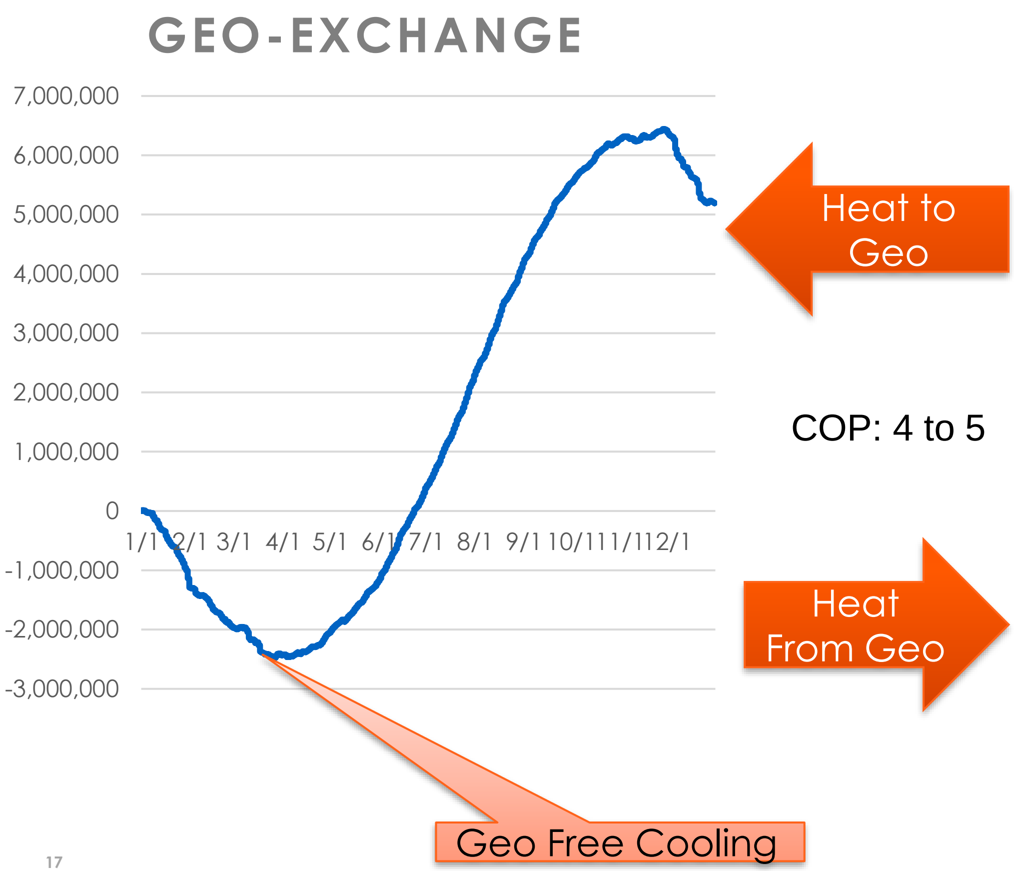


SMITH ENGINEERING

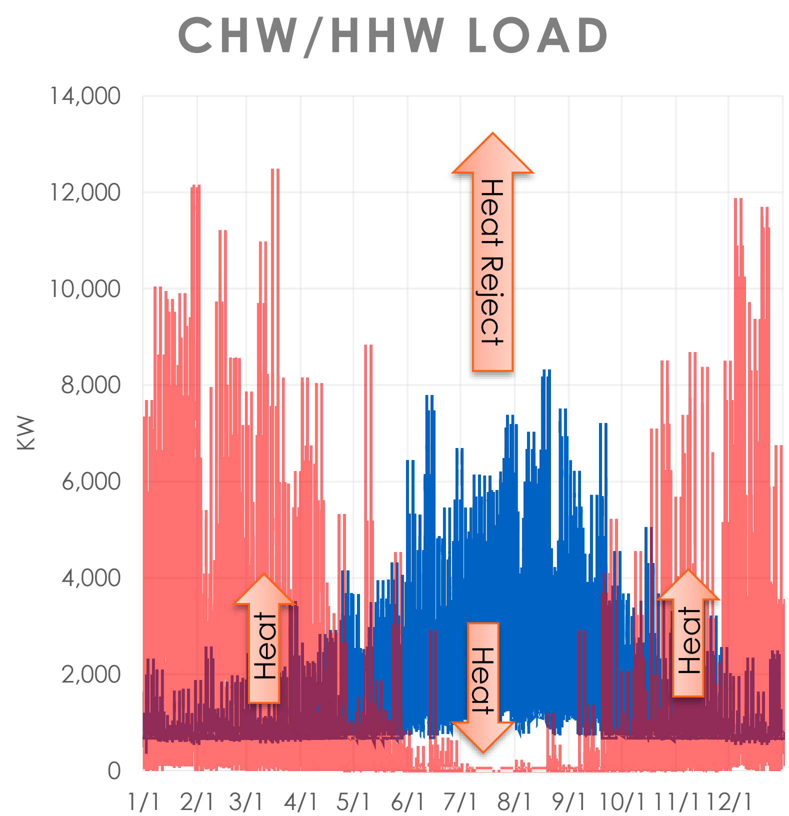
APPLICATION – GEO EXCHANGE / CHW AND HHW

Heat Source: CHW / Geo-Exchange
Heat Sink: HHW / Geo-Exchange
Special Consecration: Thermal Storage

Geo-Exchange

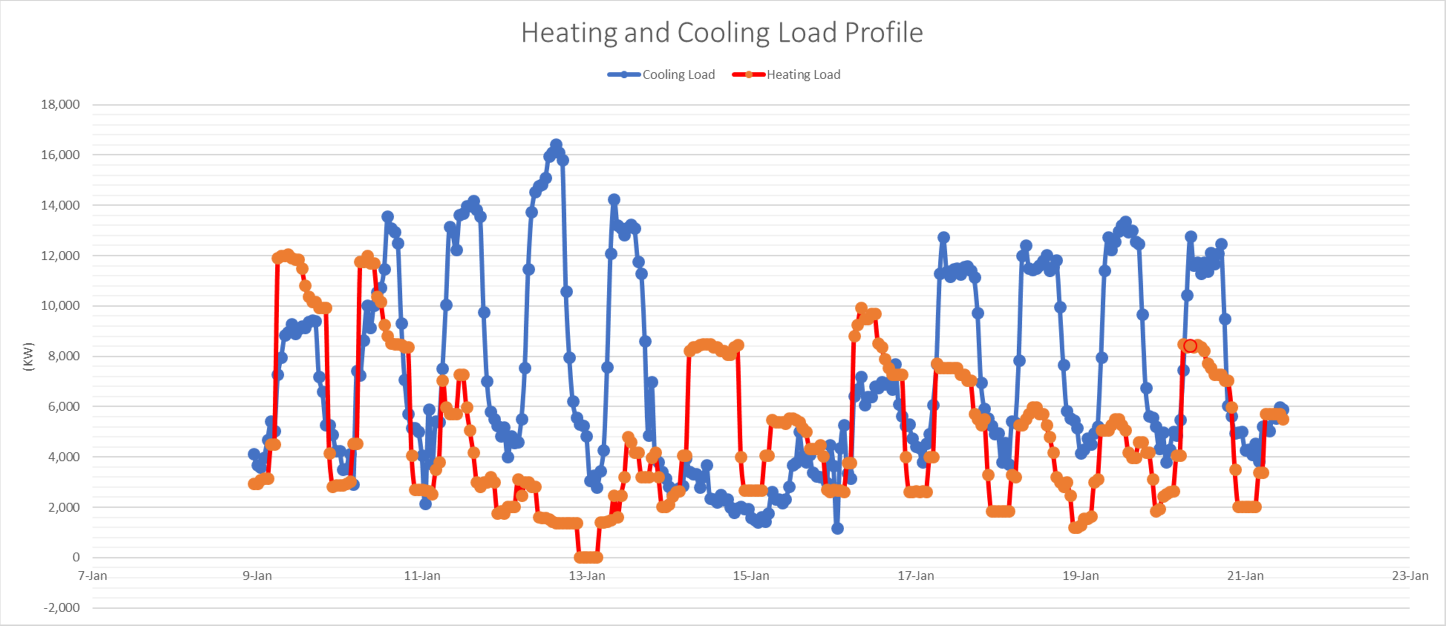


Site heating and cooling load Profile



Applications - Large Load Swings and Shifts

Thermal storage
Two heat pumps instead of one larger heat pump



SMITH ENGINEERING

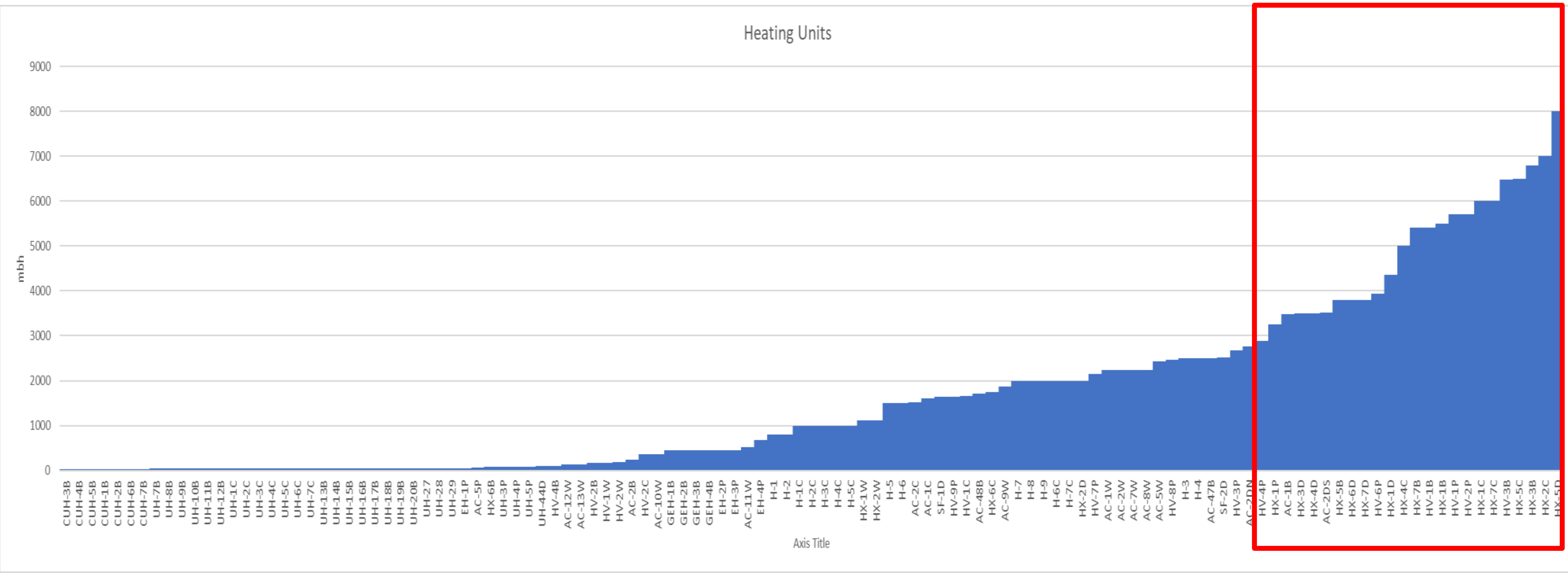
Public

Steam to Hot Water

Electrification — Steam to Hot Water

Cost Benefit

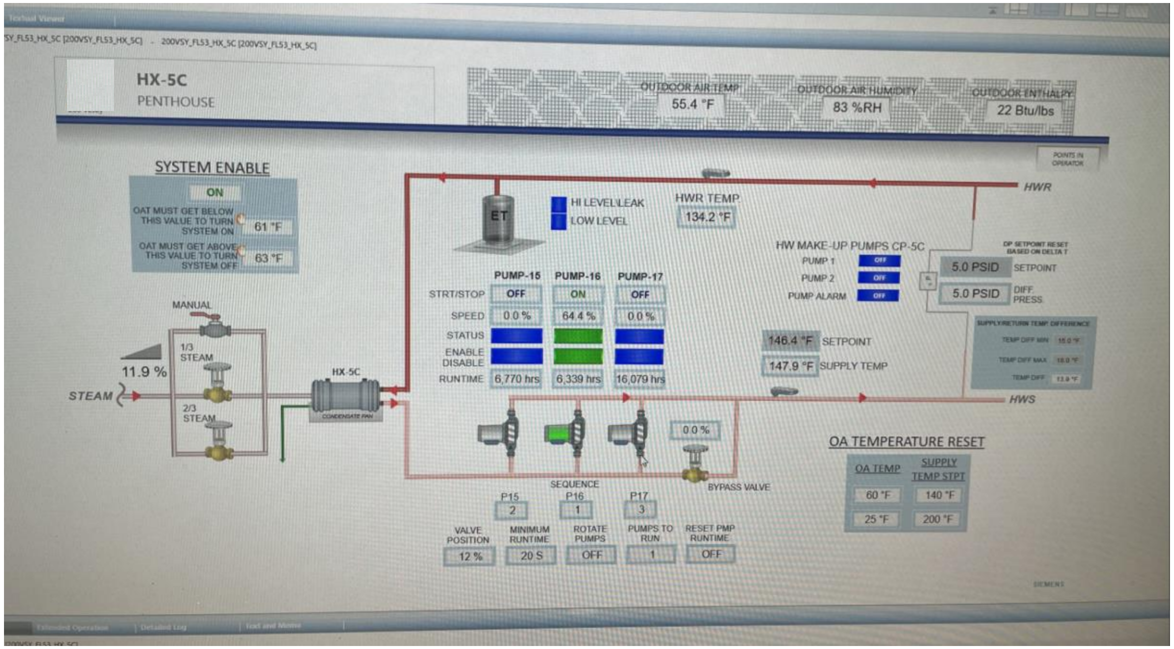
60% of the heating is performed by 19% of the units



SMITH ENGINEERING

Low HHW DT

SOLUTION



Many HHW loops are not well controlled

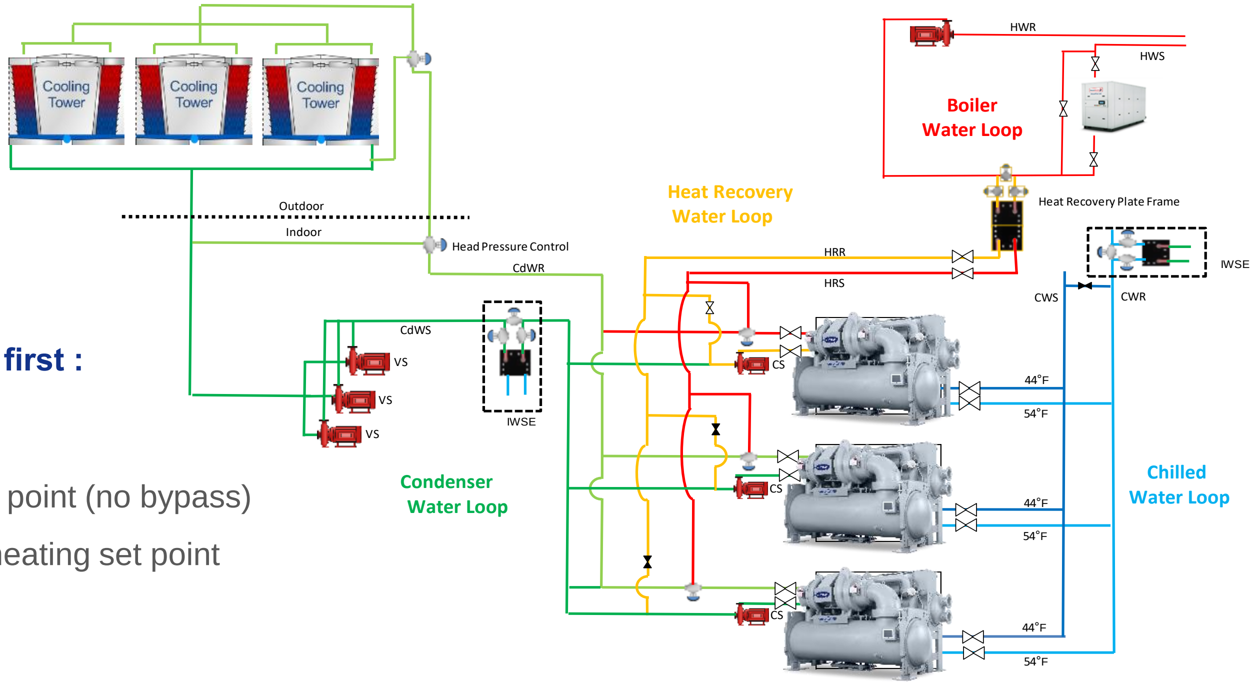
- Perimeter Fin tube
- Large VAV box reheat loops with poor HHW control

Solution:

- HHW loop DP reset based on HHW DT

Applications

Hybrid Heat Reclaim Plant



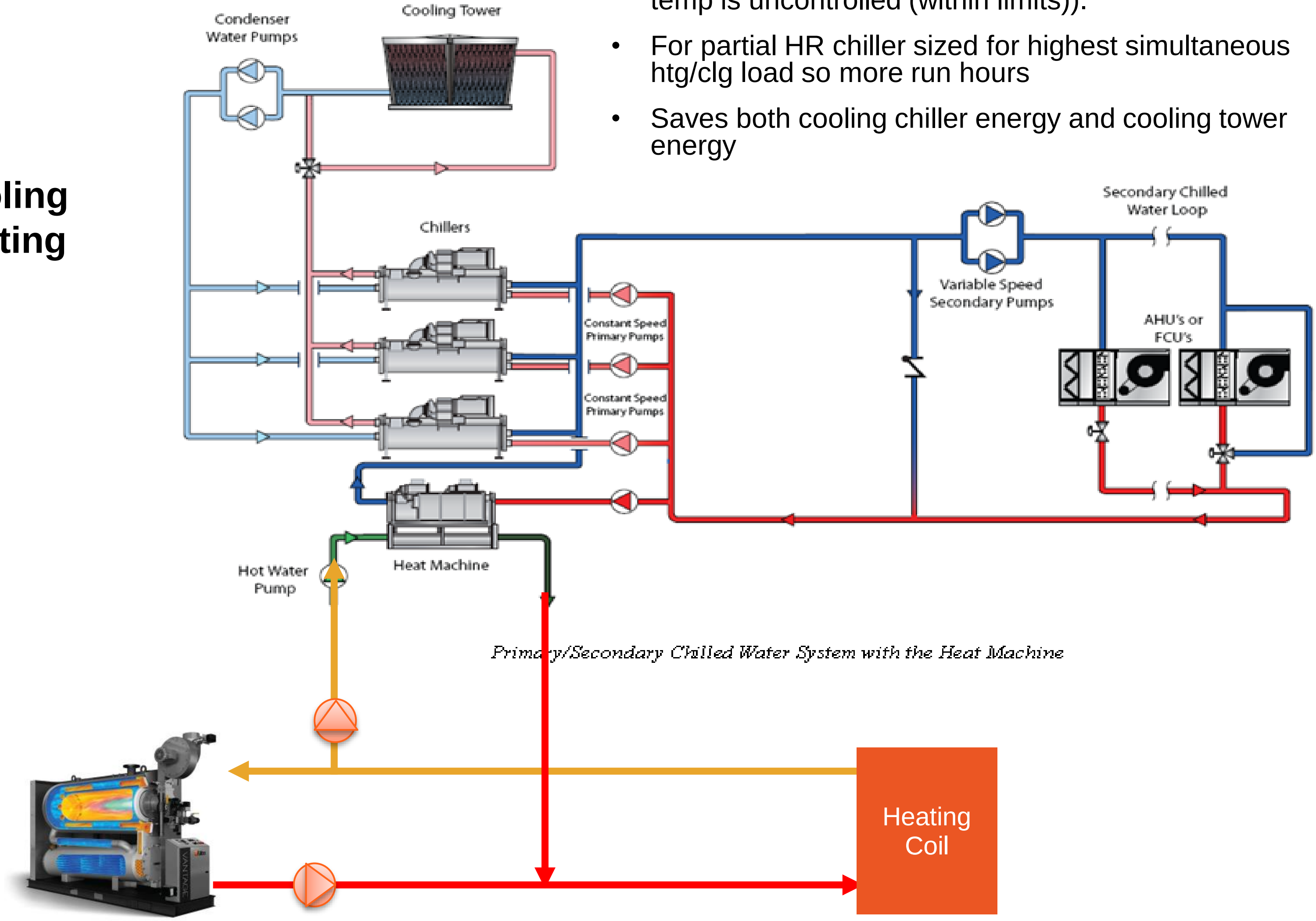
It's a high efficiency cooling plant first :

- Identical, interchangeable chillers
- Chillers stage to maintain CW set point (no bypass)
- Three way valve used to control heating set point

Chiller Plant with Dedicated Heating Chiller

- **Parallel Cooling**
- **Parallel Heating**

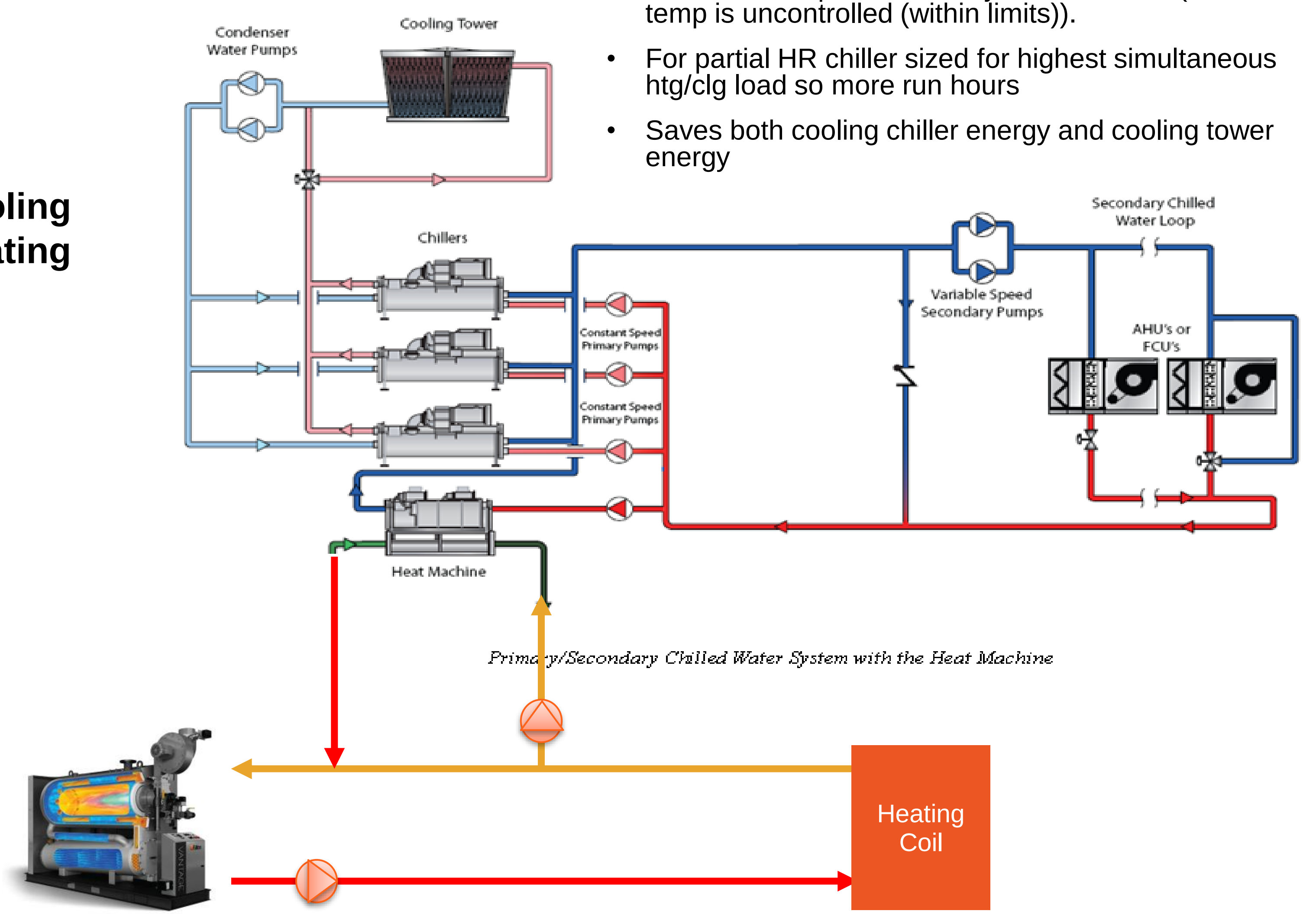
- Hot water temp controlled by heat machine (chilled water temp is uncontrolled (within limits)).
- For partial HR chiller sized for highest simultaneous htg/clg load so more run hours
- Saves both cooling chiller energy and cooling tower energy



Chiller Plant with Dedicated Heating Chiller

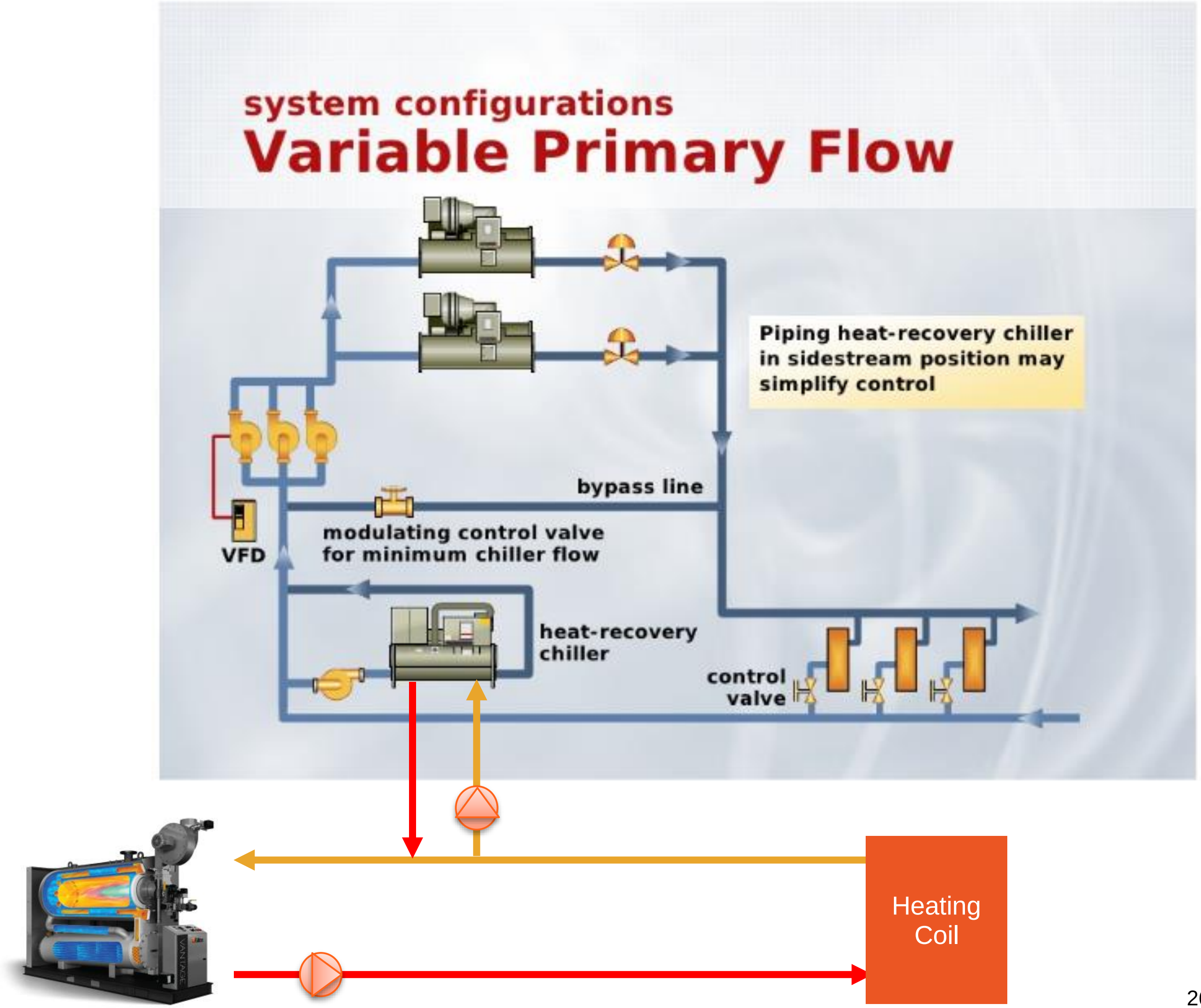
- **Parallel Cooling**
- **Sidecar Heating**

- Hot water temp controlled by heat machine (chilled water temp is uncontrolled (within limits)).
- For partial HR chiller sized for highest simultaneous htg/clg load so more run hours
- Saves both cooling chiller energy and cooling tower energy



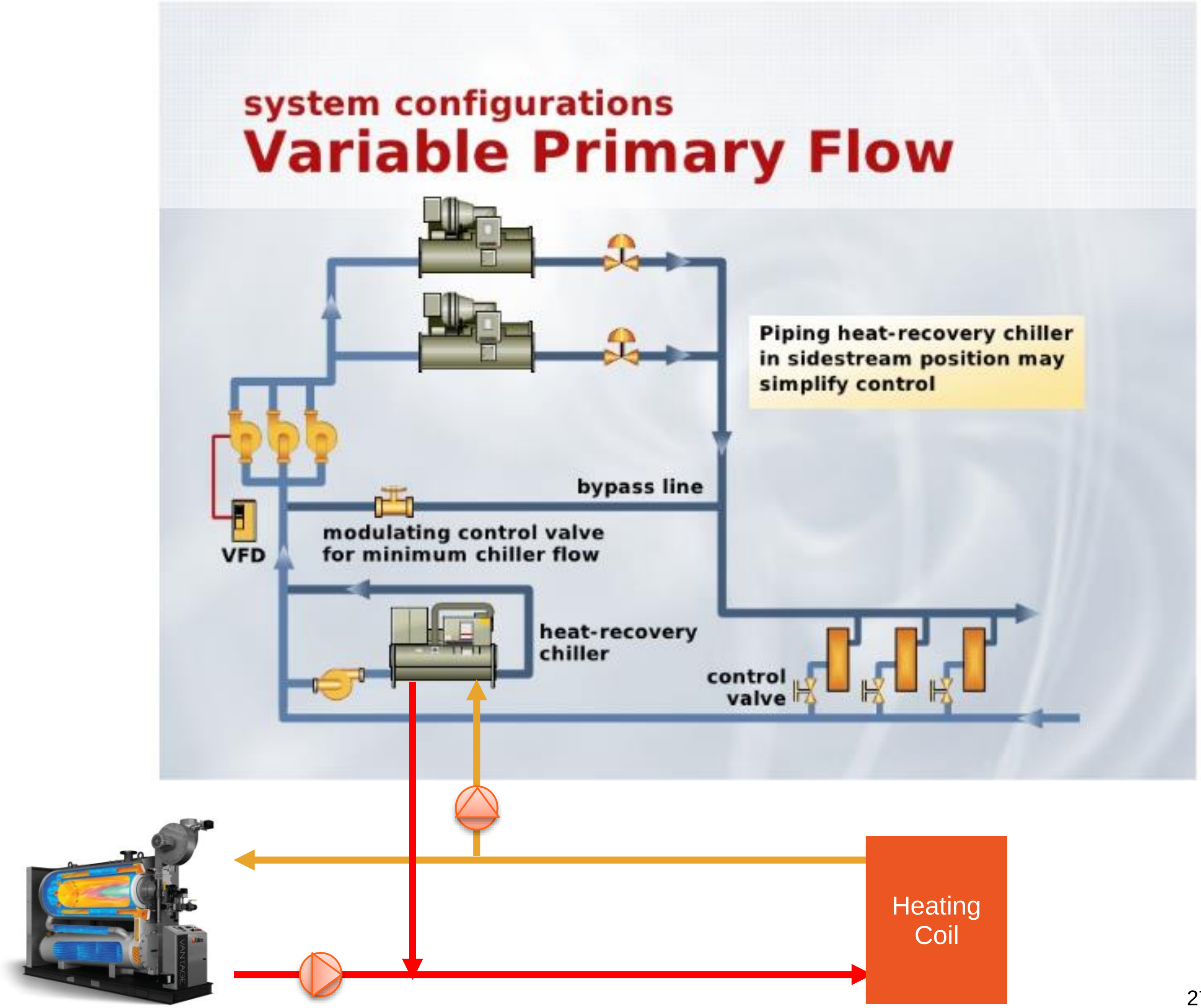
Chiller Plant with Dedicated Heating Chiller

- Sidecar Cooling
- Sidecar Heating



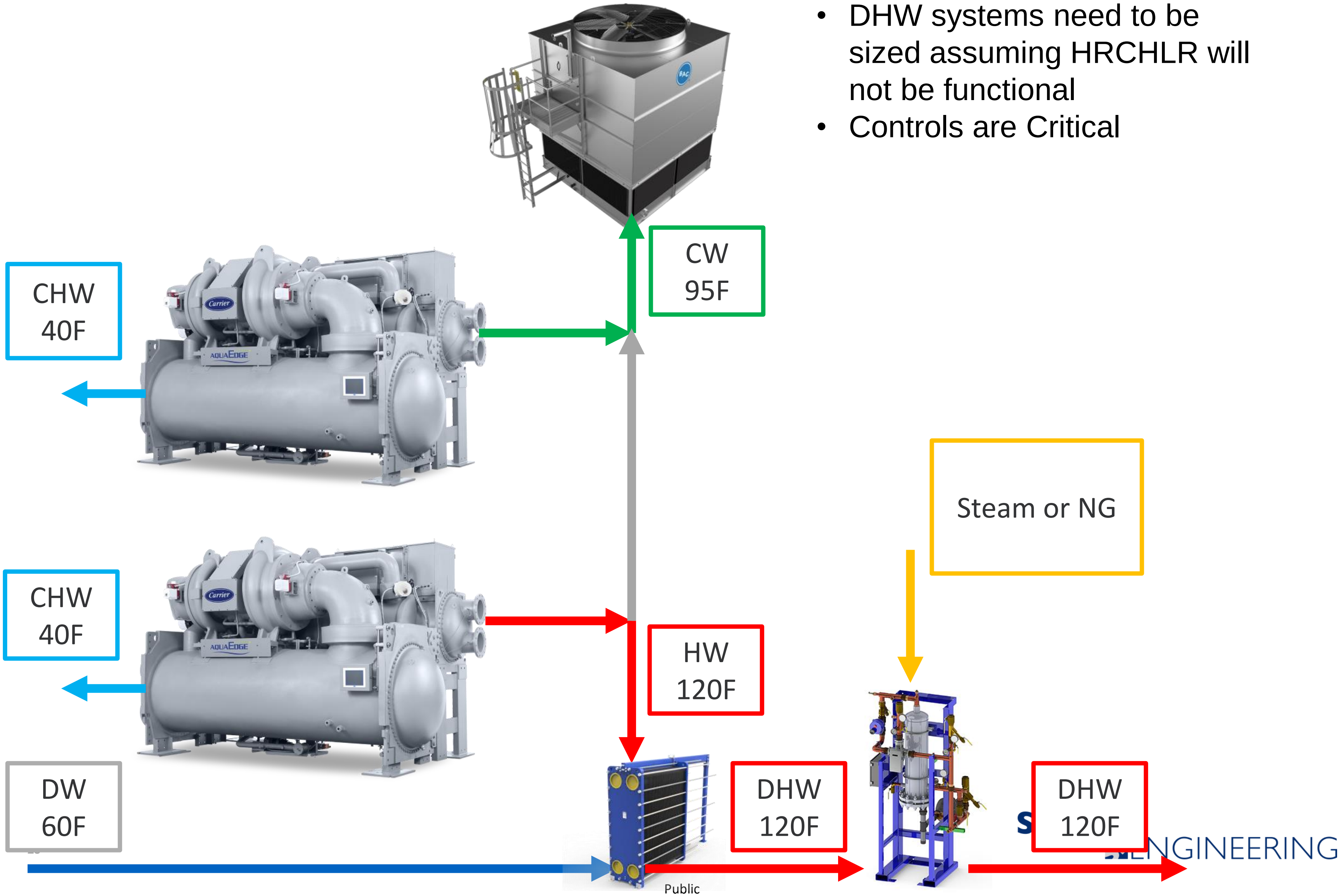
Chiller Plant with Dedicated Heating Chiller

- **Sidecar Cooling**
- **Parallel Heating**



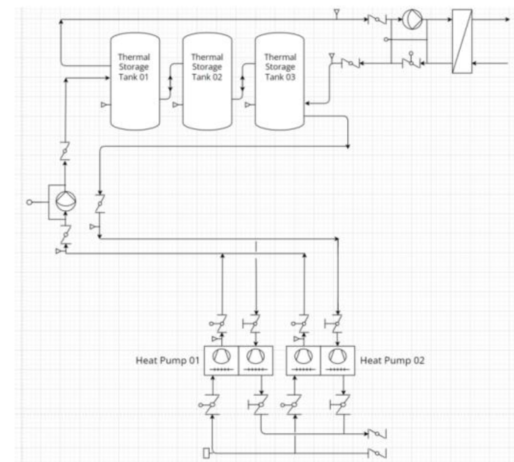
Application - Large DHW

- **Sizing is critical**
- DHW systems need to be sized assuming HRCHLR will not be functional
- Controls are Critical



Application - Small DHW

- **Sizing is critical**
- DHW systems need to be sized assuming HRCHLR will not be functional
- Controls are Critical



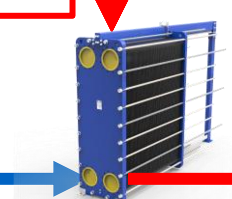
CW 95F

CHW 40F

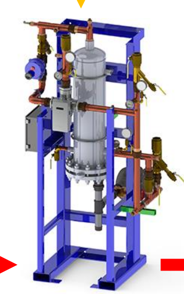
Steam or NG

HW 120F

DW 60F



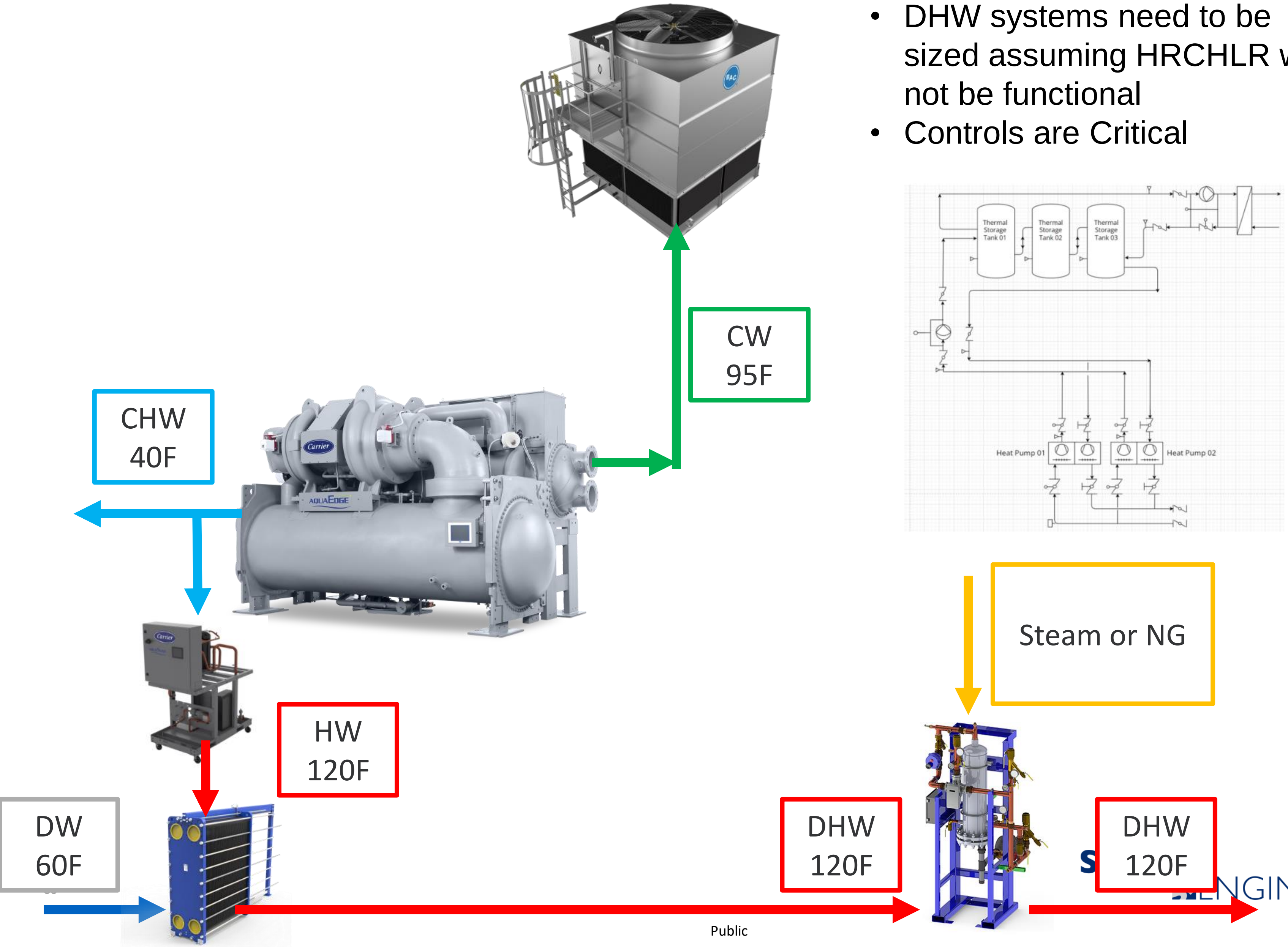
DHW 120F



DHW 120F

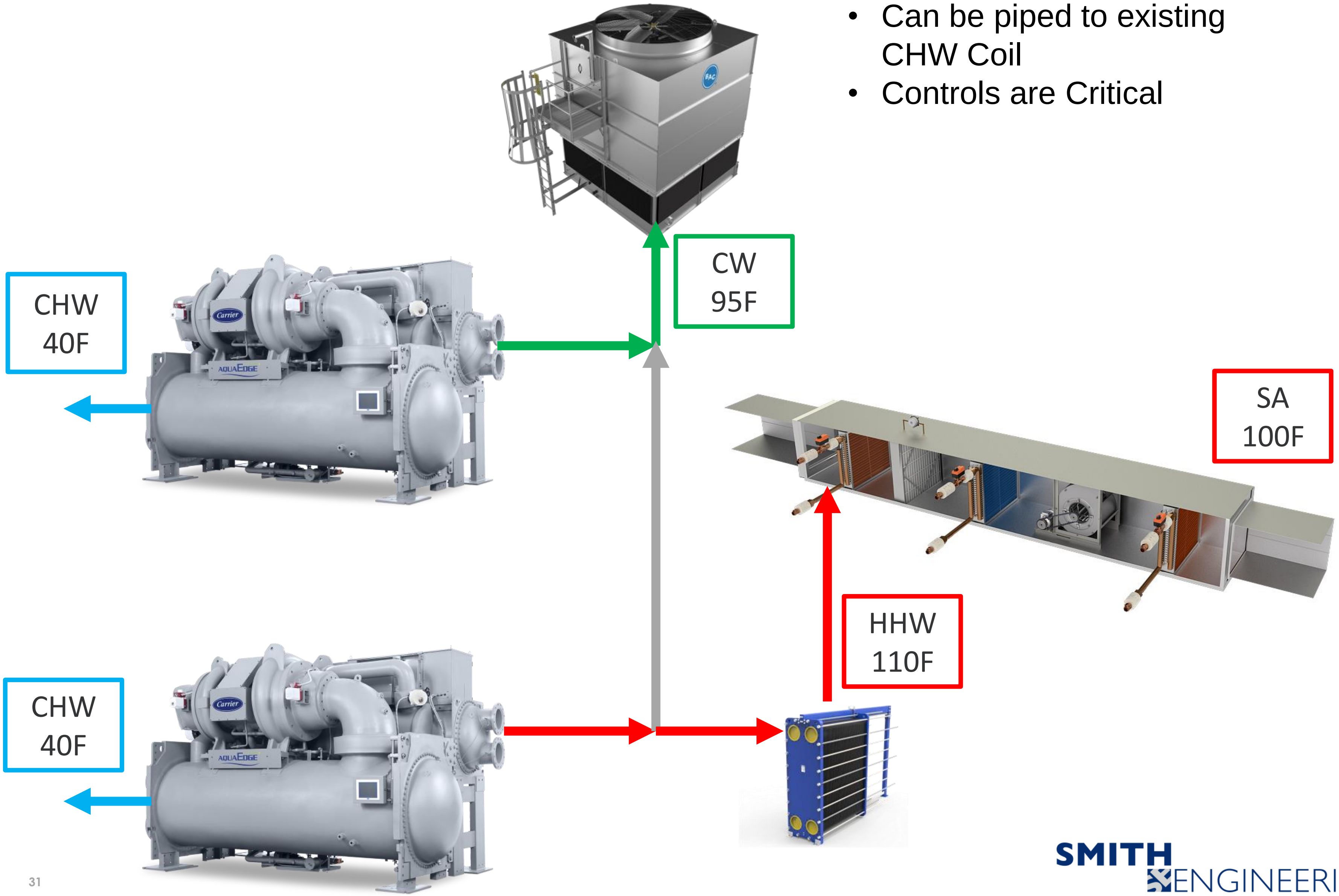
Application - Small DHW

- **Sizing is critical**
- DHW systems need to be sized assuming HRCHLR will not be functional
- Controls are Critical



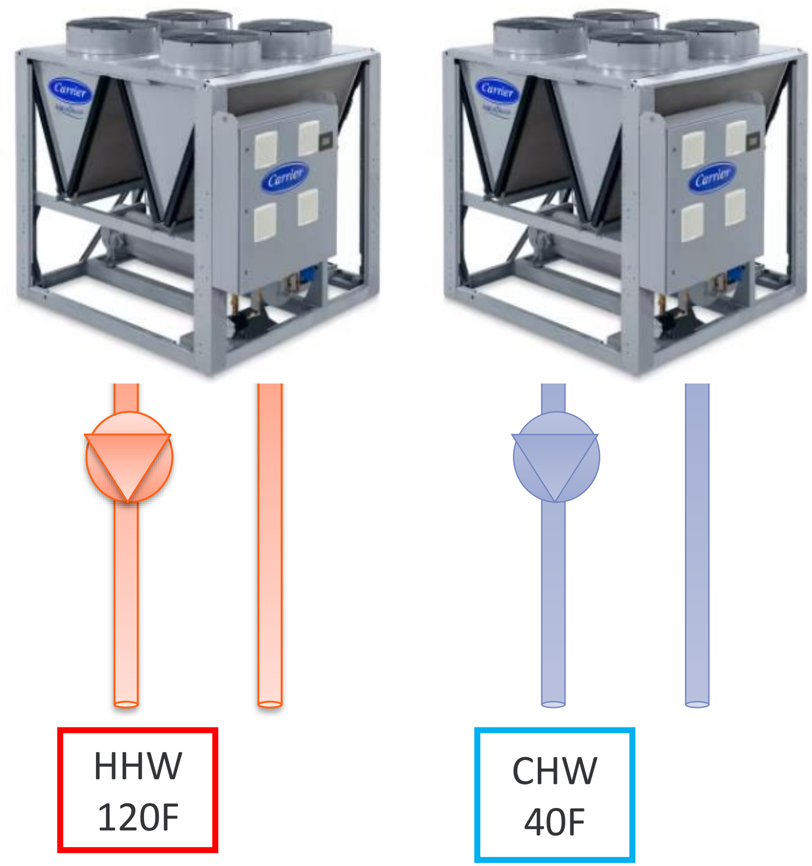
Application - DOAS

- **Sizing is critical**
- Can be piped to existing CHW Coil
- Controls are Critical



SMITH ENGINEERING

Application – Air Source

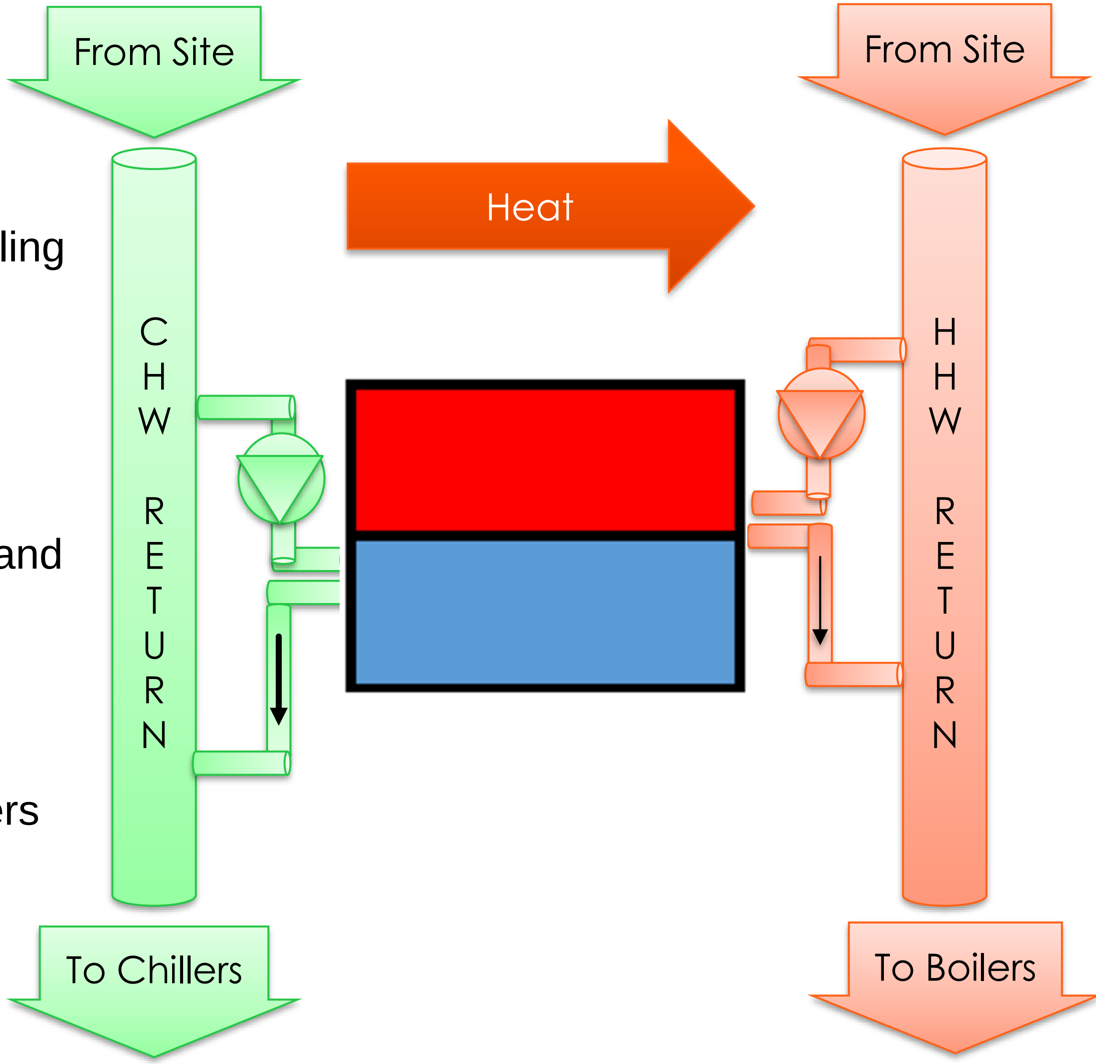


- Small Commercial Office
  - No opportunity for geo
  - No simultaneous heating and cooling
- Very forgiving
- COP drops off at low OAT
- Not practical for very large applications

Installations

GREENFIELD PHARMA MANFATURING PLANT: SIDECAR

- Heat pump Tech
  - 130F HHW
- Arrangement
  - Sidecar
  - Simultaneous Heating and Cooling
- Important Notes
  - North Carolina
  - Greenfield
  - Smaller Application
- Dealing with Load Mismatch
  - Sizing - Small relative to CHW and HHW loads
  - Storage: None
  - Geoexchange: None
- Other Notes
  - Heating: Gas Condensing Boilers
  - Heat rejection: Cooling Towers
  - Controls are Ultra Critical



SMITH ENGINEERING

Public

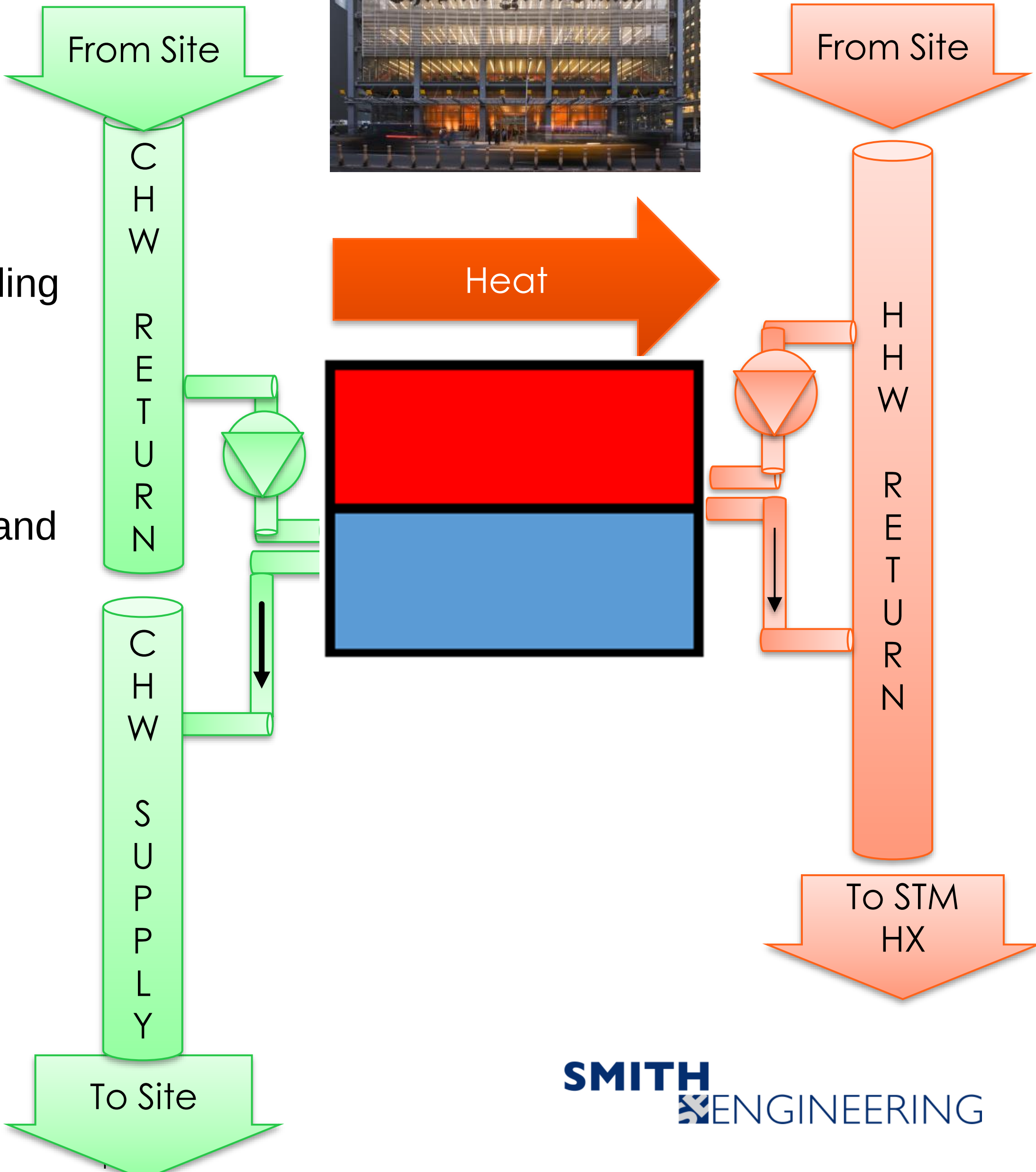
COMMERCIAL OFFICE: WFC

- Heat pump Tech
  - Not Finalized
  - 165F HHW
- Arrangement
  - Parallel to Existing Chillers
  - Series with existing STM to HHW HXs
  - Simultaneous Heating and Cooling
- Important Notes
  - NYC
    - Gets cold
- Dealing with Load Mismatch
  - Sizing - Small relative to CHW and HHW loads
  - Storage: CHW Existing
  - Geoexchange: River
- Other Notes
  - Heating – Coned Steam
  - Heat rejection – River
  - HPs and Traditional chiller
  - Controls are Ultra Critical
  - LL97 – Carbon Tax

SMITH ENGINEERING

COMMERCIAL OFFICE: NTY

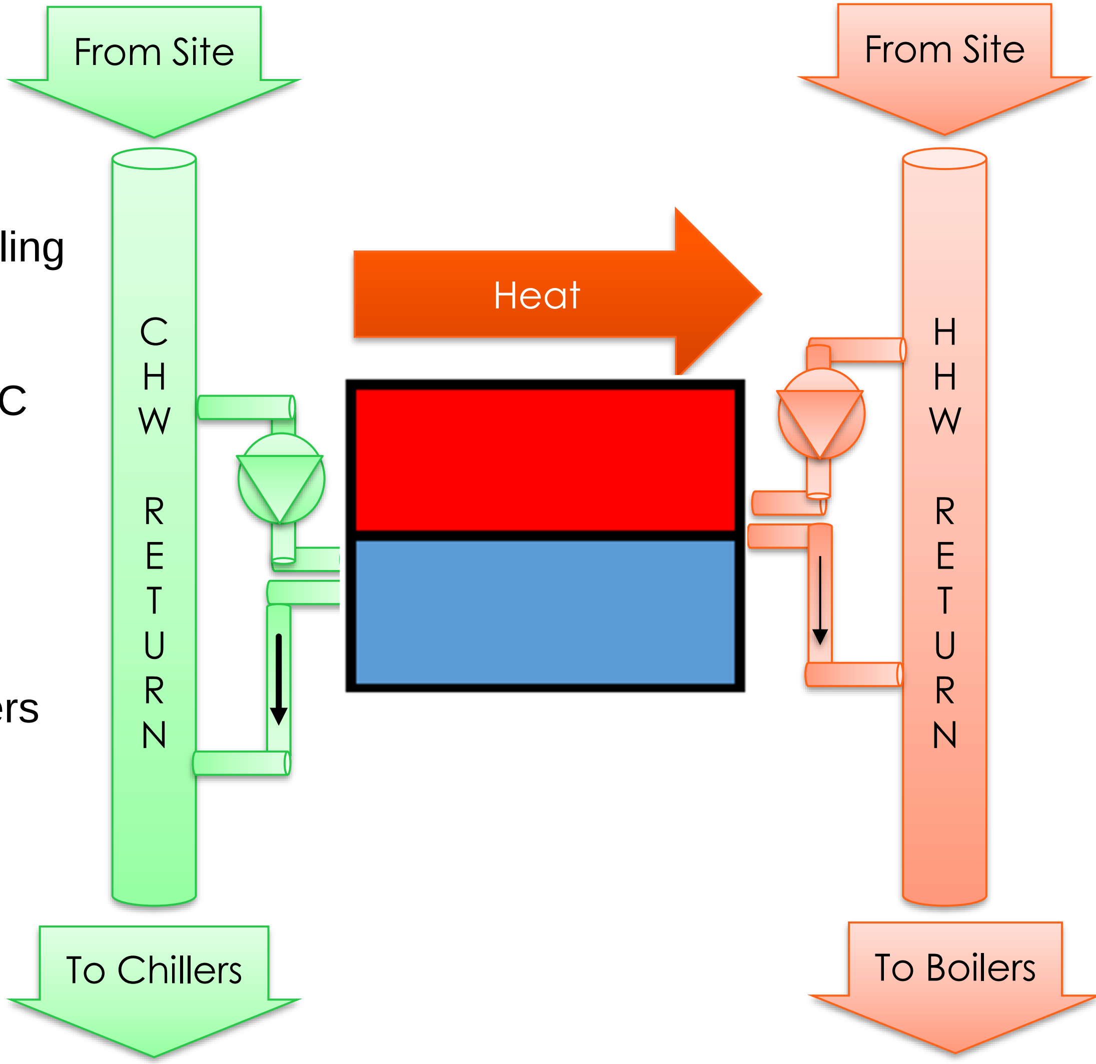
- Heat pump Tech
    - 125F HHW
- Arrangement
    - Sidecar Heating
    - Parallel Cooling
    - Simultaneous Heating and Cooling
- Important Notes
    - NYC
        - Gets cold
- Dealing with Load Mismatch
    - Sizing - Small relative to CHW and HHW loads
    - Storage: None
    - Geoexchange: None
- Other Notes
    - Heating: Coned Steam
    - Heat rejection: Cooling Towers
    - Controls are Ultra Critical



SMITH ENGINEERING

UNIVERSITY: UD

- Heat pump Tech
  - 150F HHW
- Arrangement
  - Sidecar
  - Simultaneous Heating and Cooling
- Important Notes
  - Delaware
  - Gets cold but not as cold of NYC
- Dealing with Load Mismatch
  - Sizing – Oversized, has issues
  - Storage: None
  - Geoexchange: None
- Other Notes
  - Heating: Gas Condensing Boilers
  - Heat rejection: Cooling Towers
  - Controls are Ultra Critical

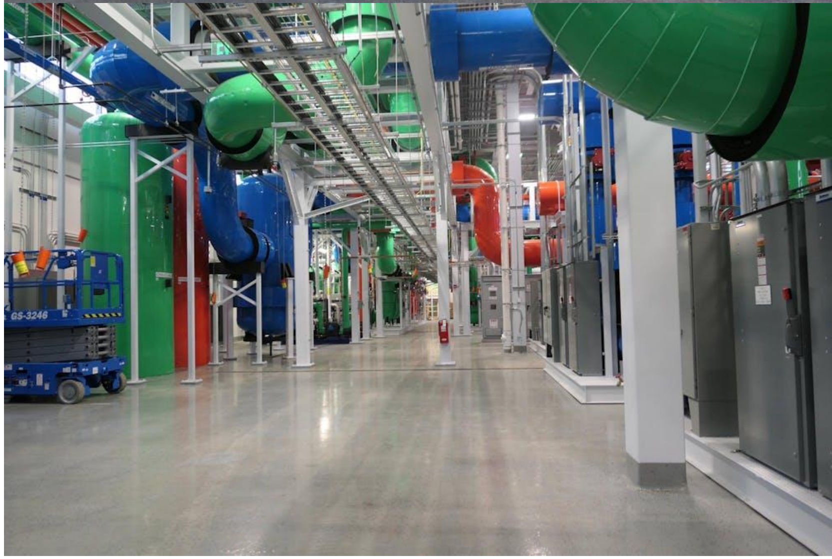


SMITH ENGINEERING

Public

UNIVERSITY: PRINCETON TIGER

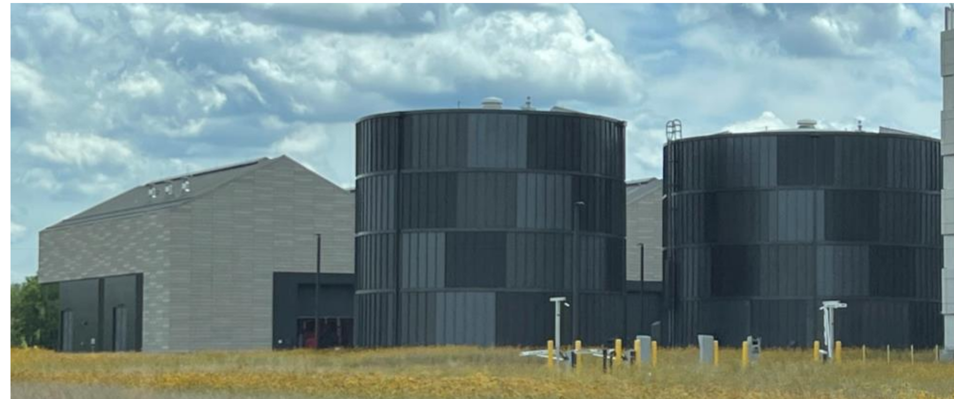
- Heat pump Tech
  - 165F HHW
- Arrangement
  - Simultaneous Heating and Cooling with Geo-Exchange
- Important Notes
  - New Jersey
  - Gets very cold
- Dealing with Load Mismatch
  - Geo-exchange
  - HHW Storage
  - CHW Storage
- Other Notes
  - Heating: Cogen and Steam Boilers at West Plant
  - Heat rejection: Cooling Towers at West Plant
  - Controls are Ultra Critical

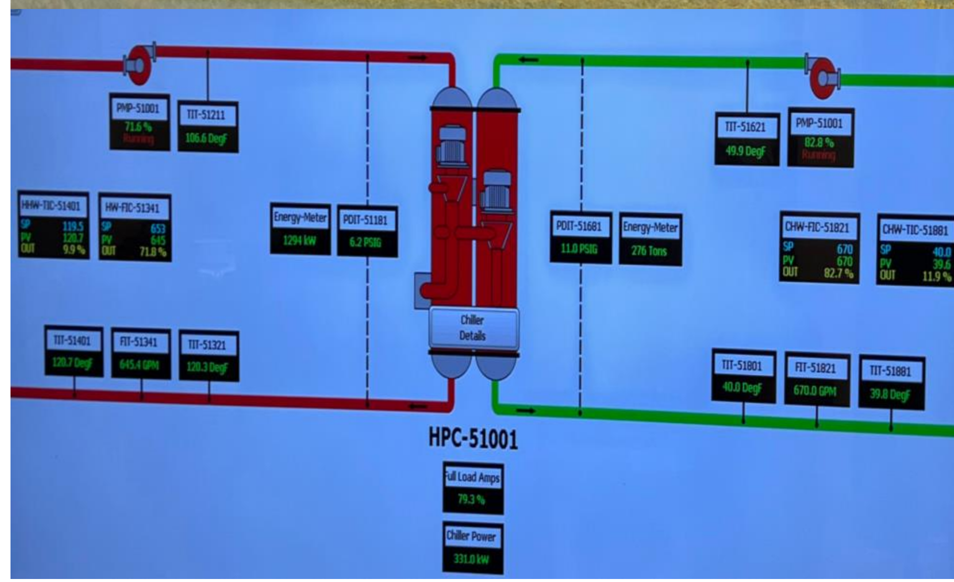


SMITH ENGINEERING

UNIVERSITY: PRINCETON CUB

- Heat pump Tech
  - 120F HHW
- Arrangement
  - Simultaneous Heating and Cooling with Geo-Exchange
- Important Notes
  - New Jersey
    - Gets very cold
- Dealing with Load Mismatch
  - Geo-exchange
  - HHW Storage
  - CHW Storage
- Other Notes
  - Heating: Back-up Condensing Boilers
  - Heat rejection: Evaporative Coolers
  - Controls are Ultra Critical

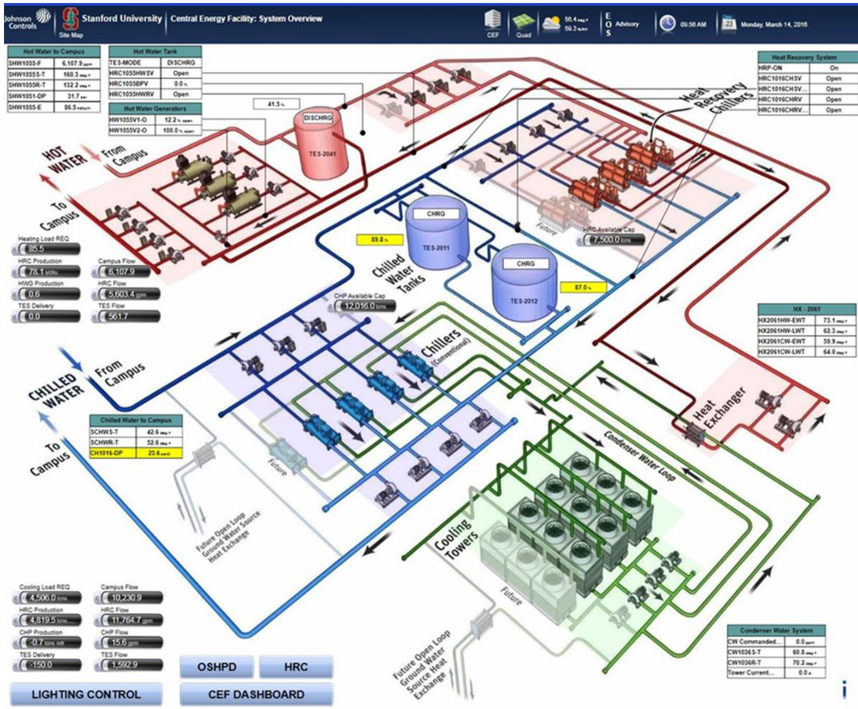




SMITH ENGINEERING

UNIVERSITY: STANFORD

- Heat pump Tech
  - 170F HHW
- Arrangement
  - Parallel to Boilers and Chillers
  - Simultaneous Heating and Cooling
- Important Notes
  - California
    - Doesn't get too cold
    - Diurnal Swing
    - Low Lift 8,760
- Dealing with Load Mismatch
  - HHW Storage
  - CHW Storage
- Other Notes
  - No geoexchange, but planned
  - Heating: Gas Condensing Boilers
  - Heat rejection: Cooling Towers
  - Controls are Critical



SMITH ENGINEERING

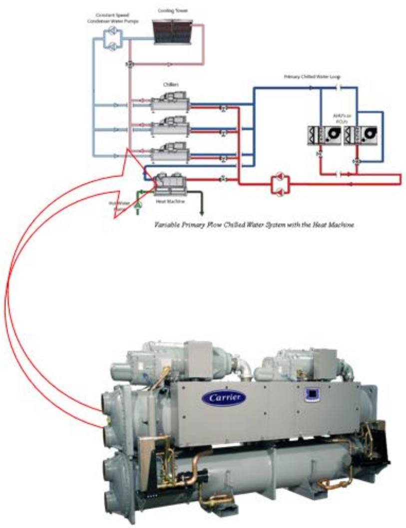
New Construction – CHOP King of Prussia

CHOP K of P – completed 2022

- Heat recovery chiller (30XW)
  - Piped in series with cooling only air-cooled chillers (30XVs) and in parallel with boilers
- Simultaneously produces chilled water and hot water
  - Controlled to hot water setpoint
- Reduced the size of gas-fired boilers
- *Has not been shut off since completion*

Lessons learned

- Piping design considered in early design
  - Increased run hours of heat recovery chiller and ensured proper sizing for heating loads



Carrier's 30XW Heat Machine

Children's Hospital of Philadelphia®

Carrier

New Construction – Lafayette ISB

Lafayette ISB – completed 2019

- Heat recovery chiller (30MP)
  - Modular scroll heat recovery chillers plus variable speed screw chillers (23XRV)
- Simultaneously produces chilled water and hot water
- Used for re-heat in vivarium during summer and heating during winter

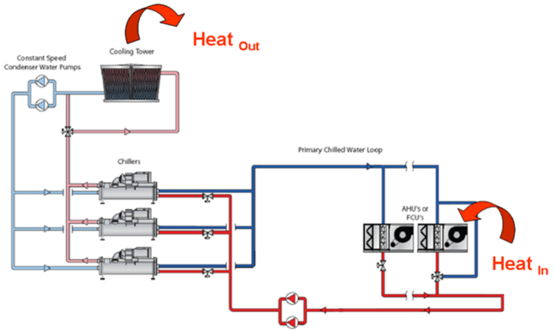
Lessons learned

- Both summer and winter heating load considered in early design
  - Overall reduction in boiler plant size
- Modular chillers allow for future addition of more chilled water or hot water if building is phased over several years

Retrofit – DSM

DSM Biomedical – completed 2023

- Heat recovery chiller (19DV) replaced one of three cooling only chillers
- Simultaneously produces chilled water and hot water
- Intended to reduce boiler size and increase chiller plant efficiency
  - *Piped in parallel with cooling only chillers on both chilled water and condenser water sides*
  - *Transfer valves bypass heat to a secondary hot water loop*

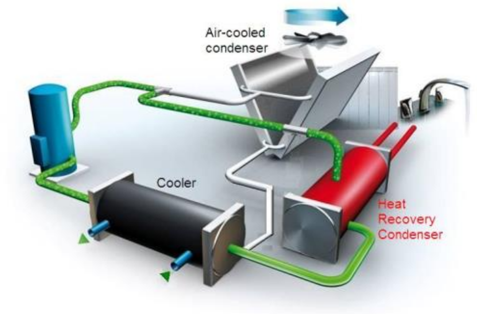


Chilled Water HVAC System

Retrofit – Woodmere Museum

Woodmere Museum

- Air-cooled chiller (30RB) with de-superheater replaced existing cooling only chiller
- Humidity control to maintain IAQ critical
- Allows boilers to completely shut off in summer



Lessons learned

- Summer heating load considered in early design
  – De-superheater sized for maximum summer hot water need
- De-superheater's partial or full heat recovery capabilities allows for precise control without much complexity
- Hot water storage tank employed

Thank You

SMITH ENGINEERING

Travis Smith, PE, CEM
Managing Partner,
Smith Engineering PLLC

www.smith-eng.com
tsmith@smith-eng.com