Heating and Cooling

National Sponsor of the CaGBC

FUEL-SWITCHING HYDRONIC SYSTEMS USING AIR-TO-WATER HEAT PUMPS

Chris DesRoches, P. Eng.
Applied Product Manager, HVAC Division
Mitsubishi Electric Sales Canada Inc.

chris.desroches@mesca.ca
905-475-3278

www.Climaveneta.ca

TOPICS

- AIR-TO-WATER HEAT PUMP RECAP
  - TECHNOLOGY OVERVIEW & DESIGN CONSTRAINTS

- FUEL-SWITCHING HYDRONIC SYSTEMS
  - ENERGY & GHG EMISSION SAVINGS COMPARISON:
    - ALL-ELECTRIC SYSTEMS VS. BACK-UP NATURAL GAS
    - COST COMPARISON: NATURAL GAS VS. ELECTRIC

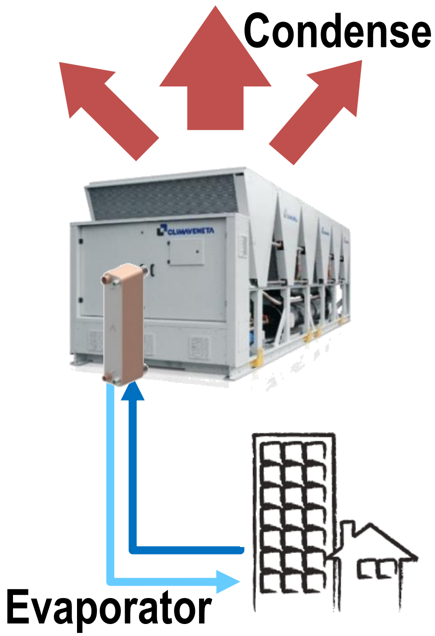
- CENTRAL AIR-TO-WATER HEAT PUMP PLANT SIZING & APPLICATIONS
  - 2-PIPE CHANGEOVER SYSTEMS
  - HEAT PUMP CASCADE SYSTEMS (2-PIPE)
  - HYBRID 4-PIPE CENTRAL PLANT
  - HEAT RECOVERY
  - HIGH-TEMPERATURE RETROFITS

LEARNING OBJECTIVES

- **Understand the concept of fuel-switching and its importance for high efficiency retrofit of existing building central plant systems.**
- **Learn design strategies and application techniques of using air-to-water heat pump plant equipment.**
- **Learn about the energy and cost savings, and emission reductions achievable with fuel-switching retrofit of traditional central plant systems with air-to-water heat pumps**

REVERSIBLE AIR-TO-WATER HEAT PUMP: OPERATING PRINCIPLE

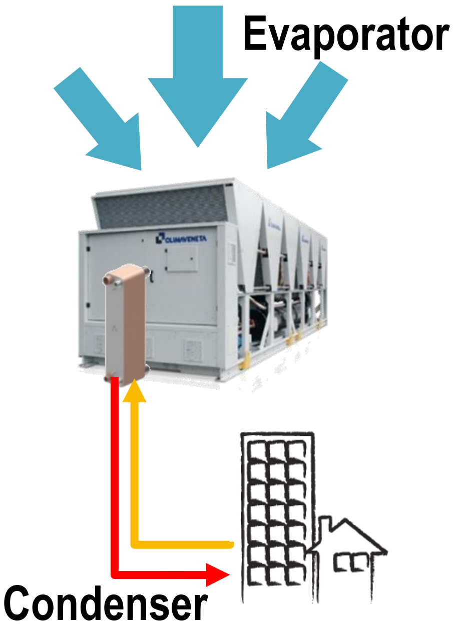
COOLING MODE



Condenser

Evaporator

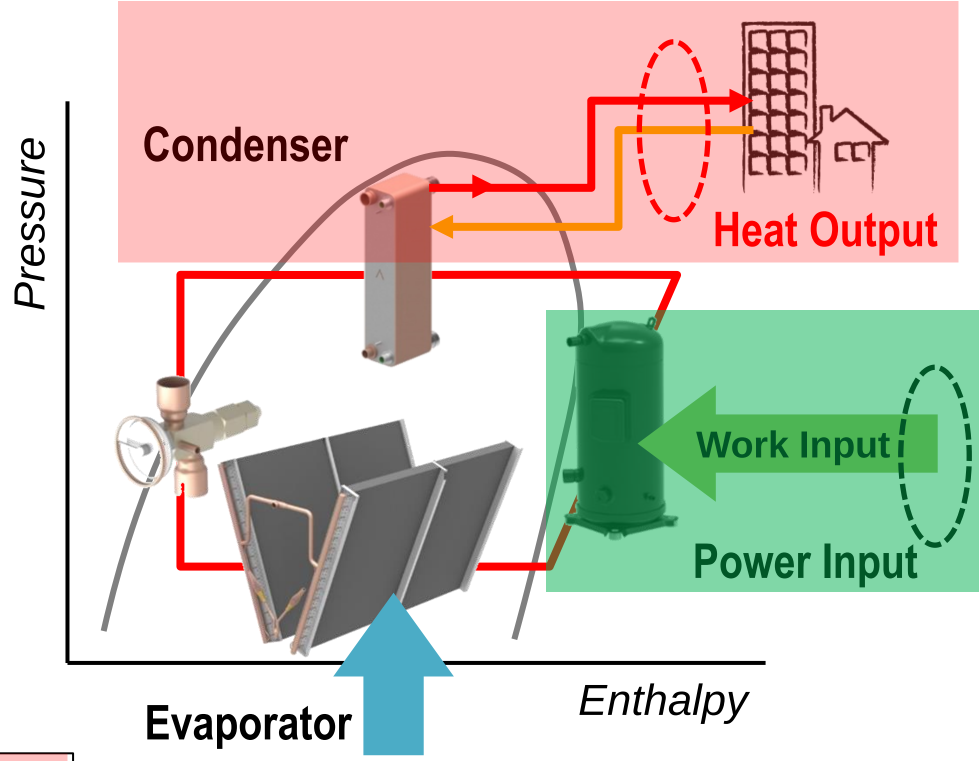
HEATING MODE



Evaporator

Condenser

VAPOR-COMPRESSION REFRIGERATION CYCLE (HEATING MODE)



Condenser

Heat Output

Work Input

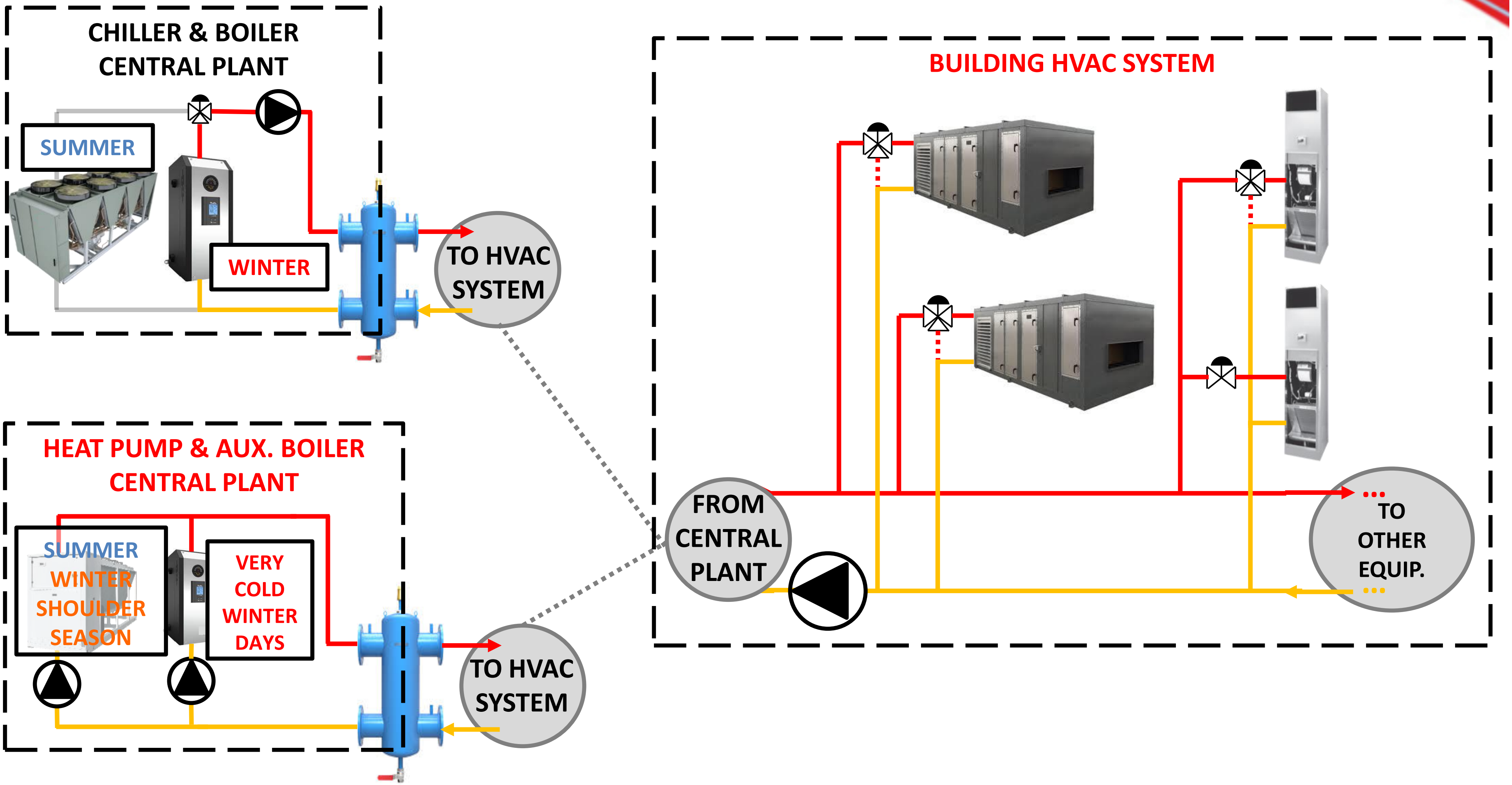
Power Input

Evaporator

Coefficient of Performance:

$$COP = \frac{Heat\ Output\ (\frac{BTU}{h}\ or\ Watts)}{Power\ Input\ (Watts)}$$

CENTRAL HYBRID HEAT PUMP PLANT



CHILLER & BOILER
CENTRAL PLANT

SUMMER

WINTER

TO HVAC
SYSTEM

HEAT PUMP & AUX. BOILER
CENTRAL PLANT

SUMMER
WINTER
SHOULDER
SEASON

VERY
COLD
WINTER
DAYS

TO HVAC
SYSTEM

BUILDING HVAC SYSTEM

FROM
CENTRAL
PLANT

...TO
OTHER
EQUIP.
...

AIR-TO-WATER HEAT PUMP: DESIGN CONSIDERATIONS

- UNDERSTAND THE INFLUENCE OF OUTSIDE AIR TEMPERATURE

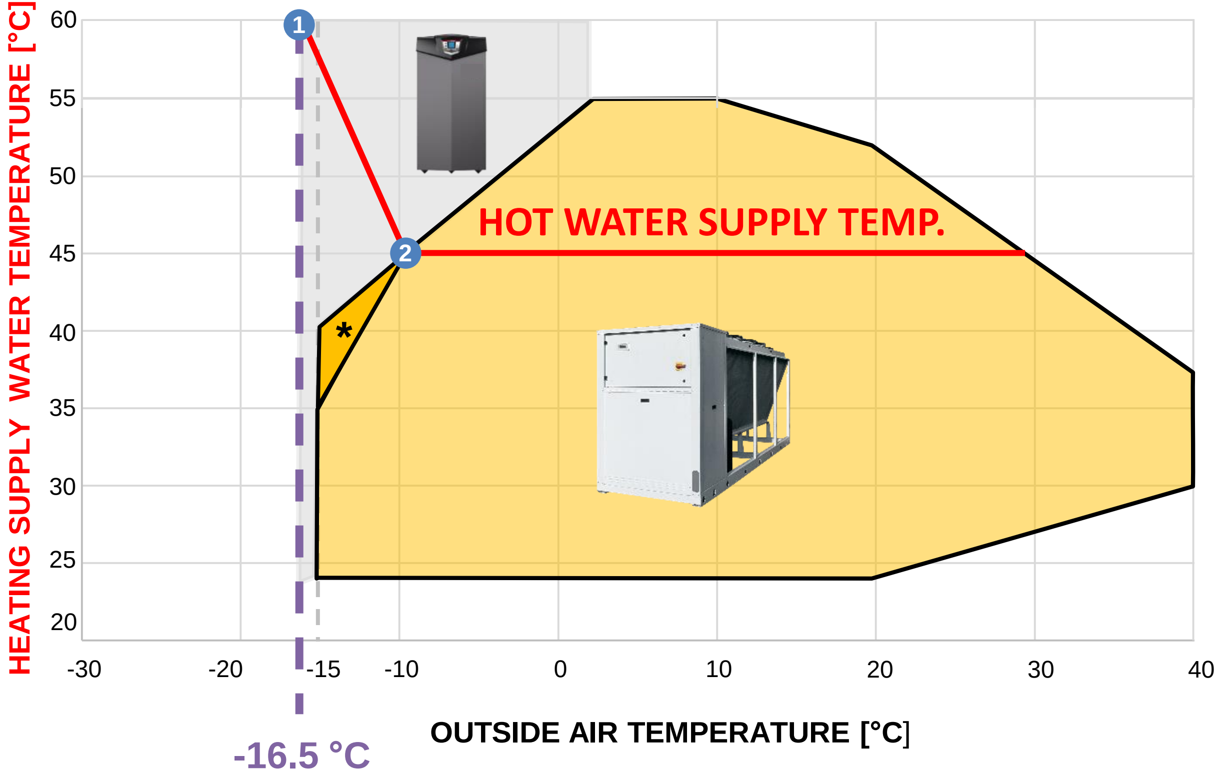
- DESIGN HYDRONIC SYSTEM BASED ON HEAT PUMP CAPABILITIES INSTEAD OF FITTING INTO EXISTING DESIGN PRACTICES

- HEAT PUMP PERFORMANCE VARIES WITH OUTSIDE AIR TEMPERATURE:
  1. SUPPLY TEMPERATURE REDUCTION (OPERATING ENVELOPE)
  2. CAPACITY REDUCTION
  3. COEFFICIENT OF PERFORMANCE REDUCTION

AIR-TO-WATER HEAT PUMP: OPERATING ENVELOPE

FULL LOAD HEATING OPERATING LIMITS

LEAVING WATER TEMP vs. OUTSIDE AIR TEMP.



London Winter Design Temp.
(ASHRAE Heating DB 99.6%)

APPLICATION CONSIDERATIONS:

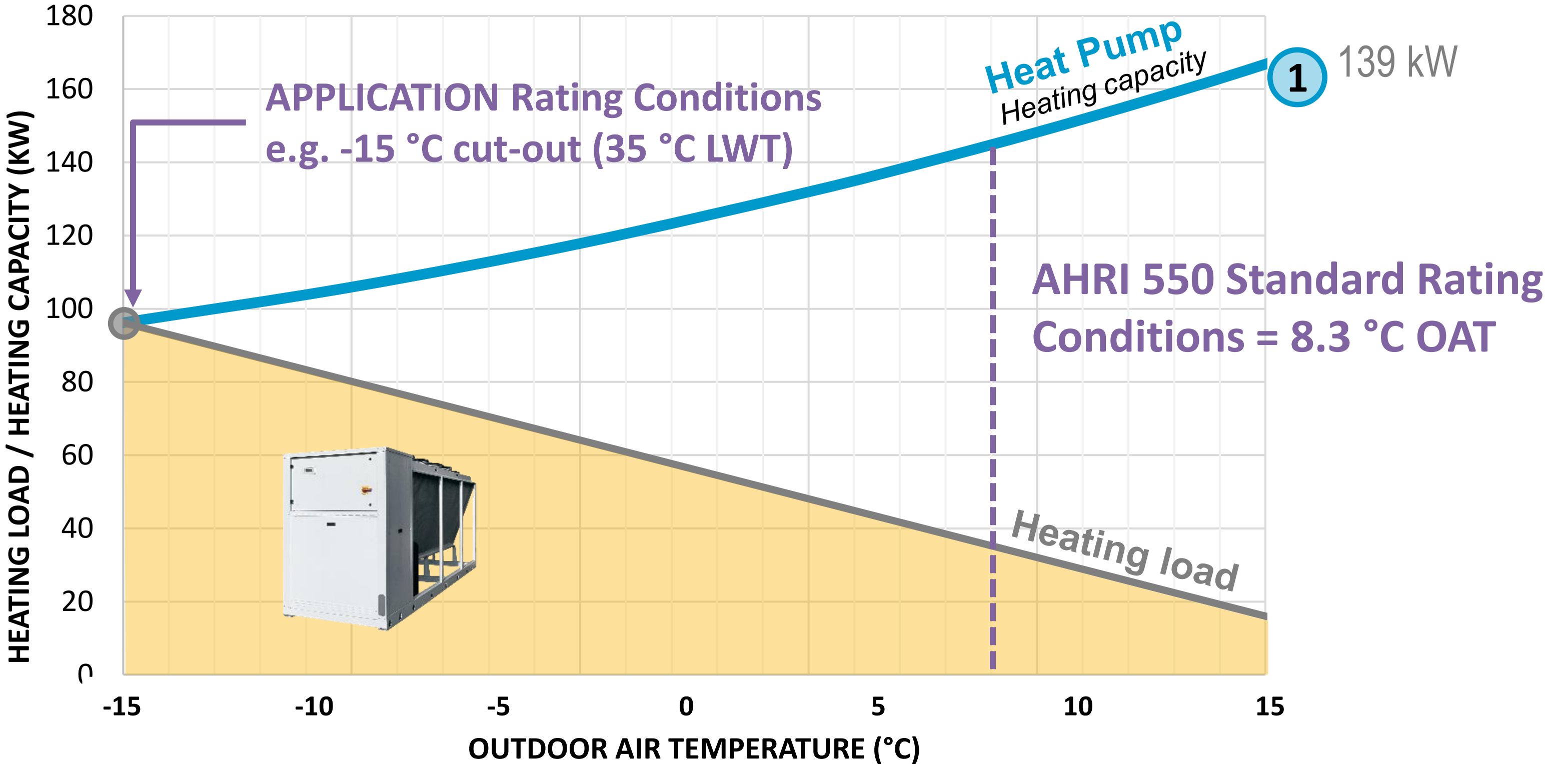
- Select **LOWEST DESIGN SUPPLY TEMPERATURE** Feasible
- Consider **HIGHER BOILER SUPPLY WATER TEMPERATURE** below ASHP cut-out
- Heat Pump **DESIGN LOAD** vs. **BUILDING HEATING LOAD** at BIVALENCE Point

AIR-TO-WATER HEAT PUMP: SIZING FOR HEATING

HEATING CAPACITY VS HEATING LOAD

138 kW ATW HP (NOMINAL)

REVERSIBLE UNIT, AIR SOURCE FOR OUTDOOR INSTALLATION



APPLICATION Rating Conditions
e.g. -15 °C cut-out (35 °C LWT)

AHRI 550 Standard Rating
Conditions = 8.3 °C OAT

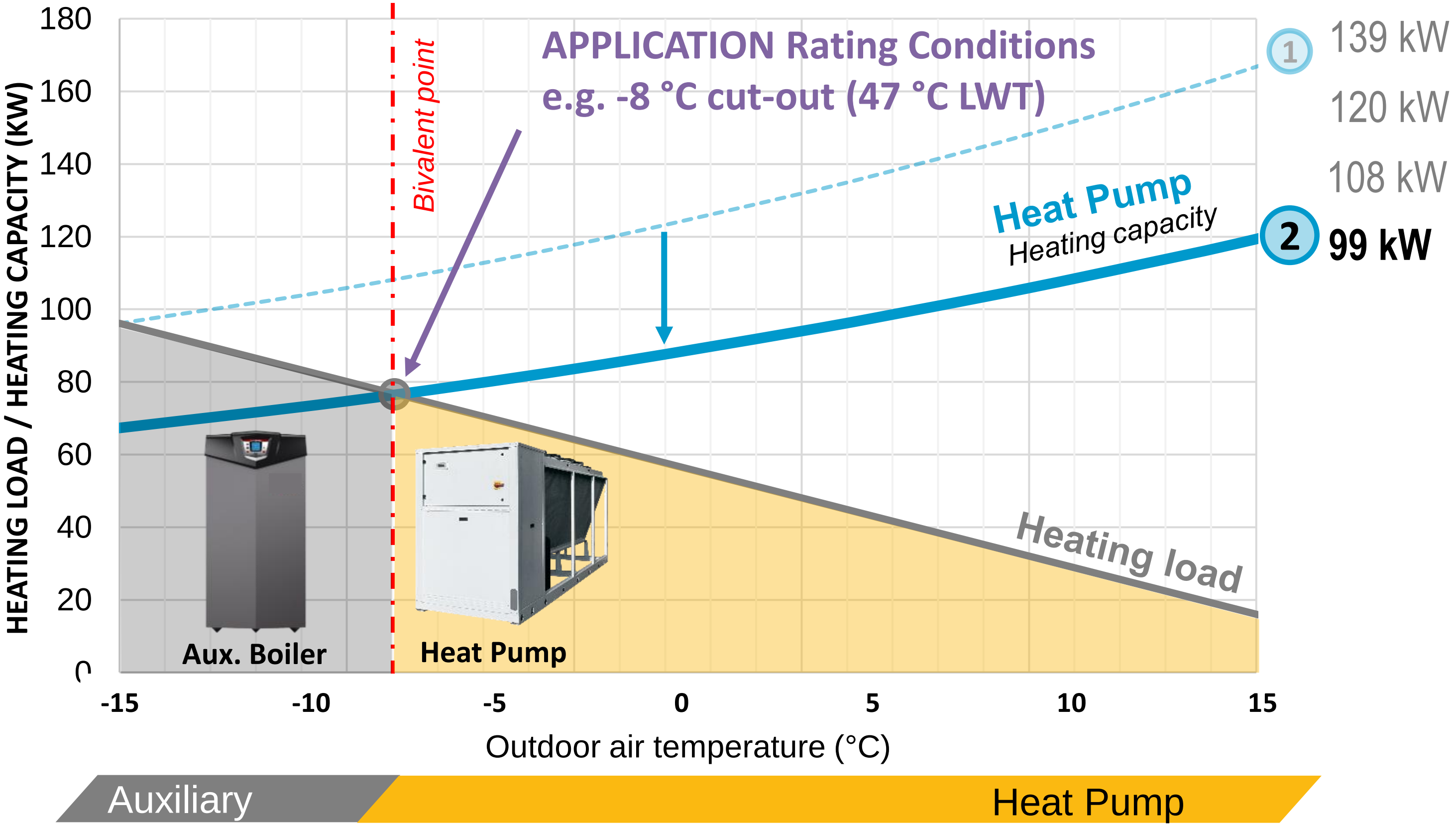
Heat Pump 100%

AIR-TO-WATER HEAT PUMP: SIZING FOR HEATING

HEATING CAPACITY VS HEATING LOAD

99 kW ATW HP (NOMINAL)

REVERSIBLE UNIT, AIR SOURCE FOR OUTDOOR INSTALLATION

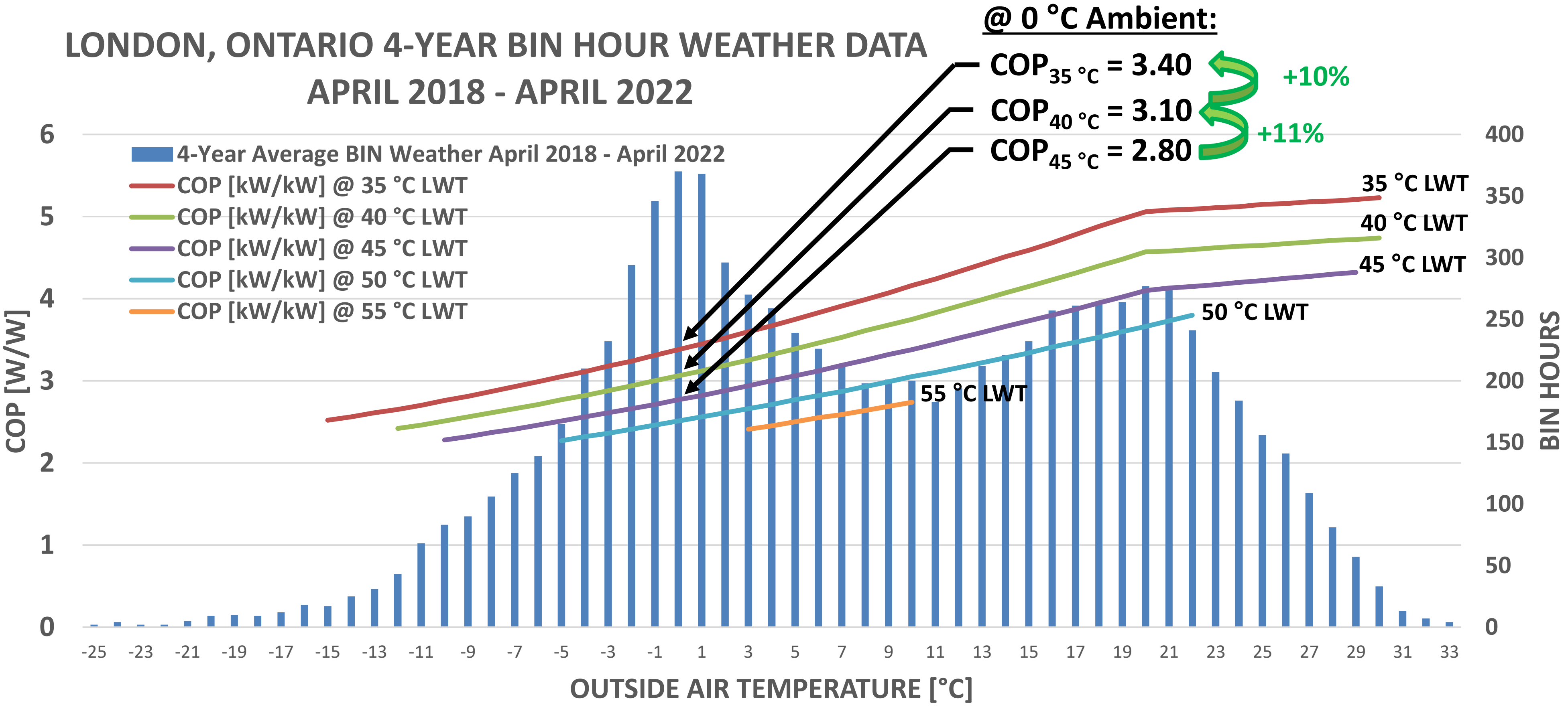


PRICE

FOOTPRINT

INFLUENCE OF OUTDOOR AIR TEMPERATURE: COP

AIR-TO-WATER HEAT PUMP COP VS. OUTSIDE AIR TEMPERATURE & BIN HOURS



LONDON, ONTARIO 4-YEAR BIN HOUR WEATHER DATA
APRIL 2018 - APRIL 2022

@ 0 °C Ambient:

$COP_{35\ °C} = 3.40$

$COP_{40\ °C} = 3.10$

$COP_{45\ °C} = 2.80$

+10%

+11%

BIN HOUR ANALYSIS FOR LONDON, ON

AUXILIARY BOILER USAGE HOURS BELOW CUT-OUT FOR VARIOUS SUPPLY WATER TEMPERATURE DESIGN SELECTION POINTS

Med-High Temp Application

LONDON ON 4-YEAR AVERAGE BIN WEATHER DATA APRIL 2019 - APRIL 2022		
Temperature Range	**4-YEAR AVERAGE ANNUAL HOURS**	**4-YEAR AVERAGE % OF HOURS**
T < -5 °C	**800**	**9.1%**
-5 °C ≤ T ≤ +10 °C	**4,087**	**46.7%**
10 °C < T < 20 °C	**2,087**	**23.8%**
20 °C ≤ T	**1,786**	**20.4%**

Total Hours Below -5 °C: 800 Hours

~ 50 °C @ -5 °C Ambient

Med Temp Application

LONDON ON 4-YEAR AVERAGE BIN WEATHER DATA APRIL 2019 - APRIL 2022		
Temperature Range	**4-YEAR AVERAGE ANNUAL HOURS**	**4-YEAR AVERAGE % OF HOURS**
T < -10 °C	**257**	**2.9%**
-10 °C ≤ T ≤ +10 °C	**4,630**	**52.9%**
10 °C < T < 20 °C	**2,087**	**23.8%**
20 °C ≤ T	**1,786**	**20.4%**

Total Hours Below -5 °C: 257 Hours

~ 45 °C @ -10 °C Ambient

Low Temp Application

LONDON ON 4-YEAR AVERAGE BIN WEATHER DATA APRIL 2019 - APRIL 2022		
Temperature Range	**4-YEAR AVERAGE ANNUAL HOURS**	**4-YEAR AVERAGE % OF HOURS**
T < -15 °C	**73**	**0.8%**
-15 °C ≤ T ≤ +10 °C	**4,814**	**55.0%**
10 °C < T < 20 °C	**2,087**	**23.8%**
20 °C ≤ T	**1,786**	**20.4%**

Total Hours Below -15 °C: 73 Hours

~ 35 to 40 °C @ -15 °C Ambient

CANADA GREEN BUILDING COUNCIL
ZERO CARBON BUILDING DESIGN STANDARD v3 (JUNE 2022)

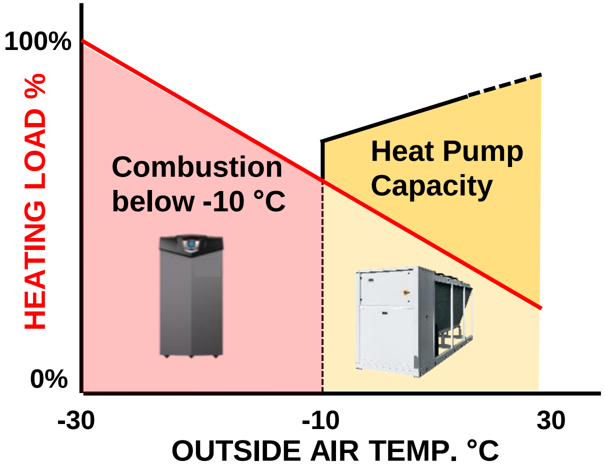
REQUIREMENTS

ONSITE COMBUSTION LIMIT FOR SPACE HEATING

Space heating systems should be designed to operate without onsite combustion whenever possible. However, to provide greater design flexibility and recognize current technological and financial barriers, some onsite combustion for space heating is permitted.

Projects must be capable of supplying all space heating with installed non-combustion-based technologies at an outdoor air temperature of -10 C or the design temperature, whichever is higher. Space heating technologies whose performance is not directly affected by outdoor air temperature (e.g., ground source heat pumps, electric resistance) must be demonstrated to be able to meet the same fraction of the annual heating demand as an air source heat pump system supported by onsite combustion. at outdoor air temperatures below -10 C.

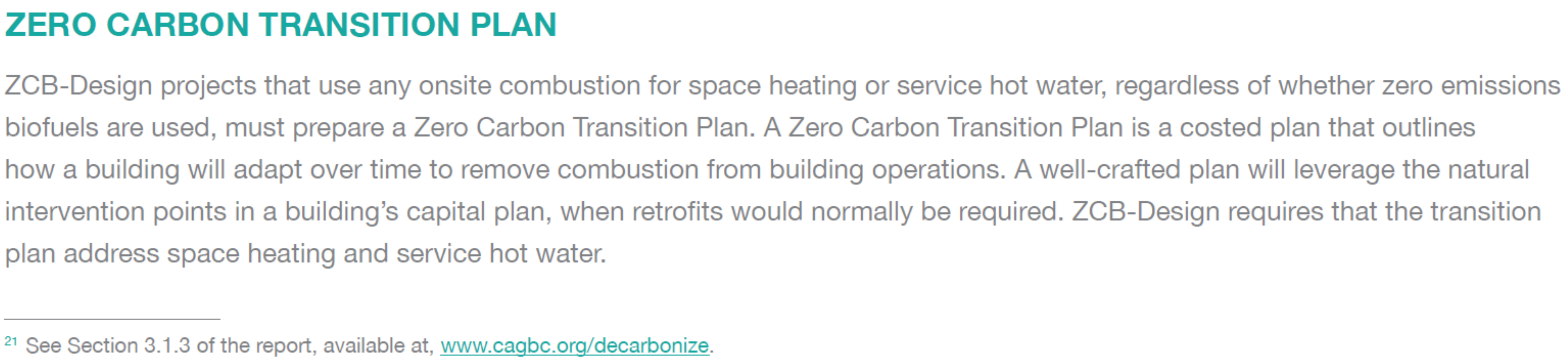
AUXILIARY COMBUSTION ACCEPTABLE PROVIDED THAT A ZERO CARBON TRANSITION PLAN ADDRESSES FUTURE ELIMINATION OF COMBUSTION BELOW -10°C LIMIT



SOURCE: CANADA GREEN BUILDING COUNCIL ZERO CARBON DESIGN STANDARD VERSION 3, PUBLISHED JUNE 2022. AVAILABLE: [CAGBC_Zero_Carbon_Building-Design_Standard_v3.pdf]

CANADA GREEN BUILDING COUNCIL

ZERO CARBON BUILDING DESIGN STANDARD v3 (JUNE 2022)



ZERO CARBON TRANSITION PLAN

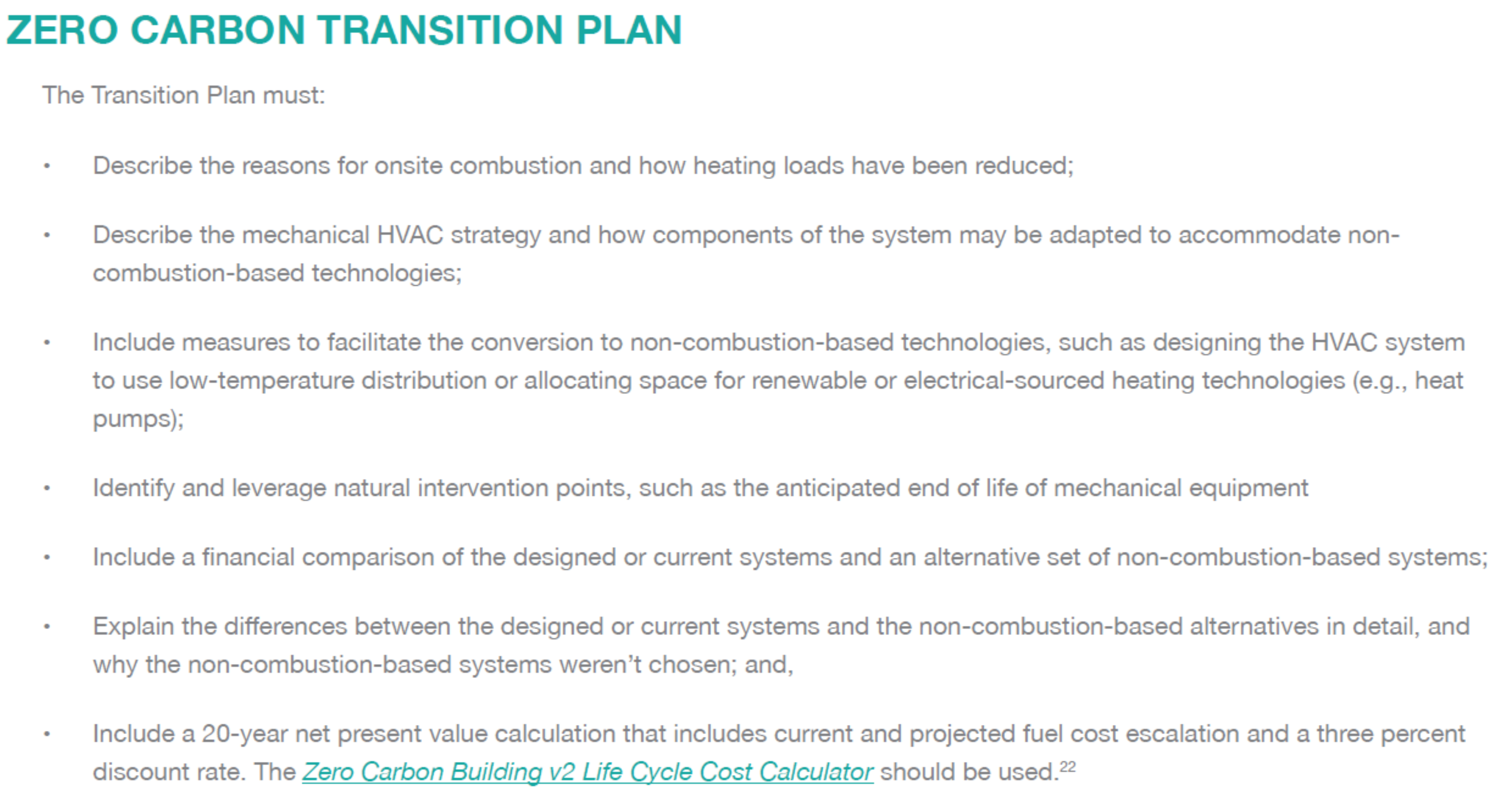
ZCB-Design projects that use any onsite combustion for space heating or service hot water, regardless of whether zero emissions biofuels are used, must prepare a Zero Carbon Transition Plan. A Zero Carbon Transition Plan is a costed plan that outlines how a building will adapt over time to remove combustion from building operations. A well-crafted plan will leverage the natural intervention points in a building's capital plan, when retrofits would normally be required. ZCB-Design requires that the transition plan address space heating and service hot water.

---

[21] See Section 3.1.3 of the report, available at, www.cagbc.org/decarbonize.

SOURCE: CANADA GREEN BUILDING COUNCIL ZERO CARBON DESIGN STANDARD VERSION 3, PUBLISHED JUNE 2022. AVAILABLE: CAGBC_Zero_Carbon_Building-Design_Standard_v3.pdf

CANADA GREEN BUILDING COUNCIL
ZERO CARBON BUILDING DESIGN STANDARD v3 (JUNE 2022)



ZERO CARBON TRANSITION PLAN

The Transition Plan must:

- Describe the reasons for onsite combustion and how heating loads have been reduced;
- Describe the mechanical HVAC strategy and how components of the system may be adapted to accommodate non-combustion-based technologies;
- Include measures to facilitate the conversion to non-combustion-based technologies, such as designing the HVAC system to use low-temperature distribution or allocating space for renewable or electrical-sourced heating technologies (e.g., heat pumps);
- Identify and leverage natural intervention points, such as the anticipated end of life of mechanical equipment
- Include a financial comparison of the designed or current systems and an alternative set of non-combustion-based systems;
- Explain the differences between the designed or current systems and the non-combustion-based alternatives in detail, and why the non-combustion-based systems weren't chosen; and,
- Include a 20-year net present value calculation that includes current and projected fuel cost escalation and a three percent discount rate. The *Zero Carbon Building v2 Life Cycle Cost Calculator* should be used.[22]

SOURCE: CANADA GREEN BUILDING COUNCIL ZERO CARBON DESIGN STANDARD VERSION 3, PUBLISHED JUNE 2022. AVAILABLE: CAGBC_Zero_Carbon_Building-Design_Standard_v3.pdf

HYBRID CENTRAL HEAT PUMP PLANT APPLICATIONS

AIR-TO-WATER HEAT PUMP APPLICATIONS:

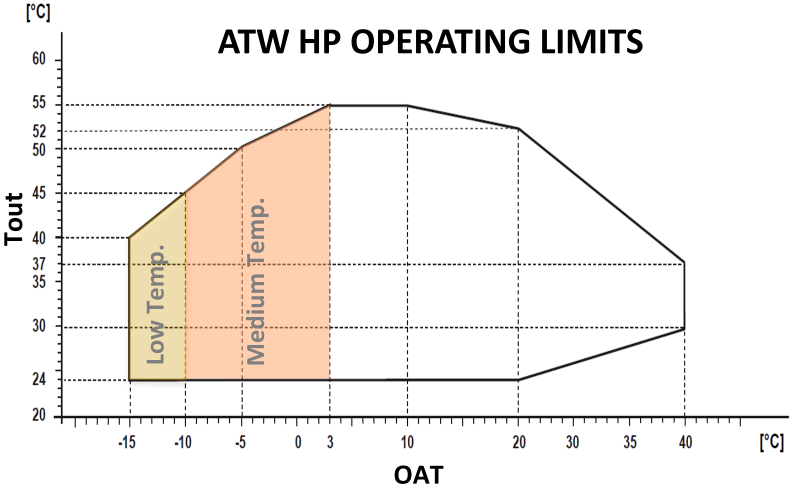
LOW TEMPERATURE HEATING APPLICATIONS:

- Water-Loop Heat Pump (WLHP)
- Radiant In-Floor Heating
- Domestic Hot Water Preheat
- Winter Ventilation OA Preheat, Summer Reheat for Dehumidification
- Snow Melt (in Heating Mode or during Cooling + Desuperheater)

MEDIUM TEMPERATURE HEATING APPLICATIONS:

- Terminal Units (Fan Coils, Cabinet Heaters, etc.)
- Central or Zoned AHU Hydronic Heating Coils
- Domestic Hot Water/Preheat

ATW HP OPERATING LIMITS



WATER LOOP HEAT PUMP SYSTEM

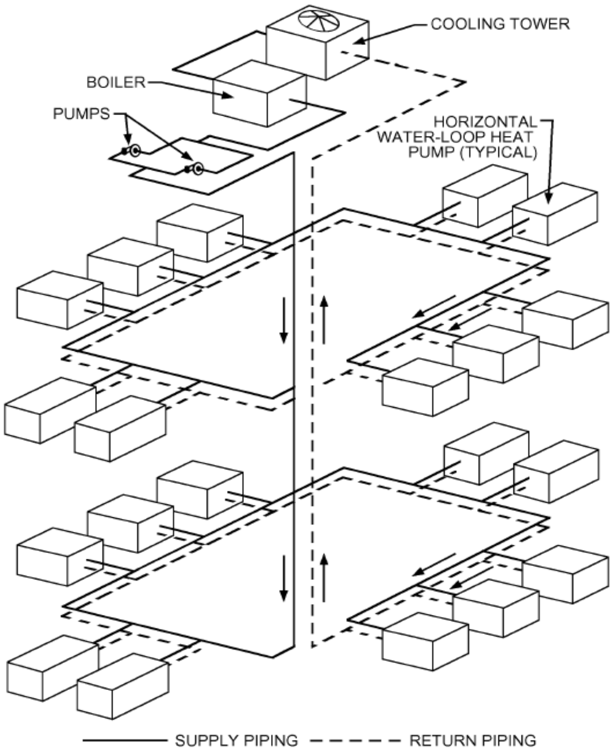


Image Source: ASHRAE HANDBOOK: 2020 HVAC SYSTEMS AND EQUIPMENT
Ch. 9 Fig. 30

WHY AIR-TO-WATER HEAT PUMPS FOR HYDRONIC SYSTEMS?
EMISSIONS COMPARISON

ONTARIO ELECTRICITY GENERATION:

0.031 kg CO_2e /kWh

SOURCE: TAF 2018 AEF: HTTPS://TAF.CA/WP-CONTENT/UPLOADS/2019/06/A-CLEARER-VIEW-ON-ONTARIOS-EMISSIONS-JUNE-2019.PDF

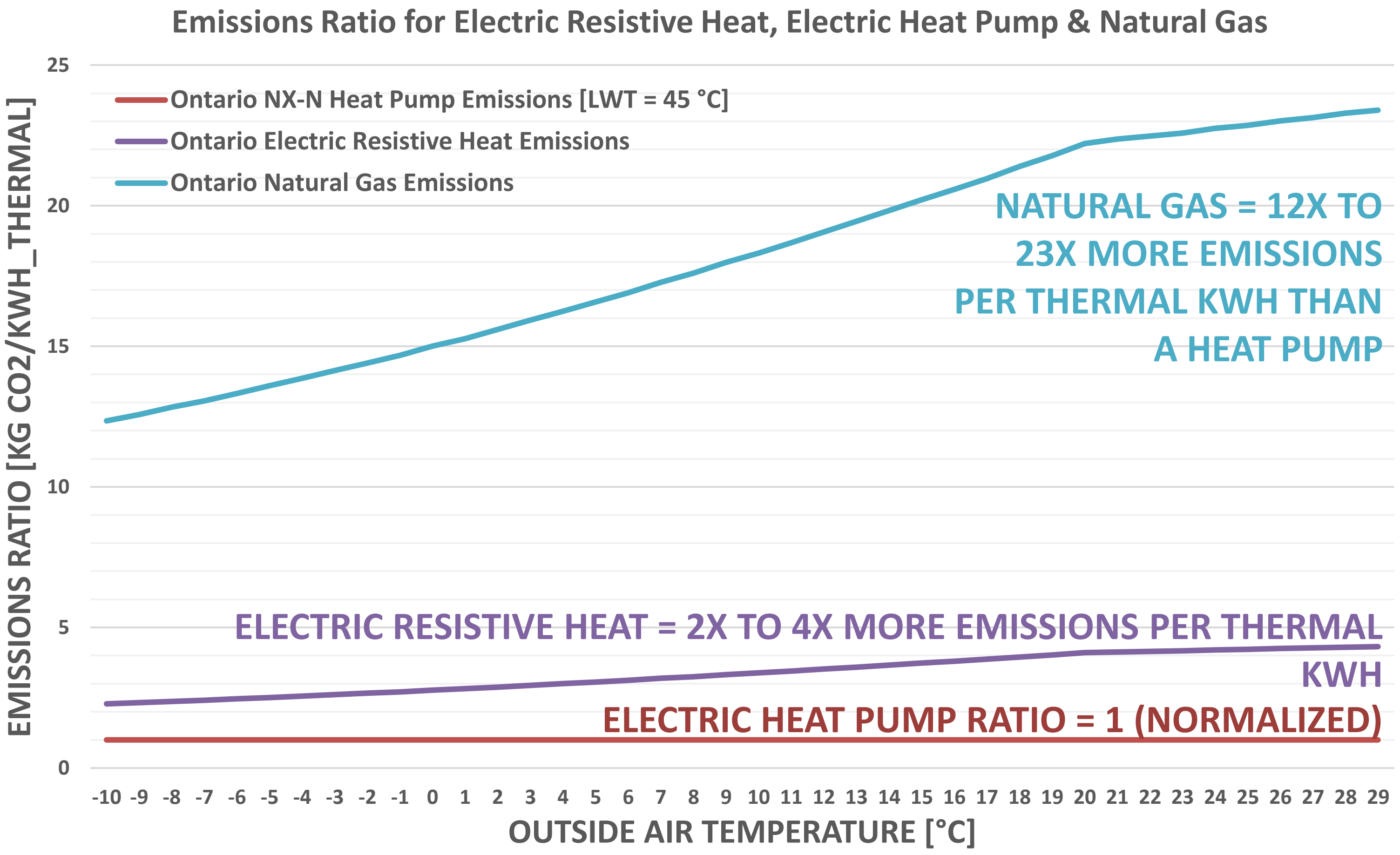
ONTARIO NATURAL GAS EMISSION INTENSITY:

1.888 kg CO_2e/m^3

= 0.18693 kg CO_2e/kWh

[1 m^3 Natural Gas = 10.1 kWh]

SOURCE: ONTARIO MINISTRY OF ENVIRONMENT AND CLIMATE CHANGE'S "GUIDELINE FOR QUANTIFICATION, REPORTING AND VERIFICATION FOR GHG EMISSIONS - JULY 2017", TABLE 400-2


Emissions Ratio for Electric Resistive Heat, Electric Heat Pump & Natural Gas

NATURAL GAS = 12X TO 23X MORE EMISSIONS PER THERMAL KWH THAN A HEAT PUMP

ELECTRIC RESISTIVE HEAT = 2X TO 4X MORE EMISSIONS PER THERMAL KWH

ELECTRIC HEAT PUMP RATIO = 1 (NORMALIZED)

COP OF VARIOUS HEATING TECHNOLOGIES

ELECTRIC BOILER

COP = 1

CONVENTIONAL NATURAL GAS BOILER

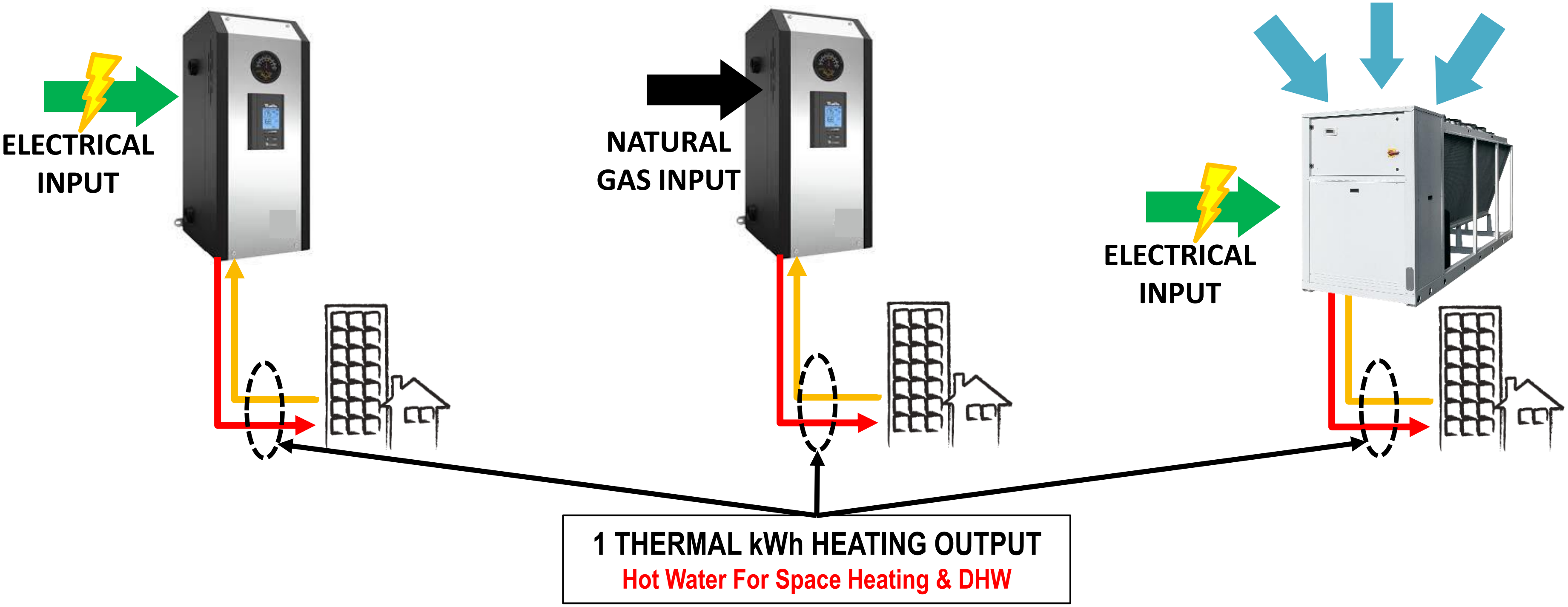
COP < 1

VARIES ACCORDING BOILER EFFICIENCY & SYSTEM RETURN TEMP (FOR CONDENSING GAS BOILERS)

AIR-TO-WATER HEAT PUMP

COP = 2-4+

VARIES ACCORDING TO OUTSIDE AIR TEMP.



ELECTRICAL INPUT

NATURAL GAS INPUT

ELECTRICAL INPUT

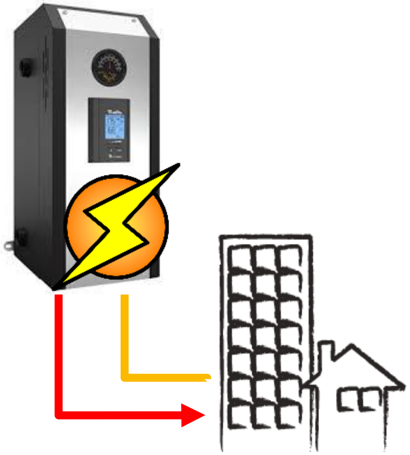
1 THERMAL kWh HEATING OUTPUT

Hot Water For Space Heating & DHW

CENTRAL PLANT COMPARISON FOR BACK-UP FUEL TYPES

WHAT DOES YOUR LOW-CARBON ELECTRIFIED SOLUTION LOOK LIKE FOR HYDRONIC SYSTEMS?

E-BOILER PRIMARY HEAT SOURCE



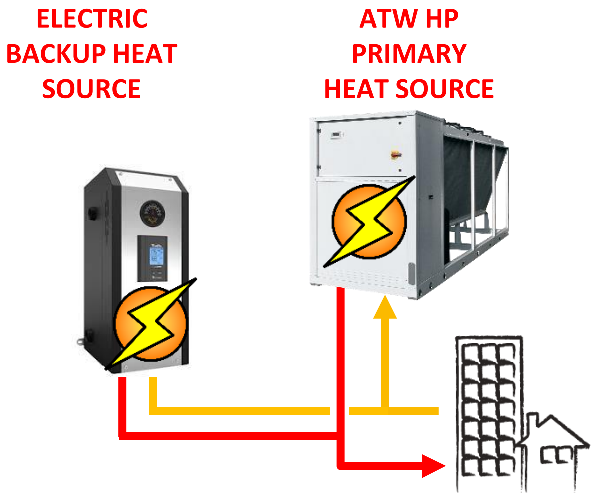
100% ELECTRIC SOLUTION:

- Requires 100% Electric Boiler @ Design Conditions
- Only COP = 1
- Higher Peak Electrical kW (Peak Capacity)
- Backup Generator Sized at Full Electric Boiler kW Load
- Excessive Demand Charges
- Significant Electrical Upgrades for Retrofits
  - Electrical Grids Cannot Support at Scale

CENTRAL PLANT COMPARISON FOR BACK-UP FUEL TYPES

WHAT DOES YOUR LOW-CARBON ELECTRIFIED SOLUTION LOOK LIKE FOR HYDRONIC SYSTEMS?

ATWHP + E-BOILER BACKUP



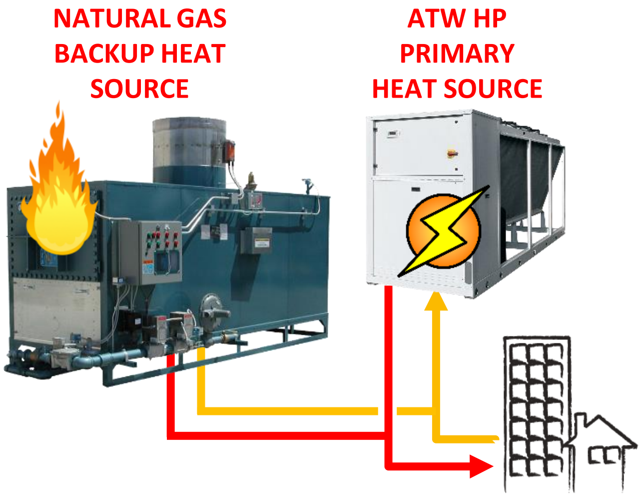
AIR-TO-WATER HEAT PUMP + 100% ELECTRIC SOLUTION:

- Cut-out Temperature of ATW Heat Pump Requires **100% Electric Boiler BACKUP** @ Design Conditions (i.e. -30 °C)
- Use Heat Pump For Fuel Switching as Much as Possible to offset
    - Leverage fewer Hours E-Boiler will run (BIN WEATHER)
- Lower kW Input of ATW vs. E-Boiler
    - Backup Capacity still at Peak e-Boiler Peak kW @ COP of 1
- Building Energy Source Fixed to Electric (No Operating Cost Resiliency)

CENTRAL PLANT COMPARISON FOR BACK-UP FUEL TYPES

WHAT DOES YOUR LOW-CARBON ELECTRIFIED SOLUTION LOOK LIKE FOR HYDRONIC SYSTEMS?

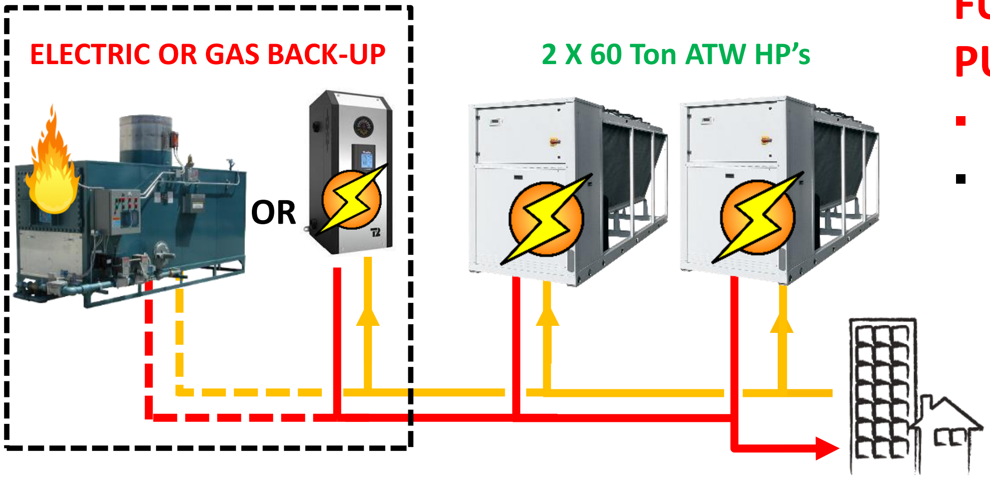
ATWHP + NG BOILER BACKUP



AIR-TO-WATER HEAT PUMP + BACKUP NATURAL GAS

- Cut-out Temperature of ATW Heat Pump Requires **100% Natural Gas Boiler BACKUP** @ Design Conditions
  - **Keep Existing Infrastructure, Extend Existing Boiler Life**
- Use Heat Pump For Fuel Switching as Much as Possible
  - Leverage fewer Hours NG-Boiler will run (BIN WEATHER)
- Significantly Reduced Electric Heat Pump Electrical Power Supply
  - **(2X Less due to COP)**
- **Dual Fuel System Provides Resilience & Redundancy for Operating Costs & Carbon Footprint**
- **No Backup Generator excessive sizing for Electric Boiler @ COP = 1**

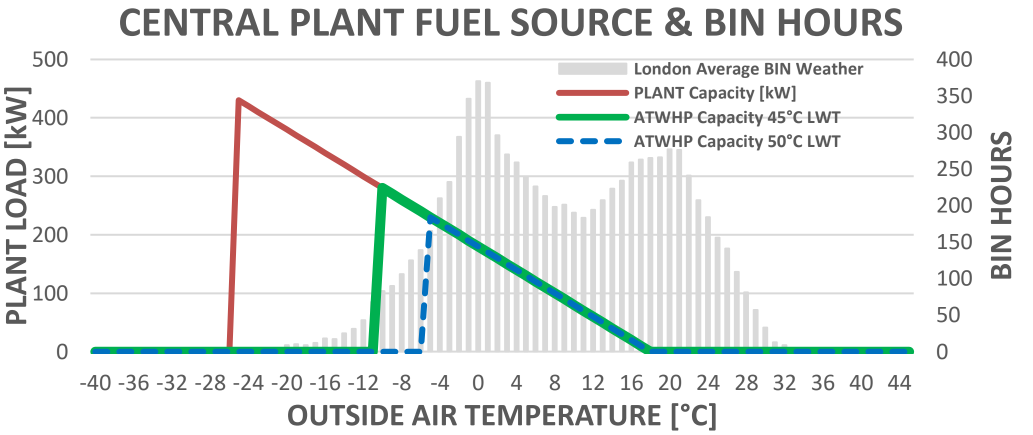
LONDON, ON CENTRAL PLANT HEATING ANALYSIS EXAMPLE: 120 TON CHILLER SYSTEM (2 X 60 TON UNITS)



FUEL SOURCE COMPARISON: AIR-TO-WATER HEAT PUMP + BACKUP NATURAL GAS OR ELECTRIC

- **500 kW Peak Load** Using TWO **60 Ton Air-to-Water** Heat Pump Units
- Comparison for Sizing Based on -10 C and – 5 C Cut-out Temperature:
  - **40% Propylene Glycol**
  - **45 °C LWT / -10 °C Cut-Out → CAP_{RATED} = 135 kW; COP_{RATED} = 2.07**
  - **50 °C LWT / -5 °C Cut-out → CAP_{RATED} = 110 kW; COP_{RATED} = 2.10**

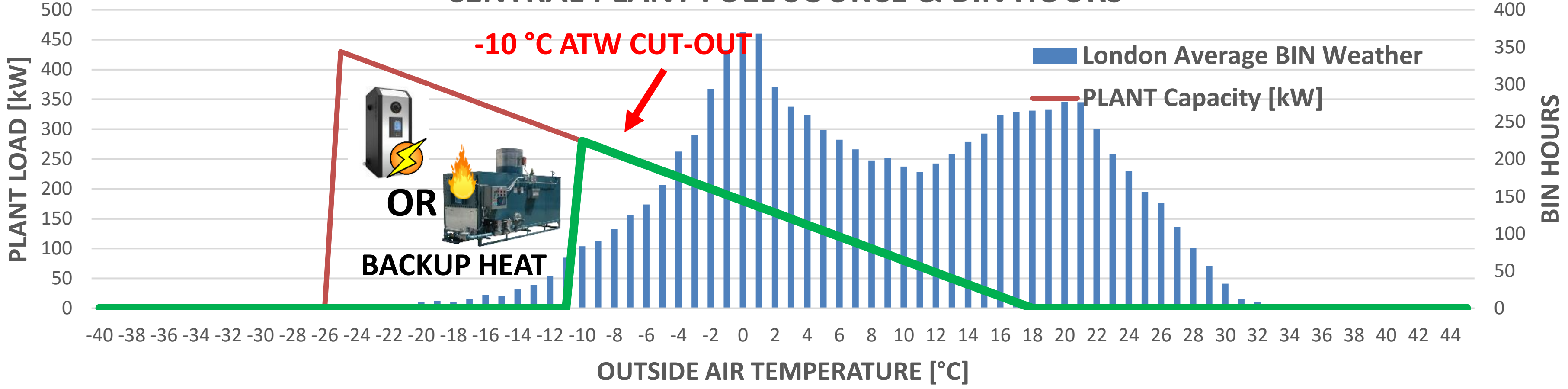
Peak Load [kW]	Ambient Temp. [°C]	Rated Capacity [kW]	Efficiency COP [W/W]
430	-25	GAS OR ELECTRIC AUX.	
280	-10	135	2.07
230	-5	110	2.10



CENTRAL PLANT COMPARISON FOR BACK-UP FUEL TYPES

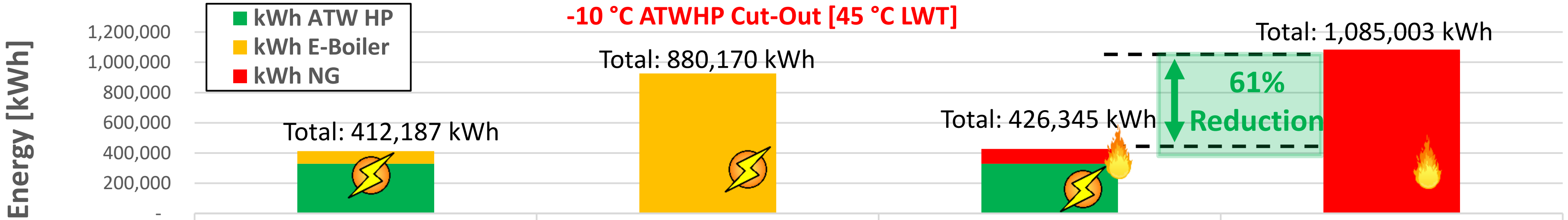
FUEL SOURCE COMPARISON CONSIDERING AIR-TO-WATER HEAT PUMP EFFICIENCIES & BACKUP FUEL USES

CENTRAL PLANT FUEL SOURCE & BIN HOURS



Central Plant Fuel Source Comparison: 2x NX-N/712P Units

-10 °C ATWHP Cut-Out [45 °C LWT]

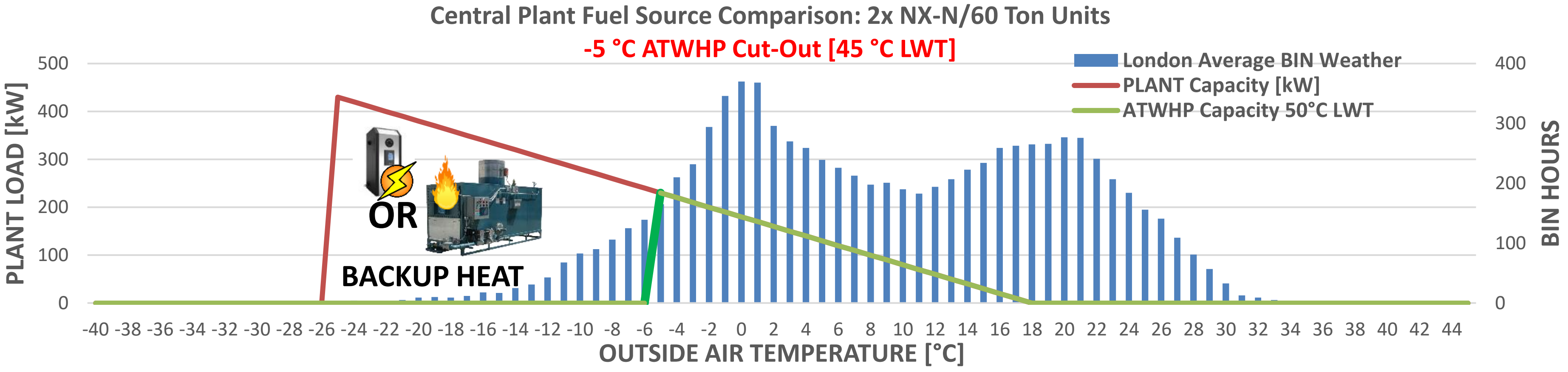


	ATWHP + E-Boiler [e kWh]	E-Boiler [e kWh]	ATWHP [e kWh] + NG Boiler [NG kWH]	NG Boiler [NG kWh]
🟥 kWh NG	-	0	96,788	1,085,003
🟨 kWh E-Boiler	82,630	926290		
🟩 kWh ATW HP	329,557	-	329,557	-

Central Plant Back-Up Type

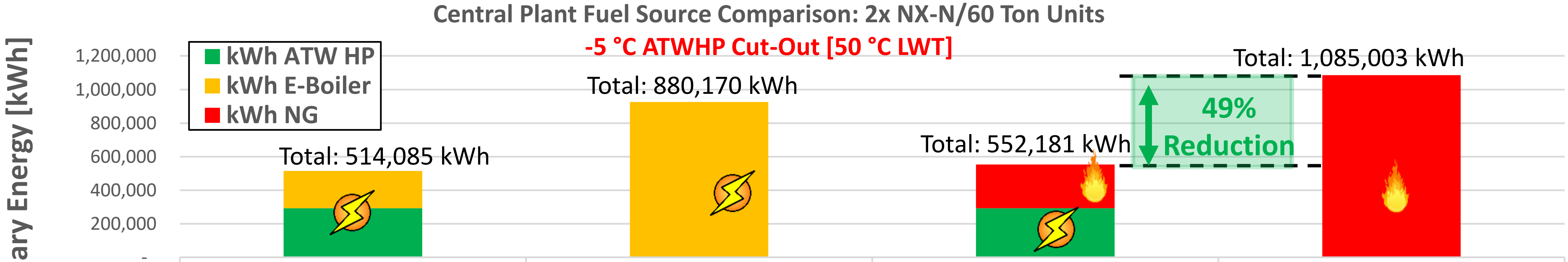
CENTRAL PLANT COMPARISON FOR BACK-UP FUEL TYPES

FUEL SOURCE COMPARISON CONSIDERING AIR-TO-WATER HEAT PUMP EFFICIENCIES & BACKUP FUEL USES



Central Plant Fuel Source Comparison: 2x NX-N/60 Ton Units

-5 °C ATWHP Cut-Out [45 °C LWT]



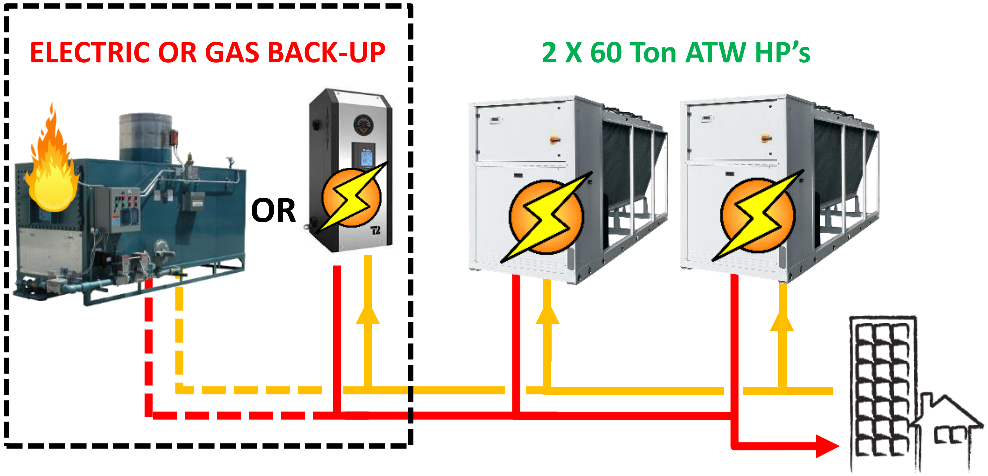
Central Plant Fuel Source Comparison: 2x NX-N/60 Ton Units

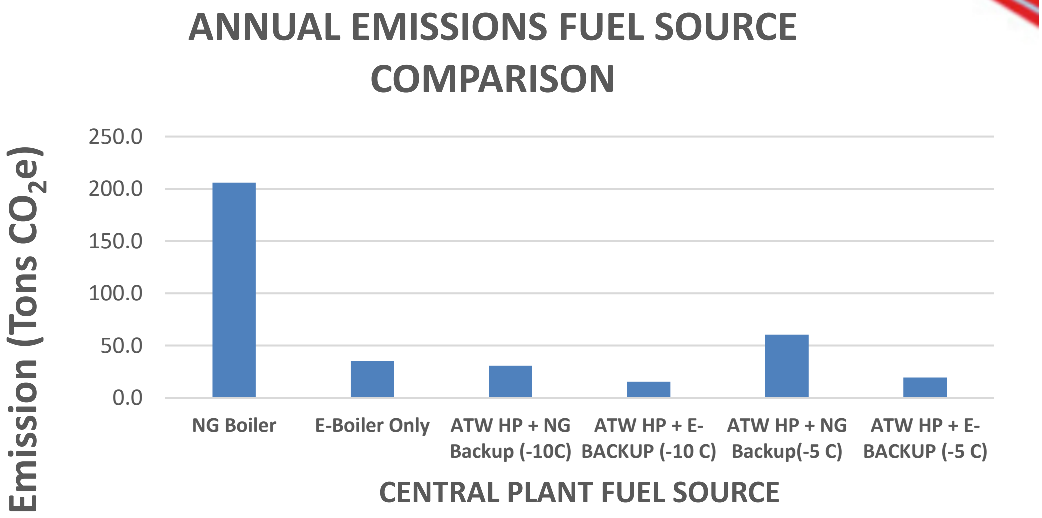
-5 °C ATWHP Cut-Out [50 °C LWT]

	ATWHP + E-Boiler [e kWh]	E-Boiler [e kWh]	ATWHP [e kWh] + NG Boiler [NG kWh]	NG Boiler [NG kWh]
🟥 kWh NG	-	0	260,436	1,085,003
🟨 kWh E-Boiler	222,340	926290		
🟩 kWh ATW HP	291,745	-	291,745	-

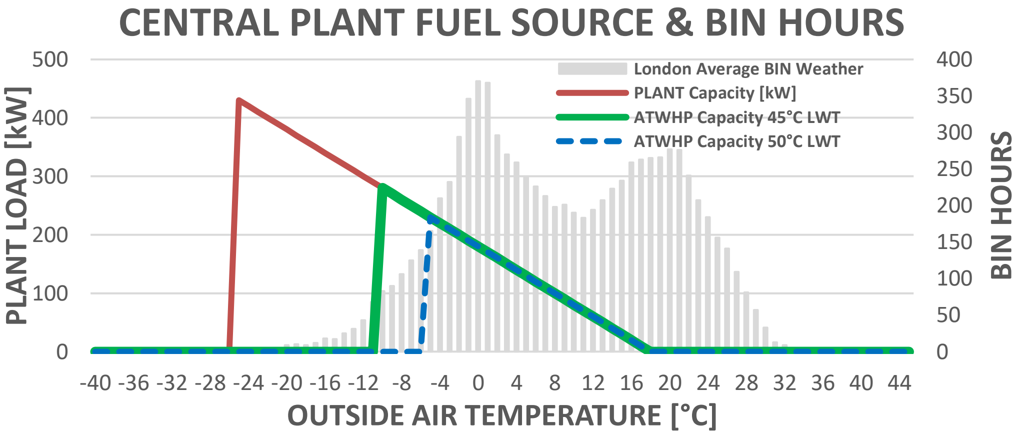
Central Plant Back-Up Type

LONDON, ON CENTRAL PLANT HEATING ANALYSIS EXAMPLE: 120 TON CHILLER SYSTEM (2 X 60 TON UNITS)




ANNUAL EMISSIONS FUEL SOURCE COMPARISON

Peak Load [kW]	Ambient Temp. [°C]	Rated Capacity [kW]	Efficiency COP [W/W]	Annual Tons CO_2e Offset (Gas Backup)
420	-23	GAS OR ELECTRIC AUX.		-
280	-10	135	2.07	175.2
230	-5	110	2.10	145.6

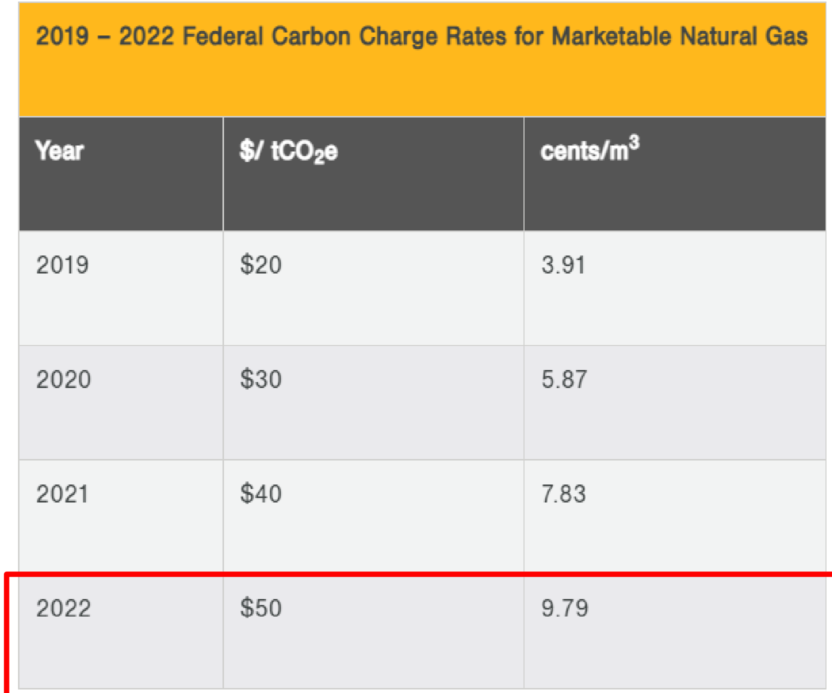

CENTRAL PLANT FUEL SOURCE & BIN HOURS

REDUCING BUILDING GHG EMISSIONS WITH AIR-TO-WATER HEAT PUMPS

HOW WILL FOSSIL FUEL PRICES BE AFFECTED IN A LOW-CARBON FUTURE?

FEDERAL CARBON CHARGE: ONTARIO (ENBRIDGE)

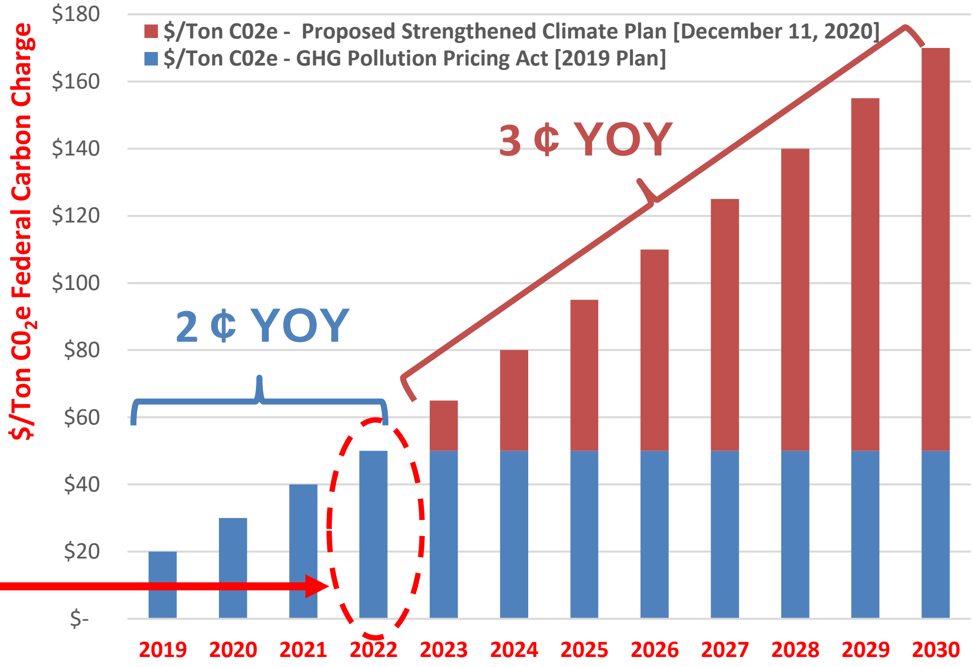
https://www.enbridgegas.com/Natural-Gas-and-the-Environment/Enbridge-A-Green-Future/Federal-Carbon-Pricing-Program



2019 – 2022 Federal Carbon Charge Rates for Marketable Natural Gas

Year	$/ tCO_2e	cents/m^3
2019	$20	3.91
2020	$30	5.87
2021	$40	7.83
2022	$50	9.79

Government of Canada Proposed Plan – December 11 2020



According to the Plan, if implemented, the Carbon tax will increase by $15/year until it reaches $170/ton by 2030

1. **Source:** Ontario Ministry of Environment and Climate Change's "Guideline for Quantification, Reporting and Verification for GHG Emissions - July 2017", Table 400-2
2. **Source:** National Inventory Report (NRI) 1990-2014: Greenhouse Gas Sources and Sinks in Canada, Part 3

2023-2030 Will see a rise in Carbon Tax by $15/Ton CO2e, which Translates to ~ 3 ¢ YOY

REDUCING GHG EMISSIONS & OPERATING COSTS WITH AIR-TO-WATER HEAT PUMPS

HOW TO COMPARE 1 $\text{kWh}_{\text{THERMAL}}$ NATURAL GAS TO ELECTRIC HEAT PUMP?

$$1\ kWh_{THERMAL,BOILER} = 1\ kWh_{THERMAL,HEAT\ PUMP}$$

$$\frac{\$/kWh_{Natural\ Gas}}{Boiler\ Efficiency\ [\%]} = \frac{\$/kWh_{Electrical}}{COP}$$

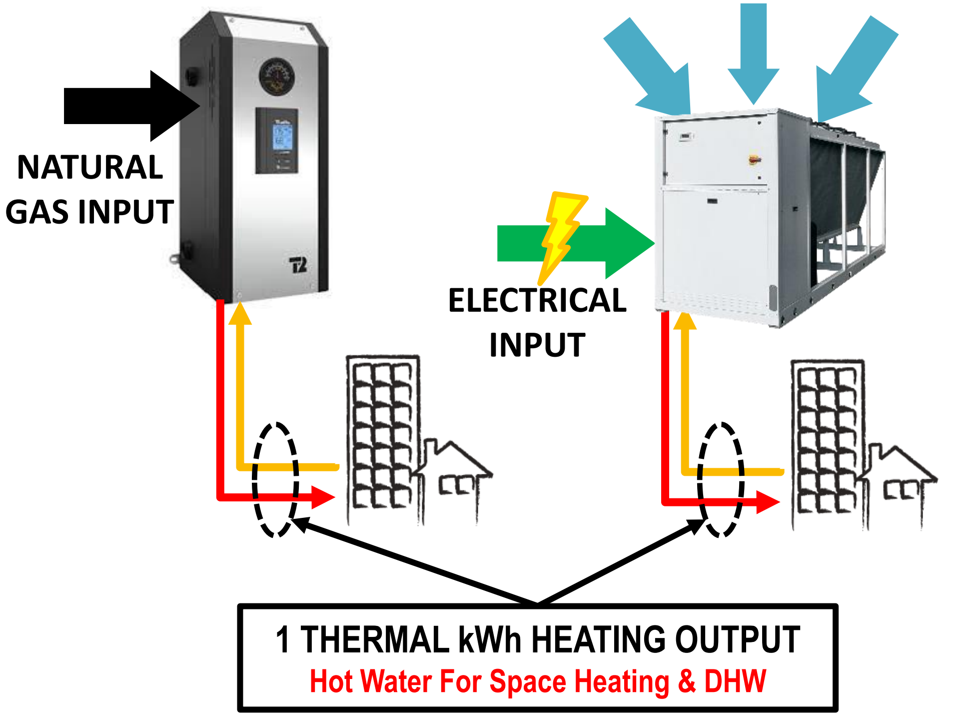
$$Breakeven\ COP_{HEAT\ PUMP} = \frac{\$/kWh_{Electrical}}{\$/kWh_{Natural\ Gas}} \times Boiler\ Efficiency$$

CONVENTIONAL BOILER

Boilers Burn Fossil-Fuels to Heat Water (NON-Renewable)

AIR-TO-WATER HEAT PUMP

Air-Source Heat Pumps Extract Heat from Environment (Renewable)



REDUCING GHG EMISSIONS & OPERATING COSTS WITH AIR-TO-WATER HEAT PUMPS

HOW TO COMPARE 1 $kWh_{THERMAL}$ PROVIDED BY NATURAL GAS OR HEAT PUMP?

$$COP_{HEAT\ PUMP,\ Breakeven} = \frac{\$/kWh_{Electrical}}{\$/kWh_{Natural\ Gas}} \times \eta_{Boiler}$$

$1\ m^3 NG = 10.5\ kWh_{Natural\ Gas}$

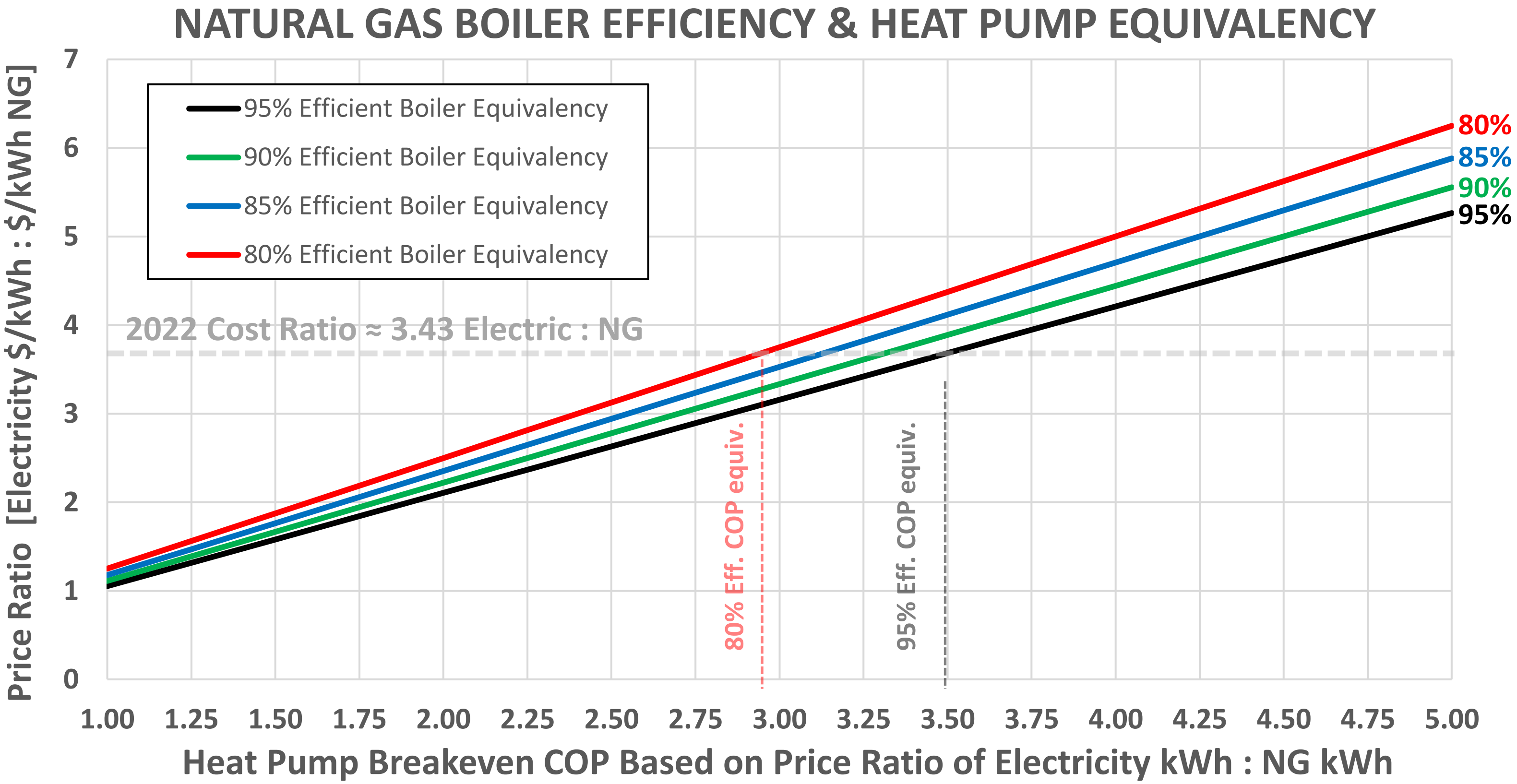
Average Natural Gas Price

= $0.40/m³ Approx. Total Effective Price from TOTAL of NG Bill (Based on 2022 Carbon Pricing @ $50/Ton CO_2e)

Avgerage Electricity Price

= $0.14/kWh

2022 Cost Ratio ≈ 3.675 E:NG
Breakeven $COP_{95\%}$ = 3.49
Breakeven $COP_{80\%}$ = 2.94



REDUCING BUILDING GHG EMISSIONS WITH AIR-TO-WATER HEAT PUMPS

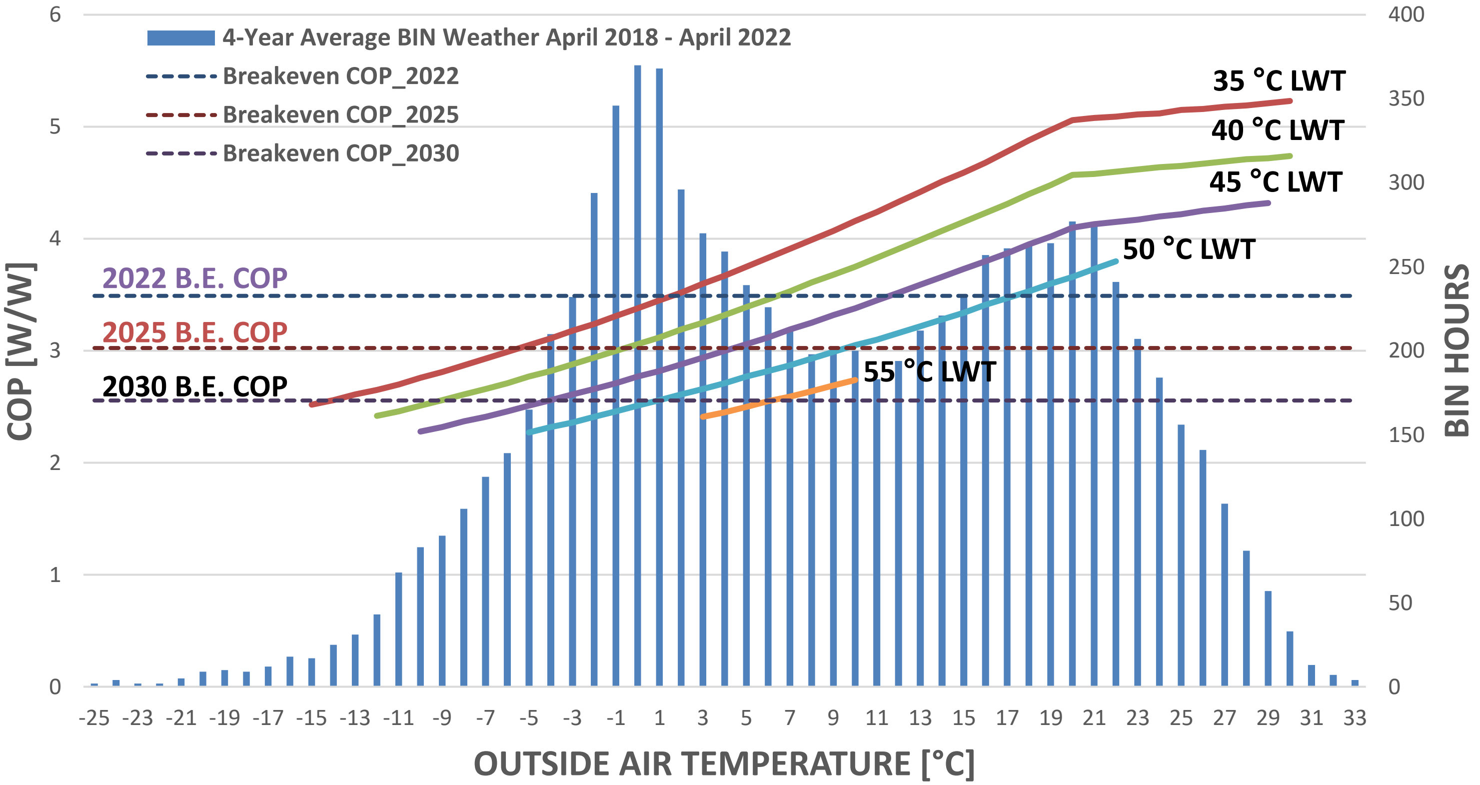
CARBON TAX IMPROVES HEAT PUMP OPERATIONAL COSTS 2022-2030

Year	Electricity Price ($/kWh)	Natural Gas ($/m^3)	Breakeven COP
2022	$0.140	$0.40	3.49
2023	$0.143	$0.43	3.31
2024	$0.146	$0.46	3.16
2025	$0.149	$0.49	3.02
2026	$0.152	$0.52	2.91
2027	$0.155	$0.55	2.80
2028	$0.158	$0.58	2.71
2029	$0.161	$0.61	2.63
2030	$0.164	$0.64	2.56

1 m^3 = 10.5 kWh$_{\text{NATURAL GAS}}$
Boiler Efficiency = 95%
$0.40/m^3 Natural Gas (2022) + $0.03
YOY (Carbon Tax Increase)

Avg. Electricity $0.14/kWh (+2% YOY)

LONDON ON 4-YEAR BIN HOUR WEATHER DATA
APRIL 2018 - APRIL 2022
BREAKEVEN COP ACCORDING TO CARBON TAX 2022-2030



AIR-TO-WATER CENTRAL PLANT: APPLICATIONS

- **2-PIPE SYSTEMS:**
  - **Simple 2-Pipe Change-Over System**
  - **Cascade Systems**

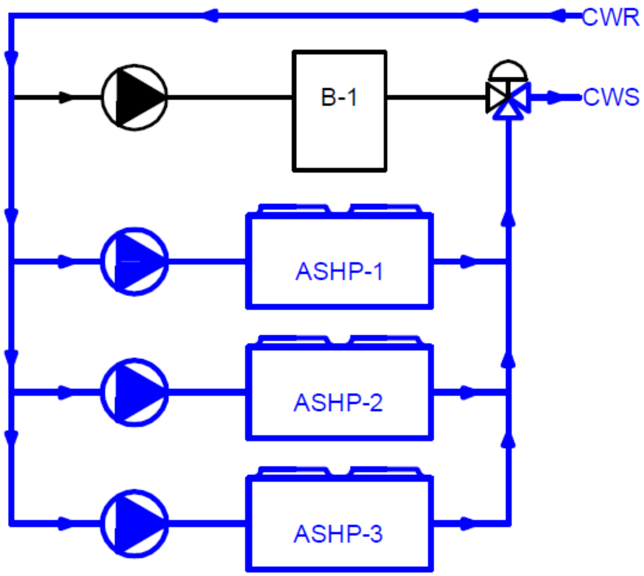
- **4-PIPE HYBRID SYSTEMS using ATW Heat Pumps**

- **PARTIAL HEAT RECOVERY in 2-Pipe & 4-Pipe Systems (Desuperheater)**

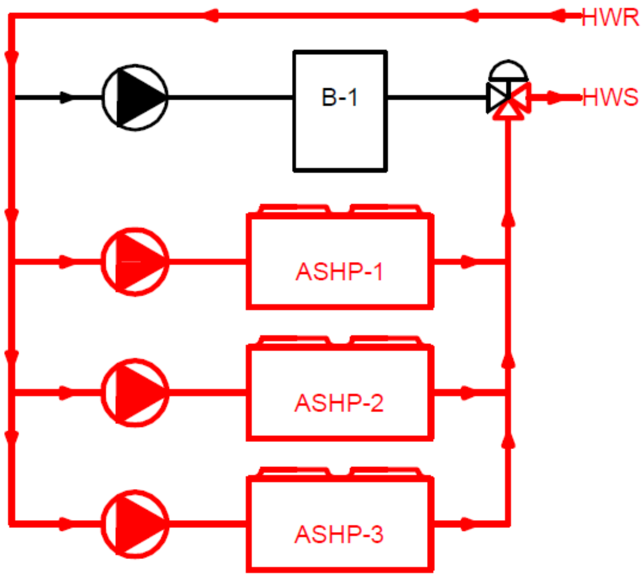
- **DOMESTIC HOT WATER**

CENTRAL HEAT PUMP PLANT:
2-PIPE CHANGEOVER COMMERCIAL SYSTEM

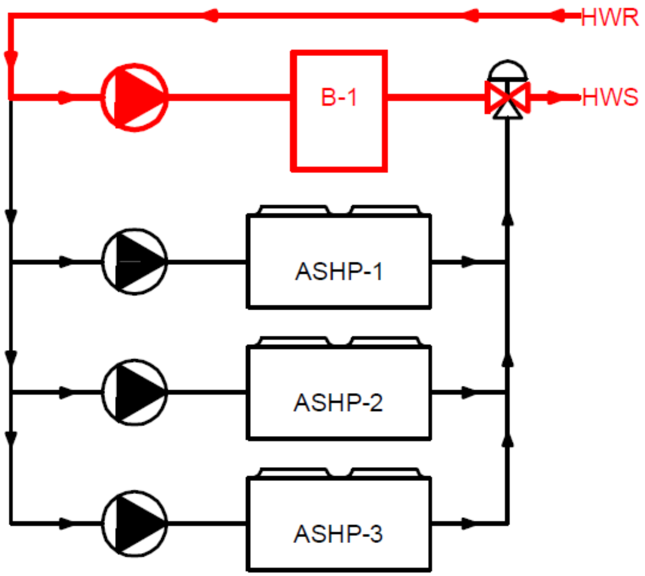
SUMMER COOLING



WINTER HEATING
AIR-TO-WATER HEAT PUMP



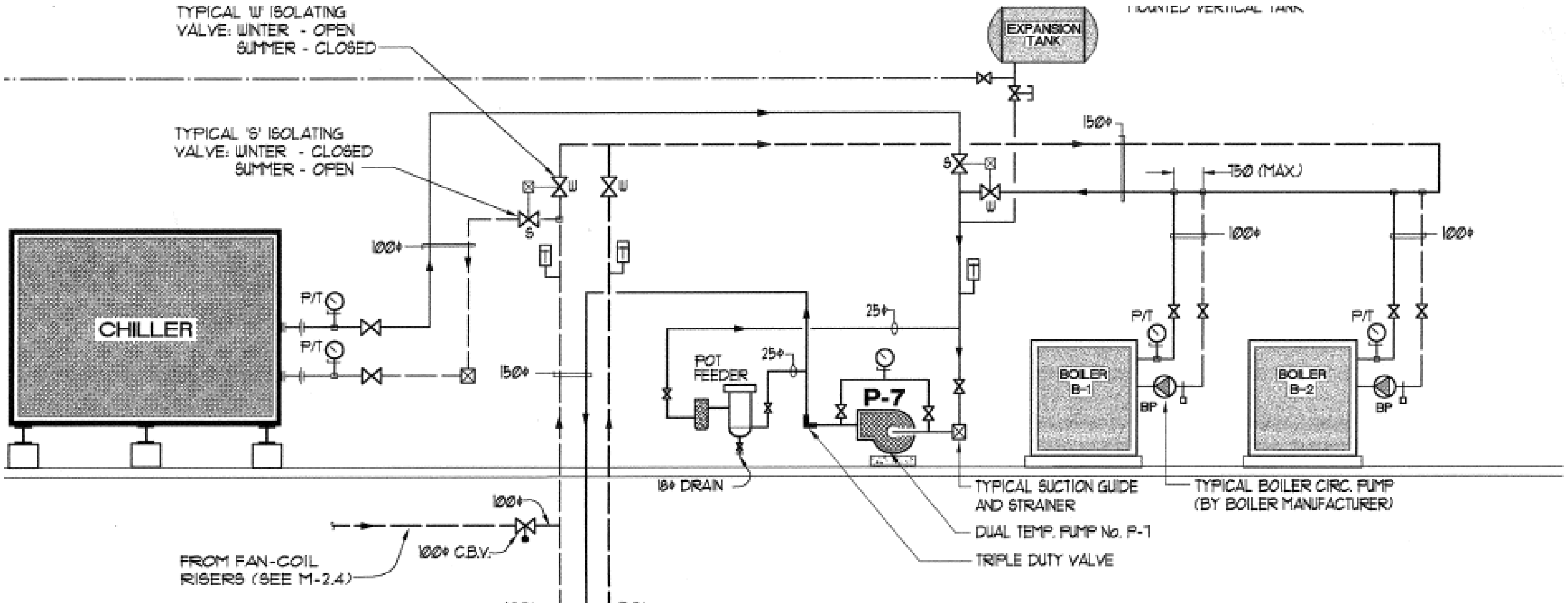
WINTER HEATING
AUXILIARY BOILER



FUEL-SWITCH RETROFIT: BIN HOUR ANALYSIS

Air-Cooled Chiller due for Replacement (110 Tons)

Upgrade with Rev. Chiller instead of like-for-like



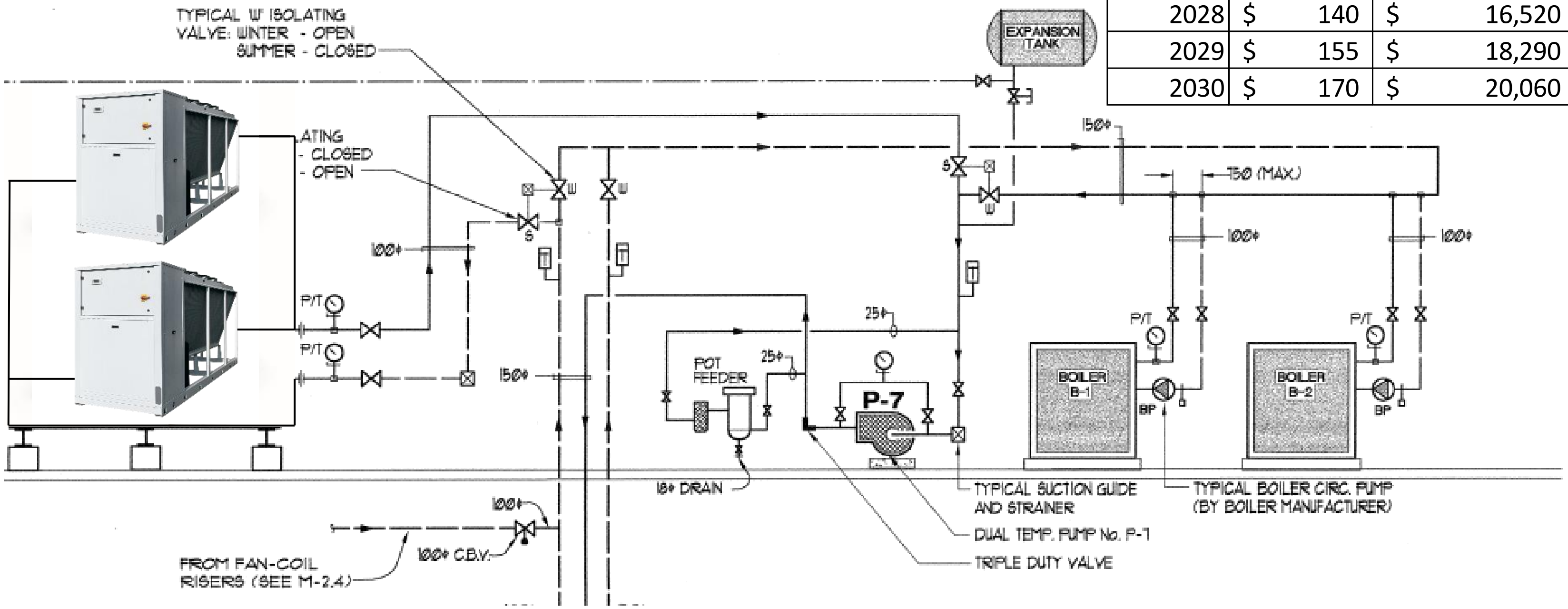
FUEL-SWITCH RETROFIT: BIN HOUR ANALYSIS

Air-Cooled Chiller due for Replacement (110 Tons)

Upgrade with Rev. Chiller instead of like-for-like

118 Tons CO2e Offset Annual Compared to NG Boiler operating at same T_{SUPPLY}

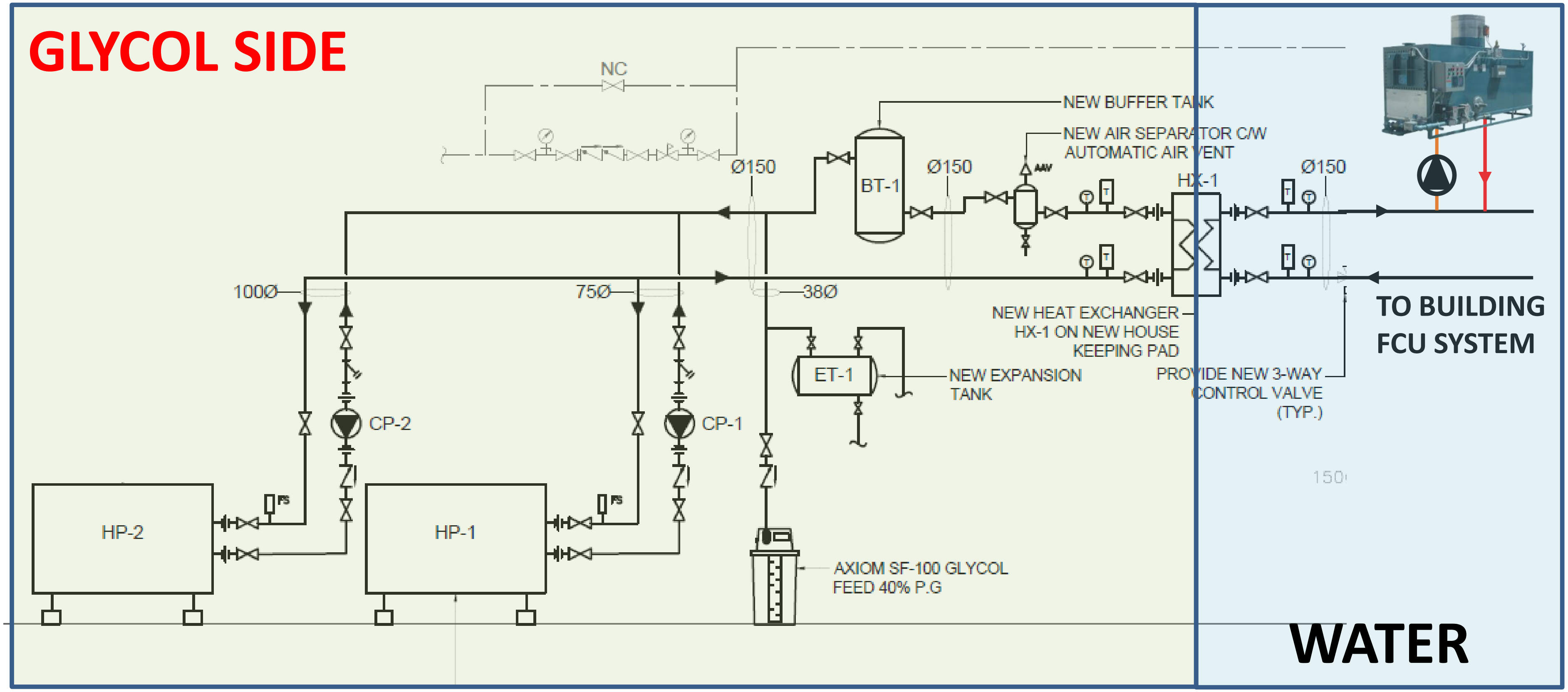
Year	Carbon Tax $/Ton CO_2e	Annual Savings based on 118 Tons CO_2e Offset Annually	Cumulative Savings based on 118 Tons CO_2e Offset Annually
2022	$ 50	$ 5,900	$ 5,900
2023	$ 65	$ 7,670	$ 13,570
2024	$ 80	$ 9,440	$ 23,010
2025	$ 95	$ 11,210	$ 34,220
2026	$ 110	$ 12,980	$ 47,200
2027	$ 125	$ 14,750	$ 61,950
2028	$ 140	$ 16,520	$ 78,470
2029	$ 155	$ 18,290	$ 96,760
2030	$ 170	$ 20,060	$ 116,820



RETROFIT APPLICATIONS: DECOUPLING GLYCOL

BUFFER TANK, EXPANSION TANK ON GLYCOL SIDE

WATER ONLY ON HX SECONDARY, WATER DISTRIBUTED THROUGH BUILDING



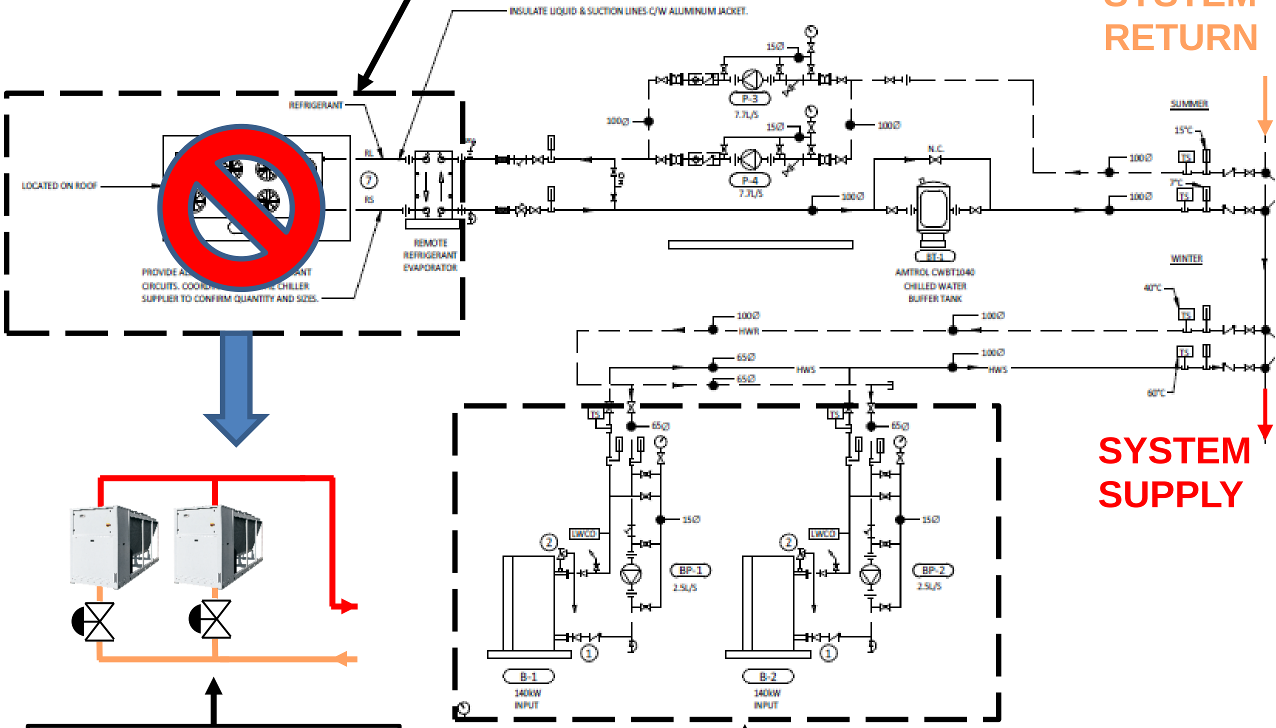
GLYCOL SIDE

TO BUILDING FCU SYSTEM

WATER

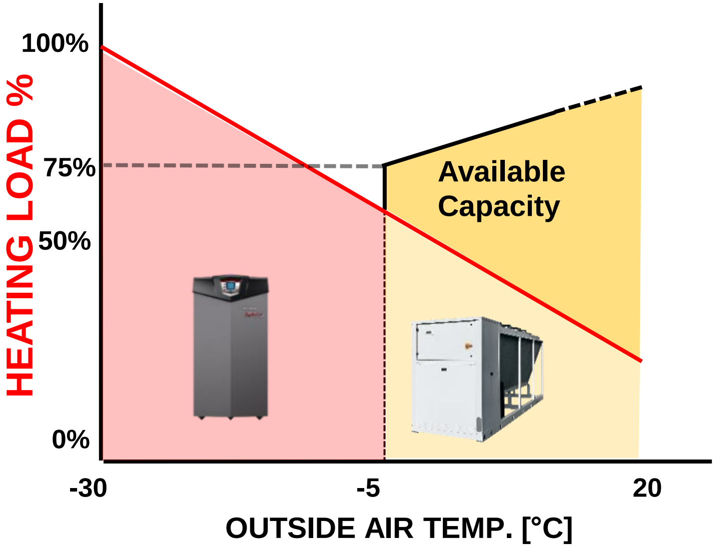
TRADITIONAL AIR-COOLED CHILLER ALTERNATIVES

Condensing Unit w/ Evaporator (80 TON)



ATW HP Units
2x40 Ton
Sized for Cooling

Heating Boilers
2x140 kW



ATW HP ADVANTAGE:

Heating Selected for:
50 °C LWT, Rated @ -5 °C OAT = 107.5 kW Each

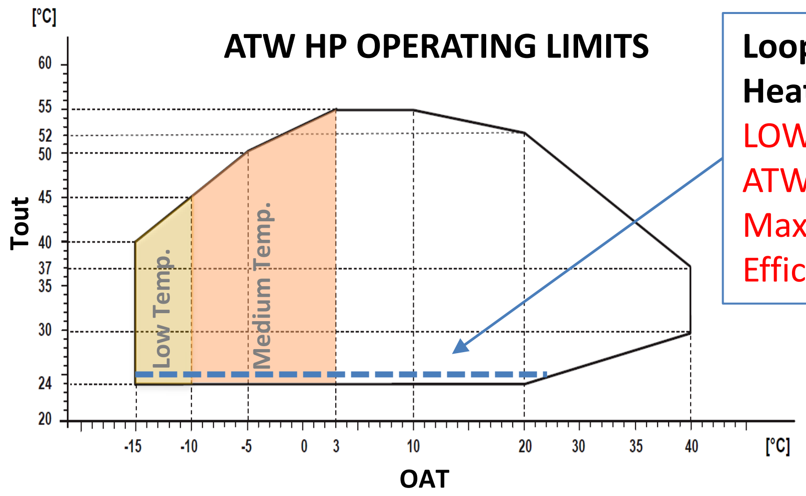
ASHP HEATING AVAILABLE: 215 kW
HEATING BOILERS: 280 kW
UP TO 75% HEATING PROVIDED BY HEAT PUMP

HYBRID CENTRAL HEAT PUMP PLANT APPLICATIONS

RETROFIT OR NEW CONSTRUCTION USING WLHP SYSTEM

WATER-LOOP HEAT PUMP SYSTEM (WLHP):

- Common in MURBs & Office Buildings
- 4-Pipe Comfort Using 2-Pipe System
- Similar ΔT for central plant & Terminal Units
- Lower Installation Costs vs. 4-Pipe System
- Heat Recovery During Shoulder Season through Water Loop
- Maximizes Air-to-Water Central Plant Heat Pump Efficiency & Extends Usability of ATW HP down to -15 °C
    - Backup Natural Gas or Electric Boiler used only below -15 °C
    - Provides Redundancy and Back-up to System, Option for Dual Fuel
- Use as Chiller in Cooling mode if Design Permits
    - Cooling Mode as Back-up
    - Apply DHW Preheat in Summer to Maximize ATW HP usage



Loop Temp in Heating for WLHP

LOW Temp from ATW Heat Pump Maximizes ASHP Efficiency

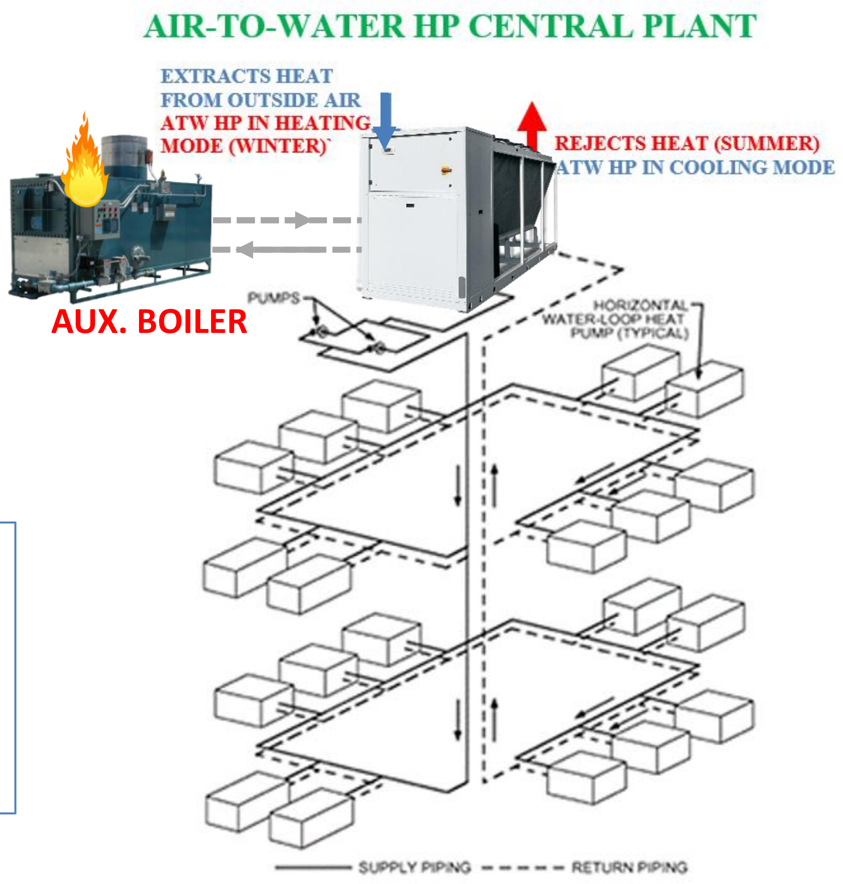


Image Source: ASHRAE HANDBOOK: 2020 HVAC SYSTEMS AND EQUIPMENT Ch. 9 Fig. 30

OPTIMIZING ATW HP SELECTION FOR HEATING AND COOLING REQUIREMENT

BEST SIZING METHOD TO ADDRESS IMBALANCE BETWEEN HEATING AND COOLING CAPACITY AT RATED CONDITIONS

EXAMPLE:
WLHP CASCADE SYSTEM
Summer Cooling: 35 Tons (123 kW) @ 35 °C Ambient
Winter Heating: 378 MBH (110 kW) @ 26 LWT/21 EWT @ -15 °C

SELECT BASED ON COOLING (35 Tons)
NX-N/452P = 35 Ton Cooling;
Summer Cooling: 35 Tons
Resulting Heating = 238.2 MBH
63% of Requirement only

Best Value from Investment Point of View

SELECT BASED ON HEATING (378 MBH)
NX-N/712P = 450 MBH Heating (120% of Req.)
Summer Cooling: 55 Tons **(57% Oversized!)**

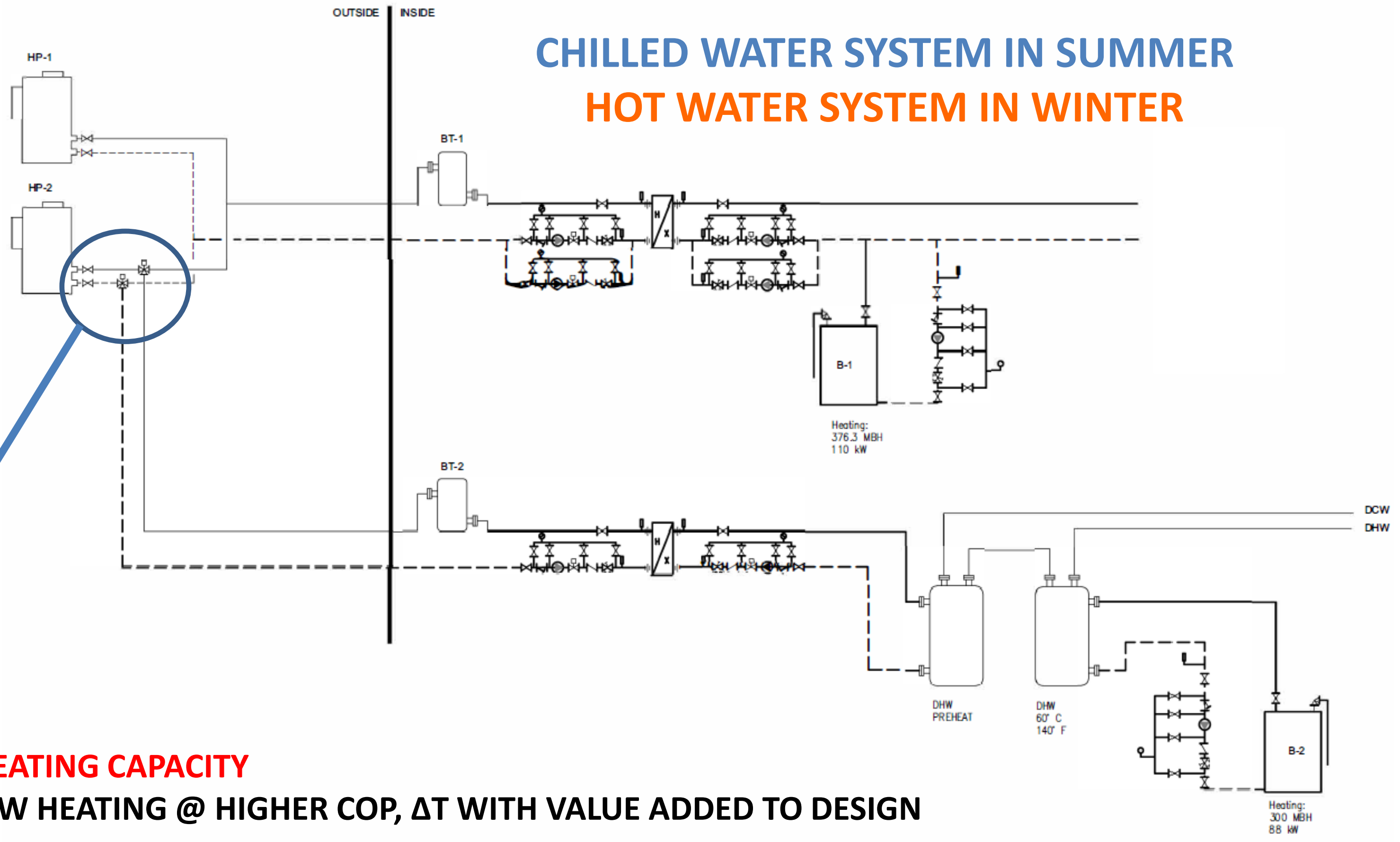
Covers more heating load to offset Boiler Usage, but Cooling is grossly oversized

ATW HP SIZING OPTIMIZED FOR HEATING REQUIREMENT

BEST SIZING METHOD TO ADDRESS IMBALANCE BETWEEN HEATING AND COOLING CAPACITY AT RATED CONDITIONS

SUMMER COOLING
WINTER HEATING

WINTER HEATING
SUMMER DHW



CHILLED WATER SYSTEM IN SUMMER
HOT WATER SYSTEM IN WINTER

DHW CHANGEOVER VALVES

HP-2: SIZED FOR MISSING HEATING CAPACITY

USED IN SUMMER FOR DHW HEATING @ HIGHER COP, ΔT WITH VALUE ADDED TO DESIGN

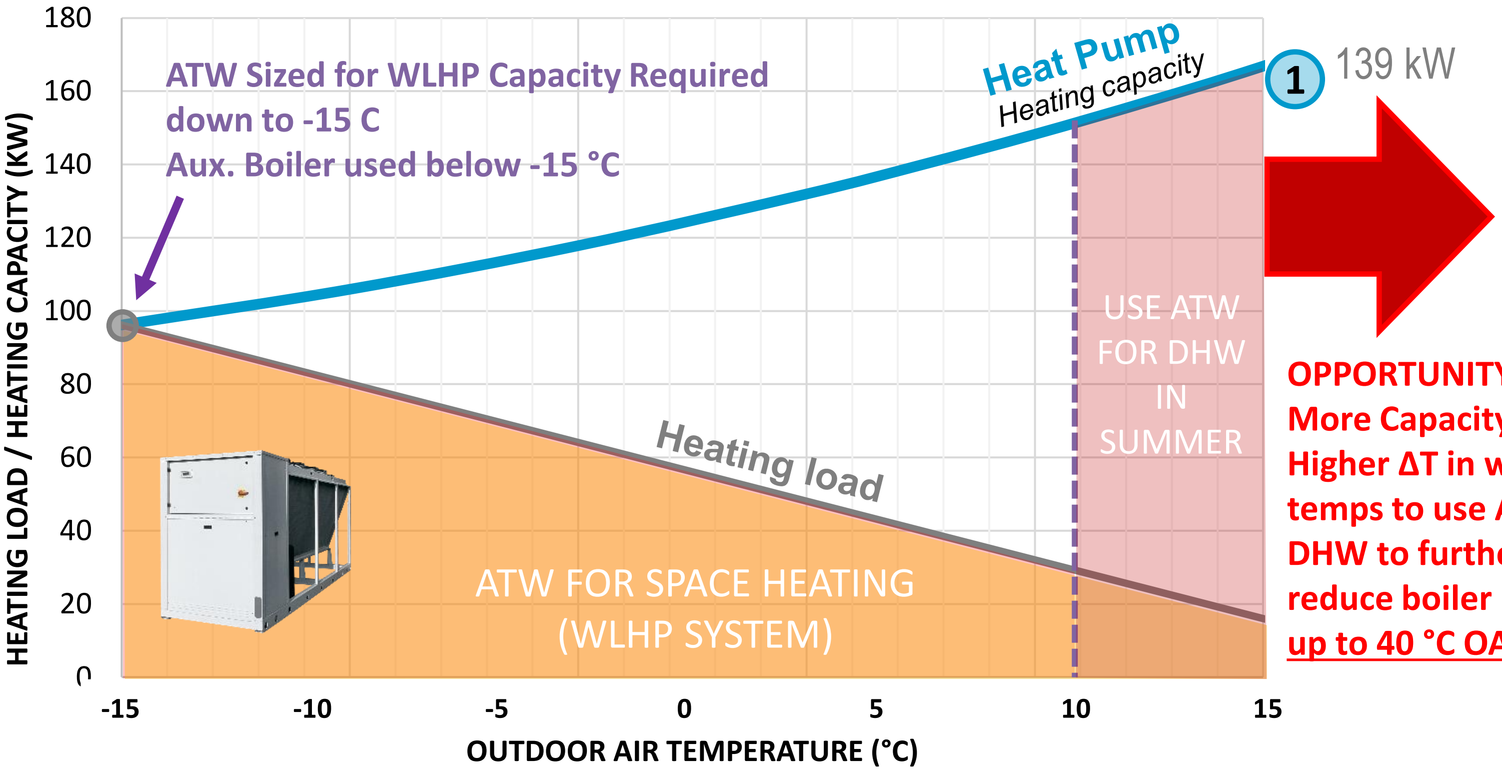
AIR-TO-WATER HEAT PUMP: SIZING FOR HEATING

HEATING CAPACITY VS HEATING LOAD

138 kW ATW HP (NOMINAL)

REVERSIBLE UNIT, AIR SOURCE FOR OUTDOOR INSTALLATION

Aux. Boiler



ATW Sized for WLHP Capacity Required down to -15 C

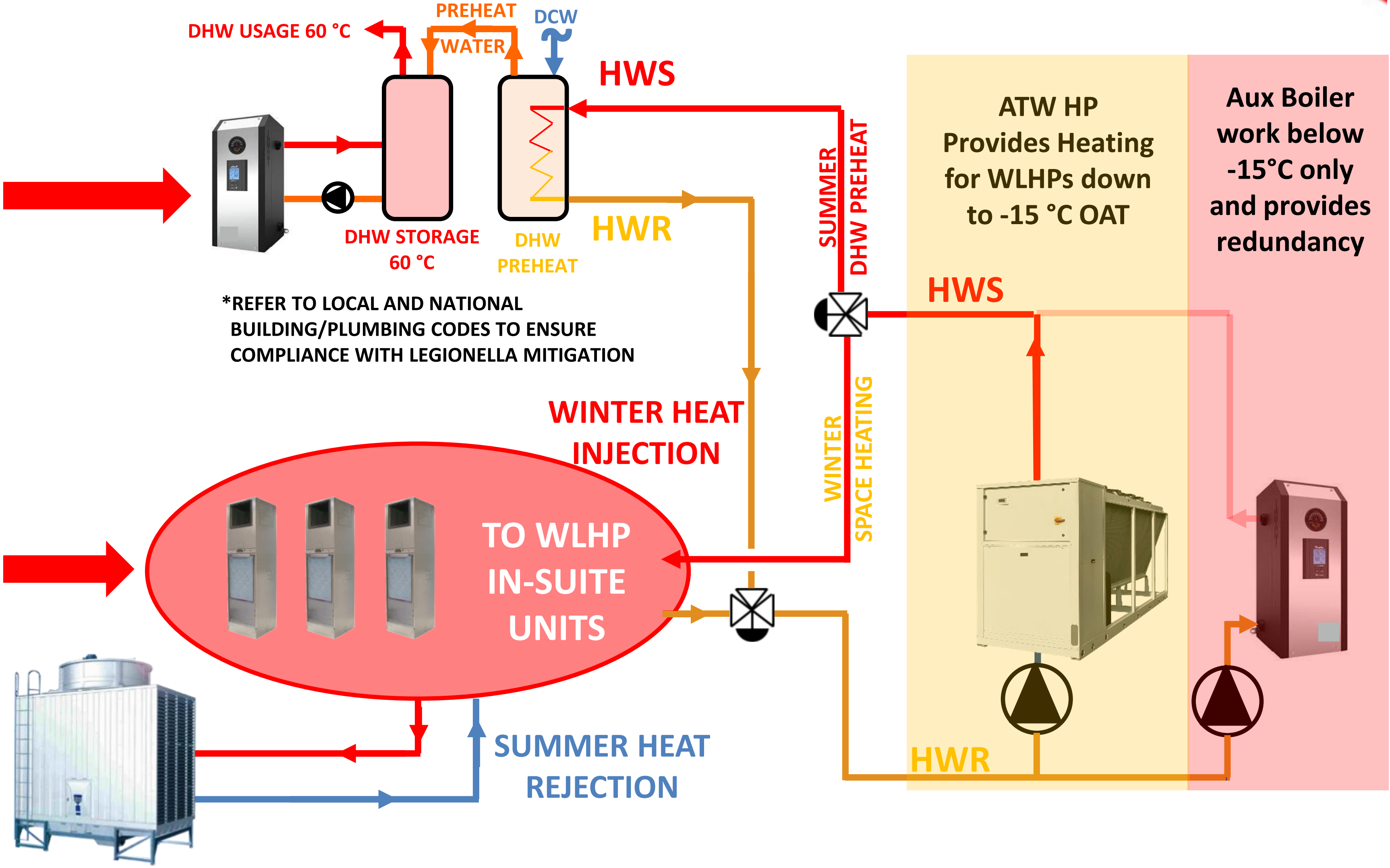
Aux. Boiler used below -15 °C

OPPORTUNITY:
More Capacity & Higher ΔT in warmer temps to use ATW for DHW to further reduce boiler usage, <u>up to 40 °C OAT</u>

MAXIMIZING ATW HP USAGE FOR DECARBONIZATION: DHW PREHEATING IN SUMMER

SUMMER:
Since ATW HP Not Needed in Summer (Fluid Cooler), put ATW HP to work to supplement DHW Natural Gas Usage with **DHW PREHEAT**

WINTER:
ATW HP Acts as Heat Injector in Winter to serve the WLHP System



DHW USAGE 60 °C

PREHEAT WATER

DCW

HWS

DHW STORAGE 60 °C

DHW PREHEAT

HWR

SUMMER DHW PREHEAT

WINTER SPACE HEATING

*REFER TO LOCAL AND NATIONAL BUILDING/PLUMBING CODES TO ENSURE COMPLIANCE WITH LEGIONELLA MITIGATION

ATW HP Provides Heating for WLHPs down to -15 °C OAT

Aux Boiler work below -15°C only and provides redundancy

HWS

WINTER HEAT INJECTION

TO WLHP IN-SUITE UNITS

SUMMER HEAT REJECTION

HWR

MAXIMIZING ATW HP USAGE FOR DECARBONIZATION: DHW PREHEATING IN SUMMER

WINTER SPACE HEATING DESIGN CONDITIONS VS. SUMMER HEAT PUMP OPERATION:

65-Ton (225 kW Cooling Cap.) Reversible Heat Pump Chiller (250 kW Heating Capacity at Std. AHRI 550 Conditions)

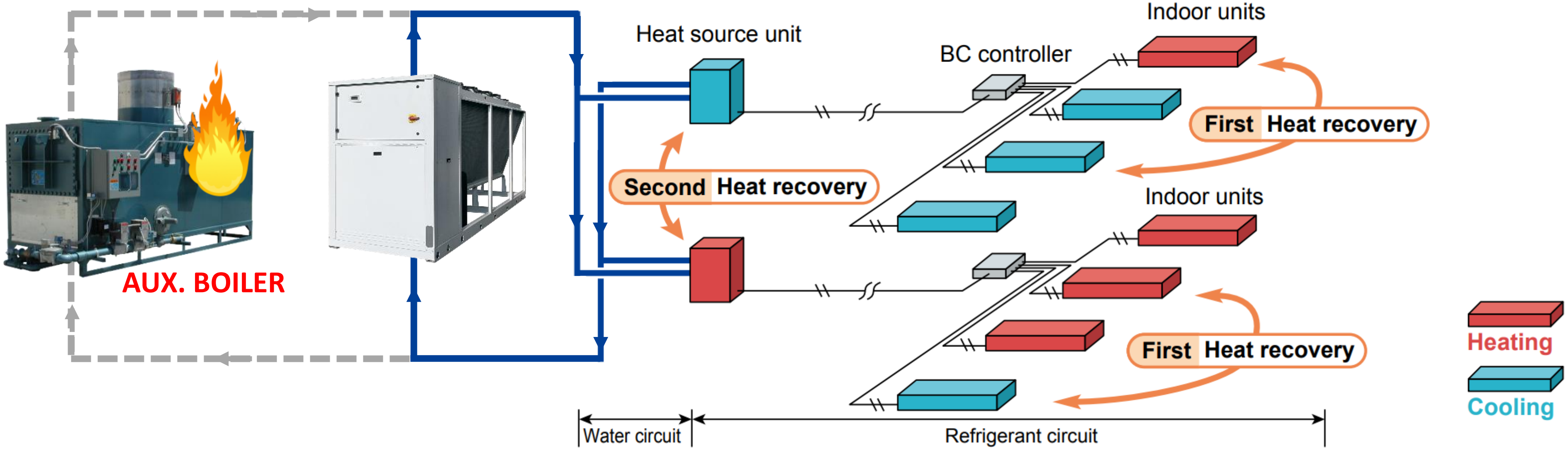
Design Parameter	Winter Design Conditions	Summer DHW Preheating Performance	
Fluid	40% Propylene Glycol Solution		
Flow Rate [L/s]	7.269		
Service	**Space Heating**	**Summer DHW Preheating**	
Ambient Design Temp [°C]	-15	20	30
Design Supply Water Temp [°C]	35	40	40
Temperature Difference ΔT [°C]	5	12.1	
Capacity @ 100% Load [kW]	139.5	**337.6** **[+242%]**	
COP [W/W]	2.385	**4.373** **[+183%]**	**4.532** **[+190%]**

AIR-TO-WATER/VRF HYBRID SYSTEM

LOW-CARBON SOLUTION, LOWER COST COMPARED TO GEOTHERMAL

ATW HP + WATER-COOLED VRF CENTRAL PLANT BENEFITS:

- Eliminates the “Operating Envelope” Challenge → Perfect comfort at indoor VRF units
- Good Retrofit for Existing Water-Cooled VRF systems to reduce boiler usage
- Supplement with Auxiliary Boiler as Required
  - Replacement: Below -15 °C **Bivalence**
  - ATW HP + Boiler **Load Sharing** provides sizing flexibility
- Optimized COP/EER of overall system in both Heating & Cooling

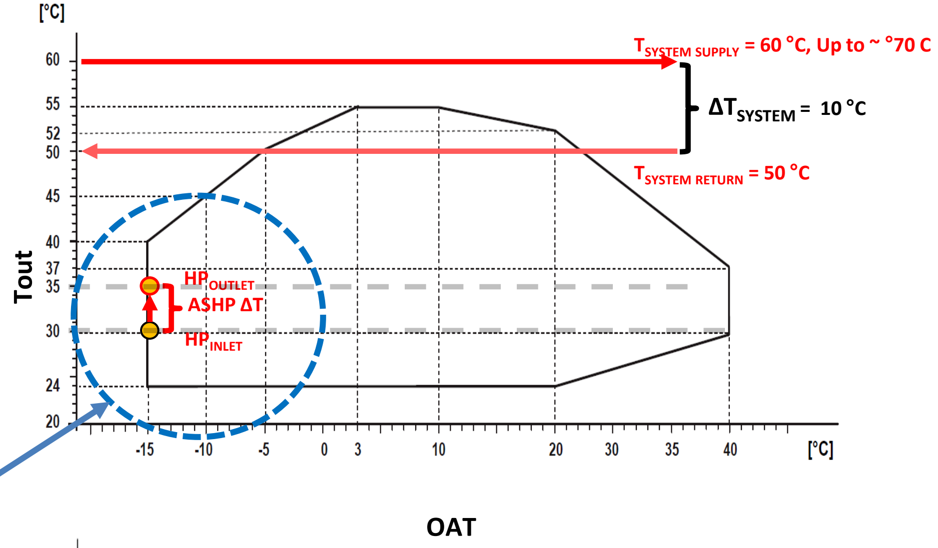


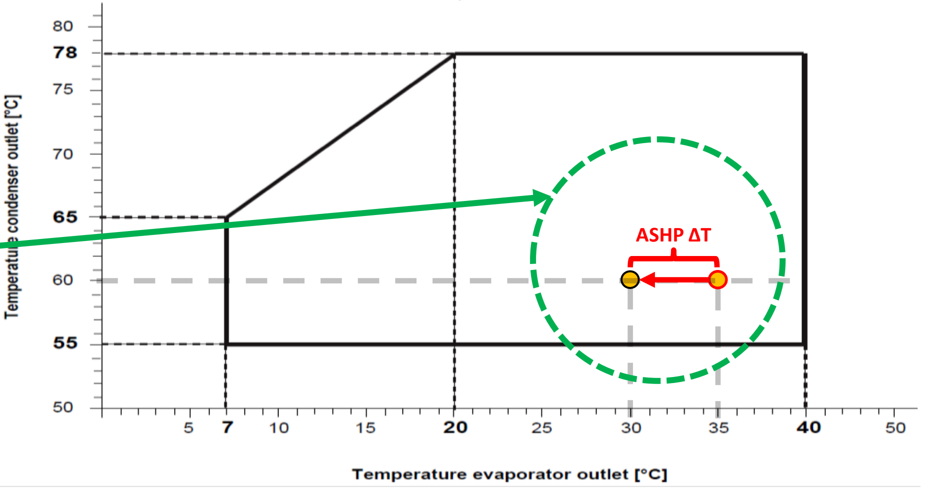
RETROFIT CHALLENGES: CASCADE SYSTEMS

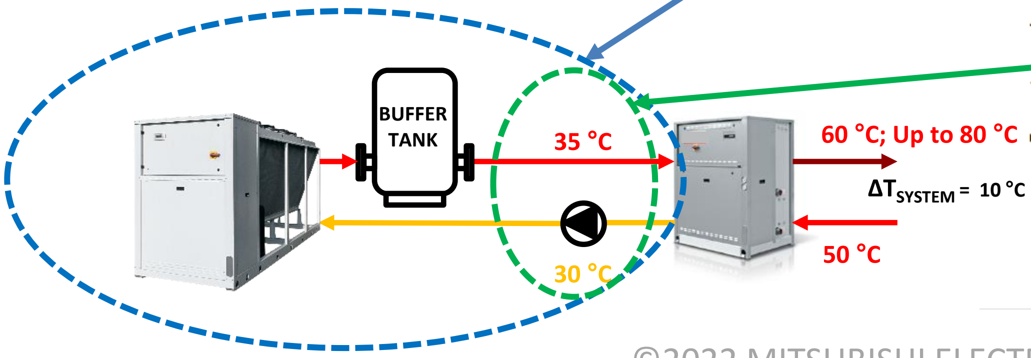
VERY-HIGH WATER TEMPERATURE SYSTEMS, FULL DOMESTIC HOT WATER PRODUCTION

SOLUTION: WATER-WATER HIGH TEMP HEAT PUMP (ENERGY RAISER)

- Retrofit Application to Match Existing System side ΔT
- Decoupling of glycol via W/W Booster Heat Pump
- Water-Water Heat Pump offers a solution for cascade system to take advantage of ASHP to extreme limits
- ASHP operates at Desired Set Point and constant ΔT

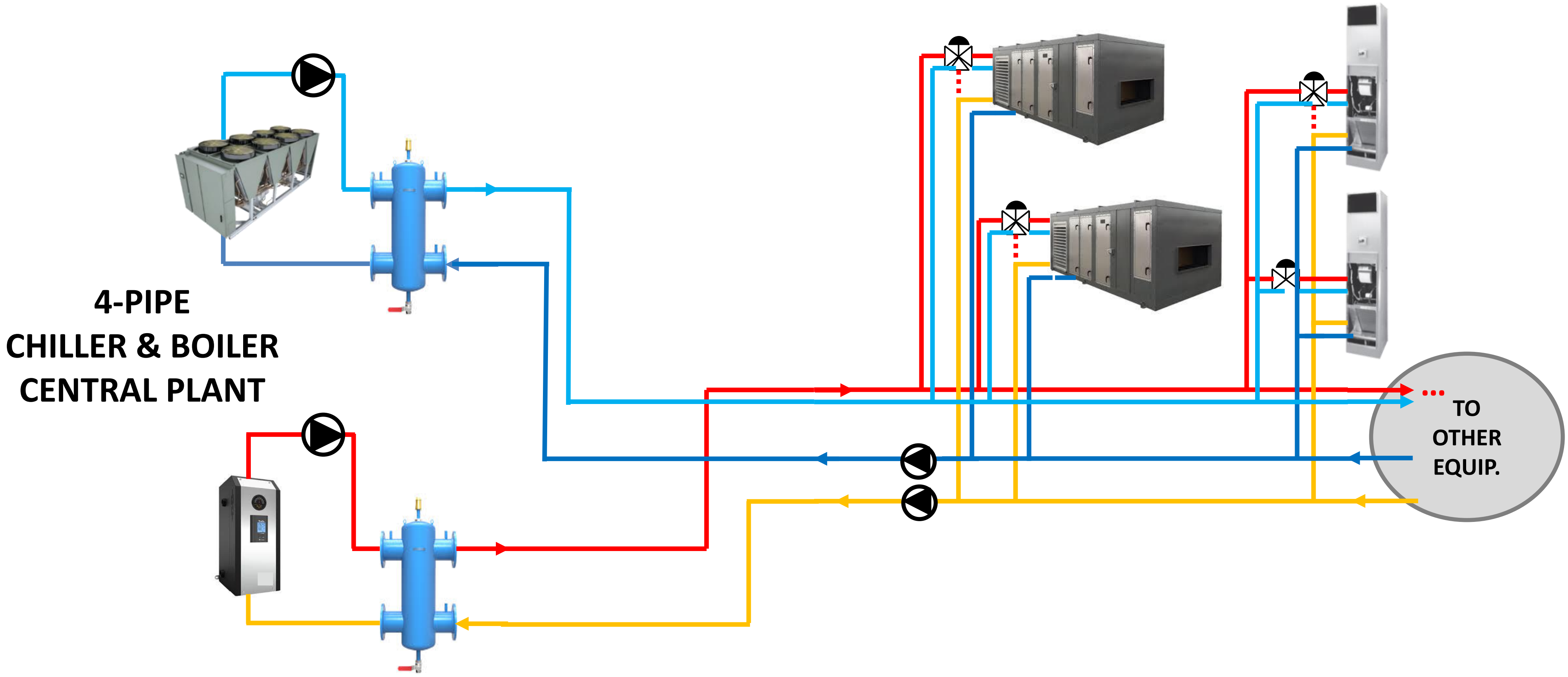




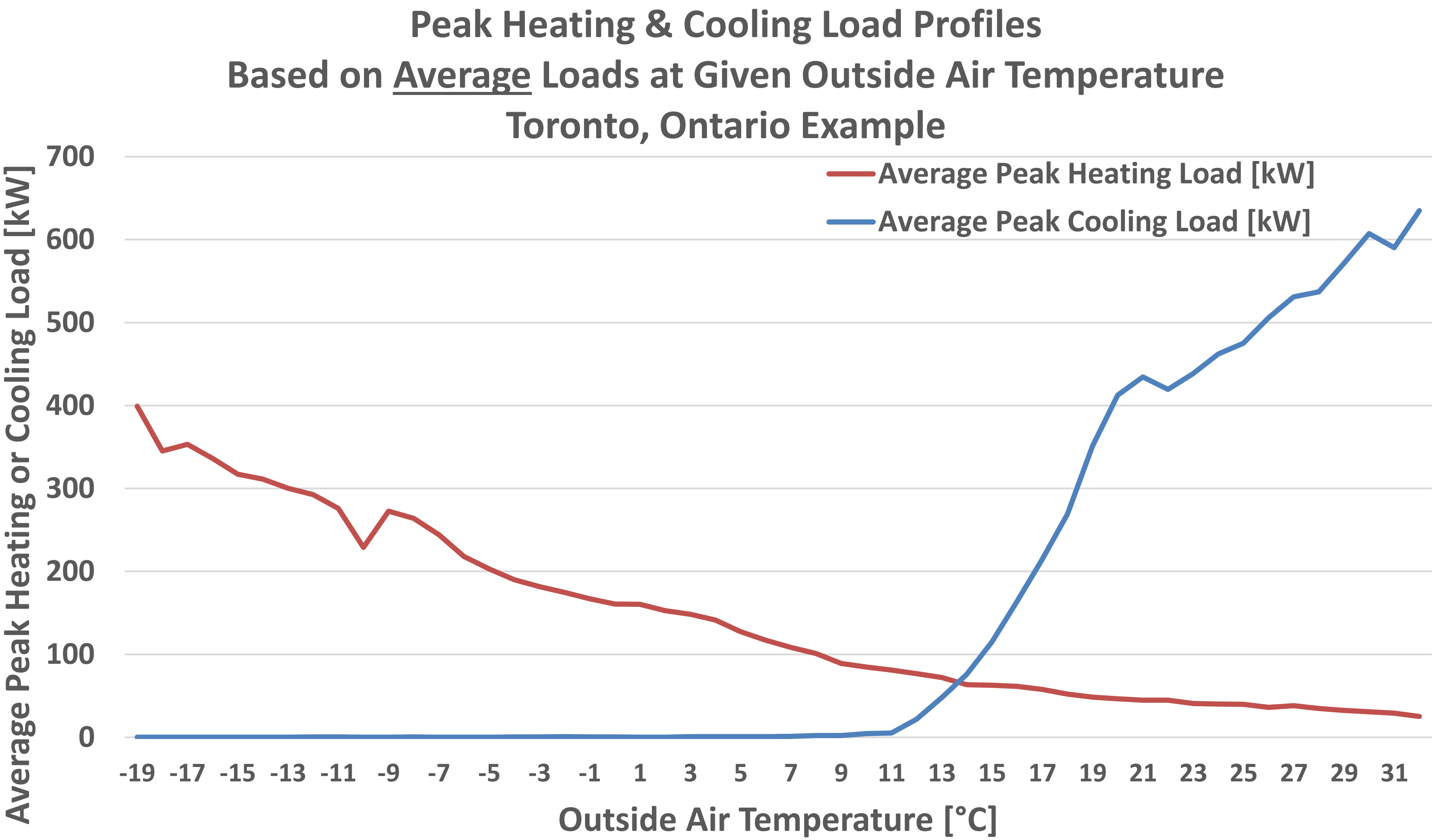


4-PIPE FUEL SWITCH RETROFIT

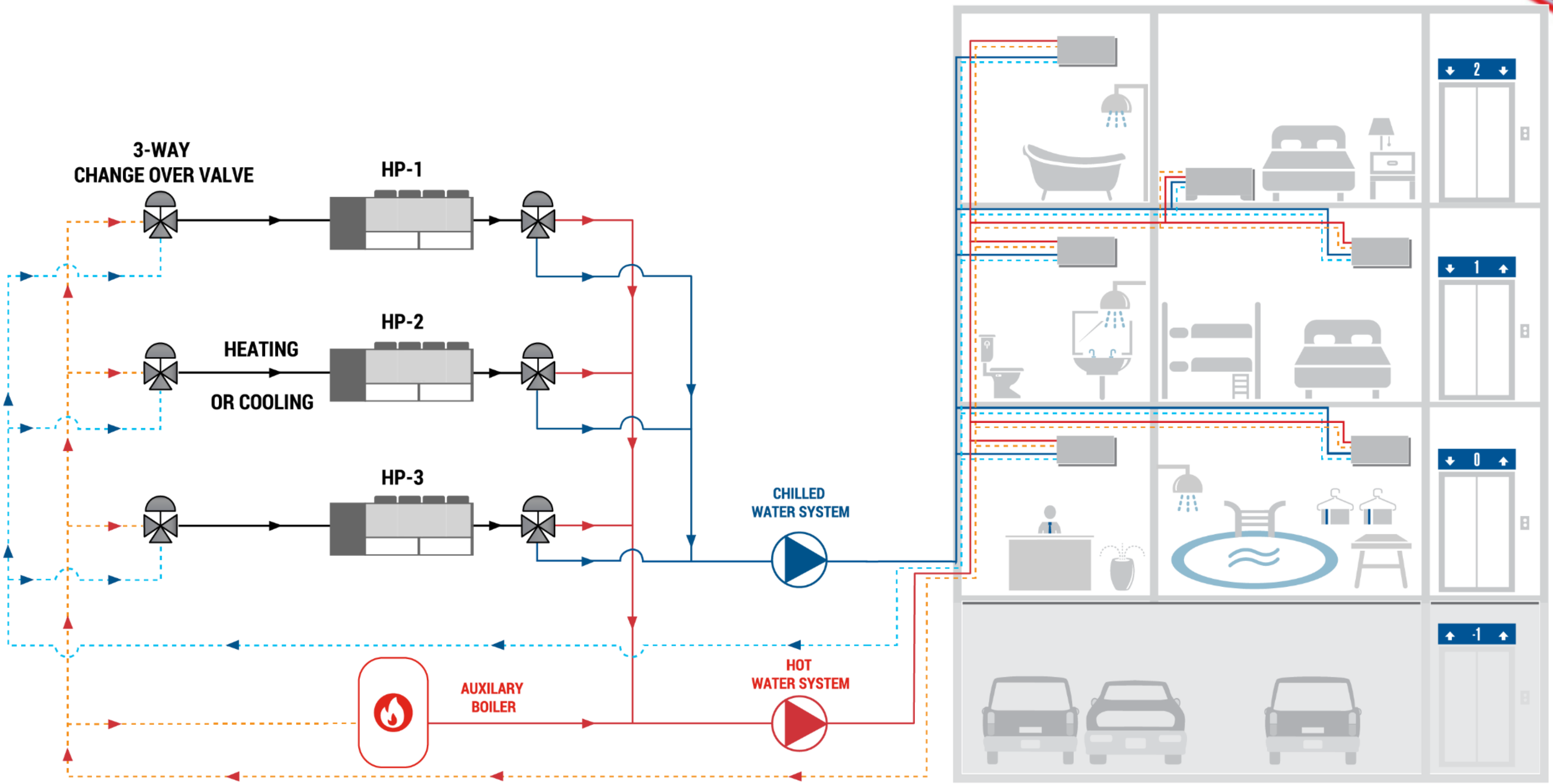
WHAT ABOUT 4-PIPE SYSTEMS?



2-PIPE AIR-TO-WATER HEAT PUMPS IN 4-PIPE SYSTEMS



4-PIPE FUEL SWITCH RETROFIT: ENERGY SAVINGS

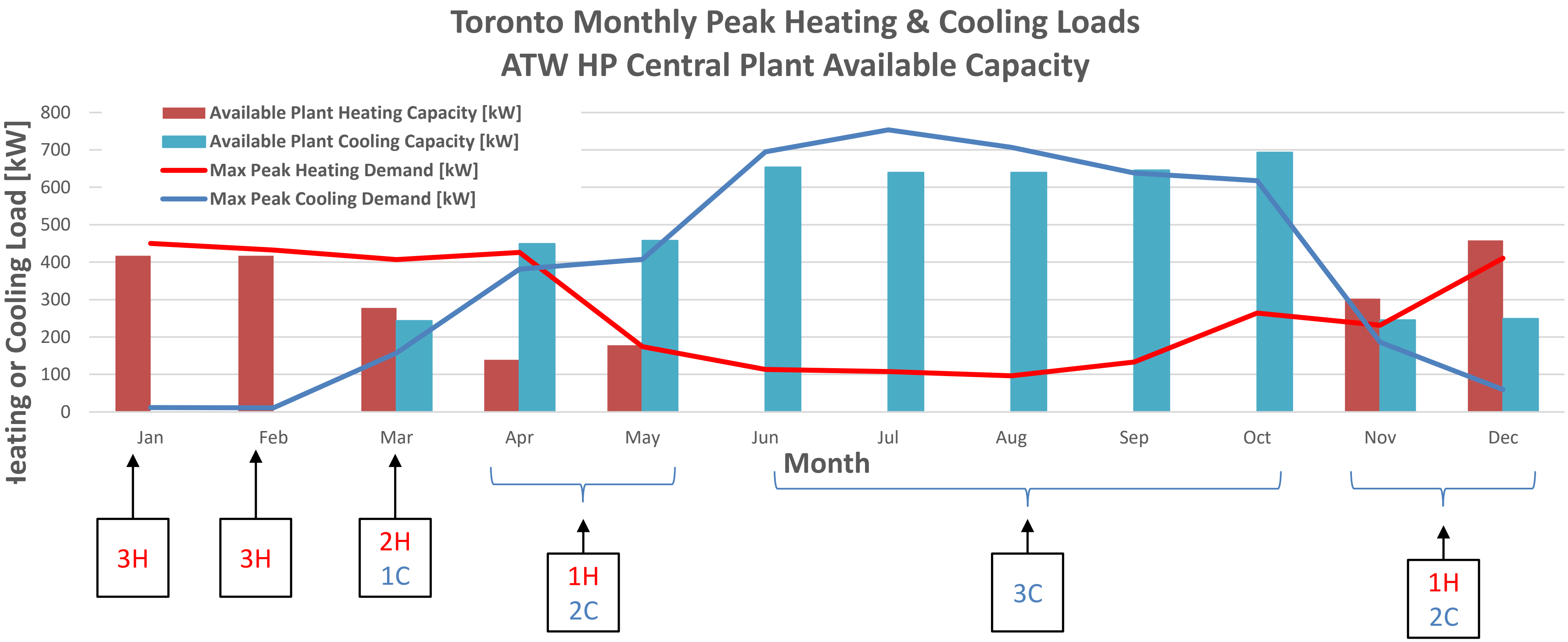


2-PIPE AIR-TO-WATER HEAT PUMPS IN 4-PIPE SYSTEMS HEATING & COOLING SIMULTANEOUSLY

Data Notes:

- Peak Loads shown Reflect Hourly instantaneous peak capacity
- Available Capacities are based on coldest temperature seen during the month for heating, and warmest temperature for cooling
- Where monthly min. Temperature was below -10 °C, available capacity listed is for -10 °C

Building Loads are **DYNAMIC**
So must be the **Heat Pump System!**

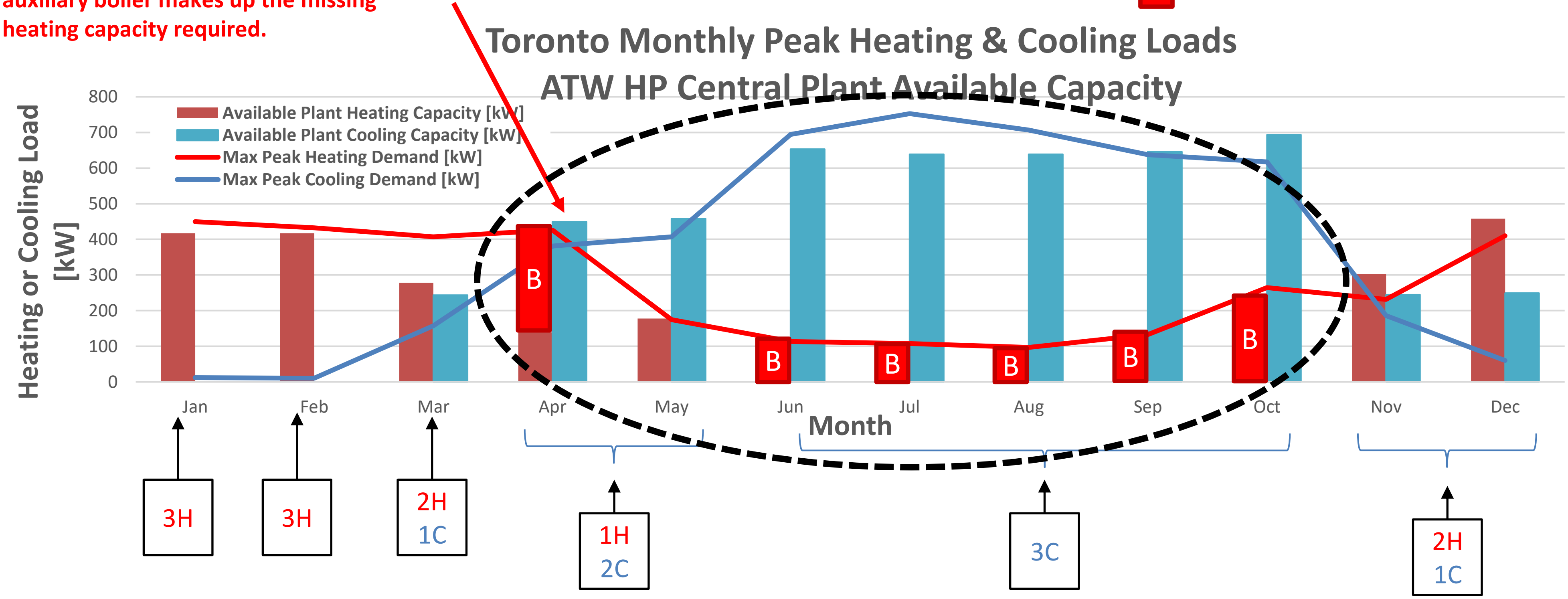


Toronto Monthly Peak Heating & Cooling Loads
ATW HP Central Plant Available Capacity

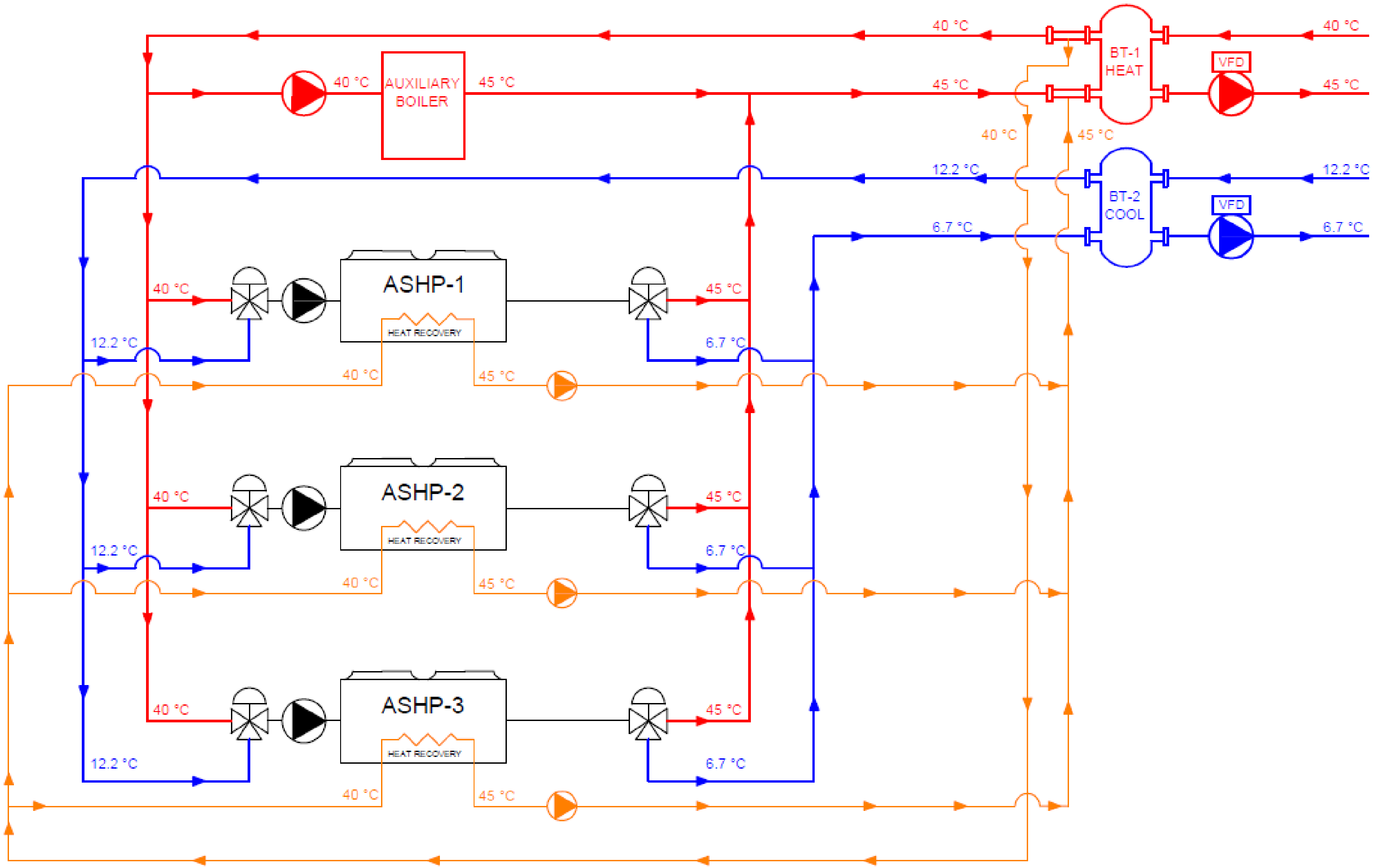
2-PIPE AIR-TO-WATER HEAT PUMPS IN 4-PIPE SYSTEMS HEATING & COOLING SIMULTANEOUSLY

In cases where equipment can not meet heating and cooling loads at the same time, cooling is prioritized, and the auxiliary boiler makes up the missing heating capacity required.

B = Load met by Auxiliary Boiler



PARTIAL HEAT RECOVERY USING DESUPERHEATER 4-PIPE SYSTEMS



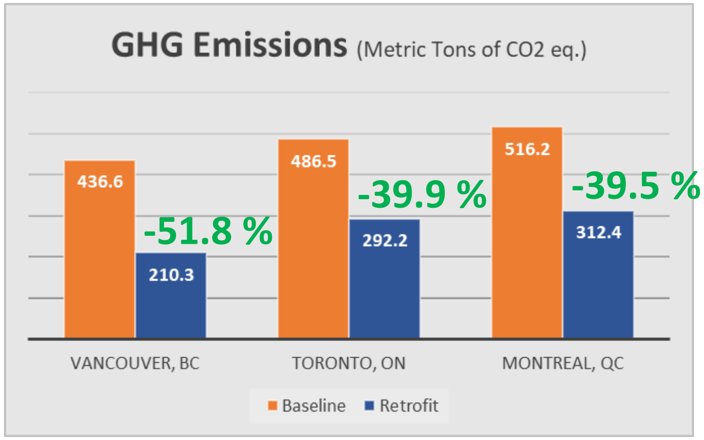
HYBRID 4-PIPE SYSTEM
FUEL SWITCH RETROFIT: ENERGY SAVINGS

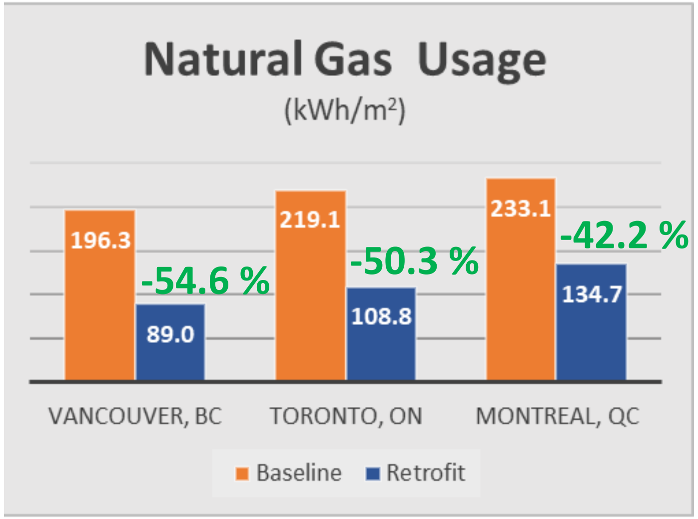
PRE-RETROFIT

	Vancouver, BC	*Toronto, ON*	*Montreal, QC*
Electric Use Intensity [kWh/m2]	174.0	186.8	186.1
Natural Gas Use Intensity [kWh/m^2]	196.3	219.1	233.1
Total EUI [kWh/m^2]	370.3	405.9	419.2

POST-RETROFIT

	Vancouver, BC	*Toronto, ON*	*Montreal, QC*
Electric Use Intensity [kWh/m2]	191.3	201.0	197.9
Natural Gas Use Intensity [kWh/m^2]	89.0	108.8	134.7
Total EUI [kWh/m^2]	**280.3**	**309.8**	**332.6**

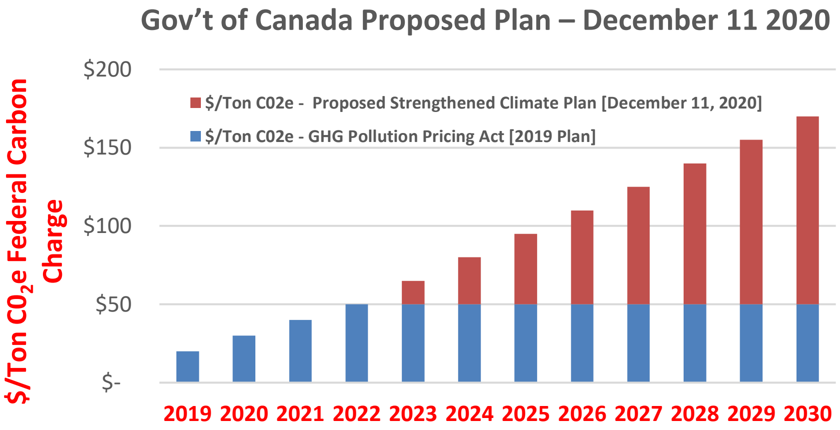

GHG Emissions (Metric Tons of CO2 eq.)


Natural Gas Usage
(kWh/m^2)

2-PIPE AIR-TO-WATER HEAT PUMPS IN 4-PIPE SYSTEMS HEATING & COOLING SIMULTANEOUSLY

Location	**Baseline Emissions [Ton CO_2e]**	**Retrofit Emissions [Ton CO_2e]**	**Annual Tonnes CO_2e offset**
Vancouver	436.6	210.3	**226.3**
Toronto	486.5	292.2	**194.3**
Montreal	516.2	312.4	**203.8**

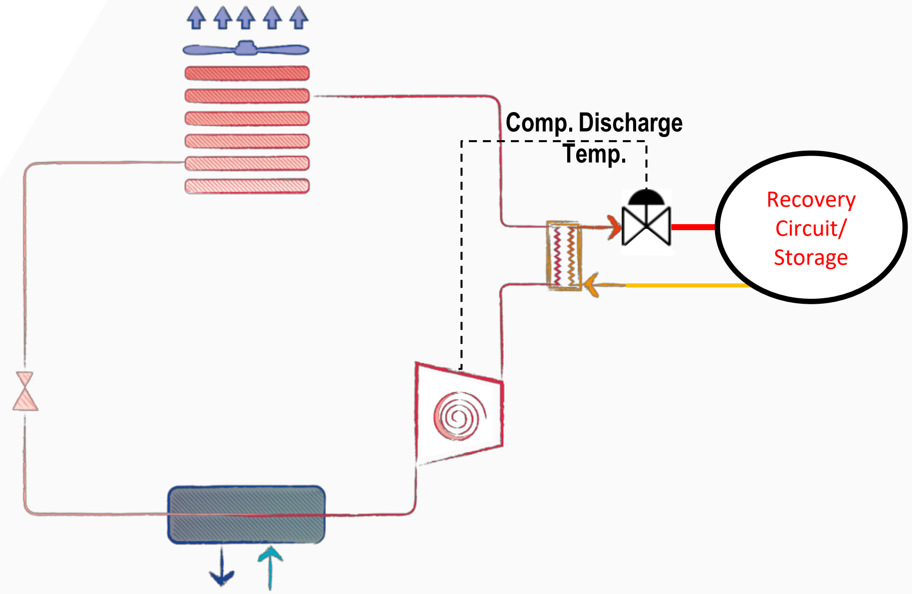
Simple Payback – ATW HP vs. Like-for-Like Replacement	
Std. Air-Cooled Chiller $/Ton	$ 1,200.00
ATW HP $/Ton	$ 2,000.00
Incremental Cost, $/Ton	$ 800.00
System Sizing (Tons Nominal)	175
Approximate Incremental Cost over like-for-like replacement	**$ 140,328.00**



**According to the Plan, if implemented, the Carbon tax will increase by $15/year until it reaches $170/ton by 2030

Year	**Canadian Federal Carbon Tax* [$/Ton CO_2e]**	**Vancouver**		**Toronto**		**Montreal**	
		Annual Savings	**Cumulative Savings**	**Annual Savings**	**Cumulative Savings**	**Annual Savings**	**Cumulative Savings**
2021	**$ 40**	$ 9,052	$ 9,052	$ 7,772	$ 7,772	$ 8,152	$ 8,152
2022	**$ 50**	$ 11,315	$ 20,367	$ 9,715	$ 17,487	$ 10,190	$ 18,342
2023	**$ 65**	$ 14,710	$ 35,077	$ 12,630	$ 30,117	$ 13,247	$ 31,589
2024	**$ 80**	$ 18,104	$ 53,181	$ 15,544	$ 45,661	$ 16,304	$ 47,893
2025	**$ 95**	$ 21,499	$ 74,679	$ 18,459	$ 64,119	$ 19,361	$ 67,254
2026	**$ 110**	$ 24,893	$ 99,572	$ 21,373	$ 85,492	$ 22,418	$ 89,672
2027	**$ 125**	$ 28,288	$ 127,860	$ 24,288	$ 109,780	$ 25,475	$ 115,147
2028	**$ 140**	$ 31,682	$ 159,542	$ 27,202	$ 136,982	$ 28,532	$ 143,679
2029	**$ 155**	$ 35,077	$ 194,618	$ 30,117	$ 167,098	$ 31,589	$ 175,268
2030	**$ 170**	$ 38,471	**$ 233,089**	$ 33,031	**$ 200,129**	$ 34,646	**$ 209,914**

PARTIAL HEAT RECOVERY (DESUPERHEATER)



Approximately

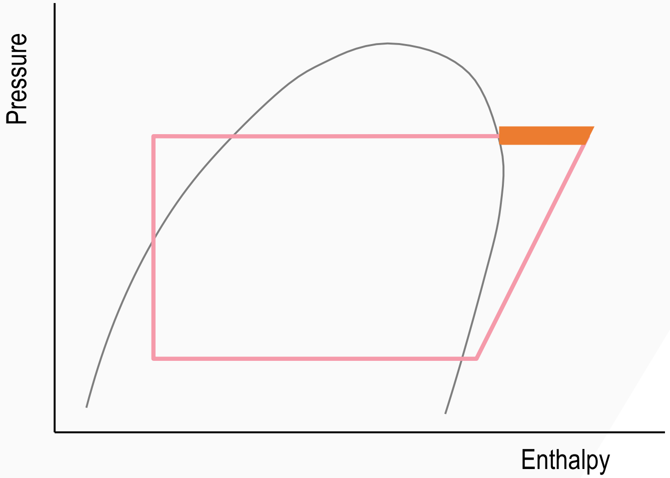
20%

of the chiller's capacity (*)

Up to

60 °C

Leaving Water Temperature

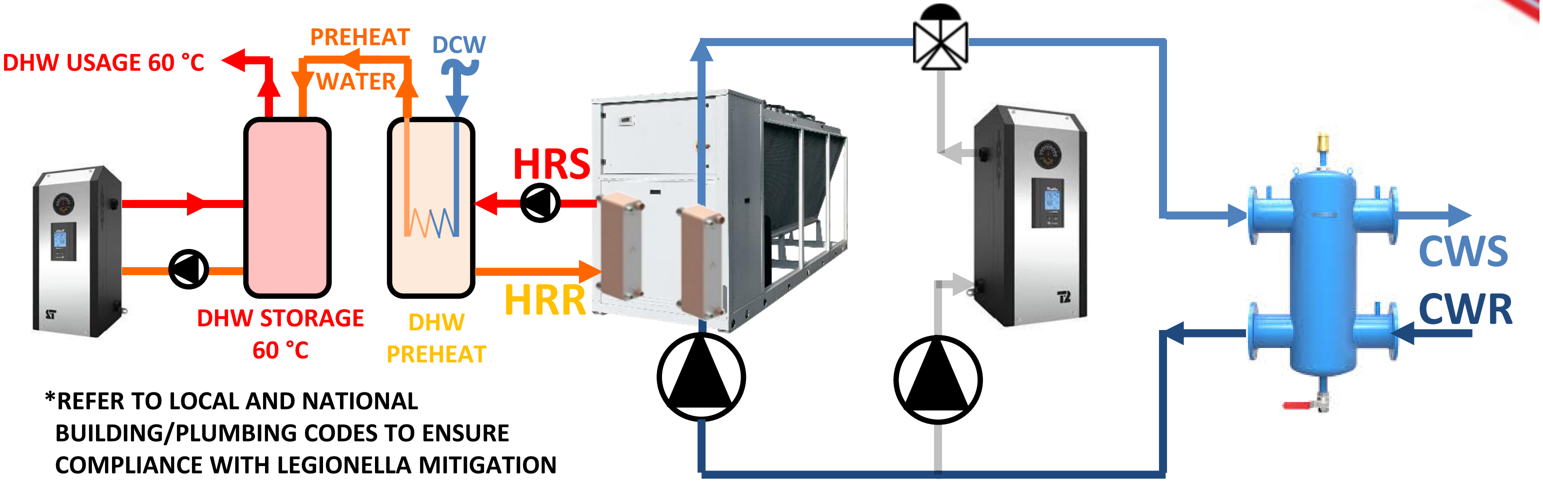


The refrigerant circuit is fitted with a **desuperheater** in series with the condenser coils.

(*) The heat recovery and its amount depend on the unit's operating conditions, in particular the outdoor air temperature and the load percentage.

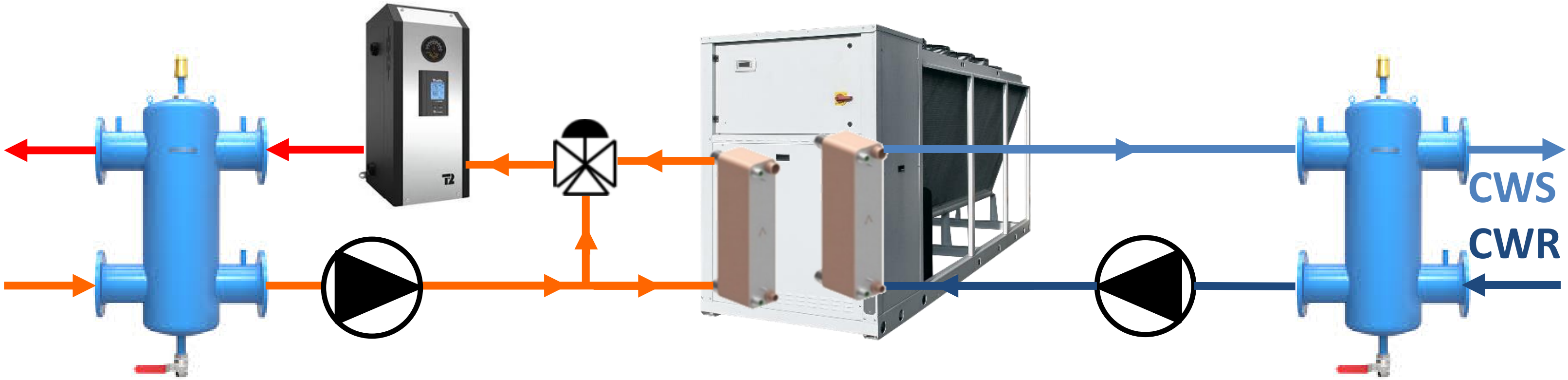
PARTIAL HEAT RECOVERY USING DESUPERHEATER

HEAT RECOVERY TO DOMESTIC HOT WATER SYSTEM (2-PIPE SYSTEM)



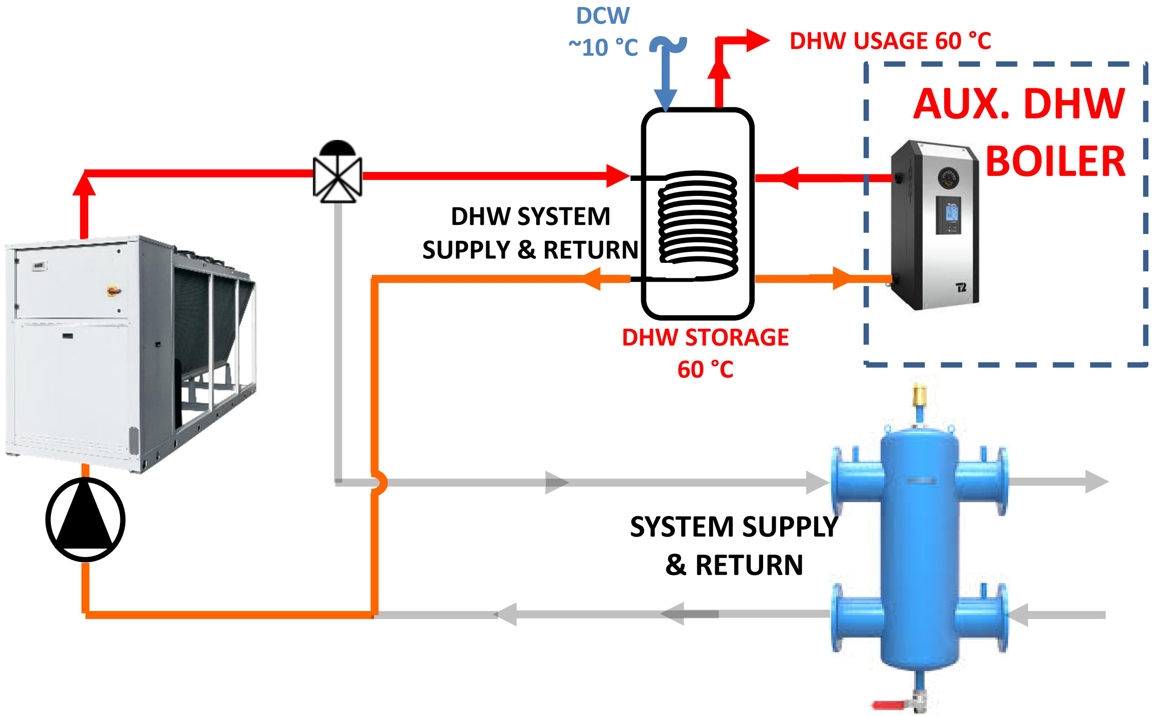
*REFER TO LOCAL AND NATIONAL BUILDING/PLUMBING CODES TO ENSURE COMPLIANCE WITH LEGIONELLA MITIGATION

HEAT RECOVERY TO BOILER PRE-HEAT (4-PIPE SYSTEM)



DOMESTIC HOT WATER PRODUCTION

DOMESTIC HOT WATER USING INDIRECT STORAGE TANK + SUPPLEMENTAL BOILER

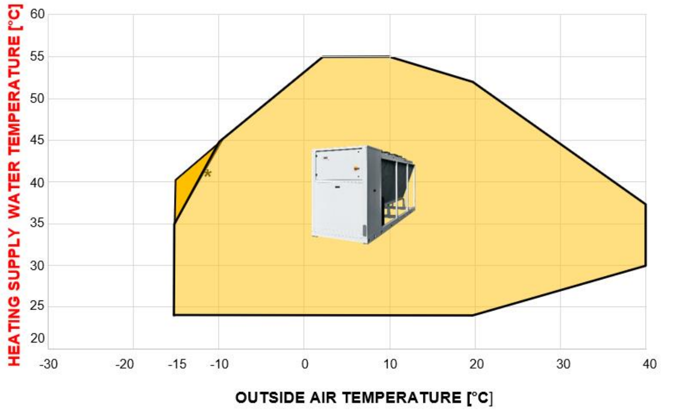


After 50% Draw from DHW Tank: T_{TANK} = ~ 35 °C → **Can Add Heat to DHW with ~ 40 °C LWT. Can Use HP down to ~ -12 ° OAT**

After 25% Draw from DHW Tank: T_{TANK} = ~ 47.5 °C → **Can Add Heat to DHW with ~ 52 °C LWT. Can Use HP down to ~ -3 °C OAT only**

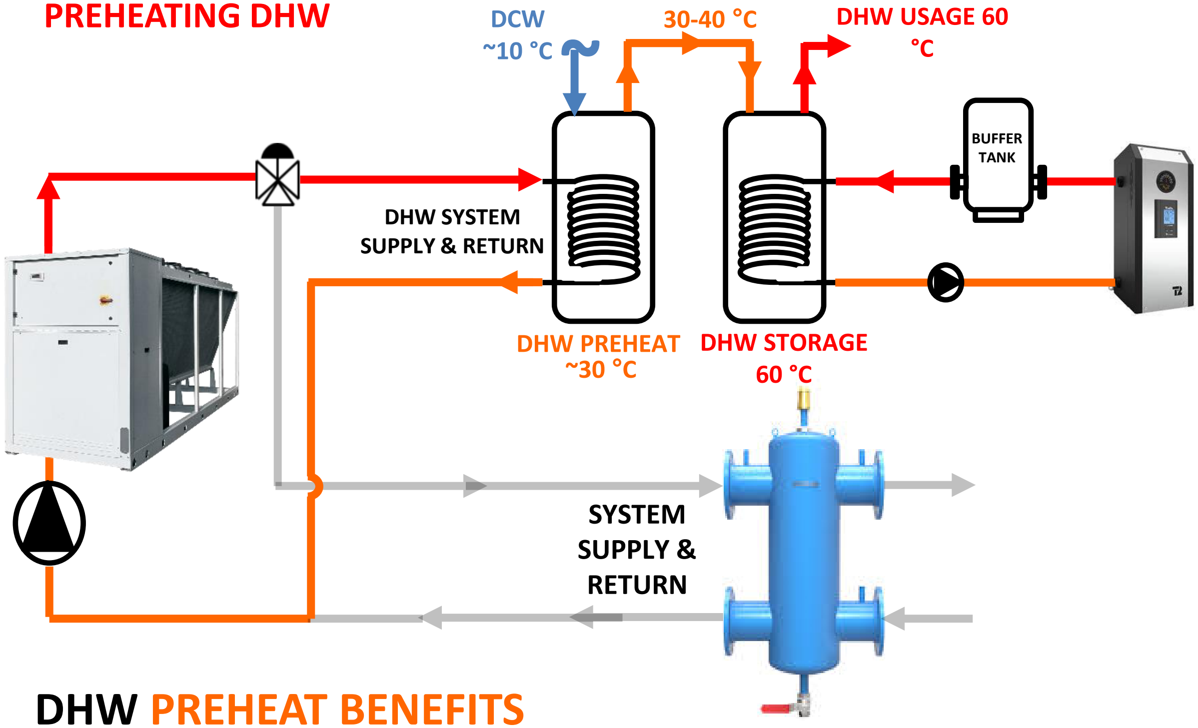
ATW HP for DHW Application:

- **Reduce Boiler work via Heat Pump**
- **Ability of Heat Pump to Add Heat to DHW tank is a function of DHW Tank Temp and Max LWT available from ATWHP according to OAT**



DOMESTIC HOT WATER PRODUCTION

DOMESTIC HOT WATER USING INDIRECT STORAGE TANK FOR PREHEATING DHW



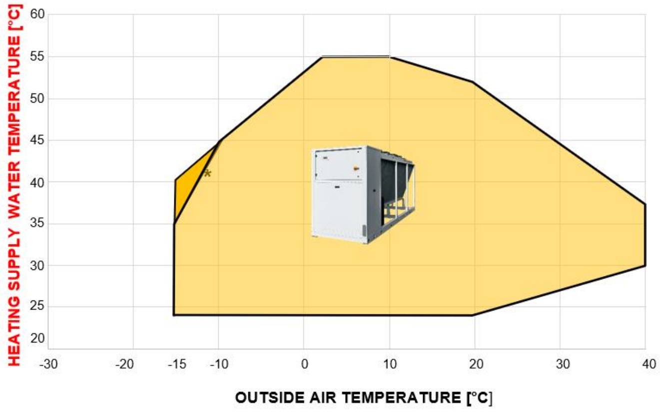
Looking at the PREHEAT Tank:

After 50% Draw from DHW Preheat Tank: T_{TANK} = ~ 20 °C

Can Add Heat to DHW Preheat with ~ 25 °C LWT. Can Use HP down to ~ -15 ° OAT

After 25% Draw from DHW Tank: T_{TANK} = ~ 24.5 °C

Can Add Heat to DHW with ~ 30 °C LWT. Can Use HP down to ~ -15 °C OAT <u>always</u>

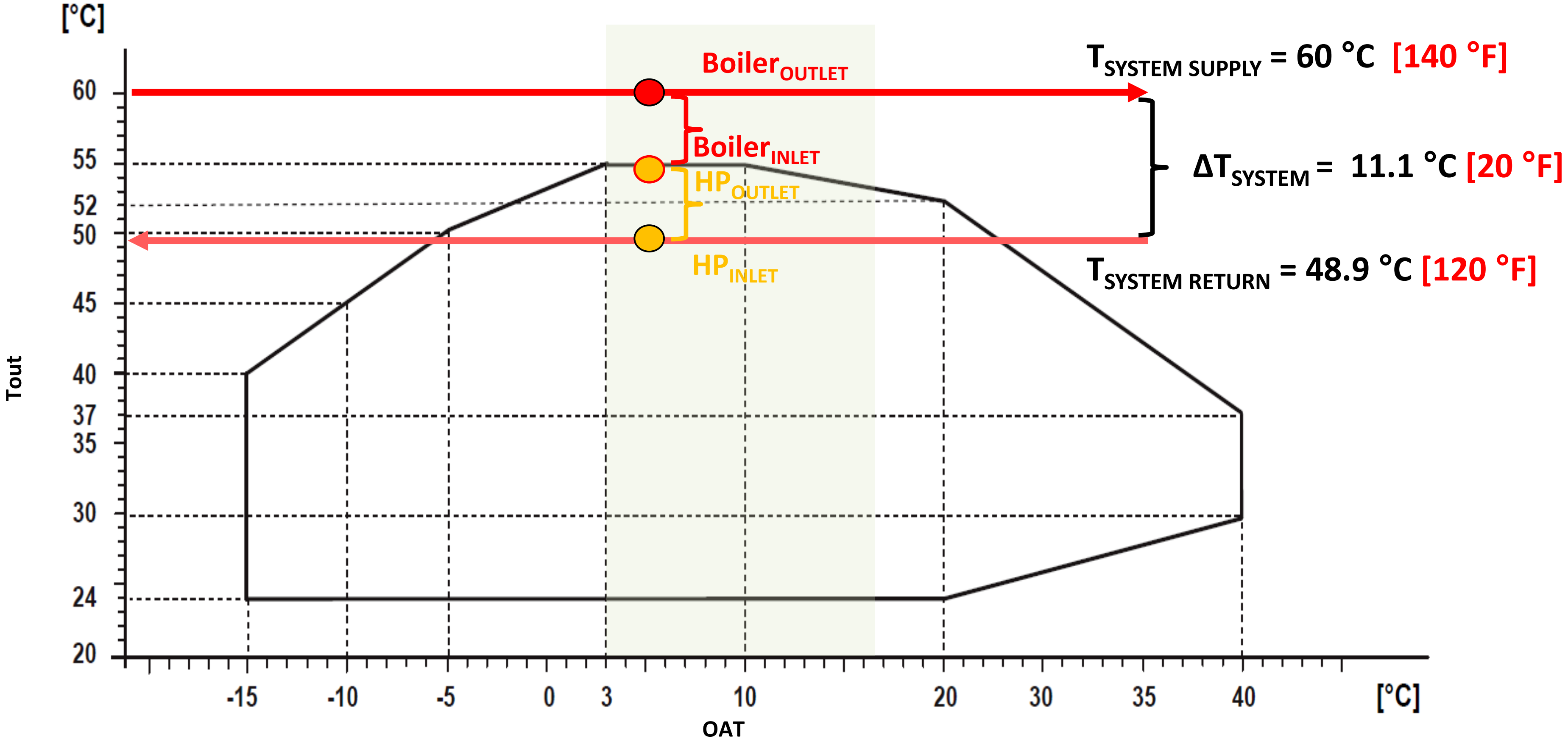


DHW PREHEAT BENEFITS

- Reduce Boiler work via Heat Pump
- Preheat Configuration allows the heat pump to add more heat, more often to the DHW system by operating at a lower temperature. Overall offsets more GHG Emissions
- Secondary DHW Tank, boiler then does a lower temperature lift

DESIGN CONSIDERATION: AUXILIARY HEAT

NX-N-G02-U 152P-812P AUXILIARY HEATING IN SERIES:



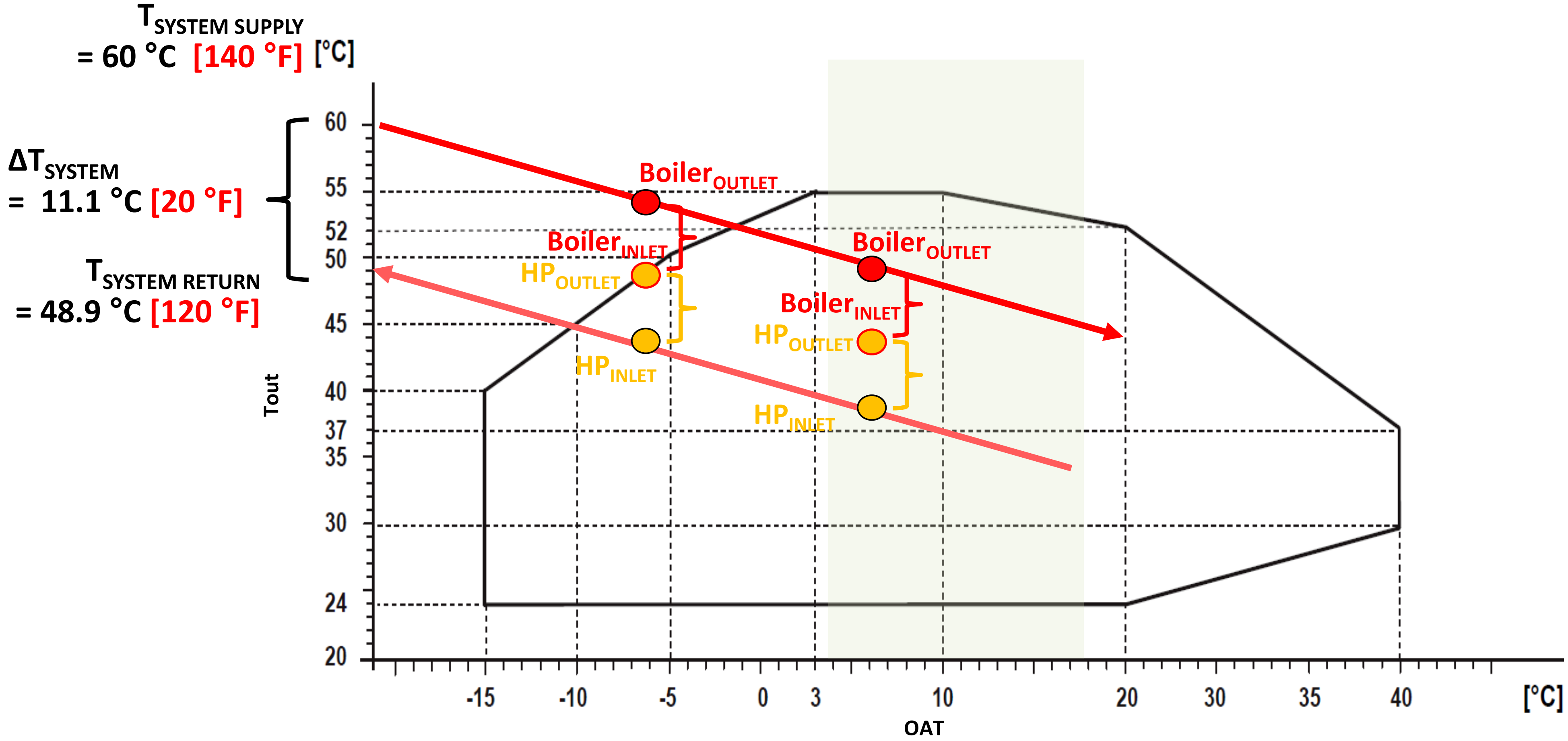
$T_{SYSTEM\ SUPPLY}$ = 60 °C [140 °F]

ΔT_{SYSTEM} = 11.1 °C [20 °F]

$T_{SYSTEM\ RETURN}$ = 48.9 °C [120 °F]

DESIGN CONSIDERATION: AUXILIARY HEAT

NX-N-G02-U 152P-812P AUXILIARY HEATING IN SERIES:



SUMMARY

- HOLISTIC APPROACH TO MECHANICAL DESIGN IS REQUIRED TO MEET GHG REDUCTION TARGETS
  - "ONE-SIZE-FITS-ALL" IS NOT ALWAYS COMPATIBLE WITH LOW CARBON
  - SIGNIFICANT SAVINGS CAN BE ACHIEVED WHILE USING CURRENT ATW TECHNOLOGY WITHIN LIMITATIONS
  - REDUCED OPERATING TEMP = INCREASED EFFICIENCY + FACILITATED INTEGRATION

- INCORPORATING OTHER MEASURES (ENVELOPE UPGRADE) ARE EQUALLY IMPORTANT
  - LESS HEAT LOSS = REDUCED RETROFIT EQUIPMENT SIZING
  - REDUCED POWER REQUIREMENT FOR ELECTRIFIED HEATING RETROFITS

- DUAL FUEL PROVIDES BUILDING RESILIENCY
  - LEVERAGE EXISTING NATURAL GAS INFRASTRUCTURE WHERE IT MAKES SENSE
  - FLEXIBILITY TO MANAGE CARBON FOOTPRINT OR OPERATING COST VIA ENERGY MANAGEMENT STRATEGY
  - TRANSITION TO LOWER EMISSION NATURAL GAS WITH RNG OVER TIME
  - FUTURE PROOFED BUILDING: ATW HP TECHNOLOGY IMPROVEMENT AT END OF LIFECYCLE
  - ELECTRICAL GRID CAPACITY MANAGEMENT

- TRANSFORMATION OF FINANCIAL/BUSINESS CASE TO SUPPORT LOW-CARBON TRANSITION
  - OPERATING OR FIRST COST IS NO LONGER THE GOVERNING CRITERIA
  - RETROFIT CODE & TARGETS WILL ACCELERATE ADOPTION
  - FINANCIAL SUPPORT FOR PRIVATE SECTOR + FUEL SWITCHING PROJECT SUPPORT WILL LAUNCH ATW INTO MAINSTREAM

QUESTIONS?

MITSUBISHI ELECTRIC

Changes for the Better

Connect for Design, Selection & Sizing Support for your next Project!

Chris DesRoches, P. Eng.
Applied Product Manager, HVAC Division
Email: chris.desroches@mesca.ca
Phone: 905-475-3278
www.Climaveneta.ca