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

ASHRAE WINNIPEG CHAPTER
TECHNICAL PRESENTATION, MARCH 16, 2023

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TOPICS

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

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

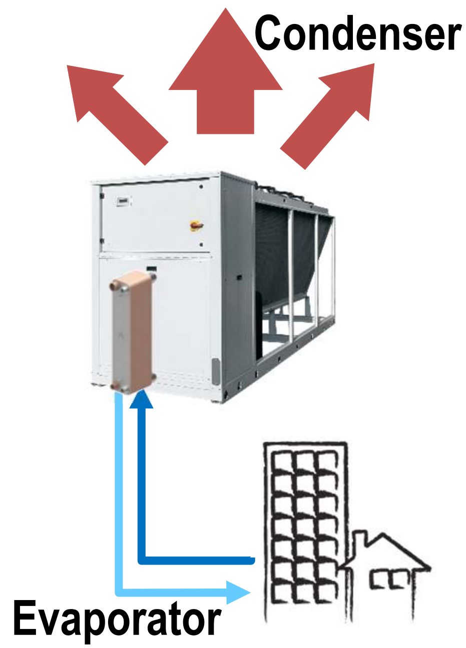
- CENTRAL AIR-TO-WATER HEAT PUMP PLANT SIZING & APPLICATIONS
  - 2-PIPE CHANGEOVER SYSTEMS
  - HEAT PUMP CASCADE SYSTEMS (2-PIPE)
  - HYBRID 4-PIPE CENTRAL PLANT
  - HEAT RECOVERY
  - HIGH-TEMPERATURE RETROFITS

LEARNING OBJECTIVES

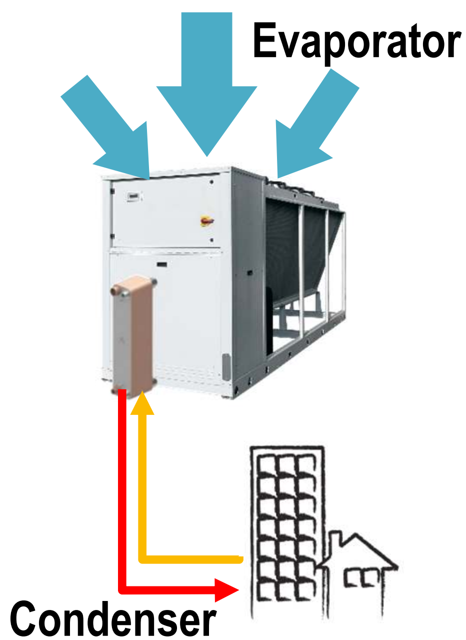
- **Understand the concept of fuel-switching and its importance for high efficiency retrofit of existing building central plant systems.**
- **Learn design strategies and application techniques of using air-to-water heat pump plant equipment.**
- **Learn about the energy and cost savings, and emission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

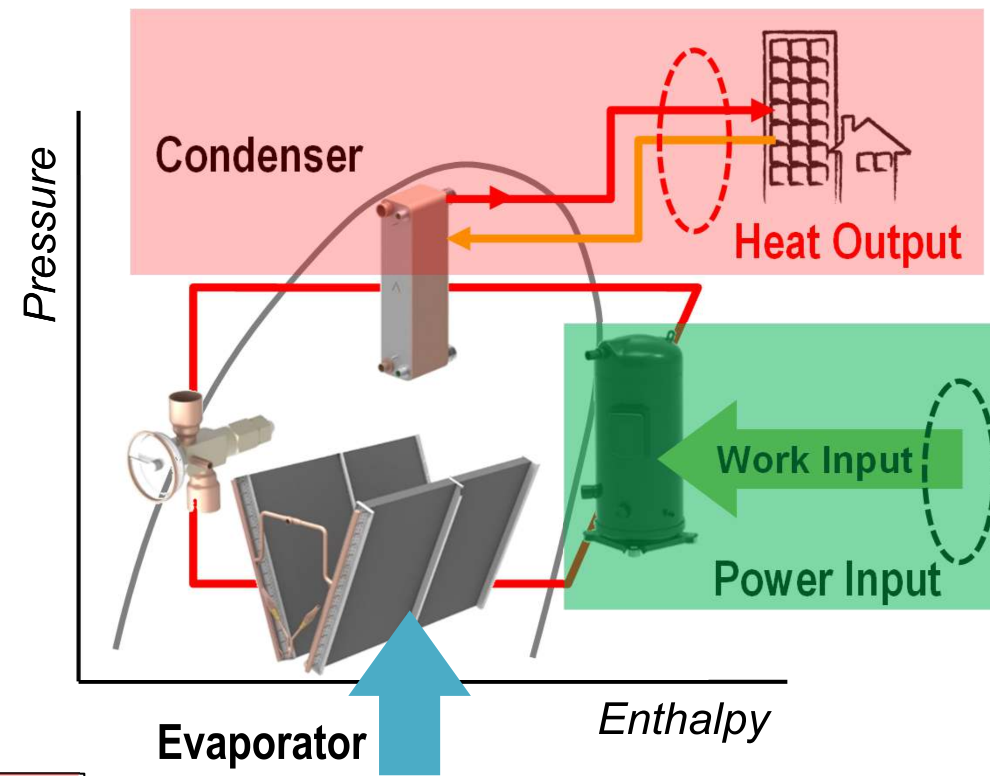
COOLING MODE



HEATING MODE



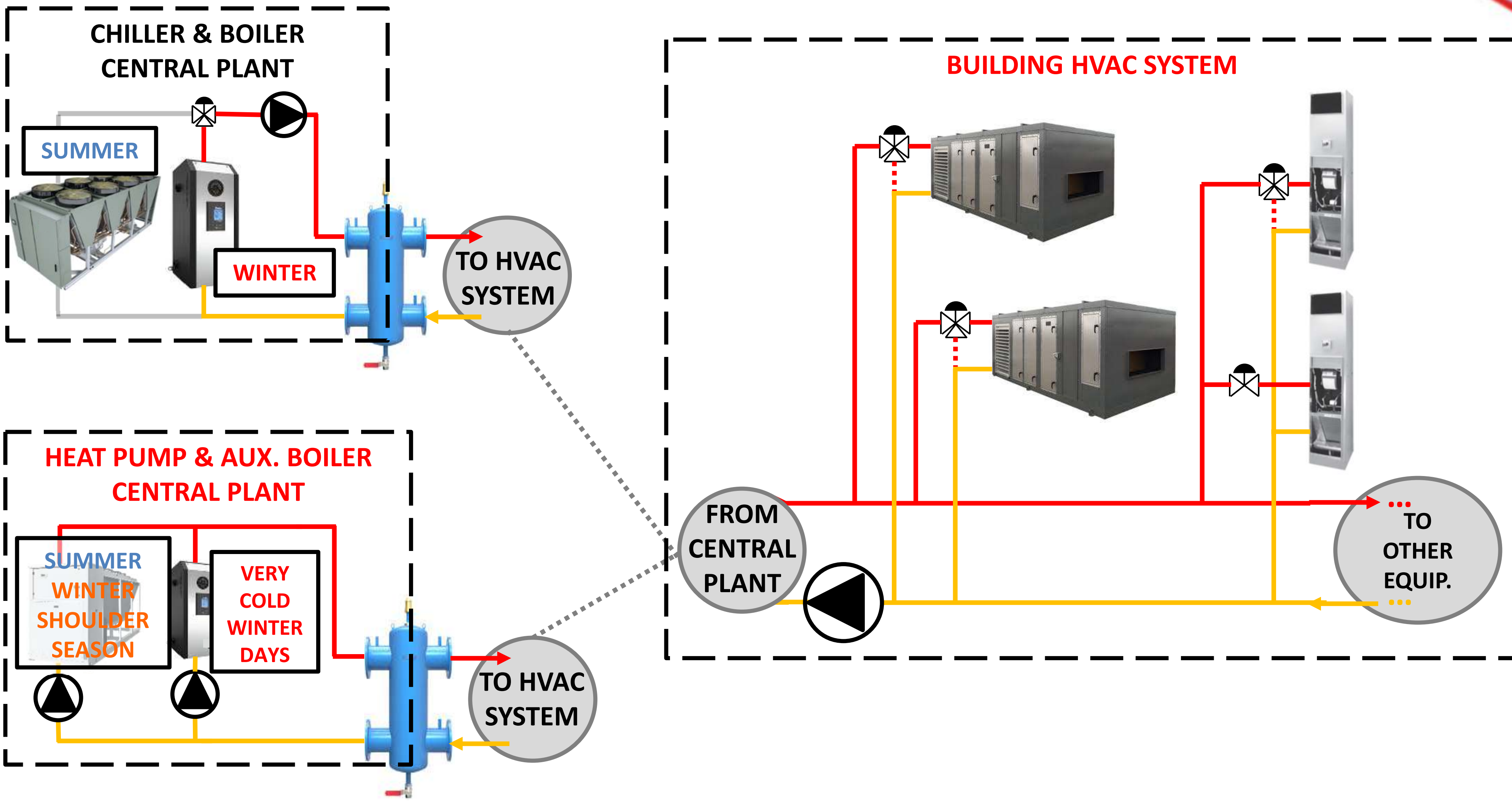
VAPOR-COMPRESSION REFRIGERATION CYCLE (HEATING MODE)



Coefficient of Performance:

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

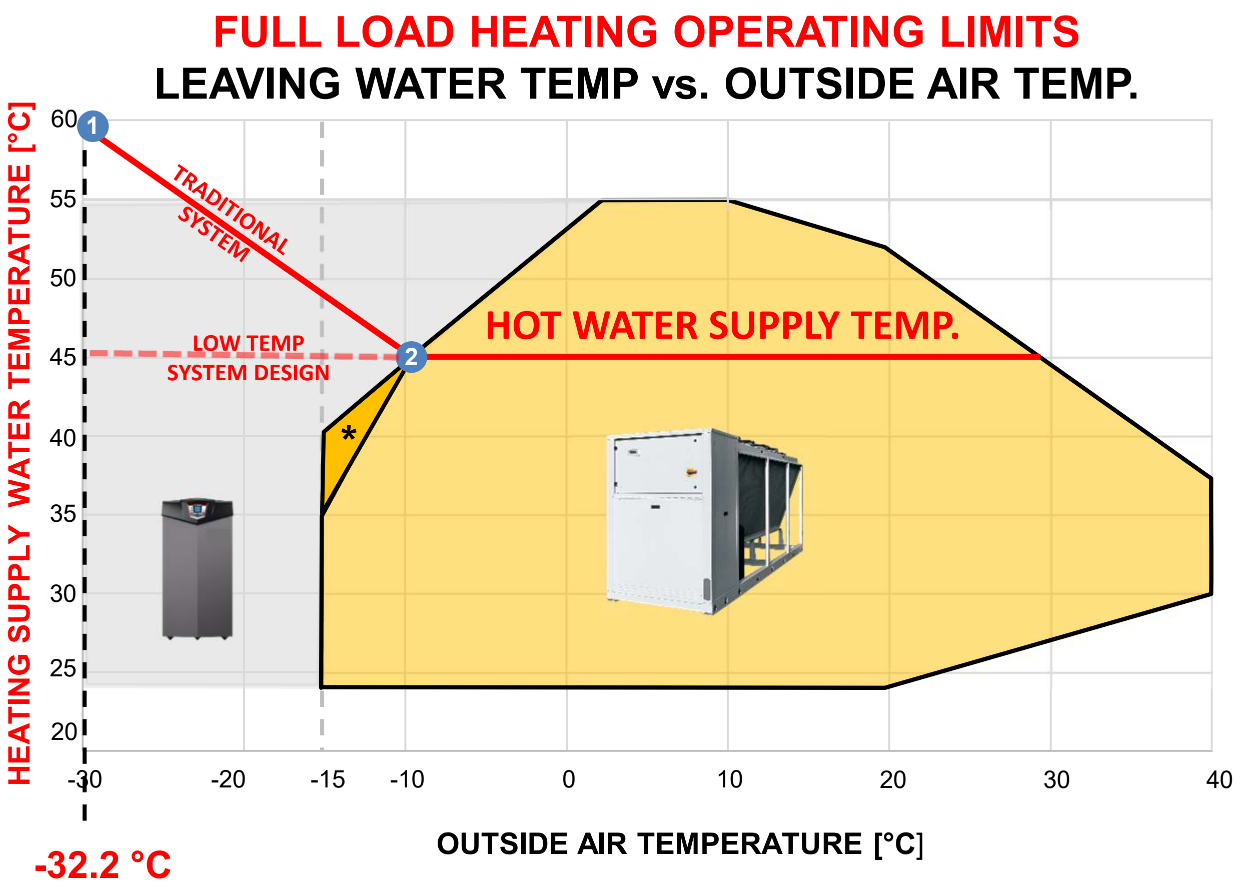
CENTRAL HYBRID HEAT PUMP PLANT



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



Winnipeg Int'l Airport Winter Design Temp (ASHRAE 99.6%D.B.)
(ASHRAE 99% D.B. = -29.9 °C)

APPLICATION CONSIDERATIONS:

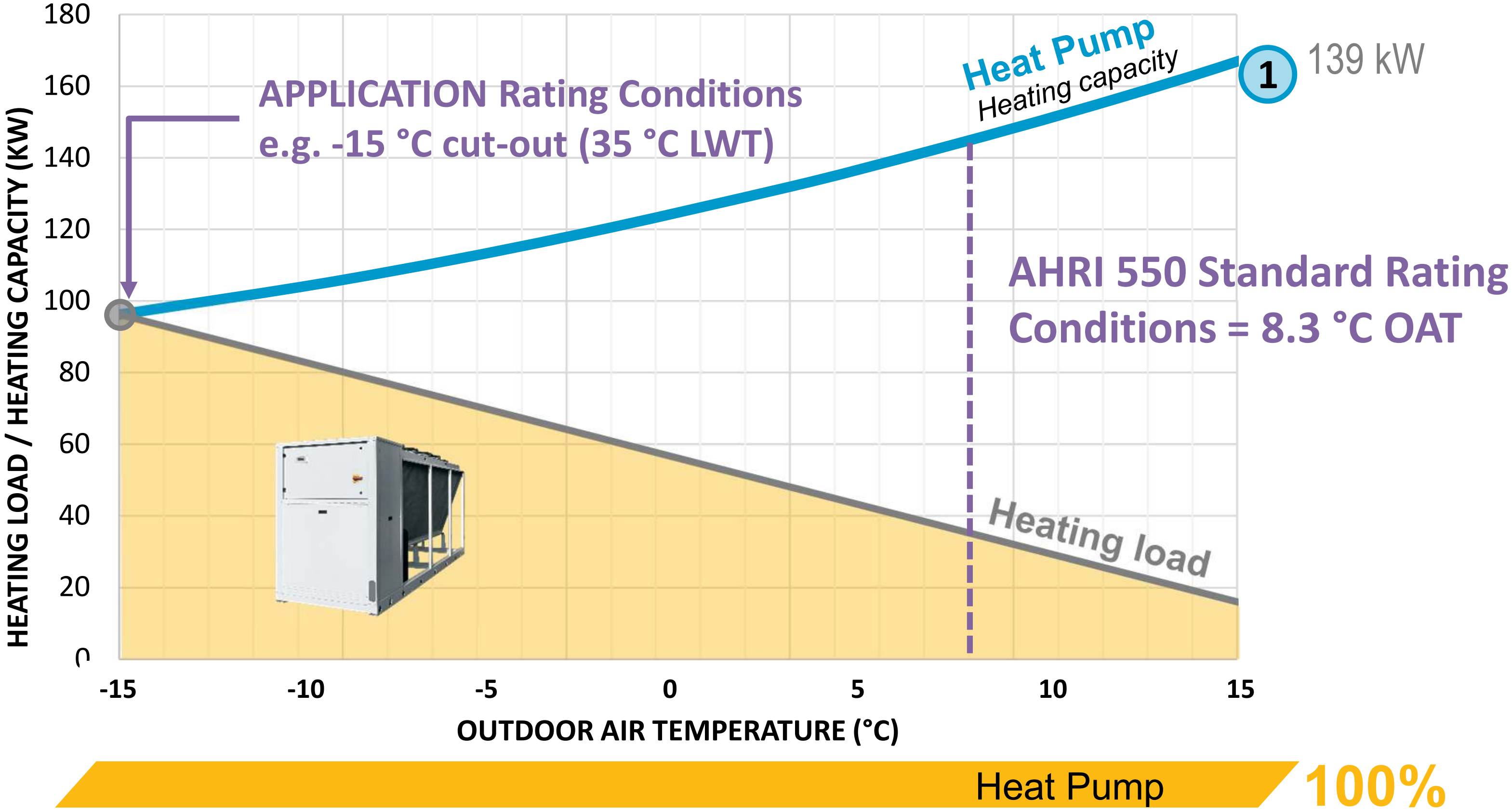
- **Select LOWEST DESIGN SUPPLY TEMPERATURE Feasible**
- **Consider HIGHER BOILER SUPPLY WATER TEMPERATURE below ASHP cut-out**
- **Can the Heat Pump meet the HEATING LOAD using a Lower Supply Temp. at Milder Conditions?**

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

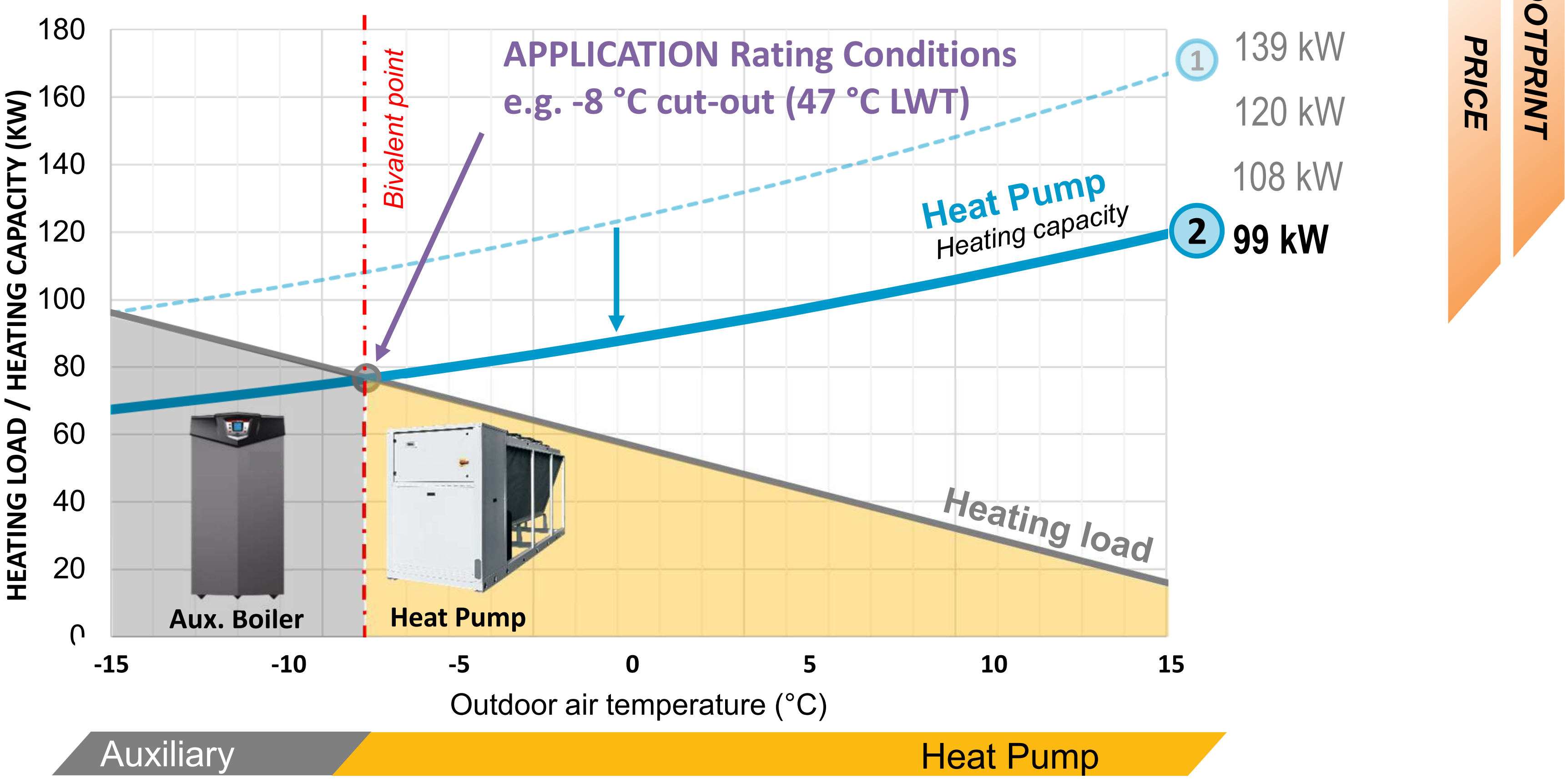


AIR-TO-WATER HEAT PUMP: SIZING FOR HEATING

HEATING CAPACITY VS HEATING LOAD

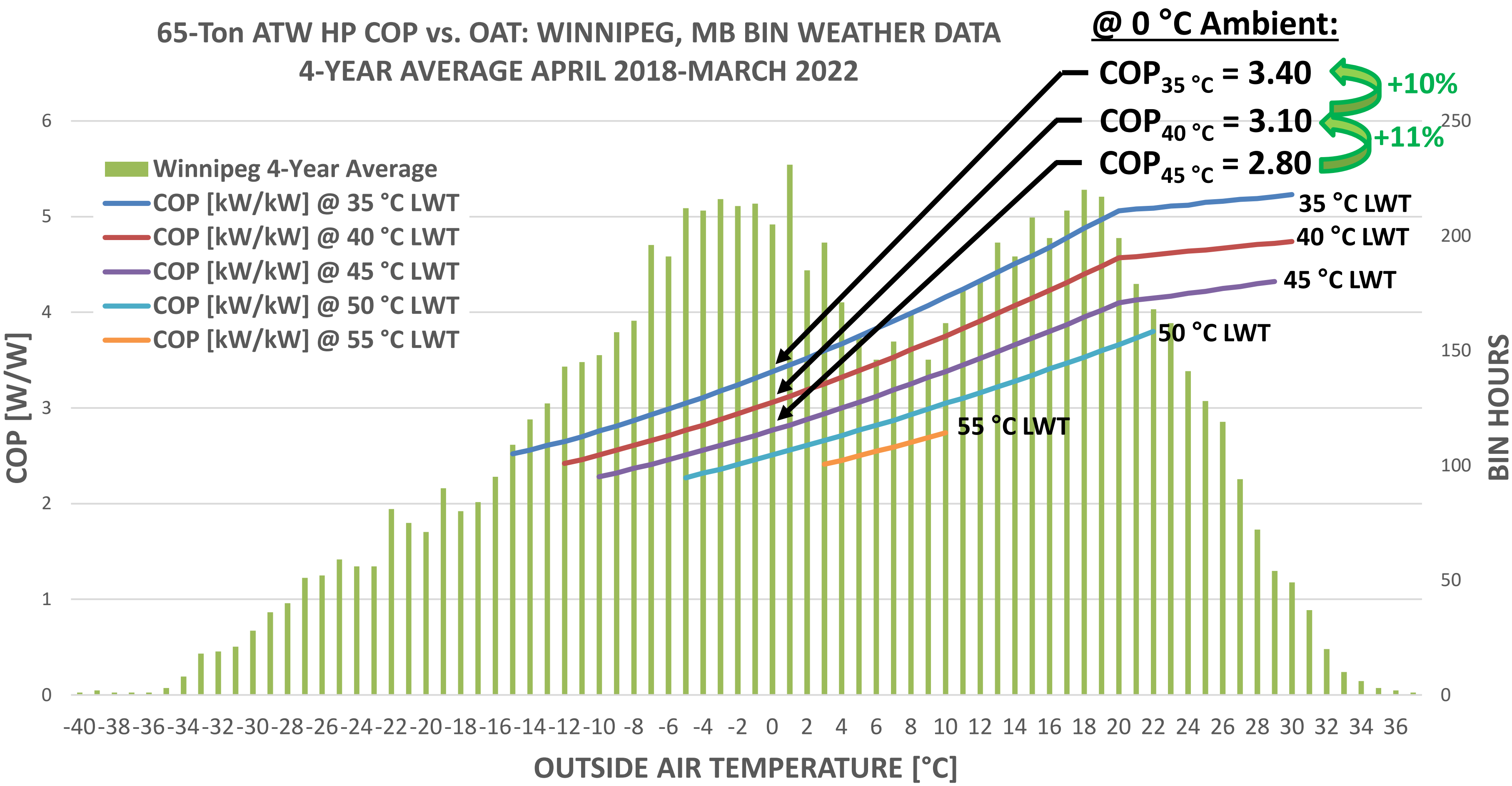
99 kW ATW HP (NOMINAL)

REVERSIBLE UNIT, AIR SOURCE FOR OUTDOOR INSTALLATION



INFLUENCE OF OUTDOOR AIR TEMPERATURE: COP

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



BIN HOUR ANALYSIS FOR WINNIPEG, ON

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

Med-High Temp Application

WINNIPEG, MB 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	2,529	28.9%
-5 °C ≤ T ≤ +10 °C	2,986	34.1%
10 °C < T < 20 °C	2,000	22.8%
20 °C ≤ T	1,245	14.2%

Total Hours Below -5 °C: 2,529 Hours

~ 50 °C @ -5 °C Ambient

Med Temp Application

WINNIPEG, MB 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	1,673	19.1%
-10 °C ≤ T ≤ +10 °C	3,842	43.9%
10 °C < T < 20 °C	2,000	22.8%
20 °C ≤ T	1,245	14.2%

Total Hours Below -10 °C: 1,673 Hours

~ 45 °C @ -10 °C Ambient

Low Temp Application

WINNIPEG, MB 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	1,029	11.7%
-15 °C ≤ T ≤ +10 °C	4,486	51.2%
10 °C < T < 20 °C	2,000	22.8%
20 °C ≤ T	1,245	14.2%

Total Hours Below -15 °C: 1,029 Hours

~ 35 to 40 °C @ -15 °C Ambient

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

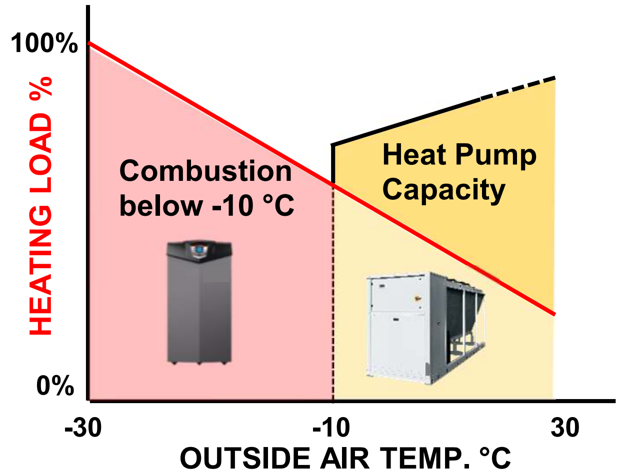
REQUIREMENTS

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

HYBRID CENTRAL HEAT PUMP PLANT APPLICATIONS

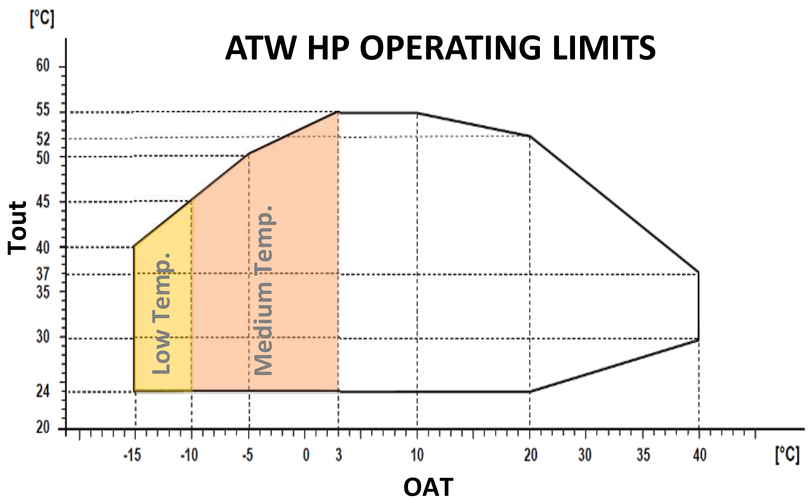
AIR-TO-WATER HEAT PUMP APPLICATIONS:

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



WATER LOOP HEAT PUMP SYSTEM

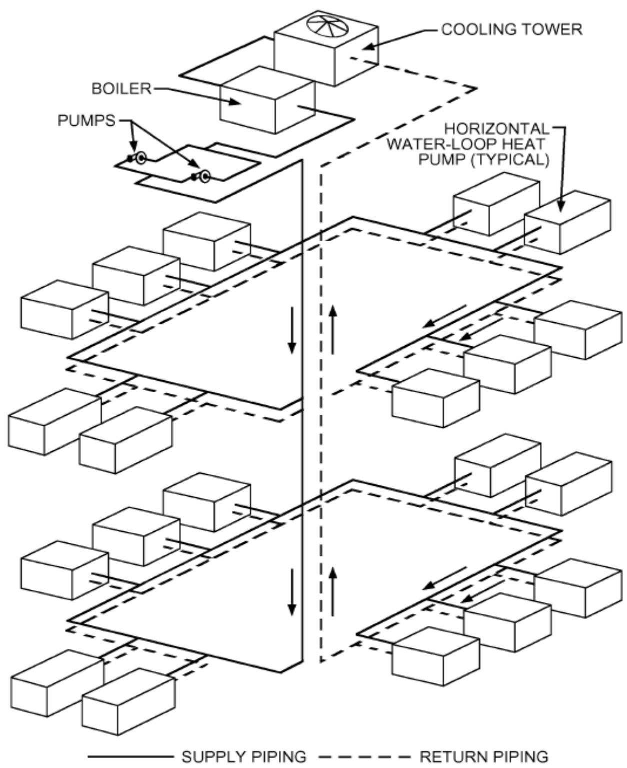


Image Source: ASHRAE HANDBOOK: 2020 HVAC SYSTEMS AND EQUIPMENT
Ch. 9 Fig. 30

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

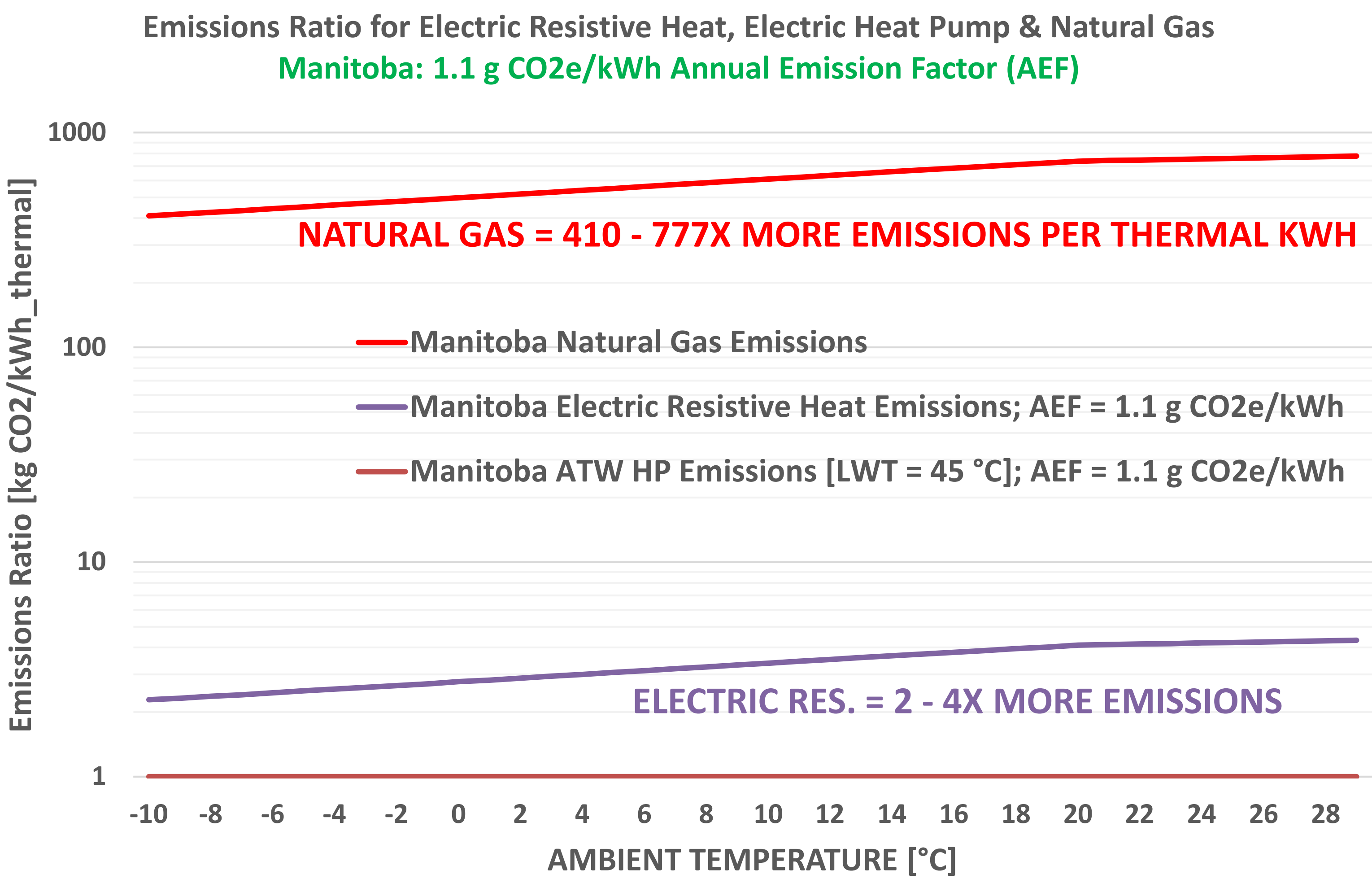
MANITOBA ELECTRICITY GENERATION:
0.0011 kg CO_2e /kWh

SOURCE: PROVINCIAL & TERRITOPRIAL ENERGY PROFILES – MANITOBA. HTTPS://WWW.CER-REC.GC.CA/EN/DATA-ANALYSIS/ENERGY-MARKETS/PROVINCIAL-TERRITORIAL-ENERGY-PROFILES/PROVINCIAL-TERRITORIAL-ENERGY-PROFILES-MANITOBA.HTML#:~:TEXT=NATIONAL%20INVENTORY%20REPORT-,DESCRIPTION%3A,CO2E%20PER%20KWH.

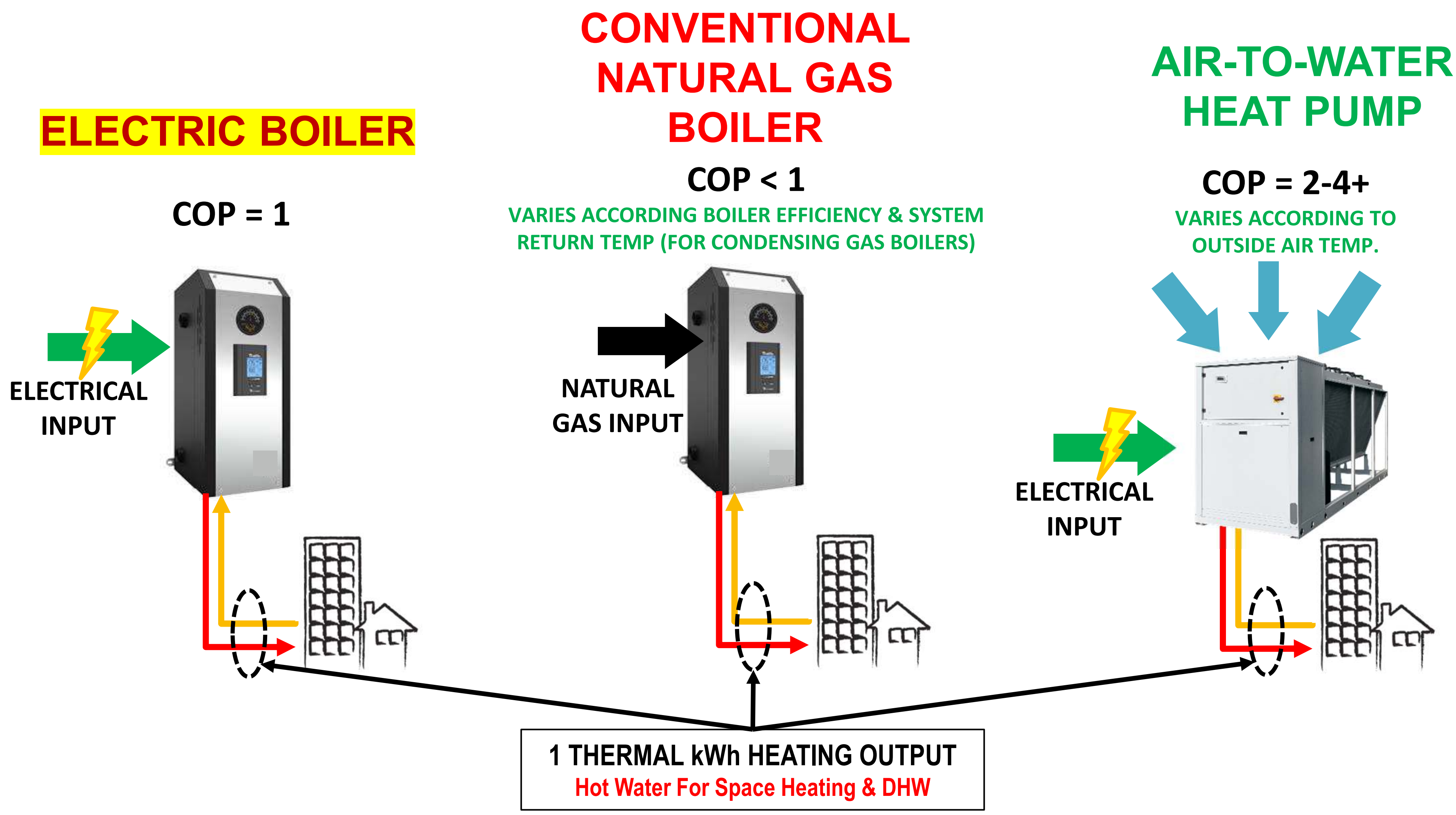
ONTARIO NATURAL GAS EMISSION INTENSITY:
1.888 kg CO_2e/m^3
= 0.18693 kg CO_2e/kWh

[1 m^3 Natural Gas = 10.5 kWh]

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



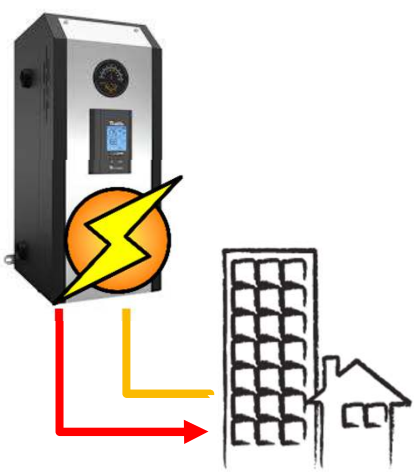
COP OF VARIOUS HEATING TECHNOLOGIES



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



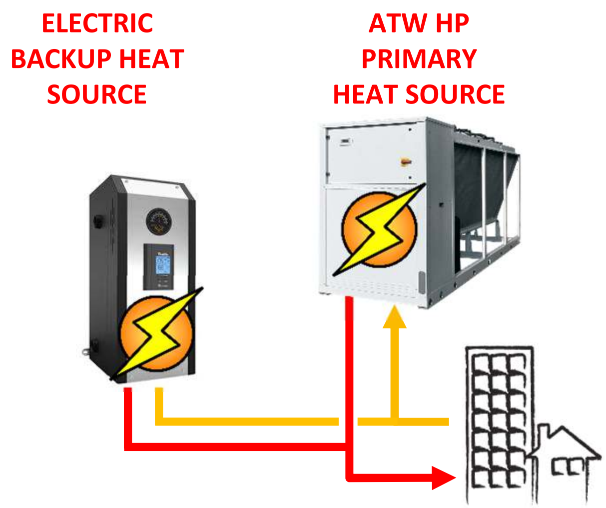
100% ELECTRIC SOLUTION:

- 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



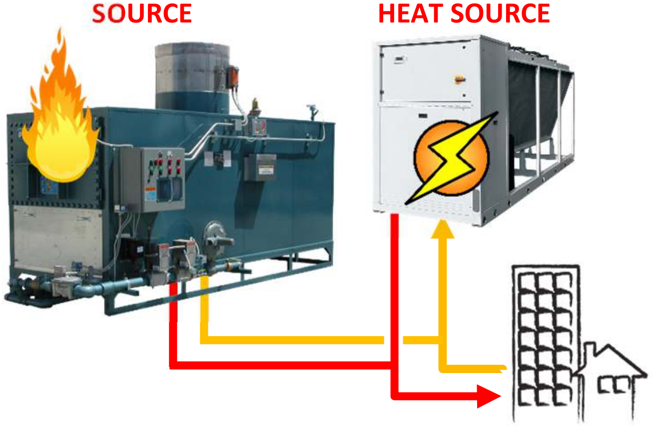
AIR-TO-WATER HEAT PUMP + 100% ELECTRIC SOLUTION:

- 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?

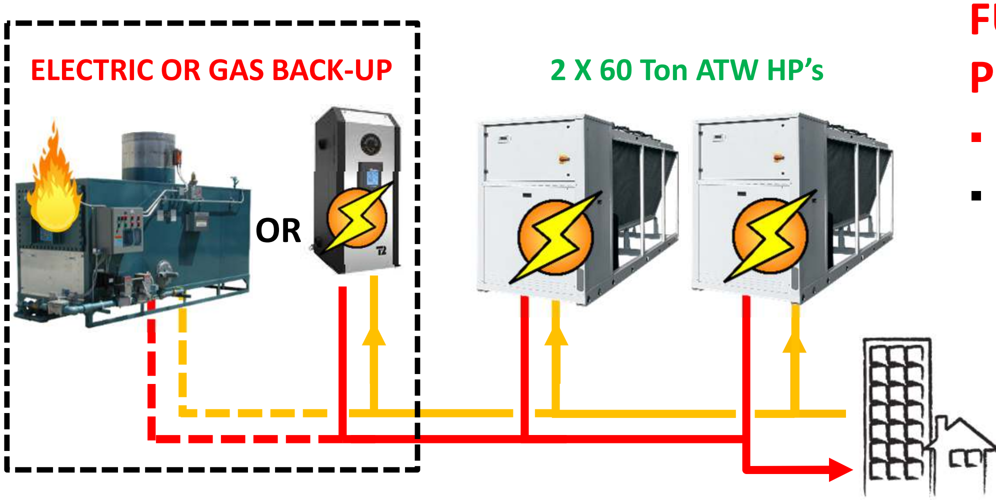
ATWHP + NG BOILER BACKUP



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**

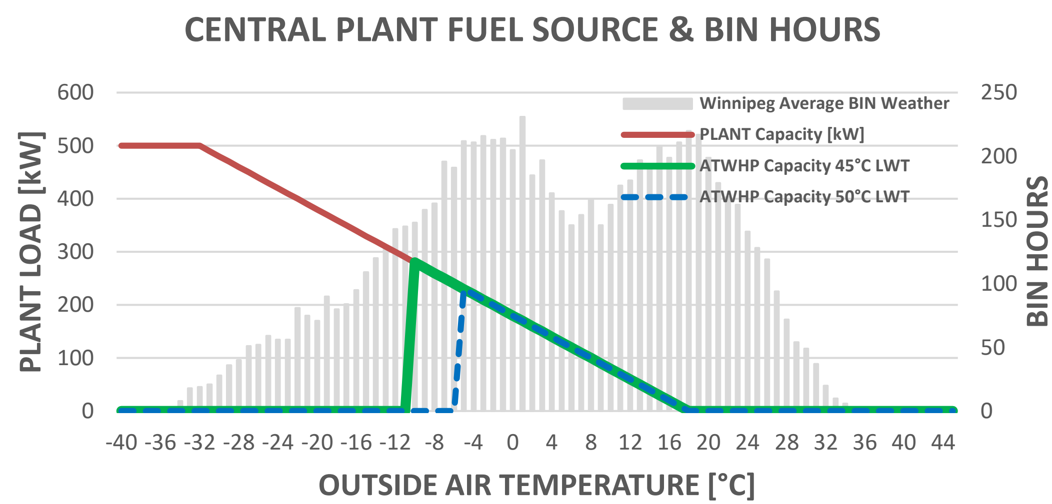
WINNIPEG, MB CENTRAL PLANT HEATING ANALYSIS EXAMPLE: 120 TON CHILLER SYSTEM (2 X 60 TON UNITS)



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

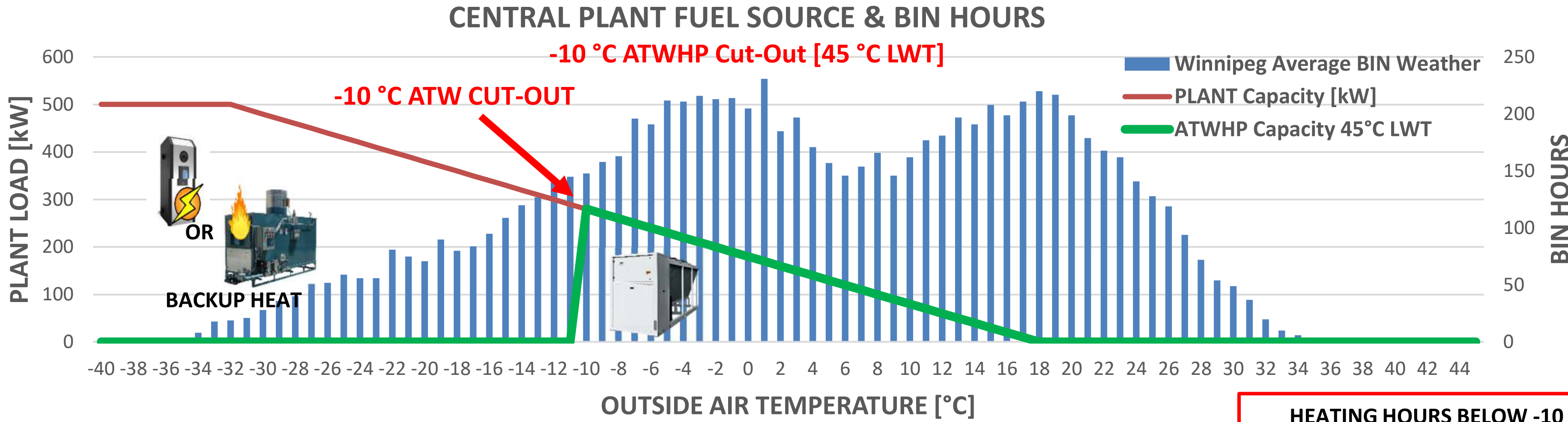
- **430 kW Peak Load** Using TWO **60 Ton Air-to-Water** Heat Pump Units
- Comparison for Sizing Based on -10 C and – 5 C Cut-out Temperature:
  - **40% Propylene Glycol**
  - **45 °C LWT / -10 °C Cut-Out → CAP_{RATED} = 135 kW; COP_{RATED} = 2.07**
  - **50 °C LWT / -5 °C Cut-out → CAP_{RATED} = 110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

Peak Load [kW]	Ambient Temp. [°C]	Rated Capacity (Each) [kW]	Efficiency COP [W/W]
500	-38	GAS OR ELECTRIC AUX.	
280	-10	140	2.07
230	-5	115	2.10

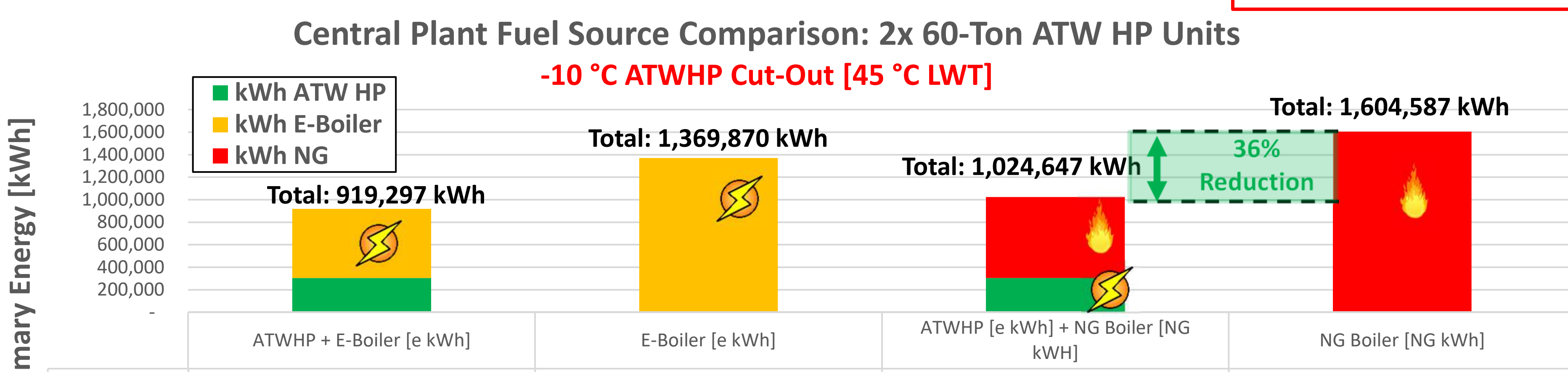


CENTRAL PLANT COMPARISON FOR BACK-UP FUEL TYPES

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



HEATING HOURS BELOW -10 °C = 1,673
HOURS BETWEEN -10 °C to +10 °C = 3,842

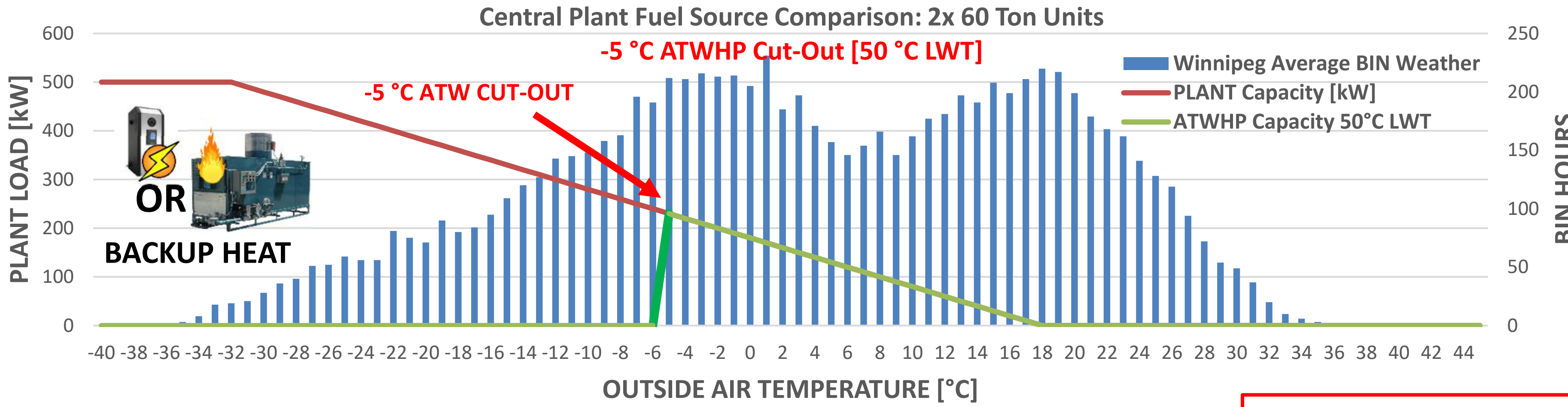


	ATWHP + E-Boiler [e kWh]	E-Boiler [e kWh]	ATWHP [e kWh] + NG Boiler [NG kWH]	NG Boiler [NG kWh]
kWh NG	-	0	720,200	1,604,587
kWh E-Boiler	614,850	1,369,870		
kWh ATW HP	304,447	-	304,447	-

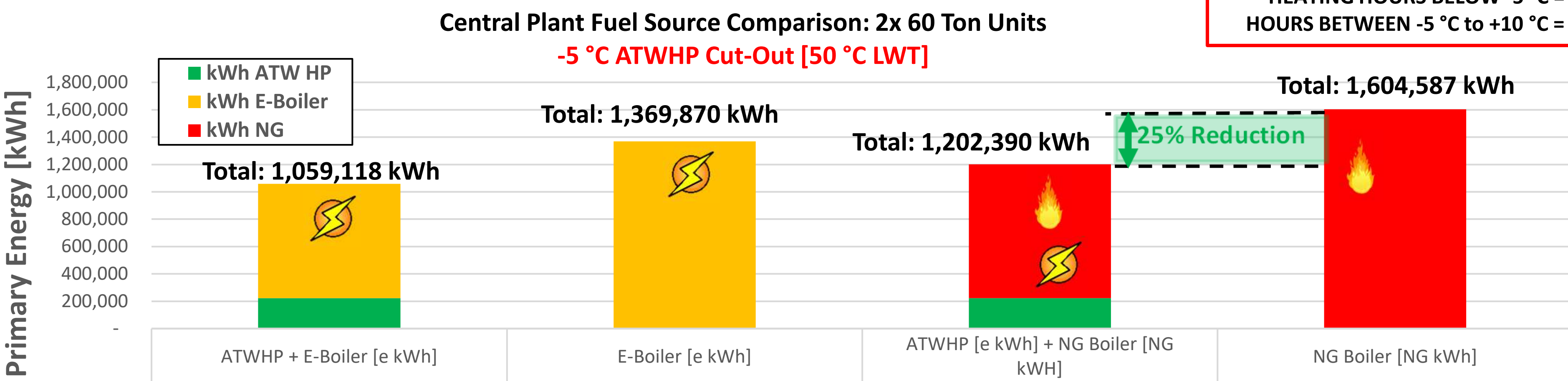
Central Plant Back-Up Type

CENTRAL PLANT COMPARISON FOR BACK-UP FUEL TYPES

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



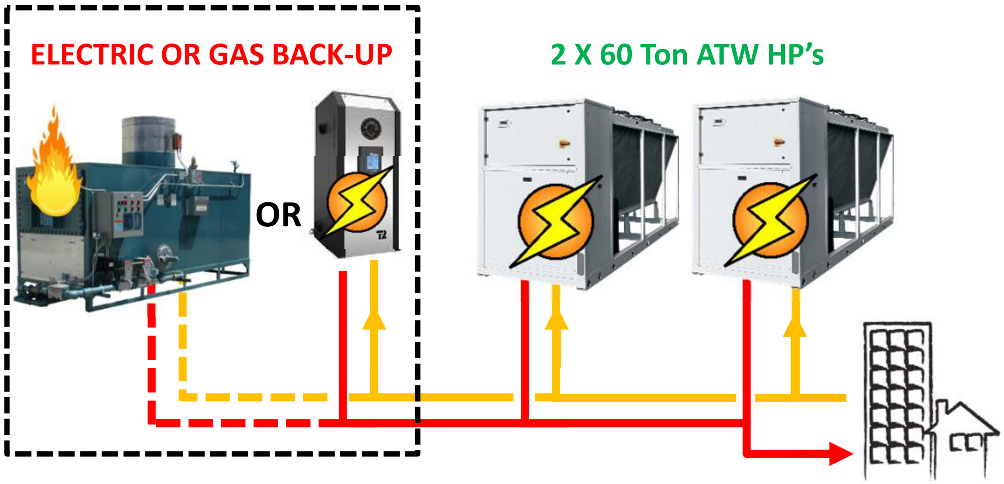
HEATING HOURS BELOW -5 °C = 2,529
HOURS BETWEEN -5 °C to +10 °C = 2,986

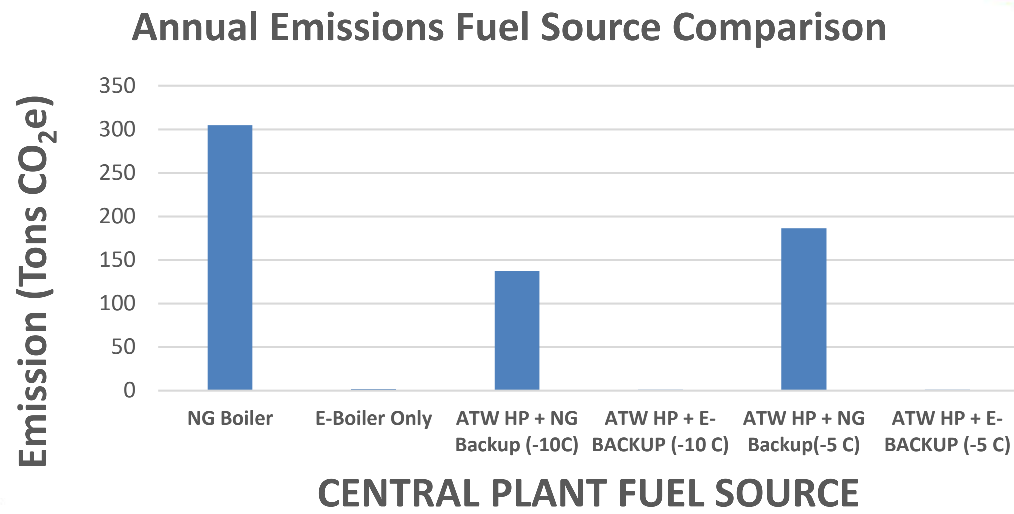


	ATWHP + E-Boiler [e kWh]	E-Boiler [e kWh]	ATWHP [e kWh] + NG Boiler [NG kWh]	NG Boiler [NG kWh]
kWh NG	-	0	979,442	1,604,587
kWh E-Boiler	836,170	1,369,870		
kWh ATW HP	222,948	-	222,948	-

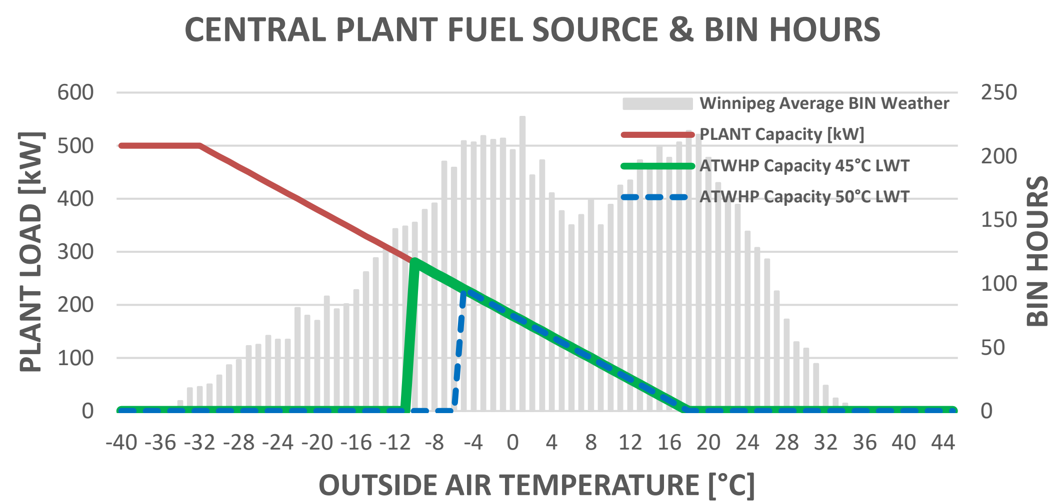
Central Plant Back-Up Type

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





Peak Load [kW]	Ambient Temp. [°C]	Rated Capacity (Each) [kW]	Efficiency COP [W/W]	Annual Tonnes CO_2e Offset (Gas Backup)
500	-38	GAS OR ELECTRIC AUX.		-
280	-10	140	2.07	167.7
230	-5	115	2.10	118.5



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

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

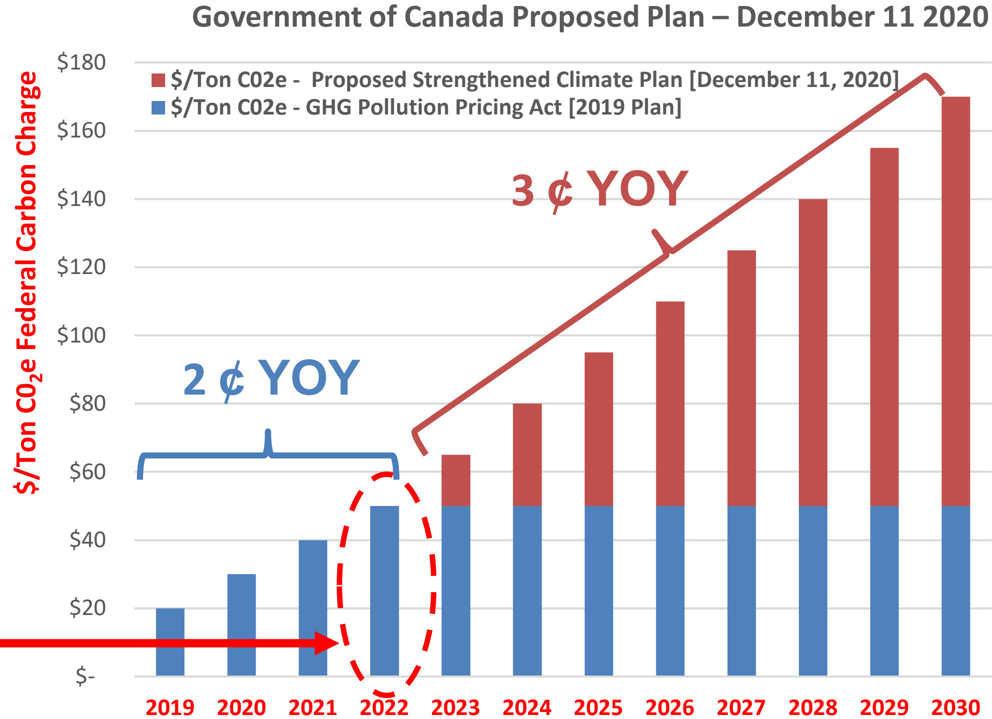
FEDERAL CARBON CHARGE: ONTARIO (ENBRIDGE)

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

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



**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

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

HOW TO COMPARE 1 $kWh_{THERMAL}$ NATURAL GAS TO ELECTRIC HEAT PUMP?

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

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

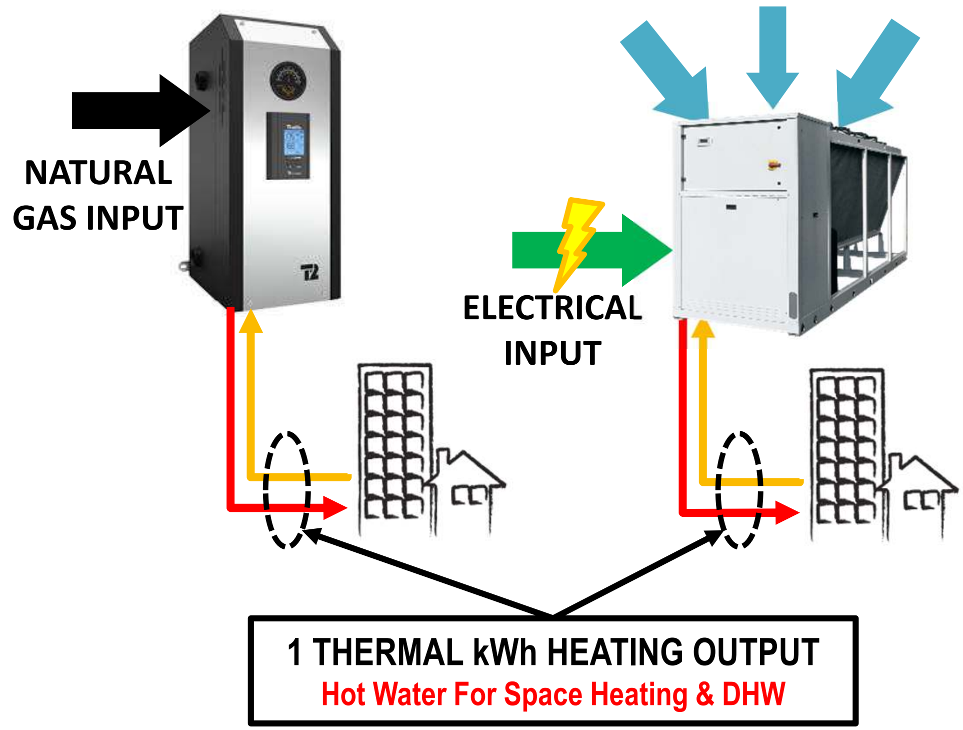
$$Breakeven\ COP_{HEAT\ PUMP} = \frac{\$/kWh_{Electrical}}{\$/kWh_{Natural\ Gas}} \times Boiler\ Efficiency$$

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)



**Above Arithmetic does not account for Electricity Demand Charges

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

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

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

MANITOBA HYDRO RATES:

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

Average Natural Gas Price

= $\$0.45/m^3$ Approx. Total Effective Price from TOTAL of NG Bill (Based on 2022 Carbon Pricing @ \$50/Ton CO_2e)

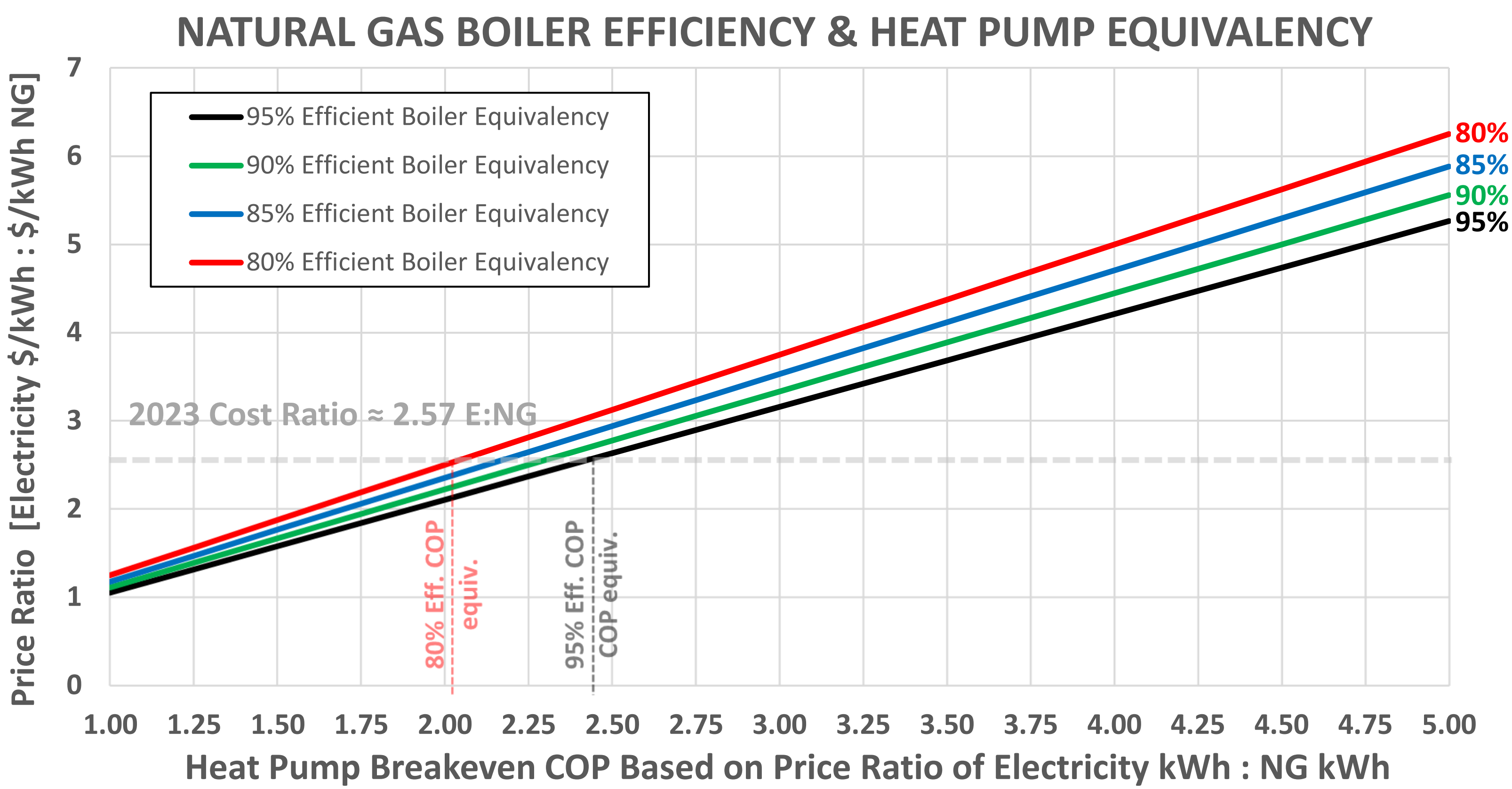
Avgerage Electricity Price

= \$0.11/kWh

2023 Cost Ratio ≈ 2.57 E:NG

Breakeven $COP_{95\%}$ = 2.44

Breakeven $COP_{80\%}$ = 2.05



**Above Arithmetic does not account for Electricity Demand Charges

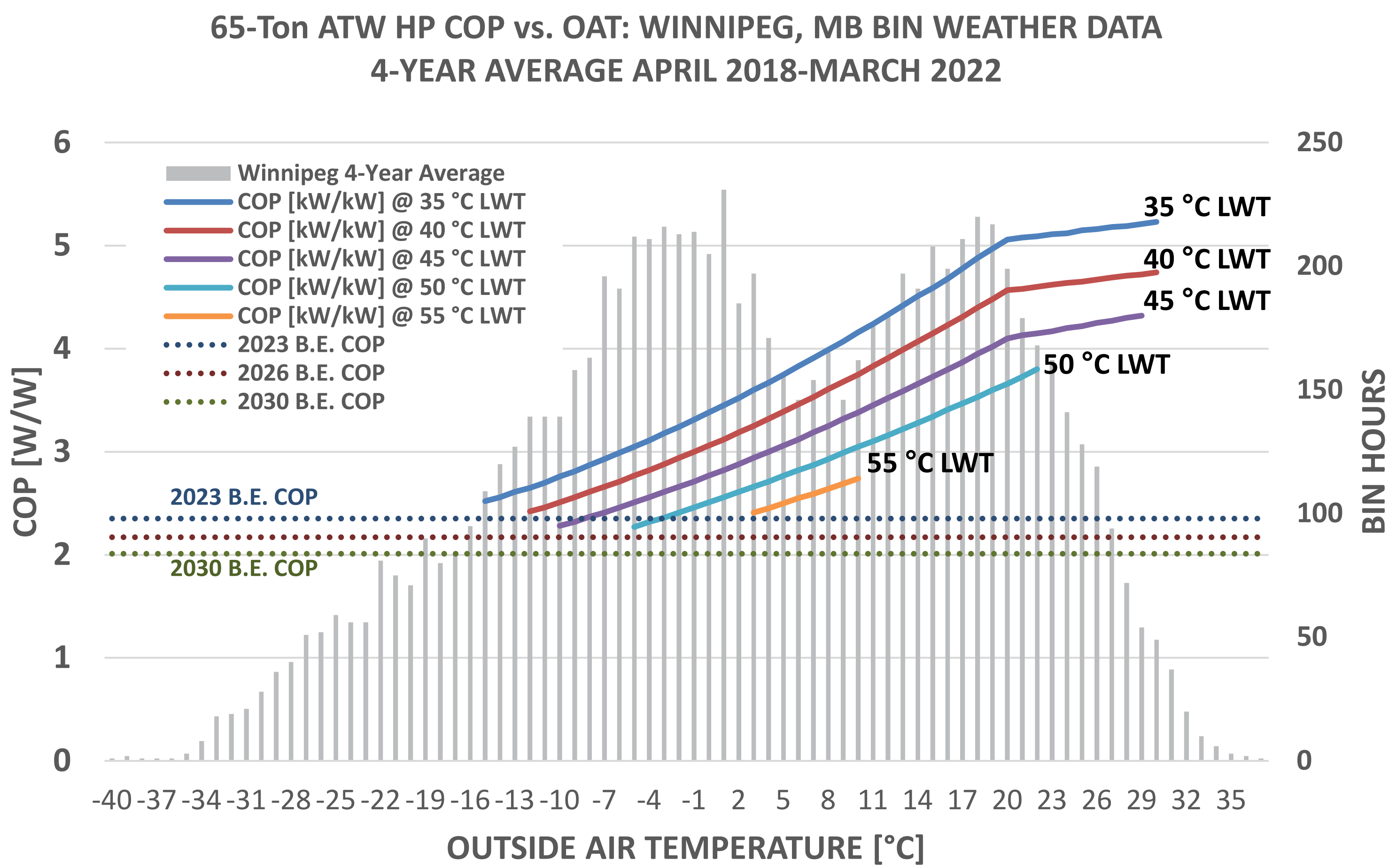
REDUCING BUILDING GHG EMISSIONS WITH AIR-TO-WATER HEAT PUMPS

CARBON TAX IMPROVES HEAT PUMP OPERATIONAL COSTS 2022-2030

Annual Average Energy Source Comparison - Manitoba			
Year	Electricity Rate [$/kWh]	Natural Gas Rate [$/m^3]	Breakeven COP (95% Eff. Boiler)
2022	$0.110	$0.45	2.44
2023	$0.113	$0.48	2.35
2024	$0.117	$0.51	2.28
2025	$0.120	$0.54	2.22
2026	$0.124	$0.57	2.17
2027	$0.128	$0.60	2.12
2028	$0.131	$0.63	2.08
2029	$0.135	$0.66	2.04
2030	$0.139	$0.69	2.01

1 m^3 = 10.5 kWh$_{NATURAL\ GAS}$
Boiler Efficiency = 95%
$0.45/m^3 Natural Gas (2022)
+ $0.03 YOY (Carbon Tax Increase)

Avg. Electricity $0.11/kWh (+3% YOY)



**Above Arithmetic does not account for Electricity Demand Charges

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

MANITOBA HYDRO EXAMPLE – GENERAL SERVICE (SMALL 3-PHASE) AND SMALL COMMERCIAL NATURAL GAS RATE GLASS

NATURAL GAS:

~ \$0.1878/m^3 (or more) Commodity
~ \$0.1213/m^3 (or less) Delivery
\$0.0979 /m^3 (2022 Tax)

Natural Gas Bill	Amount
Total m^3 Usage - NG	727.54
Basic Charge	\$ 14.00
Total Commodity + Delivery of NG	\$ 240.85
Fed Carbon Charge	\$ 71.23
Subtotal (incl. Fed. Carbon Charge)	**\$ 326.08**
Taxes	\$ 34.15
Total Bill (Incl Taxes)	**\$ 360.23**
Total \$/m^3 NG (Pre-Tax, Incl. Fed Carbon Charge)	**\$ 0.45**

Natural Gas - Small Commercial / Gaz Naturel - Commercial - petit

Meter number / N° de compteur	Service / Pour la période From / Du	To / Au	Days / Jours	Meter readings / Relevés du compteur Previous / Précédent	Present / Nouveau	Usage / Consommation		Base pressure adj/Facteur de rajustement de la pression de base		Metric conversion factor/Facteur de conversion métrique		Cubic metres (m^3) / Mètres cubes (m^3)	Reading type / Type de relevé
1064050	Jan 20 JAN/23	Feb 17 FÉV/23	28	257	517	260	x	0.98780	x	2.832784	=	727.538	Estimated Estimatif

Basic Charge / Redevance de base				\$ 14.00	
Gas Commodity (Centra) / Gaz - prix du produit	318.696 m^3	x	\$ 0.23960	76.36	
Gas Commodity (Centra) / Gaz - prix du produit	408.842	x	0.18780	76.78	
Delivery / Livraison	318.696	x	0.11960	38.12	
Delivery / Livraison	408.842	x	0.12130	49.59	
Subtotal / Total partiel				254.85	
7.00% Prov Tax / Taxe prov.				17.84	
5.00% GST / TPS				12.75	
Federal Carbon Charge / Redevance fédérale sur le carbone - 727.538 m^3 x \$ 0.0979				71.23	
5.00% GST on Federal Carbon Charge / TPS sur Redevance fédérale sur le carbone				3.56	
Natural gas charges / Frais de gaz naturel					**360.23**

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

MANITOBA HYDRO EXAMPLE – GENERAL SERVICE (SMALL 3-PHASE) AND SMALL COMMERCIAL NATURAL GAS RATE GLASS

ELECTRICITY:

NON-DEMAND RATE

LESS Than $0.095/kWh

Use $0.11 to be Conservative

Electricity - General service small 3 phase / Électricité - Service général triphasé - petite puissance

Meter number / Nº de compteur	Service / Pour la période From / Du	To / Au	Days / Jours	Meter readings / Relevés du compteur Previous / Précédent	Present / Nouveau	Multiplier / Multiplicateur	kW.h / kWh	Reading type / Type de relevé
944519	Jan 20 JAN/23	Feb 17 FÉV/23	28	24397	24711	1	314	Estimated Estimatif

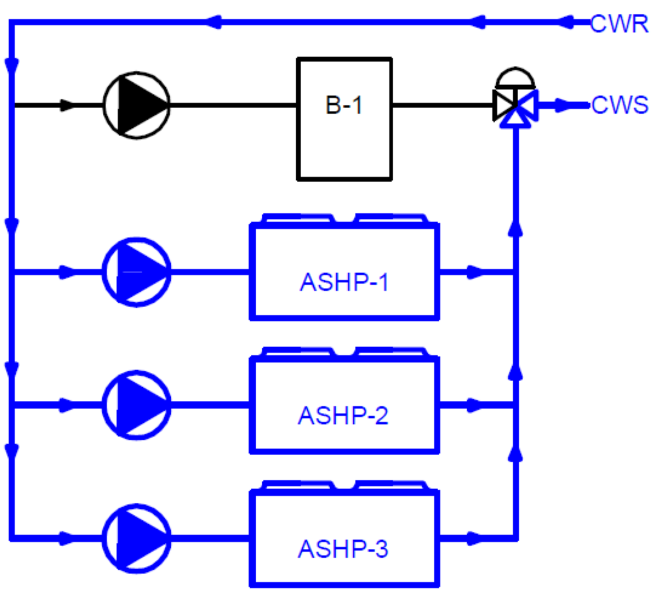
Basic Charge / Redevance de base		$ 33.69	
Energy Charge / Frais d'énergie	314.000 kW.h x $0.09485	29.78	
Subtotal / Total partiel		63.47	
5.00% City Tax / Taxe mun.		3.18	
7.00% Prov Tax / Taxe prov.		4.44	
5.00% GST / TPS		3.17	
5.00% GST on City Tax / TPS sur taxe mun		0.15	
Electricity charges / Frais d'électricité			**74.41**

AIR-TO-WATER CENTRAL PLANT: APPLICATIONS

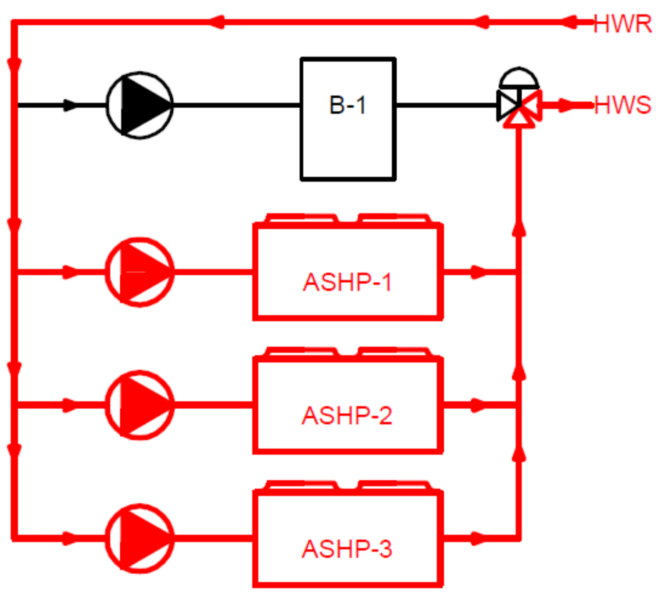
- **2-PIPE SYSTEMS:**
  - **Simple 2-Pipe Change-Over System**
  - **Cascade Systems**
- **4-PIPE HYBRID SYSTEMS using ATW Heat Pumps**
- **PARTIAL HEAT RECOVERY in 2-Pipe & 4-Pipe Systems (Desuperheater)**
- **DOMESTIC HOT WATER**

CENTRAL HEAT PUMP PLANT:
2-PIPE CHANGEOVER COMMERCIAL SYSTEM

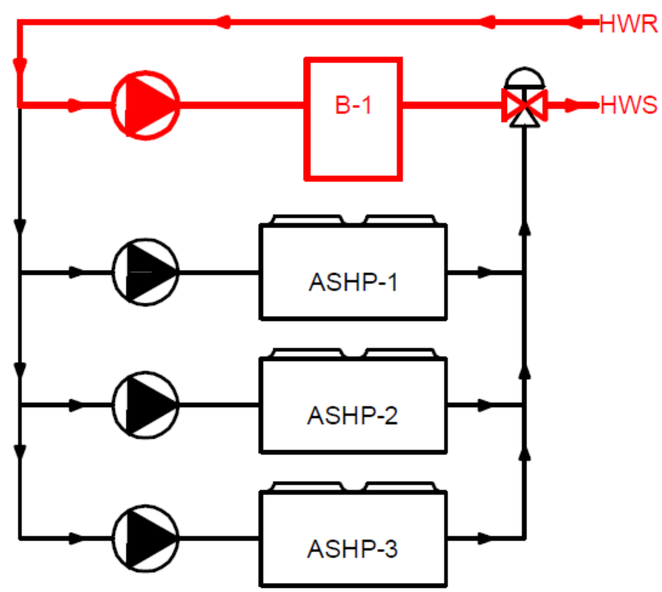
SUMMER COOLING



WINTER HEATING
AIR-TO-WATER HEAT PUMP



WINTER HEATING
AUXILIARY BOILER

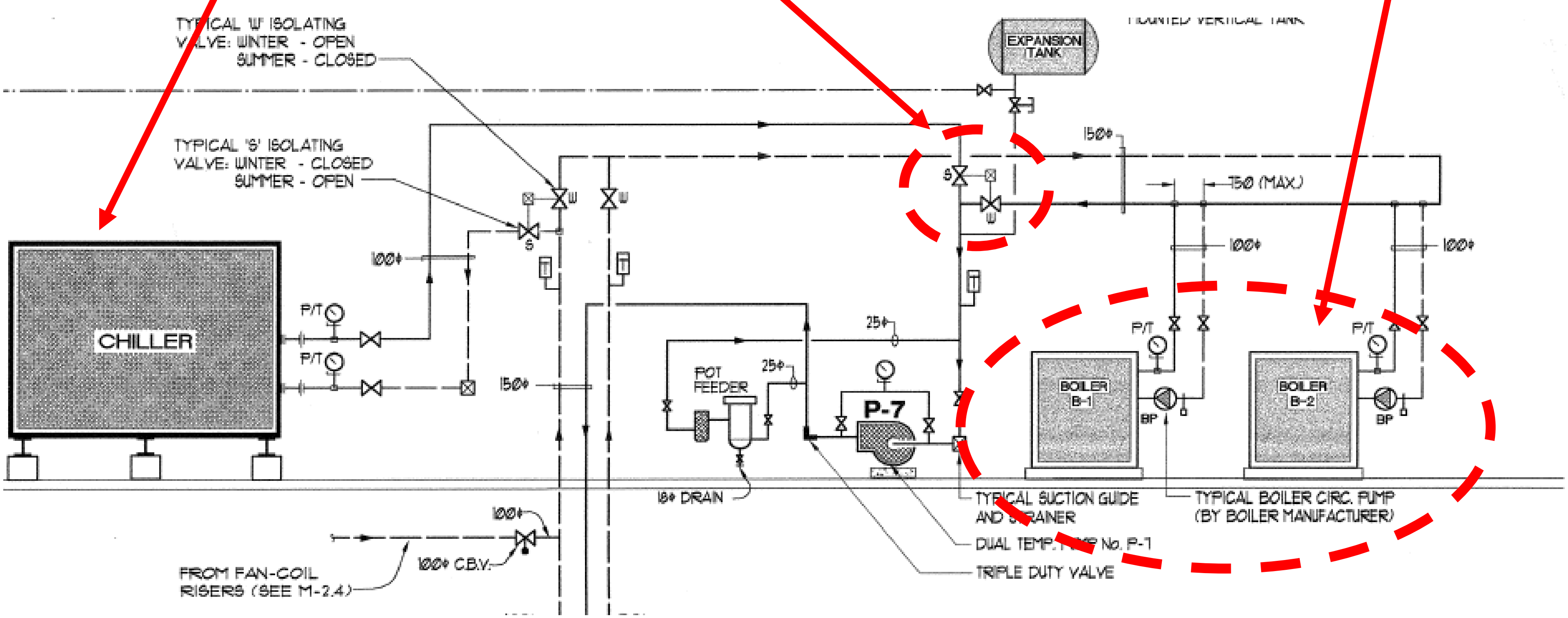


FQSF CHILLER UPGRADE: EXISTING CHILLER SYSTEM

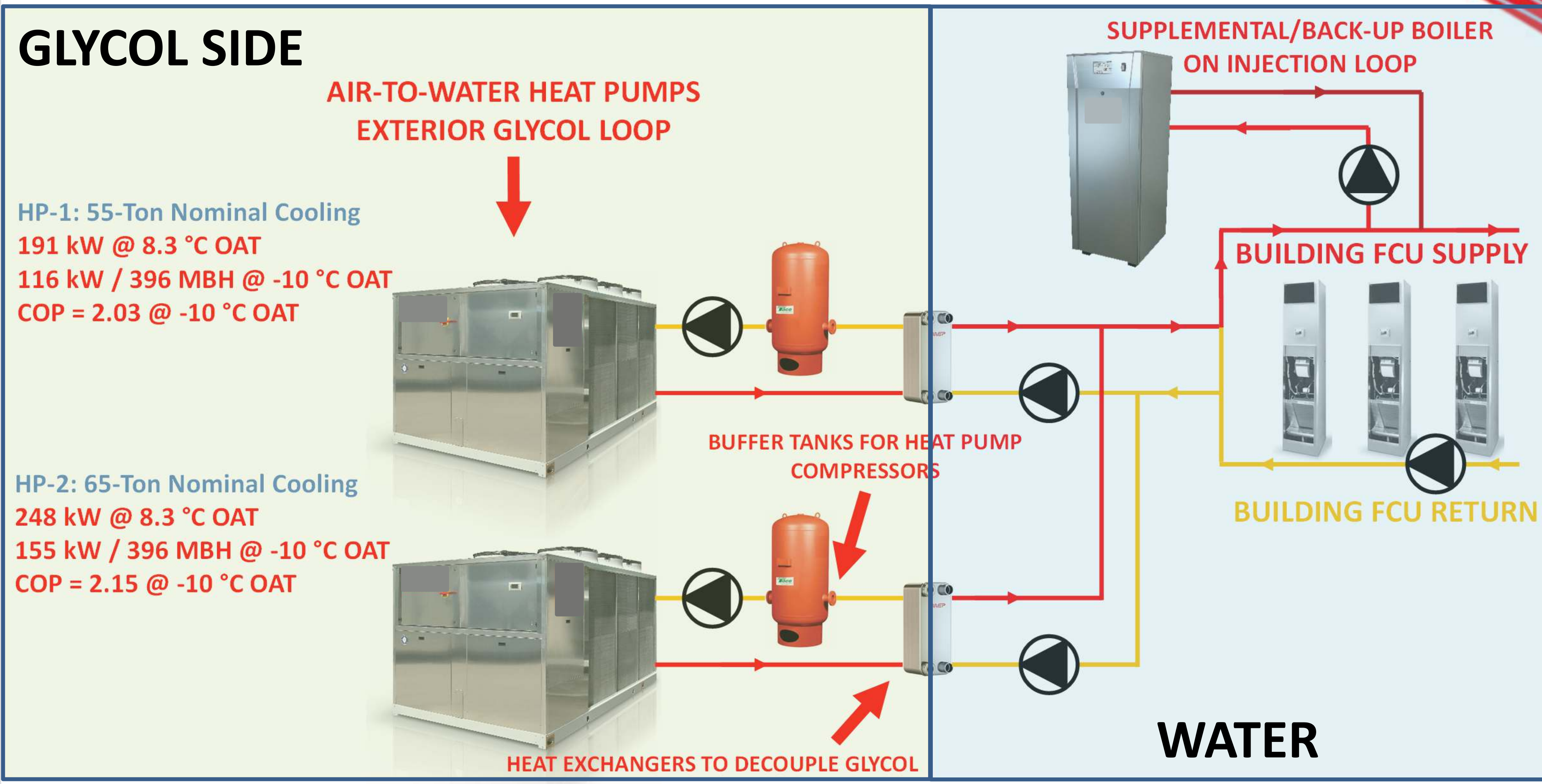
Chiller Drained in Winter
(No Glycol in System)

Seasonal
Changeover Valve

Chiller Drained in Winter
(No Glycol in System)



FQSF CHILLER UPGRADE: HYBRID CENTRAL HEAT PUMP PLANT



TORONTO MURB CHILLER UPGRADE

TORONTO MURB CHILLER UPGRADE

COST BENEFIT ANALYSIS: FUEL SWITCHING RETROFIT

PROJECT COST SUMMARY

- "Like-for-Like" Scenario based on Budgeted Reserve Fund Study of ageing chiller
- Allowance in reserve fund study for upgraded controls
- Boiler portion from reserve fund applied for retrofit as ATW Heat Pump acts as a boiler in winter.
- Reversible ATW Heat Pump project costs is actual costs at time of tender, including Engineering, Mechanical contractor, Equipment
- Incentives includes:
  - The Atmospheric Fund (TAF) Special Contribution
  - Enbridge Incentive
  - IESO Chiller Rebate (Based on NX-N exceeding IPLV requirement
- Not captured in incentives/contributions is TRCA's STEP Program for measurement & verification
- Anticipated more funding to be available to support similar projects based on Fuel Switching incentives and Enbridge Custom Program, Federal/Provincial Funding Programs

Like-for-Life Budget (Reserve Fund)		
Description	**Amount**	
Air-Cooled Chiller Replacement	$	300,000
Heating Boilers - Secondary	$	80,000
Mechanical Control System	$	20,000
Total:	**$**	**400,000**

Reversible ATW Central Plant Upgrade		
Description	**Amount**	
Reversible ATW Heat Pumps (Equipment)	$	220,000
Installation, Engineering Fees & Ancillary Equipment (Controls, Pumps, Heat Exchangers, Buffer Tanks)	$	386,200
Subtotal-Fuel Switch Budget	**$**	**606,200**

Project Incremental Costs - Chiller Upgrade/Fuel Switch		
Incremental Cost: (Equipment+Install only)	$	206,200
Incentives - Actuals	$	46,500
Incremental Cost: (Equipment+Install only), Incl. Incentives	$	159,700

SIMPLE PAYBACK ANALYSIS: FUEL SWITCHING RETROFIT

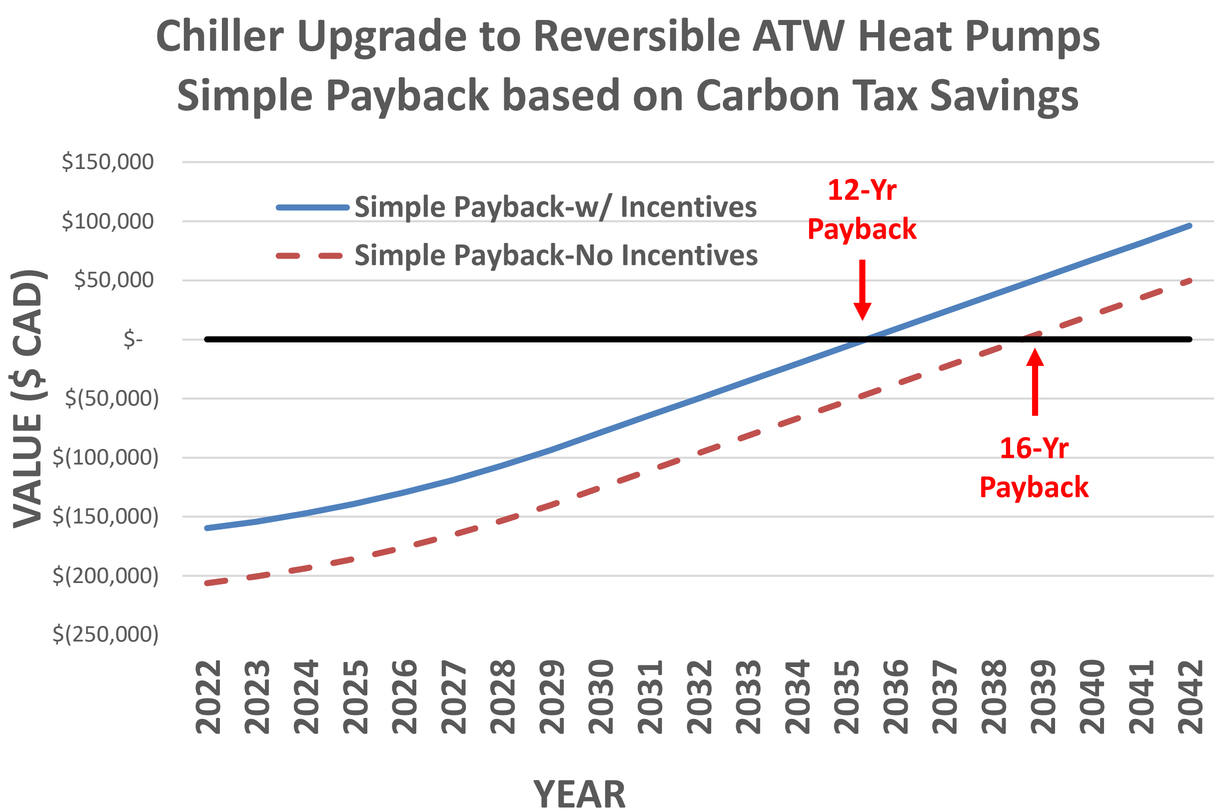
ENERGY SAVINGS

- 45,472 m^3 Natural Gas Annual Savings Approved by Enbridge for Custom Incentive
- **85.9** Tons CO_2e Emissions Offset per year (1.888 kg CO_2e/m^3 Natural Gas)

Year	$/Ton CO_2e Carbon Tax	Annaul Avoided Carbon Tax	Cumulative Savings
2023	$ 65	$ 5,584	**$ 5,584**
2024	$ 80	$ 6,872	**$ 12,456**
2025	$ 95	$ 8,161	**$ 20,616**
2026	$ 110	$ 9,449	**$ 30,065**
2027	$ 125	$ 10,738	**$ 40,803**
2028	$ 140	$ 12,026	**$ 52,829**
2029	$ 155	$ 13,315	**$ 66,143**
2030	$ 170	$ 14,603	**$ 80,746**
2031	$ 170	$ 14,603	**$ 95,349**
2032	$ 170	$ 14,603	**$ 109,952**
2033	$ 170	$ 14,603	**$ 124,555**
2034	$ 170	$ 14,603	**$ 139,158**
2035	$ 170	$ 14,603	**$ 153,761**
2036	$ 170	$ 14,603	**$ 168,364**
2037	$ 170	$ 14,603	**$ 182,967**
2038	$ 170	$ 14,603	**$ 197,570**

***Savings above are estimates based on natural gas reduction. Does not account for increased efficiencies in summer due to better performance. Performance optimization may contribute to better long-term savings, TBD during M&V.**

Project Incremental Costs - Chiller Upgrade/Fuel Switch		
Incremental Cost: (Equipment+Install only)	$	206,200
Incentives - Actuals	$	46,500
Incremental Cost: (Equipment+Install only), Incl. Incentives	$	159,700

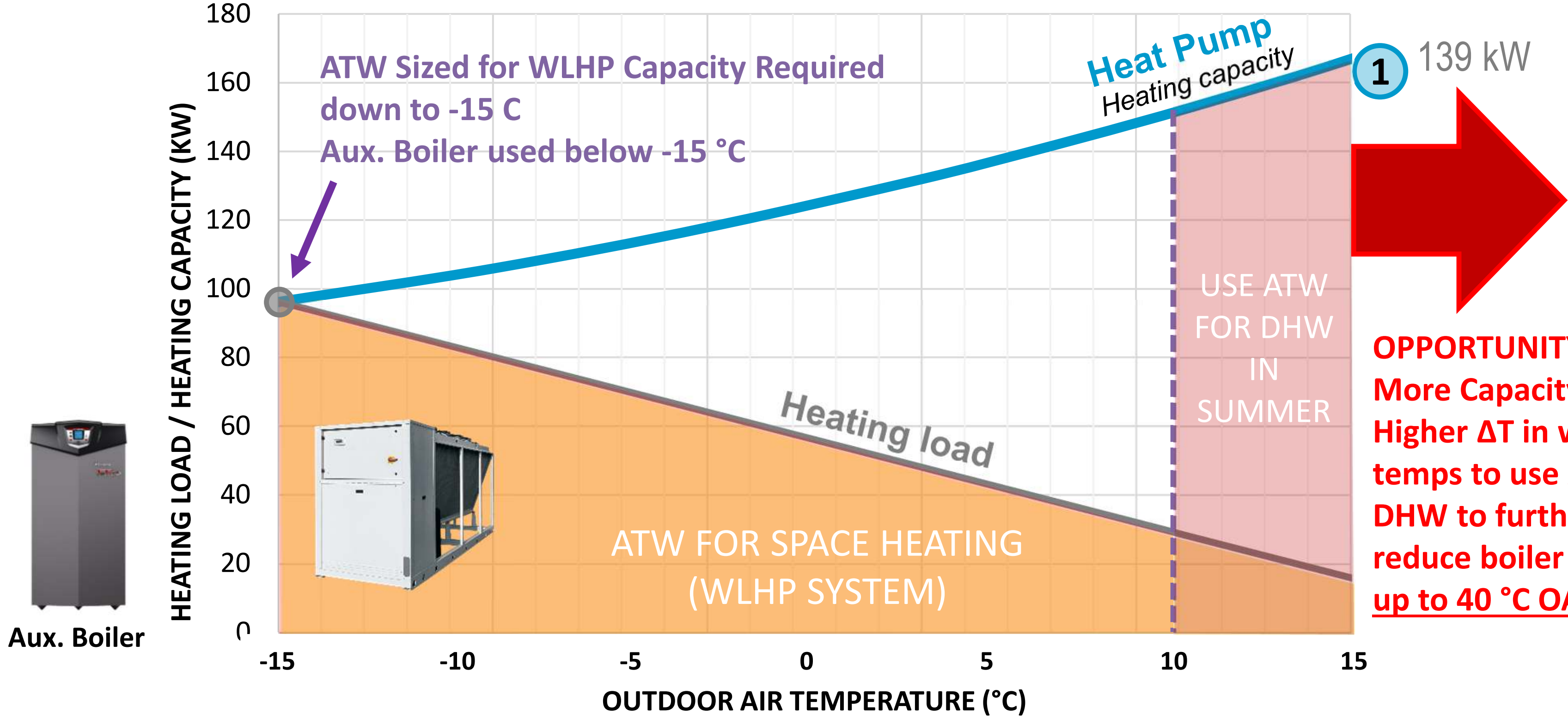


AIR-TO-WATER HEAT PUMP: SIZING FOR HEATING

HEATING CAPACITY VS HEATING LOAD

138 kW ATW HP (NOMINAL)

REVERSIBLE UNIT, AIR SOURCE FOR OUTDOOR INSTALLATION

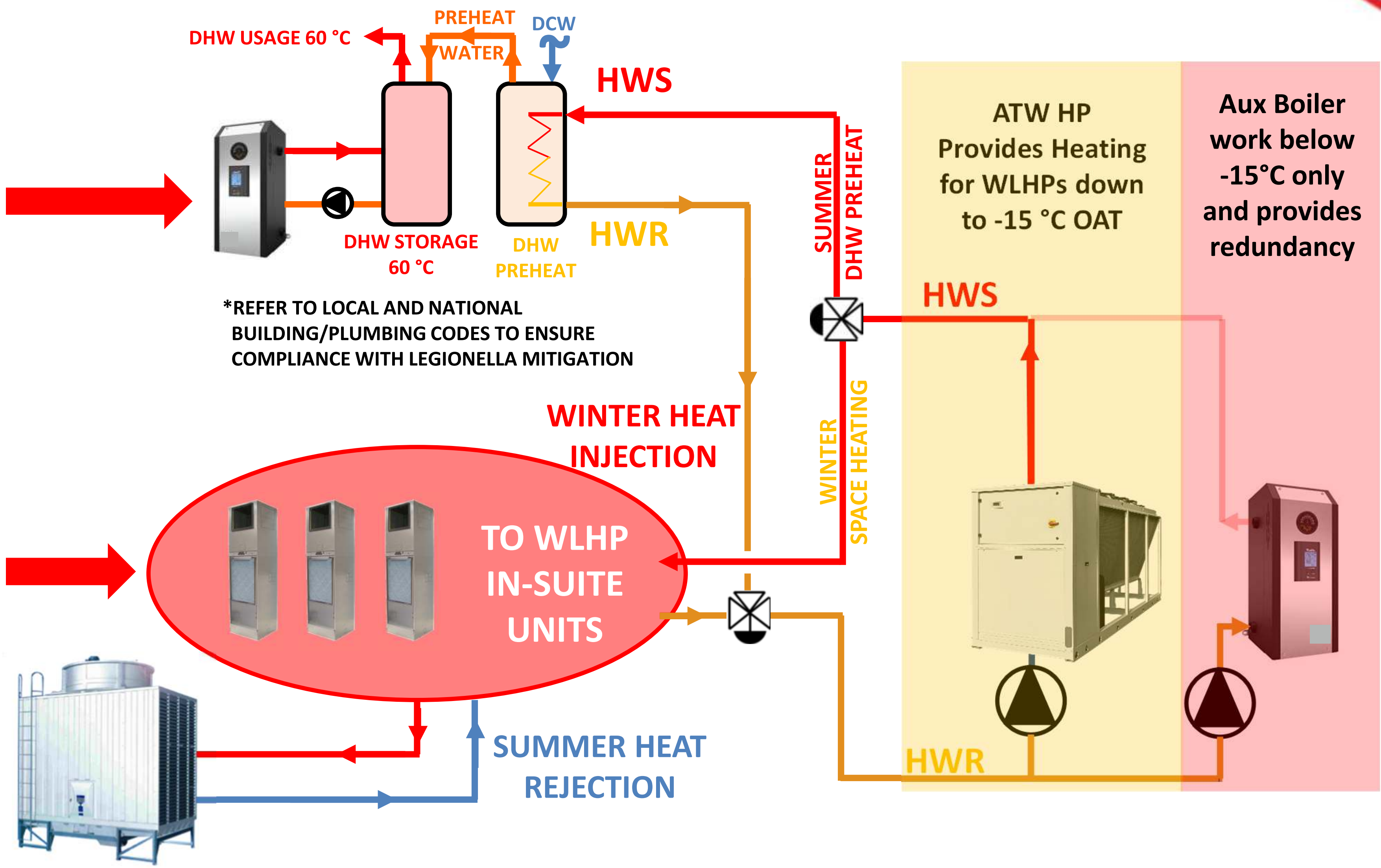


OPPORTUNITY:
More Capacity & Higher ΔT in warmer temps to use ATW for DHW to further reduce boiler usage, up to 40 °C OAT

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



MAXIMIZING ATW HP USAGE FOR DECARBONIZATION: DHW PREHEATING IN SUMMER

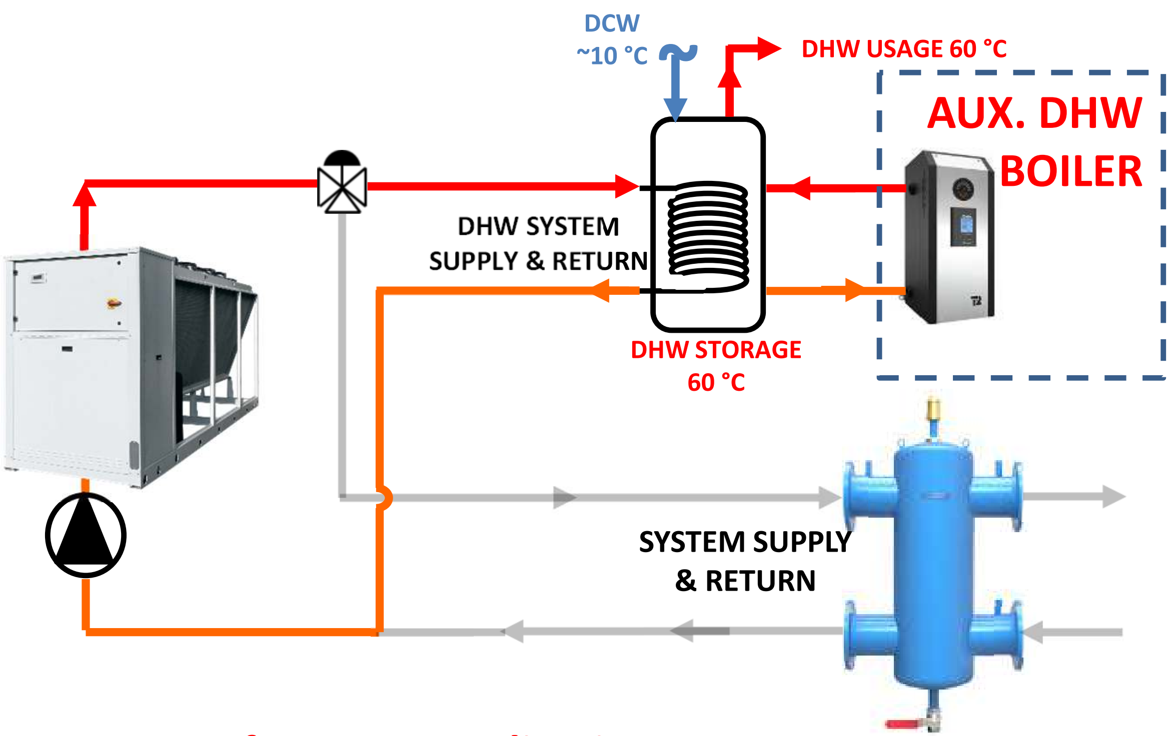
WINTER SPACE HEATING DESIGN CONDITIONS VS. SUMMER HEAT PUMP OPERATION:

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%]**

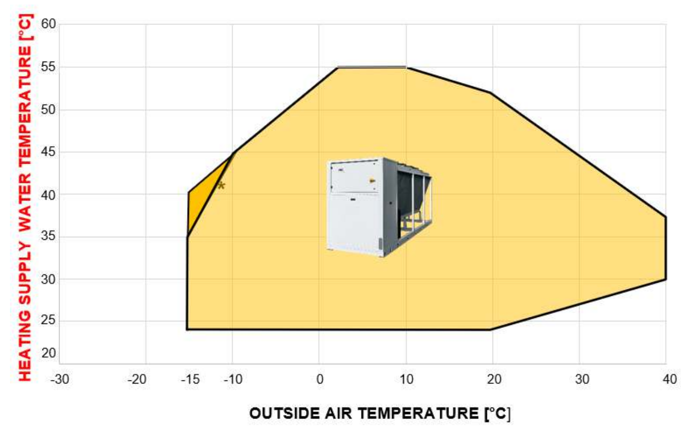
DOMESTIC HOT WATER PRODUCTION

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

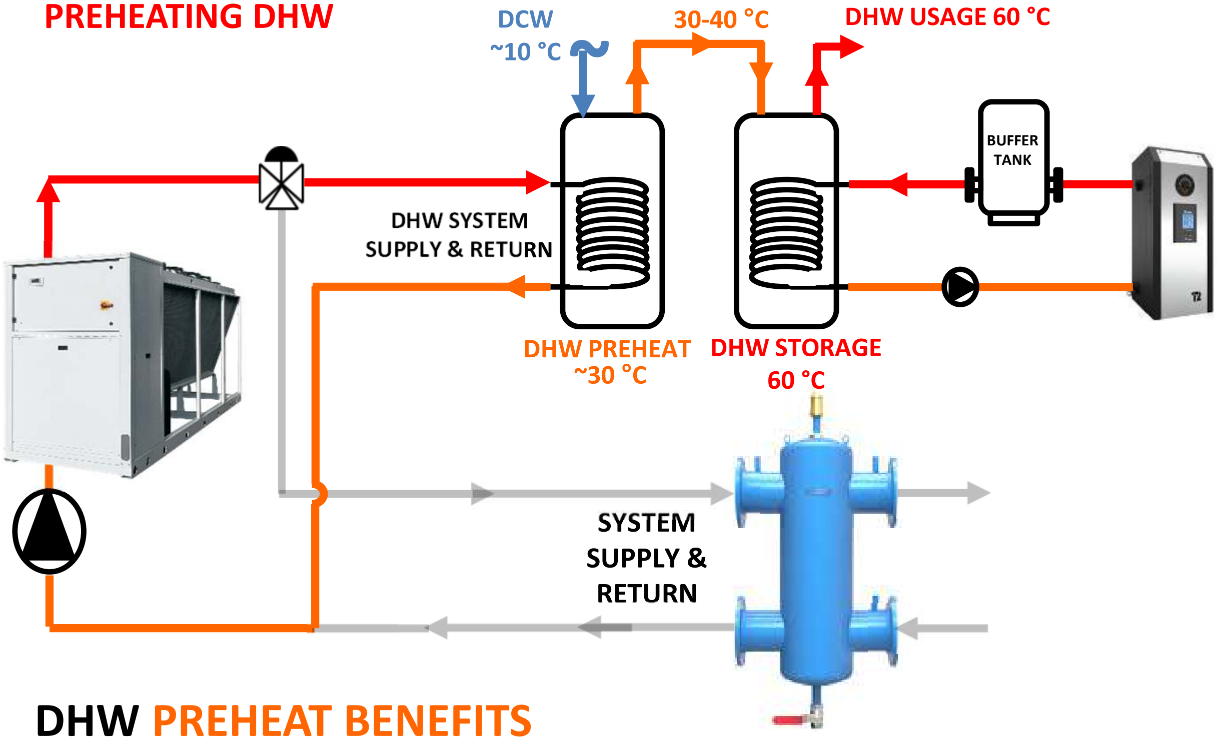


ATW HP for DHW Application:

- 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



DHW PREHEAT BENEFITS

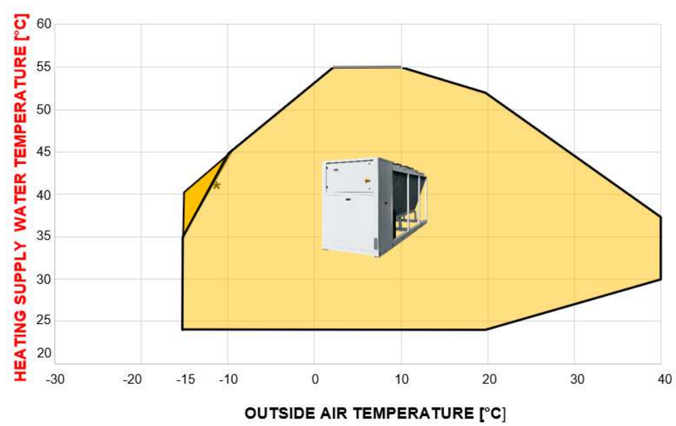
- Reduce Boiler work via Heat Pump
- Preheat Configuration allows the heat pump to add more heat, more often to the DHW system by operating at a lower temperature. Overall offsets more GHG Emissions
- Secondary DHW Tank, boiler then does a lower temperature lift

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

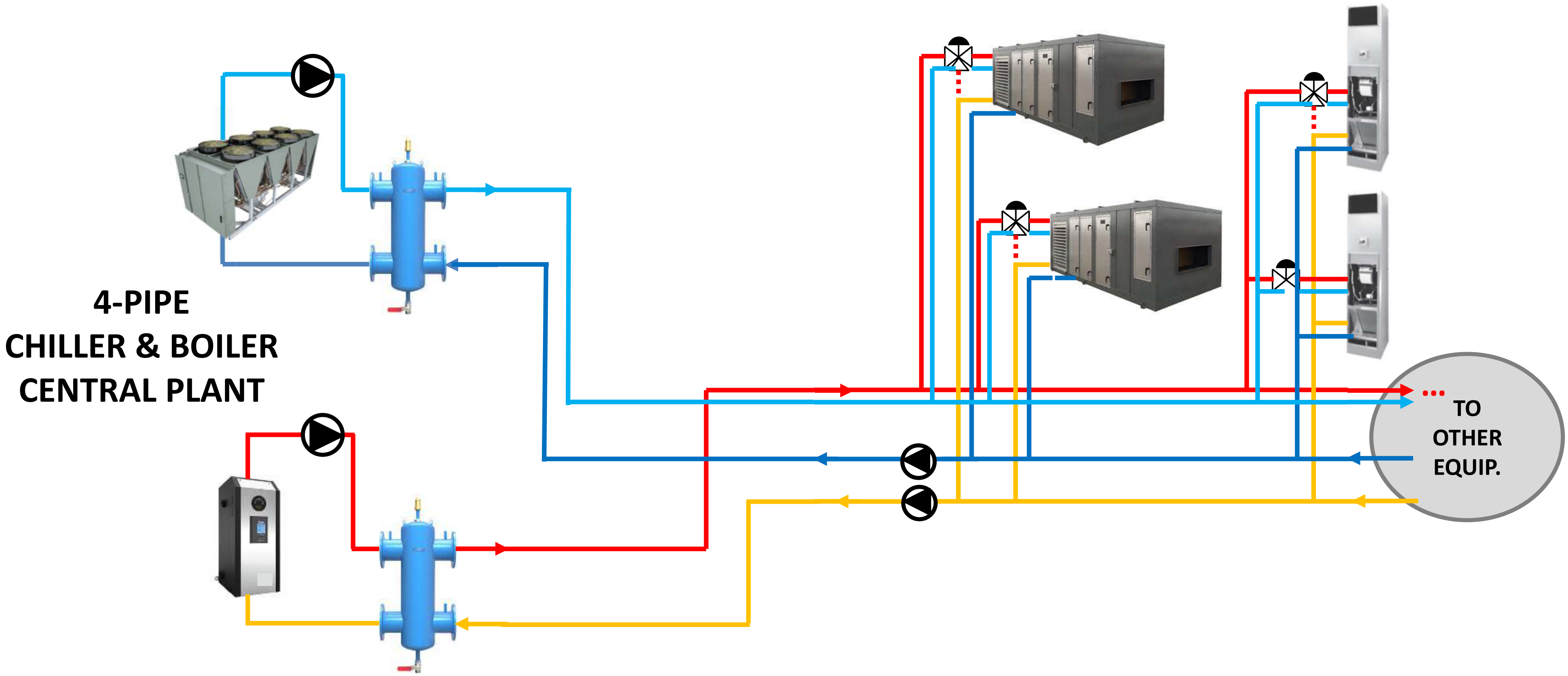
With pre-heated water @ 30 °C, DHW Tank does not drop below 45 °C

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 always

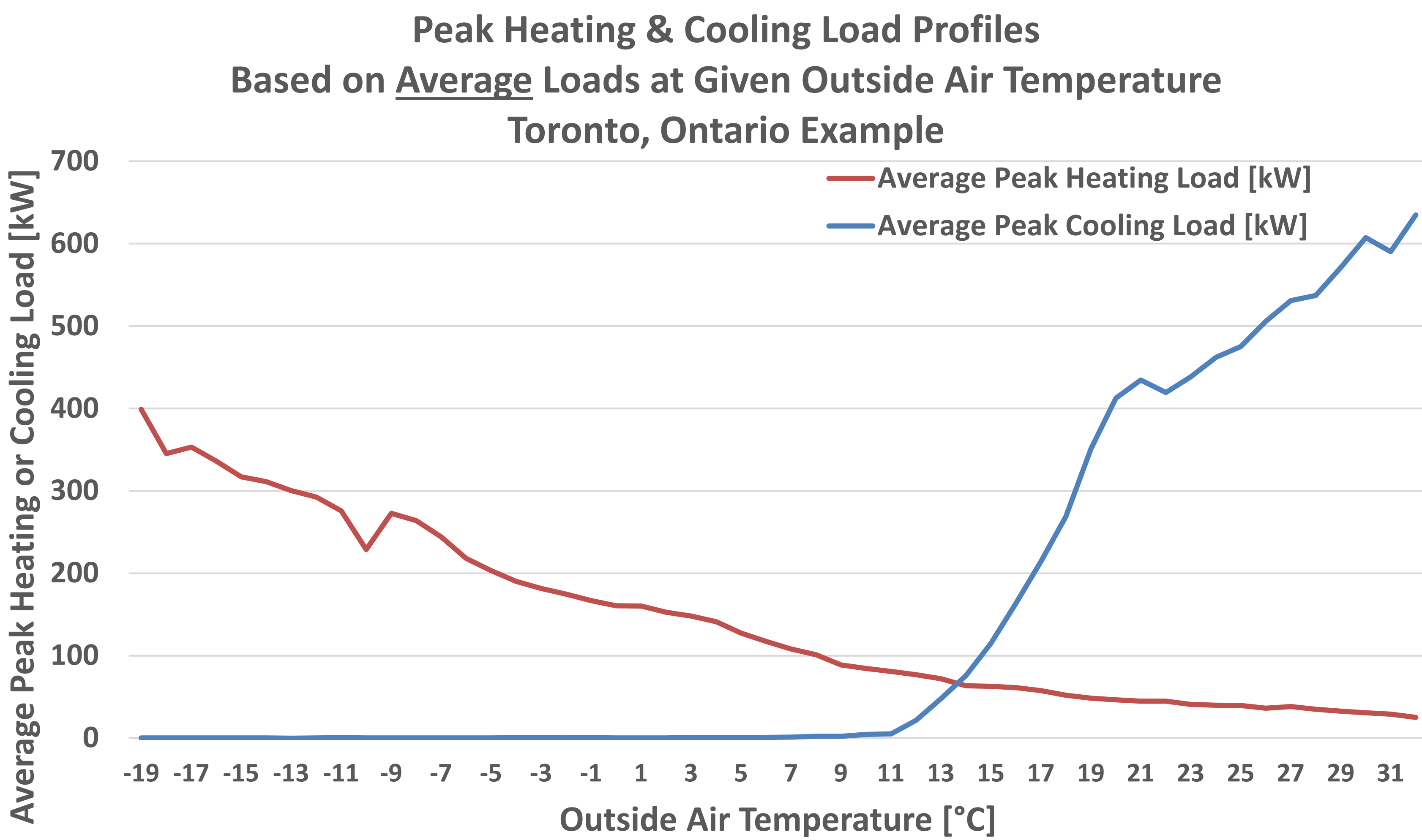


4-PIPE FUEL SWITCH RETROFIT

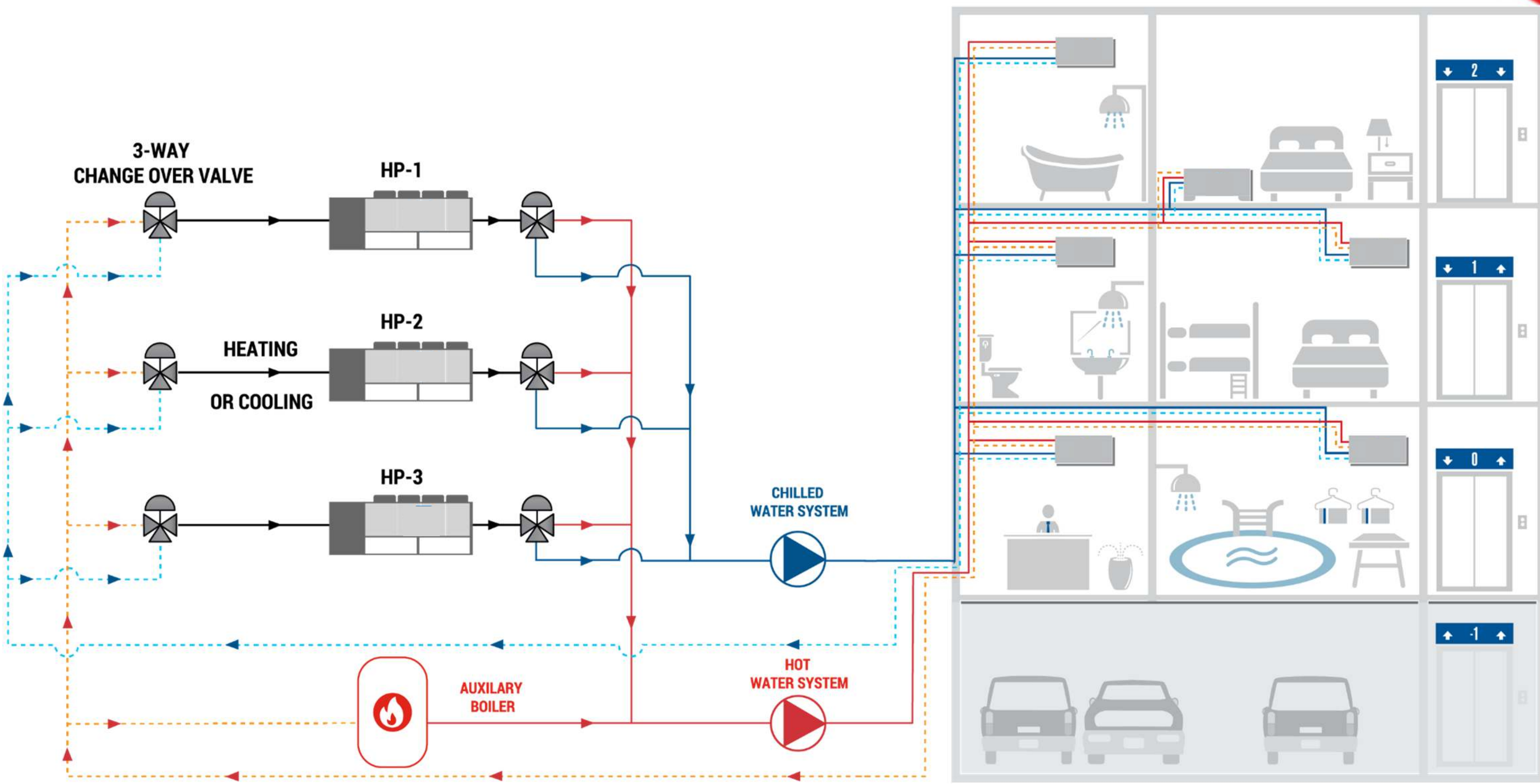
WHAT ABOUT 4-PIPE SYSTEMS?



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



4-PIPE FUEL SWITCH RETROFIT: ENERGY SAVINGS

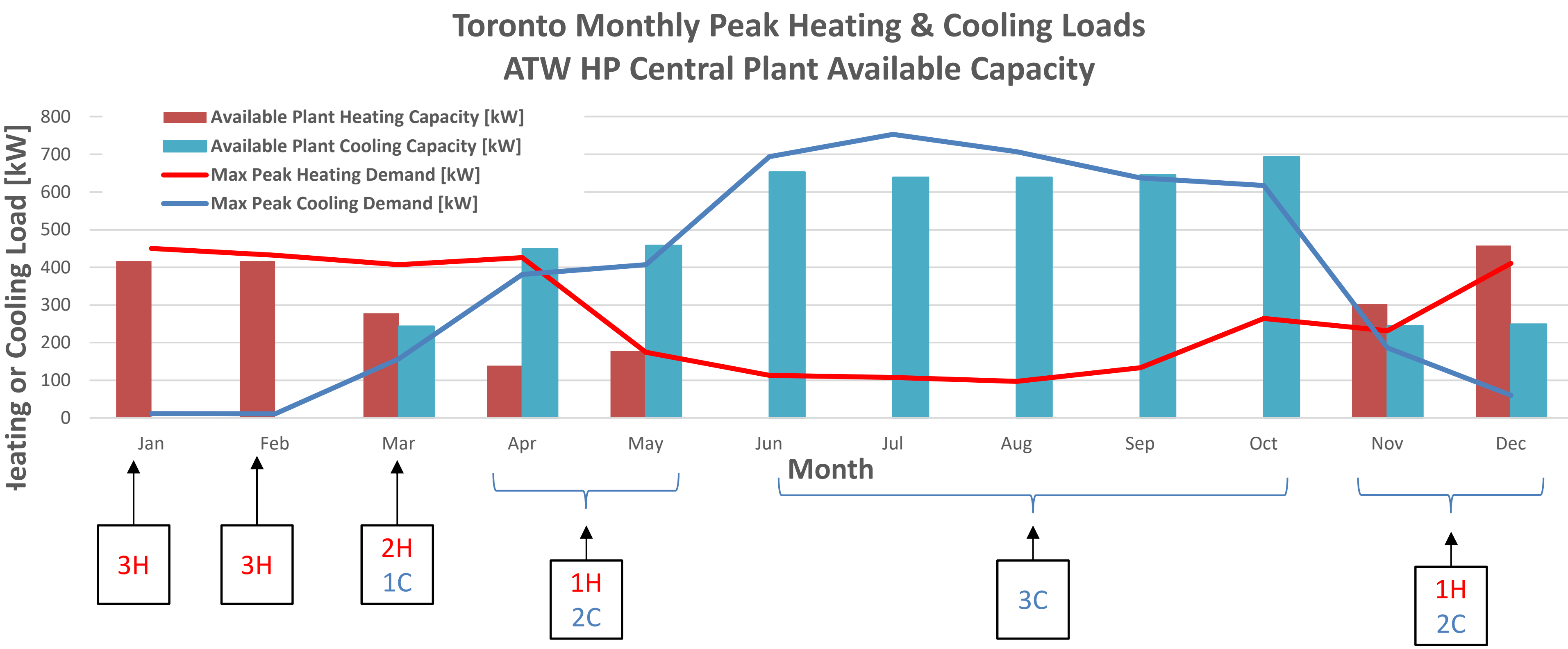


2-PIPE AIR-TO-WATER HEAT PUMPS IN 4-PIPE SYSTEMS HEATING & COOLING SIMULTANEOUSLY

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

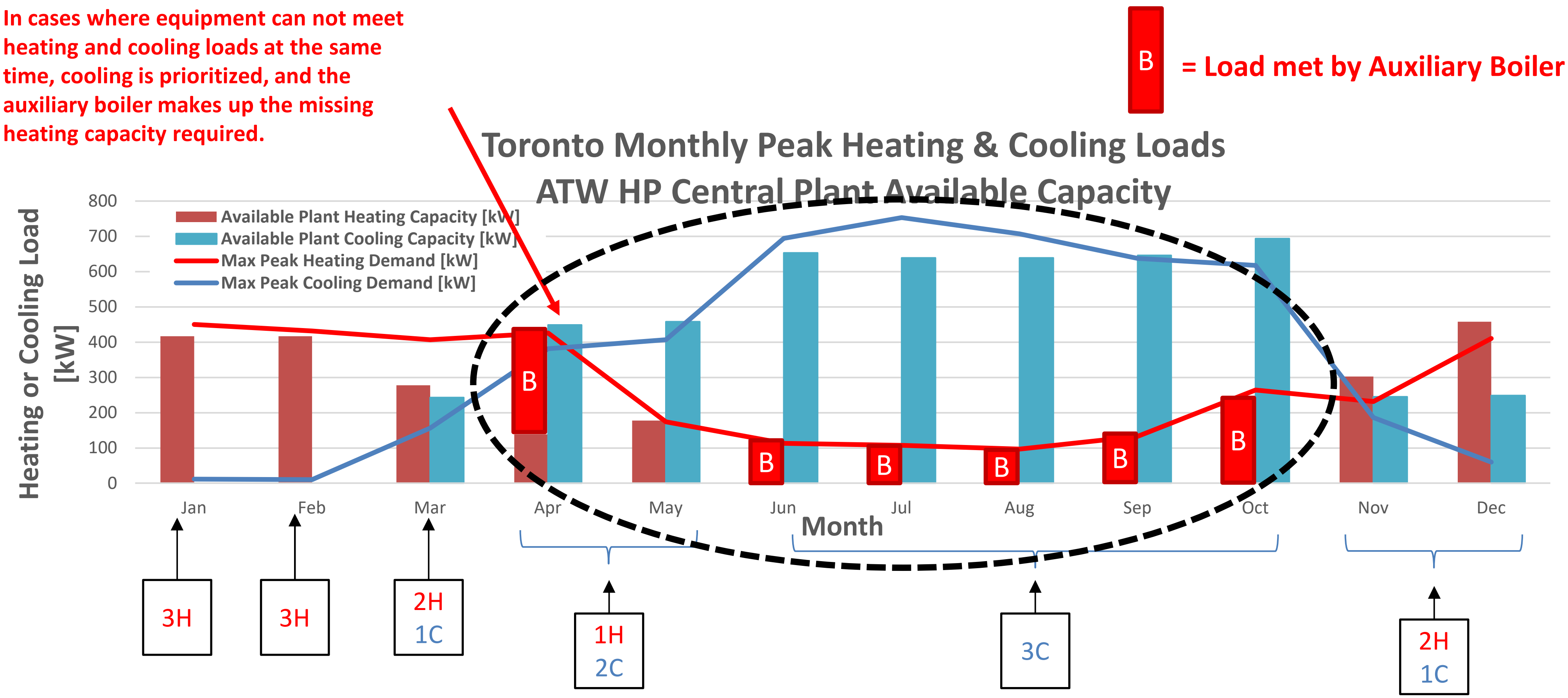
Data Notes:

- 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



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.



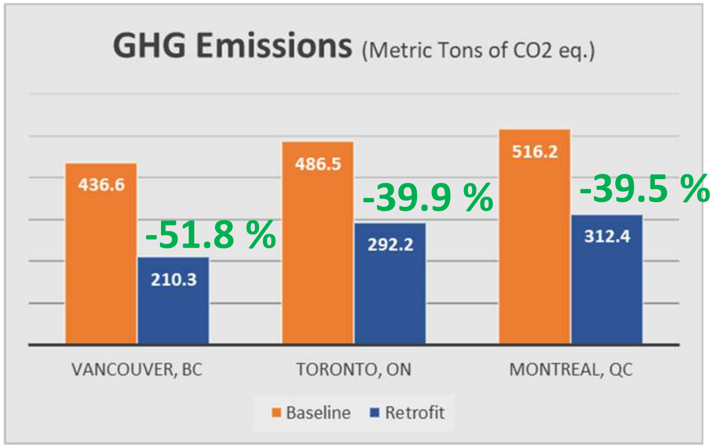
HYBRID 4-PIPE SYSTEM
FUEL SWITCH RETROFIT: ENERGY SAVINGS

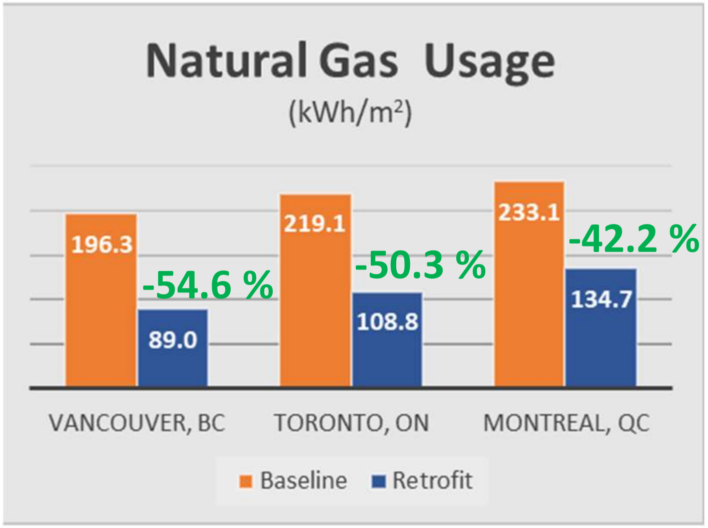
PRE-RETROFIT

	Vancouver, BC	*Toronto, ON*	*Montreal, QC*
Electric Use Intensity [kWh/m2]	174.0	186.8	186.1
Natural Gas Use Intensity [kWh/m²]	196.3	219.1	233.1
Total EUI [kWh/m²]	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/m²]	89.0	108.8	134.7
Total EUI [kWh/m²]	**280.3**	**309.8**	**332.6**

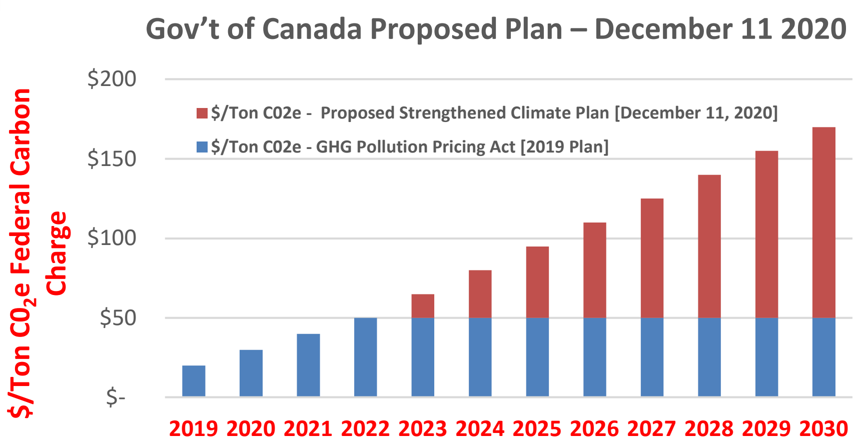




2-PIPE AIR-TO-WATER HEAT PUMPS IN 4-PIPE SYSTEMS HEATING & COOLING SIMULTANEOUSLY

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**

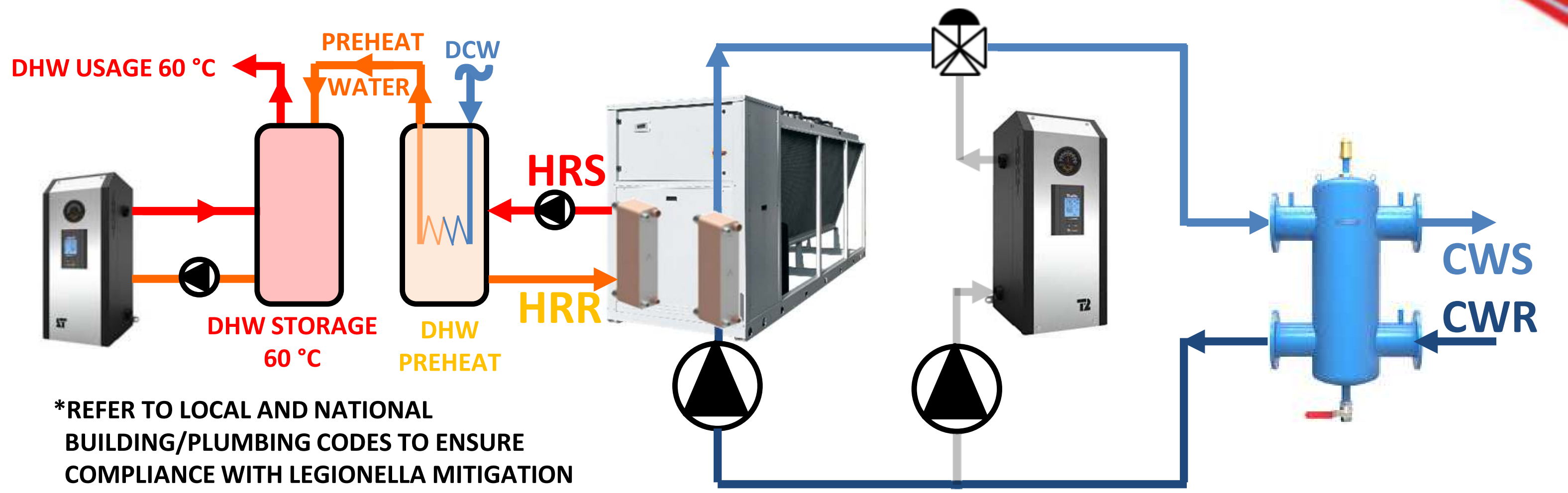


**According to the Plan, if implemented, the Carbon tax will increase by $15/year until it reaches $170/ton by 2030

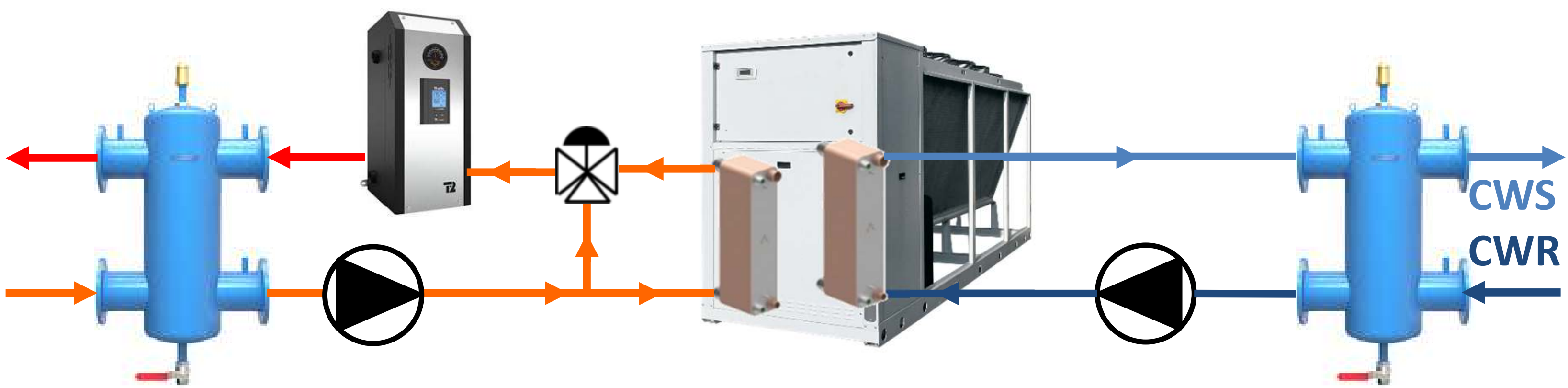
Year	Canadian Federal Carbon Tax* [$/Ton CO_2e]	Vancouver		Toronto		Montreal	
		Annual Savings	Cumulative Savings	Annual Savings	Cumulative Savings	Annual Savings	Cumulative Savings
2021	**$ 40**	$ 9,052	$ 9,052	$ 7,772	$ 7,772	$ 8,152	$ 8,152
2022	**$ 50**	$ 11,315	$ 20,367	$ 9,715	$ 17,487	$ 10,190	$ 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 USING DESUPERHEATER

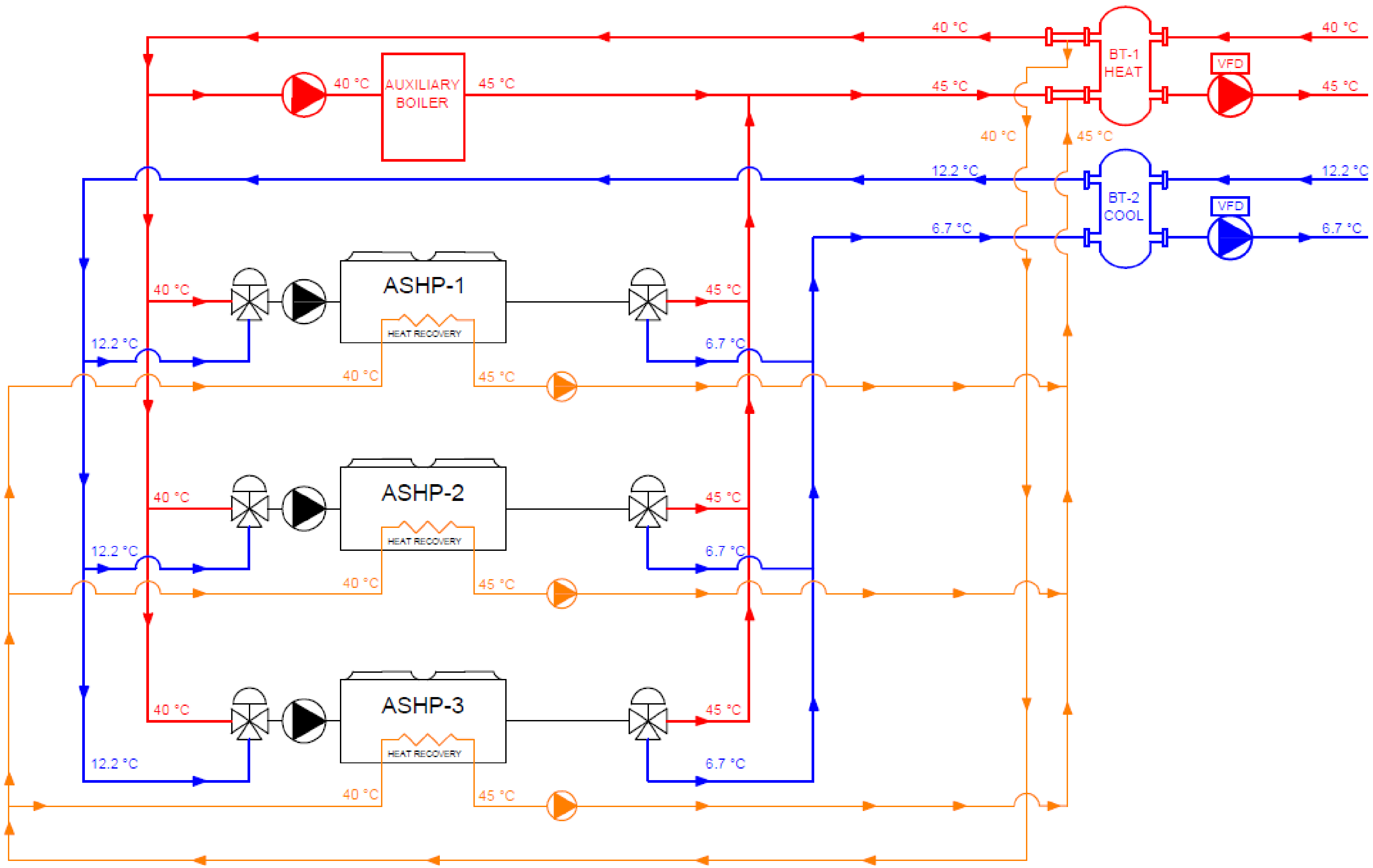
HEAT RECOVERY TO DOMESTIC HOT WATER SYSTEM (2-PIPE SYSTEM)



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



PARTIAL HEAT RECOVERY USING DESUPERHEATER 4-PIPE SYSTEMS



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

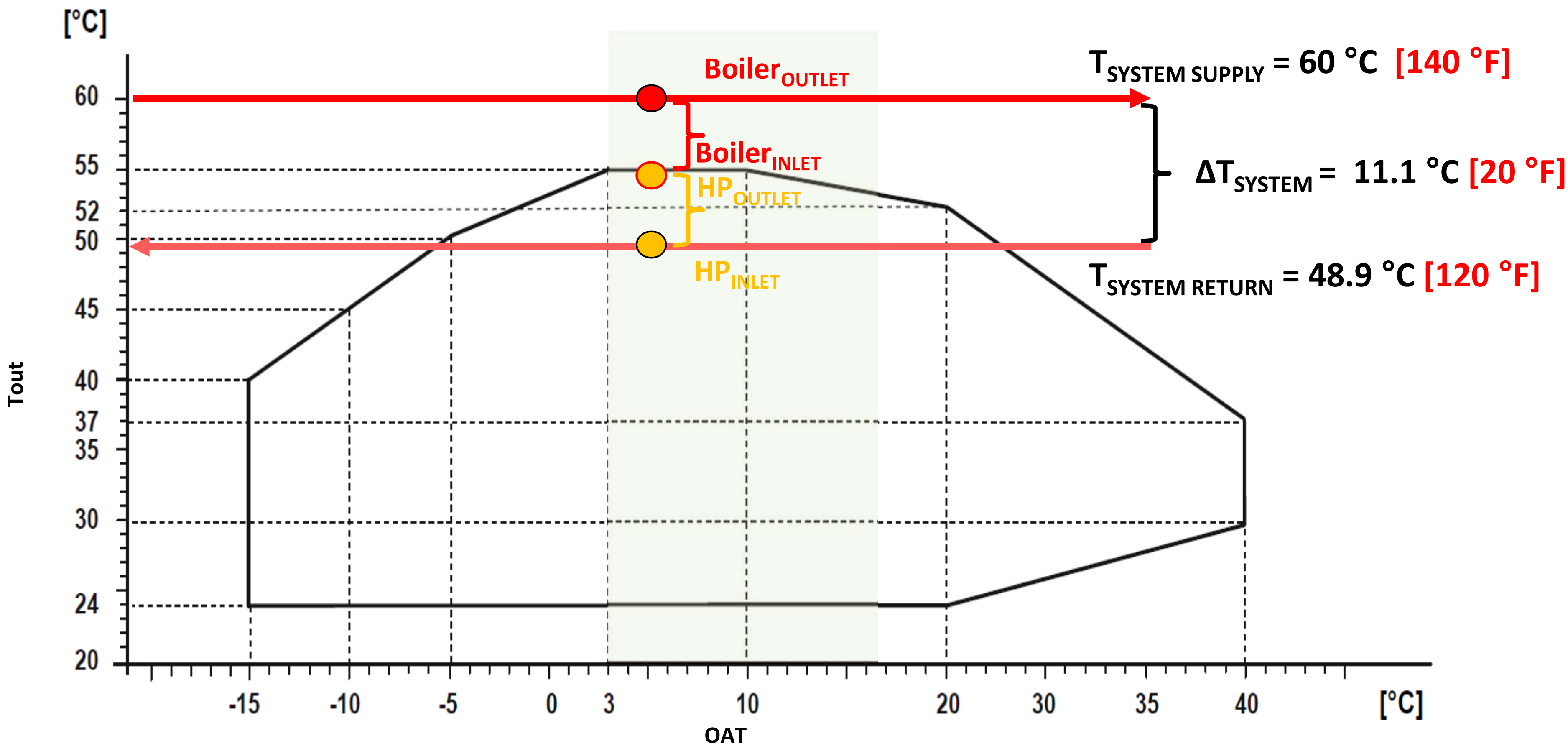
- DUAL FUEL PROVIDES BUILDING RESILIENCY
  - LEVERAGE EXISTING NATURAL GAS INFRASTRUCTURE WHERE IT MAKES SENSE
  - FLEXIBILITY TO MANAGE CARBON FOOTPRINT OR OPERATING COST VIA ENERGY MANAGEMENT STRATEGY
  - TRANSITION TO LOWER EMISSION NATURAL GAS WITH RNG OVER TIME
  - FUTURE PROOFED BUILDING: ATW HP 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?

DESIGN CONSIDERATION: AUXILIARY HEAT

AUXILIARY HEATING IN SERIES:



DESIGN CONSIDERATION: AUXILIARY HEAT

AUXILIARY HEATING IN SERIES: