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Energy-Efficient and Cost-Effective Heat Pump Operations for Commercial Buildings

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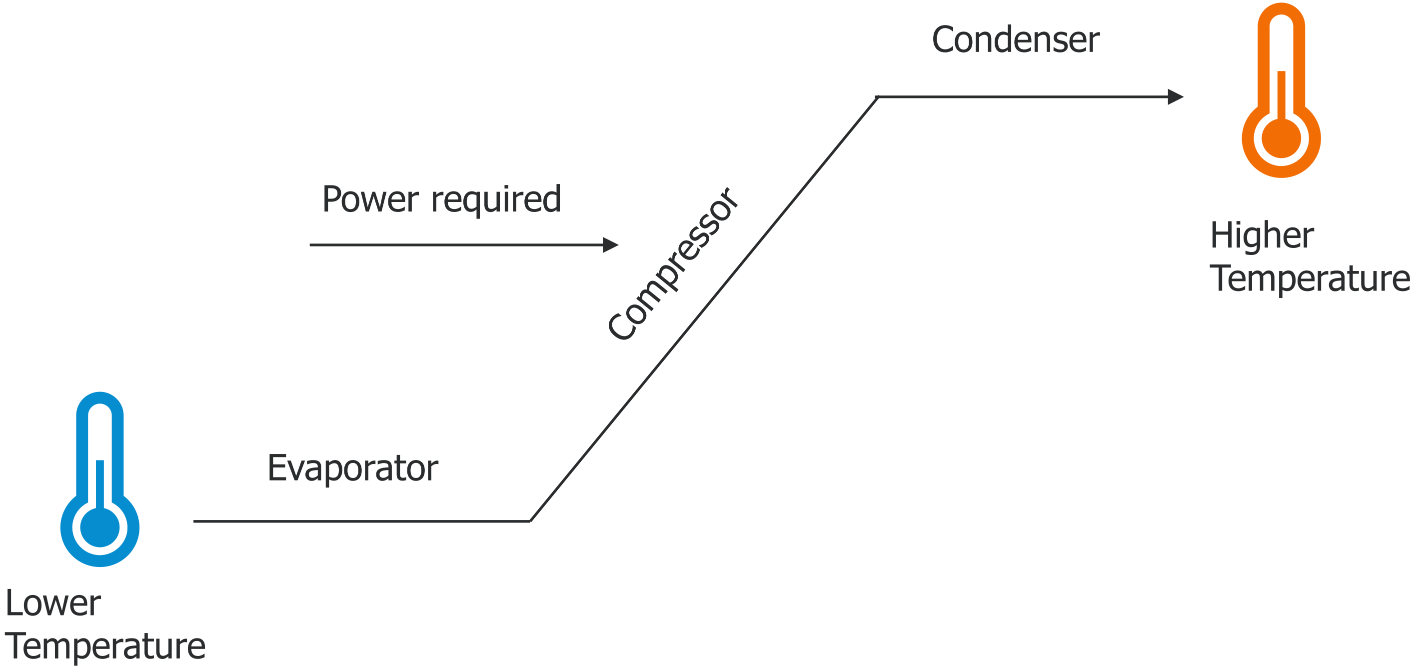
Agenda

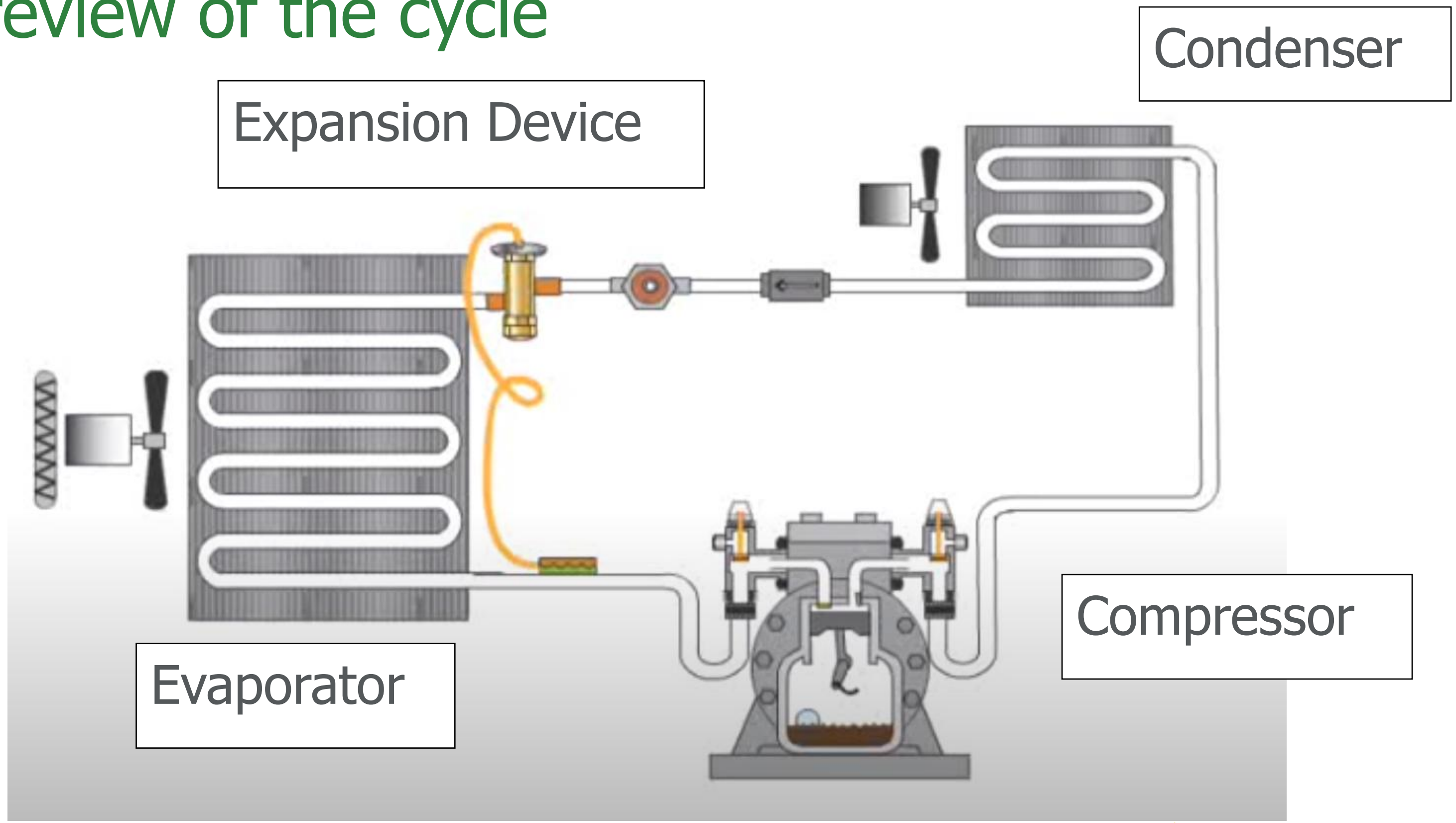
- Heat pump fundamentals
- Type of heat pumps
- Operating heat pump systems efficiently and cost effectively
- Maintenance
- Question and Answer period

Heat Pump Fundamentals

Vapour compression cycle: moving heat uphill

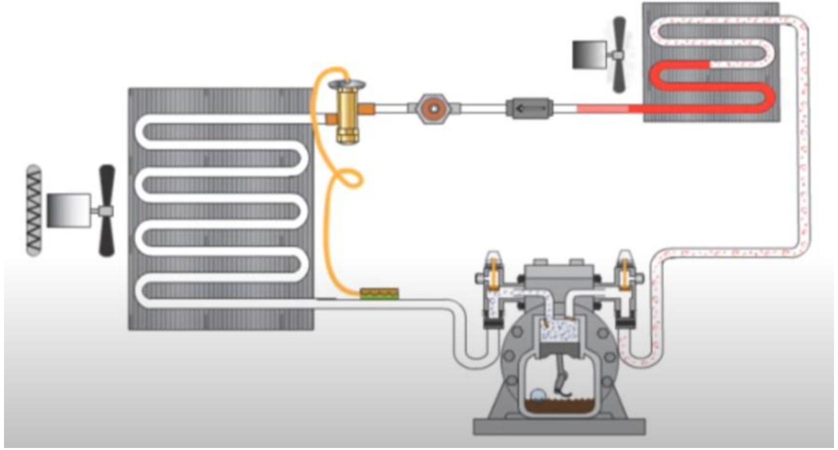


Quick review of the cycle



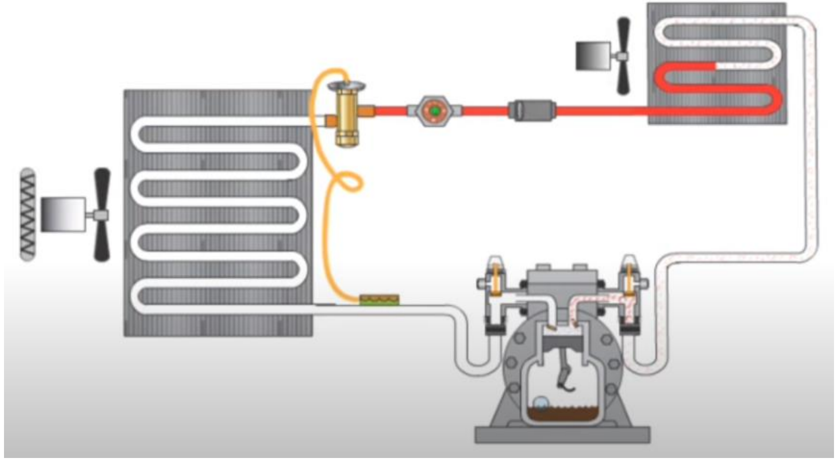
Compression

Hot refrigerant gas is sent to the condenser at high temperature and pressure by the compressor.



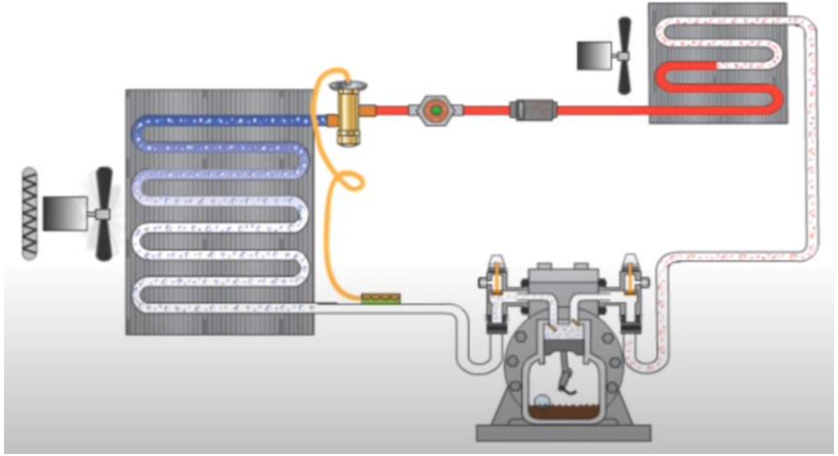
Condensing

The hot gas is turned into high pressure warm liquid at the exit of the condenser.



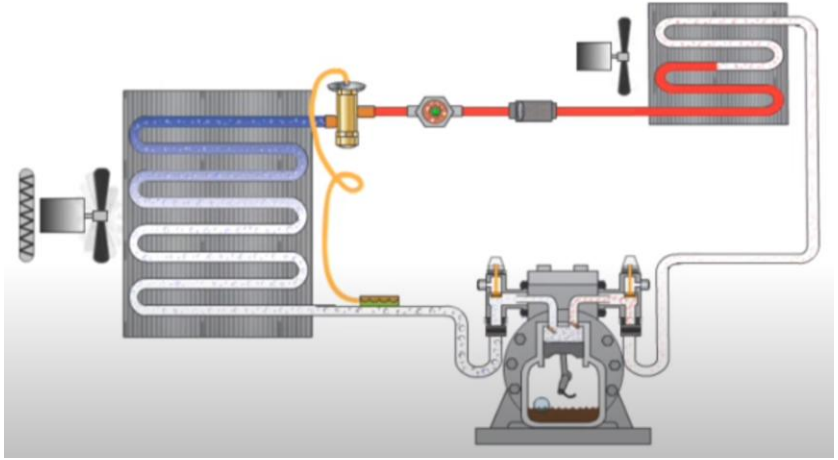
Expansion

The warm high-pressure liquid is pushed through the expansion device and becomes a mixture of low-pressure liquid and gas.

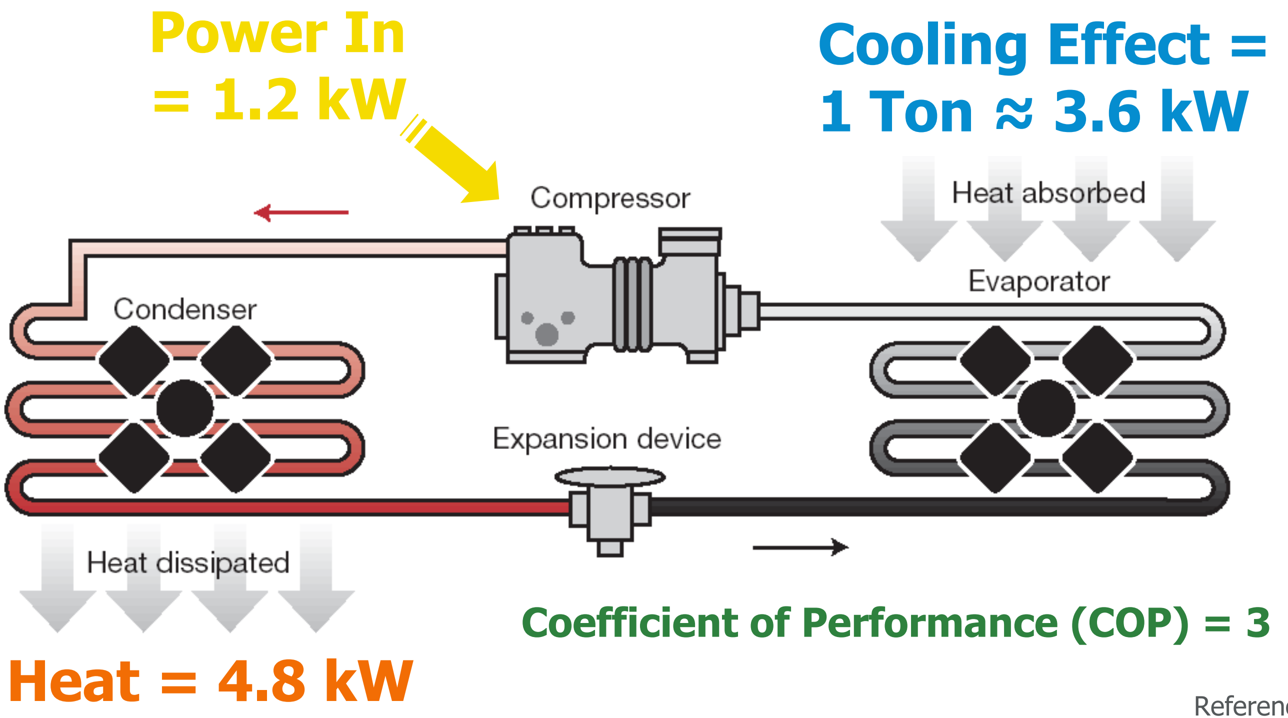


Evaporation

The low pressure and temperature liquid/gas is evaporated, producing cooling and the resulting low-pressure gas is compressed again.



In summary



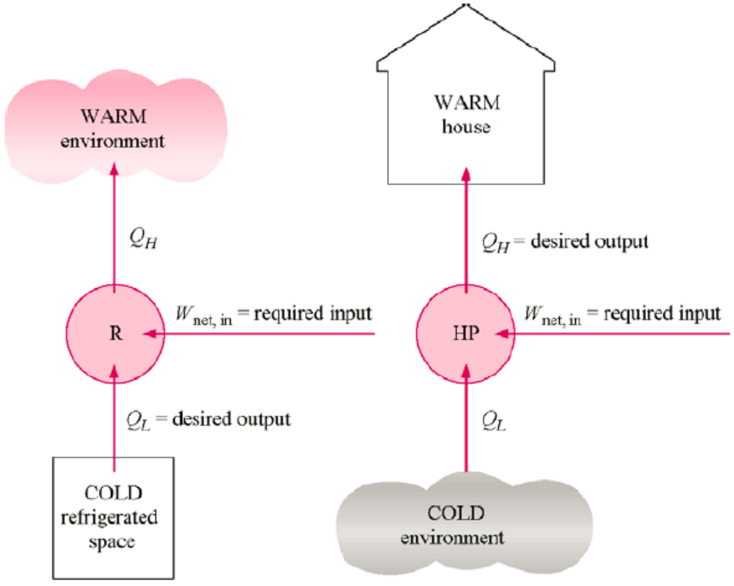
Reference: GPG 279

Coefficient of performance

(Refrigeration (R) and Heat Pumping (HP)

$$COP_R = \frac{\text{Desired output}}{\text{Required input}} = \frac{\text{Cooling effect}}{\text{Work input}} = \frac{Q_L}{W_{net,in}}$$

$$COP_{HP} = \frac{\text{Desired output}}{\text{Required input}} = \frac{\text{Heating effect}}{\text{Work input}} = \frac{Q_H}{W_{net,in}}$$



(a) Refrigerator (b) Heat pump

The Importance of Rates for Heat Pumps

The electricity bill

Sample General Service (greater than 50 kW)

- Customer Charge $ 141/ month
- Distribution Charges * $7.90/kW
- Transmission Charges * $6.82/kW
- Energy Charge (HOEP) variable / kWh
- Regulatory Charges $ 0.0045 / kWh
- Global Adjustment
  - Class B: $0.02 to + $0.12/kWh
  - Class A: based on contribution to Ontario peaks

Demand (Customer, Distribution, Transmission Charges)

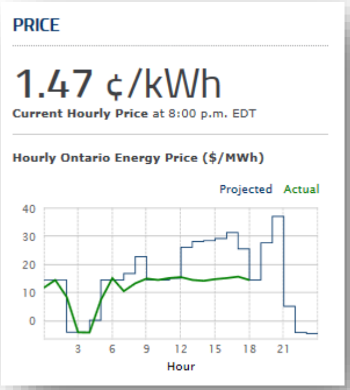
Energy (Energy Charge, Regulatory Charges, Global Adjustment)

*** Delivery = Distribution + Transmission**

- **small, non-demand <50kW users pay for delivery on a kWh basis.**

The incremental price of energy

- Electricity
  - Demand (~ $ 14.70 /kW)
  - Energy (~ $0.10 to $0.12/kWh)
- Natural Gas
  - Supply (~ $ 0.45 /m3)
- What is the incremental cost?
  - The next unit used or saved
  - Important for proper calculations.



Importance of Class A and B for heat pumps

- Impacts the **marginal cost of energy**
  - Class A: marginal cost is HOEP + Regulatory charges
    - Varies with time but often in the order of 0.02 $/kWh to 0.06 $/kWh
  - Class B: marginal cost is HOEP + Regulatory charges + GA
    - Varies but often in the order of 0.09 $/kWh to 0.12 $/kWh

Average Weighted Hourly Price (¢/kWh)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2024	4.33	2.84	2.89	2.91	2.84	3.14	3.77					
2023	3.40	2.36	2.52	2.11	1.75	3.03	4.04	3.14	3.96	3.14	3.04	3.09

2024	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Actual Rate ($/MWh)	45.88	66.32	81.71	74.27	77.63	78.40	63.71				

2023	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	N
Actual Rate ($/MWh)	53.77	82.49	80.31	98.53	99.62	82.93	49.49	76.06	50.93	84.98	7

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Economic evaluations of heat pumps

- Key factors in establishing the economic impact of heat pumps
  - ALWAYS use the marginal energy rate
  - NEVER use the blended or average electricity rate
  - ALWAYS evaluate the peak demand impact, at least on a monthly basis
    - For Class A, look at possible GA hour impact. Not currently significant but this can change!

Example

- 20 Ton heat pump to replace a gas-fired rooftop unit
  - Consider both Class A and B situations - 15% and 35% error with blended rate

Usage and cost prior to the retrofit

	Usage	Class B		Class A	
Natural gas	10,000 m3	$	4,500	$	4,500
Electricity	20,000 kWh	$	2,100	$	800
Peak demand	20 kW	$	1,800	$	1,500
Blended rate		$/kWh	0.19	$ /kWh	0.11

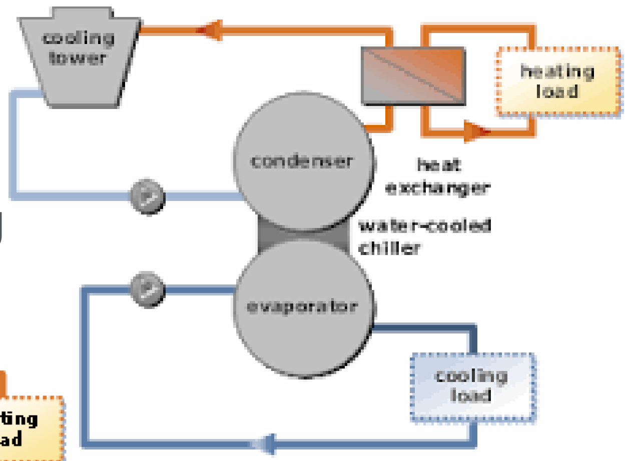
Impact of the retrofit

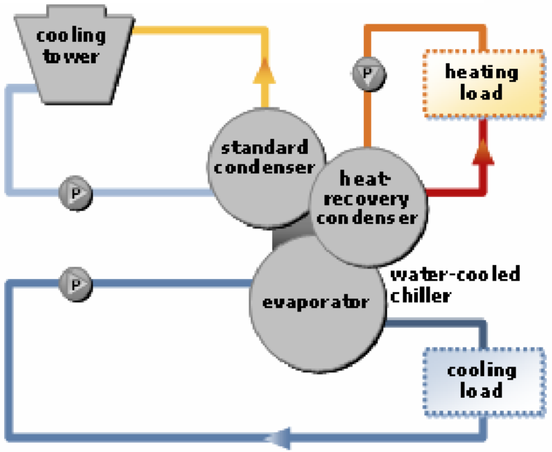
	Class B	Class A
Additional electricity	32,000 kWh	32,000 kWh
Additional winter Peak	20 kW	20 kW
Additional cost		
Blended rate	$ 6,000	$ 3,600
Energy and Demand	$ 5,200	$ 2,600

Type of Heat Pumps

Heat recovery chillers

- Revisiting an old concept
  - Use condenser heat for a low temperature building loop
    - Reheat loop
    - AHU loop
- 2 common configurations
  - Double bundle
  - Auxiliary plate exchanger
- **STOP** using free cooling





Typical application

- Medium to large office and institutional buildings with hydronic heating and cooling
  - Large office buildings
  - Hospitals
  - Large schools/Universities
  - Data centres
  - Large shopping malls
- Presence of low temperature loops

Pros

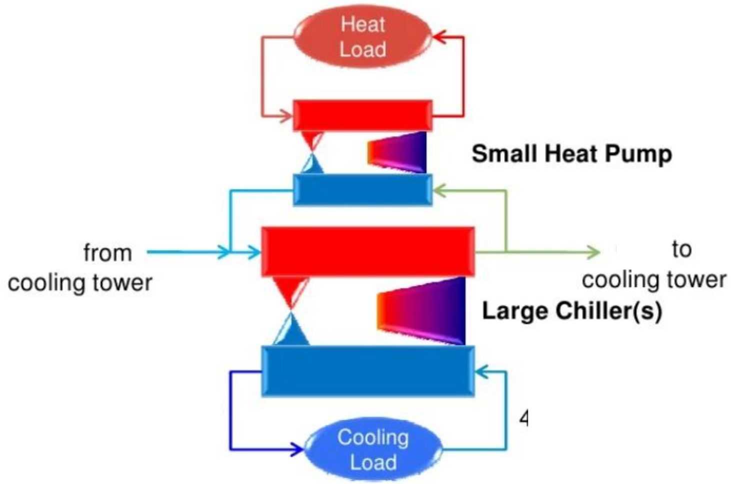
- Retrofit is not too intrusive – can keep the existing distribution system
- Can be used to recover internal heat loads such as server rooms
- Easy to integrate in existing control system

Cons

- Limited in supply temperature, typically around 45 °C , but 60 °C is possible.
- Dependant on the available cooling load during the heating season
- Additional chillers often needed for cooling-only operation

Cascade heat pumps

- Chillers or heat recovery chillers may not provide the temperature levels needed.
- For medium temperature loops, the use of a heat pump to boost the condenser water temperature can be considered.
- A secondary heat pump uses the condenser water from the main chiller to produce even warmer hot water.



Cascade Arrangement

Typical application (2)

- Similar to the heat recovery chillers
  - Requires hydronic loops
- No need for low temperature loops
  - Cooling load during the heating period must be significant

Pros

- Retrofit is not too intrusive – can keep the existing distribution system
- Can be used to recover internal heat loads such as server rooms
- Can provide water typically in the 60 °C to 80 °C range

Cons

- Significant reduction in overall COP of the system
- Higher cost than standard heat reclaim chillers
- Requires a significant cooling load during the heating season

Central air-source hydronic heat pumps

- A true heat pump system providing heating hot water.
- Can be installed in existing boiler plant to replace or supplement existing boilers.
- Does not replace the existing cooling system.
- Always verify the ambient temperature range and supply temperature range.

Hot Water Delivery Temp °F	Nominal Ambient Operating Temperature - °F (Minimum)	
	Refrigerant Listed	
	R410A	R407C
140	46	58
130	40	52
120	34	45
110	26	37
100	15	30
90	3	20
80	-4	13

Metric conversion

Hot Water Delivery Temp °C	Nominal Ambient Operating Temperature - °C (Minimum)	
	Refrigerant Listed	
	R410 A	R407C
60	8	14
54	4	11
49	1	7
43	-3	3
38	-9	-1
32	-16	-7
27	-20	-10

Typical application (3)

- Small to medium commercial building with hydronic heating loops.

Pros

- Retrofit is not too intrusive – can keep the existing distribution system
- Does not rely on internal loads to provide heating
- Applicable to a wide-range of buildings, unlike heat reclaim chillers

Cons

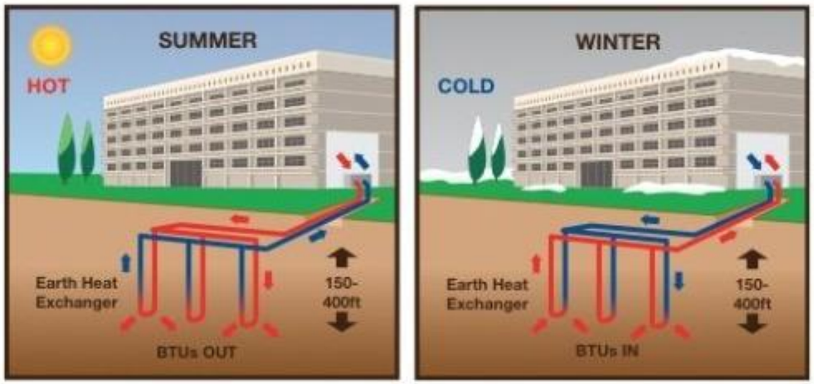
- Does not provide simultaneous heating and cooling, like a heat recovery chiller.
- Loses capacity and efficiency with lower outdoor ambient temperature
- Limited low temperature loops, maximum of typically 60 °C
- Is rarely the only source of heating due to ambient temperature limitations

Central ground-source heat pump (GSHP)

- Very high efficiency system, when well designed.
- A central heat pump, similar to a chiller, is install and provides hydronic heating in the winter and chiller water in the summer.
- The ground heat exchanger is usually composed of a series of vertical wells but can be horizontal trenches for smaller buildings or even open wells.
- Supplemental heating is required for optimal cost of the ground exchanger.

Typical application (4)

Small to large commercial and institutional buildings with hydronic heating and cooling loops.



Pros

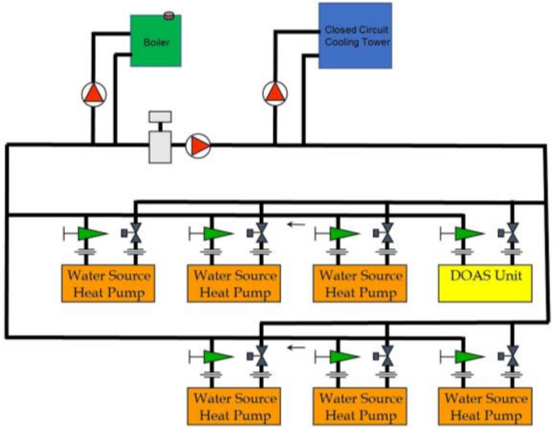
- Can be very high efficiency
- Does not rely on internal loads to provide heating
- Efficiency is not impacted by ambient temperatures
- Can be designed as stand-alone (no supplemental heating), but at a cost.

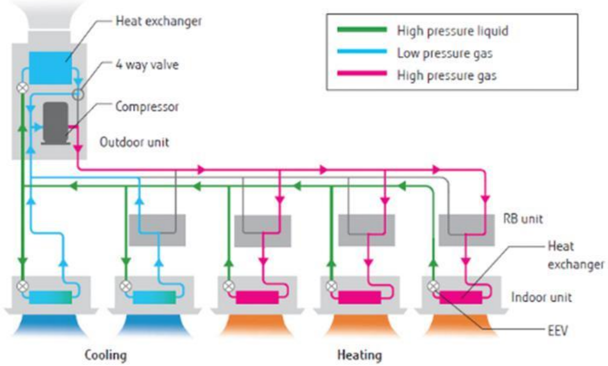
Cons

- One of the more expensive heat pump option
- Requires access to sufficient land area for the wells and is a major undertaking
- Limited to low temperature loops, maximum of typically 55 °C
- Requires a fair balance between heating and cooling loads

Distributed heat pumps

- Water-loop heat pump (WLHP): Heat pumps located throughout the building
  - Can be ground-source, air-source or boiler supplemented, with cooling tower
  - Capital-intensive in a retrofit case
- Retrofit is sometimes done using VRF (variable refrigerant flow) systems for mid-size or small buildings.
  - Two type: heat recovery and heat pump





Typical application (5)

- WLHP
  - Medium to large commercial and institutional buildings with existing water-loop heat pumps
- VRF
  - Small to medium-size commercial buildings
  - No need for a hydronic system

Pros

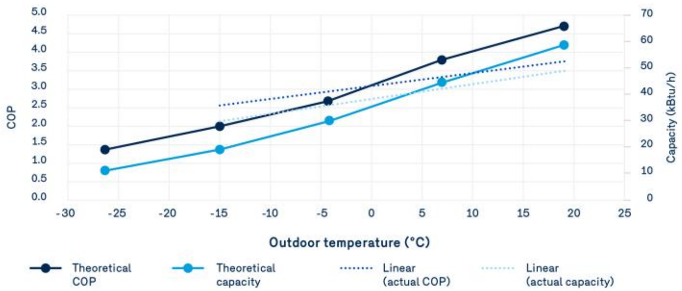
- Ground-source WLHP can be one of the most efficient system
- WLHP and VRFs can recover internal heat loads for useful heating
- VRFs can be retrofitted in a large array of buildings
- Existing WLHP can be converted to gas supplemental to heat pump supplemental

Cons

- More maintenance intensive due to distributed nature of the systems
- Can be difficult to integrate in a BAS, some requires gateway or are not integrable.
- Large amount of refrigerant for VRFs and efficiency drops with length of refrigerant piping

Air-to-air heat pumps and rooftop units

- Very common in smaller commercial applications.
  - Capacity and COP vary with outdoor temperature (OAT).
  - Modern systems can operate to low OAT (e.g. -15 ^{o}C).
  - Almost always associated with a supplemental heating source.
- Mini-split
  - Can be very efficient and low OAT.
  - Controls can be problematic with existing heating.



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Typical application (6)

- Small to large commercial and institutional buildings.
  - No need for hydronic loop
  - Direct retrofit of existing RTUs
- Add-on heating and cooling for specific spaces

Pros
- Easy retrofit, assuming electrical supply is sufficient/available.
- Can provide high efficiency even at low ambient.
- Lower cost the GSHP.

Cons
- Limited in capacity range
- Can be more challenging to integrate in a BAS, particularly mini-splits
- Performance is maintenance dependent (to minimize lift)

Heat pump water heater

- 2 or 3 times more efficient than an electric tank
- Two type
  - Packaged: Uses the room air as a heating source, resulting in a cooling of that space.
  - Split systems: Uses ambient air as a heat source, lower winter efficiency.
- Packaged system are easy to retrofit and have higher efficiency but preferably installed in a space with large heat load (e.g. boiler room).

Efficient operation

Some golden rules

Know your temperature requirements – heat pumps are more efficient at lower supply temperature and have a lower range than boilers.

Always use the lowest possible temperature lift – proper maintenance of coils and heat exchanger is much more significant.

For heat recovery chillers – avoid free cooling as the cooling load is needed to load up the chillers.

Be careful of setback – heat pumps have typically lower capacity and tend to revert to supplemental heating for warmup or can result in a peak demand event.

Integration with a Building Automation System (BAS)

- Don’t let your heat pump be an isolated island!
  - Integration into a BAS, when present, is a must for optimal operation.
- Most large heat pumps can be integrated in the same way as chillers
  - Ensure your model is BACnet compliant.
- Older VRF systems often could not be integrated, newer systems can and should be, sometimes requiring a “gateway”
- For RTUs, on-board controllers offer some functionalities, but integration is highly preferable. BACnet compatibility is again a key benefit.

Managing supplemental heating

- Supplemental heating is often required and can improve the economics and operation of heat pumps.
  - Air-source heat pumps use either central supplemental heating, such as gas-fired RTUs, gas boilers or electric coils.
  - Perimeter heating often play the role of supplemental heating, such as for mini-split but also for some RTUs.
  - Proper control of this supplemental heating is critical to efficient and economical operation of the system.

Optimal hybrid heating operation

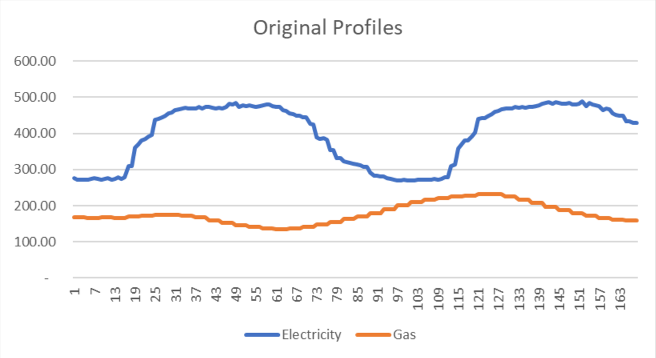
- Typically - gas and heat pump systems
- Both are enabled during the heating season
- The heat pump(s) operates as Lead until the building demand reaches a pre-defined value
  - This value is typically optimized on a monthly basis to minimize the overall utility cost, eventually also for GA.
- Need to track demand in real-time from a BAS that will manage the equipment operation based on demand.

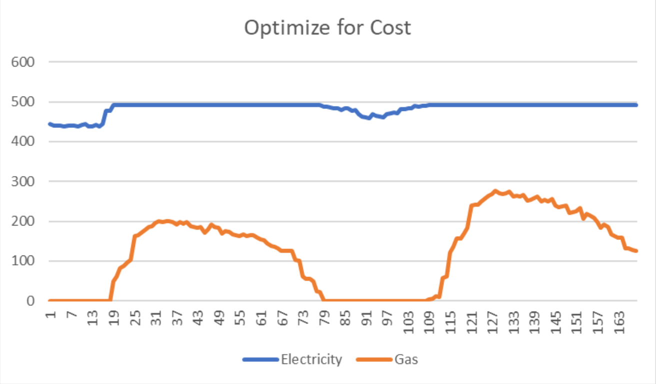
Example of hybrid plant operation

- Electricity profile shows numerous "valleys"
- A hybrid pant could allow filling those valleys by using an electric boiler or heat pump with no increase in monthly (invoiceable) demand

Class	%	Value
GHG Reduction	38%	454 Tons
Gas Reduction	66%	276,000 m3
Electricity Increase	15%	2,160,000 kWh
Cost **Reduction** - Class A	-	$ 45,900
Cost **Increase** - Class B	-	$ 148,000

Using 0.40 $/m3 for gas, marginal cost of energy of 0.03 $/kWh for Class A and 0.12 $kWh for Class B





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Maintenance

- Proper maintenance is even more critical for heat pump systems
  - Their capacity is usually limited due to cost considerations and any reduction in performance will have a direct impact on the benefits
  - The performance and service life of heat pumps is significantly impacted by poor maintenance
    - Higher condensing temperatures will lead to reduced service life and lower COP
    - Lower evaporating temperatures will reduce capacity and COP, and possibly result in comfort issues!

Maintenance, a few things to consider

- **Check air filters monthly**, clean or replace as needed. Helps reduce your lift!
- For outdoor units, **keep the outdoor coils clean**. Keep it clear of snow, ice, and debris. Helps reduce your lift!
- **Keep clearances from all sides** of the heat pump outdoor unit to manufacturer recommendations to allow for proper airflow and servicing.
- During **annual checkup**, if air flow problems are indicated, adjust air flow volume as necessary to match manufacturer's rated air flow for the unit during the cooling and/or heating mode.

Maintenance considerations, cont’d

- Ensure any flow modulation at part load is within manufacturer’s specifications.
- For hydronic loops, check the temperature difference and ensure adequate flow to individual heat pumps (WLHP). Frequent tripping of a unit could be indicative of improper flow or dirty filter.
- Check refrigerant levels periodically.
- Check the condensate drain annually by cleaning and flushing to insure proper drainage.
- Checking thermostat sensors and functionality – when baseboard are used as supplemental heating, verify periodically that their set point is below that of the heat pump (heating mode).
- Inspecting and repairing duct leaks – due to more limited capacity, air leakage is very detrimental for heat pumps.

Q&A

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