FACT SHEET

HEAT PUMP TECHNOLOGIES

This fact sheet provides an overview of heat pump technologies, including air-source, water-source, and variable refrigerant flow systems, and offers key performance metrics to consider when using this technology. The document also discusses the challenges to be aware of when using the technology, along with opportunities for energy reduction.

What Is a Heat Pump[1]?

A heat pump is a technology that uses gas compression to transfer (pump) heat from one side of the system to the other. A heat pump consists of a compressor, an evaporator coil, a condenser coil, and an expansion valve. Using these components, it utilizes a vapour compression cycle to extract heat from a source and transfer it to a sink by circulating a refrigerant through a low-pressure evaporator and a high-pressure condenser, as illustrated in *Figure 1*. Heat pumps are used in buildings to efficiently provide space heating, cooling, and hot water heating.

In a heating cycle, the evaporator coil of the heat pump extracts heat from the source (typically outdoor air or water loop) and transfers it to the refrigerant, thereby changing the refrigerant state from liquid to gas (i.e., evaporation). The compressor then compresses the refrigerant, increasing its pressure and temperature. The heat from the high temperature refrigerant is then transferred through the condenser coil to the heat sink (typically indoor air, or water loop) as the refrigerant changes from gas back to liquid (i.e., condenses). The expansion valve then drops the pressure and temperature of the refrigerant allowing it to repeat the cycle.

In a cooling cycle, a reversing valve is utilized to reverse the refrigeration cycle, thereby allowing evaporation and condensation to happen in the opposite coil.

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[1] This fact sheet deals only with electrically driven mechanical compression heat pumps, which is the most common technology. It does not cover other technologies such as, for example, natural gas-fired heat pumps.

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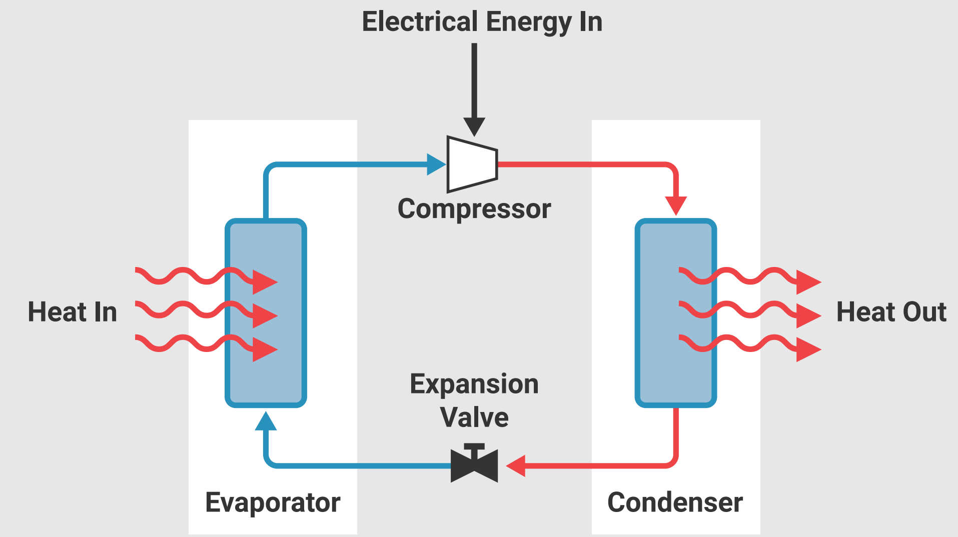

Figure 1: Heat Pump Cycle

Heat Pump Classification

Heat pumps are classified based on the heat source and sink utilized. The most common types of heat pumps found in commercial buildings are:

1. **Air-to-Air** Heat Pumps - extract heat from ambient outdoor air and transfer it to indoor air for heating.
2. **Air-to-Water** Heat Pumps – extract heat from ambient outdoor air and transfer it to a hydronic loop.
3. **Water-to-Water** Heat Pumps – extract heat from a water source (e.g., geothermal, heat recovery unit) and transfer it to a hydronic loop.
4. **Water-to-Air** Heat Pumps (i.e., distributed water-source heat pumps) – extract heat from the main hydronic loop and utilize air for space heating.
5. **Variable Flow Refrigerant (VRF)** Heat Pumps - vary the flow of the refrigerant to distributed indoor units based on heating/cooling demand. These heat pumps can be of different types in terms of their source and sink.

Performance Metrics[2]

Multiple performance metrics are used to express the amount of heating or cooling a heat pump can provide compared to the energy it consumes. It is important to understand these metrics when comparing different systems, or to measure performance of a system over time.

Coefficient of Performance (COP)

Coefficient of Performance (COP) is the ratio of thermal energy output to the electrical energy needed to run the compressor at specific source and sink temperatures. Hence, the higher the COP, the more efficient the heat pump. For air-source heat pumps, as the outdoor air temperature drops, the COP value decreases due to the increased work required by the compressor to evaporate the refrigerant.

Seasonal Energy Efficiency Ratio (SEER)

Seasonal Energy Efficiency Ratio (SEER) measures the cooling efficiency throughout a typical cooling season. It is determined by dividing the total cooling provided over the cooling season, expressed in Btu (British thermal unit), by the total energy used during the time, expressed in watts-hours (Wh). Similar to the COP, the higher the SEER the more efficient the heat pump.

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[2] The following link defines different terms regarding heat pump performance: Heating and Cooling With a Heat Pump (Canada.ca)

Energy Efficiency Ratio (EER)

Energy Efficiency Ratio (EER) measures the steady-state cooling efficiency of a heat pump and is determined by dividing the cooling capacity, expressed in Btu/h, by the electrical energy input in watts at a specific temperature. Again, the higher the EER, the more efficient the heat pump.

Kilowatt per Ton (kW/ton)

Kilowatt per Ton (kW/ton) is the ratio of electrical energy input in kilowatts (kW) to cooling provided (i.e. heat recovered) in tons. In this case, the lower the ratio, the better.

Heating Source Efficiency and Emission Comparison

Heat pumps use less energy input for the same heat output when compared to gas-fired and electric resistance heating sources. Heat pump efficiency varies depending on the source temperature and the load conditions. Table 1 presents an equipment performance comparison. While heat pumps can reduce greenhouse gas (GHG) emissions, the emissions associated with the electricity used depends on the region's and/or utility's electrical grid GHG intensity. For example, heat pumps installed in the provinces of British Columbia, Manitoba, and Quebec, where most of the electricity is sourced from hydroelectric power, will have a greater impact on GHG emissions reductions than heat pumps installed in Alberta and Saskatchewan.

Table 1: Heating Source Efficiency Comparison

Heating Source	COP	Seasonal Efficiency
Oil or Gas-Fired	<1	50-95%
Electric Resistance	1	100%
Air-Source Heat Pump	1.5-3.5	150-350%
Water-Source Heat Pump	2.5-4.5	250-450%

It is also important to consider the impact of the defrost cycle on heat pump performance. Outdoor evaporator coils will develop ice buildup during certain conditions, and a defrost cycle is required to melt the ice so the heat pump can continue to operate. This is done automatically by many units but comes at an energy penalty during the defrost cycle itself. When comparing performance metrics between different systems, it is important to know whether the COP or other rating includes an allowance for defrost cycle impact.

Air-Source Heat Pumps

An air-source heat pump (ASHP) extracts heat from outside air during the heating season and rejects heat outside during the cooling season. ASHPs can be classified as air-to-air or air-to-water heat pumps based on the heated sink (hydronic or air).

Air-to-Air Heat Pumps

In heating mode, an air-to-air heat pump extracts heat from the outside air with the evaporator coil and transfers the heat to the indoor coil (i.e. the condenser coil) located in HVAC units such as air handlers and fan coil units. The supply air is heated by passing over the coil before being distributed via ductwork to different spaces. In cooling mode, the process is reversed, and heat is extracted from the spaces being served and rejected outside.

Air-to-Water Heat Pumps

The same concept of extracting heat from outdoor air is used for air-to-water heat pumps. However, air-to-water heat pumps deliver useful heat into a hydronic system instead of air passing through the condenser coil.

Commercial air-to-water heat pumps are commonly available as 2-pipe and 4-pipe systems. 2-pipe air-to-water heat pumps are designed to provide only heating or cooling while 4-pipe heat pumps are able to provide heating and cooling simultaneously. The latter targets buildings where the requirement for both heating and cooling exists year-round.

Water-Source Heat Pumps

A water-source heat pump (WSHP) extracts heat from a water source (e.g. geothermal, main hydronic loop, heat recovery loop) and can be classified as a water-to-water or water-to-air heat pump.

Water-to-Water Heat Pumps

Water-to-water heat pumps extract heat from a source of water and transfer it through a heat exchanger to a central hydronic heating system. These heat pumps can extract heat from a ground source or exhaust air.

In ground source systems, a heat transfer fluid is circulated through a closed or open loop that is buried in the ground or a body of water to extract and reject heat. A heat exchanger transfers heat between the ground source and the heat pump loops.

Alternatively, heat may be recovered from general exhaust fans equipped with heat recovery coils. This heat can be recovered and transferred to the source side of the water-source heat pumps. These systems can be coupled with one or more boilers for supplementary heating to maintain loop temperatures.

Water-to-Air Heat Pumps (Distributed WSHPs)

Water-to-air heat pumps (i.e. distributed WSHPs) are typically independent, packaged systems distributed throughout a building, each with a reversing valve, allowing them to operate in either heating or cooling mode. Distributed water-source heat pumps are typically paired with a boiler and a cooling tower, or a geo-exchange field for supplementary heating and heat rejection in a hybrid sys-tem. The distributed WSHPs are connected to a common hydronic distribution system.

Buildings with simultaneous heating and cooling loads are well suited for a water-to-air heat pump system. Heat pumps in heating mode extract heat from the hydronic loop, while heat pumps in cooling mode reject heat to the hydronic loop. In this manner, a WSHP system provides a form of heat recovery and reduces the need to operate the boiler(s) or cooling tower(s).

Variable Refrigerant Flow (VRF)

Variable Refrigerant Flow (VRF) systems are ductless air-source or water-source heat pumps, which distribute heat directly through the refrigerant loop. Moreover, unlike traditional HPs, VRF systems vary the flow of refrigerant to indoor units based on heating/cooling demand.

In a VRF system, multiple indoor fan coil units are connected to an outdoor unit. The outdoor unit is equipped with one or multiple compressors that vary their speed to vary the refrigerant delivered. This allows the unit to adjust energy consumption based on heating and cooling needs, making it a more efficient system when compared to typical air-source heat pumps.

VRF systems are available as either heat pump systems (2-pipe) or heat recovery systems (3-pipe). A VRF heat pump system provides either heating or cooling as required. However, a VRF heat recovery system is utilized for applications where simultaneous heating and cooling are required, as illustrated in *Figure 2*. This allows heat to be transferred from one zone to another through the refrigerant loop with limited compressor energy use.

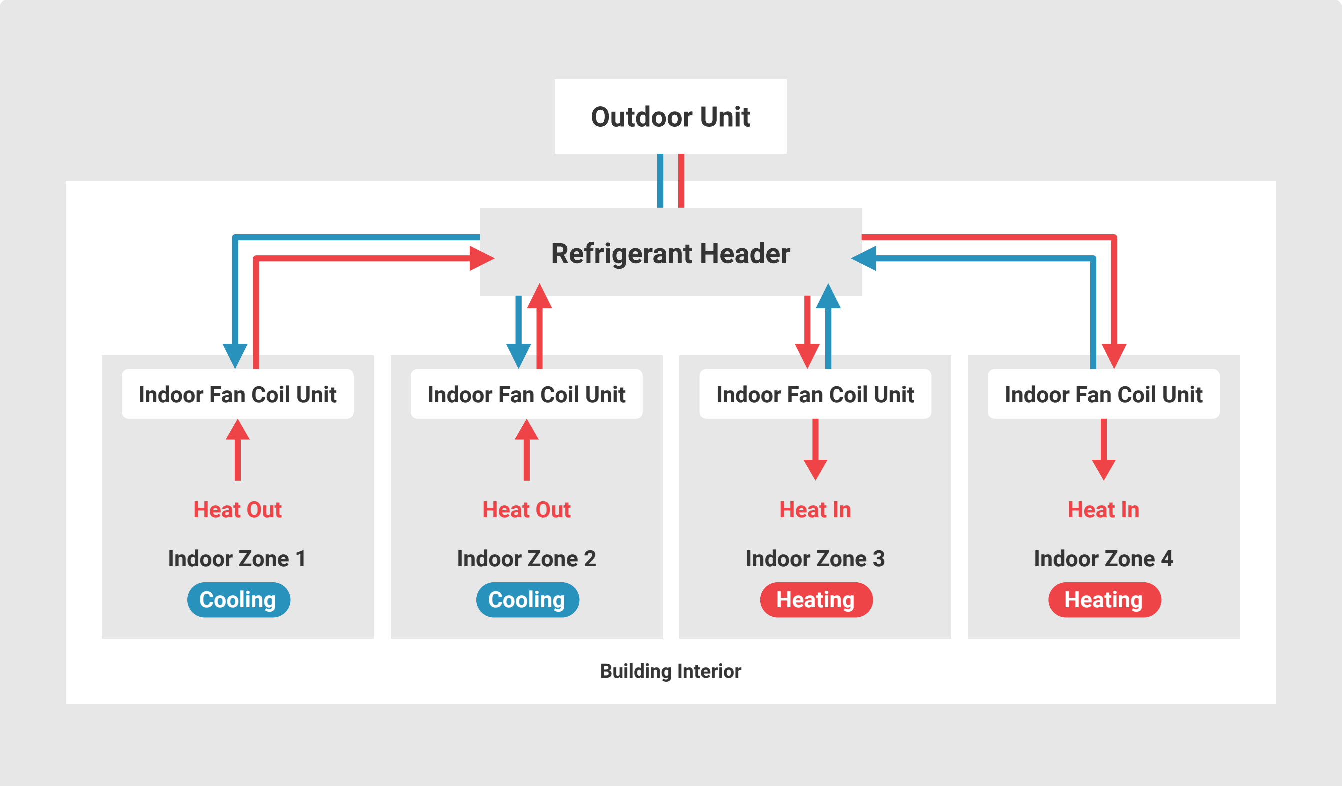

Figure 2: VRF Heat Recovery System Schematic

Considerations for Tuning Up Existing Heat Pump Systems

This section provides a summary of the various tune-up opportunities for existing heat pump systems, as well as insights into some of the challenges encountered during the commissioning of heat pump installations.

Air-to-Water and Water-to-Water Heat Pumps

System Performance vs Outdoor Air Temperature

As outdoor air temperatures decrease, the heating capacity of an air source heat pump decreases. As heat pump capacities drop, a supplemental heating source (e.g. gas-fired or electric resistance) may be required. Commercially available heat pumps often cannot maintain a constant supply water temperature. To maximize heating from the heat pump, supplemental heating must be controlled to maintain water temperatures that are below the supply water temperature of the heat pump.

Through functional testing and manufacturer's literature, the lowest temperature at which the heat pump can reliably supply water is able to be determined. The supplemental heating source(s) can then be configured to heat water at this lowest heat pump leaving temperature, ensuring that the heat pump contributes as much as possible to overall heating. Otherwise, considering the heat pump supply temperature swing (i.e. temperature threshold within operating limits), the supplementary system may take over and limit the chance of the heat pumps to provide heating. It is important to understand that heat pumps typically cannot maintain a constant supply temperature, and if the boilers are set to the same setpoint, the heat pump will likely fail to operate in priority.

Through a functional test, the heat pump lockout temperature setpoint (i.e. the outdoor air temperature limit that prevents the operation of the heat pump below this temperature) can be determined when the supplementary heating is disabled, and the supply temperature can be maintained. The boiler setpoint temperature must then be set so as to take over only when this limit is reached by the heat pump.

Operating Temperatures

Heat pump systems operate more efficiently when building heating water temperatures are as low as possible (i.e. below 50°C), and as such are more efficient when paired with a low temperature hydronic system. Therefore, operating temperature requirements in a hydronic system are critical when evaluating heat pumps' potential. Heat pumps cannot operate consistently and effectively if the heating system requires it to operate to its limit. For example, if the maximum heat pump supply temperature is 50°C, the acceptable temperature swing should be at least 5°C, and the heating system should be able to be satisfied at 45°C.

If a heat pump is used in conventional hydronic systems with temperatures above 50°C, the heat pump is not likely to operate in its safe temperature range, resulting in premature failure. In addition, most commercially available heat pumps specify return water temperatures below 45°C. Hence, heat pumps may fail to operate efficiently if return water temperatures are higher.

It is always recommended to perform a test to observe how the building operates with lower supply water temperatures prior to installing a heat pump system.

Alternatively, a potential solution is decoupling high temperature loads from low temperature loads or major loads that can be retrofitted to low temperature. In this case, high temperature loads can be supplied by a dedicated boiler or high temperature heat pump. This will allow the main loop temperature to remain lower within the main heat pump's operating conditions.

Air-to-Water Heat Pumps

Ambient Outdoor Temperature Lockout

In a hybrid heating system using natural gas or electric heat as backup to the heat pump, air-source heat pumps are typically controlled to lock out well above their design temperatures. This method of control does not fully utilize the heat pump's potential. In this case it is recommended that the control strategy be revised to remove the ASHP temperature lockout as it limits the heat pumps' ability to provide heating, while prioritizing the supplemental heating source. Air-source heat pumps can operate well below the typical lockout temperatures if the main loop heating temperatures are well within their operating range. This can be confirmed through a functional test.

Distributed Water-Source Heat Pumps

Demand Limiting

To minimize electrical demand during morning warm-up, distributed heat pumps can be staggered on rather than all coming on at the same time. One control strategy to achieve this is to enable heat pumps in the morning based on the deviation from setpoint of the respective zone. Zones that are further away from setpoint (i.e. cooler) will have distributed heat pumps turn on sooner, and zones that are close to setpoint (i.e. warmer) will turn on later.

Loop Temperature Control

There is an opportunity to save energy by reducing the need to operate the boiler(s) and cooling tower(s). A loop temperature control strategy resets the loop temperature setpoint to minimize the combined energy consumed by the heat pumps, boiler(s), and cooling tower(s) based on operating conditions.

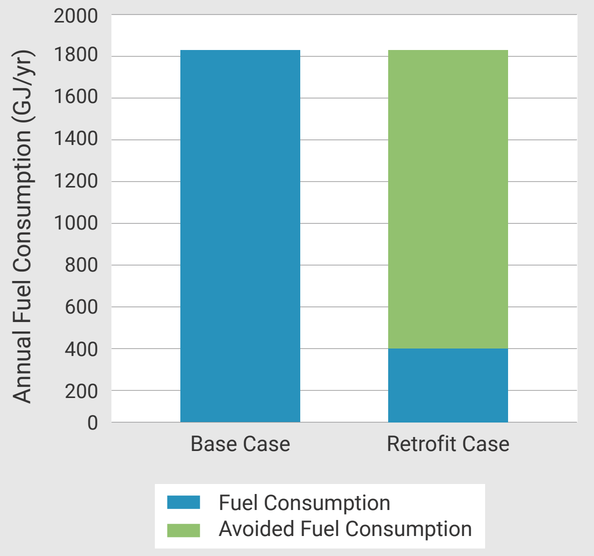

Figure 3: Energy Savings Potential from Reducing Supply Water Temperatures

Variable Refrigerant Flow (VRF) Heat Pumps

Direct Digital Control (DDC) Integration

Variable Refrigerant Flow (VRF) heat pump systems are typically equipped with their own propriety controllers and are not controlled by a centralized DDC system. However, it is recommended to integrate the VRF system controller through a common protocol (e.g., BACnet) to provide feedback such as status and alarm to the DDC system, providing better insight into system performance and operation. In addition, the integration allows for ensuring that setpoints, and schedules remain appropriate.

CASE STUDY: Hybrid Heat Pump System

Heating in a commercial building located in British Columbia's Lower Mainland is provided by a district energy system (DES) and a 4-pipe air-source heat pump.

The air-source heat pump is designed to provide primary heating and cooling, supplemented by the DES. The heat pump can also operate in heat recovery mode, recovering heat from the chilled water to the heating water. However, following a trend analysis it was observed that the 4-pipe air-source heat pump had never operated in heating mode.

The following observations were made as to why the air-source heat pump had limited operation:

- The main loops' supply-water temperature exceeded the air-source heat pumps' operating range.
- The operating-mode control strategy of the air-source heat pump lacked consideration of potential short cycling and its impact on limiting heat pump capacity.

The building's terminal heating coils were designed for high entering-water temperatures of 60°C. However, trends showed a low delta-T during peak heating season, less than design, suggesting the building can operate with lower heating water temperatures year-round.

Therefore, under design conditions, the existing heat pump could in fact serve the building's heating loads without the supplementary heating from the DES. However, the high supply water temperature had prevented the heat pump from operating properly. By reducing the supply water temperatures, the air-source heat pump can now provide first-stage heating as intended and eliminate unnecessary heating from the DES. Energy savings calculations demonstrate a 79% reduction in annual natural gas use.

Key Takeaways

- Operate air-source heat pumps within their ambient air temperature operating range to maximize available capacity and reduce heat provided by supplementary heating sources.
- Reduce main hydronic loop supply water temperatures to ensure heat pumps operate within their reliable operating range.
- Revise control strategies to properly sequence the supplemental heating source to maintain the heat pump's ability to provide first-stage heating.

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