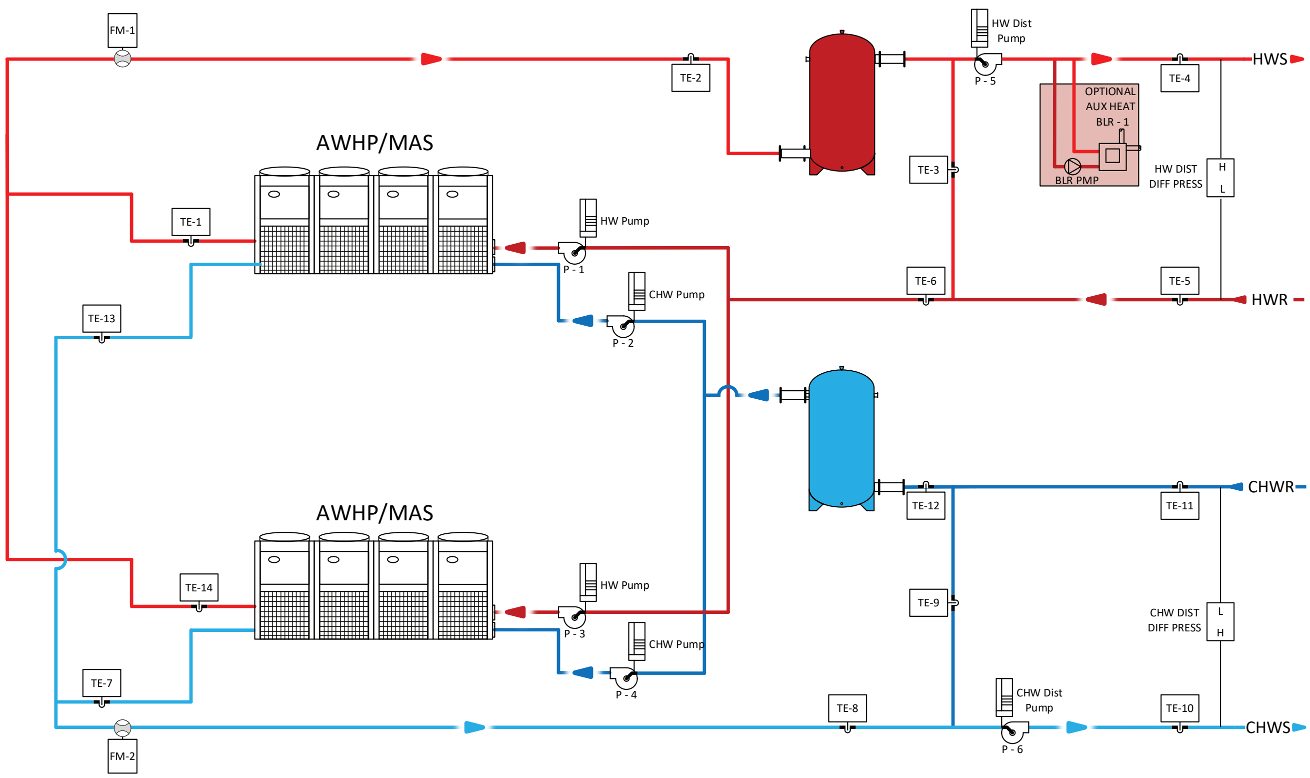
Application Guide

Thermafit™ Modular (AXM/MAS) Air-to-Water Heat Pump System

Part of the Comprehensive Heat Pump Chiller Systems



⚠SAFETY WARNING

Only qualified personnel should install and service the equipment. The installation, starting up, and servicing of heating, ventilating, and air-conditioning equipment can be hazardous and requires specific knowledge and training. Improperly installed, adjusted or altered equipment by an unqualified person could result in death or serious injury. When working on the equipment, observe all precautions in the literature and on the tags, stickers, and labels that are attached to the equipment.

February 2026

APP-APG021B-EN

Preface

As a leading HVAC manufacturer, we deem it our responsibility to serve the building industry by regularly disseminating information that promotes the effective application of building comfort systems. For that reason, we regularly publish educational materials, such as this one, to share information gathered from laboratory research, testing programs, and practical experience.

This publication focuses on modular air-to-water heat pump hydronic systems. It discusses system design considerations and options, piping and airside considerations, and system operation and control.

We encourage engineering professionals who design building comfort systems to become familiar with the contents of this guide and to use it as a reference. Architects, building owners, equipment operators, and technicians may also find this publication of interest.

Trane has a policy of continuous product and product data improvements and reserves the right to change design and specifications without notice. As such, all data in this application guide should be considered for reference only, please consult with a Trane® sales associate for current equipment operating ranges and performance.

Table of Contents

Introduction to Modular Air-to-Water Heat Pump Systems

Modular air-to-water heat pump (AWHP) systems use air as the heat source and sink. They can be used to provide efficient, scalable, and redundant solutions for heating and cooling in various building applications. These systems are adaptable, integrating multiple modules and module banks, managed by system controls to meet specific load requirements.

Trane offers both two-pipe and four-pipe modular units which can be integrated together into a heat pump chiller system. This offers flexibility through hydronic parallel operation, enabling additional modules to activate as needed to meet load demands.

- Trane's **Thermafit™ AXM model**, a two-pipe modular heat pump, operates in either cooling or heating mode, but not both simultaneously. AXM modules include dual refrigeration circuits and a single brazed plate heat exchanger that switch roles based on the mode.
- Conversely, the four-pipe (or multi-pipe) **Thermafit™ MAS model** includes a single refrigeration circuit and two brazed plate heat exchangers in each module, so it can provide simultaneous cooling and heating from a single bank.

This guide presents various system configurations for modular air-to-water heat pumps, emphasizing heating- or cooling-dominant solutions that reduce complexity and installation costs while maintaining high efficiency. It describes several configurations for the AXM two-pipe heat pump, including a base system with two or more AXM module banks to enable simultaneous heating and cooling. It also covers cooling-only, heating-only, and simultaneous heating and cooling modes using the four-pipe MAS heat pump, as well as combined systems consisting of heat pumps and chillers. Additionally, it compares the AXM and MAS systems, highlighting their unique features and operational benefits. Lastly, this guide provides technical specifics, including system and unit sizing, modes of operation, auxiliary heat, and pumping control strategies to equip designers with the knowledge required for informed decision-making during system design.

Understanding Modular Air-to-Water Heat Pumps

Modular air-to-water heat pumps (AWHPs) are versatile and efficient solutions for providing both heating and cooling in various applications. These heat pumps are designed to be scalable, allowing multiple modules and banks to be integrated into a single system to meet the specific load requirements of a building. A bank consists of individual modules managed and controlled by a primary controller to provide heating and cooling. Multiple banks can be independently controlled by a BAS.

Trane offers both two-pipe and four-pipe modular AWHP units. Understanding the differences between them is critical for selecting the right product for your system.

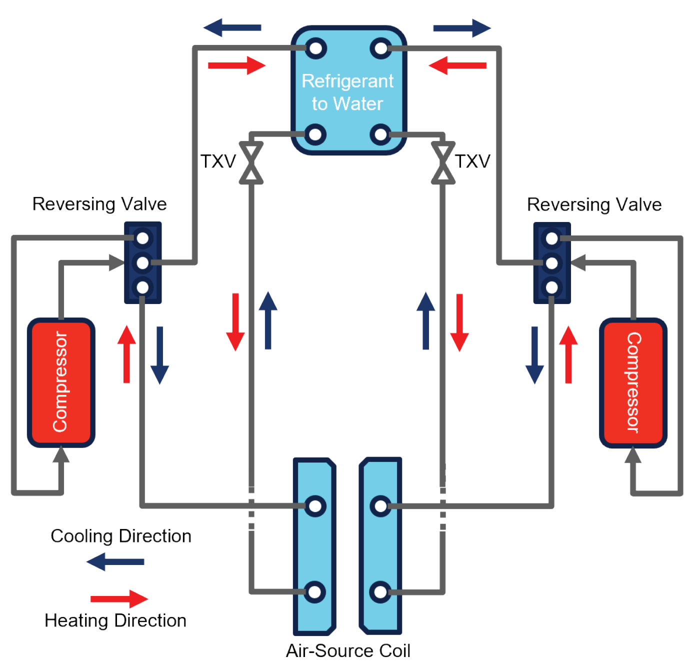
Individual heat pump modules within a bank operate in parallel and are piped together with an integral hydronic header. When the operating modules in a single bank can no longer meet the building load, additional heat pump modules will be brought online. In the case of four-pipe units, modules may change modes to provide the needed heating or cooling capacity.

For the full sequence of loading and unloading modular units within a bank, refer to the product's Installation, Operation, and Maintenance (IOM) manual.

Two-Pipe Modular Heat Pumps (AXM)

A bank of two-pipe modular heat pumps, such as Trane's Thermafit™ AXM model, can operate in either cooling or heating mode, but not do both simultaneously. All modules within the bank operate in the same mode, cycling based on the cooling or heating load. Each module includes dual refrigeration circuits and a single refrigerant-to-water brazed plate heat exchanger, which functions as either an evaporator or a condenser depending on the operating mode (Figure 1).

Figure 1. Refrigerant flow schematic of a two-pipe AWHP (single module with two refrigeration circuits)



Key Features of the Trane AXM

Trane model AXM units are available with the following features (Figure 2 (p. 4)):

- **Modular, packaged heat pump configuration:** Each module is designed for easy integration and scalability.
- **Module capacity:** Each module provides 30 tons cooling or 360 MBh heating.
- **Module bank capacity range:** Multiple modules can be combined to form a larger bank, with all modules operating in the same mode (heating or cooling) at any given time. This allows for scalability and flexibility in system design to meet various building load requirements. Each bank can be configured with a minimum of 1 module and a maximum of 12 modules. A minimum of two modules is recommended if there is a concern about loss of temperature control during defrost mode and there is no source of supplemental heat.
- **Efficiency compliance:** Meets ASHRAE Standard 90.1-2022 minimum heating and cooling efficiency requirements.
- **Dual refrigeration circuits:** Ensures reliable operation and redundancy with two separate refrigeration circuits within each module, allowing continued operation even if one circuit requires maintenance.
- **Heat exchanger:** A brazed plate heat exchanger is used for both heating and cooling by switching roles based on the mode. In cooling mode, it functions as the evaporator, absorbing heat from the building's fluid loop. In heating mode, it functions as the condenser, rejecting heat to the building's fluid loop. The heat pump also includes a refrigerant-to-air heat exchanger that functions as the source (during heating mode) or sink (during cooling mode) heat exchanger depending on the operating mode.
- **Mode changeover:** The transition between heating and cooling modes, known as "changeover," is controlled by the BAS or manually by an operator via the unit controller. Centralized control ensures reliable and efficient operation.
- **Module defrost controls:** Refrigeration circuit switches to operate in cooling mode temporarily, thereby using waste heat to melt ice that has built up on the outdoor refrigerant-to-air heat exchanger.
- **Module bank defrost controls:** Limits the number of modules simultaneously operating in defrost mode to no more than 50 percent of the active modules, which minimizes heating capacity derates.
- **Optional module pump package:** Available to simplify installation.
- **Variable flow loops:** The flow rate through the heat pump bank is designed to be variable in both heating and cooling modes. As the number of operating modules changes, the modules will open or close their hydronic isolation valves, so the system must adjust the flow rate accordingly. By using variable-speed pumps that are controlled based on system demand, pump energy use is reduced at part load.

For additional features and options, refer to the product catalog (TF-PRC001*-EN). Note that Trane will update product designs and specifications over time. For the most current equipment operating range and performance, consult your Trane Sales Associate.

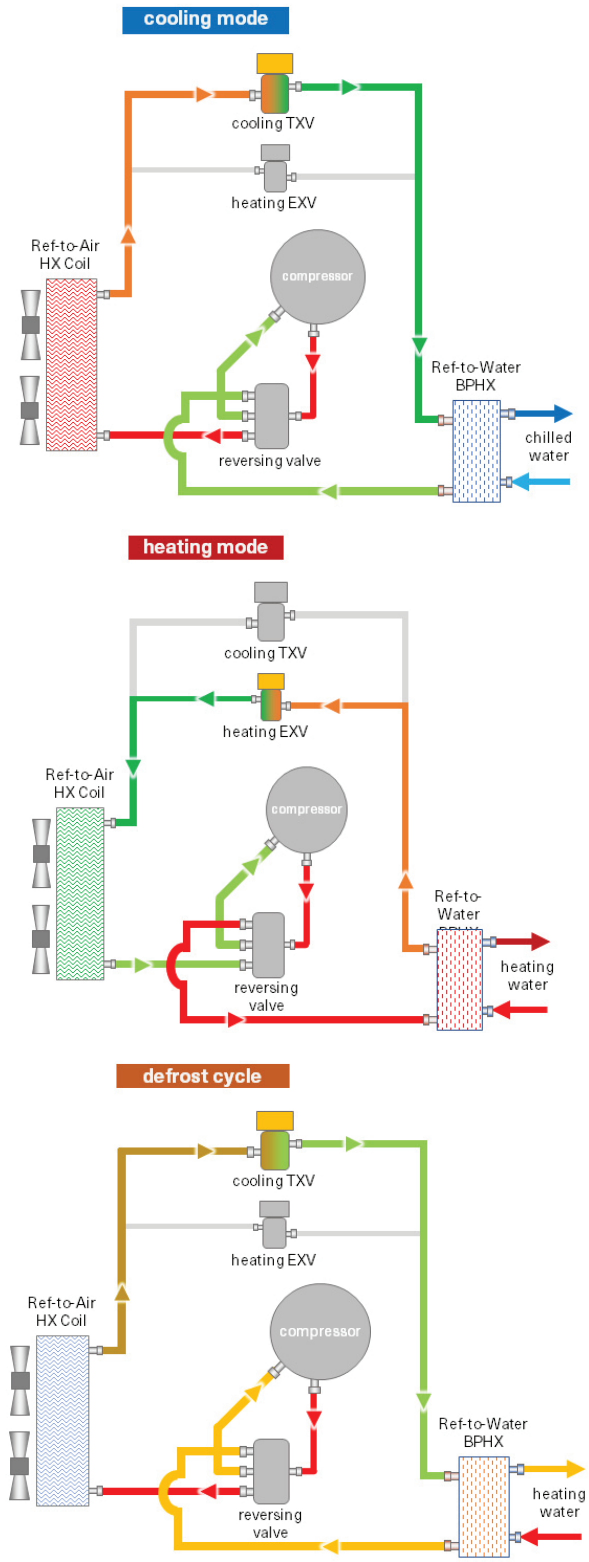
Figure 2. Components of the Trane model AXM heat pump

Operating Modes of the AXM

Figure 3 depicts refrigerant flow for the following three operating modes:

- **Cooling mode:** The refrigerant-to-water heat exchanger (functioning as the evaporator) absorbs heat from the chilled-water loop, providing cooling to the building. The outdoor refrigerant-to-air heat exchanger (functioning as the condenser) then rejects the absorbed heat to the outdoor air, similar to an air-cooled chiller.
- **Heating mode:** The outdoor refrigerant-to-air heat exchanger (functioning as the evaporator) absorbs heat from the outdoor air, similar to an air-source heat pump. The refrigerant-to-water heat exchanger (functioning as the condenser) then transfers this heat to the hot-water loop, providing heating to the building.
- **Defrost mode:** The system temporarily switches from heating mode to cooling mode, which supplies heat for melting ice on the outdoor refrigerant-to-air heat exchanger. The heat used for defrosting is extracted from the hot-water loop, which ensures efficient defrosting without significantly impacting heating performance. A defrost cycle typically lasts two to five minutes.

Figure 3. Operating modes of a Trane AXM



AXM Cooling/Heating Changeover Control

Effective management of the cooling-to-heating and heating-to-cooling changeover process is critical for system performance. Exceeding the operating limits of the specific AWHP will cause the unit to protect itself by preventing compressor operation. The key operational factors include:

- **Outdoor air temperature:** Ensure the AWHP operates within the permissible range of outdoor air temperatures, in both cooling and heating mode.
- **Heat exchanger fluid temperatures:** Monitor entering and leaving fluid temperatures to stay within permissible ranges.
- **Fluid flow rates:** Maintain fluid flow rates within the permissible range.

The unit controller is responsible for managing changeover between cooling and heating modes. It uses both a minimum time delay and the entering fluid temperature limits to determine when mode transitions can occur, regardless of a BAS request. This prevents rapid switching between modes, and minimizes operational issues associated with extreme temperature changes. The unit will transition modes if the entering fluid temperature is within the upper and lower temperature limits. If the entering fluid temperature is not within the limits, the minimum time delay will prevent the unit from switching modes until the timer expires, at which time the unit is allowed to operate.

If a system tempering valve is installed, it is used by the BAS to accelerate moderation of the entering fluid temperature after the mode transition. These coordinated control strategies ensure smooth transitions, protect the unit from safety trips, and minimize system downtime.

AXM Operating Ranges

The Trane AXM has a broad operating range, making it suitable for various environmental conditions. Actual heat pump performance must be confirmed using the Trane® Select Assist™ selection program.

Outdoor (Ambient) Dry-Bulb Temperature

- Cooling mode: 0°F to 115°F (-17.8°C to 46.1°C)
- Heating mode: -18°F to 95°F (-27.8°C to 35°C)

Leaving (Supply) Fluid Temperatures

- Leaving cooling fluid temperature: 20°F to 65°F (-6.7°C to 18.3°C)
- Leaving heating fluid temperature: 75°F to 140°F (23.9°C to 60°C)

Note: *Leaving fluid temperatures of 42°F and below requires appropriate glycol concentration.*

Fluid Flow Rate and ΔT

- Module fluid flow rate: 0.8 to 4 gpm/ton (calculated based on cooling tons but applies to both cooling and heating flow rates)
- Fluid ΔT: 6°F to 20°F (3.3°C to 11°C)
- Module bank fluid flow rate: Minimum flow rate for the bank is the flow rate for a single module; maximum flow rate for the bank is the sum of flow rates for all modules operating in the bank.

Figure 4. Heating mode operating map of Trane AXM

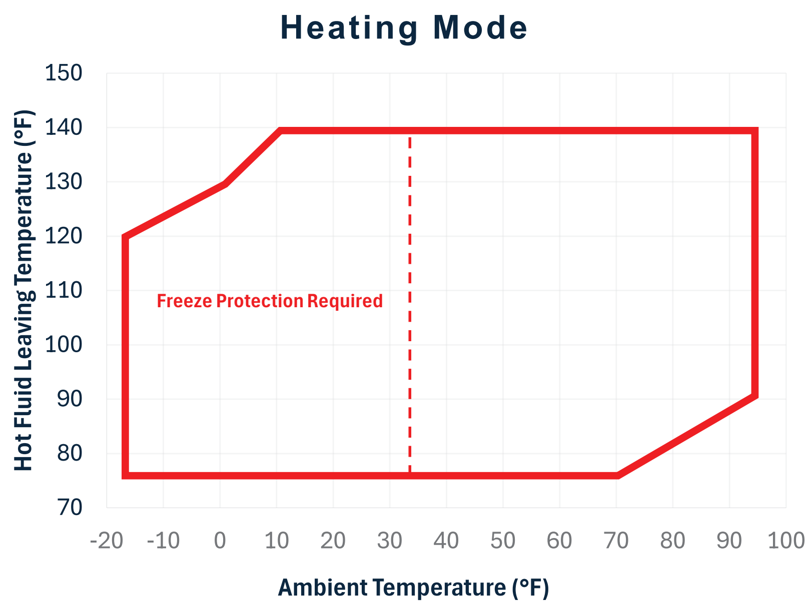
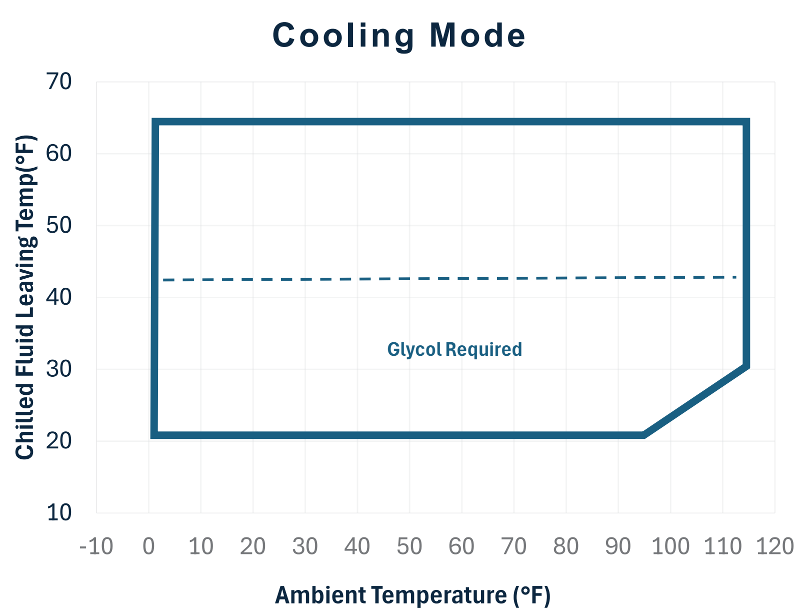


Figure 5. Cooling mode operating map of Trane AXM



Four-Pipe Modular Heat Pumps (MAS)

Four-pipe modular heat pumps, such as Trane's MAS model, offer the capability to provide simultaneous cooling and heating from a bank of modules, meeting both cooling and heating setpoints from a single bank.

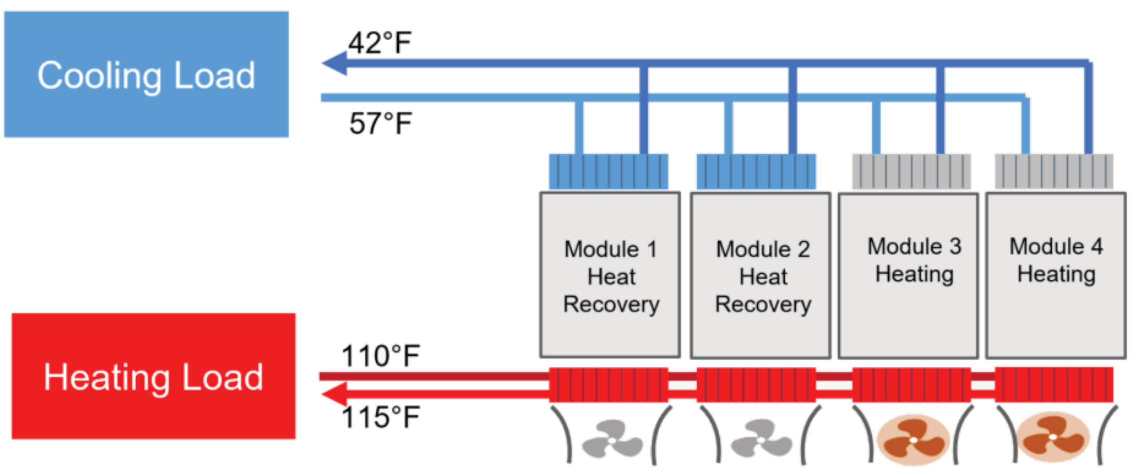
Key Features of the Trane MAS

Trane model MAS units are available with the following features (Figure 6):

- **Modular, packaged heat pump configuration:** Each module is designed for easy integration and scalability.
- **Module capacity:** Each module provides 30 tons cooling and 360 MBh heating.
- **Module bank capacity range:** Multiple modules can be combined to form a larger bank. Each bank can be configured with a minimum of 3 modules and a maximum of 10 modules.
- **Efficiency compliance:** Meets ASHRAE Standard 90.1-2022 minimum heating efficiency requirements.
- **Single refrigeration circuit:** Tandem vapor injection scroll compressors on a single circuit.
- **Three heat exchangers:** Each module contains a heating brazed plate heat exchanger, a cooling brazed plate heat exchanger, and an outdoor air coil that can serve as either a heat source or heat sink. This configuration allows flexible operation in different modes, including simultaneous heating and cooling.
- **Independent module operation:** Each module in the bank can operate in a different mode to satisfy the building's heating and cooling needs. This independent operation allows for greater flexibility and efficiency. The MAS bank will prioritize simultaneous operation first, meaning that a single module will operate in heat recovery mode instead of having one module operate in cooling mode and another in heating mode.
- **Defrost controls:** Modules are sequentially operated in defrost mode to minimize the impact on heating capacity.
- **Optional module pump package:** Available to simplify installation.
- **Variable flow loops:** Both chilled-water and hot-water loops use variable flow to enhance system efficiency. As required by load and mode, a module will open or close its hydronic isolation valves, so the system must adjust the flow rate accordingly based on the number of operating modules. For example, in a bank with four modules, if two modules are in heat recovery mode and two are in heating mode, the system will provide the flow equivalent of two modules for chilled water and the flow equivalent of four modules for hot water (Figure 7).

Figure 6. Components of the Trane model MAS heat pump

Figure 7. Four-pipe bank with two modules operating in heat recovery mode and two modules operating in heating mode



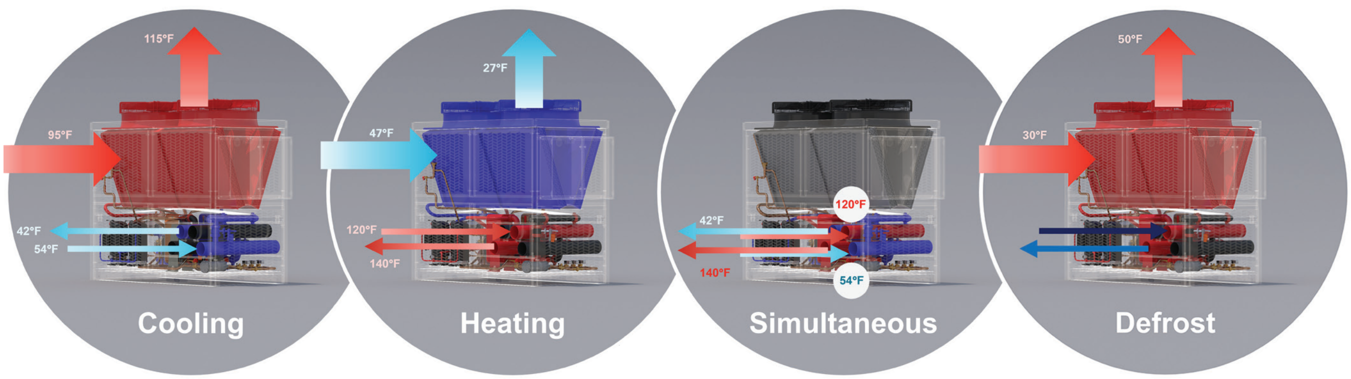
Operating Modes of the MAS

Figure 8 depicts fluid flows for the following four operating modes:

- **Cooling mode:** The cooling refrigerant-to-water heat exchanger (functioning as the evaporator) absorbs heat from the chilled-water loop, providing cooling to the building. The outdoor refrigerant-to-air heat exchanger (functioning as the condenser) then rejects the absorbed heat to the outdoor air, similar to an air-cooled chiller.
- **Heating mode:** The outdoor refrigerant-to-air heat exchanger (functioning as the evaporator) absorbs heat from the outdoor air, similar to an air-source heat pump. The heating refrigerant-to-water heat exchanger (functioning as the condenser) then transfers this heat to the hot-water loop, providing heating to the building.

- **Heat recovery simultaneous mode:** The cooling refrigerant-to-water heat exchanger (functioning as the evaporator) absorbs heat from the chilled-water loop, providing cooling to the building. Simultaneously, the heating refrigerant-to-water heat exchanger (functioning as the condenser) transfers this heat to the hot-water loop, to the building. In simultaneous mode, the MAS operates like a heat-recovery chiller.
- **Defrost mode:** The system temporarily switches to supply heat for melting ice on the outdoor refrigerant-to-air heat exchanger, by sourcing heat from the heating refrigerant-to-water heat exchanger, thereby temporarily cooling the hot-water loop. When switching to and from defrost mode, the module compressors will cycle off while the modular refrigerant valves change positions. Defrosting typically take two to five minutes to complete, and an additional five minutes are needed to cycle compressors on/off during the transition periods before a module goes back to heating.

Figure 8. Operating mode of a Trane MAS



MAS Operating Ranges

The Trane MAS has a broad operating range, making it suitable for various environmental conditions. Actual heat pump performance must be confirmed using the Trane® Select Assist™ selection program.

Outdoor (Ambient) Dry-Bulb Temperature

- Cooling mode: 0°F to 115°F (-17.8°C to 46.1°C)
- Heating mode: -18°F to 95°F (-27.8°C to 35°C)

Leaving (Supply) Fluid Temperatures

- Leaving chilled fluid temperature: 20°F to 65°F (-6.7°C to 18.3°C)
- Leaving heating fluid temperature: 75°F to 140°F (23.9°C to 60°C)

Fluid Flow Rate and ΔT

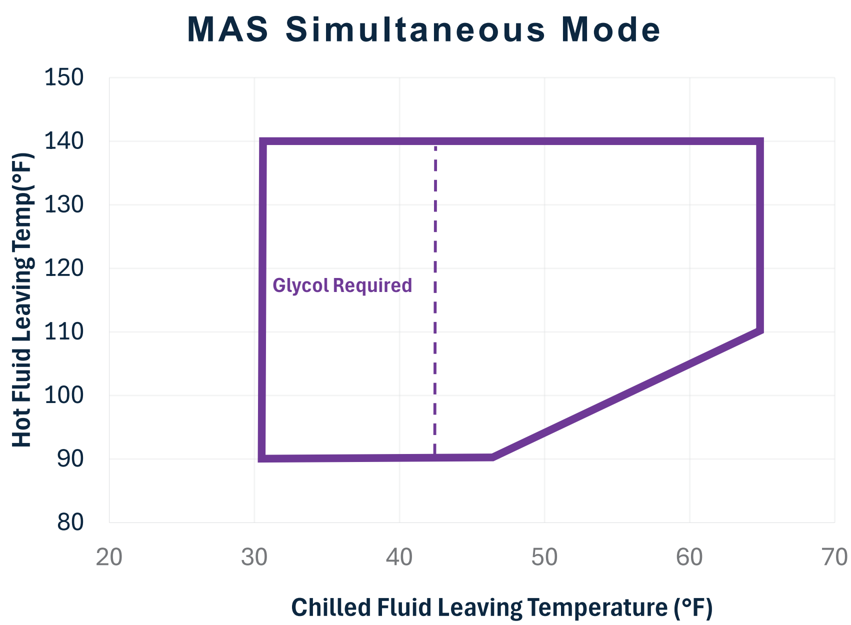
- Module fluid flow rate: 1 to 4 gpm/ton (calculated based on cooling tons but applies to both cooling and heating flow rates)
- Approximate fluid ΔT: 6°F to 20°F (3.3°C to 11°C)
- Module bank fluid flow rate: Minimum flow rate for the bank, in both heating and cooling, is the flow rate for a single module; maximum flow rate for the bank is the sum of flow rates for all modules operating in the bank.

MAS four-pipe heat pump banks can operate individual modules in different modes simultaneously, and all modules share the same fluid flow rate. The heating design flow rate required to provide a specific design ΔT will vary depending on the modes of operation and ambient temperature. By considering the specific requirements of your building and the capabilities of each system, you can make informed design flow rate decisions that maximize performance. MAS performance reports typically show three different modes of operation at full load: cooling, heating, and simultaneous mode. When comparing the performance of each mode, you may notice the condenser heat exchanger pressure drop varies. This is because the pressure drop is a function of the heat exchanger flow rate. For example, an MAS equipment selection may show a 4 ft. condenser pressure drop in heating mode at a cold ambient design temperature and a 13 ft. condenser pressure drop in simultaneous mode, even though each mode produces the same heating ΔT. This is because the MAS has significantly more capacity available in simultaneous mode compared to heating mode due to the compressor lift being lower in simultaneous mode.

The question then arises: what is the best differential pressure setpoint for pump control? The preferred method is to control the pumps to the higher of the two pressure drops, which is typically in simultaneous mode. With this method, the modules operating in simultaneous mode will provide the design ΔT, while the units in heating mode at low ambient conditions will provide a lower ΔT, resulting in the mixed temperature leaving the module bank being slightly less than the setpoint.

Because the preferred system configuration for these systems is variable primary/variable secondary, there should always be excess flow in the decoupler pipe. As the system stabilizes at a specific load, the excess flow on the primary side will increase the return temperature to the module bank, allowing the desired system setpoint to be met. Further optimization around flow rate control can be done, but caution is advised, especially to avoid under-pumping the module banks. The primary pumps can be reset to reduce flow rates and pump energy, but the design hot water temperature, ΔT, and lift limitations of the heat pump all need to be considered.

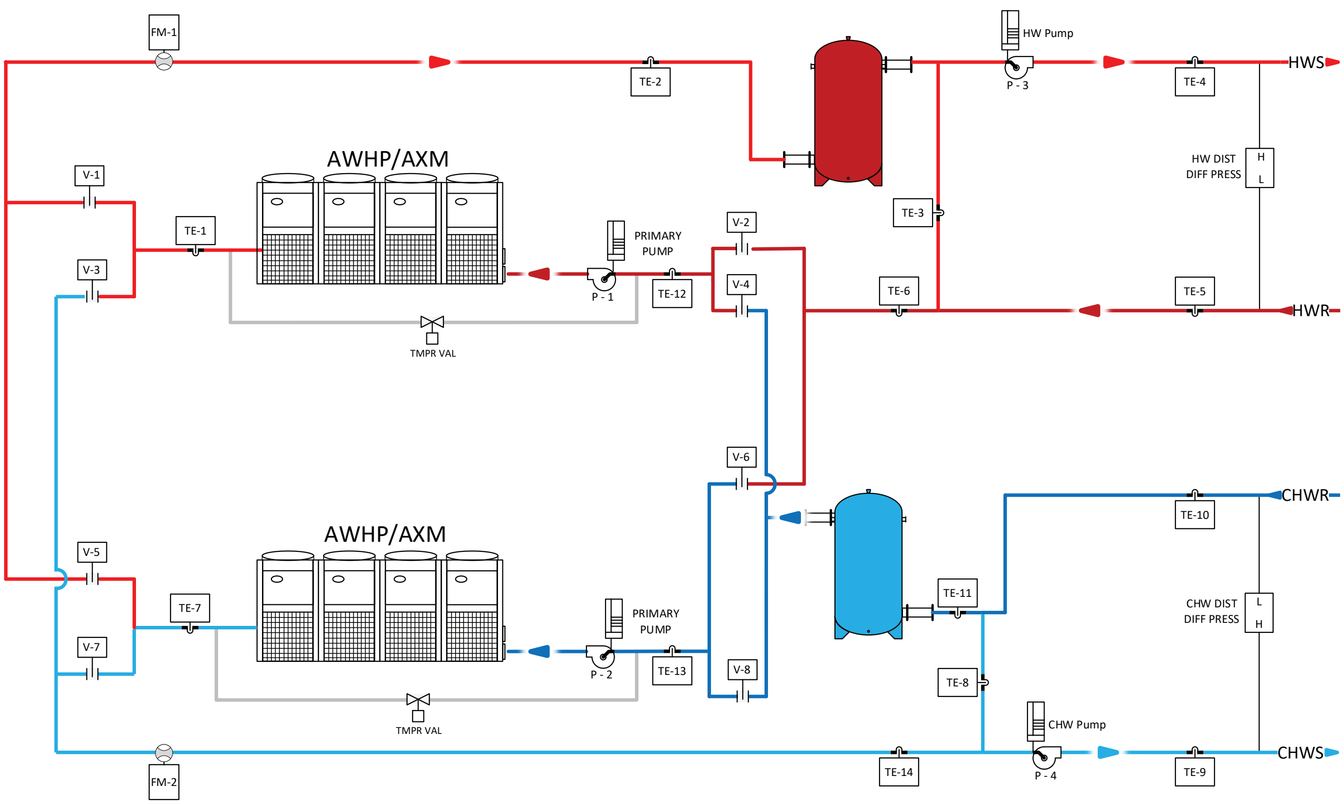
Figure 9. Simultaneous heat recovery mode operating map of Trane MAS. For MAS heating and cooling operating maps, refer to the AXM heating and cooling map figures on page 7.



Base System Configuration

The base system configuration described in this guide is shown in Figure 10 and uses four-pipe distribution that consists of separate heating and cooling distribution loops. These loops serve airside equipment through two-way valves, which provide variable flow in both the heating and cooling circuits. This design offers significant pumping energy savings and operational flexibility, as supply temperatures, flow rates, and ΔTs can be optimized to suit the design of the airside system components.

Figure 10. Base AXM heat pump system configuration



At the heart of the system are the decoupler pipes. These pipes provide hydronic isolation that allows for optimization of flow rates and temperatures in both the distribution and production loops. The system circulates the same fluid through the production loop and the heating and cooling distribution loops.

Oftentimes, an antifreeze (glycol) solution is used in the production circuit due to the heat pumps being located outside, allowing this same solution to circulate through both distribution loops. This is the simplest and safest approach, as it does not rely on any powered or mechanical freeze protection strategy. Alternatively, fluid isolation heat exchangers can be added between the production loop and distribution loops if the design engineer wishes to avoid antifreeze in the distribution loops.

Decoupling

Decoupling simplifies system design and allows for an array of sizes and types of production units to be used to best match the building load requirements. The principal requirement for the heat pump equipment is that it must produce the required fluid temperature for cooling or heating. The fluid flow rate and pressure drop are of much less concern, since the decoupler pipe allows for natural balancing of flow rates.

The decoupler pipe must be configured and sized to meet the following requirements (Figure 11):

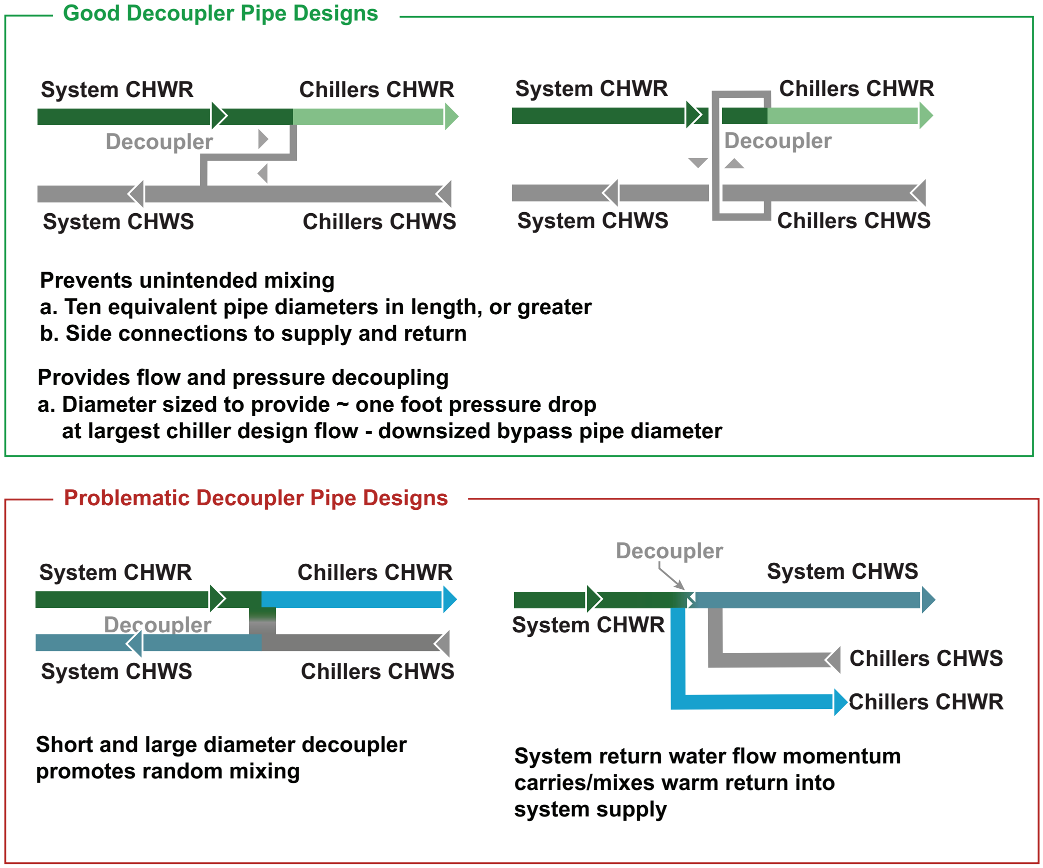
1. Prevent unintended mixing of the return and supply fluid streams.
2. Provide adequate flow and pressure decoupling between the fluid production and distribution loops.

Decoupler pipe configuration: The decoupler pipe should be configured so that it enters and exits the side of the return and supply system piping with tee-type connections. This is to prevent fluid velocity momentum in the supply or return pipe from inducing flow and/or mixing in the decoupler pipe.

Decoupler pipe diameter: The decoupler pipe should be sized based on either 1.5 modules worth of flow or the minimum flow of the pump, whichever is larger. Oversizing this pipe increases the likelihood of undesired flow mixing and increases installation cost.

Decoupler pipe length: The decoupler pipe length should be at least ten (10) equivalent pipe diameters (elbows get counted appropriately). Another rule-of-thumb is for this pipe to have about 1.0 ft. H_2O of pressure drop at the decoupler design flow. In a large chilled-water or hot-water system, a somewhat higher pressure drop will not cause operational problems.

Figure 11. Decoupler pipe design recommendations



To ensure proper design and installation of the decoupling piping, it is crucial to include detailed requirements in the project specifications. This will guide the contractor in configuring and sizing the decoupler pipe correctly. The specifications should emphasize the importance of preventing unintended mixing of the return and supply fluid streams and providing adequate flow and pressure decoupling.

Pumping Configurations and Control Strategies

For more information on VPF system design, refer to the Trane application guide titled “Modular Heat Pump Chillers in Variable Primary Flow Hydronic Systems” (PKG-APG001*-EN)”.

Variable Flow System Configurations

Modular heat pumps can be operated in variable primary/variable secondary (VP/VS) or variable primary flow (VPF) hydronic configurations. This guide emphasizes the VP/VS setup with decoupling because it achieves optimal flow rates in both the production and distribution loops.

Primary (Production Loop) Flow Management

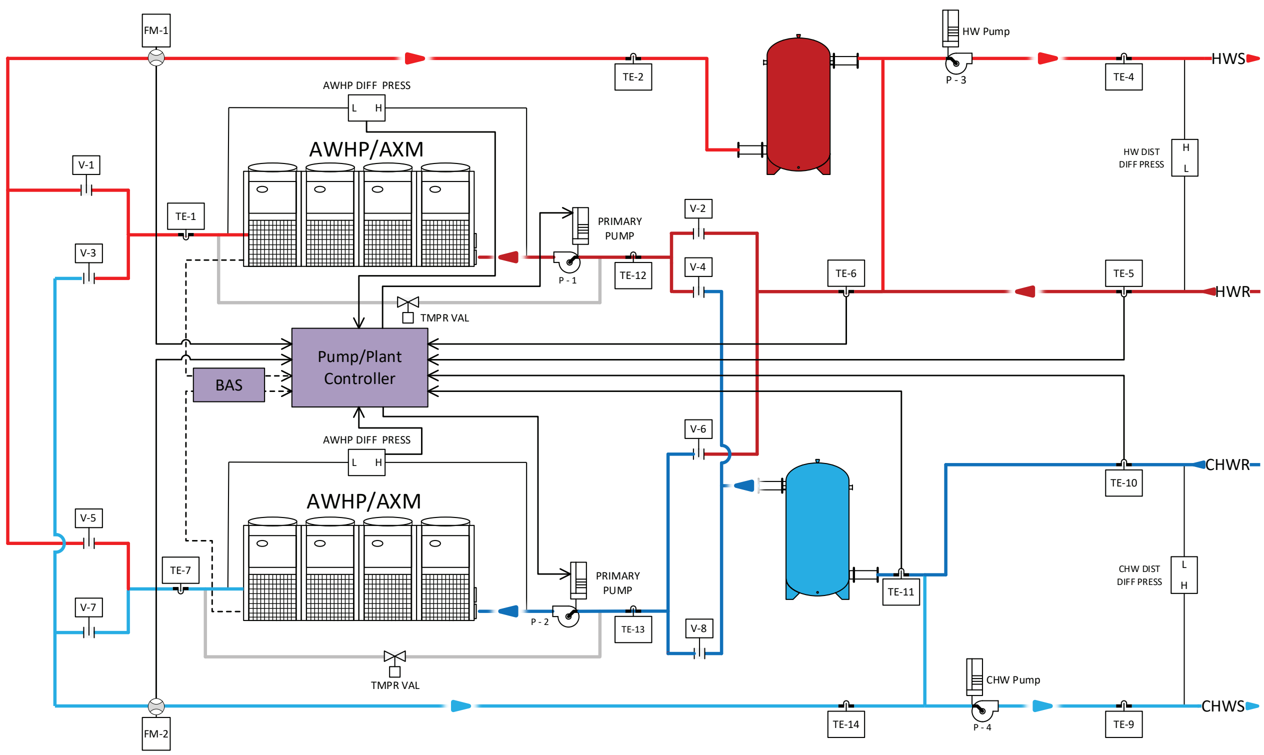
Flow in the primary (production) loop is managed by adjusting the speed of the primary pumps, ensuring safe operation while adapting to varying distribution system demands. For both Trane model AXM and MAS units, factory-installed electronic isolation valves on the supply and return fluid piping connections to each brazed plate heat exchanger enable variable flow in the primary loop. These isolation valves prevent flow through a module when its compressors are off, reducing the total flow rate required by the module bank. When additional capacity is needed, the valve in the next module opens, allowing compressor operation. The production loop flow rate and primary pump speed depend on the number of modules operating with their valves open. Since these valves are two-position (open or closed), the flow rate changes in a stepwise manner. The flow range for the bank depends on the module’s mode of operation and the number of operating modules. Because the primary pumps respond to the number of operating modules, there is no variable flow rate change per minute limitation that packaged heat pumps/chillers typically have.

In any modular heat pump or chiller system, there are two key issues regarding primary pump control. First, the unit must be provided with adequate flow to operate. When modules stage on and off, the automatic isolation valves in those modules open and close, changing the operating flow requirements. Automatic isolation valves are not standard with all modular equipment, so it is important to specify this detail. Second, primary flow must be sufficient to ensure the required system flow at the controlled fluid setpoint is achievable.

For systems with multiple modular banks, dedicated pumps serving each bank are strongly recommended. This ensures consistent flow to each module, simplifies system control, and improves reliability and resilience—since a single pump failure only impacts its associated bank. While manifolded pumps can provide redundancy, they are generally not advised for such configurations due to increased control complexity and a higher risk of flow imbalance.

Differential pressure pump control with flow verification is the preferred method of control, with sequences provided by Trane® Design Assist™ (TDA). In this scheme, differential pressure sensors and transducers are placed across the modular heat pump bank, producing an output analogous to flow through the heat pump refrigerant to fluid heat exchanger(s). A flow meter, recommended to have 1% accuracy when reading between 2 to 20 fps, is placed in the primary supply fluid stream. High-quality flow meters are crucial for preventing potential issues and reducing troubleshooting costs. The BAS receives a communicated point from each heat pump’s unit controller, indicating the number of operating modules per unit.

Figure 12. Differential pressure pump control with flow verification control requirements



Differential pressure pump control requires a sensor selected for the range and accuracy needed to measure both the expected minimum and maximum differential pressure. Each module's design flow and subsequent pressure drop are known. The primary fluid pump speed is controlled to the higher of the differential pressure setpoint or the heat exchanger minimum flow. The pump speed corresponding to the minimum rate is determined during commissioning and defined within the controller as the minimum pump speed. This method allows the pump to automatically respond when module isolation valves open or close and to changes in distribution flow by monitoring the temperature difference between the system and primary return temperature differential of 1°F (adj) to ensure primary flow is always slightly greater than distribution flow. This is standard variable primary-variable secondary primary pump control.

The flow meter monitoring system flow for either chilled or heated fluid is used to double-check the flow. For example, if strainers are clogged, primary flow would be less than expected at the differential pressure setpoint. If the flow meter readings are more than 10% less than the expected loop flow based on the number of operating modules, an alarm is triggered. The control system will apply a correction factor to the differential pressure setpoint, according to the number of modules operating. This correction factor is determined during test and balancing (TAB) as it depends on the number of modules in the bank.

Advantages:

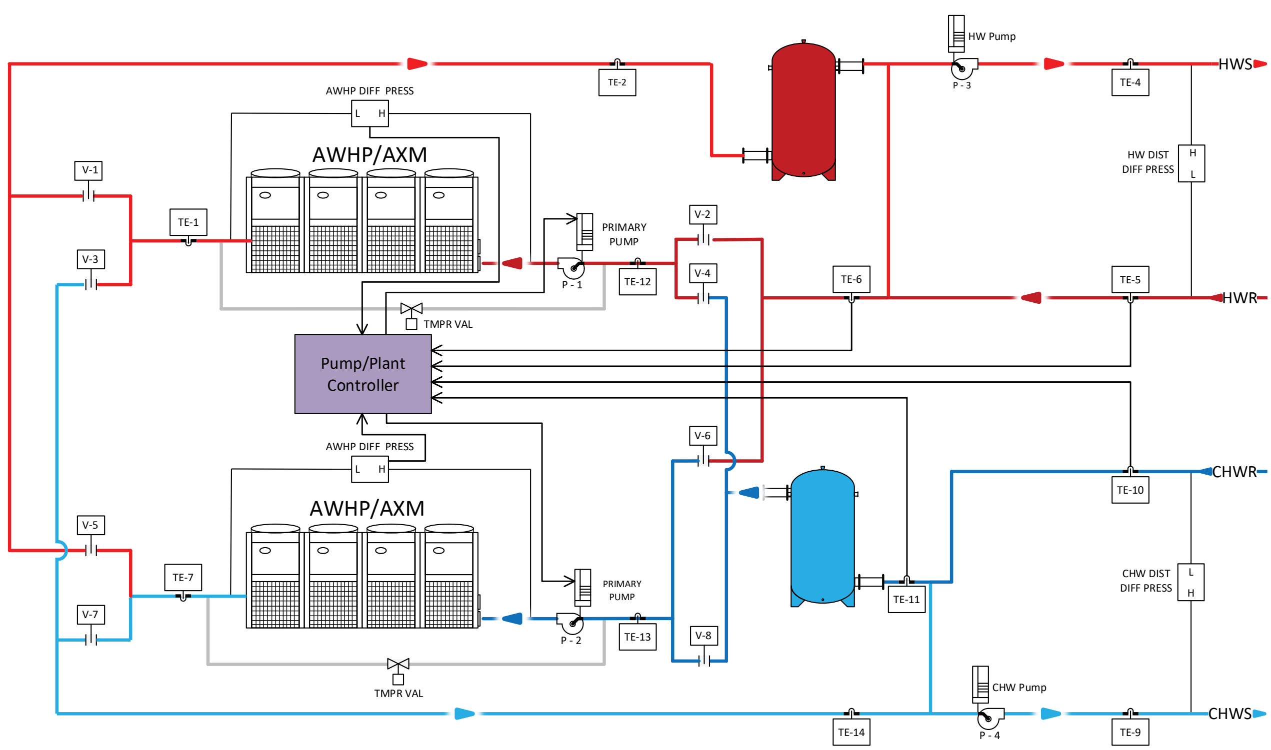
- Detects clogged strainers based on actual system flow.
- Allows active flow correction.
- Enables BTU accounting for energy measurement.
- Aids in commissioning, balancing, and troubleshooting.
- Ensures proper piping layout when included in the design phase.
- Prevents change orders later in design.

Disadvantages:

- Additional initial cost.
- Requires flow meter installation, calibration, and maintenance.

Differential pressure pump control is a cost-effective alternative to the previous method, often chosen when budgets are tight and flow meters are excluded to reduce initial costs. This scheme (Figure 13) relies on a differential pressure sensor selected for the required range and accuracy to measure both the expected minimum and maximum differential pressure. Each module's design flow and subsequent pressure drop are known.

Figure 13. Differential pressure pump control



Advantages:

- Lower initial cost due to the exclusion of flow meters.
- Simple and well-understood pump control.
- No need for flow meter calibration.

Disadvantages:

- Potential flow impediments from clogged or dirty strainers.
- Operators may not realize when strainer maintenance is needed.

Consider an example of pump operation: When a single module operates with both compressors active in cooling mode, the leaving chilled water fluid temperature increases as system load rises. When another module is engaged (after the setpoint plus differential to start is exceeded for the specified delay time), the module unit controller opens the next motorized isolation valve, causing the differential pressure across the heat pump to drop. Flow then occurs through two modules in parallel, prompting the pump speed to increase to maintain the design differential pressure through the now two operating modules. The opposite occurs as modules stage off. Although variables change in heating mode, the concept remains the same. However, if internal strainers are not maintained the differential pressure across the module bank will be higher than expected and the flow will be less than expected. A recommended best practice is to install an easily serviceable external strainer upstream of the heat pump to ensure internal strainers remain clean. The preventative maintenance schedule should include regular cleaning of both external and internal strainers.

The key point is that the differential pressure setpoint remains constant regardless of the number of operating modules, unless adjusted for mitigating factors.

Secondary (Distribution Loop) Flow Management

The speed of secondary distribution pumps is typically controlled to maintain a target differential pressure (dP) at a specific point in the system, usually at the most remote equipment (coil, terminal unit, etc.). The flow rate in the distribution system is determined by the operation of two-way modulating control valves on the coils and the pump speed. To ensure that the distribution pumps receive their required minimum flow, a system or end-of-loop bypass is recommended. This bypass can be implemented using three-way valves on some airside coils or a dedicated bypass pipe with a modulating two-way valve. Placing a bypass at the end of the hydronic loop allows it to modulate flow effectively based on real-time measurements from flow meters, ensuring that the minimum required flow is consistently achieved.

In variable primary-variable secondary flow systems, primary flow is slightly greater than distribution flow. This control scheme uses matched temperature sensors placed in the system return and the heat pump return—one upstream of the decoupler pipe (system fluid return) and one downstream (heat pump fluid return). By maintaining a ΔT of 0.5°F to 1°F from system to heat pump return, excess flow is guaranteed, minimizing primary pumping to just above the distribution system's needs. A mechanism is still required to ensure pump speed is not reduced below the heat pump heat exchanger's minimum flow.

These control schemes are denoted on Figure 12 (p. 17) and Figure 13 (p. 18). Each of the plant diagrams apply to both AXM and MAS configurations. However, more pumps and control points are needed for MAS due to the dedicated pipes through the heat pumps.

Multiple Heat Pump Banks

Multiple heat pump module banks may be needed in the following situations:

- **Large capacity requirements:** When the required system capacity exceeds the maximum number of modules allowed in a single bank, additional banks can be added in parallel to meet the required capacity.
- **Cooling-dominant systems:** For systems in which the cooling demand is higher than the heating demand, heat pumps can be paired with dedicated (cooling-only) chillers. These chillers, piped in parallel with the heat pumps, act as lead units during periods of peak cooling, optimizing overall efficiency.
- **Dedicated heat recovery needs:** If specialized heat recovery is required (such as for reheat, dehumidification, or process heating), dedicated heat recovery units (DHRU) can be integrated into the distribution loop to reclaim waste heat during simultaneous heating and cooling demands.
- **Use of AXM units:** Because AXM units operate as two-pipe systems, all modules within a bank must operate in either heating or cooling mode. To provide simultaneous heating and cooling using AXM units, at least two separate banks—one dedicated to heating and one to cooling—must be installed.

Pressure Balancing Cooling/Heating Loops

Each hydronic system design is unique, and where there is mixing between the cooling and heating loops, the designer must be careful to specify proper circuit isolation and component pressure ratings to avoid potential balancing and operational issues. Pressure differences between heating and cooling distribution loops can lead to fluid migration from the higher-pressure loop to the lower-pressure loop, causing an imbalance in flow rates, loss of efficiency, and potential damage to equipment, such as pumps and valves.

System and Unit Sizing

Proper sizing of a modular heat pump system and heat pump equipment, including redundancy, is critical to reliable and efficient system operation and affordable first cost. High hot-water supply (HWS) temperatures will not only result in increased system energy use but are not likely to be attainable with commonly available heat pump technologies. Past assumptions must be discarded and low-temperature HWS concepts embraced.

Historic “rules-of-thumb” for sizing system capacity should not be used. Computerized load analysis for new buildings, and accurate load history for existing buildings, are essential to proper system design and meeting an owners’ environmental and financial goals. This section discusses many of the important points relative to modular heat pump system design.

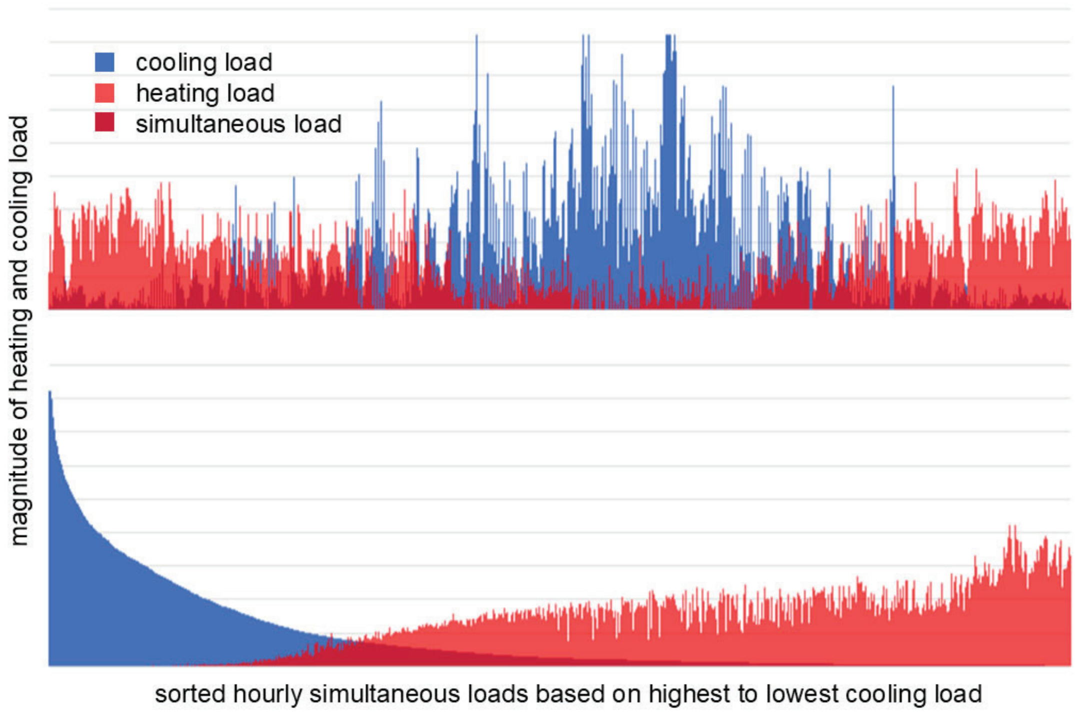
Building Load Evaluation

Understanding building loads has always been key to proper equipment sizing, but it is especially important for heat pump chiller systems. Knowing not only the peak loads but also the simultaneous loads and how many hours are spent at different capacities allows the system designer to make informed decisions about heat recovery, unloading, redundancy, and resiliency.

Gathering hourly or sub-hourly building load data can be difficult. Early in the design process, using a prototype building model (such as the PNNL EnergyPlus™ models) may be necessary since there may not yet be enough information to create an accurate building model. As the design progresses, however, energy modeling software (such as TRACE™ 3D Plus) can be used to generate an accurate load profile for the proposed building.

In the case of an existing building, it is often best to trend building operation to determine actual building loads, rather than relying on a model. Once a load profile has been generated, one useful way to visualize the data is to sort it by cooling load—largest to smallest—while also showing the simultaneous heating load (Figure 14).

Figure 14. Hourly heating and cooling loads plotted chronologically (top chart) and sorted based on highest to lowest cooling load (bottom chart)



For more information on exhaust-air energy recovery, refer to the Trane application manual, *Air-to-Air Energy Recovery* (SYS-APM003*-EN).

Effective use of exhaust-air energy recovery can substantially reduce the ventilation heating load during occupied periods, allowing it to approach the much-lower unoccupied load. The benefit of exhaust-air energy recovery depends on how much exhaust air is available for recovery, and the effectiveness of the energy-recovery technology.

Air-to-Water Heat Pump Plant Sizing

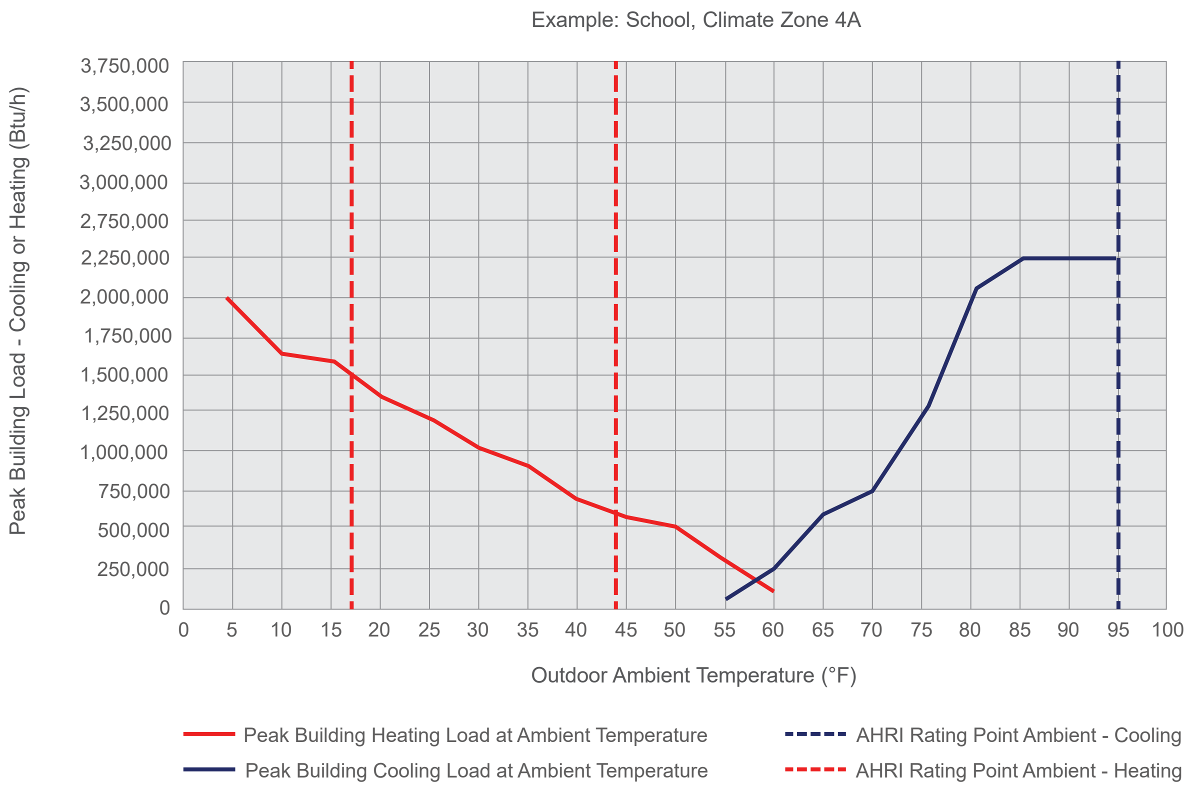
An AWHP system needs to be sized to satisfy both the peak cooling load and the peak heating load. That is, the same equipment is expected to satisfy both loads. Not only is the magnitude of these peak loads different, but the capacity of the equipment varies with the outdoor air temperature. The heating capacity of an AWHP, when operating at the winter design ambient temperature, is typically much lower than the unit's “nominal” cooling capacity. This can result in substantially different equipment selections for cooling and heating.

Figure 15 plots the peak loads versus outdoor air temperature for an example school building. Not surprisingly, the design operating conditions are not necessarily the same as the AHRI standard rating conditions, so actual performance of the equipment will differ from its rated performance. Design engineers must also remember that the “nominal” capacity of the equipment often differs from its “as-applied” capacity, so it should not be used for equipment selection.

In this example, the peak heating load is approximately 2,000,000 Btu/h, and this occurs when the ambient temperature is 4°F, which is much colder than the AHRI standard rating temperatures of 17°F and 47°F. The peak heating load is approximately 2,250,000 Btu/h, and this occurs when the ambient temperature is 95°F. While this ambient temperature is the same as the AHRI standard rating temperature, the design chilled-water supply temperature may be colder (e.g., 40°F to 42°F) than the AHRI rating condition (44°F).

In both cases, the capacity of the AWHP operating at actual (as-applied) design conditions must be determined using the manufacturer's equipment selection software.

Figure 15. Peak building loads versus ambient temperature



The process for sizing the heating capacity of an AWHP requires the design engineer to consider several factors, some which may be unfamiliar. These factors include, but are not limited to:

- Design hot-water supply (HWS) temperature.
- Design heating outdoor air temperature.
- Equipment cost.
- Operating cost.

- Electrical infrastructure cost to support peak demand.
- Carbon footprint reduction through building electrification.

These factors are interrelated, so any trade-offs need to be understood and aligned with the priorities of the building owner.

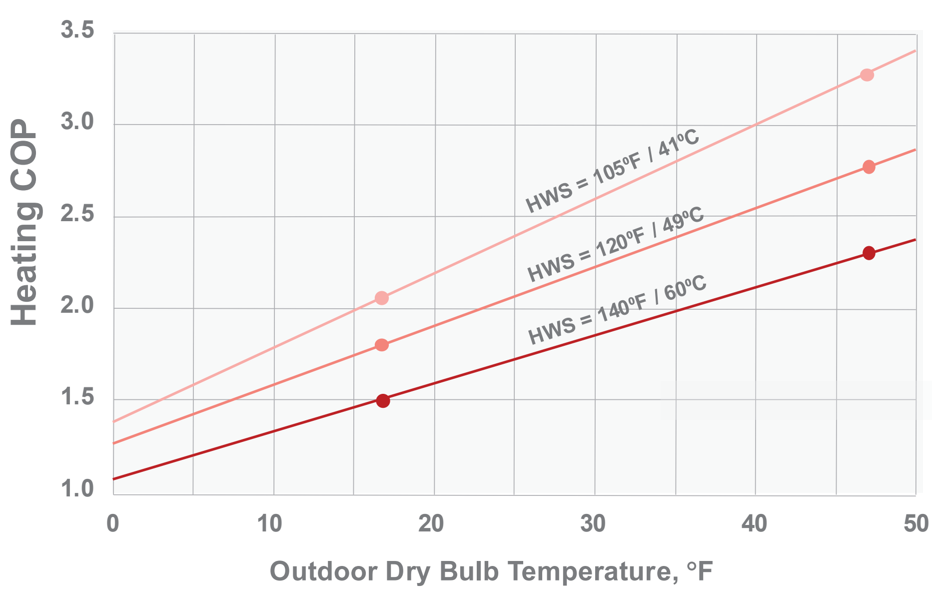
Impact of Hot-Water-Supply Temperature

The hot-water supply (HWS) temperature is perhaps the most significant factor to consider. Figure 16 plots the ASHRAE Standard 90.1-2022 minimum heating efficiency requirements for AWHPs at three common HWS temperatures. The chart linearly extends the required heating COP across the range of typical heating outdoor temperatures. This demonstrates the relationship between HWS temperature, outdoor air temperature, and the unit's COP_H (Coefficient of Performance when Heating: a higher COP is better) at full load:

- Lower HWS temperature increases COP_H.
- Colder outdoor air temperature decreases COP_H.

COP impacts operating cost, electrical demand, and carbon footprint. Since a primary driver for electrifying heating systems is to reduce the carbon footprint, the importance of the HWS temperature is clear. A lower HWS temperature reduces the negative impact of colder outdoor air temperature and raises the unit's COP_H. Note that even lower HWS temperatures than those represented in Figure 15 are feasible in some systems.

Figure 16. ASHRAE Standard 90.1-2022 minimum heating COP at standard rating conditions (17°F and 47°F outdoor dry bulb temperature) for various HWS temperatures



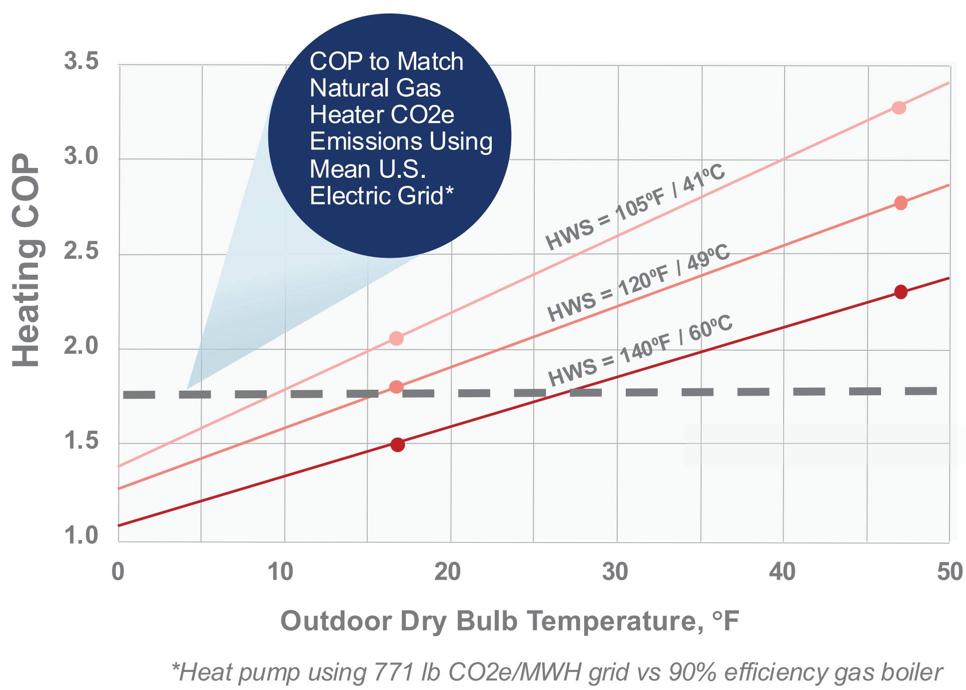
Switching from on-site fossil fuel heating to electrified heating does not guarantee a reduction in atmospheric carbon emissions. In fact, electrified heating can sometimes increase carbon emissions. To ensure the system is indeed achieving the goal of decarbonization the design team must ask: What is the electrified heating system efficiency required to reduce atmospheric carbon emissions compared to on-site high-efficiency natural gas (or other fossil fuel) heating?

To answer this question, the carbon emission rate of the electric grid must be known. Electrical power production usually comes from a mixture of energy sources, including natural gas, coal, nuclear, hydroelectric, wind turbines, solar arrays, and others. Each has its own carbon emission rate profile. The mixture of energy sources and, therefore, the carbon emission rate of an electric grid varies by location.

Electric grid data for this analysis is sourced from the United States Environmental Protection Agency's (EPA) Emissions & Generation Resource Integrated Database (eGRID).

Based on the mean carbon emission rate for the U.S. electric grid (771 lb/ MWH), the electrified heating system efficiency required to match the emission rate of an on-site natural gas boiler (90 percent efficient) is 1.75 COP_H. This is shown on Figure 17 as a horizontal dashed line. For electrified heating to emit less carbon it must operate above this line. For example, using an AWHP that meets the ASHRAE 90.1-2022 minimum efficiency at HWS temperature of 120°F at outdoor temperatures below 17°F would result in higher carbon emissions than using a fossil fuel boiler, (a cleaner or dirtier grid, or a less-efficient boiler, will change this threshold). And a higher HWS temperature drives this crossover point to an even warmer outdoor air temperature and conversely a lower HWS temperature would drive the crossover point to a colder outdoor air temperature.

Figure 17. Minimum COP_H needed to result in less carbon emissions than an on-site natural gas boiler



Depending on the building location, the needed COP_H of the electrified heating system could be as high as 3.0 for the most carbon intensive (dirtiest) grids, or as low as 1.5 for the least carbon intensive (cleanest) grids. In general, the higher the system COP_H the easier it will be to achieve the goal of reducing carbon emissions.

To minimize overall carbon emissions, a system should changeover to use gas heat when the outdoor temperature drops below this crossover temperature. As the electric grid becomes "greener" throughout the life of the building, this changeover temperature can be adjusted to maximize environmental performance.

This discussion demonstrates that a single heat source may not provide the lowest carbon emissions at all operating conditions. Therefore, it is important to design and operate the system to minimize carbon emissions over the course of the year.

Space Heating Equipment Options

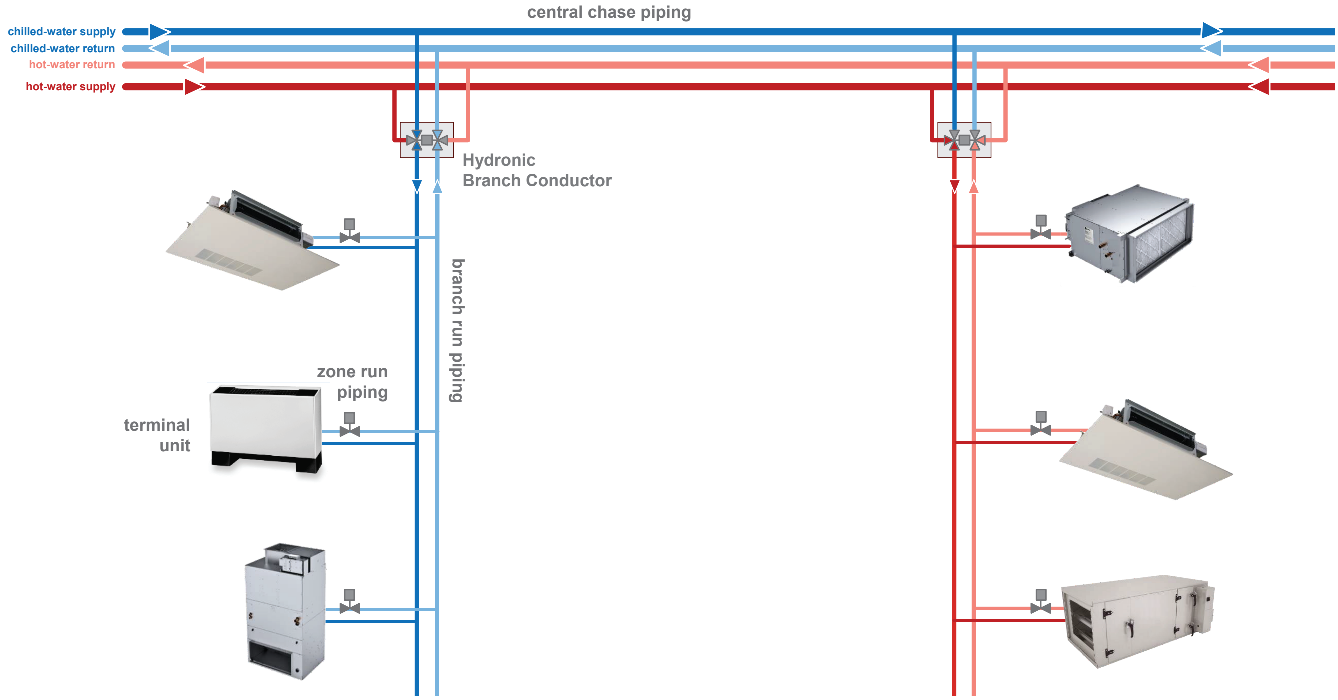
Of course, the hot-water supply (HWS) temperature must be considered when selecting coils for the air handling or terminal equipment. Terminal units (e.g., fan-coils, blower coils, VAV terminals) typically have fewer coil options than central air-handling units, and will likely drive the final design HWS temperature decision. Average system heating coil ΔT must be evaluated to prevent high fluid flow rates from causing excessive pump energy use.

There are numerous options available for low-temperature HWS central and terminal (zone level) heating equipment.

For more information on the use of Hydronic Branch Conductors, refer to the Trane application guide, *Hydronic Branch Conductor* (APP-APG024*-EN).

- **Hydronic Branch Conductor:** This is a valve control unit used in a distributed hydronic heating and cooling system. It can direct either hot water or chilled water to and from a specific area of the building, based on that area's current need for heating or cooling. It simplifies zone comfort control by using the same branch piping for both cooling and heating, uses dual-purpose coils in the terminal units and air handlers, adapts to varying heating and cooling zone demands, and improves energy efficiency by allowing for the use of a lower HWS temperature.

Figure 18. Hydronic Branch Conductor used in a system



- **High-capacity heating coils:** For central air-handling units, more heating coil options are typically available to allow for heating with a lower HWS temperature, with an acceptable fluid ΔT and airside pressure drop.
- **Dual-purpose coils:** For both terminal units and central air-handling units, consider using a dual-purpose coil, which is using the same coil for both cooling and heating. Cooling coils are typically constructed with more surface area (face area, rows, fins) than heating coils, so if a cooling coil is supplied with hot water, it becomes a high-capacity heating coil. This enables the use of a lower HWS temperature, a higher fluid ΔT, and a lower pressure drop (both waterside and airside). Hydronic Branch Conductors, six-way valves, or high-accuracy Pressure Independent Control Valves (PICVs) are widely available to enable this changeover operation. This is an excellent way to retrofit an existing central AHU or terminal unit to enable it to use a lower HWS temperature.
- **Radiant heaters:** Radiant heating devices are commonly designed for a lower HWS temperature, making them a natural complement to AWHP-based systems.

So, what HWS temperature is needed to heat the space? It varies depending on the type of heating equipment used. Table 1 summarizes common minimum HWS temperatures, and the corresponding fluid ΔT range, which can satisfy typical commercial heating applications.

Table 1. Hydronic heating conditions for various airside heating equipment

Equipment Type	Minimum HWS Temperature	Expected ΔT at Minimum HWS Temperature
DOAS air-handling unit	>80°F	20-40°F
Central VAV air-handling unit	80-105°F	18-30°F
Single-zone VAV air-handling unit	100-105°F	12-26°F
VAV terminal units (4-row coil)	100-105°F	8-20°F
Fan-coil units (w/ changeover coil)	100-115°F	8-12°F

A dedicated outdoor air system (DOAS) often includes an exhaust-air energy recovery device to precondition the entering outdoor air, and the supply-air temperature during heating season is commonly no warmer than 70°F. This allows a DOAS unit to be selected using a lower HWS temperature at a substantial ΔT.

For more information, refer to the Trane *Engineers Newsletter* titled "Heating with Lower-Temperature Hot Water" (ADM-APN084*-EN).

The most challenging application for lower HWS temperatures is typically in-space fan-coil units. Often, this requires the use of a dual-purpose (or changeover) coil. In most cases, when the cooling coil in a fan-coil unit uses 45°F chilled water to supply 55°F air, the same coil can change over and use 105°F HWS temperature to heat the same flow rate of air from 60°F to 95°F. Even though the DOAS unit (which is commonly part of a fan-coil system) could use an even lower HWS temperature, this might require significant upsizing of the fan-coils. In general, a HWS temperature of 100°F to 115°F is needed to avoid the need to upsize fan-coils in an existing building.

Key Hydronic System Sizing Parameters

Proper sizing of hydronic system components—including pipes, pumps, and buffer tanks—is critical to ensuring reliable, efficient operation of modular AWHP systems across all load and ambient conditions. When designing these systems, evaluate and document the following four key sizing parameters:

1. Primary Pump Differential Pressure (dP) Setpoint: The primary pump dP setpoint, for both cooling and heating, governs pump speed and ensures appropriate flow delivery to the modular heat pumps.
   - Set the dP using manufacturer's product performance data for each system mode.
   - In AXM systems, a unique dP setpoint should be set for cooling and for heating.
   - In MAS systems, product reports typically include separate flow rates and pressure drops for each heat exchanger in different modes (e.g., heating and simultaneous modes for the condenser heat exchanger). Use the highest reported pressure drop and flow rate for each heat exchanger to ensure adequate flow to the modules.

2. Minimum Flow Rate: Each mode (cooling/heating) requires a minimum flow rate through the modular bank to maintain stable operation.
   - Calculate minimum flow as the total required flow (in each mode) divided by the number of modules in the bank.
   - For MAS systems with multiple published heat exchanger flow rates, select the highest minimum flow for each heat exchanger to ensure adequate flow to the modules.
3. Decoupler Pipe Sizing: Properly sizing decoupler pipes for both cooling and heating loops is essential for effective hydronic separation between primary (production) and secondary (distribution) loops.
   - The decoupler pipe should be sized at no less than 1.5 times the minimum flow rate.
   - System designers should analyze multiple operational scenarios, account for modules operating in different modes or at varying outdoor temperatures and ensure the decoupler size will support any required excess flow to maintain loop balance.
4. System Fluid Volume: Providing adequate system (loop) fluid volume is necessary for stable temperature control and to prevent excessive compressor cycling.
   - Fluid volume requirements are described in System Fluid Volume section. Calculate the loop volume for both cooling and heating based on total system flow rates and desired loop time.

Table 2. Hydronic system sizing considerations

Parameter	Cooling	Heating
Primary Pump dP Setpoints*	Cooling Pressure Drop	Heating Pressure Drop
Minimum Flow*	Cooling Flow / Number of Modules	Heating Flow / Number of Modules
Minimum Decoupler Size	Cooling Minimum Flow x 1.5	Heating Minimum Flow x 1.5
Recommended Loop Volume	2 to 5 minutes x System Cooling GPM	4 to 10 minutes x System Heating GPM

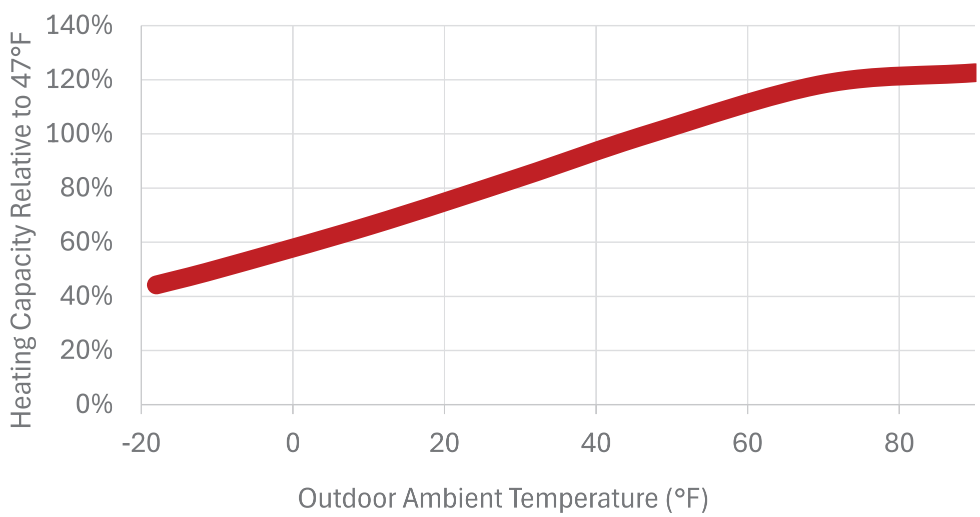
**It is recommended to control cooling and heating pumps to the higher of the pressure drops and flow rates between the different modes for MAS banks.*

Air-to-Water Heat Pump System Sizing

Outdoor air temperature has a significant impact on the full-load heating capacity of an AWHP. Since AWHP heating capacity is significantly reduced at colder outdoor (ambient) temperatures, a thorough analysis of unit capacity, size, and selection is essential. While the heating capacity of an AWHP is rated (for AHRI) at 17°F and 47°F outdoor air temperatures, the actual heating capacity of a unit will vary based on the site-specific design outdoor air temperature.

Figure 19 shows the relationship between AWHP heating capacity and outdoor air temperature, normalized to the 47°F AHRI rating point. A wide line is used because there is some variation in capacity change between unit sizes.

Figure 19. Impact of ambient temperature on AXM capacity (HWS temperature = 120°F)

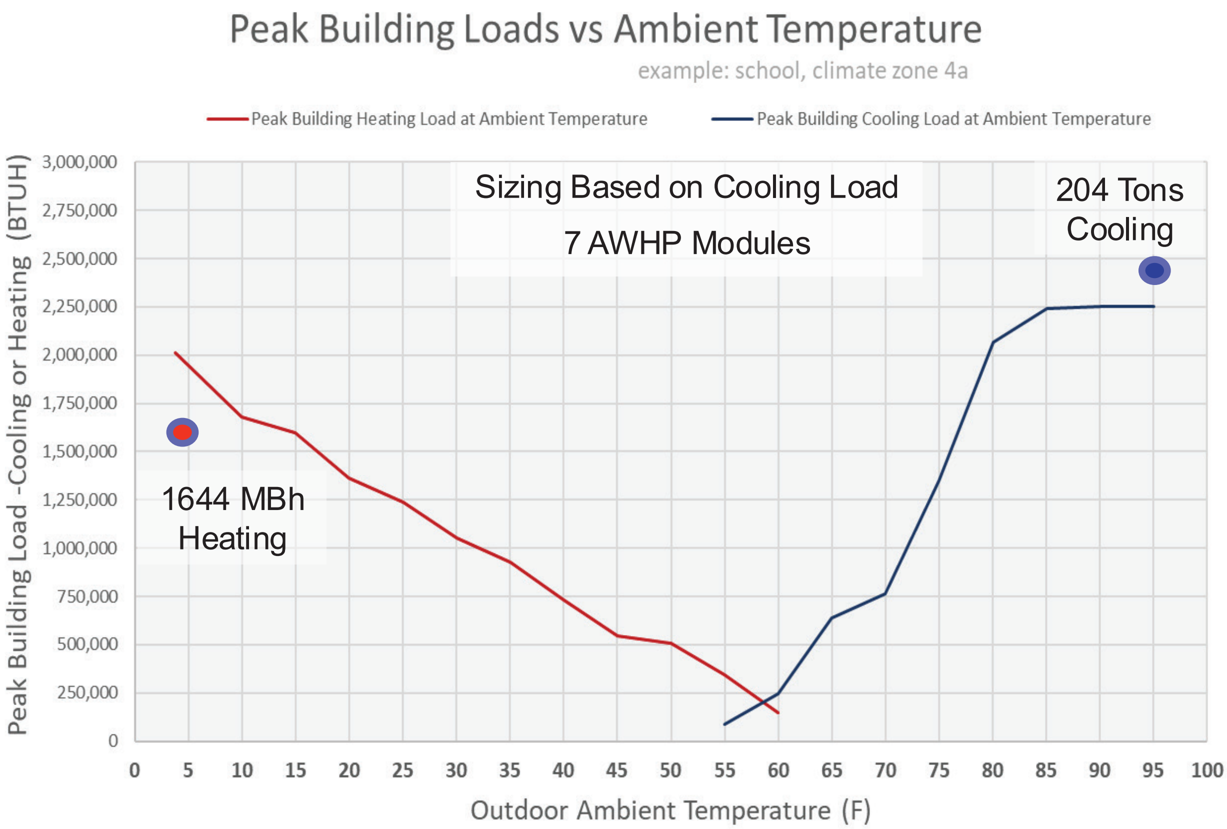


Example: AXM System Sizing

For this example, consider a school building with a high ventilation rate to analyze system heating and cooling capacity. The peak (design) heating load is 2000 MBh and the peak (design) cooling load is 2250 MBh, or 188 tons (Figure 20).

When this system is sized based on the peak (design) cooling load, seven (7) AXM modules are selected, with a total capacity of 204 tons. This results in 8 percent oversizing compared to the peak cooling load. In heating mode, these seven AXM modules result in a heating capacity of 1644 MBh, which is sufficient to offset 82 percent of the peak heating (design) load. Supplemental heat from an electric or gas boiler can be used to address the heating capacity shortfall and may represent the best balance between system first cost and carbon emissions reduction. Alternatively, sizing the system to offset the entire peak heating load would result in excess cooling capacity and a much higher equipment cost.

Figure 20. Modular AWHP system capacity based on cooling load



Uncertainty regarding actual building loads and use may cause some design engineers to add safety factors to their design assumptions. This tendency seems to be more prevalent with regards to building heating, since the consequences of inadequate heating capacity are especially concerning. In either case, oversizing equipment has negative consequences to system first cost.

It is important to use realistic assumptions when estimating building loads and applying safety factors. Make sure the building design load is based on a detailed computerized load analysis and based on the “Block Load” for the system, not the “Sum-of-Peaks” of coil loads. Lastly, since most heating operating hours are at low loads, it is important to evaluate the system for adequate capacity turn-down capability.

Final AWHP selection should consider the heating capacity impact of defrost operation (see “Defrost Implications on Sizing”, p. 34). For this example, the design outdoor air temperature is 4°F. According to the defrost derate chart (Figure 21 (p. 35)), a 0.90 capacity factor should be applied to account for defrost. When selecting equipment, this ensures that the installed capacity can still offset the heating load during and after defrost mode.

Trane AXM and MAS units are available in 30-ton (nominal) modules and module banks can be configured up to 10 AXM modules or 12 MAS modules. Table 3 lists quantities of AXM modules that could be considered for this school example, including heating and cooling load coverage implications. A bank of either seven (7) or eight (8) modules would be slightly undersized for the peak heating load, so a boiler could be added to supplement system heating capacity. A bank of nine (9) modules is the minimum number required to meet the entire peak heating load with AWHPs. A bank of ten (10) modules could be considered, which would provide extra capacity during and after a defrost cycle, as well as providing some level of redundancy. And when the installed AWHP capacity is higher, it allows for the heat pumps to catch up quicker after a defrost cycle.

Table 3. Example of AXM equipment sizing options (2000 MBh design heating load, 188 tons design cooling load)

Module Quantity	Heating Capacity (MBh)	Cooling Capacity (Tons)	Heating Load Coverage	Cooling Load Coverage
7	1655	204	82% of design (undersized)	108% of design
8	1879	233	94% of design (slightly undersized)	124% of design
9	2113	263	106% of design (meets heating load)	140% of design
10	2348	292	117% of design (extra capacity for defrost and redundancy)	156% of design

AXM and MAS Sizing Considerations

Unit application and sizing should be carefully assessed for each project to maximize equipment efficiency and minimize installation costs. Trane AXM units, which use a two-pipe changeover design, are applied differently than MAS units, which feature a four-pipe configuration and can provide simultaneous heating and cooling.

AXM units are commonly used in two-pipe systems that alternate between heating during winter and cooling during summer. A single module operates in either cooling or heating mode and should be sized for the greater of the two loads if no supplemental heating or cooling equipment is present.

AXM units can be installed in a four-pipe system, where separate heating and cooling pipes connect to the heat pumps and are switched via isolation valves. In this type of system, at least two module banks are required—one dedicated to cooling and the other to heating.

Simultaneous Heating and Cooling

It is essential to evaluate the building load profile when sizing AWHP units:

- How much cooling is needed during heating-dominant operation?
- How much heating is needed during cooling-dominant operation?

By understanding these simultaneous heating and cooling demands, heat recovery can effectively be incorporated into the system design.

MAS units are ideal for buildings with simultaneous cooling and heating loads, due to their efficient heat recovery capabilities. To avoid unnecessary cost, the MAS units can be sized to meet the peak heat recovery demand and then use additional AWHPs, chillers or auxiliary heating units for the remaining loads. Table 4 demonstrates this for a decoupled system using 25% ethylene glycol. The heating design load is 2100 MBh at 5°F ambient, the cooling design load is 200 Tons at 95°F ambient, and the peak simultaneous load is 1300 MBh. The HWS is 115°F and chilled water supply (CHWS) temperature is 42°F both with a 15°F ΔT. Using MAS modules exclusively, Option 1 requires 10 MAS modules to meet the full heating load and has more than enough capacity to meet the cooling and simultaneous load, whereas Option 2 sizes the MAS bank for the simultaneous heating load using 3 modules in the bank, and uses 6 AXM modules for the remaining cooling and heating loads. Note that chillers and auxiliary heating units could also have been used in this application.

Table 4. Example of MAS and AXM equipment sizing options (2100 MBh design heating load, 200 tons design cooling load)

Parameter		Option 1 10 MAS	Option 2 3 MAS + 6 AXM
MAS	Heating (MBh)	2237	671
	Cooling (Tons)	300	86
	Simultaneous (MBh)	4309	1293
AXM	Heating (MBh)	-	1444
	Cooling (Tons)	-	171
Total	Heating (MBh)	2237	2115
	Cooling (Tons)	300	257
	Simultaneous (MBh)	4309	1293

Systems that use modular heat pump chillers, whether configured as multiple modules in one bank or spread across several banks can be beneficial. They provide better control of flow and capacity, which is useful during low load operation. And they can switch between cooling and heating modes, while optimizing heat recovery, without needing a separate heat recovery chiller.

As an example, two banks of four AXM modules (eight modules in total) are used to provide the required peak heating and cooling capacity. Cooling operation is disabled below 40°F dry bulb, and heating operation is disabled above 70°F dry bulb. When the outdoor temperature is above 70°F, all eight modules can provide cooling; when the temperature is below 40°F, all eight modules can provide heating. Between 40°F and 70°F, one bank of four units can be used to satisfy the cooling load, while the other bank can be used to satisfy the heating load. In this mild temperature range, the AXM performs efficiently, so a dedicated heat recovery unit (DHRU) offers only a small efficiency benefit. However, a small DHRU can eliminate the need to run two banks at low loads, extending equipment life and improving system control and efficiency.

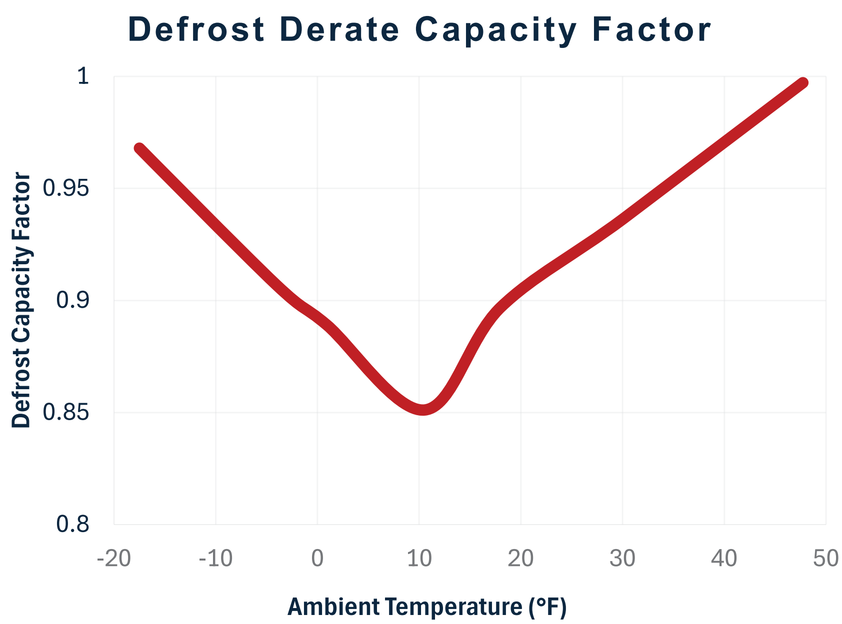
Defrost Implications on Sizing

When outdoor air temperatures drop below 47°F dry bulb temperature, the outdoor coil in an AWHP can freeze, triggering a defrost cycle. Trane AXM and MAS units use intelligent controls to defrost automatically as needed, minimizing defrost duration and frequency while maintaining heating efficiency. These controls limit defrost to half of the modules in heating mode, which reduces the impact on system supply temperature. During defrost, the AWHP temporarily switches to operate in cooling mode, so the heat rejected through the outdoor coil can melt the ice.

MAS units are less susceptible to defrost because modules operating in simultaneous heat recovery mode do not need to enter defrost mode, which ensures continuous heating and improved reliability during cold weather.

The heating capacity derate in Figure 21 was generated using lab tested data. However, there are several real-world factors—such as outdoor dry-bulb and wet-bulb temperatures, solar exposure, installation clearances, coil cleanliness, wind speed, and more—that can influence the frequency at which an AWHP goes into defrost and for how long. Since it is not possible to predict all factors influencing defrost frequency/duration, defrost derates are intended for general estimation of heating capacity available at the given ambient temperatures.

Figure 21. AXM/MAS defrost derate capacity factor for heating capacity as a function of ambient temperature



As the ambient dry-bulb temperature decreases, the moisture content (humidity ratio) of the air also tends to decrease, reducing the amount of frost that can build up on the outdoor coil during heating mode. This is why the capacity derate factor becomes less severe when the ambient dry-bulb temperature is below 10°F.

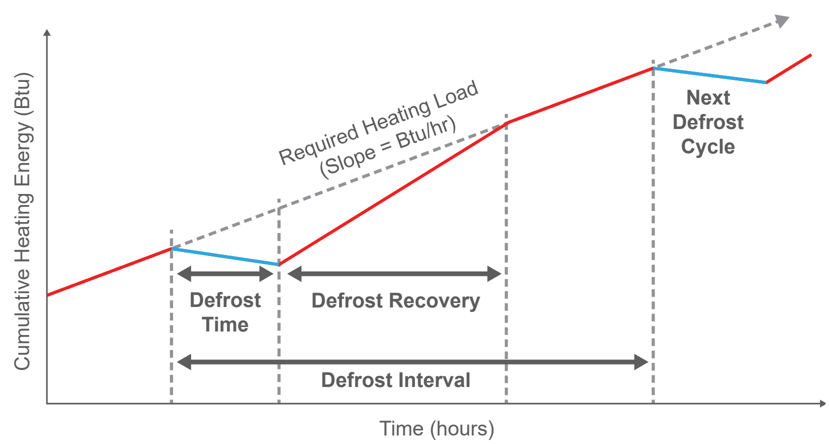
Defrost Impact on System Design

Once the AWHP defrost cycle is understood at the unit level, it is also important to understand its influence on system operation. As mentioned, the defrost capacity derate factor is used to estimate available heating capacity when operating below 47°F outdoors.

In a typical comfort heating application, the AWHP is sized for the peak (design) heating load. For off-peak heating loads, the AWHP will likely operate unloaded.

During defrost cycle, the module ceases to produce its full heating capacity and will remove energy from the loop (blue sloped line in Figure 22). Once the defrost cycle has completed, the heat pumps will operate at a higher heating capacity until they catch back up to the building heating load. (The charts in this guide are based on the worst-case scenario when half of the modules in a bank are in defrost mode. If less than half of the available modules are in defrost mode, this energy removal impact will be lower.)

Figure 22. Defrost impact on cumulative heating over time



Every system will experience unique gaps in heating capacity when modules enter defrost mode. This impact of defrost can be addressed through thoughtful system design:

- For heating-dominant applications, size the AWHPs to meet the peak heating load, unless supplemental heat sources are available. This ensures excess capacity during periods below peak heating demand.
- For cooling-dominant applications, size the AWHPs to meet the peak cooling load. This typically results in surplus heating capacity, which can be confirmed by analyzing load profiles and unit selections.
- The number of modules directly affects how much heating capacity is lost during defrost. For example, in a system with four modules, if one of four modules enters defrost mode, 25 percent of system heating capacity is unavailable. But if the system uses eight modules, this impact drops to 12.5 percent.
- Including an additional (N+1) module provides redundancy and helps offset the loss of capacity during defrost cycles, allowing the system to recover more quickly.

System Configurations

There are numerous system configurations possible with modular heat pumps (Trane MAS and AXM), so they cannot all be covered here. Therefore, this section will detail several systems for either heating- or cooling-dominant applications and do so with the aim of reducing complexity and installed cost while providing high levels of efficiency.

In all configurations, the BAS is responsible for enabling the heat pumps, selecting the operating mode and supply temperature setpoint, along with positioning control valves to direct chilled fluid to/from the respective loop. The supply temperature setpoint can also be set at the unit controller. The total number of modules used in each system is based on the peak heating and cooling loads and available capacity at design conditions.

Trane unit controllers can unload a module bank to a single module operating a single compressor, so capacity and flow turn-down is a function of the number of modules used in the system. The control incorporates a five-minute delay when adding or removing compressors or modules. If a module has more than one compressor, the controller stages the additional compressor as needed. To bring a new module online, the controller first opens its motorized control valve (which has a 35-second stroke time), verifies flow, and then starts the next compressor.

AXM System Configurations

The following system configurations are based on the Trane AXM two-pipe heat pump.

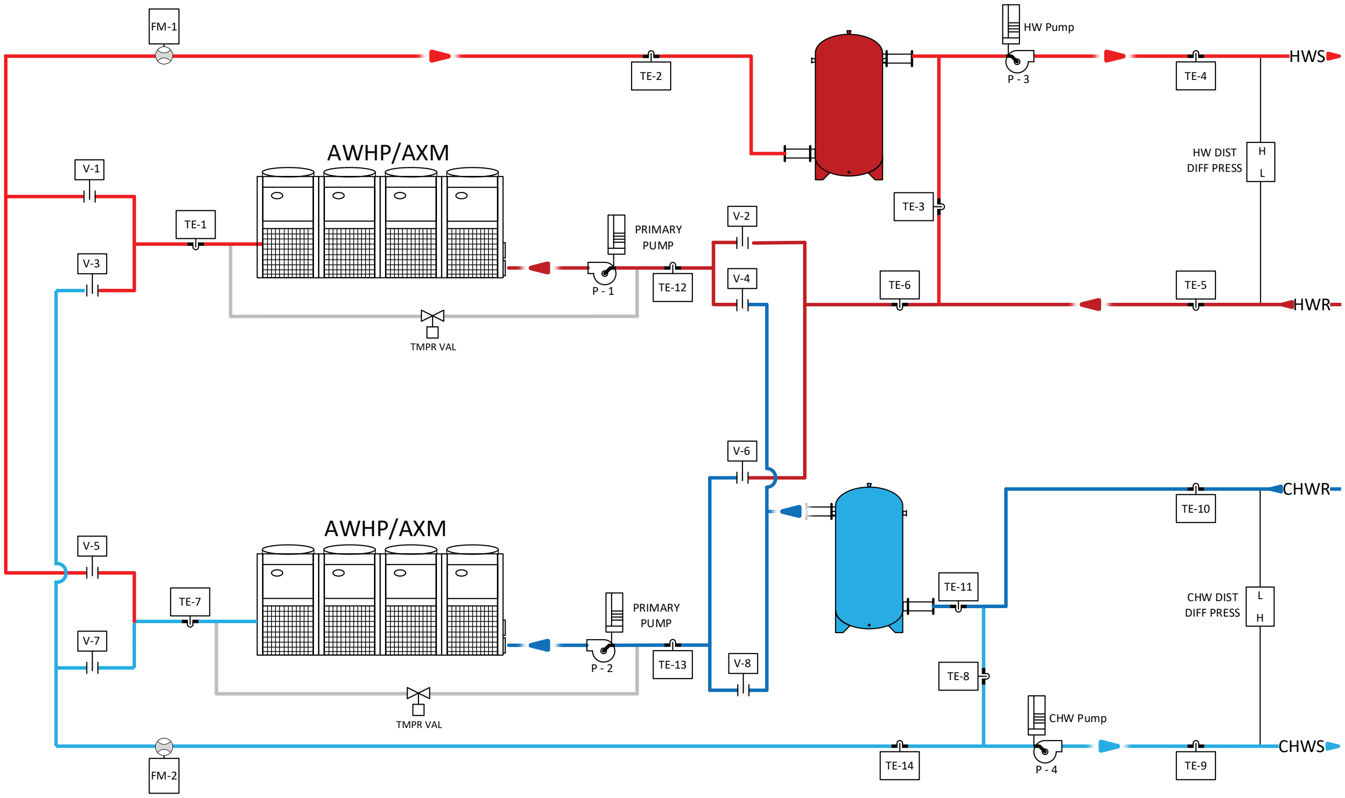
Base AXM System Configuration

The base configuration consists of at least two AXM banks to provide simultaneous heating and cooling (heat recovery is not included in the AXM). There is no limit to the number of banks in the system, making it suitable for both standard and heating-dominant applications.

Each AXM unit has two pipes—a supply and a return—for either chilled or heated fluid. The system uses variable primary/variable secondary (VP/VS) pumping, with dedicated primary pumps for each heat pump bank. External control valves direct flow from the heat pump banks to the heating or cooling loops.

Distribution pumps can be either dedicated or manifolded within the distribution loop. At least two AXM heat pump banks are required for simultaneous heating and cooling, as each bank can only operate in one mode (heating or cooling) at a given time (Figure 23).

Figure 23. Base AXM heat pump system configuration



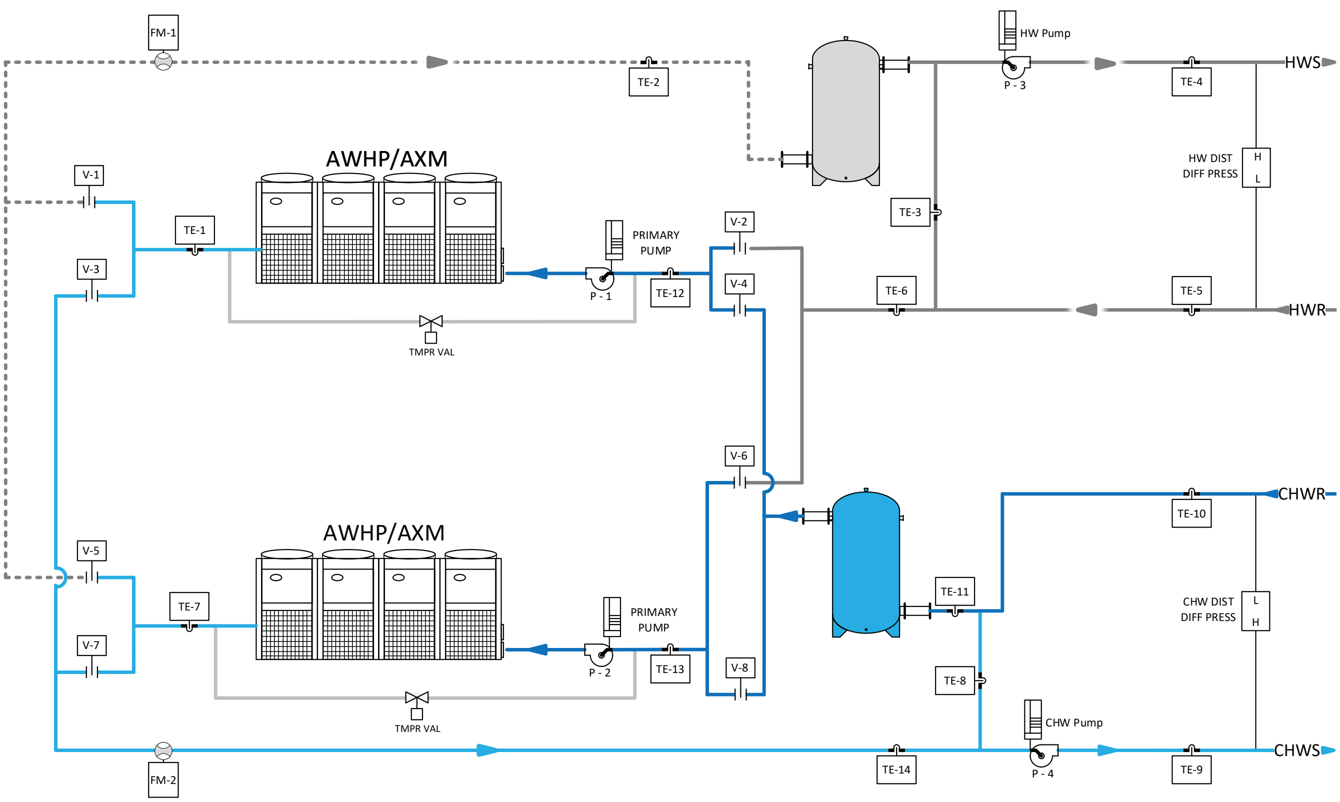
The maximum hot-water supply temperature is 140°F, based on the capability of the heat pump. Unless separate boilers or chillers are included, the installed heat pump capacity must meet both the heating and cooling design loads.

Modes of Operation

There are three operating modes for this base AXM system configuration: cooling, heating, and simultaneous heating and cooling.

Cooling-only mode. When the system requires only cooling, all operating modules are in cooling mode, rejecting heat to the ambient air. The refrigerant-to-air heat exchanger (outdoor coil) functions as a heat sink as heat is extracted from the cooling loop and rejected to the ambient air (Figure 24).

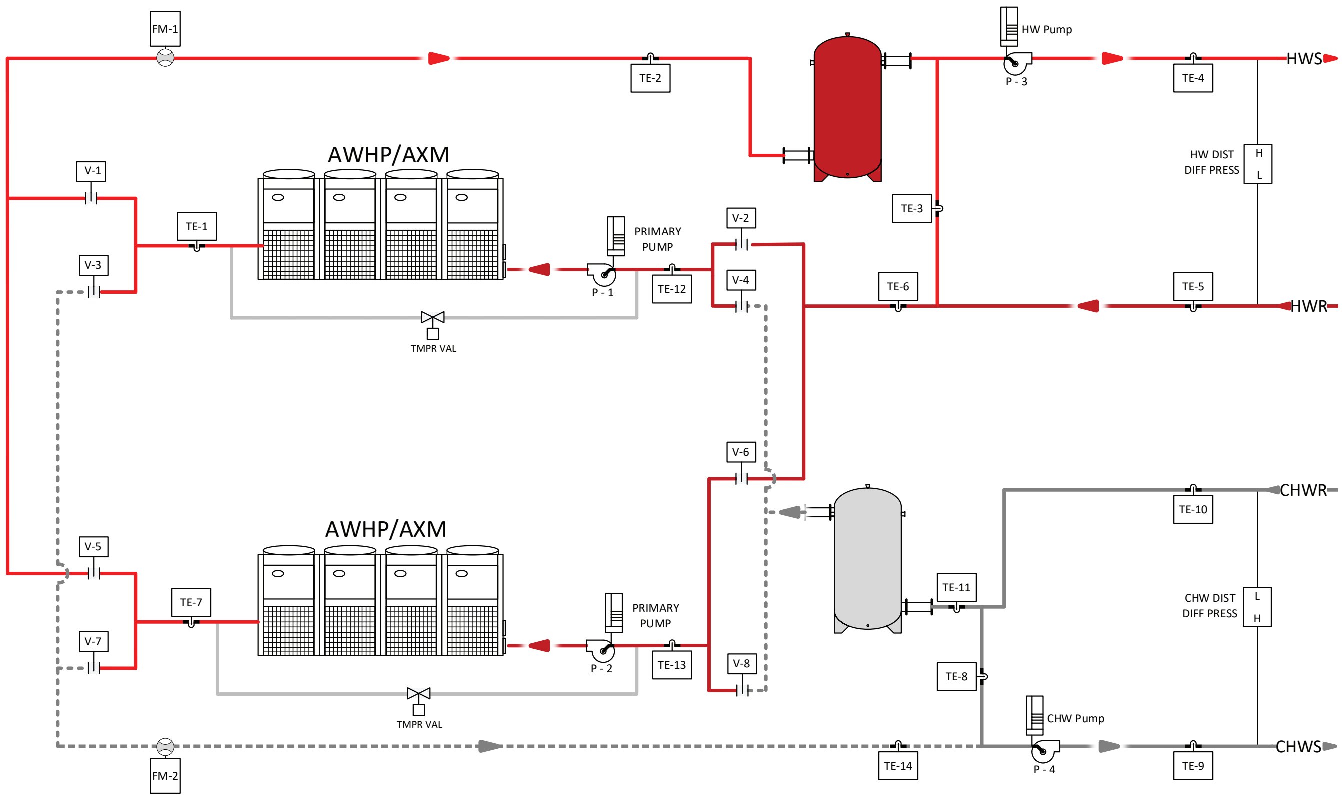
Figure 24. Base AXM system (cooling-only mode)



If multiple AXM banks are used in this system configuration, all banks are available to operate in cooling mode. The unit controller manages the staging of modules within each bank. As the system cooling load increases, the chilled-water supply temperature increases. If this temperature rises above the setpoint plus an adjustable deadband, the controller sequentially activates additional compressors or modules, one at a time, to maintain the desired supply fluid temperature.

Heating-only mode. When the system requires only heating, all operating modules are in heating mode, sourcing heat from the ambient air. The refrigerant-to-air heat exchanger (outdoor coil) functions as a heat source as heat is extracted from the ambient air and added to the heating loop (Figure 25).

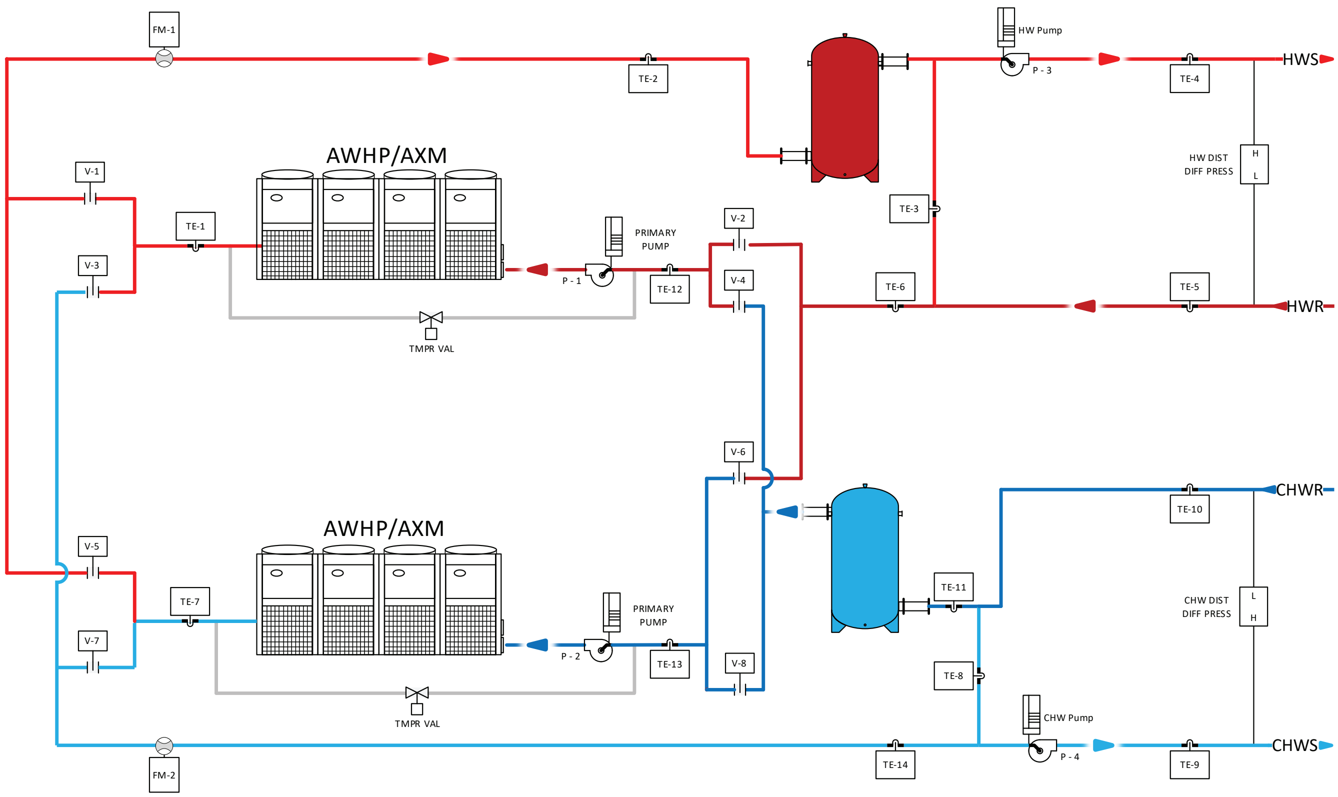
Figure 25. Base AXM system (heating-only mode)



If multiple AXM banks are used in this system configuration, all banks are available to operate in heating mode. The unit controller manages the staging of modules within each bank. As the system heating load increases, the hot-water supply temperature decreases. If this temperature falls below the setpoint minus an adjustable deadband, the controller sequentially activates additional compressors or modules, one at a time, to maintain the desired supply fluid temperature.

Simultaneous heating and cooling mode. At times, the system may need to deliver both heating and cooling simultaneously, although typically one load will dominate. Therefore, this mode can be classified as either cooling-dominant or heating-dominant. During simultaneous operation, all modules in one bank provide cooling while the modules in the other bank provide heating (Figure 26). Sequencing and module rotational schedules determine which banks operate in each mode.

Figure 26. Base AXM system (simultaneous heating and cooling mode)



In this base AXM system configuration, at least two modular banks should be used if simultaneous heating and cooling are needed.

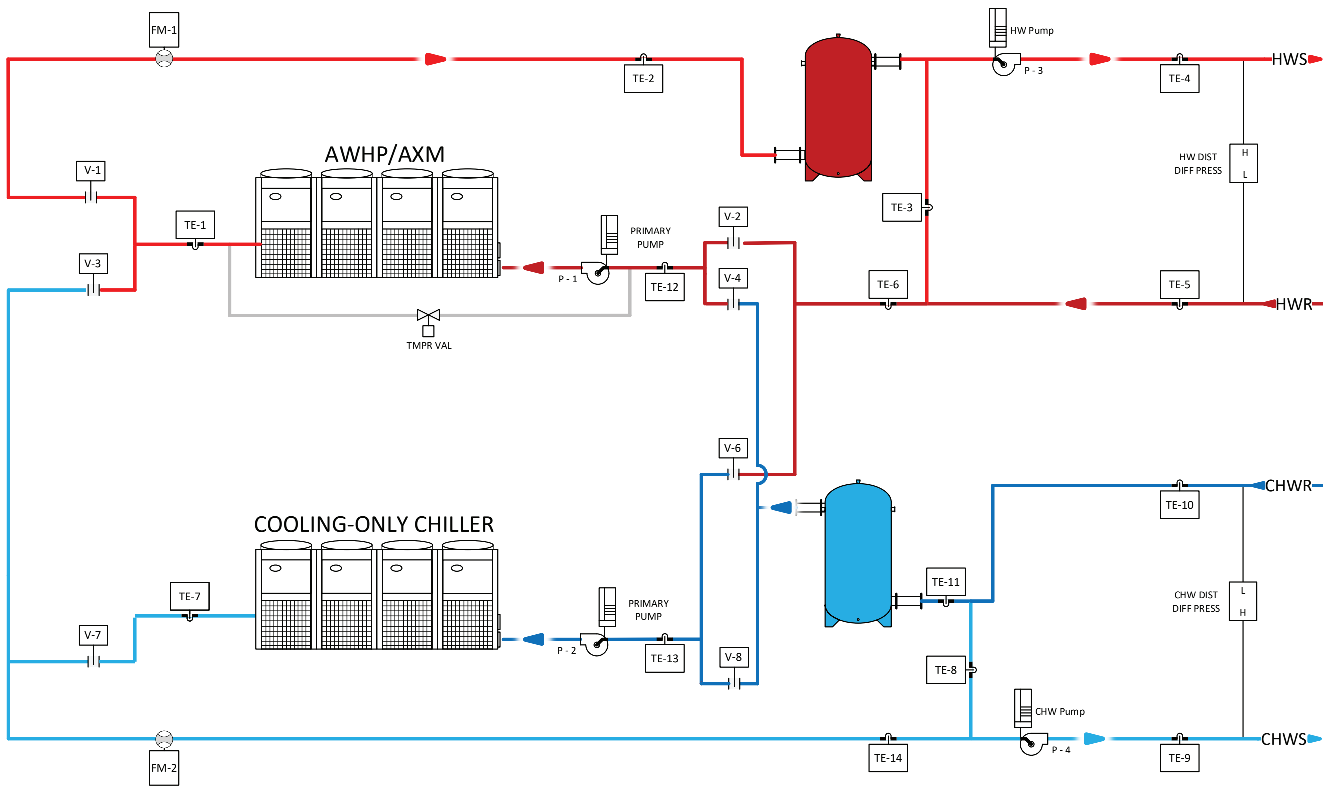
The BAS provides an enable signal for either heating and or cooling mode, along with a supply temperature setpoint. Once the module has proven flow, and entering fluid temperature limits and timers are satisfied, compressors are cycled on and off to maintain this setpoint.

Mode transitions and tempering valves. For the Trane AXM heat pump, the unit controller uses an adjustable delay timer to moderate the mode transition by adhering to the minimum entering fluid temperature in heating mode which is 55°F (12.8°C), and the maximum entering fluid temperature in cooling mode which is 105°F (40.6°C). In this base system configuration, a system tempering valve is included which the BAS modulates to accelerate entering water temperature moderation following a mode transition. Coordinating these controls during commissioning will ensure smooth transitions.

Cooling-Dominant AXM System Configuration

In this system configuration, one bank of heat pumps is replaced with a cooling-only chiller (packaged or modular) to more efficiently meet the dominant cooling loads (Figure 27).

Figure 27. Cooling-dominant AXM system (using a cooling-only chiller)



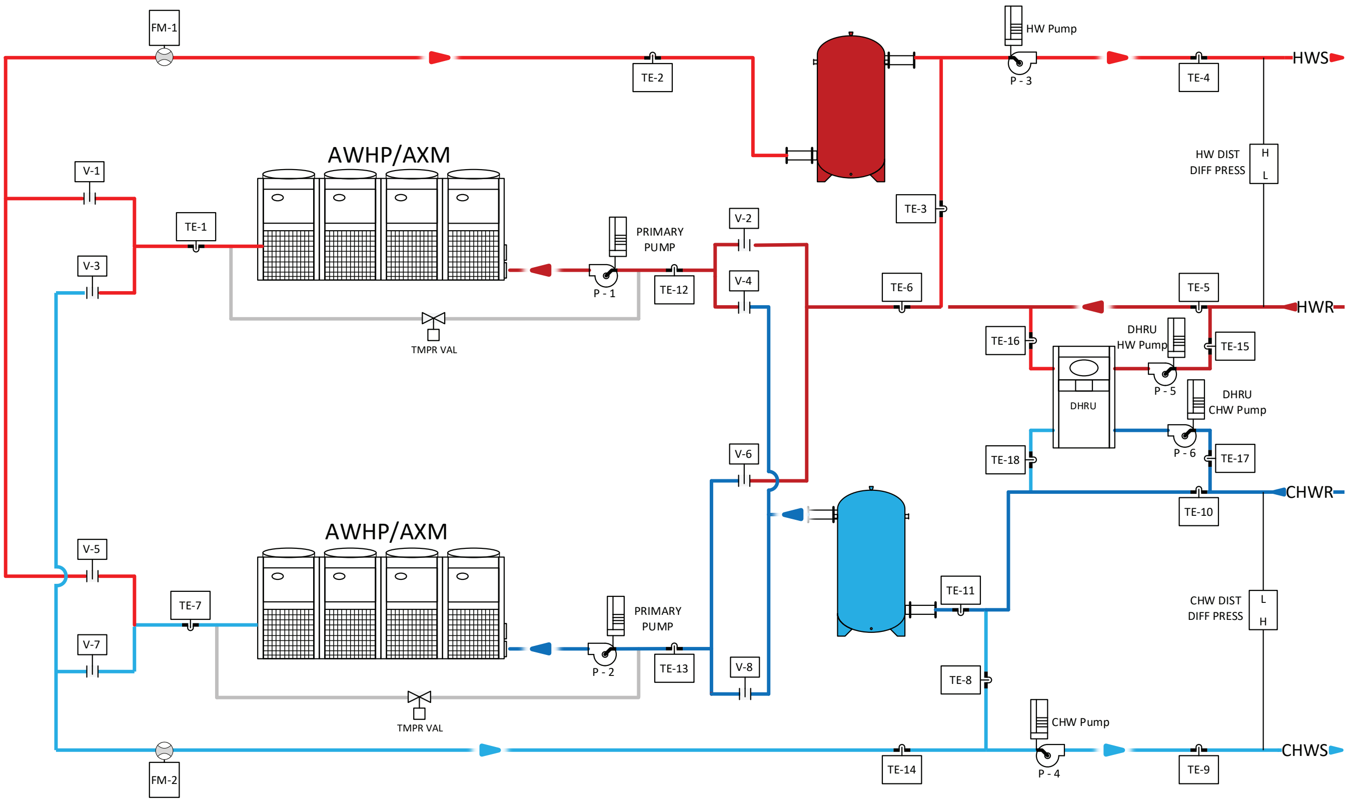
When the peak cooling load exceeds the peak heating load (cooling-dominant), this configuration is preferable because a chiller is more efficient and costs less than a heat pump.

If the building owner prefers all units to be of the same type, then the base system configuration (using all heat pumps) might still be used, but at a cost premium.

AXM System with Dedicated Heat Recovery

When simultaneous cooling and heating loads exist, it is likely more efficient to operate a heat recovery unit than to operate one AWHP in cooling mode and one AWHP in heating mode. Therefore, in this configuration, a dedicated heat recovery unit (DHRU) is added to the base system (Figure 28).

Figure 28. AXM system with a dedicated heat recovery unit (DHRU)



This DHRU is piped in the sidestream position to maximize the amount of heat shifted from the cooling loop to the heating loop. If the DHRU is a packaged chiller or a single module, the DHRU pump(s) can be constant flow; if the DHRU includes multiple modules, the DHRU pump(s) must be variable flow.

Comparison of MAS and AXM Units

There are several important differences between the MAS and AXM units that impact their respective system designs. The Trane MAS unit is a four-pipe heat pump, so the first notable difference between the MAS and AXM units is the absence of control valves in the supply and return piping for the MAS unit.

In the Trane AXM unit, the refrigerant-to-air heat exchanger (coil) acts as the heat source during heating mode and as the heat sink during cooling mode. The single refrigerant-to-fluid heat exchanger adds or removes heat to or from the system fluid passing through a single set of pipes. This dictates the need for external valve control to ensure the heated or chilled fluid is sent to the proper distribution loop.

In the Trane MAS unit, heat is exchanged between two of three heat exchangers–one each in the chilled and heated fluid loops, and one being the air coil. The unit determines which heat exchangers are active based on supply temperatures and system demand. MAS attempts to operate in heat recovery mode as a priority, sourcing or sinking heat from or to the air coil within a given module when the heating and cooling loads are not balanced. Modules control their heat source/sink heat exchangers internally.

MAS units include internal automatic motorized isolation valves per module. The unit controller opens and closes these isolation valves as modules are staged on and off. Modules are added based on the deviation of the supply fluid temperature from setpoint. A flow switch internal to each module serves to prove flow prior to engaging compressors as they are staged on by the unit controller. Because the heat source/sink heat exchangers are controlled by the MAS unit controller, the BAS is not capable of controlling the isolation valves.

Furthermore, there is an additional (set of) pump(s) because the pipes are dedicated to heated or chilled fluid. Tempering valves and bypass are not included, although a tempering valve could be used if fluid temperatures are expected to drift outside of the allowable operational range (see ”AXM Operating Ranges”, p. 6).

MAS System Configurations

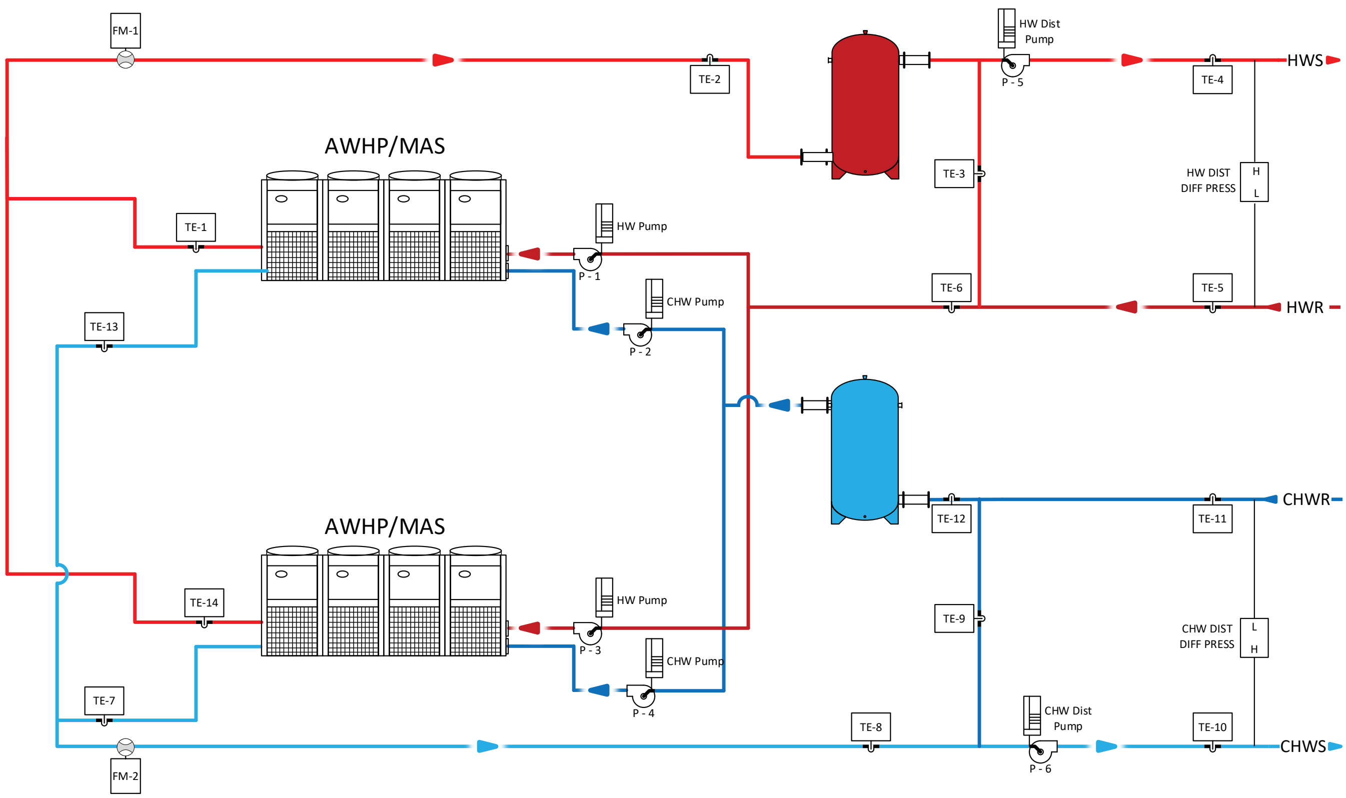
The following system configurations are based on the Trane MAS four-pipe heat pump.

Base MAS System Configuration

The base configuration consists of at least one bank of MAS heat pumps that serves four-pipe distribution, one chilled-water loop and one hot-water loop, so cooling and heating can be provided where needed. Unlike the AXM configurations discussed earlier, MAS is a four-pipe unit, so both chilled and heated fluid can be supplied simultaneously from one bank of heat pump modules. So, there is no minimum number of heat pump banks in this system.

The system uses variable primary/variable secondary (VP/VS) pumping, with a set of dedicated primary pumps for each heat pump bank and a set of distribution pumps for each loop (Figure 29). The primary and secondary pumps will include VFDs.

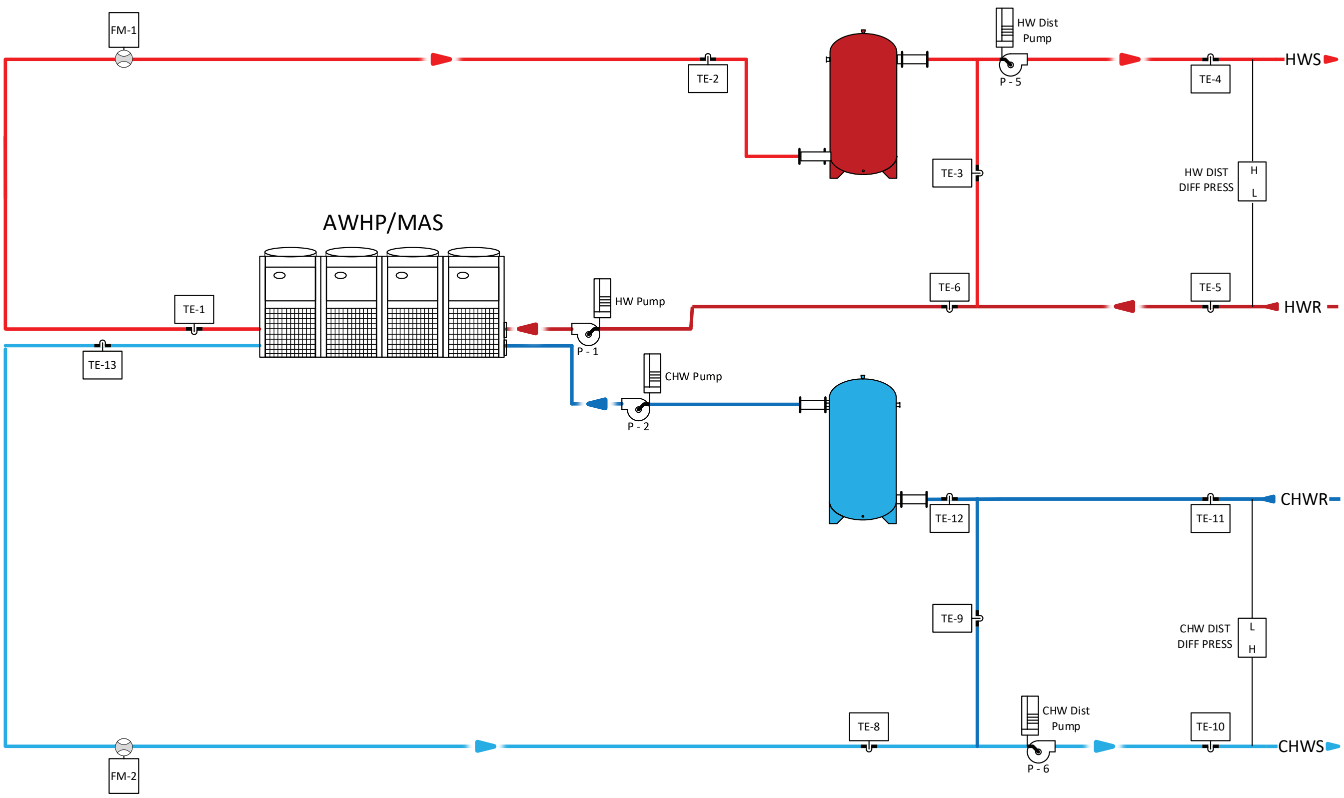
Figure 29. Base MAS heat pump system configuration



The maximum hot-water supply temperature is 140°F, based on the capability of the heat pump. Unless separate boilers or chillers are included, the installed heat pump capacity must meet both the heating and cooling design loads.

If only a single bank is used (Figure 30), at least three modules should be used to allow for adequate turndown, provide redundancy, and ensure acceptable temperature control.

Figure 30. Base MAS heat pump system with a single bank of modules

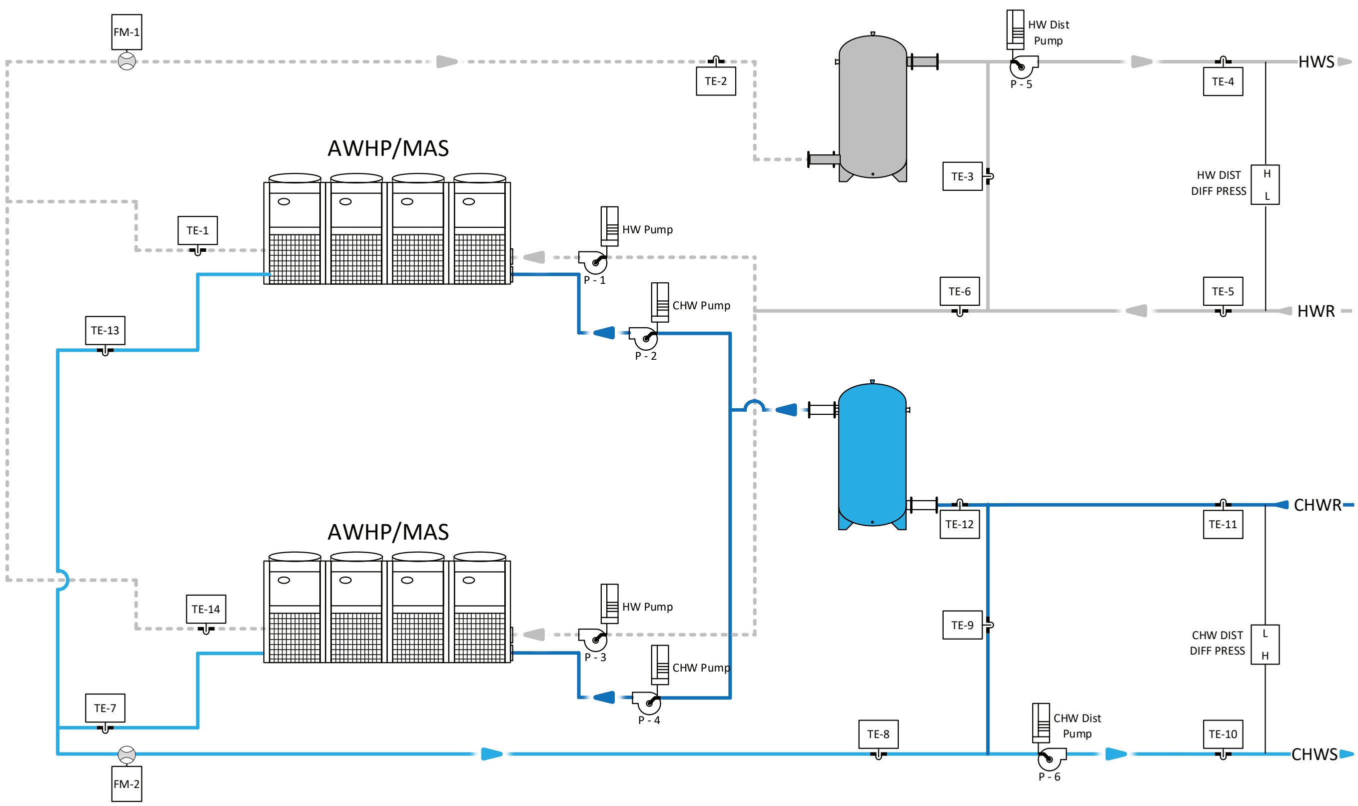


Modes of Operation

There are three operating modes for this base MAS system configuration: cooling, heating, and simultaneous heating and cooling.

Cooling-only mode. When the system requires only cooling, all operating modules are in cooling mode, rejecting heat to the ambient air. The refrigerant-to-air heat exchanger (outdoor coil) functions as a heat sink as heat is extracted from the cooling loop and rejected to the ambient air (Figure 31).

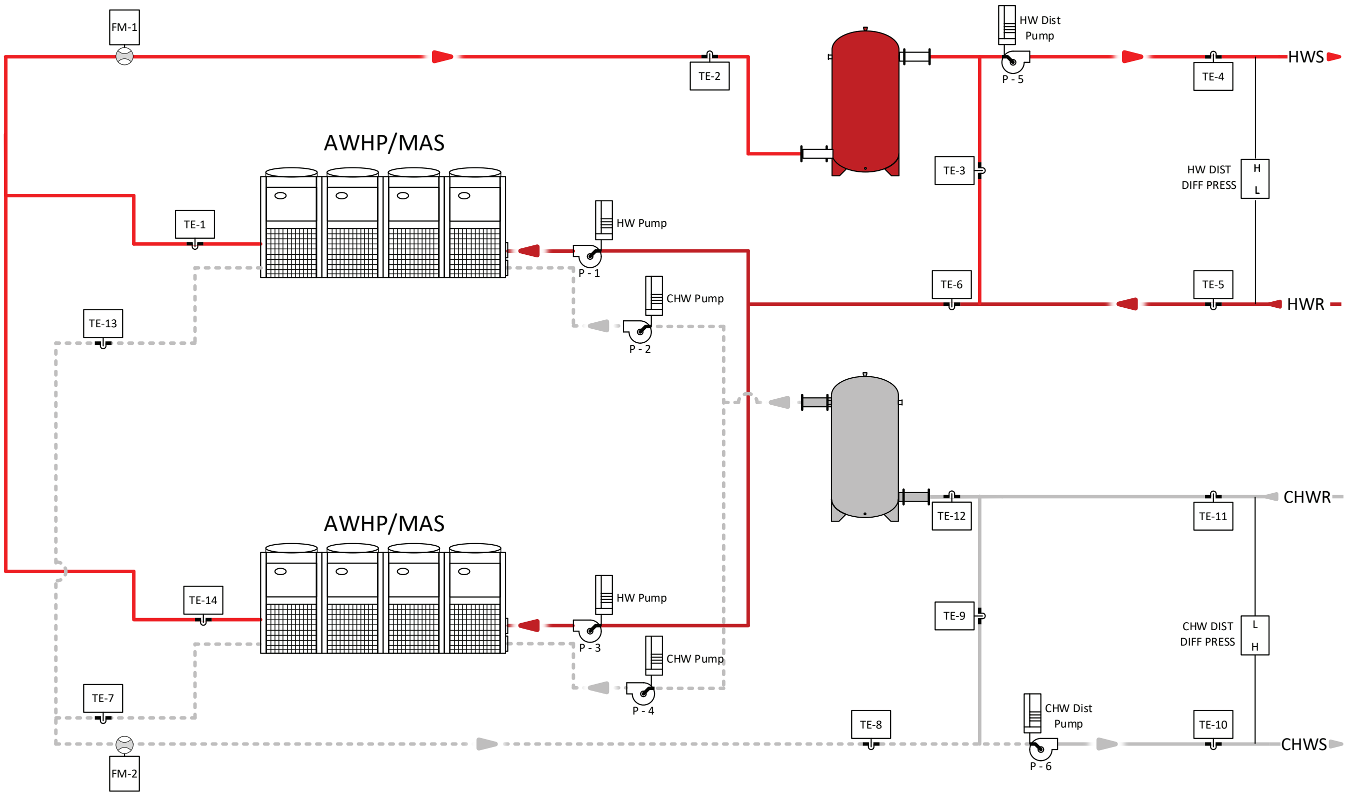
Figure 31. Base MAS system (cooling-only mode)



If multiple MAS banks are used in this system, all banks are available to operate in cooling mode, so all heat removed from the cooling loop is rejected to ambient air. Staging of compressors or modules within a modular heat pump occurs within its unit controller. The module unit controller commands additional MAS units on and off based on supply fluid temperature. As the chilled fluid supply temperature increases above the chilled fluid setpoint plus a user defined deadband, additional compressors or modules are staged on, one at a time, to maintain the supply fluid setpoint. Trane unit controllers incorporate a five-minute delay when adding or removing compressors or modules.

Heating-only mode. When the system requires only heating, all operating modules are in heating mode, sourcing heat from the ambient air. The refrigerant-to-air heat exchanger (outdoor coil) functions as a heat source as heat is extracted from the ambient air and added to the heating loop (Figure 32).

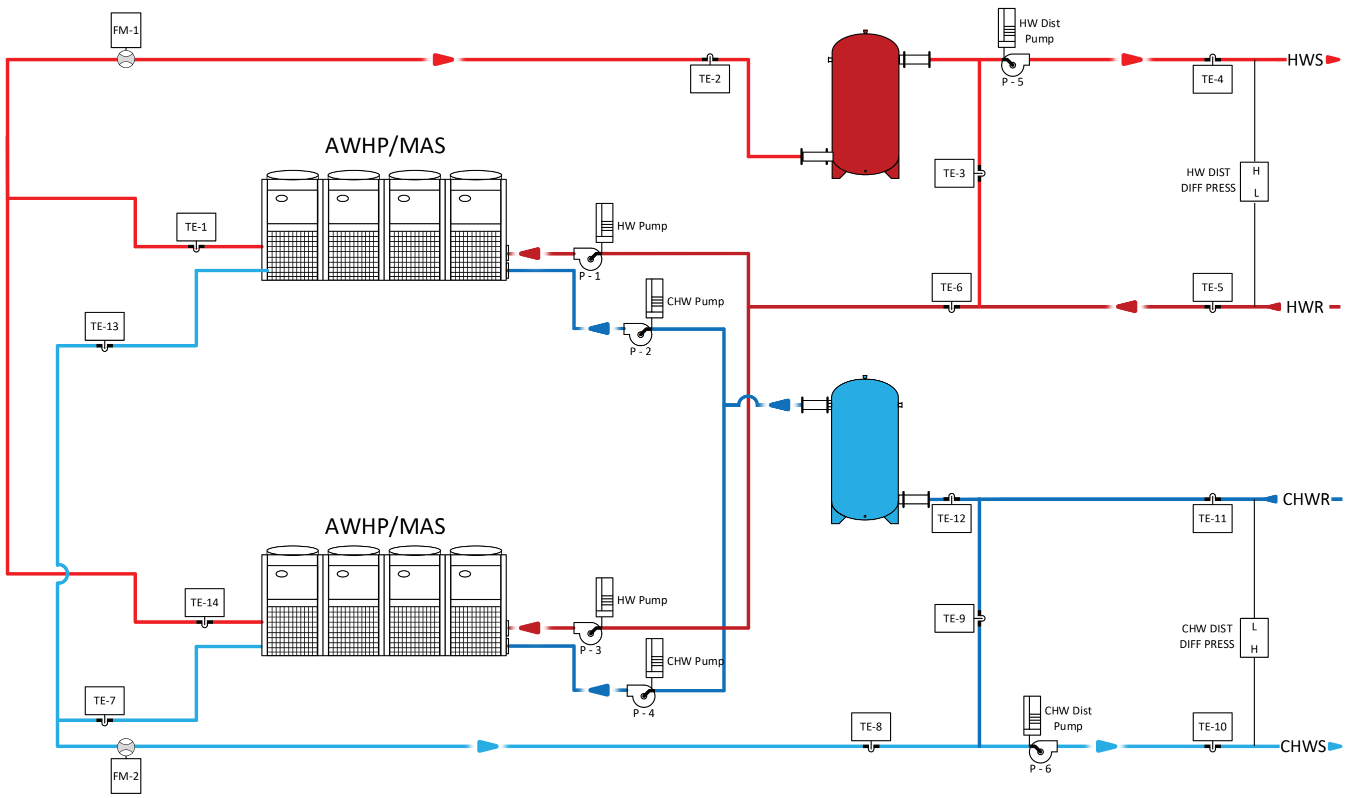
Figure 32. Base MAS system (heating-only mode)



If multiple MAS banks are used in this system configuration, all banks are available to operate in heating mode. The unit controller manages the staging of compressors or modules within each bank. As the system heating load increases, the hot-water supply temperature decreases. If this temperature falls below the setpoint minus an adjustable deadband, the controller sequentially activates additional compressors or modules, one at a time, to maintain the desired supply fluid temperature.

Simultaneous heating and cooling mode. At times, the system may need to deliver both heating and cooling simultaneously, although typically one load will dominate. Therefore, depending on demand, this mode will be either cooling-dominant or heating-dominant (Figure 33).

Figure 33. Base MAS system (simultaneous heating and cooling mode)



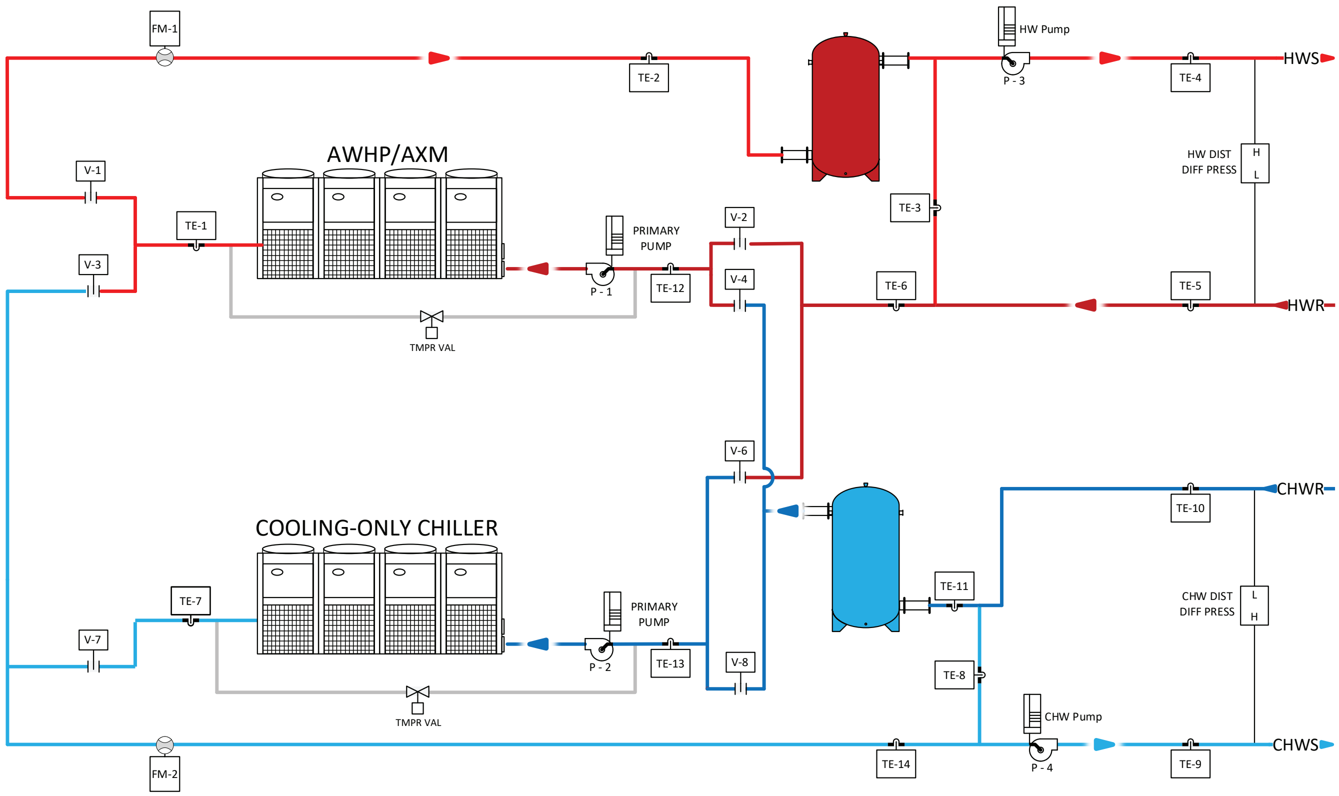
One or two MAS modules can operate in simultaneous mode, while a third module operates in either heating or cooling mode as needed. This simultaneous (heat recovery) mode is the most efficient operating mode, so it is prioritized. Additional modules are used to satisfy any remaining heating or cooling load. If cooling-only or heating-only operation is desired, modules must be locked out of simultaneous mode.

The BAS provides an enable signal for either heating and or cooling mode, along with a supply temperature setpoint. Once the module has proven flow, compressors are cycled on and off to maintain this setpoint.

Cooling-Dominant MAS System Configuration

In this system configuration, one bank of heat pumps is replaced by one or more cooling-only chillers (packaged or modular) to more efficiently meet the dominant cooling loads (Figure 34).

Figure 34. Cooling-dominant MAS system (using cooling-only chillers)

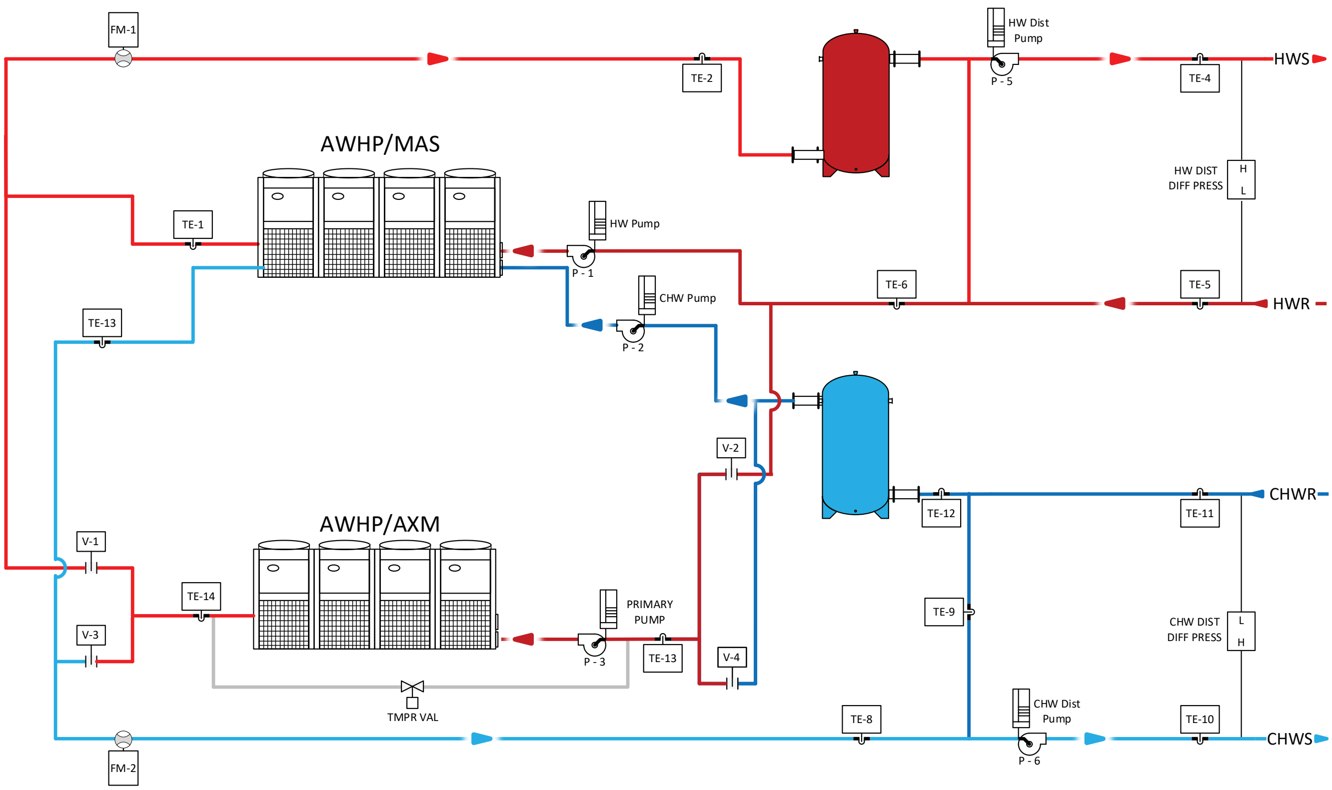


When the peak cooling load exceeds the peak heating load (cooling-dominant), this configuration is preferable because a chiller is more efficient and costs less than a heat pump.

Heating-Dominant MAS System Configuration

In this system configuration, one bank of MAS heat pumps is replaced with one or more two-pipe AXM heat pumps to more efficiently meet the dominant heating loads (Figure 35). Either packaged or modular heat pumps can be used.

Figure 35. Heating-dominant MAS system (using two-pipe AXM heat pumps)



System Options

Auxiliary or Supplemental Heating

Auxiliary heat refers to heating that is provided by a source other than the AWHPs, which operates only when AWHPs are unable to function due to extremely low outdoor temperatures or equipment failure. For example, many AWHPs cannot operate if the outdoor air temperature drops below -18°F, which may occur in a northern climate but is rare elsewhere, except during extreme weather events.

Regardless of climate, it is essential to plan for an alternative (auxiliary) heat source to address this situation. When designing for full auxiliary heating, size the system to meet expected extreme conditions. Since auxiliary heat is only needed occasionally, its impact on annual carbon emissions is minimal, so high-efficiency fossil fuel boilers can be a practical option.

Supplemental heat refers to heating that is provided by a source other than the AWHPs, which operates alongside the operating AWHPs. Incorporating supplemental heat into the system allows for design optimization.

Sizing the AWHPs heating capacity to meet the peak heating load can result in significant oversizing for cooling mode, higher installed costs, and frequent compressor cycling at low loads. Instead, a more efficient approach is to “right-size” the AWHPs to meet typical heating loads and use supplemental heating equipment to meet the peak heating load. This strategy is especially practical when auxiliary heat is already required due to rare extreme weather events.

Effective system design and sequencing are essential to ensure the supplemental heating equipment only operates when necessary and does not reduce the load handled by the AWHPs.

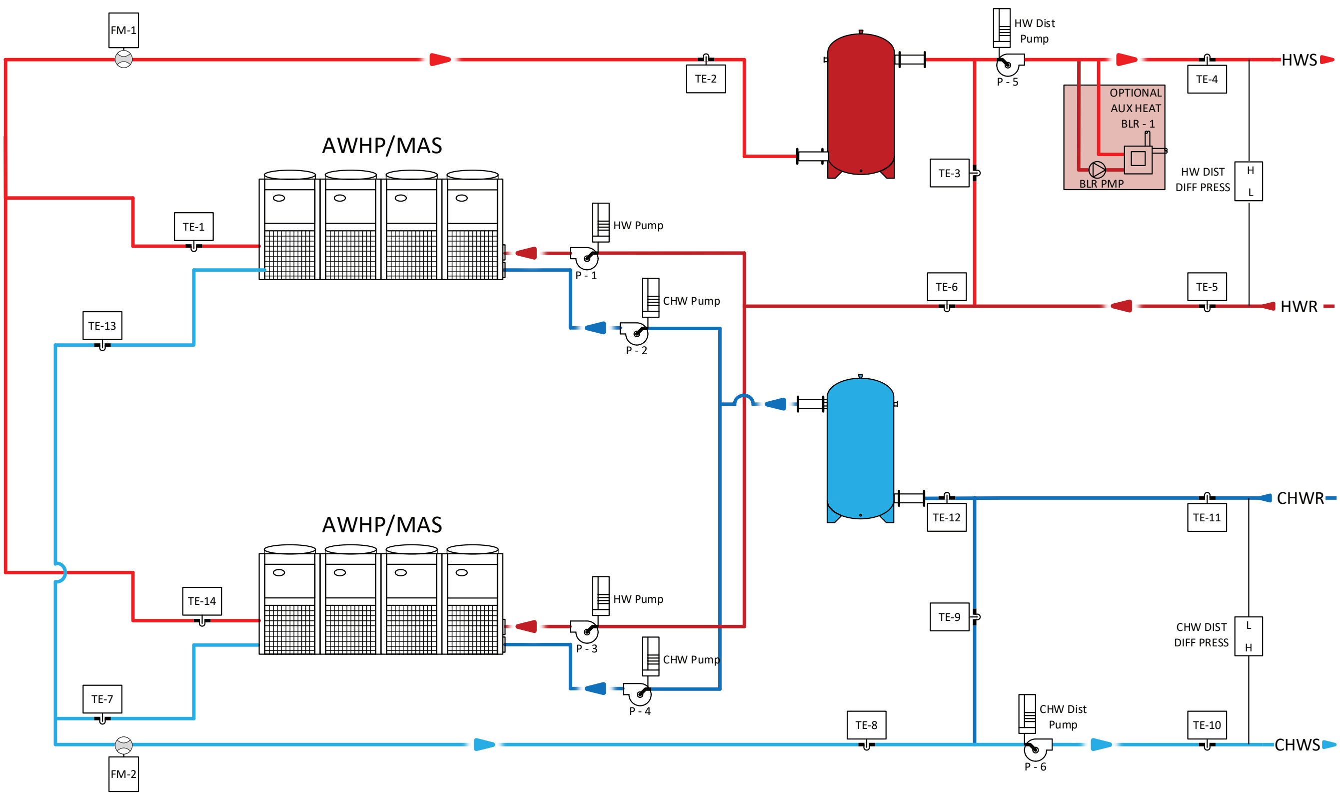
Auxiliary heat will be common in many systems, for one (or more) of the following reasons:

- AWHPs have a minimum outdoor air temperature operating limit. Below this minimum operating limit, the compressors will be locked out of operation. An auxiliary heat source would then be required. The design engineer should evaluate the local weather data for 50- or 100-year extremes to help determine if an auxiliary heating system is required.
- Resilient buildings often require backup power generation to maintain operation through utility power failures. AWHPs would require the need for large generation capacity and fuel storage. Natural gas, propane, or fuel oil boilers may greatly reduce the required generator capacity, minimizing the cost and space required for the backup generation infrastructure.
- To provide redundancy in the event of an AWHP failure, rather than adding more AWHP units to the plant, evaluate other low-cost auxiliary heat sources, such as electric or natural gas boilers. If they only operate occasionally, due to AWHP failure or maintenance, their impact on the building’s carbon footprint is likely to be minimal. Note that electric boilers may require upsizing of the building electrical service and gas boilers require a natural gas supply.

- The building's life cycle carbon footprint may be reduced by using natural gas or propane for auxiliary heat. The current electrical grid is NOT carbon free, and will not be for some time. The carbon impact of generating electricity varies throughout the country. As shown in Figure 17 (p. 25), under some conditions, heating with a high-efficiency gas boiler results in lower carbon emissions than heating with AWHPs. This is a result of a significant decrease in heat pump's COP at colder outdoor temperatures and the efficiency (carbon impact) of generating and delivering electricity to the building. As the grid becomes cleaner over time, use of the boiler can be reduced (or eliminated) to minimize ongoing carbon emissions.

When auxiliary heat is added to the hydronic system, it is typically best to connect it into the hot-water distribution loop supply pipe (Figure 36). This location allows the auxiliary heat source to supplement the AWHP capacity when required, or to provide standalone heating (requiring operation of the distribution loop pumps only) when the AWHPs cannot operate.

Figure 36. Auxiliary heat source connected to distribution loop supply pipe



As discussed previously, control of the auxiliary heat source will vary depending on building operating conditions. One suggested means for controlling the auxiliary boiler is to use the downstream temperature sensor. If the auxiliary boiler is controlled to setpoint at that location that is 1°F or 2°F lower than the system supply temperature setpoint, it will not take load off the AWHPs. It will operate only when the heat pumps are incapable of meeting the supply setpoint.

Heating Redundancy

Redundancy involves including extra equipment that is not needed during normal operation but is available to maintain system performance if the primary equipment fails or needs maintenance. Redundancy is not meant to serve as a safety margin for capacity, since failures can occur during periods of peak demand. There are several ways to provide redundancy:

- Incorporate an auxiliary heat source that can supply backup heating when needed, potentially at minimal or no additional installed cost if already included in the design.
- Add one or more (N+1) extra modules to deliver redundancy for both heating and cooling (see below).
- Use a properly sized cooling-only chiller to provide backup cooling. In many cases, this chiller will be more efficient at cooling than an AWHP and can serve as the primary cooling unit to improve overall system efficiency throughout the year.

Redundant AWHP modules. Redundancy with modular heat pumps offers smaller, more manageable capacity increases compared to packaged units. Because each modular heat pump consists of multiple modules, adding a single module provides incremental redundancy at a lower capacity than adding an entire packaged unit.

For N+1 redundancy, only one additional module is typically required. For example, a system with ten 30-ton modules serving a 300-ton load only needs one extra 30-ton module—resulting in a total installed capacity of 330 tons (1.1 times the required heating load). Splitting the system into two banks of five modules each also requires just one redundant module for the same effect. If extra modules are added to each bank, the total redundant capacity increases proportionally.

As long as the maximum bank size is not exceeded, redundant modules can be rotated into operation based on run hours. If the system exceeds the allowable number of modules per bank, use multiple, parallel banks.

Antifreeze

Glycols are commonly used in HVAC systems to prevent damage from corrosion and freezing. Glycol suppliers provide concentration data for freeze protection and burst protection.

Freeze protection indicates the concentration of glycol required to prevent any ice crystals from forming at a given temperature. Freeze protection is mandatory in those cases where no ice crystals can be permitted to form (e.g., a coil runaround loop) or where there is inadequate expansion volume available. Also, HVAC systems that must start during cold weather following prolonged winter shutdowns may require freeze protection. However, freeze protection should be specified only when the fluid must remain 100 percent liquid at all times.

Burst protection indicates the concentration required to prevent damage to equipment (e.g., coil tube bursting). Burst protection requires a lower concentration of glycol, which results in less degradation of heat transfer capacity. As the temperature drops below the inhibited glycol solution's freezing point, ice crystals will begin to form. Because the water freezes first, the remaining glycol solution is further concentrated and remains fluid. The combination of ice crystals and fluid make up a flowable slush. The system fluid volume increases resulting from the slush formation is absorbed by the expansion tank. The solution never fully freezes and therefore no damage is done to the unit or piping. Burst protection is usually sufficient in systems that are inactive during winter and have adequate space to accommodate the expansion of an ice/slush mixture. Given sufficient concentration of glycol for burst protection, no damage to the system will occur. Burst protection is also appropriate for closed-loop systems which must be protected despite power or pump failure (e.g., an air-cooled chiller that does not need to run during subfreezing weather).

For either freeze or burst protection, the required concentration of glycol depends on the operating conditions of the system and the lowest expected ambient or fluid temperature. Often the concentration is selected based on a temperature that is at least 5°F lower than the lowest anticipated design operating temperature. Table 5 is an excerpt from product information bulletins published by The Dow® Chemical Company. It is important that equipment selections are made at the required glycol concentration to ensure proper sizing.

When designing for glycol, it is crucial to select pumps that are compatible with glycol fluid conditions. This ensures reliable performance and prevents issues related to material compatibility and increased fluid viscosity. Proper pump selection will also help maintain system efficiency and longevity.

Table 5. Typical antifreeze concentrations by volume

Temperature, °F	DOWTHERM™ SR-1 (ethylene glycol)		DOWFROST™ HD (propylene glycol)	
	Freeze	Burst	Freeze	Burst
20	16.8%	11.5%	18%	12%
10	26.2%	17.8%	29%	20%
0	34.6%	23.1%	36%	24%
-10	40.9%	27.3%	42%	28%
-20	46.1%	31.4%	46%	30%
-30	50.3%	31.4%	50%	33%
-40	54.5%	31.4%	54%	35%
-50	58.7%	31.4%	57%	35%
-60	62.9%	31.4%	60%	35%

System Fluid Volume

Adequate system fluid volume is an important system design parameter because it provides for stable fluid temperature control and helps limit unacceptable short cycling of compressors. The temperature sensors used for system control are located in the supply (outlet) and return (inlet) fluid connections to the building piping. This location allows the building piping system volume to act as a buffer, slowing the rate of change of the system fluid temperature.

If there is not sufficient fluid volume in the system to provide an adequate buffer, temperature control can suffer, resulting in erratic system operation and excessive compressor cycling. The situation can be more severe during heating operation when individual modules switch to defrost mode. The modules in defrost mode not only stop providing heating, but they also cool down the circulating fluid, increasing the heating demand and potentially causing a drop in the heating fluid temperature. The AXM/MAS defrost cycle time is 2 to 5 minutes with 5 additional minutes to cycle compressors between heating mode and defrost mode for MAS.

Loop volume sizing is based on the following recommended loop times: 2 to 5 minutes for the cooling fluid and 4 to 10 minutes for the heating fluid. For instance, a bank of five 30-ton modules (150 tons total) with a cooling loop time of 4 minutes and a design flow of 2.4 gpm per ton would require a loop volume of 1,440 gallons (calculated as 150 × 2.4 × 4).

Several factors influence loop volume sizing:

- Applications needing precise temperature control (such as healthcare or laboratory settings) should use higher loop times. Less critical applications may use lower loop times.
- Systems with fluctuating loads benefit from longer loop times for improved thermal stability, while steady loads can use shorter loop times.
- Fewer modules mean higher loop volumes are needed, as each compressor’s operation has a greater impact on supply temperature and the module bank’s relative load.
- Heat pumps undergoing defrost cycles should use higher loop times to limit temperature drops, as defrost operation cools the circulating hot fluid. Systems with auxiliary heating or high thermal mass—such as radiant floors—are less affected and may use shorter loop times.
- MAS modules operating in simultaneous heating and cooling mode are not impacted by defrost cycles and will require less heating loop volume than heating-only heat pump systems.

If the system loop volume (internal fluid volume of pipes and heat exchangers) does not meet the minimum loop volume recommendations, loop volume can be increased by either adding a buffer tank or increasing the supply/return header pipe diameters. A buffer tank in the heating loop should be located in the supply piping to better mitigate the effects of defrost cycles, while a buffer tank in the cooling loop should be located in the return piping.

Note: Some systems use an isolation heat exchanger between the primary and secondary distribution loops (often to isolate glycol from the building piping). In this case, the loop volume would include the volume of the loops on both sides of this heat exchanger.

Summary

Trane Thermafit modular air-to-water heat pump systems offer an efficient and scalable solution for providing both heating and cooling with flexibility and redundancy. This application guide highlights key considerations for designing and operating these systems:

- **Decarbonization goals:** Ensure the system meets project-specific decarbonization goals by understanding electrical grid emissions and selecting equipment efficiencies and operating temperatures accordingly.
- **Equipment selection:** Account for the coldest expected design conditions since outdoor air temperature significantly impacts AWHP unit capacity and the maximum available hot-water supply (HWS) temperature.
- **Lower HWS temperatures:** Design and operate with lower HWS temperatures (95°F to 105°F) for more efficient AWHP operation. Using dual-purpose coils for both cooling and heating can facilitate this.
- **Flexible hydronic configurations:** This system can incorporate a combination of two-pipe and four-pipe heat pumps, packaged AWHPs, and packaged chillers, providing an efficient and scalable solution for both cooling- and heating-dominant load profiles.

Features and operating modes of Trane model AXM:

- **Single brazed-plate heat exchanger:** Functions as both the evaporator (cooling mode) and the condenser (heating mode).
- **Banking capability:** Multiple modules form a larger bank, all operating in the same mode; operating mode is controlled by a BAS or the unit controller.
- **Cooling mode:** Heat is absorbed from the chilled-water loop and rejected to the ambient air.
- **Heating mode:** Heat is absorbed from the ambient air and rejected to the hot-water loop.
- **Defrost cycle:** Automatically initiated to melt ice from the air coil.

Features and operating modes of Trane model MAS:

- **Three heat exchangers:** Evaporator, condenser, and air coil for flexible operation.
- **Independent module operation:** Each module can operate in different modes.
- **Cooling mode:** Heat is absorbed from the chilled-water loop and rejected to the ambient air, like an air-cooled chiller.
- **Heating mode:** Heat is absorbed from the ambient air and rejected to the hot-water loop, like an air-source heat pump.
- **Simultaneous heating and cooling (heat recovery) mode:** Heat is absorbed from the chilled-water loop and rejected to the hot-water loop.
- **Defrost mode:** Automatically initiated to melt ice from the air coil.

System pumping configurations:

- **Four-pipe distribution:** Separate heating and cooling distribution loops.
- **Decoupling:** Simplifies system design and allows for optimization of flow rates and temperatures.
- **Variable flow design:** Variable primary/variable secondary (VP/VS) system design with decoupling used to optimize primary and secondary flow rates and to enhance energy efficiency and performance.

Defrost implications for sizing:

- **Defrost cycle:** Impacts heating capacity, especially at low outdoor air temperatures.
- **Defrost mitigation:** Include surplus capacity, number of modules, loop volume, and N+1 configuration to mitigate defrost impact.

Weather extremes and auxiliary heat:

- **Auxiliary heat:** Required when AWHPs cannot operate due to extreme conditions.
- **Supplemental heat:** Used to supplement AWHP capacity during peak heating loads.

Redundancy:

- **Redundant AWHP units:** Provides all-electric heat pump redundancy.
- **Multiple module banks:** Used when required capacity exceeds the maximum number of modules.

For the latest version of this application guide and other heat pump system support materials, contact your local Trane Sales Representative.

Definitions

The following definitions are used in the discussion of Comprehensive Heat Pump Chiller Systems; these definitions may or may not align with their use in other HVAC systems.

Air-to-Water Heat Pump (AWHP): A unit that heats or cools fluid by transferring energy between the fluid and the air via a refrigeration circuit that includes a reversing valve. AWHPs may contain more than one refrigeration circuit and can be configured as a two-pipe or four-pipe unit.

Auxiliary Heat: Heat from an auxiliary source that operates only when the AWHPs cannot operate to meet the full heating requirement due to a machine limitation.

Block Load: A building modeling method that considers the design load profiles and airflows of individual spaces contained in a zone or system to find the collective maximum load or airflow at any specific instance in time—also called coincident load or airflow. For systems with coil or fan sizing displayed as “Block,” a load calculation program determines fan and/or coil sizes based on this maximum simultaneous load or airflow. “Block” sizing methodology is commonly used for VAV systems because the airflow can be varied. See also **Sum of Peaks Load.**

Building Automation System (BAS): A multiple-capability energy management system (EMS) that coordinates overall operation of the building in which it is installed. Some example functions include equipment monitoring, equipment protection from power failure, and building security.

Building Electrification: The process of transitioning a building’s heating energy source from on-site fossil fuels to electric sources.

Decarbonization: The process of reducing carbon emissions.

Defrost Mode: The operational mode controlling the unit to periodically melt the unacceptable accumulation of ice on evaporator tubes and fins. This is typical for an air-source heat pump operating in heating mode, where the refrigerant-to-air heat exchanger is operating as the source heat exchanger.

Four-Pipe Distribution: A fluid distribution system in which separate piping loops are used to distribute heated and cooled fluid. It can deliver heating and cooling to the fluid piping loops and can do so simultaneously.

Four-Pipe Unit: A unit that contains connections for four fluid pipes: two pipes are used for heated fluid; two pipes are used for cooled fluid. One pipe in each set is for supply and the other is for return. This unit can provide simultaneous heating and cooling. Four-pipe units may also be called multi-pipe units.

Heat Pump Chiller System: A system that has the flexibility to accommodate a mix of chillers and heat pump units in a common production loop.

Heat Recovery: The process of using waste heat from the cooling process for useful heating in the building. To be beneficial, this requires a simultaneous demand for cooling and heating.

Module: An individual component of a module heat pump chiller bank, equipped with its own refrigeration circuit(s), heat exchanger(s), and compressor(s). It can provide heating or cooling independently or in combination with other units.

Module Bank: A group of modules managed by a primary controller, where individual heat pump modules within a bank operate in parallel and are piped together with an integral hydronic header, working together to meet the system's heating or cooling demands. Multiple module banks can be integrated into a larger system and controlled by a central building automation system (BAS). In this guide, a module bank is often referred to simply as a bank.

Reversing Valve: A valve that redirects the refrigerant flow such that the evaporator and condenser switch functions in the refrigeration circuit. Heat pumps typically include one reversing valve per refrigeration circuit.

Sum of Peaks Load: A building modeling method that determines the fan and/or coil sizes based on the sum of the individual space loads or airflows for spaces contained in a zone or system—also called non-coincident load or airflow. These individual maximum values may not occur at the same time. This method typically yields a higher value than the block load method. "Sum-of-Peaks" sizing methodology is most commonly used for constant-volume systems because the maximum value must be supplied at all times and cannot be varied, this is sometimes called "peak load." See also **Block Load.**

Supplemental Heat: Heat from an alternate source that is used in addition to heat provided by the operating AWHPs.

Turn-Down (Capacity): The minimum thermal load a unit can satisfy, without cycling its last compressor. It can be stated as a percentage of the system design load or as a percentage of unit full-load capacity at the specified operating conditions.

Turn-Down (Flow): The percentage of design flow at which a piece of equipment can operate and still perform reliably. It is calculated as the (unit minimum allowed flow / unit design flow) x 100%. Note that the refrigerant-to-fluid heat exchanger minimum flow rate for a unit is the same in all modes of operation. However, the design cooling and heating flow rates of the unit may be different. As such, flow turn-down may differ based on the current operating mode.

Two-Pipe Distribution: A fluid distribution system in which the same piping loop is used to distribute either heated or cooled fluid. It requires a changeover to provide either heating or cooling to the fluid piping loop and cannot provide both simultaneously.

Two-Pipe Unit: A unit that contains connections for two fluid pipes. One pipe is for supply fluid and other is for return. This unit is capable of heating or cooling fluid, but not both simultaneously.

References and Resources

[1] AHRI, Standard 550/590. *Standard for Performance Rating Water-chilling and Heat Pump Water Heating Packages Using the Vapor Compression Cycle*. Arlington, VA. AHRI. 2023.

[2] ANSI/ASHRAE/IES, Standard 90.1-2022. *Energy Standard for Sites and Buildings Except Low-Rise Residential Buildings*. Atlanta. ASHRAE. 2022.

[3] Trane (2022). *Modular Chillers in Variable Primary Flow Chilled-Water Systems*, application guide. PKG-APG001C-EN.

[4] Trane (2022). “Heating with Lower-Temperature Hot Water,” *Engineers Newsletter*. ADM-APN084-EN.

[5] Trane (2023). “Modular Chiller Plant Design,” Trane *Engineers Newsletter Live*. APP-CMC084-EN.

[6] Trane (2024). *Hydronic Branch Conductor,* applications guide. APP-APG-024A-EN.

[7] Trane (2021). *Heating with Compressors in HVAC Systems*, applications engineering manual. SYS-APM005E-EN.

[8] Trane (2020). *Air-to-Air Energy Recovery*, applications engineering manual. SYS-APM003-EN.

Trane - by Trane Technologies (NYSE: TT), a global climate innovator - creates comfortable, energy efficient indoor environments for commercial and residential applications. For more information, please visit trane.com or tranetechnologies.com.

APP-APG021B-EN 17 Feb 2026
Supersedes APP-APG021A-EN (22 Aug 2022)