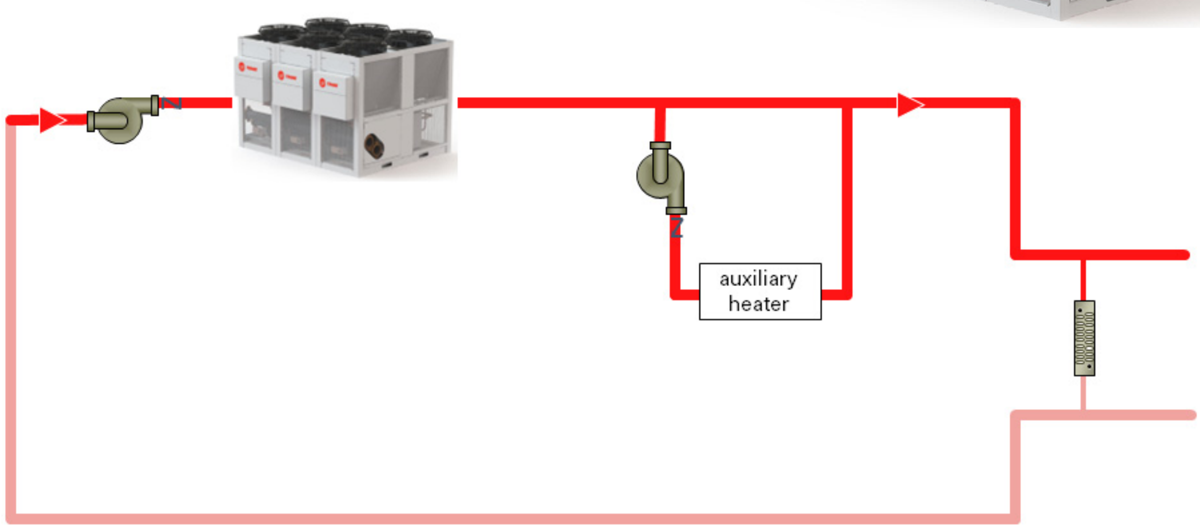
Application Guide Supplement

Modular Air-to-Water Heat Pumps



⚠ 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.

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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 for cooling and heating. This manual discusses system design considerations and options, piping, airside considerations, and system operation and control.

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

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 range and performance.

Table of Contents

Definitions

The following definitions apply for terms as used in Comprehensive Chiller-Heater Systems. Please note that 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.

Building Automation System (BAS): A multiple capability energy management system that relates to the overall operation of the building in which it is installed. Some examples are equipment monitoring, equipment protection from power failure, and building security.

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

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.

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

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**.**

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

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

Turn-Down (flow): The percentage of design flow a piece of equipment can be turned down to and still perform reliably. It is calculated as the (unit min allowed flow / unit design flow) x 100. Note that the unit refrigerant-to-fluid heat exchanger minimum flow is the same in all modes of operation however, the unit design cooling and heating flows may be different. So the flow Turndown may be different in different modes of operation.

Two-Pipe Distribution: A fluid distribution system in which the same piping loop is used to distribute either heating or cooling. 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 for supply and one for return. The unit is capable of heating or cooling the fluid, but not both simultaneously.

Introduction to Modular Air-to-Water Heat Pump Systems

EQUIPMENT

Air-to-water heat pump units are air-to-water refrigeration units with the ability to produce chilled or heated fluid with one refrigerant-to-water heat exchanger (changeover). A refrigerant reversing valve is used to switch between cooling and heating modes. It may also be referred to as an air-to-water heat pump chiller or once the context is understood to be hydronic systems it may simply be called an air-to-water heat pump (AWHP). This is how they will be referred to in this application guide.

Trane offers the AXM air-to-water heat pump, a modular packaged unit similar to an air-cooled chiller. The AXM module is available as a 30 nominal ton unit and up to 10 units can be combined to produce a package up to 300 nominal cooling tons. It uses a total of two scroll compressors divided into two circuits. The AXM can deliver 140°F fluid temperature down to 20°F outdoor air temperature and is capable of heating operation down to 0°F outdoor air temperature while delivering 130°F fluid temperature.

SYSTEMS

Some design principles from chilled water systems transfer well to chiller-heater systems using AWHP equipment. But many new issues emerge that require consideration and a new way of thinking when modular equipment is being evaluated.

Reliability

A reliable system design is always important, but the consequences of a heating system failure are more significant than cooling system failure. AWHPs have operating limits that become more restrictive as outdoor air temperatures drop. Redundancy and reliable back up heating strategies must be developed. What happens when that 50-year weather event occurs?

Flexibility

Heat pump equipment may serve two systems with varying expectations of cooling systems versus the heating systems. For example, a cooling system may be designed for a 10°F to 12°F degree ΔT while a heating system may be designed for a 20°F to 30°F degree ΔT. That is a substantial difference and the system must be able to accommodate both needs.

OAT Impact

Heat pump capacity and maximum supply fluid temperature are reduced as the outdoor air temperature (OAT) drops. The equipment has outdoor air temperature operating limits. The sizing strategy for the equipment is impacted by outdoor air temperature design conditions, the dual cooling and heating role of the equipment, and the availability of auxiliary heat sources. Several strategies for sizing system components to deliver reliable, flexible, and cost effective operation are discussed in this guide.

Defrost

To ensure reliable heat exchange with the ambient air, a given AWHP circuit will occasionally operate in defrost mode. This results in periodic heating interruption with sourcing of heat from the hydronic system during the defrost cycle. Equipment sizing, buffer tank and/or supplemental boiler use can all be part of a strategy to mitigate the impact of defrost on the heating system.

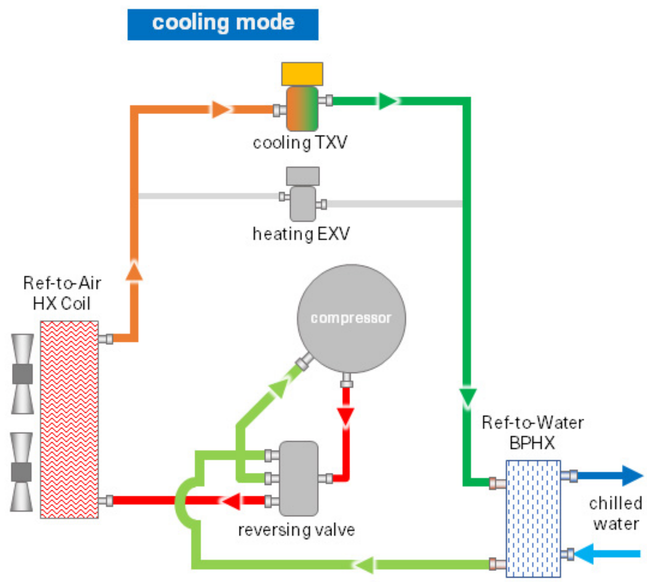
This application guide serves as a supplement to the ACX Chiller-Heater Application guide (SYS-APG003*-EN) to provide specific content pertaining to modular AWHPs.

Air-to-Water Heat Pump Unit Modes of Operation

AWHPs can operate in three modes: cooling mode, heating mode and defrost mode. The following figures show the refrigeration circuit operation in each mode including the respective heat source and sink in each mode.

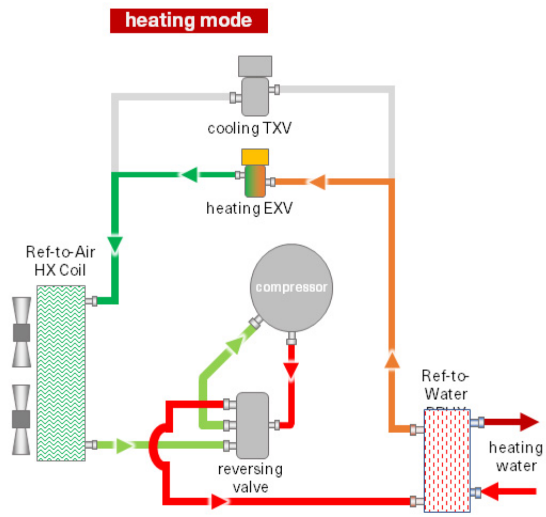
1. Cooling Mode – As shown in Figure 1, the evaporator (refrigerant-to-water heat exchanger) is the energy *source* for the refrigeration circuit, absorbing heat from the chilled water. The condenser (refrigerant-to-air coil) is the energy *sink* by rejecting heat to ambient air. In this mode, the AXM has the same operation as an air-cooled chiller.

Figure 1. Cooling mode operation—simplified diagram



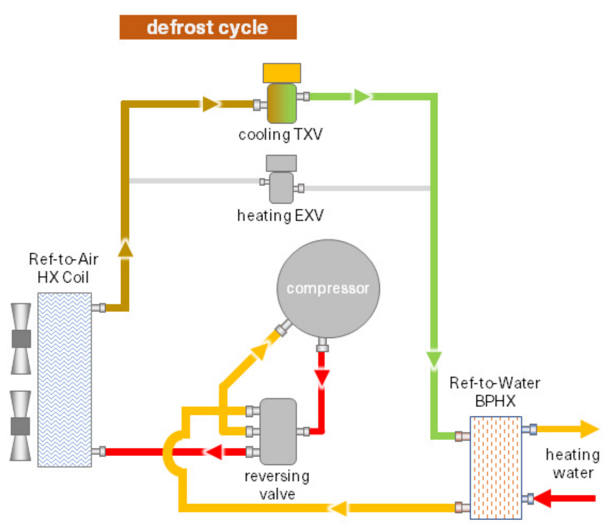
2. Heating Mode – As shown in Figure 2, the condenser (refrigerant-to-air coil) is the energy *source* in the circuit, absorbing heat from the outdoor air, while the evaporator heat exchanger is the energy sink in the circuit by rejecting heat to the hot water circuit.

Figure 2. Heating mode operation—simplified diagram



3. Defrost Cycle – As shown in Figure 3, the refrigeration circuit is in the cooling mode supplying heat to melt ice built up on the outdoor air coil (refrigerant-to-air coil). The return heating water is the source for the heat energy used to defrost the outdoor air coil. The heat energy for defrost is extracted from the heating fluid loop.

Figure 3. Defrost cycle operation—simplified diagram



COOLING/HEATING CHANGEOVER CONTROL

Each AWHP unit mode of operation has a specific permissible range of operation. This includes limits on minimum and maximum outdoor air temperatures, entering and leaving heat exchanger fluid temperatures, and fluid flow rates. When the system operating conditions are beyond the operating limits of the unit it will protect itself by not allowing compressor operation. When designing a system, it is important to understand the specified unit's operating limits to ensure the unit can cool and heat as required.

In addition, there may be limits to how frequently the BAS can request the unit to switch between modes and how long it must operate in each mode before it can be switched back to the previous mode. When switching modes, time will need to be allowed so that the system temperatures can moderate enough for the unit to start in the new mode of operation. If the BAS rapidly switches the unit from heating to cooling or visa-versa the extreme temperature from the previous mode may cause the unit operational issues in the newly commanded mode. For example, if the unit is operating in cooling mode producing 42°F chilled water and its operation is changed to heating mode with a requested setpoint of 120°F, this would initially result in a low condensing pressure which may cause the unit to trip a safety diagnostic to protect itself. In this example, allowing a time duration for the loop to warm up before starting the heat pump could be a way to mitigate this trip potential.

The defrost cycle is automatically initiated by the unit control when frost is built-up on the air-to-refrigerant coil that impacts unit performance. The BAS can monitor the unit mode of operation or leaving fluid temperature to detect defrost mode operation. If required, the BAS can initiate operation of an auxiliary heater to mitigate the impact of defrost operation on the system heating supply fluid temperature.

TRANE® THERMAFIT™ MODEL AXM TWO-PIPE AIR-TO-WATER HYDRONIC HEAT PUMP

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AXM units are available with the following features:

- Modular Packaged Heat Pump configuration
- Each module is 30 nominal cooling tons
- Modular unit capacity range of 60 to 300 nominal cooling tons
- Meets 90.1-2019 heating efficiency requirements
- Dual Refrigeration Circuits
- Open-Protocol Microelectronic Controls (cPCO)
- Module pump package - optional

See unit catalog for more features and options

The Trane AXM Air-to-water heat pump unit has a broad operating range. Below are examples of its typical acceptable operating ranges.

AXM ambient operating range:

- Cooling Mode: 40°F to 115°F OAT (4.4°C to 46.1°C)
- Heating Mode: 0°F to 65°F OAT (-17.8 to 18.3°C)

AXM supply fluid temperature range:

- Leaving Chilled Fluid Temperature: 30°F to 65°F (-1.1°C to 18.3°C)
  - Leaving fluid temperatures 42°F and below require appropriate glycol concentration
- Leaving Heating Fluid Temperature: 65°F to 140°F (18.3°C to 60°C)

AXM typical operation flow/Delta T range:

- Flow: 0.8 to 4 gpm/ton (calculated based on cooling tons but applies to both cooling and heating flows)
  - Corresponding Chilled/Heated Fluid Temperature Delta T: 6°F to 30°F (3.4°C to 10°C)
- Specific minimum and maximum allowed flow rates vary by unit size and must be obtained via the selection software.

The above limits are represented in Figure 4 and Figure 5, AXM Operating maps.

Figure 4. AXM Operating map—cooling mode

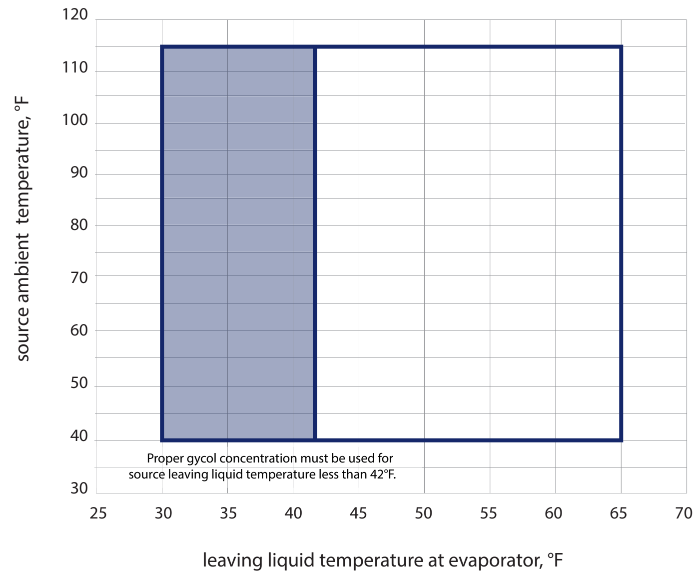
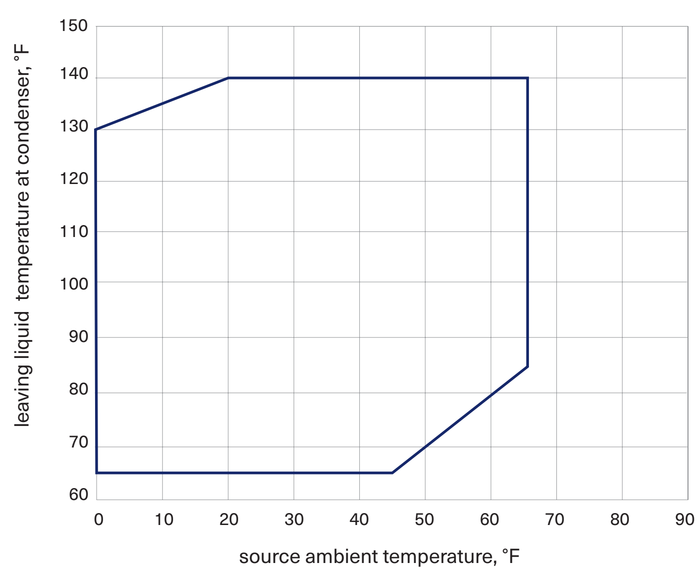


Figure 5. AXM Operating map—heating mode



System and Unit Sizing

Proper design of an electrified system including various potential operating conditions, system and heat pump equipment sizing as well as redundancy is critical to reliable and efficient system operation, as well as reasonable first cost. Commonly used high temperature hot water conditions will not only result in high system energy consumption, but are not even attainable with commonly available heat pump technologies. Historic commonly used high temperature heating assumptions must be abandoned, and low-temperature supply heating concepts embraced.

Historic “rules-of-thumb” for system capacity sizing must be abandoned. Computerized load analysis for new buildings and accurate load history for existing buildings is essential to proper system design and meeting owners environmental and financial goals. This section discusses many of the important points of system design relative to modular AWHPs in a system.

MINIMUM MODULE QUANTITY

The quantity of individual modules in a given unit is important for several factors, including but not limited to: minimum load and flow turndown, defrost implications, physical size of the unit, and equipment cost. Capacity and flow must be defined at both design and minimum conditions in order to properly size the heat pump plant. Trane recommends that for a given unit it shall consist of no less than two modules. Having multiple modules allows the impact of defrost to be minimized. An example of this is shown below. Consider the following hypothetical sizing examples—for these examples ‘tons’ are used to frame the capacity, but the concept applies to MBH for cooling and heating as well.

Example 1 (capacity): Design load is 50 tons and minimum required capacity turn down is 15 tons.

Select two (2) 30-ton modules for a total of 60 tons. This configuration yields enough capacity to meet design plus 20 percent and unloads to 15 tons. If one module were to be selected the unit would fall short on design capacity. If three modules were selected then the unit would be quite oversized, therefore two modules would be the minimum number of recommended modules for this example.

Example 2 (flow): Design load is 120 tons and the heat pump will be applied in a variable primary flow system with a desired turndown in flow rate of 25 percent.

Select four (4) 30-ton modules for a total of 120 tons. A four-module unit will allow for a turndown in flow rate of 25 percent. In a variable flow, modular system fluid is only flowing through modules that are active, this system would allow for stepped flow increments from 25 to 100 percent.

In each of the above examples there are enough modules to ensure unit operation during a module defrost cycle.

The quantity of modules in an array impacts the affects of defrost on the system. Trane recommends at least two modules for a given AWHP system. The unit controls allow for one module to enter defrost at a time. In a two-module system there would be approximately 50 percent of the unit available for heating while one unit is in defrost. In a three-module system there would be approximately 66 percent of the unit available for heating while one unit is in defrost.

EFFECT OF DELTA T

Careful evaluation of the design delta T and quantity of modules must be considered to ensure stable unit and system operation. Each module contains two scroll compressors that cycle on and off to meet the design leaving fluid temperature. If a large delta T is desired, then more compressors in the system will yield better temperature control and stability. A quick way to evaluate this can be made by dividing the delta T by the number of compressors being considered, this will reveal the +/- temperature control the unit is capable of.

Example 1: 10°F delta T in a two-module unit. 10°F / 4 compressors = 2.5°F per compressor. This unit would be capable of temperature control of +/- 2.5°F when staging compressors.

Example 2: 30°F delta T in a two-module unit. 30°F / 4 compressors = 7.5°F per compressor. This unit would be capable of temperature control of +/- 7.5°F when staging compressors. This example illustrates why more compressors would be recommended if more precise temperature control is desired.

Example 3: 30°F delta T in a five-module unit. 30°F / 10 compressors = 3°F per compressor. This unit would be capable of temperature control of +/- 3°F when staging compressors. This example illustrates how adding compressors can increase temperature control.

These examples illustrate the importance of understanding the requirements of the system or load and how the selection of the temperature difference and unit configuration all interact when designing a system.

AIR-TO-WATER HEAT PUMP PLANT SIZING

The air-to-water heat pump system needs to be sized to handle both the cooling and the heating peak loads. The same equipment is expected to satisfy both loads. Not only is the magnitude of the peaks different but the capacity of the equipment varies with the outdoor air temperature and design leaving temperature. The AWHP heating capacity at the design heating ambient temperature is typically much less than the unit "Nominal" cooling capacity. This may result in substantially different equipment selections for design cooling and heating.

Table 1. Capacity examples based on two (2) 30-ton modules

Cooling: 54/44 chilled-water at 95°F ambient			
Model	Cooling Capacity (tons)	Power Input (kW)	EER (Btu/Wh)
2xAXM030	59.2	73.97	9.62

Notice the delivered capacity is close to the nominal rating for cooling tons.

Heating: 95/105 hot-water at 0°F ambient			
Model	Heating Capacity (MBtu/h)	Power Input (kW)	COP
2xAXM030	419.0	54.62	2.03

Heating: 95/105 hot-water at 25°F ambient			
Model	Heating Capacity (MBtu/h)	Power Input (kW)	COP
2xAXM030	565.8	57.32	2.62

Notice that with a 25°F increase in ambient temperature the heating capacity increases by about 35 percent. As the capacity of the unit increases so does the required flow rate. When evaluating AWHP performance it is important to understand the ambient range that the unit will operate at and what the performance impact of the ambient is.

Heating Water Supply Temperature

The heating sizing process for heat pumps requires the designer to consider several factors, some familiar and some less familiar. Those factors include but are not limited to:

- design heating water supply temperature
- design heating outdoor air temperature
- equipment cost
- operating cost
- electrical infrastructure cost to support peak demand,
- carbon footprint reduction.
  - Minimizing the design hot water temperature yields higher equipment COPs. A unit delivering 105°F HW has a COP around 2.6, while the same unit at the same ambient would have a COP around 1.8 when delivering 140°F HW.

These factors are interrelated, so the trade-off decisions need to be understood and align with the priorities of the building owner.

Defrost Implications to Sizing

Low outdoor air temperatures cause the outdoor coil temperature to drop below freezing potentially resulting in frost accumulation. Defrost typically only occurs below 47°F OAT. Air-to-water heat pump units will automatically enter defrost operation when its required. The Trane® AXM unit control has intelligent defrost control to minimize defrost while maximizing unit heating efficiency and capacity. The controls algorithm minimizes the quantity of modules allowed to defrost to no more than 50 percent of the bank to help minimize the temperature impact on the system.

Defrost operation results in a weighted performance derate to the equipment heating capacity. Some judgment is involved by the designer because the frequency and therefore impact of defrost operation is dependent on actual operating conditions.

Antifreeze

Glycols are 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 the given temperature. **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.

The Trane® AXM modular AWHP requires glycol in the fluid circuit when leaving unit temperature is 42°F and below. Glycol should also be considered to protect the unit in heating defrost mode as the heat exchangers will be subject to cold refrigerant conditions during this mode. The type and concentration of glycol shall be evaluated based on conditions the unit may operate in.

System Configuration

Modular AWHPs can be configured to operate in variable or constant flow systems. When modular chillers are applied in variable primary flow systems they must be configured with factory installed motorized water isolation valves for each heat exchanger. The following section provides design guidance when applying modular AWHPs in primary-secondary and variable-primary-flow systems. For more information on applying modular units in variable flow systems refer to the Trane Application Guide: Modular Chiller in Variable-Primary-Flow Chilled-Water Systems (PKG-APG001*-EN).

PRIMARY/SECONDARY SYSTEMS

Decoupling–Hydronic Isolation

Decoupling the primary loop from the secondary loop greatly simplifies system design. Numerous sizes and types of heat pumps and or chillers can be applied to best match building load requirements. The principal requirement for the heat pump selection is that it can produce supply water **temperature** required for cooling or heating. Unit flow and pressure drop requirements are of much less concern as the decoupler allows for natural balancing of required flows.

The primary-secondary chilled-water system decoupler pipe must be configured and sized to meet two primary requirements:

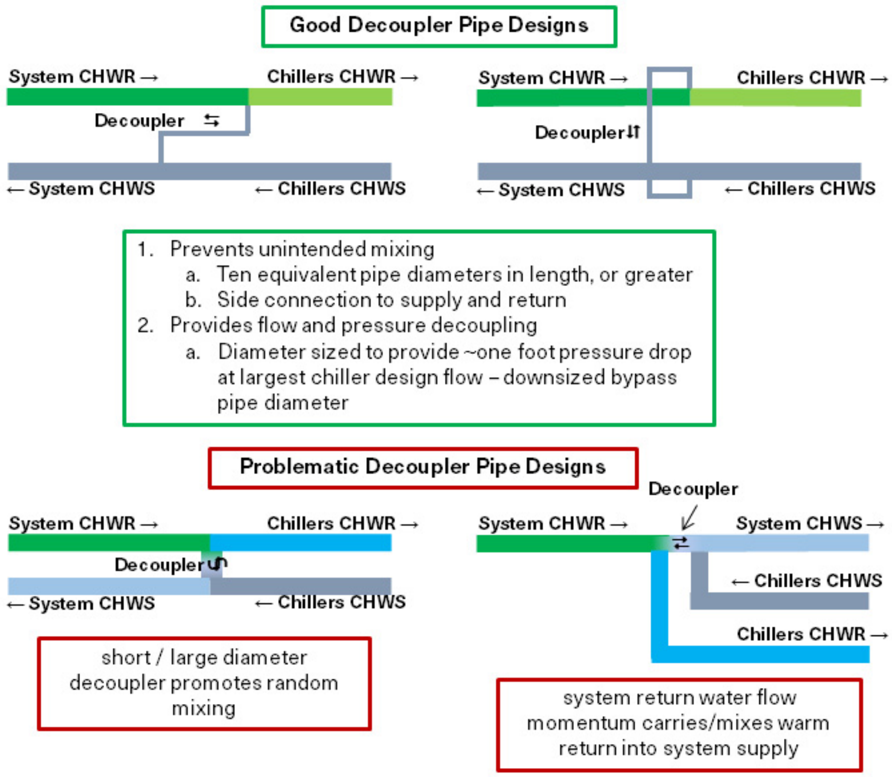
1. Prevent unintended mixing of the return and supply water streams.
2. Provide *adequate* flow and pressure decoupling between the fluid production and distribution loops.

Achieving these requirements typically means observing several principles. (See Figure 6.)

1. The decoupler pipe should be configured so that it enters and exits in and out the side of the return and supply system piping with tee type connections. This is to prevent water velocity momentum in the supply or return pipe from inducing flow and/or mixing in the decoupler pipe. (See Figure 6.)
2. The decoupler pipe diameter sizing differs depending on the plant operating intent.
   a. For systems with constant heat pump flow it should be sized based on the higher of the cooling or heating design flow of the largest unit in the plant. This typically means no larger, often a size smaller, than the diameter of piping connecting to the largest unit. In multiple unit systems it should **NOT** be sized for **system** design flow, such as equal to the distribution piping diameter.
   b. For Variable-Primary and Variable-Secondary systems, with varying flow through the operating heat pumps, it should be sized based on either the minimum flow of the heat pump or the minimum flow of the pump, whichever is larger. The minimum flow for the modular heat pump will be driven by the quantity of modules in the array.

   Larger is not better. Larger increases the likelihood of undesired flow mixing and increases installation cost.
3. The decoupler pipe length should be approximately ten (10) equivalent pipe diameters long or greater (elbows get counted appropriately). Another rule of thumb is for the pipe to have about one (1) foot of pressure drop at the decoupler design flow. In large chilled-water or hot-water systems a somewhat higher pressure drop will not cause operational problems.

Figure 6. Decoupler pipe connection examples



VARIABLE-PRIMARY-FLOW SYSTEMS

Bypass Considerations

Variable-primary-flow systems are a common consideration with modular heat pumps. Modular designs can often allow for high turndown flow rates. For example, a unit consisting of four modules turns down to 25 percent of design flow. Many pumps only turn down to around 30 percent which means the heat pump is capable of lower flow than the pump is. To remedy this, multiple smaller pumps can be manifolded and staged to allow for lower flow rates.

Heat Pump Minimum Flow Bypass

Variable-primary systems utilizing modular heat pump units do not require an external minimum flow bypass line close to the chiller. his is because the modular unit is controlled to be the bypass. Each individual module contains a motorized butterfly valve that is open when that module's compressors are active and closed when inactive. If the modular unit is allowed to close all of its valves when there is no load, then the pump could dead head or restrict flow to the system. he modular unit is controlled to allow one or more valves to always stay open, so the unit is acting as the low flow bypass.

Figure 7. Example modular system with bypass line and valve

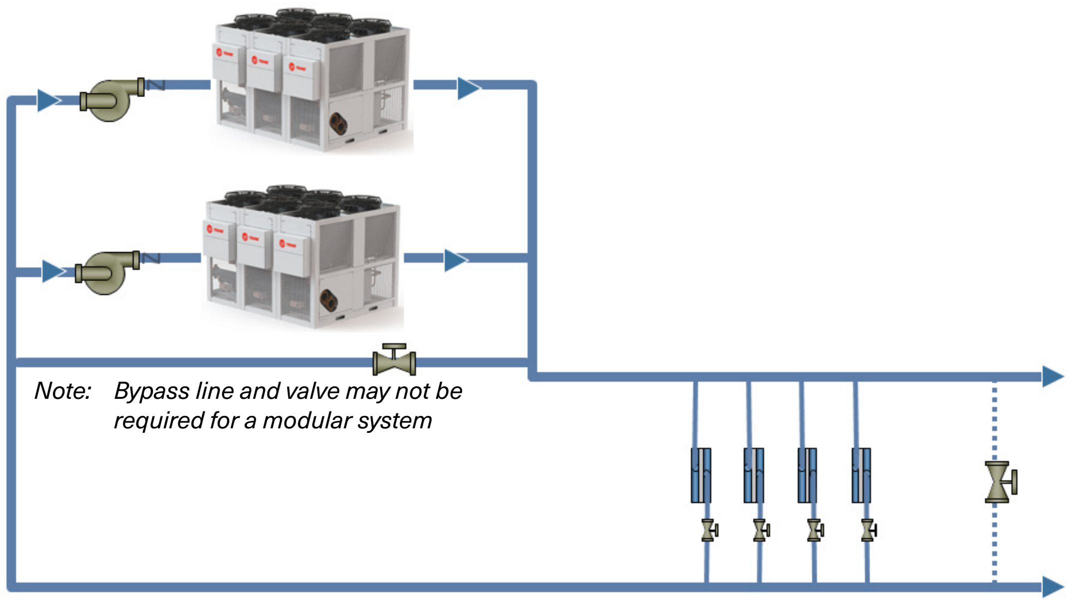


Figure 7 shows a typical variable-primary-flow system with a minimum flow bypass line and modulating valve. This is not required for a system utilizing modular units designed for variable flow systems. Using three modules as an example, the unit could be configured such that one out of the three motorized water valves in the unit would always remain open. This would equate to a minimum flow of 33 percent. If further turn down in flow is desired then an external bypass may be worth evaluating.

SYSTEM (END-OF-LOOP) BYPASS

A system or end-of-loop bypass is required in a variable-primary system with modular units. This is not the same as bypass as described above. This bypass is located out in the system, preferably at the end of the loop. One or more three-way valves that add up to at least one module of flow could be considered. If three-way valves are not an option then including a dedicated bypass line with a modulating two-way valve sized for at least one module of flow would need to considered.

Figure 8. Three-way valve for bypass

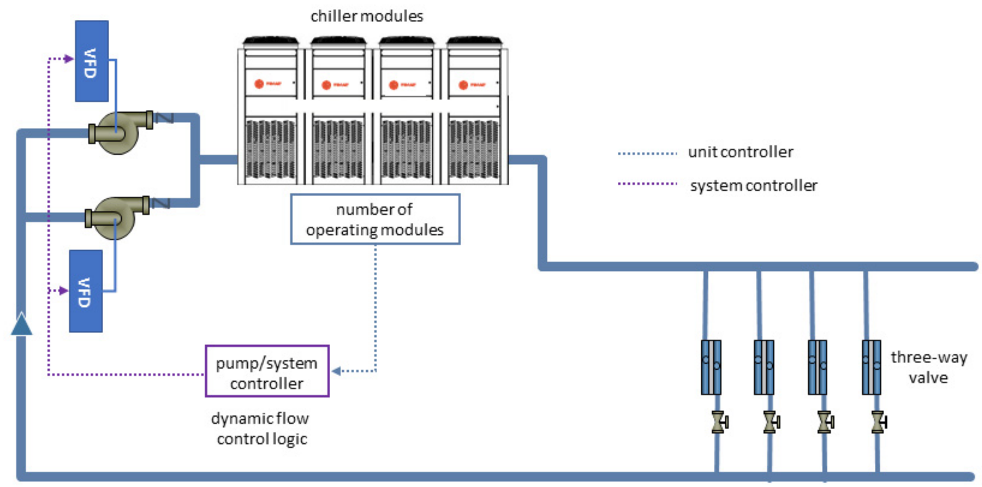
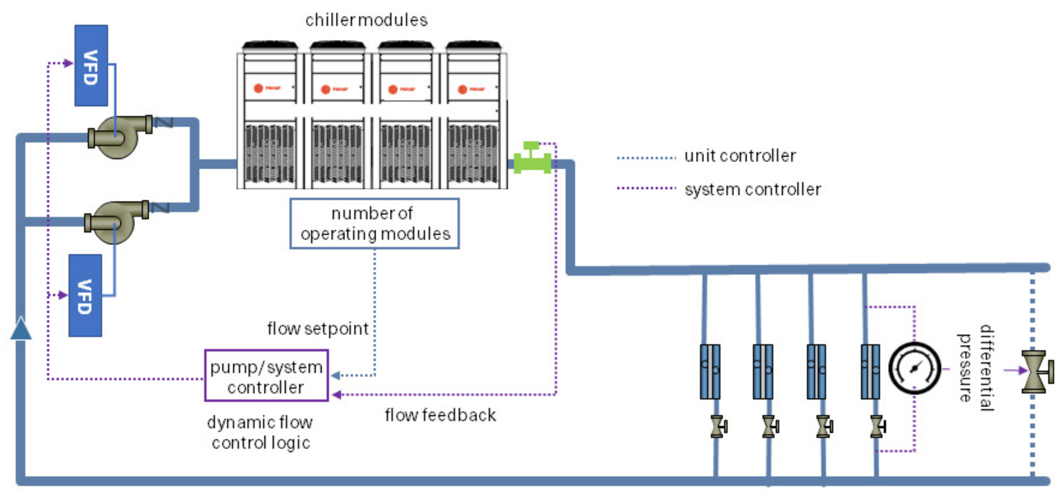


Figure 9. Dedicated bypass with modulating two-way valve



For more information on modular units in variable-primary-flow systems see Application Guide: Modular Chillers in Variable-Primary-Flow Chilled-Water Systems (PKG-APG001*-EN).

System Fluid Volume

Important! Adequate system fluid volume in the fluid loops is **critical** to system reliability and comfort.

HEATING LOOP VOLUME

The heating loop minimum fluid volume requirement is typically higher than chilled water loops. The key reason heating loops require greater volume is to compensate for unit defrost operation. When a unit goes into defrost the unit leaving fluid temperature drops rapidly, particularly if only two modules are running and one goes into defrost. In a system with inadequate fluid volume at least three issues can occur.

1. The cold fluid can cause the air-handlers or terminal units to dump cold air into the space causing occupant discomfort.
2. The cold fluid can cause low temperature alarms or freeze stat trips in AHUs.
3. The return fluid temperature to the heat pump can get cold enough to cause a heat pump unit diagnostic.

Mitigating these problems for multiple module containing systems that do not defrost all modules at the same time requires a heating loop minimum fluid volume of 0.62 gals/per Mbh at the AHRI 120°F LHWT / 47°F OAT heating rating point. This is approximately eight gallons per rated heating ton at those conditions.

The system volume is calculated based on the piping, coil and heat pump internal volumes. For systems which do not meet the recommended fluid volume a volume tank must be installed in the production plant heating supply line.

COOLING LOOP VOLUME

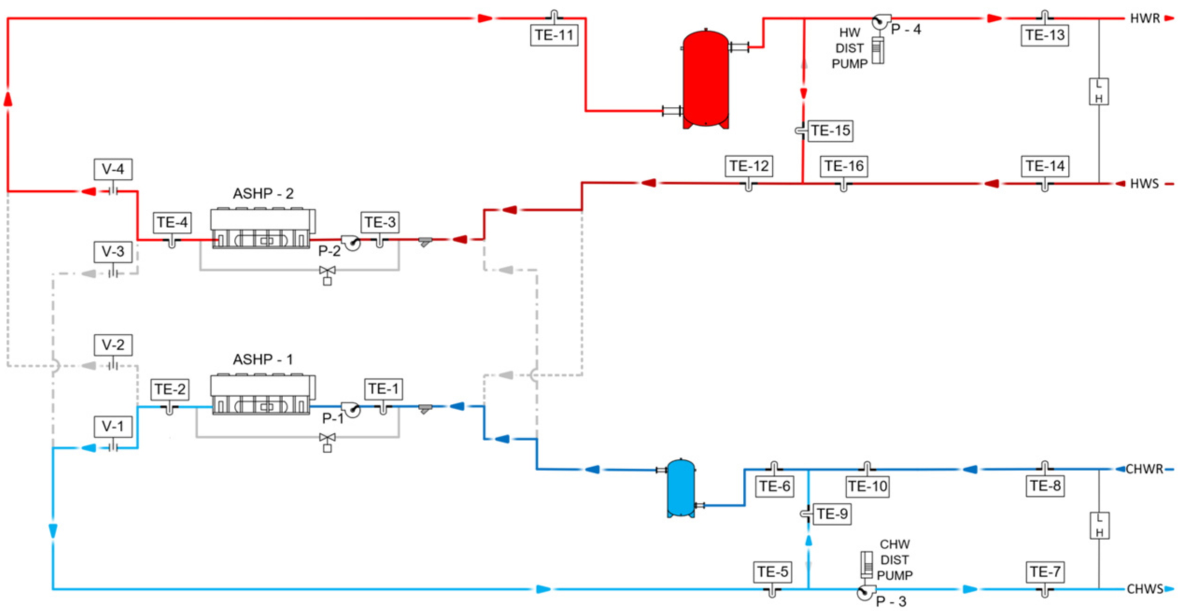
For the chilled water section of the system the typical minimum fluid volume requirements of providing for a three-minute circulation time is recommended. That translates to a volume of water in the chilled water loop equal to or exceeding three times the cooling mode design evaporator flow rate. For systems with a rapidly changing load profile the amount of volume should be increased.

If the installed system volume does not meet the above recommendations, the following items should be given careful consideration to increase the volume of water in the system and, therefore, reduce the rate of change of the return water temperature.

- A volume buffer tank located in the plant return chilled-water piping to the chiller.
- Larger system supply and return header piping (which also reduces system pressure drop and pump energy use).

The following system example shows a possible location for hot water and chilled water buffer tanks in a primary-secondary system. The tank could also be located on the return side of the heat pump if desired. The application of buffer tanks applies to both primary-secondary and variable-primary-flow systems.

Figure 10. System example with possible hot water and chiller water buffer tank locations



Summary

A modular air-to-water cooling/heating plant does not need to be complex to design or operate. Applying the appropriate design concepts provides for a highly flexible, efficient and reliable electrified system.

Trane optimizes the performance of homes and buildings around the world and offers a broad portfolio of advanced controls and HVAC systems, comprehensive building services, and parts. For more information, visit www.Trane.com.

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