Application Guide

Modular Heat Pump Chillers in Variable Primary Flow Hydronic 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.

December 2025 **PKG-APG001D-EN**

Preface

This application guide is intended to provide reliable strategies to implement variable primary flow (VPF) with Trane modular chillers and heat pumps. The guidance in this bulletin should not be taken as a recommendation to apply VPF in all systems. The design engineer must take into consideration all possible equipment configurations to determine the best design for each job. Other possible configurations include constant flow and primary-secondary (decoupled) piping with variable primary and variable secondary flows.

Modular Chiller Bank Operation

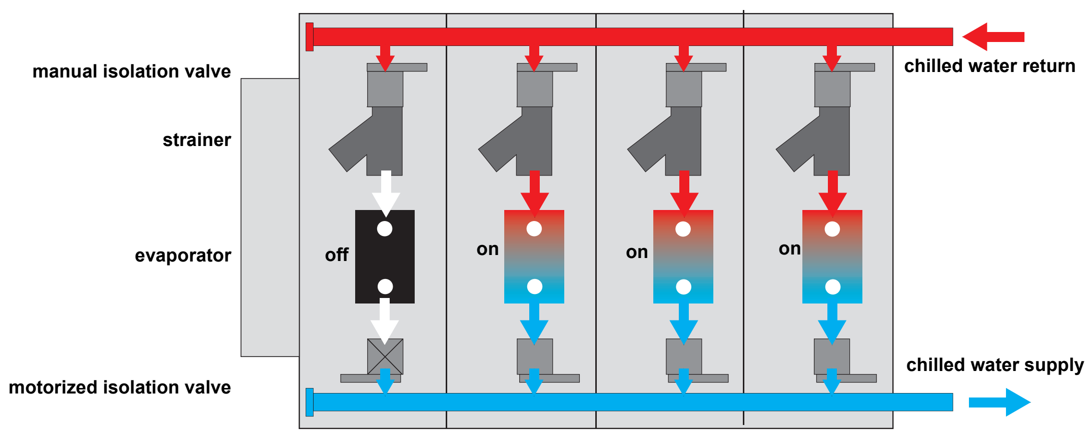
Individual chiller modules in a modular chiller bank operate in parallel to one another. When the operating modules can no longer meet the building load (as determined by the system leaving fluid temperature), the next module in the sequence will be brought on-line to supplement the chiller bank capacity. Refer to the manufacturer's installation, operation, and maintenance (IOM) manual for the full sequence for modular chiller loading and unloading.

When demand increases, resulting in the system leaving fluid temperature to drift outside of the temperature setpoint differential, the primary controller commands a module to open the isolation valve of the next module in the operating sequence, as shown in Figure 1. The stroke time on the motorized butterfly valve is 35 seconds.

Rapid bypass valve and pump speed control response is critical during staging of chiller bank modules. This ensures that the operating chillers are not starved of flow when the additional module isolation valve is being opened.

Although it is possible to incorporate various control strategies for VPF with modular chillers, this guide will focus on a sub-set of scenarios that, when properly applied, are repeatable and reliable for these units.

Figure 1. Typical four-module chiller hydronics



Variable Primary Flow Considerations

This document will provide multiple system configurations for modular chillers utilizing variable primary flow pumping. Each configuration will have trade-offs of energy, resilience, and cost. The designer of the system will need to weigh these trade-offs for each application.

System Considerations

- If the number of individual chilled water loads (e.g., air-handling units, AHU) or processes) in a hydronic system is small, there can be excessive system flow transients that must be addressed, such as slowing control valve actuation or selecting a different system configuration such as primary/secondary.
- AHU control valve proportional-integral-derivative (PID) loops should be tuned for stable operation. PID loops that “hunt” and “over control” valves, not only put the system reliability at risk, but also waste energy.
- A system flow bypass is **REQUIRED** to ensure that chiller modules receive their required flow. Three-way valves on the AHU coils that equal the design flow of one and a half modules, or a dedicated bypass line with a modulating two-way valve, must be considered. The dedicated bypass line is typically sized for 1.5 times the largest design flow of a single module and is recommended to be placed at the “end” of the hydronic loop, ensuring adequate loop volume in the bypass line.
- Recommended chiller manufacturer system loop time and volume requirements must be observed. Please contact the chiller manufacturer for accurate loop time/volume requirements. If a buffer tank is required to add volume to the system to meet the minimum loop time requirement it should be a mixing type tank.

Control Considerations

The devices used for chiller flow monitoring, bypass flow control and pump speed control must be high accuracy, industrial quality devices. They are critical to reliable system operation.

- If a flow meter is used to directly measure hydronic system flow, an electromagnetic type is recommended for reliable long term operation. Manufacturers’ installation recommendations must be followed (i.e. minimum upstream and downstream piping lengths). The flow meter should be hardwired to the controller for responsiveness. Use of values communicated across a building automation system (BAS) link is not recommended.
- If a dedicated bypass line with two-way valve is used for the system bypass, the bypass valve control loop should be the most responsive in the system to ensure adequate chiller module flow. Prioritize control loop speed in the following order: bypass valve responsiveness first, pump speed responsiveness second, and AHU valve control loops should operate the slowest.

- Differential pressure transducers can be used to measure system flow instead of a flow meter. There are two potential issues to keep in mind with that application:
  1. The performance of the chiller modules' strainers and brazed plate heat exchangers must be rigorously maintained. Clogged strainers or dirty brazed plate heat exchangers increase the differential pressure across the chiller bank and lower the flow rate. Lower flow rates through modular chiller heat exchangers can result in harmful operation and potentially lead to chiller lockout or component failure.
  2. For systems with a low brazed plate heat exchanger pressure drop (less than 2 psi), controlling flow rate using differential pressure sensors is not recommended because accurate measurement is difficult; a flow meter should be used instead.
- A comprehensive sequence of operation should be included in the design documents.
- Thorough system commissioning is required, including:
  - Temperature and pressure sensors and flow meter calibration
  - Bypass valve responsiveness and stability
  - AHU control valve stability
  - Pump speed control responsiveness and stability

Modular Chiller VPF Layout

This manual is to serve as guidance using best practices for modular units in variable primary flow systems. While there are numerous ways this can be accomplished the intent of this guide is to offer a few practical and simple control methods. The best solution will often depend on the equipment type, system needs, and tolerance for control complexity. Every application is unique so the control used should consider the needs of the system being served.

Differential Pressure Control

Differential pressure (DP) must be controlled at two points in this system: the distribution DP and the chiller bank DP. Pump speed and bypass valve position are used to control the distribution DP and chiller bank DP values. Some engineers prefer to use pump speed to control distribution DP, while others use pump speed to control chiller bank DP (Table 1).

Table 1. Methods used for differential pressure control

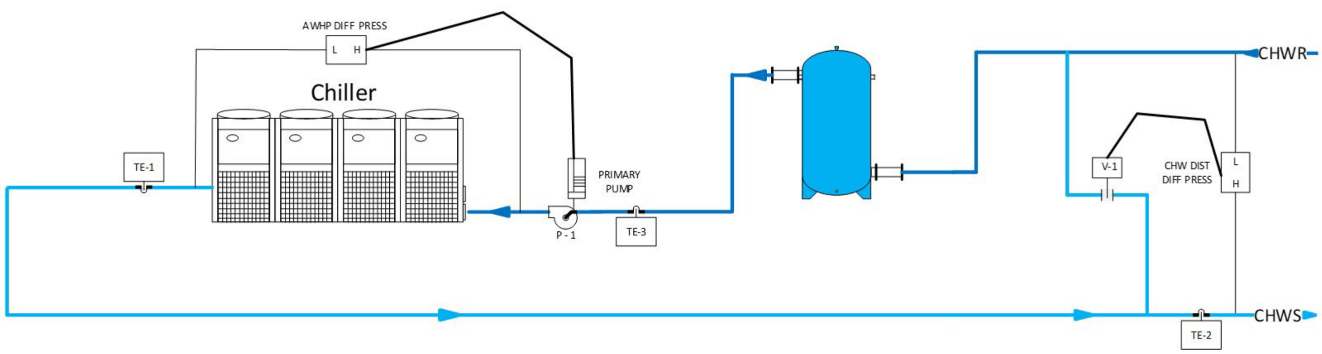
Method 1	Method 2
distribution DP used to control bypass valve position	distribution DP used to control pump speed
chiller bank DP used to control pump speed	chiller bank DP used to control bypass valve position

Method 1: Chiller DP control layout

- pump control = chiller/heat pump differential pressure (DP)
- bypass control = three-way valves or dedicated bypass line and valve

This setup uses a differential pressure sensor located across the chiller/heat pump (Figure 2). This DP sensor is connected to a pump controller that modulates the primary pump VFD. This pump speed will ramp up and down to maintain a constant DP across this chiller/heat pump. As the unit stages modules on and off (opening and closing automatic isolation valves) the primary pump speed modulates to maintain the required DP.

Figure 2. Primary pump controlled to chiller DP, bypass valve controlled to distribution DP



There must be a means to maintain minimum flow in the system. Two ways this can be accomplished are either 1) a minimum flow bypass line with control valve or 2) one or more three-way valves at the loads.

If a bypass line is used, the valve in this bypass is modulated to maintain the distribution system differential pressure (Figure 2). As two-way valves at the loads modulate further closed, the distribution system differential pressure rises, causing the bypass valve to modulate further open.

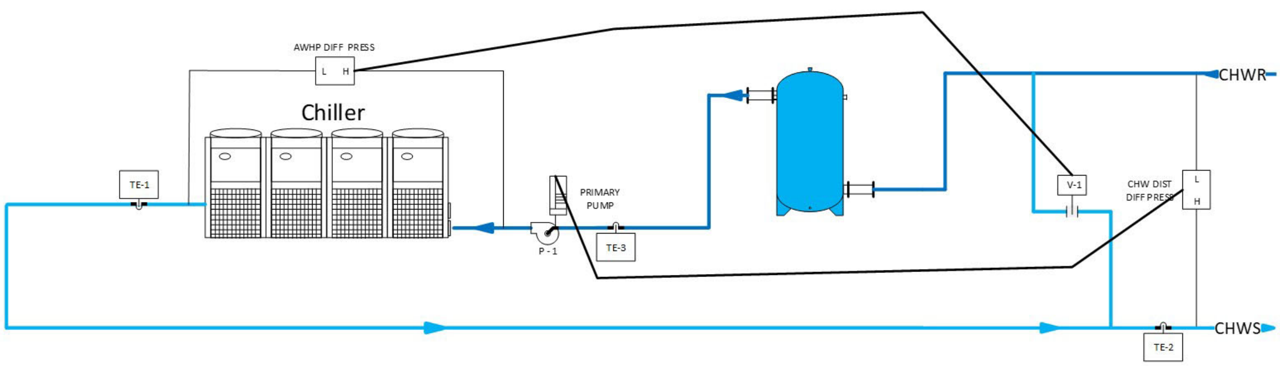
The location of this bypass should be towards the end of the distribution loop or at least 2/3 down the line.

Method 2: System DP control layout

- pump control = distribution system differential pressure (DP)
- bypass control = three-way valves or dedicated bypass line and valve

This setup uses a differential pressure sensor located out in the distribution loop, typically at the most remote coil (Figure 3). This DP sensor is connected to a pump controller that modulates the primary pump VFD. This pump speed will ramp up and down to maintain a constant DP across this coil. As the unit stages modules on and off (opening and closing automatic isolation valves) the minimum flow bypass valve modulates to maintain the required DP across the chiller.

Figure 3. Primary pump controlled to distribution DP, bypass valve controlled to chiller DP



Bypass Valve Control

There is one principle that must always be remembered in hydronic systems with two-way control valves: “Pumps Make Pressure, Valves Control Flow."

In a VPF system the pumps must be controlled so that there is always enough pressure available to meet the higher of the AHU flow demand or the chiller's minimum flow requirement. But in order for the chiller modules to actually receive their required minimum flow rate, the bypass valve must control properly as well.

When the AHUs are demanding less flow than the chiller modules require, the bypass valve needs to modulate open to bypass sufficient extra flow around the distribution system. The bypass valve is controlled by maintaining the module flow requirement with feedback from the system flow meter or chiller bank differential pressure sensor. This control logic must be active whenever the chiller bank is operating.

On an increase in the number of operating modules, this must be completed in a maximum of 10 seconds. On a decrease in the number of operating modules, the decrease in required minimum flow setpoint to the bypass valve control loop should be delayed by 90 seconds.

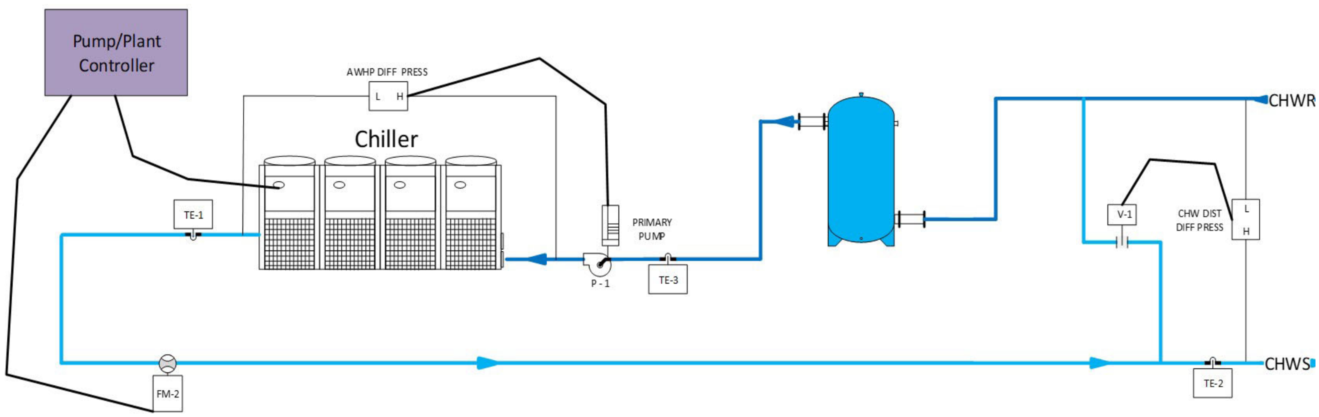
Optional Flow Verification

As described earlier, Thermafit™ modular chillers and heat pumps have an internal strainer in each module. If those strainers begin to plug up this creates a false DP reading for the pump or bypass valve. These units also have brazed plate heat exchangers which can also be plugged if proper water quality is not maintained, again leading to an incorrect DP reading.

To mitigate these effects on system control, a flow meter can be installed in the system piping. While this method will help with flow control in the above mentioned situations, the internal and system strainers must still be properly maintained to avoid entering this condition.

Figure 4 depicts a flow meter added to the previous example. Pump control is still based on measured differential pressure, the same as described for the two previous methods. The flow meter is used only to confirm the flow rate.

Figure 4. Optional flow meter added for system control



Thermafit™ modular chillers and heat pumps have the capability to communicate a signal to the BAS, indicating the number of automatic isolation valves that are currently open. With this information, one can read a table of the design flow per module to verify the correct flow rate (Table 2). If the operational flow rate is below the required flow rate then an action can be taken, typically either by generating a flow alarm or sending a signal to increase the pump speed.

Example

The example modular chiller depicted in Table 2 consists of four modules, with a total design flow rate of 200 gpm. This means that each module requires 50 gpm in order to provide the design ΔT. For example, if the unit controller is communicating that three modules have their isolation valves open, the pump should be providing 150 gpm.

Table 2. Example table of chiller bank minimum required flow rates

operating modules	minimum required flow rate (gpm)
1	50
2	100
3	150
4	200

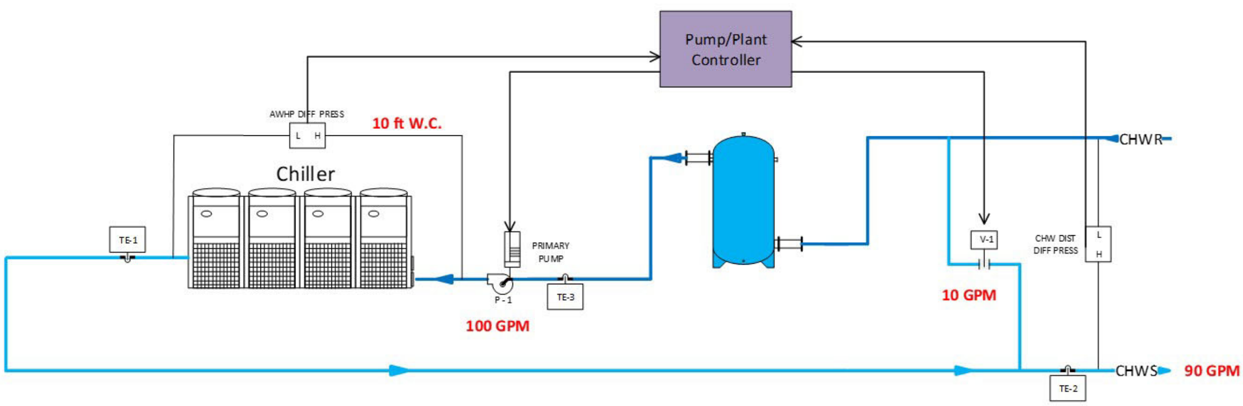
It is not recommended to use BAS outputs from a chiller/heat pump to control pump speed directly, due to the potential communication lag in the BAS. Using a separate controller that is wired between the DP sensor and pump VFD is recommended.

System Control Examples

Example 1) Pumps control to chiller/heat pump differential pressure

For this example, the chiller DP control loop speed/flow demand is higher than the system DP requirement. Shown in Figure 5 is a four-module chiller bank that has two modules in operation. The design flow for each module is 50 gpm. The design pressure drop for the chiller is 10 ft. H_2O, so that is the DP setpoint for the pump. To meet the critical distribution branch DP setpoint, the system requires a flow rate of 90 gpm. Since the system flow requirement is lower than the minimum flow requirement of the chiller bank (100 gpm with two modules operating), the bypass valve is open.

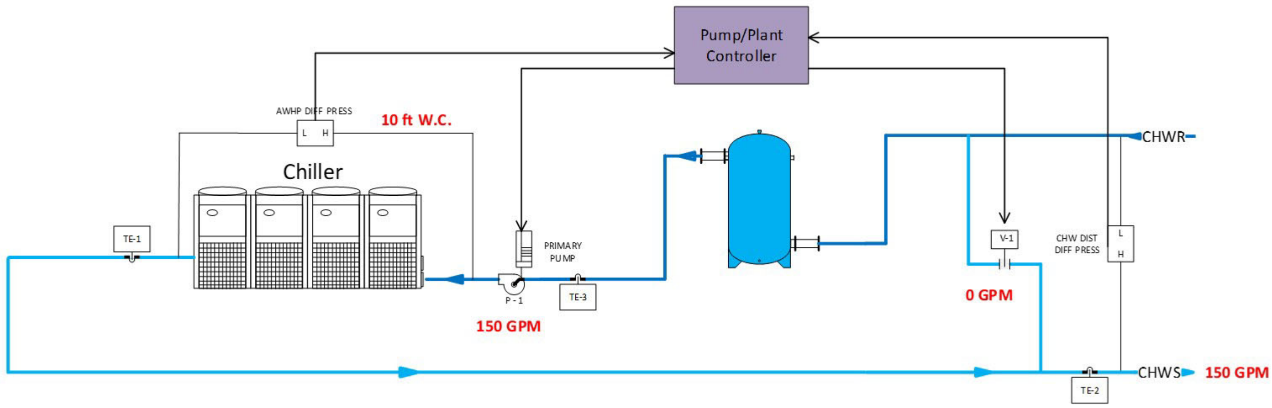
Figure 5. Example 1



Example 2) Pumps control to chiller/heat pump differential pressure

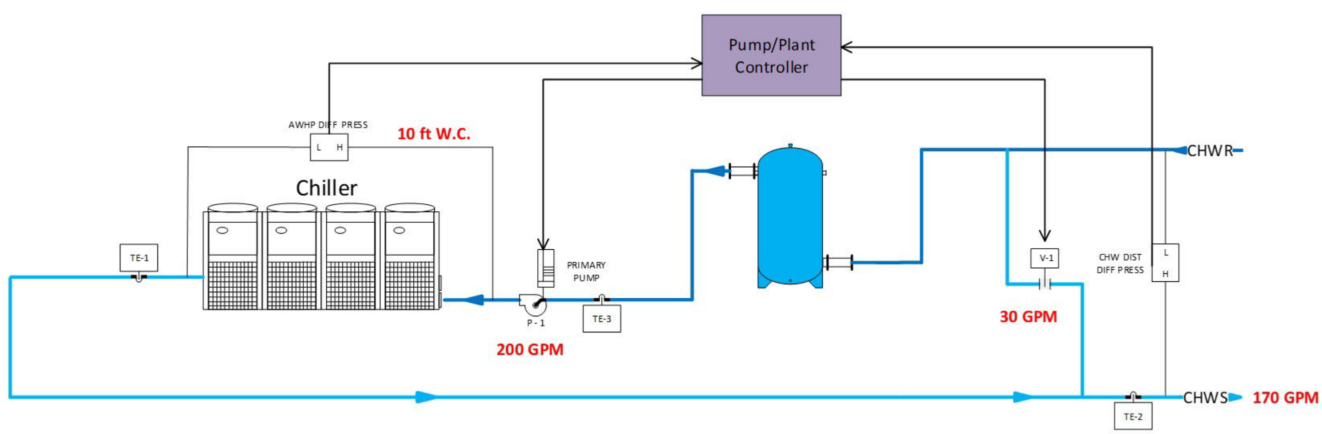
For this example, the chiller DP control loop speed/flow demand is lower than the system DP requirement. Figure 6 depicts the same four-module chiller bank, but now with three modules in operation. To meet the critical distribution branch DP setpoint, the system requires a flow rate of 170 gpm. Since the system flow requirement is higher than the minimum flow requirement of the chiller bank (150 gpm with three modules operating), the bypass valve is closed.

Figure 6. Example 2 (three modules operating)



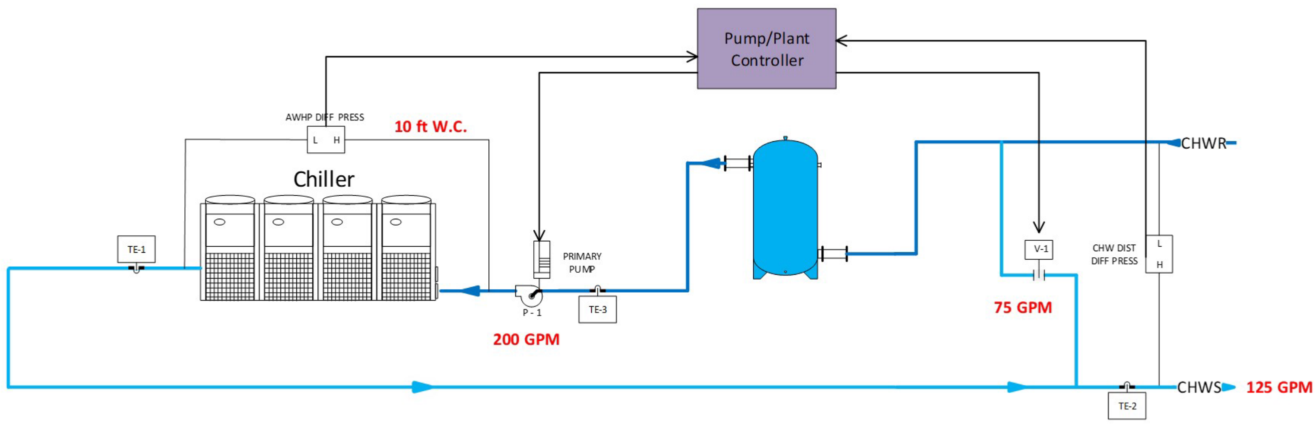
Because the chiller bank is not providing enough flow, but the system demand is still present, the fluid temperature entering the chiller is going to rise. Once the leaving fluid temperature rises above the setpoint plus deadband, and all timers have expired, the next module will be engaged. The next available module will open its automatic isolation valve, causing the chiller DP to decrease. This will be measured by the chiller DP sensor and a signal is sent to the pump VFD to increase pump speed. Now there are four modules in operation, so the chiller bank is providing 200 gpm. Because the chiller bank requires more flow than the system, the bypass valve again opens (Figure 7).

Figure 7. Example 2 (four modules operating)



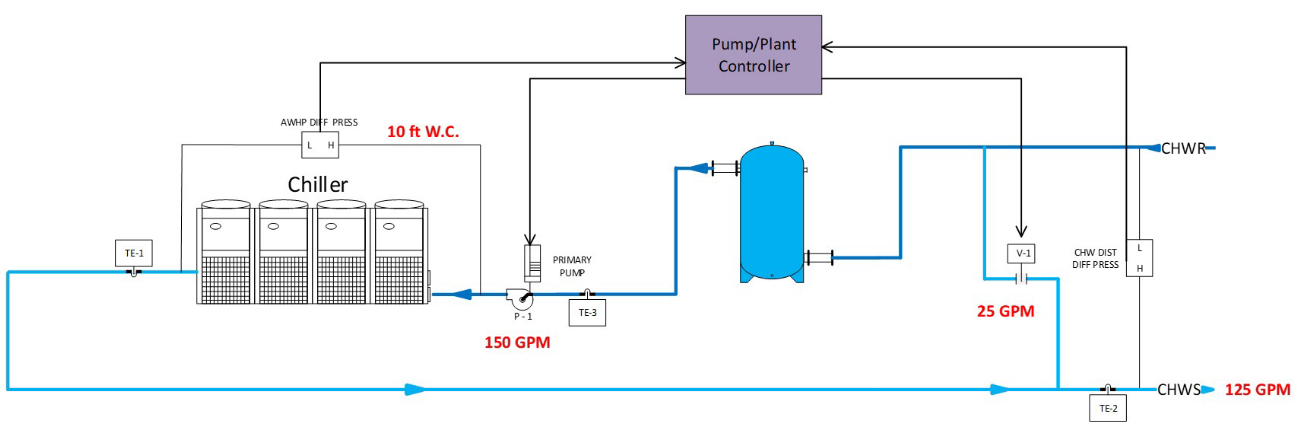
Now the system demand is starting to decrease, and some two-way valves in the system begin to modulate down or close all the way. Because the pump is still delivering 200 gpm, the system DP will begin to rise. This rising DP is communicated to the pump controller and a signal is sent to the bypass valve to begin opening, which reduces the system pressure. Now the system demand is 125 gpm, so the bypass valve is open to allow 75 gpm of bypass flow, while the pump speed is still set to deliver 200 gpm (Figure 8).

Figure 8. Example 2 (four modules operating, bypass opening)



With the bypass open and a relatively large amount of supply fluid mixing with return fluid, the reduced entering fluid temperature to the chiller is sensed and the unit will begin to turn down. If the design ΔT was 42°F supply with 57°F return, with 75 gpm of bypass flow, the resulting entering fluid temperature to the chiller would drop to about 51°F, meaning a module needs to shut down. The module that was first on would begin to close its automatic isolation valve, leading to an increase in the chiller DP, which then results in a control signal sent to the pump controller to reduce the VFD speed. Now the chiller is back to three modules operating and a flow rate of 150 gpm, with the bypass closing down some to allow only 25 gpm of bypass flow (Figure 9). This sequence would continue until the unit reaches its minimum flow rate.

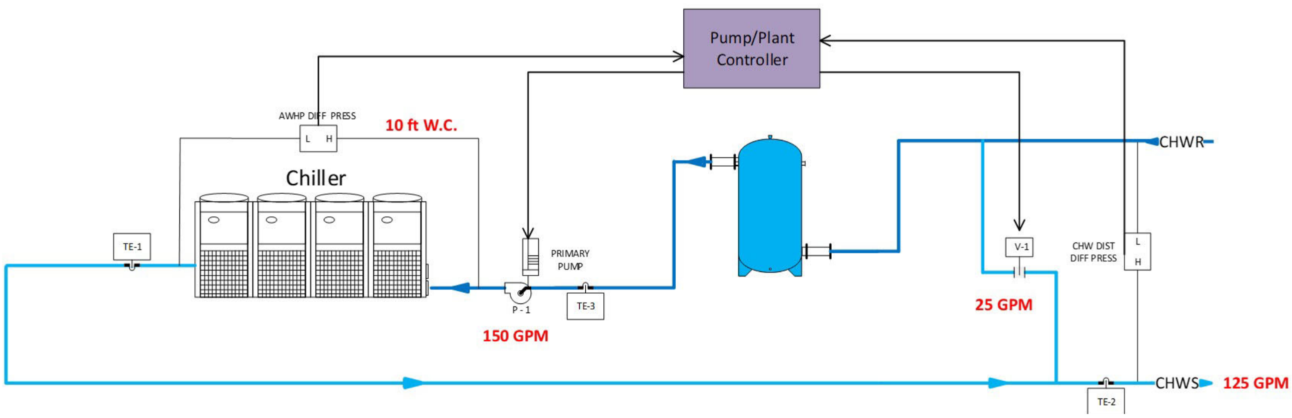
Figure 9. Example 2 (three modules operating again)



Example 3) Pumps control to distribution system differential pressure and bypass valve controls to chiller/heat pump differential pressure

For this example, the chiller DP control loop speed/flow demand is higher than the system DP requirement. Shown in Figure 10 is a four-module chiller bank that has three modules in operation. The system flow demand is 125 gpm and the chiller bank wants 150 gpm top meet its minimum flow requirements. The system DP is driving the pump speed, but the chiller DP is low so it is commanding the bypass valve to open further to maintain the required minimum chiller flow rate. At this moment, the bypass valve is allowing 25 gpm of bypass flow, making the total flow rate equal to 150 gpm.

Figure 10. Example 3

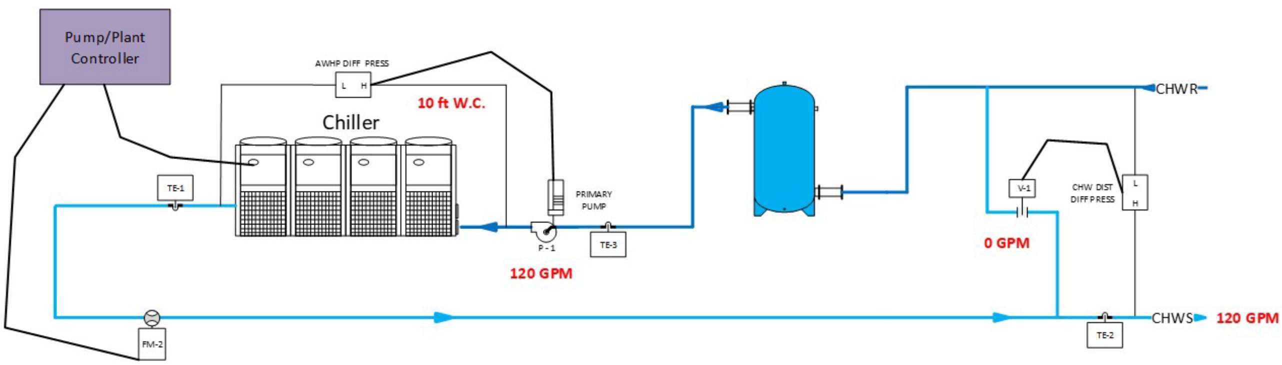


As the system flow demand begins to rise, the bypass valve begins to modulate further closed. Eventually the system flow demand and chiller flow demand will be equal and the bypass will be fully closed. As this happens, the chiller flow rate remains unchanged until the entering fluid temperature reaches a threshold to indicate that another module needs to come on-line. Once the next module has come on-line, the chiller flow demand will be 200 gpm and the bypass will again need to open as long as the chiller demand exceeds the system demand.

Example 4) Pumps control to chiller/heat pump differential pressure (with flow verification) and bypass valve controls to distribution system differential pressure

The flow calculated based on the number of modules with motorized isolation valves open is greater than what is being measured at the flow meter. Figure 11 depicts the same four-module chiller bank with the pumps controlling to the chiller DP, but flow verification via flow meter has been included. The DP setpoint for the pumps is again 10 ft. H_2O, but the measured flow rate is only 120 gpm.

Figure 11. Example 4



The BAS is indicating that three modules have their isolation valves open, so according to Table 3 the pumps should be moving 150 gpm. A possible cause could be clogging of the internal strainers in the modules, leading to a false DP reading. In this condition, the BAS could simply generate an alarm for the operator so they know to check the machine. Or the BAS could override the pump speed to increase the flow rate to 150 gpm. The bypass valve is shown as closed, indicating that the system is asking for more flow, so the chiller bank would be starving the system of flow until the flow rate is increased.

Table 3. Example 4 (chiller bank minimum required flow rates)

operating modules	minimum required flow rate (gpm)
1	50
2	100
3	150
4	200

As seen throughout this guide, there are several methods for controlling pumps and bypass valves in variable primary flow (VPF) applications using modular chillers and heat pumps. The best solution will often depend on the equipment type, system needs, and tolerance for controls complexity. Contact your local Trane representative for more information.

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PKG-APG001D-EN 2 Dec 2025 Supersedes
PKG-APG001C-EN (01 Dec 2022)