Addendum I to
ASHRAE Guideline 36-2024

Public Review Draft

Proposed Addendum I to Guideline 36-2024, High-Performance Sequences of Operation for HVAC Systems

First Public Review (July 2026)
(Draft shows Proposed Changes to Current Guideline)

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(This foreword is not part of this guideline. It is merely informative and does not contain requirements necessary for conformance to the guideline. It has not been processed according to the ANSI requirements for a guideline and may contain material that has not been subject to public review or a consensus process. Unresolved objectors on informative material are not offered the right to appeal at ASHRAE or ANSI.)

FOREWORD

Note: In this addendum, changes to the current guideline are indicated in the text by underlining (for additions) and strikethrough (for deletions) unless the instructions specifically mention some other means of indicating the changes. Only these changes are open for review and comment at this time. Additional material is provided for context only and is not open for comment except as it relates to the proposed substantive changes.

This addendum adds sequences of operation (SOOs) for two common designs of hot water and chilled water plants using air-to-water heat pumps (AWHPs):

1. Modular AWHPs. These plants are composed of AWHP modules that can produce hot water, chilled water, and (usually) simultaneous hot water and chilled water. The latter is also called heat recovery mode with energy transferred from the chilled water to the hot water. In this mode, for some manufacturers, the outdoor air coil can be used to adjust for imbalances of HW and CHW loads, either rejecting or absorbing energy from outdoor air. The SOOs herein assume that the modules are all controlled by a factory controller, including staging, not the building automation system (BAS) so staging sequences are not included for this type of AWHP. Both primary-only and primary-secondary distribution systems are addressed.
2. 2-pipe and 4-pipe AWHPs. These plants are composed of separate AWHPs piped together in the field, each with built in primary pumps controlled by the unit's internal controller. The 2-pipe AWHPs can provide either chilled water or hot water, but not both at the same time. The 4-pipe AWHPs can provide both HW and CHW simultaneously with heat recovery, i.e. energy is transferred from the chilled water to the hot water. For some manufacturers, the outdoor air coil can be used to adjust for imbalances of HW and CHW loads. Defrost is assumed to be internally controlled by the heat pump controller, but all other logic, including staging, is assumed to be by the proposed BAS sequences.

Since Guideline 36 scope is limited to control logic, the sequences in this proposed addendum do not address design issues such as buffer tank sizing and location in the system, physical location of bypass valves, etc. Designers should look to other ASHRAE and manufacturer guides for these design considerations as well as the following:

1. The design of the AWHP system can have a significant impact on how the system should be controlled. This is especially true for the heating side since modules in heat pump mode will have less capacity at lower outdoor air temperatures and are impacted by the need to periodically defrost. Systems may require additional modules and benefit from the uses of a buffer or thermal

storage tank for greater stability and capacity. Designers may also wish to consider time averaged ventilation schemes that allow reduction or interruption in ventilation during defrost events that impact the plant's ability to meet the load as evidenced by space temperature, leaving air temperature, leaving water temperature setpoint, or other indicators. For example, the time averaged ventilation provisions of ASHRAE 62.1, California Title 24, and other codes. Designers should also review design guides and consult with system suppliers about recommended best design practices.

2. The heat pump modules (2 pipe, 4 pipe, and heat recovery) all have their own integrated controls for operation of the compressors, fans, pumps, and reversing valves. These controls will typically be integrated to the BAS to allow the BAS to enable a module on/off and to set the desired setpoints. But the operation within the module will be done by the factory integrated controller. There is variation from supplier to supplier and model to model for how the internal control logic specifically works, and manufacturers are frequently updating the logic since this is a relatively new product line for most manufacturers. Care is needed both in design, and in project commissioning to assure that the BAS control strategy works correctly with the internal logic of the module controllers.
3. The designer needs to determine if they want to have the BAS sequence the heat pump modules or if they want to utilize a packaged, factory provided sequencer. There are pros and cons to both approaches. The sequences provided for modular systems reflect the use of a packaged sequencer while the field applied modules use the BAS. But some modular suppliers allow the uses of the BAS and there are packaged sequencers available for control of individual modules. One benefit is that the BAS has knowledge of flow and load that the manufacturer’s controller may not since flow meters are not usually included in their control package. The BAS can then consider flow minimums and module minimum and maximum capacity, as well as temperature, in staging logic. A packaged (or factory provided) sequence controller may have other knowledge or advanced logic including algorithms and use of AI as well as insight into states such as defrost status, that the BAS does not which can result in improved efficiency and reliability. Designers are encouraged to carefully evaluate the options and edit this document to reflect the desired direction.
4. Additional information:

- https://docs.nrel.gov/docs/fy24osti/87812.pdf
- https://b2electrification.org/sites/b2electrification.org/files/posts/B2E%20Commercial%20Building%20Electrification%20Guide%20Final_0.pdf
- https://sustainableenergyaction.org/wp-content/uploads/2025/03/BENEFIT_Transition-to-All-Electric-Guide.pdf

Addendum l to Guideline 36-2024

(IP and SI Units)

PART 3 SETPOINTS, DESIGN AND FIELD DETERMINED

3.1 INFORMATION PROVIDED BY DESIGNER

3.1.1. Modular Air-To-Water Heat Pump Plant

3.1.1.1. Chilled Water Plant

a. CHWSTmin, the lowest chilled water supply temperature setpoint

b. CHWSTmax, the highest chilled water supply temperature setpoint

c. CH-LOT, the outdoor air lockout temperature below which the cooling plant is prevented from operating

The Lockout temperature is a safety to prevent plant operation when it should not be needed, e.g., due to Plant Request from a zone or AHU with unusually cold setpoint. It is typically 60°F for plants serving systems with airside economizers. To keep the plant enabled under all conditions, such as plants with heat recovery heat pumps that operate in cold weather, make the setpoint below the coldest expected outdoor air temperature.

d. CHWFdesign, design primary CHW loop flow in gpm

e. CHWFmin, minimum primary CHW loop flow in gpm

f. CHW-DP-Plant, the differential pressure setpoint across modular heat pump header

g. NCHWP, the number of chilled water pumps that operate at design conditions

3.1.1.2. Hot Water Plant

a. HWSTmin, the lowest hot water supply temperature setpoint

b. HWSTmax, the highest hot water supply temperature setpoint

c. HW-LOT, the outdoor air lockout temperature above which the heating plant is prevented from operating

The Lockout temperature is a safety to prevent plant operation when it should not be needed, e.g. due to a Plant Request from a zone or AHU with unusually high setpoint. It is typically 75°F for systems with zone level reheat. It can be lower, e.g. 65°F, for dual fan dual duct systems and systems that use fan powered terminal units to meet heating loads since they do not require reheat to prevent over-cooling zones with low, or no, cooling loads.

To keep the plant enabled under all conditions, make the setpoint above the hottest expected outdoor air temperature.

d. HWFdesign, design primary loop flow

e. HWFmin, minimum primary HW loop flow in gpm

f. HW-DP-Plant, the differential pressure setpoint across modular heat pump header

g. NHWP, the number of hot water pumps that operate at design conditions

3.1.2. 2-Pipe and 4-Pipe Air-To-Water Heat Pump Plant

3.1.2.1. Cooling Parameters:

a. Temperature Setpoints

1) CHWSTmin, the lowest chilled water supply temperature setpoint

2) CHWSTmax, the highest chilled water supply temperature setpoint

3) CH-LOT, the outdoor air lockout temperature below which the chiller plant is prevented from operating

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The Lockout temperature is a safety to prevent plant operation when it should not be needed, e.g., due to Plant Request from a zone or AHU with unusually cold setpoint. It is typically 60°F for plants serving systems with airside economizers. To keep the plant enabled under all conditions, such as plants with heat recovery heat pumps that operate in cold weather, make the setpoint below the coldest expected outdoor air temperature.

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b. For each heat pump unit, QcX, design cooling capacity of Heat Pump X at design outdoor air and hot water temperatures, in tons.

c. CHWFdesign, design primary CHW loop flow, in gpm

d. N-CHWP, the number of chilled water pumps that operate at design conditions

3.1.2.2. Heating Parameters

a. Temperature Setpoints

1) HWSTmin, the lowest chilled water supply temperature setpoint

2) HWSTmax, the highest hot water supply temperature setpoint

3) HWSTdesign, the design hot water supply temperature

Design HWST is that corresponding to design capacity Qh for each heat pump.

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4) OATdesign, the design outdoor air temperature

Design OAT is that corresponding to design capacity Qh for each heat pump.

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5) HW-LOT, the outdoor air lockout temperature above which the boiler plant is prevented from operating

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The Lockout temperature is a safety to prevent plant operation when it should not be needed, e.g. due to a Plant Request from a zone or AHU with unusually high setpoint. It is typically 75°F for systems with zone *level reheat. It can be lower, e.g. 65°F, for dual fan dual duct systems and systems that use fan powered terminal units to meet heating loads since they do not require reheat to prevent over-cooling zones with low, or no, cooling loads.*

To keep the plant enabled under all conditions, make the setpoint above the hottest expected outdoor air temperature.

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a. For each heat pump unit, QhX, design heating capacity of Heat Pump X at design outdoor air and hot water temperatures, in Btu/h.

b. HWFdesign, design primary HW loop flow, in gpm

c. N-HWP, the number of hot water pumps that operate at design conditions

3.2 INFORMATION PROVIDED BY (OR IN CONJUNCTION WITH) THE TESTING, ADJUSTING, AND BALANCING CONTRACTOR

3.2.1. Modular Air-To-Water Heat Pump Plant

3.2.1.1. CHW-DPmax, the maximum chilled water differential pressure setpoint, in psi

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Instructions for establishing CHW-DPmax should be provided in the Test and Balance Specification. For example:

1. *Fully open all control valves serving coils that are located downstream of the differential pressure sensor.*
2. *Close the minimum flow bypass valve (if applicable).*
3. *Fully close all control valves serving coils that are located upstream of the differential pressure sensor.*
4. *Start pump(s). Manually adjust speed slowly until design flow (or design pressure drop, for coils without calibrated balance valves) is just achieved through all open coils without modulating any balance valves. One coil should be just at design flow, while others should be at or above design flow.*
5. *Once flow condition in previous step is achieved, note the BAS differential pressure sensor and handheld digital pressure sensor readings to verify accuracy of BAS reading; report BAS reading to controls contractor.*

3.2.1.2. HW-DPmax, the maximum chilled water differential pressure setpoint, in psi

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Instructions for establishing HW-DPmax should be provided in the Test and Balance Specification. For example:

1. *Fully open all control valves serving coils that are located downstream of the differential pressure sensor.*
2. *Close the minimum flow bypass valve (if applicable).*
3. *Fully close all control valves serving coils that are located upstream of the differential pressure sensor.*

4. *Start pump(s). Manually adjust speed slowly until design flow (or design pressure drop, for coils without calibrated balance valves) is just achieved through all open coils without modulating any balance valves. One coil should be just at design flow, while others should be at or above design flow.*

3.2.2. 2-Pipe and 4-Pipe Air-To-Water Heat Pump Plant

3.2.2.1. CHW-DPmax, the maximum chilled water differential pressure setpoint, in psi

Instructions for establishing CHW-DPmax should be provided in the Test and Balance Specification. For example:

1. *Fully open all control valves serving coils that are located downstream of the differential pressure sensor.*
2. *Close the minimum flow bypass valve (if applicable).*
3. *Fully close all control valves serving coils that are located upstream of the differential pressure sensor.*
4. *Start pump(s). Manually adjust speed slowly until design flow (or design pressure drop, for coils without calibrated balance valves) is just achieved through all open coils without modulating any balance valves. One coil should be just at design flow, while others should be at or above design flow.*
5. *Once flow condition in previous step is achieved, note the BAS differential pressure sensor and handheld digital pressure sensor readings to verify accuracy of BAS reading; report BAS reading to controls contractor.*

3.2.2.2. HW-DPmax, the maximum chilled water differential pressure setpoint, in psi

Instructions for establishing HW-DPmax should be provided in the Test and Balance Specification. For example:

1. *Fully open all control valves serving coils that are located downstream of the differential pressure sensor.*
2. *Close the minimum flow bypass valve (if applicable).*
3. *Fully close all control valves serving coils that are located upstream of the differential pressure sensor.*
4. *Start pump(s). Manually adjust speed slowly until design flow (or design pressure drop, for coils without calibrated balance valves) is just achieved through all open coils without modulating any balance valves. One coil should be just at design flow, while others should be at or above design flow.*

underlined for ease of review.

4.20 MODULAR AIR-TO-WATER HEAT PUMP PLANT

Informative Notes for the Designer

- *Modular AWHPs. These plants are composed of AWHP modules that can produce hot water, chilled water, and (usually) simultaneous hot water and chilled water. The latter is also called heat recovery mode with energy transferred from the chilled water to the hot water. In this mode, for some manufacturers, the outdoor air coil can be used to adjust for imbalances of HW and CHW loads, either rejecting or absorbing energy from outdoor air. The SOOs herein assume that the modules are all controlled by a factory controller, including staging, not the building automation system (BAS) so staging sequences are not included for this type of AWHP. Both primary-only and primary-secondary distribution systems are addressed.*
- *2-pipe and 4-pipe AWHPs. These plants are composed of separate AWHPs piped together in the field, each with built in primary pumps controlled by the unit's internal controller. The 2-pipe AWHPs can provide either chilled water or hot water, but not both at the same time. The 4-pipe AWHPs can provide both HW and CHW simultaneously with heat recovery, i.e. energy is transferred from the chilled water to the hot water. For some manufacturers, the outdoor air coil can be used to adjust for imbalances of HW and CHW loads. Defrost is assumed to be internally controlled by the heat pump controller, but all other logic, including staging, is assumed to be by the proposed BAS sequences.*
- *Since Guideline 36 scope is limited to control logic, the sequences in this proposed addendum do not address design issues such as buffer tank sizing and location in the system, physical location of bypass valves, etc. Designers should look to other ASHRAE and manufacturer guides for these design considerations as well as the following:*
- *The design of the AWHP system can have a significant impact on how the system should be controlled. This is especially true for the heating side since modules in heat pump mode will have less capacity at lower outdoor air temperatures and are impacted by the need to periodically defrost. Systems may require additional modules and benefit from the uses of a buffer or thermal storage tank for greater stability and capacity. Designers may also wish to consider time averaged ventilation schemes that allow reduction or interruption in ventilation during defrost events that impact the plant's ability to meet the load as evidenced by space temperature, leaving air temperature, leaving water temperature setpoint, or other indicators. For example, the time averaged ventilation provisions of ASHRAE 62.1, California Title 24, and other codes. Designers should also review design guides and consult with system suppliers about recommended best design practices.*
- *The heat pump modules (2 pipe, 4 pipe, and heat recovery) all have their own integrated controls for operation of the compressors, fans, pumps, and reversing valves. These controls will typically be integrated to the BAS to allow the BAS to enable a module on/off and to set the desired setpoints. But the operation within the module will be done by the factory integrated controller. There is variation from supplier to supplier and model to model for how the internal control logic specifically works, and manufacturers are frequently updating the logic since this is a relatively new product line for most manufacturers. Care is needed both in design, and in project commissioning to assure that the BAS control strategy works correctly with the internal logic of the module controllers.*
- *The designer needs to determine if they want to have the BAS sequence the heat pump modules or if they want to utilize a packaged, factory provided sequencer. There are pros and cons to both approaches. The sequences provided for modular systems reflect the use of a packaged sequencer while the field applied modules use the BAS. But some modular suppliers allow the uses of the BAS and there are packaged sequencers available for control of individual modules. One benefit is that the BAS has knowledge of flow and load that the manufacturer's controller may not since flow meters are not usually included in their control package. The BAS*

can then consider flow minimums and module minimum and maximum capacity, as well as temperature, in staging logic. A packaged (or factory provided) sequence controller *may have other knowledge or advanced logic including algorithms and use of AI as well* as *insight into states such as defrost status, that the BAS does not which can result in improved efficiency and reliability. Designers are encouraged to carefully evaluate the options and edit this document to reflect the desired direction.*

- *Additional information:*
    - *https://docs.nrel.gov/docs/fy24osti/87812.pdf*
    - *https://b2electrification.org/sites/b2electrification.org/files/posts/B2E%20Commercial%20Building%20Electrification%20Guide%20Final_0.pdf*
    - *https://sustainableenergyaction.org/wp-content/uploads/2025/03/BENEFIT_Transition-to-All-Electric-Guide.pdf*

4.20.1. Modular Heat Pumps and Master Controller

Required?	Description	Type	Device
R	Cooling on/off	DO	DI on Modular Heat Pump Master Controller or through network interface
R	Heating on/off	DO	DI on Modular Heat Pump Master Controller or through network interface
R	AWHP status	DI	DO on Modular Heat Pump Master Controller or through network interface
R	CHWST Setpoint	AO	AI on Modular Heat Pump Master Controller or through network interface
R	HWST Setpoint	AO	AI on Modular Heat Pump Master Controller or through network interface
R	AWHP Fault Code	AI	AO from Modular Heat Pump Master Controller or through network interface
O	HW supply temperature	AI	AO on Modular Heat Pump Master Controller or through network interface
O	HW return temperature	AI	AO on Modular Heat Pump Master Controller or through network interface
O	CHW supply temperature	AI	AO on Modular Heat Pump Master Controller or through network interface
O	CHW return temperature	AI	AO on Modular Heat Pump Master Controller or through network interface
Include the following point only if heat pump requires flow through the inactive heat exchanger for freeze protection.			
A	HW flow requested for freeze protection	DI	DO on Modular Heat Pump Master Controller or through network interface
Include the following for optional performance monitoring. Typically, a single power connection is provided for up to 4 modules.			
O	AWHP power	AI	Power (kW) meter

4.20.2. Chilled Water Pumps

Required?	Description	Type	Device
R	CHWP Start	DO	Connect to VFD Run or Starter Contact; typ. each CHWP
R	CHWP Status	DI	Status through VFD interface, VFD status contact or current switch; typ. each CHWP
Provide one speed point for each group of variable speed CHW pumps controlled to the same speed (e.g., all primary pumps or all secondary pumps, if applicable). Speed point not required for constant speed pumps.			
A	CHWP Speed	AO	Connect to VFD Speed on all CHW pumps controlled to same speed
Provide a CHW differential pressure sensor hardwired to the pump controller for any pump or set of pumps serving multiple control valves. Additional pressure sensors may be provided with feedback sent over the network to the pump controller. CHW DP not required for constant speed pumps.			
A	CHW System Differential Pressure	AI	Differential Pressure Transducer near end of distribution system
O	CHWP Alarm	DI	Fault point through VFD interface or programmed VFD contact; typ. each CHWP

4.20.3. CHW Loop

Required?	Description	Type	Device
For primary-only systems, provide differential pressure sensor across the CHW header serving the heat pump modules. This point is optional for primary-secondary systems.			
A	CHW Header Differential Pressure	AI	Differential Pressure Transducer
CHW flow meter for primary-only plants must be located on the plant side of the CHW minimum flow bypass where provided.			
R	CHW supply or return flow	AI	Flow meter
CHW bypass valve is required for variable flow primary-only plants. Delete for primary/secondary plants.			
A	CHW Min Flow Bypass Valve	AO	Modulating valve sized for minimum flow of one chiller
R	CHW supply temperature	AI	Temperature sensor
CHW return temperature for primary-only plants must be located on plant side of the CHW minimum flow bypass to allow for correct load calculations.			
R	CHW return temperature	AI	Temperature sensor
O	CHW system gauge pressure	AI	Gauge pressure transducer

4.23.1. Hot Water Pumps

Required?	Description	Type	Device
R	HWP Start	DO	Connect to VFD Run or Starter Contact; typ. each HWP
R	HWP Status	DI	Status through VFD interface, VFD status contact or current switch; typ. each HWP
Provide one speed point for each group of variable speed HW pumps controlled to the same speed (e.g., all primary pumps or all secondary pumps, if applicable). Speed point not required for constant speed pumps.			

Required?	Description	Type	Device
A	HWP Speed	AO	Connect to VFD Speed on all HW pumps controlled to same speed
Provide a HW differential pressure sensor hardwired to the pump controller for any pump or set of pumps serving multiple control valves. Additional pressure sensors may be provided with feedback sent over the network to the pump controller. HW DP not required for constant speed pumps.			
A	HW System Differential Pressure	AI	Differential Pressure Transducer
O	HWP Alarm	DI	Fault point through VFD interface or programmed VFD contact; typ. each CHWP

4.23.2. HW Loop

Required?	Description	Type	Device
For primary-only systems, provide differential pressure sensor across the HW header serving the heat pump modules. This point is optional for primary-secondary systems.			
A	HW System Differential Pressure	AI	Differential Pressure Transducer near end of distribution system
HW flow meter for primary-only plants must be located on the plant side of the HW minimum flow bypass where provided.			
R	HW supply or return flow	AI	Flow meter
HW bypass valve is required for variable flow primary-only plants. Delete for primary/secondary plants.			
A	HW Min Flow Bypass Valve	AO	Modulating valve sized for minimum flow of one chiller or as recommended by the manufacturer
R	HW supply temperature	AI	Temperature sensor
HW return temperature for primary-only plants must be located on plant side of the CHW minimum flow bypass to allow for correct load calculations.			
R	HW return temperature	AI	Temperature sensor
O	HW system gauge pressure	AI	Gauge pressure transducer

4.28 2-PIPE AND 4-PIPE AIR-TO-WATER HEAT PUMP PLANT

4.28.1. 4-pipe Heat Recovery Heat Pumps

Required?	Description	Type	Device
R	AWHR cooling on/off	DO	DI on heat pump control panel or through network interface; typ. each heat pump
R	AWHR heating on/off	DO	DI on heat pump control panel or through network interface; typ. each heat pump
R	AWHR status	DI	DO on heat pump control panel or through network interface; typ. each heat pump
R	CHWST Setpoint	AO	AI on heat pump control panel or through network interface; typ. each heat pump
R	HWST Setpoint	AO	AI on heat pump control panel or through network interface; typ. each heat pump

Required?	Description	Type	Device
R	AWHR Fault Code	AI	From heat pump controller through network interface; typ. each heat pump
O	AWHP power	AI	Power (kW) meter

4.28.1. 2-pipe Changeover Heat Pumps

Required?	Description	Type	Device
R	AWHP enable	DO	DI on heat pump control panel or through network interface; typ. each heat pump
Changeover point is recommended to be hardwired to relays, valves, and valve end switches as shown in Figure A-37 to ensure changeover valves are not inadvertently configured incorrectly, e.g. HW interconnected with chilled water system and vice versa, or valves indexed to hot water while the heat pump is operating in chilled water mode and vice versa. Alternatively, the valves and AWHP mode may each be individually controlled by the BAS with software and the user interface configured to prevent these issues.			
R	AWHP heating/cool changeover	DO	DI on heat pump control panel or through network interface; typ. each heat pump.
R	AWHP status	DI	DO on heat pump control panel or through network interface; typ. each heat pump
R	CHWST Setpoint	AO	AI on heat pump control panel or through network interface; typ. each heat pump
R	HWST Setpoint	AO	AI on heat pump control panel or through network interface; typ. each heat pump
R	AWHP Fault Code	AI	From heat pump controller through network interface; typ. each heat pump
O	AWHP power	AI	Power (kW) meter

4.28.2. Chilled Water Pumps

Required?	Description	Type	Device
R	CHWP Start	DO	Connect to VFD Run or Starter Contact; typ. each CHWP
R	CHWP Status	DI	Status through VFD interface, VFD status contact or current switch; typ. each CHWP
Provide one speed point for each group of variable speed CHW pumps controlled to the same speed (e.g., all primary pumps or all secondary pumps, if applicable). Speed point not required for constant speed pumps.			
A	CHWP Speed	AO	Connect to VFD Speed on all CHW pumps controlled to same speed
Provide a CHW differential pressure sensor hardwired to the pump controller for any pump or set of pumps serving multiple control valves. Additional pressure sensors may be provided with feedback sent over the network to the pump controller. CHW DP not required for constant speed pumps.			
A	CHW Differential Pressure	AI	Differential Pressure Transducer
O	CHWP Alarm	DI	Fault point through VFD interface or programmed VFD contact; typ. each CHWP

4.28.3. CHW Loop

Required?	Description	Type	Device
R	CHW supply or return flow	AI	Flow meter
R	CHW supply temperature	AI	Temperature sensor
R	CHW return temperature	AI	Temperature sensor
O	CHW system gauge pressure	AI	Gauge pressure transducer

4.31.1. Hot Water Pumps

Required?	Description	Type	Device
R	HWP Start	DO	Connect to VFD Run or Starter Contact; typ. each HWP
R	HWP Status	DI	Status through VFD interface, VFD status contact or current switch; typ. each HWP
Provide one speed point for each group of variable speed HW pumps controlled to the same speed (e.g., all primary pumps or all secondary pumps, if applicable). Speed point not required for constant speed pumps.			
A	HWP Speed	AO	Connect to VFD Speed on all HW pumps controlled to same speed
Provide a HW differential pressure sensor hardwired to the pump controller for any pump or set of pumps serving multiple control valves. Additional pressure sensors may be provided with feedback sent over the network to the pump controller. HW DP not required for constant speed pumps.			
A	HW Differential Pressure	AI	Differential Pressure Transducer
O	HWP Alarm	DI	Fault point through VFD interface or programmed VFD contact; typ. each CHWP

4.31.2. HW Loop

Required?	Description	Type	Device
R	HW supply or return flow	AI	Flow meter
R	HW supply temperature	AI	Temperature sensor
R	HW return temperature	AI	Temperature sensor
O	HW system gauge pressure	AI	Gauge pressure transducer

Add Section 5.25 and 5.26 as follows: Note: the section below is new, but additions are not underlined for ease of review.

5.25 MODULAR AIR-TO-WATER HEAT PUMP/CHILLER PLANT

This sequence is for a single modular 4-pipe air-to-water heat recovery heat pump (AWHP) with multiple modules. It is assumed to include a "Modular Heat Pump Master Controller" provided by the AWHP manufacturer and connected to each module that performs the following logic:

AWHP module lead/lag alternation

AWHP module staging (enable/disable)

AWHP module heating, cooling, and heat recovery modes

Modulation of AWHP module CHW isolation valves for primary-only distribution systems, or start/stop of primary CHW pumps for primary/secondary distribution systems

Modulation of AWHP module HW isolation valves for primary-only distribution systems, or start/stop of primary HW pumps for primary/secondary distribution systems

Defrost and staging/sequencing of defrost between circuits

See Figure A-35 for primary-only-variable flow distribution system. See Figure A-36 for primary-secondary distribution system with dedicated factory mounted primary pumps. Note that the CHWS/R and HWS/R temperature sensors wired to the master controller must be installed on the secondary side of the common leg for primary-secondary distribution systems, as shown in Figure A-36, to ensure the master controller stages heat pumps correctly,

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5.25.1. See Sections 3.1.1 and 3.2.1 for operating parameters and setpoints.

5.25.2. Chilled Water Plant

5.25.2.1. Enable/Disable

a. The chiller plant shall include an enabling schedule that allows operators to lock out the plant during off-hours, holidays, or any other scheduled event, e.g., to allow off-hour operation of HVAC systems except the chiller plant. The default schedule shall be 24/7 (adjustable).

b. Enable the plant when the plant has been disabled for at least 15 minutes and:

1) Number of Chiller Plant Requests > I (I = Ignores shall default to 0, adjustable), and

2) OAT>CH-LOT, and

3) The chiller plant enable schedule is active.

c. Disable the plant when it has been enabled for at least 15 minutes and:

1) Number of Chiller Plant Requests ≤ I for 3 minutes, or

2) OAT<CH-LOT – 1°F, or

3) The chiller plant enable schedule is inactive.

Chiller Plant Requests are generated by coil control valves. If the plant serves critical valves whose positions are not known to the plant controller, e.g., pneumatic controls, the Chiller Plant Request variable can be set to 1 manually by the operator such that the plant is enabled strictly based on OAT lockout and schedule per subsequent logic.

At a future date, Importance multipliers (IM) shall be added to Chiller Plant Requests in AHU and fan coils sequences to ensure that critical coils can independently cause the plant to start. For example, setting the importance multiplier of a large air handler's Chiller Plant Requests to 4 will cause 4 requests so that air handler alone can start the plant even if I=4. Unimportant coils can be assigned an IM of zero so that they cannot cause the plant to start. Small coils can be assigned IM values between zero and one so that several are required to be active before the plant will start.

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d. When the plant is enabled:

1) Command the Modular-Heat-Pump heat pump master controller to COOL mode.

2) Enable CHW pumps per Section 5.25.2.3.

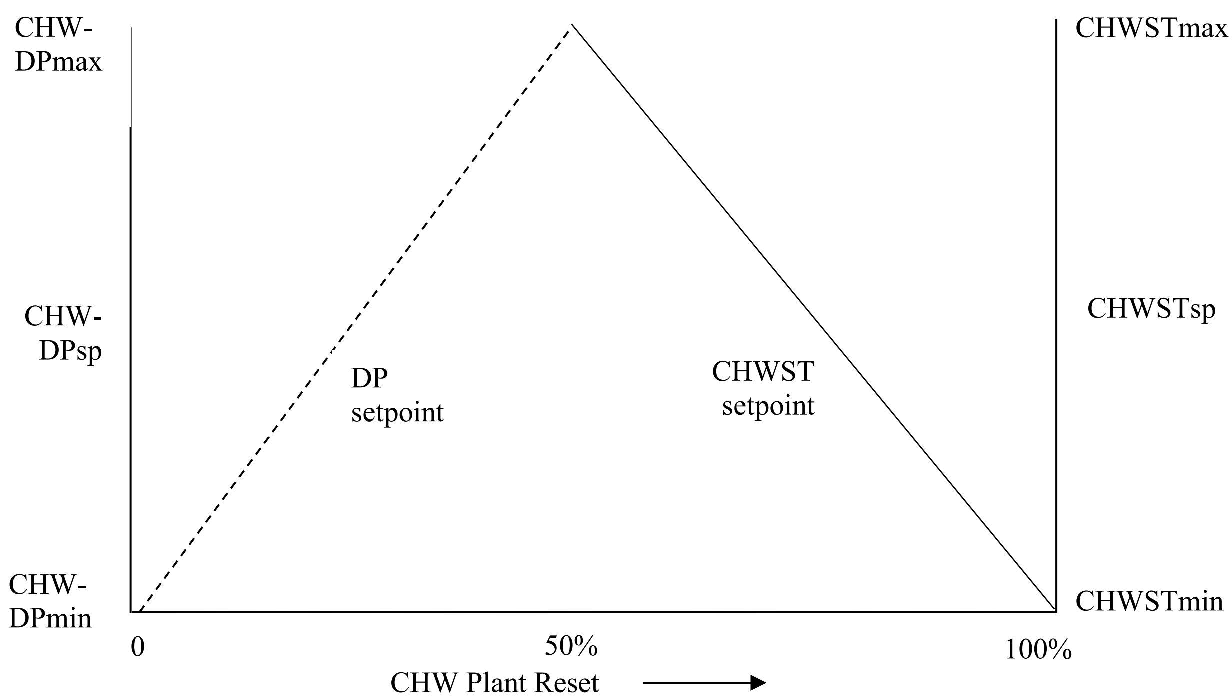
e. When the plant is disabled:

1) Command the Modular-Heat-Pump heat pump master controller to disable COOL mode.

2) Disable CHW pumps per Section 5.25.2.3.

5.25.2.2. Chilled Water Plant Reset

a. Chilled water supply temperature setpoint CHWSTsp and distribution system differential pressure setpoint CHW-DPsp shall be reset based on the current value of the logic variable called "CHW Plant Reset" as shown below and described subsequently.



The recommended logic first resets differential pressure setpoint to maximum before resetting chilled water supply temperature setpoint down towards design. Parametric plant analysis performed in a variety of climate zones during the development of ASHRAE's "Fundamentals of Design and Control of Central Chilled-Water Plants" Self-Directed Learning Course showed that the pump energy penalty incurred with this approach is more than offset by chiller energy savings resulting from keeping the chilled water supply temperature setpoint as high as possible.

b. From 0% loop output to 50% loop output, reset DP setpoint from CHW-DPmin to CHWP-DPmax.

c. From 50% loop output to 100% loop output, reset CHWST setpoint from CHWSTmax to CHWSTmin.

d. CHW Plant Reset variable shall be reset using Trim & Respond logic with the parameters shown in Table 5.25.2:

Table 5.25.2 Trim & Respond Variables

Variable	Value
Device	Any CHW Pump Distribution Loop
SP0	100%
SPmin	0%
SPmax	100%
Td	15 minutes
T	5 minutes
I	2
R	Chilled-Water Reset Requests
SPtrim	-2%
SPres	+3%
SPres-max	+7%

Informative note: The number of ignored requests can be adjusted to balance responsiveness to demand (fewer ignores) vs energy efficiency (more ignores). The value that is set should be considered as a function of the total number of downstream zones or systems that can send requests. As a default, set the number of ignored requests to 10% of the total downstream zones or systems, rounded to the nearest integer.

The reset starts at CHWSTmin because starting at a high temperature often causes the chiller to bring down CHWST too quickly and pass the CHWST setpoint, leading the chiller to cycle off. Additionally, if the loop reset starts at a CHWST that cannot satisfy the load at startup (e.g., CHWST setpoint = 60°F, but an AHU requires 55°F supply air), there is a resultant delay in satisfying the load as the reset loop winds up before CHWST setpoint resets down.

e. CHWST Plant Reset loop shall be enabled when the Chilled Water Plant is enabled and disabled when the Plant is disabled.

f. CHW temperature setpoint shall be written to the Modular-Heat-Pump controller via network interface.

5.25.2.3. Chilled Water Pumps

Retain the following paragraph for primary/secondary plants. Delete for primary-only plants.

a. All heat pumps are assumed to have dedicated primary pumps controlled by the heat pump controller.

b. CHW pumps shall be lead/lag controlled per Section 5.1.15.3.

c. Run lead CHW pump when either of the following is enabled and shut off otherwise.

1) Chilled Water Plant is enabled, or

Include the following if the AWHP requires flow through the inactive mode heat exchanger (e.g. HW heat exchanger when the unit is in CHW mode and vice versa) for freeze protection. Delete otherwise.

2) The Modular Heat Pump Master Controller freeze protection pump start/stop output is enabled

d. CHW pumps shall be staged as a function of CHWFR, the ratio of current chilled water flow, $FLOW_C$, to design flow, and the number of pumps, N-CHWP, that operate at design conditions. Pumps are assumed to be equally sized.

$$\text{CHWFR} = \frac{FLOW_C}{SCHWF_{design}}$$

Flow is used, as opposed to speed, to keep the chilled water pumps operating near to their best efficiency point. Staging at slightly less than design flowrate for operating pumps yields good results for most applications (note that when fewer than design pumps are enabled, pumps will be able to produce greater than design flow since they will be operating further out their pump curves).

1) Start the next lag pump whenever the following is true for 10 minutes:

$$\text{CHWFR} > \frac{Number\ of\ Operating\ Pumps}{NCHWP} - .03$$

2) Shut off the last lag pump whenever the following is true for 10 minutes:

$$\text{CHWFR} < \frac{Number\ of\ Operating\ Pumps - 1}{NCHWP} - .03$$

Retain the following two sections if the remote DP sensor(s) is hardwired to the secondary pump controller. Delete otherwise.

e. When any pump is proven on, pump speed will be controlled by a reverse acting PID loop maintaining the differential pressure signal at a setpoint CHW-DPsp determined by the reset scheme described herein. All pumps receive the same speed signal. PID loop output shall be mapped from minimum pump speed at 0% to maximum pump speed at 100%.

1) Where multiple DP sensors exist, a PID loop shall run for each sensor. Secondary CHW pumps shall be controlled to the high signal output of all DP sensor loops.

Retain the following three sections if the remote DP sensor(s) is not hardwired to the secondary pump controller, but a local DP sensor is hardwired to the secondary pump controller. Delete otherwise.

f. Remote secondary loop DP shall be maintained at a setpoint of CHW-DPsp determined by the reset scheme described herein. CHW-DPsp shall be maintained by a reverse acting PID loop running in the controller to which the remote sensor is wired; the loop output shall be a DP setpoint for the local secondary loop DP sensor hardwired to the secondary pump controller. Reset local DP from 5 psi at 0% loop output to LocalCHW-DPmax at 100% loop output.

g. When any secondary CHW pump is proven on, pump speed will be controlled by a reverse acting PID loop maintaining the local secondary DP signal at the DP setpoint output of the remote sensor control loop. All pumps receive the same speed signal. PID loop output shall be mapped from minimum pump speed at 0% to maximum pump speed at 100%.

h. Where multiple remote DP sensors exist, a PID loop shall run for each sensor. The DP setpoint for the local DP sensor shall be the highest DP setpoint output from each of those remote loops.

The above situation arises in very large buildings where it may be impractical to homerun the remote DP sensor all the way back to the heat pump plant.

The above cascading control logic prevents pump speed instability issues that would otherwise be caused by running the pump speed control loop over the BAS network. It also provides some fault tolerance should the network fail—instead of the loop either winding all the way up or all the way down, DP is controlled to the last known setpoint sent from the remote controller until network communication is restored.

Retain the following paragraph for primary-only plants. Delete for primary/secondary plants.

i. CHW Bypass Valve

1) When any CHW pump is proven on, bypass valve loop shall be enabled. When enabled, the bypass valve loop shall be biased to start with the valve 100% open. Valve position shall be controlled by a direct acting PID loop maintaining the CHW differential pressure signal across the modular heat pumps at setpoint CHW-DP-Plant, with output mapped from minimum position (CHW-BPVmin) at 0% to 100% open at 100%.

The following sequence should not be necessary since minimum flow should always be maintained if design DP across the modular heat pump cooling side is met, but added just to be sure.

---

2) When any CHW pump is proven on, bypass valve minimum position CHW-BPVmin shall be the output of a reverse acting PID loop maintaining the CHW flow at the minimum flow setpoint CHWFmin.

3) When no CHW pumps are on, the bypass valve shall be 100% open and PID loops shall be disabled.

5.25.3. Hot Water Plant

5.25.3.1. Enable/Disable

a. The Hot Water Plant shall include an enabling schedule that allows operators to lock out the plant during off-hours, e.g. to allow off-hour operation of HVAC systems except the Hot Water Plant. The default schedule shall be 24/7 (adjustable).

b. Enable the plant when the plant has been disabled for at least 15 minutes and:

1) Number of Heating Hot-Water Plant Requests > I (I = Ignores shall default to 0, adjustable), and

2) OAT<HW-LOT, and

3) The Hot Water Plant enable schedule is active.

c. Disable the plant when it has been enabled for at least 15 minutes and:

1) Number of Heating Hot-Water Plant Requests ≤ I for 3 minutes, or

2) OAT>HW-LOT + 1°F, or

3) The Hot Water Plant enable schedule is inactive.

d. When the plant is enabled:

1) Command the Modular-Heat-Pump heat pump master controller to HEAT mode.

2) Enable HW pumps per Section 5.25.3.3.

e. When the plant is disabled:

1) Command the Modular-Heat-Pump heat pump master controller to disable HEAT mode.

2) Disable HW pumps per Section 5.25.3.3.

5.25.3.2. Hot Water Supply Temperature Reset

a. Plant hot water supply temperature setpoint shall be reset using Trim & Respond logic with the parameters shown in Table 5.25.3:

Table 5.25.3 Trim & Respond Variables

Variable	Value
Device	Any HW Pump Distribution Loop
SP_0	SP_{max}
SP_{min}	HWSTmin
SP_{max}	HWSTmax
T_d	10 minutes
T	5 minutes
I	See note
R	Hot-Water Reset Requests
SP_{trim}	-1.1°C (-2ºF)
SP_{res}	+1.7°C (+3ºF)
$SP_{res\text{-}max}$	+3.9°C (+7ºF)

Informative note: The number of ignored requests can be adjusted to balance responsiveness to demand (fewer ignores) vs energy efficiency (more ignores). The value that is set should be considered as a function of the total number of downstream zones or systems that can send requests.

As a default, set the number of ignored requests to 10% of the total downstream zones or systems, rounded to the nearest integer.

Hot water supply temperature is reset downwards under low load conditions to minimize piping heat losses, improve controllability, and maximize heat pump efficiency.

The reset starts at HWSTmax because starting at a low temperature often causes the heat pump to bring up HWST too quickly and pass the HWST setpoint, leading the heat pump to cycle off. Additionally, if the loop reset starts at a HWST that cannot satisfy the load at startup (e.g., HWST setpoint = 80°F, but a coil requires 95°F supply air), there is a resultant delay in satisfying the load as the reset loop winds up before HWST setpoint resets down.

HW pump DP setpoint is not reset in this sequence (unlike CHW plant reset) because HW pump energy acts simply as electric resistance heat so the energy savings from DP setpoint reset are too small to justify the added complexity.

Informative note regarding compressor cycling mitigation under low load: When applying T&R logic to the hot-water distribution loop served by fixed-step compressor heat pumps, control strategy adjustments may be required to reduce unnecessary compressor cycling during periods of low heating load, in addition to providing adequate system volume using buffer tanks. Because T&R logic continuously resets the HW supply temperature setpoint based on zone heating requests, the control loop may reduce the setpoint faster than the heat pump can unload, particularly when only a single compressor step is active. This condition can lead to short cycling or repeated staging transitions. If this occurs, the following mitigation strategies should be considered:

a. *Lengthened Reset Timing: Increase the trim-and-respond interval "T" during low-load (one module) operation. A longer T-parameter reduces the frequency of setpoint reductions, preventing the compressor from staging off prematurely and stabilizing the first capacity step.*

b. *Conditional Trim Inhibition: Suspend downward trim actions until at least two compressor stages are enabled. This approach prevents reset actions from occurring when the plant is operating at its minimum heating output, reducing the likelihood of unnecessary cycling.*

These mitigations act to increase the effective thermal mass of the system by slowing or pausing reductions in the HW supply temperature setpoint. The trade-off is that the compressors will operate at a slightly higher temperature lift, which will reduce efficiency, but overall, the result will be improved overall runtime stability and reduced cycling. Note the above strategies will need to be coordinated with the specific heat pump controller's minimum on, minimum off, and re-enable timers.

b. HWST Supply Temperature Reset loop shall be enabled when the plant is enabled and disabled when the plant is disabled.

c. HW temperature setpoint shall be written to the Modular-Heat-Pump controller via network interface.

5.25.3.3. Hot Water Pumps

Retain the following paragraph for primary/secondary plants. Delete for primary-only plants.

a. All heat pumps are assumed to have dedicated primary pumps controlled by the heat pump controller.

b. HW pumps shall be lead/standby controlled per Section 5.1.15.3.

c. Run lead HW pump when the Hot Water Plant is enabled and shut off otherwise.

d. HW pumps shall be staged as a function of HWFR, the ratio of current hot water flow, $FLOW_H$, to design flow, and the number of pumps, N-HWP, that operate at design conditions. Pumps are assumed to be equally sized.

$$\text{HWFR} = \frac{FLOW_H}{HWF_{design}}$$

Flow is used, as opposed to speed, to keep the hot water pumps operating near to their best efficiency point. Staging at slightly less than design flowrate for operating pumps yields good results for most applications (note that when fewer than design pumps are enabled, pumps will be able to produce greater than design flow since they will be operating further out their pump curves).

1) Start the next lag pump whenever the following is true for 10 minutes:

$$\text{HWFR} > \frac{Number\ of\ Operating\ Pumps}{NHWP} - .03$$

2) Shut off the last lag pump whenever the following is true for 10 minutes:

$$\text{HWFR} < \frac{Number\ of\ Operating\ Pumps - 1}{NHWP} - .03$$

Retain the following two sections for where the remote DP sensor(s) is hardwired to the plant controller. Delete otherwise.

e. When any pump is proven on, pump speed shall be controlled by a reverse acting PID loop maintaining differential pressure at HW-DPmax. All pumps receive the same speed signal. PID loop output shall be mapped from minimum pump speed at 0% to maximum pump speed at 100%.

f. Where multiple DP sensors exist, a PID loop shall run for each sensor. HW pumps shall be controlled to the high signal output of all DP sensor loops.

Retain the following three sections where the remote DP sensor(s) is not hardwired to the plant controller, but a local DP sensor is hardwired to the plant controller. Delete otherwise.

g. Remote secondary loop DP shall be maintained at a setpoint of HW-DPsp determined by the reset scheme described herein. HW-DPsp shall be maintained by a reverse acting PID loop running in the controller to which the remote sensor is wired; the loop output shall be a DP setpoint for the local secondary loop DP sensor hardwired to the secondary pump controller. Reset local DP from 5 psi at 0% loop output to LocalHW-DPmax at 100% loop output.

h. When any secondary HW pump is proven on, pump speed will be controlled by a reverse acting PID loop maintaining the local secondary DP signal at the DP setpoint output of the remote sensor control loop. All pumps receive the same speed signal. PID loop output shall be mapped from minimum pump speed at 0% to maximum pump speed at 100%.

i. Where multiple remote DP sensors exist, a PID loop shall run for each sensor. The DP setpoint for the local DP sensor shall be the highest DP setpoint output from each of those remote loops.

The above situation arises in very large buildings where it may be impractical to homerun the remote DP sensor all the way back to the heat pump plant.

The above cascading control logic prevents pump speed instability issues that would otherwise be caused by running the pump speed control loop over the BAS network. It also provides some fault tolerance should the network fail—instead of the loop either winding all the way up or all the way down, DP is controlled to the last known setpoint sent from the remote controller until network communication is restored.

Retain the following paragraph for primary-only plants. Delete for primary/secondary plants.

j. HW Bypass Valve

1) When any HW pump is proven on, bypass valve loop shall be enabled. When enabled, the bypass valve loop shall be biased to start with the valve 100% open. Valve position shall be controlled by a direct acting PID loop maintaining the HW differential pressure signal across the modular heat pumps at setpoint HW-DP-Plant, with output mapped from minimum position (HW-BPVmin) at 0% to 100% open at 100%.

The following sequence should not be necessary since minimum flow should always be maintained if design DP across the modular heat pump cooling side is met but added just to be sure.

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2) When any HW pump is proven on, bypass valve minimum position HW-BPVmin shall be the output of a reverse acting PID loop maintaining the HW flow at the minimum flow setpoint HWFmin.

3) When no HW pumps are on, the bypass valve shall be 100% open and PID loops shall be disabled.

5.25.4. Performance Monitoring

5.25.4.1. All calculations listed below shall be performed at least once every 30 seconds. Time averaged values shall be recorded at least once every 5 minutes. The averaging period shall equal the trending interval.

5.25.4.2. Cooling

a. Total plant cooling power. Calculate total plant cooling power as the sum of heat pump power when indexed to cooling mode and CHW pump power. For motors with VFDs, power shall be actual power as read through the VFD network interface. For fixed speed motors (e.g., primary pumps without VFDs), power shall be assumed to be fixed at BHP (from equipment schedule) * 0.746 / 0.93 (approximate motor efficiency). For some equipment with multiple internal power users, such as AWHPs, a field mounted power meter is required.

b. Total Plant Cooling Load. Calculate plant cooling load using flowrate, *FLOW*; chilled water return temperature upstream of the first heat pump, *CHWRT*; and loop chilled water supply temperature leaving the plant, *CHWST*.

$$Q_{Plant} = \frac{FLOW \quad (CHWRT - CHWST)}{24} [tons]$$

c. Calculate plant cooling coefficient of performance (COP) as plant load divided by total plant power.

d. Summary Data. For the total plant, statistics shall be calculated for runtime, kWh, average efficiency (COP), peak demand (tons), average demand (tons) and average load (ton-hours), all on an instantaneous, year-to-date, and previous-year basis.

Below is an example summary of the performance monitoring parameters. Summary table should be edited based on plant configuration, available statistics and desired units of measurement.

Instantaneous				Year-to-date						Previous Year					
Lifetime Runtime (hours)	Electrical Demand (kW)	CHW Demand (ton)	Efficiency (COP)	Runtime (hours)	Avg Daily Energy Use (kWh)	Avg Daily CHW Load (ton-hr)	Avg CHW Demand (ton)	Peak CHW Demand (ton)	Avg Efficiency (COP)	Runtime (hours)	Avg Daily Energy Use (kWh)	Avg Daily CHW Load (ton-hr)	Avg CHW Demand (ton)	Peak CHW Demand (ton)	Avg Efficiency (COP)

5.25.4.3. Heating

a. Total plant heating power. Calculate total plant heating power as the sum of heat pump power when indexed to heating mode and CHW pump power. For motors with VFDs, power shall be actual power as read through the VFD network interface. For fixed speed motors (e.g., primary pumps without VFDs), power shall be assumed to be fixed at BHP (from equipment schedule) * 0.746 / 0.93 (approximate motor efficiency). For some equipment with multiple internal power users, such as AWHPs, a field mounted power meter is required.

b. Total Plant Heating Load. Calculate plant heating load using flowrate through the primary circuit, *FLOW*; hot water return temperature upstream of the first heat pump, *HWRT*; and hot water supply temperature, *HWST*.

$$Q_{plant} = 0.49 * FLOW * (HWST - HWRT) \left[\frac{\mathrm{kBtu}}{\mathrm{h}}\right]$$

c. Calculate plant heating coefficient of performance (COP) as plant load converted to kW (divide Qplant (kBtu/h) by 3.41) divided by total plant power.

d. Summary Data: For the total plant, statistics shall be calculated for runtime, energy use (Btu), cumulative load (Btu), average demand (Btu/h), peak demand (Btu/h), and actual efficiency (COP). All statistics shall be presented on an instantaneous, year-to-date, and previous year basis.

Below is an example summary of the performance monitoring parameters. Summary table should be edited based on plant configuration, available statistics and desired units of measurement.

Instantaneous				Year-to-date						Previous Year					
Lifetime Runtime (hours)	Electrical Demand (kW)	HW Demand (kBtuh)	Efficiency (COP)	Runtime (hours)	Avg Daily Energy Use (kWh)	Avg Daily HW Load (kBtu)	Avg HW Demand (kBtu/h)	Peak HW Demand (kBtu/h)	Avg Efficiency (COP)	Runtime (hours)	Avg Daily Energy Use (kWh)	Avg Daily HW Load (kBtu)	Avg HW Demand (kBtu/h)	Peak HW Demand (kBtu/h)	Avg Efficiency (COP)

5.25.4.4. Combined Heat Pump Efficiency

a. Total Plant Power. Calculate total plant power as the sum of heat pump power (heat pumps indexed to heating, cooling, or heat recovery) and the CHW and HW pump power. For motors with VFDs, power shall be actual power as read through the VFD network interface. For fixed speed motors (e.g., primary pumps without VFDs), power shall be assumed to be fixed at BHP (from equipment schedule) * 0.746 / 0.93 (approximate motor efficiency). For some equipment with multiple internal power users, such as AWHPs, a field mounted power meter is required.

b. Calculate plant combined coefficient of performance (COP_{Tot}) as the sum of the heating and cooling plant load converted to kW divided by total plant power:

$$COP_{Tot} = \frac{Q_{plant,heat} + Q_{plant,cool}}{Total\ Plant\ Power * 3.412}$$

c. Summary Data. Actual total efficiency (COP_{Tot}) shall be presented on an instantaneous, year-to-date, and previous year basis.

Below is an example summary of the performance monitoring parameters. Summary table should be edited based on plant configuration, available statistics and desired units of measurement.

Instantaneous				Year-to-date						Previous Year					
Lifetime Runtime (hours)	Electrical Demand (kW)	Total CHW & HW Demand (kBtuh)	Total Efficiency (COP)	Runtime (hours)	Avg Daily Energy Use (kWh)	Avg CHW + HW Load (kBtu)	Avg CHW + HW Demand (kBtu/h)	Peak CHW + HW Demand (kBtu/h)	Avg Total Efficiency (COP)	Runtime (hours)	Avg Daily Energy Use (kWh)	Avg Daily CHW + HW Load (kBtu)	Avg CHW + HW Demand (kBtu/h)	Peak CHW + HW Demand (kBtu/h)	Avg Total Efficiency (COP)

5.25.5. Alarms

5.25.5.1. Maintenance interval alarm when pump has operated for more than 1500 hours: Level 5. Reset interval counter when alarm is acknowledged.

5.25.5.2. Maintenance interval alarm when AWHP has operated for more than 1000 hours: Level 5. Reset interval counter when alarm is acknowledged.

5.25.5.3. AWHP alarm: level 2

5.25.5.4. Pump alarm is indicated by the status input being different from the output command for 15 seconds.

a. Commanded on, status off: Level 2. Do not evaluate alarm until the device has been commanded on for 15 seconds.

b. Commanded off, status on: Level 4. Do not evaluate the alarm until the device has been commanded off for 60 seconds.

5.25.5.5. High chiller side leaving chilled water temperature (more than 5°F above setpoint) for more than 15 minutes when chiller has been enabled in cooling mode for longer than 15 minutes: Level 3

5.25.5.6. Low heating side leaving hot water temperature (more than 5°F below setpoint) for more than 15 minutes when heat pump has been enabled in heating mode for longer than 15 minutes: Level 3

5.25.5.7. HW flow less than 70% of HWFmin for 5 minutes: Level 3

5.25.5.8. AWHP distribution system HW DP less than 70% of HW-DPmin for 5 minutes: Level 3

5.25.5.9. CHW flow less than 70% of CHWFmin or 5 minutes: Level 3

5.25.5.10. AWHP distribution system CHW DP less than 70% of CHW-DPmin for 5 minutes: Level 3

5.25.5.11. CHW System low gauge pressure

a. if CHW system gauge pressure falls 1 psig below the scheduled expansion tank pre-charge pressure for 5 minutes, (indicating need to fill): Level 3.

b. if CHW system gauge pressure falls below 0.9 times the scheduled expansion tank pre-charge pressure for 1 minute, (indicating possible leak): Level 2.

5.25.5.12. HW System low gauge pressure

a. if HW system gauge pressure falls 1 psig below the scheduled expansion tank pre-charge pressure for 5 minutes, (indicating need to fill): Level 3.

b. if HW system gauge pressure falls below 0.9 times the scheduled expansion tank pre-charge pressure for 1 minute, (indicating possible leak): Level 2.

Automatic Fault Detection will be added in a future addendum.

5.26 2-PIPE AND 4-PIPE AIR-TO-WATER CHILLED WATER PLANT

This sequence is for a plant consisting of one 4-pipe heat recovery heat pump (AWHR) and two 2-pipe changeover heat pumps (AWHPs), both with built in primary pumps that are controlled by each unit's internal controller. The internal controller also controls internal staging of compressors (if there are multiple compressors), control of the outdoor air coil fan, and defrost. See Figure A-37.

5.26.1. See Sections 3.1.1 and 3.2.1 for operating parameters and setpoints.

5.26.2. Cooling Plant Enable/Disable

5.26.2.1. The Cooling Plant shall include an enabling schedule that allows operators to lock out the plant during off-hours, e.g. to allow off-hour operation of HVAC systems except the chiller plant. The default schedule shall be 24/7 (adjustable).

5.26.2.2. Enable the Cooling Plant in the lowest stage when the plant has been disabled for at least 15 minutes and:

a. Number of Chiller Plant Requests > I (I= Ignores = 0, adjustable), and

b. OAT>CH-LOT, and

c. The cooling plant enable schedule is active.

5.26.2.3. Disable the Cooling Plant when it has been enabled for at least 15 minutes and:

a. Number of Chiller Plant Requests ≤ I for 3 minutes, or

b. OAT<CH-LOT – 1°F, or

c. The cooling plant enable schedule is inactive.

5.26.3. Heating Plant Enable/Disable

5.26.3.1. The Heating Plant shall include an enabling schedule that allows operators to lock out the plant during off-hours, e.g. to allow off-hour operation of HVAC systems except the heating plant. The default schedule shall be 24/7 (adjustable).

5.26.3.2. Enable the Heating Plant in the lowest stage when the plant has been disabled for at least 15 minutes and:

a. Number of Heating Hot-Water Plant Requests > I (I = Ignores shall default to 0, adjustable), and

b. OAT<HW-LOT, and

c. The heating plant enable schedule is active.

5.26.3.3. Disable the Heating Plant when it has been enabled for at least 15 minutes and:

a. Number of Heating Hot-Water Plant Requests ≤ I for 3 minutes, or

b. OAT>HW-LOT + 1°F, or

c. The heating enable schedule is inactive.

5.26.4. Lead/Lag Alternation

5.26.4.1. 2-pipe heat pump/chillers (AWHP) shall be lead/lag controlled per Section 5.1.15.3., both in heating and cooling modes.

5.26.4.2. If the Heating Plant and Cooling Plant are both enabled, the 4-pipe air-to-water heat recovery (AWHR) heat pump/chiller shall operate in Stage 1 for both Plants. Else it shall operate in Stage 3 and the 2-pipe AWHPs shall operate in Stages 1 and 2 based on lead/lag order.

5.26.4.3. 2-pipe AWHPs

a. If an AWHP is on in heating mode, it is removed from the staging order of the cooling mode until it has been off for 15 minutes.

b. If an AWHP is on in cooling mode, it is removed from the staging order of the heating mode until it has been off for 15 minutes.

c. If an AWHP is to be staged on in heating mode:

1) Index changeover valves for heating mode.

2) Enable AWHP and command it to operate in heating mode

d. If an AWHP is to be staged on in cooling mode:

1) Index changeover valves for cooling mode.

2) Enable AWHP and command it to operate in cooling mode

e. If an AWHP is to be staged off:

1) Disable AWHP and wait 3 minutes or as required for internal shutdown cycle to time out (determine empirically).

2) Index changeover valves for heating mode.

Changeover valves must always be open to one system to allow for expansion/contraction of water that is within the heat pump. The changeover valves in Figured A-37 are shown to include failsafe wiring and spring-return valve actuators to ensure HW is never inadvertently open to the CHW system and vice versa.

5.26.5. Cooling Plant

5.26.5.1. Staging

a. All heat pumps are assumed to have integral primary pumps controlled by the heat pump controller.

b. Chillers are staged in part based on required capacity, $Q_{required}$, relative to nominal capacity of a given stage, which is the sum of the design cooling capacity of each heat pump active in each stage. This ratio is the operative part load ratio, *OPLR.*

c. If both primary and secondary chilled water temperatures and flow rates are available, use those in the primary for calculating $Q_{required}$.

d. $Q_{required}$ is calculated based on chilled water return temperature (*CHWRT*), active chilled water supply temperature setpoint ($CHWST_{SP}$), and measured flow through the associated circuit flow meter (*GPM*), as shown in the equation below. $Q_{required}$

used in logic shall be a 5-minute rolling average of instantaneous values sampled at a minimum of every 30 seconds.

$$Q_{required} = \frac{GPM * (CHWRT - CHWST_{SP})}{24} \ [tons]$$

Required capacity, as opposed to actual load, is used to provide more stable staging since chilled water supply temperature setpoint changes less dynamically than actual chilled water supply temperature.

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e. When a stage up or stage down transition is initiated, hold $Q_{required}$ fixed at its last value until the longer of the successful completion of the stage change (e.g. lag heat pump proven on) and 15 minutes.

As staging occurs, flowrate and return temperature may fluctuate, so Qrequired may be unstable.

---

f. *OPLR* shall be calculated as follows:

$$OPLR \quad = \frac{Q_{required}[tons]}{Sum\ of\ QcX\ for\ Heat\ Pumps\ in\ stage}$$

The following SPLR setting assumes heat pumps have positive displacement compressors with fixed speed primary pumps.

---

g. Staging part load ratio, *SPLR,* shall be 90%:

h. Staging shall be executed per the table below subject to the following requirements.

1) Each stage shall have a minimum runtime of 15 minutes.

2) Timers shall reset to zero at the completion of every stage change.

3) Stage up and down conditionals may depend on *OPLR* calculated relative to the current stage, next lower stage, or next higher stage. This is denoted with stage subscripts on OPLR in the table below, e.g. *OPLR1* means *OPLR* calculated using Stage 1 nominal capacity.

4) Primary CHW flow in the staging logic shall be the primary flow meter reading if there is one; if there is no flow meter in the primary circuit, assume flow is the sum of the design flow of each primary chilled water pump that is proven on.

Chiller Stage	**Chillers on**	**Stage up to next stage if either:**		**Stage down to lower stage if:**
1	Lead	**Efficiency Condition:** for 15 minutes current stage *OPLR1* greater than *SPLR*	**Failsafe Condition:** [for 15 minutes secondary CHW flow > the primary flow for Stage 1] or [for 5 minutes secondary CHWST > primary CHWST + 2°F]	–

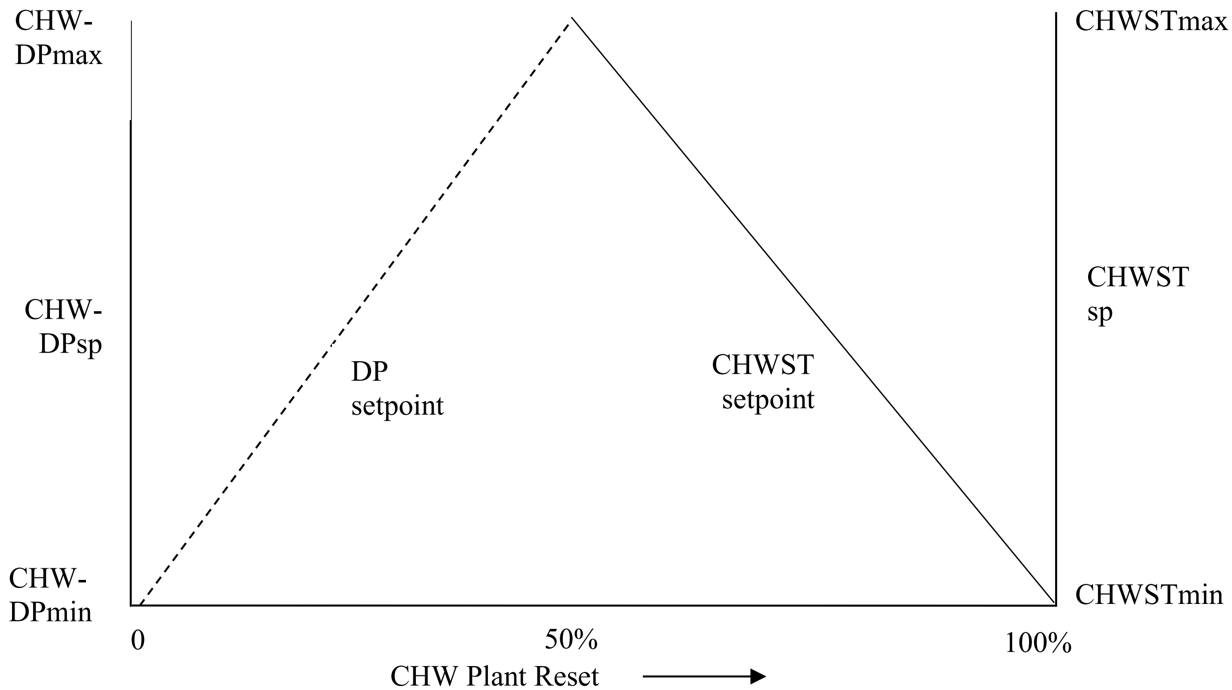
Chiller Stage	**Chillers on**	**Stage up to next stage if either:**		**Stage down to lower stage if:**
2	Lead + Lag1	**Efficiency Condition:** for 15 minutes current stage *OPLR2* greater than *SPLR*	**Failsafe Condition:** [for 15 minutes secondary CHW flow > the primary flow for Stage 2] or [for 5 minutes secondary CHWST > primary CHWST + 2°F]	for 15 minutes next available lower stage *OPLR1* less than *SPLR* and the next available lower stage failsafe condition is not true.
3	Lead + Lag1 and Lag2	–	–	for 15 minutes next available lower stage *OPLR2* less than *SPLR* and the next available lower stage failsafe condition is not true.

Primary-secondary staging needs to ensure that secondary flow does not exceed primary flow. When secondary flow exceeds primary flow, the secondary CHWST degrades (elevates), in turn causing lower secondary CHWRT. This in turn decreases the load on the chillers while causing the secondary flowrate to only increase further. Staging logic avoids this positive feedback scenario by staging up as soon as secondary flow begins to approach the design primary flow for the stage, or the presence of secondary recirculation has been confirmed by secondary CHWST exceeding primary by 2°F.

The flow staging conditionals effectively act as failsafe logic for the enabled chiller(s) not making CHWST setpoint as well. If enabled chiller(s) cannot make setpoint because they are fully loaded or otherwise, secondary flowrate will rise until the point where staging is triggered on the flow conditionals.

5.26.5.2. Chilled Water Plant Reset

a. Chilled water supply temperature setpoint CHWSTsp and distribution system differential pressure setpoint CHW-DPsp shall be reset based on the current value of the logic variable called “CHW Plant Reset” as shown below and described subsequently.



The recommended logic first resets differential pressure setpoint to maximum before resetting chilled water supply temperature setpoint down towards design. Parametric plant analysis performed in a variety of climate zones during the development of ASHRAE's "Fundamentals of Design and Control of Central Chilled-Water Plants" Self-Directed Learning Course showed that the pump energy penalty incurred with this approach is more than offset by chiller energy savings resulting from keeping the chilled water supply temperature setpoint as high as possible.

b. CHW Plant Reset shall be reset using Trim & Respond logic (see Guideline 36) with the following parameters:

Variable	Value
Device	Any CHW Pump
SP_0	100%
SP_{min}	0%
SP_{max}	100%
T_d	15 minutes
T	5 minutes
I	See note
R	Cooling CHWST Reset Requests
SP_{trim}	-2%
SP_{res}	+3%
$SP_{res-max}$	+7%
Informative note: The number of ignored requests can be adjusted to balance responsiveness to demand (fewer ignores) vs energy efficiency (more ignores). The value	

that is set should be considered as a function of the total number of downstream zones or systems that can send requests. As a default, set the number of ignored requests to 10% of the total downstream zones or systems, rounded to the nearest integer.

The reset starts at CHWSTmin because starting at a high temperature often causes the chiller to bring down CHWST too quickly and pass the CHWST setpoint, leading the chiller to cycle off. Additionally, if the loop reset starts at a CHWST that cannot satisfy the load at startup (e.g. CHWST setpoint = 60°F, but an AHU requires 55°F supply air), there is a resultant delay in satisfying the load as the reset loop winds up before CHWST setpoint resets down.

c. CHWST Plant Reset loop shall be enabled when the plant is enabled and disabled when the plant is disabled.

d. When a plant stage change is initiated, CHW Plant Reset logic shall be disabled and value fixed at its last value for the longer of 15 minutes and the time it takes for the plant to successfully stage.

Locking out continued reset during a staging event prevents CHW loop instability resulting from staging from driving the plant reset.

5.26.5.3. Chilled Water Pumps

a. CHW pumps shall be lead/lag controlled per Section 5.1.15.3.

b. Run lead CHW pump when Cooling Plant is enabled and shut off otherwise.

c. CHW pumps shall be staged as a function of CHWFR, the ratio of current secondary chilled water flow, $FLOW_C$, to design flow, and the number of pumps, NCHWP, that operate at design conditions. Pumps are assumed to be equally sized.

$$\mathrm{CHWFR} = \frac{FLOW_C}{CHWF_{design}}$$

Flow is used, as opposed to speed, to keep the chilled water pumps operating near to their best efficiency point. Staging at slightly less than design flowrate for operating pumps yields good results for most applications (note that when fewer than design pumps are enabled, pumps will be able to produce greater than design flow since they will be operating further out their pump curves).

1) Start the next lag pump whenever the following is true for 10 minutes:

$$\mathrm{CHWFR} > \frac{Number\ of\ Operating\ Pumps}{NCHWP} - .03$$

2) Shut off the last lag pump whenever the following is true for 10 minutes:

$$\mathrm{CHWFR} < \frac{Number\ of\ Operating\ Pumps - 1}{NCHWP} - .03$$

Retain the following two sections if the remote DP sensor(s) is hardwired to the secondary pump controller. Delete otherwise.

d. When any pump is proven on, pump speed will be controlled by a reverse acting PID loop maintaining the differential pressure signal at a setpoint CHW-DPsp determined by the reset scheme described herein. All pumps receive the same speed signal. PID loop output shall be mapped from minimum pump speed at 0% to maximum pump speed at 100%.

e. Where multiple DP sensors exist, a PID loop shall run for each sensor. Secondary CHW pumps shall be controlled to the high signal output of all DP sensor loops.

Retain the following three sections if the remote DP sensor(s) is not hardwired to the secondary pump controller, but a local DP sensor is hardwired to the secondary pump controller. Delete otherwise.

f. Remote secondary loop DP shall be maintained at a setpoint of CHW-DPsp determined by the reset scheme described herein. CHW-DPsp shall be maintained by a reverse acting PID loop running in the controller to which the remote sensor is wired; the loop output shall be a DP setpoint for the local secondary loop DP sensor hardwired to the secondary pump controller. Reset local DP from 5 psi at 0% loop output to LocalCHW-DPmax at 100% loop output.

g. When any secondary CHW pump is proven on, pump speed will be controlled by a reverse acting PID loop maintaining the local secondary DP signal at the DP setpoint output of the remote sensor control loop. All pumps receive the same speed signal. PID loop output shall be mapped from minimum pump speed at 0% to maximum pump speed at 100%.

h. Where multiple remote DP sensors exist, a PID loop shall run for each sensor. The DP setpoint for the local DP sensor shall be the highest DP setpoint output from each of those remote loops.

5.26.6. Heating Plant

5.26.6.1. Staging

a. All heat pumps are assumed to have integral primary pumps controlled by the heat pump controller.

b. Heat pumps are staged in part based on required capacity, $Q_{required}$, relative to capacity of a given stage, Q_{stage}, adjusted for current outdoor air temperature and hot water temperature. This ratio is the operative part load ratio, *OPLR*.

c. If both primary and secondary hot water temperatures and flow rates are available, use those in the primary for calculating $Q_{required}$.

d. $Q_{required}$ is calculated based on hot water return temperature (*HWRT*), active hot water supply temperature setpoint ($HWST_{SP}$), and measured flow through the associated circuit flow meter (*GPM*), as shown in the equation below. $Q_{required}$ used in logic shall be a 5-minute rolling average of instantaneous values sampled at a minimum of every 30 seconds.

$$Q_{hXadjusted} = \frac{Q_{hX} * f_{current}}{f_{design}} \; [Btu/h]$$

e. When a stage up or stage down transition is initiated, hold $Q_{required}$ fixed at its last value until the longer of the successful completion of the stage change (e.g. lag heat pump proven on) and 15 minutes.

As staging occurs, flowrate and return temperature may fluctuate, so Qrequired may be unstable. As detailed subsequently, Qrequired impacts plant part load ratio, which drives condenser water return temperature setpoint and tower control. As such, if Qrequired is unstable, so too would be condenser water return temperature, and thus chiller lift.

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f. *OPLR* shall be calculated as follows:

$$OPLR = \frac{Q_{required}[tons]}{Sum\ of\ QcX\ for\ Heat\ Pumps\ in\ stage}$$

where QhXadjusted is the heating capacity of heat pump X adjusted for the current outdoor air temperature OATcurrent (in Fahrenheit) and the current hot water supply temperature HWSTcurrent (in Fahrenheit), given the design heating capacity QhX (in Btu/h), the design outdoor air temperature OATdesign (in Fahrenheit), and the design hot water supply temperature HWSTdesign (in Fahrenheit) from Section 3.1.2.2, calculated as follows:

$$Q_{hXadjusted} = \frac{Q_{hX} * f_{current}}{f_{design}} \; [Btu/h]$$

$$\begin{aligned} f_{current} = {} & 0.465 + 3.91 * 10^{-3} * OAT_{current} + 7.60 * 10^{-5} * OAT_{current}^2 \\ & + 4.94 * 10^{-4} * HWST_{current} - 8.24 * 10^{-6} * HWST_{current}^2 \\ & - 2.40 * 10^{-6} * OAT_{current} * HWST_{current} \end{aligned}$$

$$\begin{aligned} f_{design} = {} & 0.465 + 3.91 * 10^{-3} * OAT_{design} + 7.60 * 10^{-5} * OAT_{design}^2 \\ & + 4.94 * 10^{-4} * HWST_{design} - 8.24 * 10^{-6} * HWST_{design}^2 \\ & - 2.40 * 10^{-6} * OAT_{design} * HWST_{design} \end{aligned}$$

The regression equations above were determined from a typical AWHP with positive displacement compressors.

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g. Staging part load ratio, *SPLR,* shall be 90%:

The above SPLR setting assumes heat pumps have positive displacement compressors with fixed speed primary pumps.

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h. Staging shall be executed per the table below subject to the following requirements.

1) Each stage shall have a minimum runtime of 15 minutes.

2) Timers shall reset to zero at the completion of every stage change.

3) Stage up and down conditionals may depend on *OPLR* calculated relative to the current stage, next lower stage, or next higher stage. This is denoted with stage subscripts on OPLR in the table below. E.g. *OPLR1* means *OPLR* calculated using Stage 1 nominal capacity.

4) Primary HW flow in the staging logic shall be the primary flow meter reading if there is one; if there is no flow meter in the primary circuit, assume flow is the sum of the design flow of each primary chilled water pump that is proven on.

Heat pump Stage	**Heat pumps on**	**Stage up to next stage if either:**		**Stage down to lower stage if:**
1	Lead	**Efficiency Condition:** for 15 minutes current stage *OPLR1* greater than *SPLR*	**Failsafe Condition:** [for 15 minutes secondary HW flow > the design primary flow for Stage 1] or [for 5 minutes secondary HWST < primary HWST - 2°F]	
2	Lead + Lag1	**Efficiency Condition:** for 15 minutes current stage *OPLR2* greater than *SPLR*	**Failsafe Condition:** [for 15 minutes secondary HW flow > the design primary flow for Stage 2] or [for 5 minutes secondary HWST < primary HWST - 2°F]	for 15 minutes next available lower stage *OPLR1* less than *SPLR* and the next available lower stage failsafe condition is not true.
3	Lead + Lag1 and Lag2	–	–	for 15 minutes next available lower stage *OPLR2* less than *SPLR* and the next available lower stage failsafe condition is not true.

5.26.6.2. Hot Water Supply Temperature Reset

a. Plant hot water supply temperature setpoint shall be reset using Trim & Respond logic with the parameters shown in Table: 6.26.6.2a

Table 5.26.6.2a Trim & Respond Variables	
Variable	Value
Device	Any HW Pump Distribution Loop
SP_0	SP_{max}
SP_{min}	HWSTmin
SP_{max}	HWSTmax
T_d	10 minutes
T	5 minutes

I	See note
R	Hot-Water Reset Requests
SP_{trim}	-1.1°C (-2ºF)
SP_{res}	+1.7°C (+3ºF)
$SP_{res-max}$	+3.9°C (+7ºF)
Informative note: The number of ignored requests can be adjusted to balance responsiveness to demand (fewer ignores) vs energy efficiency (more ignores). The value that is set should be considered as a function of the total number of downstream zones or systems that can send requests. As a default, set the number of ignored requests to 10% of the total downstream zones or systems, rounded to the nearest integer.	

Hot water supply temperature is reset downwards under low load conditions to minimize piping heat losses, improve controllability, and maximize heat pump efficiency.

The reset starts at HWSTmax because starting at a low temperature often causes the heat pump to bring up HWST too quickly and pass the HWST setpoint, leading the heat pump to cycle off. Additionally, if the loop reset starts at a HWST that cannot satisfy the load at startup (e.g., HWST setpoint = 80°F, but a coil requires 95°F supply air), there is a resultant delay in satisfying the load as the reset loop winds up before HWST setpoint resets down.

HW pump DP setpoint is not reset in this sequence (unlike CHW plant reset) because HW pump energy acts simply as electric resistance heat so the energy savings from DP setpoint reset are too small to justify the added complexity.

Informative note regarding compressor cycling mitigation under low load: When applying T&R logic to the hot-water distribution loop served by fixed-step compressor heat pumps, control strategy adjustments may be required to reduce unnecessary compressor cycling during periods of low heating load, in addition to providing adequate system volume using buffer tanks. Because T&R logic continuously resets the HW supply temperature setpoint based on zone heating requests, the control loop may reduce the setpoint faster than the heat pump can unload, particularly when only a single compressor step is active. This condition can lead to short cycling or repeated staging transitions. If this occurs, the following mitigation strategies should be considered:

a. Lengthened Reset Timing: Increase the trim-and-respond interval "T" during low-load (one module) operation. A longer T-parameter reduces the frequency of setpoint reductions, preventing the compressor from staging off prematurely and stabilizing the first capacity step.

b. Conditional Trim Inhibition: Suspend downward trim actions until at least two compressor stages are enabled. This approach prevents reset actions from occurring when the plant is operating at its minimum heating output, reducing the likelihood of unnecessary cycling.

These mitigations act to increase the effective thermal mass of the system by slowing or pausing reductions in the HW supply temperature setpoint. The trade-off is that the compressors will operate at a slightly higher temperature lift, which will reduce efficiency, but overall the result will be improved overall runtime stability and reduced cycling. Note the above strategies will need to be coordinated with the specific heat pump controller's minimum on, minimum off, and re-enable timers.

b. HWST Supply Temperature Reset loop shall be enabled when the plant is enabled and disabled when the plant is disabled.

c. When a plant stage change is initiated, HW Supply Temperature Reset logic shall be disabled and value fixed at its last value for the longer of 15 minutes and the time it takes for the plant to successfully stage.

5.26.6.3. Hot Water Pumps

a. HW pumps shall be lead/lag controlled per Section 5.1.15.3.

b. Run lead HW pump when Heating Plant is enabled and shut off otherwise.

c. HW pumps shall be staged as a function of HWFR, the ratio of current secondary hot water flow, $FLOW_H$, to design flow, and the number of pumps, NHWP, that operate at design conditions. Pumps are assumed to be equally sized.

$$\text{HWFR} = \frac{FLOW_H}{HWF_{design}}$$

Flow is used, as opposed to speed, to keep the hot water pumps operating near to their best efficiency point. Staging at slightly less than design flowrate for operating pumps yields good results for most applications (note that when fewer than design pumps are enabled, pumps will be able to produce greater than design flow since they will be operating further out their pump curves).

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1) Start the next lag pump whenever the following is true for 10 minutes:

$$\text{HWFR} > \frac{Number\ of\ Operating\ Pumps}{NHWP} - .03$$

2) Shut off the last lag pump whenever the following is true for 10 minutes:

$$\text{HWFR} < \frac{Number\ of\ Operating\ Pumps - 1}{NHWP} - .03$$

Retain the following two sections for where the remote DP sensor(s) is hardwired to the plant controller. Delete otherwise.

d. When any pump is proven on, pump speed shall be controlled by a reverse acting PID loop maintaining differential pressure at HW-DPmax. All pumps receive the same speed signal. PID loop output shall be mapped from minimum pump speed at 0% to maximum pump speed at 100%.

e. Where multiple DP sensors exist, a PID loop shall run for each sensor. HW pumps shall be controlled to the high signal output of all DP sensor loops.

Retain the following three sections where the remote DP sensor(s) is not hardwired to the plant controller, but a local DP sensor is hardwired to the plant controller. Delete otherwise.

f. Remote secondary loop DP shall be maintained at a setpoint of HW-DPsp determined by the reset scheme described herein. HW-DPsp shall be maintained by a reverse acting PID loop running in the controller to which the remote sensor is wired; the loop output shall be a DP setpoint for the local secondary loop DP sensor hardwired to the secondary pump controller. Reset local DP from 5 psi at 0% loop output to LocalHW-DPmax at 100% loop output.

g. When any secondary HW pump is proven on, pump speed will be controlled by a reverse acting PID loop maintaining the local secondary DP signal at the DP setpoint output of the remote sensor control loop. All pumps receive the same speed signal. PID loop output shall be mapped from minimum pump speed at 0% to maximum pump speed at 100%.

h. Where multiple remote DP sensors exist, a PID loop shall run for each sensor. The DP setpoint for the local DP sensor shall be the highest DP setpoint output from each of those remote loops.

The above situation arises in very large buildings where it may be impractical to homerun the remote DP sensor all the way back to the heat pump plant.

The above cascading control logic prevents pump speed instability issues that would otherwise be caused by running the pump speed control loop over the BAS network. It also provides some fault tolerance should the network fail—instead of the loop either winding all the way up or all the way down, DP is controlled to the last known setpoint sent from the remote controller until network communication is restored.

5.26.1. Performance Monitoring

5.26.1.1. All calculations listed below shall be performed at least once every 30 seconds. Time averaged values shall be recorded at least once every 5 minutes. The averaging period shall equal the trending interval.

5.26.1.2. Cooling

a. Total plant cooling power. Calculate total plant cooling power as the sum of heat pump power when indexed to cooling mode and CHW pump power. For motors with VFDs, power shall be actual power as read through the VFD network interface. For fixed speed motors (e.g., primary pumps without VFDs), power shall be assumed to be fixed at BHP (from equipment schedule) * 0.746 / 0.93 (approximate motor efficiency). For some equipment with multiple internal power users, such as AWHPs, a field mounted power meter is required.

b. Total Plant Cooling Load. Calculate plant cooling load using flowrate, *FLOW*; chilled water return temperature upstream of the first heat pump, *CHWRT*; and loop chilled water supply temperature leaving the plant, *CHWST*.

$$Q_{Plant,cool} = \frac{FLOW * (CHWRT - CHWST)}{24}\,[tons]$$

c. Calculate plant cooling coefficient of performance (COP) as plant load divided by total plant power.

d. Summary Data. For the total plant, statistics shall be calculated for runtime, kWh, average efficiency (COP), peak demand (tons), average demand (tons) and average load (ton-hours), all on an instantaneous, year-to-date, and previous-year basis.

Below is an example summary of the performance monitoring parameters. Summary table should be edited based on plant configuration, available statistics and desired units of measurement.

Instantaneous				Year-to-date						Previous Year					
Lifetime Runtime (hours)	Electrical Demand (kW)	CHW Demand (ton)	Efficiency (COP)	Runtime (hours)	Avg Daily Energy Use (kWh)	Avg Daily CHW Load (ton-hr)	Avg CHW Demand (ton)	Peak CHW Demand (ton)	Avg Efficiency (COP)	Runtime (hours)	Avg Daily Energy Use (kWh)	Avg Daily CHW Load (ton-hr)	Avg CHW Demand (ton)	Peak CHW Demand (ton)	Avg Efficiency (COP)

5.26.1.3. Heating

a. Total plant heating power. Calculate total plant heating power as the sum of heat pump power when indexed to heating mode and CHW pump power. For motors with VFDs, power shall be actual power as read through the VFD network interface. For fixed speed motors (e.g., primary pumps without VFDs), power shall be assumed to be fixed at BHP (from equipment schedule) * 0.746 / 0.93 (approximate motor efficiency). For some equipment with multiple internal power users, such as AWHPs, a field mounted power meter is required.

b. Total Plant Heating Load. Calculate plant heating load using flowrate through the primary circuit, *FLOW*; hot water return temperature upstream of the first heat pump, *HWRT*; and hot water supply temperature, *HWST*.

$$Q_{plant,heat} = 0.49 * \ FLOW(HWST - HWRT)\ [\frac{\text{kBtu}}{\text{h}}]$$

c. Calculate plant heating coefficient of performance (COP) as plant load converted to kW (divide Qplant (kBtu/h) by 3.41) divided by total plant power.

d. Summary Data: For the total plant, statistics shall be calculated for runtime, energy use (Btu), cumulative load (Btu), average demand (Btu/h), peak demand (Btu/h), and actual efficiency (COP). All statistics shall be presented on an instantaneous, year-to-date, and previous year basis.

Below is an example summary of the performance monitoring parameters. Summary table should be edited based on plant configuration, available statistics and desired units of measurement.

Instantaneous				Year-to-date						Previous Year					
Lifetime Runtime (hours)	Electrical Demand (kW)	HW Demand (kBtuh)	Efficiency (COP)	Runtime (hours)	Avg Daily Energy Use (kWh)	Avg Daily HW Load (kBtu)	Avg HW Demand (kBtu/h)	Peak HW Demand (kBtu/h)	Avg Efficiency (COP)	Runtime (hours)	Avg Daily Energy Use (kWh)	Avg Daily HW Load (kBtu)	Avg HW Demand (kBtu/h)	Peak HW Demand (kBtu/h)	Avg Efficiency (COP)

5.26.1.4. Combined Heat Pump Efficiency

a. Total Plant Power. Calculate total plant power as the sum of heat pump power (heat pumps indexed to heating, cooling, or heat recovery) and the CHW and HW pump power. For motors with VFDs, power shall be actual power as read through the VFD network interface. For fixed speed motors (e.g., primary pumps without VFDs), power shall be assumed to be fixed at BHP (from equipment schedule) * 0.746 / 0.93 (approximate motor efficiency). For some equipment with multiple internal power users, such as AWHPs, a field mounted power meter is required.

b. Calculate plant combined coefficient of performance (COP_{Tot}) as the sum of the heating and cooling plant load converted to kW divided by total plant power:

$$COP_{Tot} = \frac{Q_{plant,heat} + Q_{plant,cool}}{Total\ Plant\ Power\ \times 3.412}$$

c. Summary Data. Actual total efficiency (COP_{Tot}) shall be presented on an instantaneous, year-to-date, and previous year basis.

Below is an example summary of the performance monitoring parameters. Summary table should be edited based on plant configuration, available statistics and desired units of measurement.

Instantaneous				Year-to-date						Previous Year					
Lifetime Runtime (hours)	Electrical Demand (kW)	Total CHW & HW Demand (kBtuh)	Total Efficiency (COP)	Runtime (hours)	Avg Daily Energy Use (kWh)	Avg CHW + HW Load (kBtu)	Avg CHW + HW Demand (kBtu/h)	Peak CHW + HW Demand (kBtu/h)	Avg Total Efficiency (COP)	Runtime (hours)	Avg Daily Energy Use (kWh)	Avg Daily CHW + HW Load (kBtu)	Avg CHW + HW Demand (kBtu/h)	Peak CHW + HW Demand (kBtu/h)	Avg Total Efficiency (COP)

5.26.2. Alarms

5.26.2.1. Maintenance interval alarm when pump has operated for more than 1500 hours: Level 4. Reset interval counter when alarm is acknowledged.

5.26.2.2. Maintenance interval alarm when heat pump/chiller has operated for more than 1000 hours: Level 4. Reset interval counter when alarm is acknowledged.

5.26.2.3. Heat pump/chiller alarm: level 2

5.26.2.4. High chiller leaving chilled water temperature (more than 5°F above setpoint) for more than 15 minutes when chiller has been enabled in cooling mode for longer than 15 minutes: Level 3

5.26.2.5. Low heat pump leaving hot water temperature (more than 5°F below setpoint) for more than 15 minutes when heat pump has been enabled in heating mode for longer than 15 minutes: Level 3

5.26.2.6. Pump alarm is indicated by the status input being different from the output command for 15 seconds.

a. Commanded on, status off: Level 2. Do not evaluate the alarm until the equipment has been commanded on for 15 seconds.

b. Commanded off, status on: Level 4. Do not evaluate the alarm until the equipment has been commanded off for 60 seconds.

5.26.2.7. CHW System low gauge pressure

a. if CHW system gauge pressure falls 1 psig below the scheduled expansion tank pre-charge pressure for 5 minutes, (indicating need to fill): Level 3.

b. if CHW system gauge pressure falls below 0.9 times the scheduled expansion tank pre-charge pressure for 1 minute, (indicating possible leak): Level 2.

5.26.2.8. HW System low gauge pressure

a. if HW system gauge pressure falls 1 psig below the scheduled expansion tank pre-charge pressure for 5 minutes, (indicating need to fill): Level 3.

b. if HW system gauge pressure falls below 0.9 times the scheduled expansion tank pre-charge pressure for 1 minute, (indicating possible leak): Level 2.

Automatic Fault Detection will be added in a future addendum.

Add Figure A-35, A-36,and A-37 as follows: Note: these sections below are new, but additions are not underlined for ease of review.

Figure A-35. Primary-Only Modular Air-to-water Heat Pump/Chiller Plant

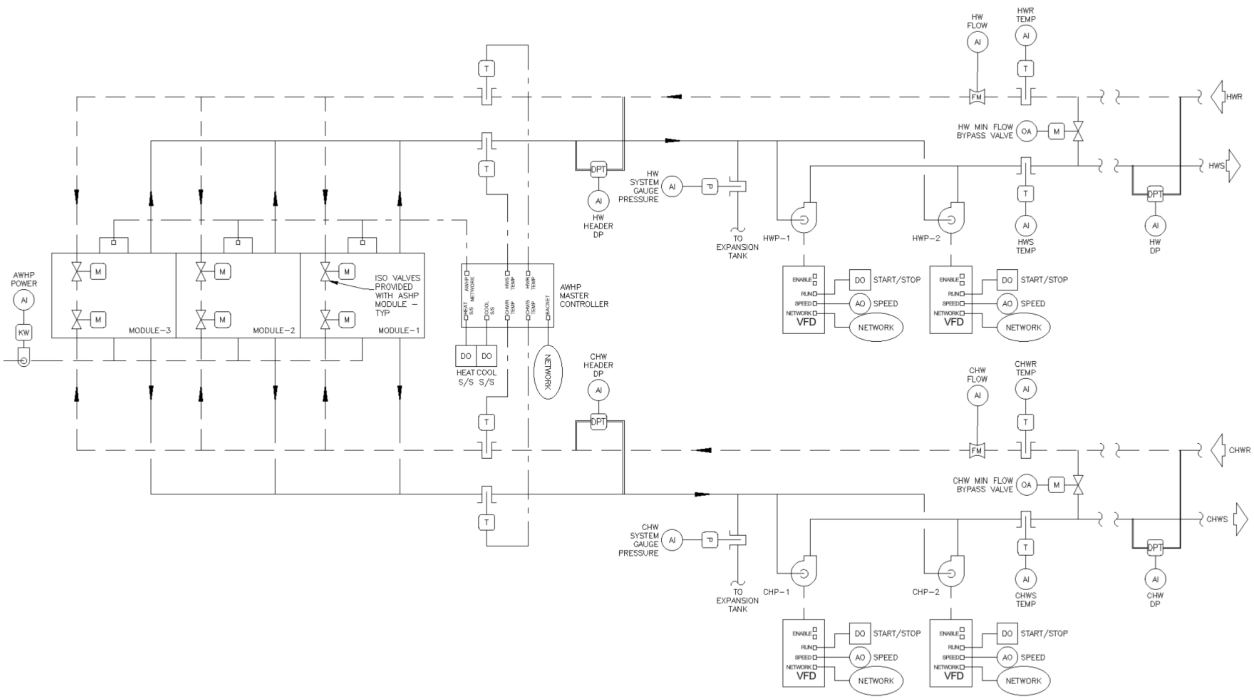

Figure A-36. Primary-Secondary Modular Air-to-water Heat Pump/Chiller Plant

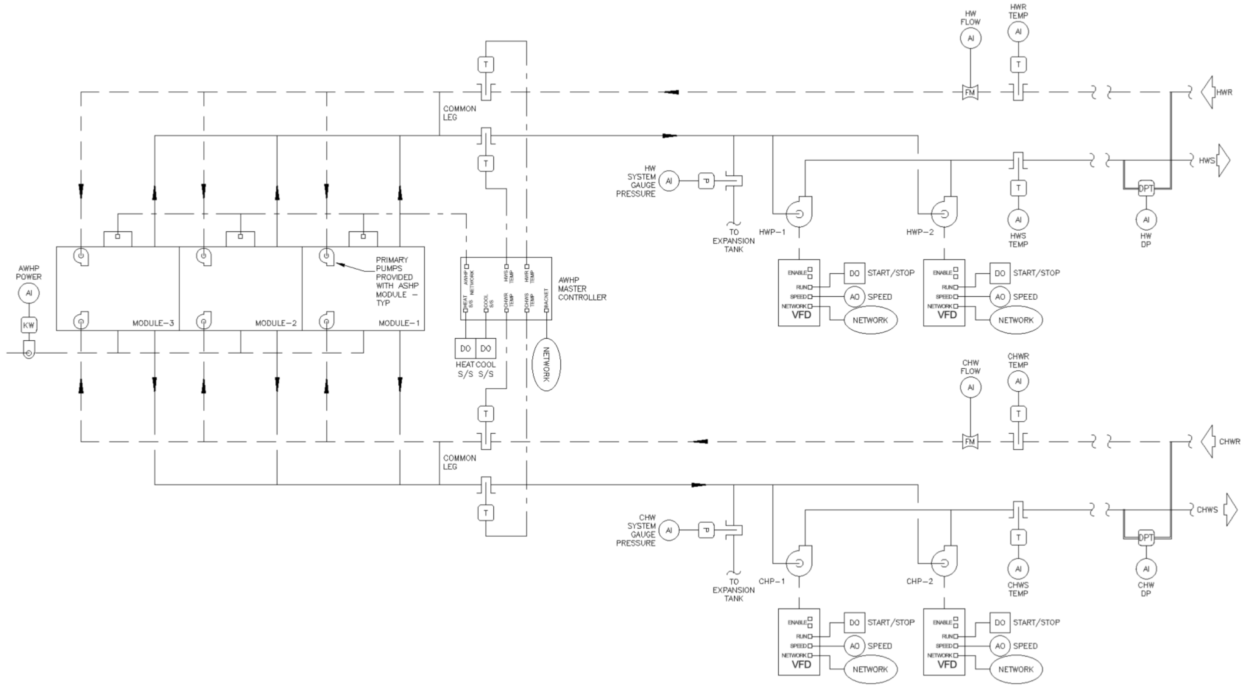

Figure A-37. 2-Pipe and 4-Pipe Air-To-Water Chilled Water Plant