ADDENDA

ASHRAE Addendum x to
ASHRAE Guideline 36-2018

High Performance Sequences of Operation for HVAC Systems

Approved by ASHRAE on July 9, 2021.

This addendum was approved by a Standing Guideline Project Committee (SGPC) for which the Standards Committee has established a documented program for regular publication of addenda or revisions, including procedures for timely, documented, consensus action on requests for change to any part of the guideline. Instructions for how to submit a change can be found on the ASHRAE® website (https://www.ashrae.org/continuous-maintenance).

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FOREWORD

This addendum includes the CHW plant sequences and associated logic variables and hardwired control points developed as part of ASHRAE Research Project 1711: Advanced Sequences of Operation for HVAC Systems – Phase II Central Plants and Hydronic Systems. Typos and minor language clarity issues identified since final publication of the RP-1711 sequences on December 31, 2019, have been cleaned up in this version.

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.

Addendum x to Guideline 36-2018

Add Section 3.1.7. as follows:

3.1.7. Chilled Water Plant

3.1.7.1. Temperature Setpoints

a. CHWSTminX, the lowest chilled water supply temperature setpoint for Chiller X

b. CHWSTmax, the maximum chilled water supply temperature setpoint used in plant reset logic.

60°F is a typical value. However, CHWSTmax should be adjusted based on the constraints imposed by the chillers comprising the plant and the coils the plant serves. If a chiller's internal setpoint cannot be reset to 60°F, or there are no conditions under which 60°F will be capable of satisfying certain coil loads, using a lower CHWSTmax is advisable.

Retain the following two parameters for water-cooled plants. Delete otherwise.

c. CWRTdesX, the condenser water return (chiller condenser leaving) temperature at chiller selection conditions for Chiller X.

d. CWSTdesX, the condenser water supply (chiller condenser entering) temperature at chiller selection conditions for Chiller X

e. CH-LOT, the outdoor air lockout temperature below which the chiller 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, make the setpoint below the coldest expected outdoor air temperature.

3.1.7.2. Differential Pressure Setpoints

a. CHW-DPmin, the minimum differential pressure setpoint used in plant reset logic

CHW-DPmin is dictated by minimum flow control in primary-only plants but has no lower limit in primary-secondary plants. In primary-only plants, minimum DP needs to be high enough to drive design minimum flow for the largest chiller (CHW-MinFlowX) through the minimum flow bypass valve (usually around 5 psi when the valve is selected properly). Typically, a TAB test is NOT needed to establish this value; minimum flow bypass valve Cv and CHW-MinFlowX are sufficient to establish the required DP across the minimum flow bypass valve. Where multiple DP sensors exist, a unique CHW-DPmin should be established for each loop. Note that where primary-only plants use cascading DP sensor logic—i.e., a local DP setpoint is *reset at the plant to maintain remote DPs at setpoint—only the local plant DP sensor need be assigned a minimum DP setpoint high enough to achieve design minimum flow through the minimum flow bypass.*

3.1.7.3. Chiller Flow Setpoints

a. CHW-MinFlowX, the minimum chiller chilled water flowrate per manufacturer's recommendations for Chiller X, in gpm.

b. CHW-DesFlowX, the design chiller chilled water flowrate for Chiller X, in gpm

Retain the following parameter for water-cooled plants with variable speed condenser water pumps. Delete otherwise.

c. CW-DesFlowX, the design chiller condenser water flowrate for Chiller X, in gpm

Retain the following parameters for water-cooled plants. Delete otherwise.

3.1.7.4. Chiller Lift Setpoints

a. LIFTminX, the minimum allowable lift at minimum load for Chiller X, as determined from the manufacturer's recommendations, where lift is the difference between condenser water return temperature and chilled water supply temperature.

Except for some magnetic bearing chillers, a minimum differential pressure must be maintained between the condenser and evaporator, aka head pressure. These sequences require at a minimum that the user identify the minimum allowable lift at minimum load for each chiller, LIFTminX, per the chiller manufacturer's recommendations. These variables are used to reset condenser water temperature setpoint from the cooling tower.

LIFTminX values can also be used to control minimum head pressure indirectly when direct control head pressure control is not available. Most chillers have head pressure control loops built into the chiller's controller, but not all do.

When chillers have built in head pressure control, an analog head pressure output from the chiller panel can be used to control a device that reduces flow through the condenser when condenser water temperature is too cold, e.g., on initial start when the cooling tower basin is cold. The chiller's head pressure output should be hardwired to the control system, rather than directly to any device. This allows the control sequences to use this signal to maintain minimum lift via both tower speed limiting and condenser water flow control (e.g., via valve throttling or pump speed limiting for variable speed CW pumps), ensuring that the tower fan speed control sequence maintaining condenser water temperature and the head pressure control sequence do not "fight" one another. When chillers do not have built-in head pressure control, the BAS can instead run a head pressure control loop for each chiller that maintains lift at LIFTminX. This loop output is then used to limit tower speed, CW pump speed, and/or throttle CW isolation valve in the same way that a chiller's internal head pressure control loop otherwise would.

b. LIFTmaxX, design lift at design load for Chiller X, as determined by subtracting CHWSTminX from CWRTdesX.

3.1.7.5. Capacity

a. QchX, design capacity of Chiller X, in tons.

Retain the following parameter for variable primary-variable secondary plants with a flow meter in the decoupler, or flow meters in both the primary and secondary loops, and for primary-only plants with headered variable speed pumps using differential pressure pump speed control. Delete otherwise.

b. PCHWFdesign, design primary loop flow, in gpm

Retain the following parameter for primary-secondary systems with a flow meter in the secondary loop. Delete otherwise.

c. SCHWFdesign, design secondary loop flow, in gpm (for each loop)

3.1.7.6. Minimum Cycling Load

a. MinUnloadCapX, the load below which Chiller X will engage hot gas bypass (HGB) or begin cycling (if the chiller does not have HGB), in tons.

MinUnloadCapX should be provided by the chiller manufacturer.

Retain the following parameters for plants with waterside economizers. Delete otherwise.

3.1.7.7. Waterside Economizer Design Information

a. DA_{HX}, design heat exchanger approach

b. DT_{WB}, design cooling tower wetbulb temperature

c. DA_{CT}, design cooling tower approach

d. HXFdesign, design waterside economizer chilled water flow in gpm

Retain the following parameter for plants where the CHW flowrate through the heat exchanger is controlled by a modulating bypass valve. Delete otherwise.

e. $HX_{DP\text{-}Design}$, design waterside economizer chilled water pressure drop

f. HXCWFdesign, design waterside economizer condenser water flow in gpm

Retain the following parameters for cooling towers that have a level sensor used to control makeup water and to generate high and low water level alarms. Delete otherwise.

3.1.7.8. Cooling Tower Level Control

a. T-level-high-alarm, maximum level just below overflow

b. T-level-low-alarm, minimum level

c. T-level-min-fill, lowest normal operating level

d. T-level-max-fill, highest normal operating level

Delete this clause if neither primary nor secondary chilled water pumps are headered.

3.1.7.9. Headered Pump Design Quantities

Retain the following parameters if primary chilled water pumps are headered.

a. N-PCHWP, the number of primary chilled water pumps that operate at design conditions

Retain the following parameters if secondary chilled water pumps are headered.

b. N-SCHWP, the number of secondary chilled water pumps that operate at design conditions

Add Section 3.2.3. as follows:

3.2.3. Chilled Water Plant

Retain the following parameter for plants with DP controlled variable speed pumps. Delete otherwise.

3.2.3.1. 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.*

Retain the following parameter for plants that do not have a remote DP sensor wired back to the plant controller, but instead have a local plant DP sensor hardwired to the plant controller and a remote sensor(s) communicating over the network. Delete otherwise. This is common in large buildings and campus systems. In such cases, the remote DP sensor(s) is used to reset a setpoint for the local sensor.

3.2.3.2. LocalCHW-DPmax, the maximum chilled water differential pressure setpoint local to the plant, in psi

Instructions for establishing LocalCHW-DPmax should be provided in the Test and Balance Specification and should generally follow the scheme of determining the setpoint for CHW-DPmax: the value recorded from the local DP sensor when the remote CHW-DPmax reading is recorded becomes LocalCHW-DPmax.

Retain the following parameter for water-cooled plants with variable speed condenser water pumps. Delete otherwise.

3.2.3.3. Cw-DesPumpSpdStage, the condenser water pump speed that delivers design condenser water flow through the chillers and waterside heat exchangers, CW-DesFlowX and HXCWFdesign, operating in a chiller stage.

For plants with variable speed condenser water pumps, the speed required to yield design flow through the operating chillers and waterside economizer heat exchangers (as applicable) varies with plant stage.

Instructions for determining Cw-DesPumpSpdStage for each Stage should be provided in the Test and Balance Specification. For example:

1) *Configure the plant to the lowest stage of chiller operation. Open the CW isolation valve of the chiller(s) in the stage and enable the CW pump(s) to operate in the stage and the corresponding number of cooling towers for the stage.*
2) *Reduce CW pump speed in 2% increments until condenser water flow through any chiller with an open CW isolation valve drops to 100% of design as determined by condenser differential pressure.*
3) *Note the speed setpoint and report to controls contractor.*
4) *Repeat the preceding steps for each chiller stage.*

Retain the following parameter for water-cooled plants with fixed speed condenser water pumps. Delete otherwise.

3.2.3.4. MinCWVlvPos, minimum head pressure control valve position

Minimum head pressure can be maintained by modulating condenser water isolation valves (for constant speed CW pumps) or limiting pump speed (for variable speed CW pumps). If chillers are provided with condenser water flow switches, a minimum head pressure control valve position is needed to ensure minimum flow is maintained while the head pressure control loop is enabled. Performance is improved if calorimetric type switches are used since they can have a much lower flow setpoint than paddle switches and are more reliable when subjected to corrosive open condenser water. If condenser water flow switches are not provided, or they are jumpered out as allowed by many manufacturers, MinCWVlvPos can be set to 0%.

For constant speed pumps, instructions for establishing MinCWVlvPos should be provided in the Test and Balance Specification. For example:

1. *Configure the plant for the lowest stage of chiller operation. Open the head pressure control valve of the test chiller and enable a CW pump and the corresponding number of cooling towers for that stage.*
2. *Throttle the head pressure control valve of the test chiller in 2% increments until the flow rate through the chiller's condenser decreases to 110% of the minimum condenser water flow switch setpoint as determined by condenser differential pressure.*
3. *Note the valve position setpoint and report to controls contractor.*

Retain the following parameter for water-cooled plants with variable speed condenser water pumps. Delete otherwise.

3.2.3.5. MinCWPspeed, minimum condenser water pump speed

Minimum head pressure can be maintained by modulating condenser water isolation valves (for constant speed CW pumps) or limiting pump speed (for variable speed CW pumps). If chillers are provided with condenser water flow switches, a minimum head pressure control valve position is needed to ensure minimum flow is maintained while the head pressure control loop is enabled. Performance is improved if calorimetric type switches are used since they can have a much lower flow setpoint than paddle switches and are more reliable when subjected to corrosive open condenser water. If condenser water flow switches are not provided, or they are jumpered out as allowed by many manufacturers, MinCWPspeed can be set to the minimum speed determined per 3.2.3.9 but no lower.
For variable speed pumps, instructions for establishing MinCWPspeed should be provided in the Test and Balance Specification. For example:

1) *Configure the plant for the lowest stage of chiller operation. Open the CW isolation valve of the test chiller and enable a CW pump and the corresponding number of cooling towers for that stage.*
2) *Reduce CW pump speed of the test chiller in 2% increments until the flow rate through the chiller's condenser decreases to 110% of the minimum condenser water flow switch setpoint as determined by condenser differential pressure.*
3) *Note the minimum speed setpoint and report to controls contractor.*

Retain the following parameter for plants with a waterside economizer where CHW flowrate through the heat exchanger is controlled by a variable speed heat exchanger pump. Delete otherwise.

3.2.3.6. HxPumpDesSpd, the waterside economizer heat exchanger pump speed that delivers design heat exchanger flow, HXFdesign, through the CHW side of the waterside economizer heat exchanger

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

1) *Starting from 100% speed, decrease HX pump speed in 2% increments until differential pressure measured across the waterside economizer heat exchanger is within 5% of design.*
2) *Note the design speed setpoint and report to controls contractor.*

Retain the following parameter for primary-only plants and primary-secondary plants with variable speed primary pumps that are intended to operate at one or more fixed speeds. Delete otherwise.

3.2.3.7. Ch-MaxPriPumpSpdStage, the primary chilled water pump speed necessary to deliver design chilled water flow, CHW-DesFlowX, through the operating chiller(s) in the stage

Instructions for establishing Ch-MaxPriSpdStage should be provide in the Test and Balance Specification. For example:

1) *Starting from 100% speed, decrease primary chilled water pump speed in 2% increments until differential pressure measured across the chiller evaporator is within 5% of design.*
2) *Note the design speed setpoint and report to controls contractor.*

Retain the following parameter for variable primary-variable secondary systems. Delete otherwise.

3.2.3.8. Ch-MinPriPumpSpdStage, the primary chilled water pump speed necessary to deliver minimum chilled water flow, CHW-MinFlowX, through the operating chiller(s) in the stage

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

1) *Open isolation valves of all chillers.*
2) *Start all non-redundant primary pumps at 100% speed.*
3) *Decrease primary pump speed in 2% increments starting from 100% until flowrate through any chiller, as measured by either evaporator barrel differential pressure or a flow meter, decreases to 110% of CHW-MinFlowX.*
4) *Note the speed setpoint and report to controls contractor.*

Retain the following section for plants with variable speed pumps or fans. Delete otherwise.

3.2.3.9. Minimum Speeds

a. Where minimum speeds are not required for flow control per other balancer provided setpoints above, minimum speed setpoints for all VFD-driven pumps and tower fans shall be determined in accordance with the test and balance specifications for the following as applicable:

1. Cooling Tower Fans
2. Condenser Water Pumps
3. Chilled Water Pumps

There needs to be corresponding instructions in the TAB specifications. For example:

1) *Start the fan or pump.*
2) *Manually set speed to 6 Hz (10%) unless otherwise indicated in control sequences. For equipment with gear boxes, use whatever minimum speed is recommended by manufacturer.*
3) *Observe fan/pump in field to ensure it is visibly rotating. If not, gradually increase speed until it is.*
4) *The speed at this point shall be the minimum speed setpoint for this piece of equipment.*

Also, specifications should require the contractor to run each tower fan through entire speed range and program out speeds (using the on-board VFD software) that cause tower vibration.

Add Section 4.10. as follows:

4.10 Chilled Water Plant

4.10.1. Chillers

Required?	Description	Type	Device
R	CH on/off	DO	DI on chiller control panel or through network interface; typ. each chiller
R	Chiller status	DI	DO on chiller control panel or through network interface; typ. each chiller
R	CHWST Setpoint Reset	AO	AI on chiller control panel or through network interface; typ. each chiller
R	Chiller Fault Code	AI	From chiller controller through network interface; typ. each chiller
Required for parallel or series piped chillers with headered primary CHW pumps. Delete otherwise. *A modulating valve is recommended on primary-only variable flow systems to allow for slow changes in flow during chiller staging. Sometimes electric valve timing may be sufficiently slow that 2-position valves can provide stable performance. Two-position valves are acceptable on primary-secondary systems.*			
A	CH CHW isolation valve	AO or DO	Modulating or 2-position butterfly valve, line size; typ. each chiller
Retain the following two points for optional valve end switch status feedback.			
O	CH CHW isolation valve closed end switch	DI	Valve end switch contact; typ. each chiller
O	CH CHW isolation valve open end switch	DI	Valve end switch contact; typ. each chiller
Retain the following points for optional analog valve position feedback.			
O	CH CHW isolation valve position feedback	AI	Valve position feedback contact; typ. each chiller
Required for series piped chillers and primary-only parallel CHW plants with waterside economizers. Delete otherwise.			
A	CH CHW bypass valve	DO	2-position butterfly valve, line size; typ. each chiller for series chiller plants; only one for parallel chiller plants
Required for plants with headered condenser water pumps. Delete otherwise. CW isolation valves may be two-position for chillers that do not require head pressure control or for plants with variable speed condenser pumps but no waterside economizer.			
A	CH CW isolation valve	AO or DO	Modulating or 2-position butterfly valve, line size; typ. each chiller
Retain the following two points for optional valve end switch status feedback.			
O	CH CW isolation valve closed end switch	DI	Valve end switch contact; typ. each chiller
O	CH CW isolation valve open end switch	DI	Valve end switch contact; typ. each chiller
Retain the following points for optional analog valve position feedback.			
O	CH CW isolation valve position feedback	AI	Valve position feedback contact; typ. each chiller

Required?	**Description**	**Type**	**Device**
Required for primary-only CHW plants, optional for other plant types.			
Primary-only plant sequences use the demand limit point to promote stable staging. Flowrates can change rapidly through operating chiller(s) when an additional chiller is brought online; limiting output can help prevent a low supply temperature trip condition. This is not an issue for primary/secondary plants, but the demand limit point may be retained for custom electric utility driven load shed logic not covered by this guideline. Note that load shed logic is covered in Thermal Zone Guideline 36 sequences and the reduced demand generated by zones ultimately serves to reduce plant output.			
A	CH Demand Limit	AO	AI on chiller control panel or through network interface; typ. each chiller
Head pressure control output required only for chillers that require head pressure control. This is an output from the chiller controller head pressure control loop.			
A	Head pressure control signal from CH	AI	AO from chiller control panel; typ. each chiller
CH CHW supply temperature is required for (1) variable primary-variable secondary plants using primary and secondary supply temperatures to reset primary pump speed that do not have a CHWST sensor in the primary loop, (2) head pressure control for chillers that do not have a head pressure control signal. Optional otherwise.			
A	CH CHW supply temperature	AI	From chiller controller via interface or via temperature sensor; typ. each chiller
CH CW return temperature is required for head pressure control for chillers that do not have a head pressure control signal. Optional otherwise.			
A	CH CW return temperature	AI	From chiller controller via interface or via temperature sensor; typ. each chiller
O	CH CHW return temperature	AI	From chiller controller via interface or via temperature sensor; typ. each chiller
O	CH CW supply temperature	AI	From chiller controller via interface or via temperature sensor; typ. each chiller
O	CH evaporator buddle CHW differential pressure	AI	From chiller controller via interface or via temperature sensor; typ. each chiller
O	CH condenser buddle CW differential pressure	AI	From chiller controller via interface or via temperature sensor; typ. each chiller
O	CH refrigerant evaporator temperature	AI	From chiller controller via interface; typ. each chiller
O	CH refrigerant condenser temperature	AI	From chiller controller via interface; typ. each chiller
O	Chiller local/auto switch	DI	From chiller controller via interface; typ. each chiller

4.10.2. 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.			
A	CHW Differential Pressure	AI	Differential Pressure Transducer

O	CHWP Alarm	DI	Fault point through VFD interface or programmed VFD contact; typ. each CHWP

4.10.3. Primary CHW Loop

Required?	Description	Type	Device
CHW flow required for primary-only plants; the flow meter must be located on the plant side of the CHW minimum flow bypass where provided. Optional for variable primary-variable secondary plants. Not required nor recommended for constant primary-variable secondary plants.			
A	CHW supply or return flow	AI	Flow meter
CHW bypass valve is required for variable flow primary-only plants. Delete otherwise.			
A	CHW Min Flow Bypass Valve	AO	Modulating valve sized for minimum flow of one chiller
CHW supply temperature sensor required for primary-only plants. Optional for primary-secondary Plants.			
A	CHW supply temperature	AI	Temperature sensor
CHW return temperature required for primary-only plants; locate on plant side of the CHW minimum flow bypass to allow for correct load calculations. Optional for primary-secondary plants.			
A	Plant CHW return temperature	AI	Temperature sensor
Optional sensor for monitoring temperature coming back from coils in primary-only plants with a CHW bypass and no waterside economizer. Located on the load side of minimum flow bypass. Delete for all other plant configurations.			
O	Loop CHW return temperature	AI	Temperature sensor
O	CHW system gauge pressure	AI	Gauge pressure transducer
Optional flow meter for primary pump speed control in variable primary-variable secondary plants.			
O	Decoupler flow	AI	Bi-directional flow meter

The following points apply if the plant has a secondary loop. Delete otherwise. "R" in this section should be interpreted as required for secondary loop operation.

4.10.4. Secondary CHW Loop

Required?	Description	Type	Device
R	Secondary CHW supply temperature	AI	Temperature sensor
Retain this sensor for primary-secondary plants without waterside economizers. Delete otherwise. For plants with waterside economizers, this reading is captured by the sensor upstream of the WSE defined in 4.10.8.			
A	Secondary CHW return temperature	AI	Temperature sensor
R	Secondary CHW supply or return flow	AI	Flow meter

The following points apply for water-cooled plants. Delete otherwise.

4.10.5. Condenser Water Pumps

Required?	Description	Type	Device
R	CWP Start	DO	Connect to VFD Run or Starter Contact; typ. each CWP
R	CWP Status	DI	Status through VFD interface, VFD status contact or current switch; typ. each CWP
CWP speed is required for WSE applications and optional for others. If VFDs are provided on CWPs in applications where one CWP is dedicated to each chiller, provide a unique CWP speed point per chiller; otherwise a single common speed point is appropriate.			
A	CWP Speed	AO	Connect to VFD Speed on all CWPs
O	CWP Alarm	DI	Fault point through VFD interface or programmed VFD contact; typ. each CWP

The following points apply for water-cooled plants. Delete otherwise.

4.10.6. Cooling Towers

Required?	Description	Type	Device
R	Start CT	DO	Connect to VFD Run; typ. each tower
R	CT Status	DI	Status through VFD interface, VFD status contact, or current switch; typ. each tower
R	CT Speed	AO	Connect to VFD Speed on all cooling towers
O	CT Alarm	DI	Fault point through VFD interface or programmed VFD contact; typ. each CT
R	Tower basin level	AI	Level sensor mounted in standpipe connected to equalizer
Keep the following inlet and outlet isolation valve points if cooling towers have actuated isolation valves. They may have a valve only on the supply with an oversized equalizer used to avoid valves on the outlet, or they may have valves at both inlet and outlet. Delete otherwise.			
A	CT inlet (and outlet) isolation valve	DO	2-position line size valve; typ. each tower
Retain the following two points for optional valve end switch status feedback. Delete otherwise.			
O	CT inlet (and outlet) isolation valve closed end switch	DI	Valve end switch contact; typ. each tower
O	CT inlet (and outlet) isolation valve open end switch	DI	Valve end switch contact; typ. each tower
Keep the following tower bypass, basin heater, and basin temperature points for freezing climates where basins will not be drained during winter months due to continued plant operation. Delete otherwise.			
A	CT bypass valve to cold water basin	DO	2-position line size 3-way valve
A	CT basin heater enable	DO	Connect to basin heater enable contact; typ. each tower
A	CT basin heater status	DI	Connect to basin heater status contact; typ. each tower
A	CT basin temperature	AI	Temperature sensor; typ. each tower
Keep the following piping heat trace points for freezing climates with outdoor piping. Delete otherwise.			
A	Piping heat trace enable	DO	Connect to heat trace enable contact
A	Piping heat trace status	DI	Connect to heat trace status contact

The following points apply for water-cooled plants. Delete otherwise.

4.10.7. Condenser Water Loop

Required?	Description	Type	Device
If controlling cooling towers to maintain CWST (see 5.20.12.2), CWST sensor must be hardwired to the same controller as the cooling towers.			
R	Common CW supply temperature from towers	AI	Temperature sensor
If controlling cooling towers to maintain CWRT (as opposed to CWST, see 5.20.12.2), CWRT sensor must be hardwired to the same controller as the cooling towers.			
R	Common CW return temperature to towers	AI	Temperature sensor
R	Makeup water valve	DO	Line sized ball valve

Retain the following points if the plant has a waterside economizer. Delete otherwise. "R" in this section should be interpreted as required for waterside economizer operation.

4.10.8. Waterside Economizer

Required?	Description	Type	Device
R	WSE HX CW isolation valve	DO	2-position line size valve
Retain the following two points for optional valve end switch status feedback.			
O	WSE HX CW isolation valve closed end switch	DI	Valve position feedback contact
O	WSE HX CW isolation valve open end switch	DI	Valve position feedback contact
R	WSE CW return temperature	AI	Temperature sensor
R	CHW return temperature before WSE	AI	Temperature sensor
A	CHW return temperature after WSE	AI	Temperature sensor
Retain the following two points if CHW flowrate through the heat exchanger is controlled by a modulating bypass valve. Delete otherwise.			
A	WSE CHW bypass valve	AO	Modulating butterfly valve, line size
A	WSE CHW differential pressure	AI	Differential pressure transducer
Retain the following four points if the plant has a waterside economizer and CHW flowrate through the heat exchanger is controlled by a heat exchanger pump. Delete otherwise. Note: WSE entering CHW temperatures is located in the pipe entering the HX, not the CHWR main upstream of the WSE.			
A	CHW HX Pump Start	DO	Connect to VFD Run
A	CHW HX Pump Speed	AO	Connect to VFD Speed
A	CHW HX Pump Status	DI	Status through VFD interface, VFD status contact or current switch
O	CHW HX Pump Alarm	DI	Fault point through VFD interface or programmed VFD contact; typ. each HX pump.
A	WSE entering CHW temperature	AI	Temperature sensor

4.10.9. Miscellaneous Plant Points

Required?	Description	Type	Device
Temperature and relative humidity sensors are necessary for calculating wet bulb temperature for waterside economizer sequences. Sensors are optional for plants without waterside economizers.			
A	Outdoor Air Temperature	AI	Temperature sensor
A	Relative humidity sensor	AI	Relative humidity sensor
The Emergency Chiller Off switch is required by most codes and ASHRAE Standard 15. This point is not needed if Emergency Chiller Off switch is hardwired to shut off chillers.			
O	Emergency Chiller Off Switch	DI	Connect to break glass switch contacts located outside chiller room primary entry

Add Section 5.20. as follows:

5.20 Chilled Water Plant

Retain the applicable variables listed in Paragraphs 3.1.7 and 3.2.3. Delete variables that are not applicable.

5.20.1. See Paragraph 3.1.7 for CHWSTminX, CWRTdesX, CWSTdesX, CH-LOT, CHW-MinFlowX, CHW-DesFlowX, LIFTminX, LIFTmaxX, QchX, PCHWFdesign, SCHWFdesign, MinUnloadCapX, DAHX, DTWB, DACT, HXFdesign, and HXDP-Design. See Paragraph 3.2.3 for CHW-DPmax, LocalCHW-DPmax, Cw-

DesPumpSpdStage, MinCWVlvPos, MinCWPspeed, HxPumpDesSpd, Ch-MaxPriPumpSpdStage, and CH-MinPriPumpSpdStage.

5.20.2. Plant Enable/Disable

5.20.2.1. 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).

5.20.2.2. Enable the 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 shall default to 0, adjustable), and

b. OAT>CH-LOT, and

c. The chiller plant enable schedule is active.

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

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

b. OAT<CH-LOT – 1°F, or

c. 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 less than one so that several are required to be active before the plant will start.

Retain the following two clauses (5.20.2.4 and 5.20.2.5) if the plant has a waterside economizer. Delete otherwise.

5.20.2.4. When the plant is enabled:

a. If the plant is enabled in WSE Mode (see 5.20.4.15):

1. Open the CW isolation valve of the waterside economizer.

Retain the following sentence for primary-only plants. Delete otherwise.

2. Stage on lead primary CHW pump, CW pump, and cooling tower(s) per 5.20.6, 5.20.9, and 5.20.12 respectively.

Retain the following sentence for primary-secondary plants. Delete otherwise.

3. Stage on lead secondary CHW pump, CW pump, and cooling towers per 5.20.7, 5.20.9, and 5.20.12 respectively.

b. If the plant is enabled in Chiller Mode (see 5.20.4.15):

Retain the following sentence for plants with headered primary CHW pumps. Delete otherwise.

1. Open the CHW isolation valve of the lead chiller.

Retain the following sentence for plants with headered CW pumps. Delete otherwise.

2. Open the CW isolation valve of the lead chiller.

Retain the following sentence for primary-secondary plants. Delete otherwise.

3. Stage on lead primary CHW pump, secondary CHW pump, CW pump, and cooling towers per 5.20.6, 5.20.7, 5.20.9, and 5.20.12 respectively.

Retain the following sentence for primary-only plants. Delete otherwise.

4. Stage on lead primary CHW pump, CW pump, and cooling towers per 5.20.6, 5.20.9, and 5.20.12 respectively.

5. Once the lead pumps are proven on, enable the lead chiller.

5.20.2.5. When the plant is disabled:

a. Shut off all enabled chillers, if any.

Retain the following sentence for plants with headered primary CHW pumps. Delete otherwise.

Where chillers have a CHW request network point, consider increasing the delay to 10 minutes to ensure that flow is not cut off too soon. Where chillers do not have this point (e.g., older chillers without network interfaces), the default delay is appropriate.

b. For each enabled chiller, close the CHW isolation valve after 3 minutes or the chiller is not requesting CHW flow.

Retain the following sentence for plants with headered CW pumps. Delete otherwise.

Where chillers have a CW request network point, consider increasing the delay to 10 minutes to ensure that flow is not cut off too soon. Where chillers do not have this point (e.g., older chillers without network interfaces), the default delay is appropriate.

c. For each enabled chiller, close the CW isolation valve after 3 minutes or the chiller is not requesting CW flow.

Retain the following sentence for primary-secondary plants. Delete otherwise.

d. Disable the operating primary CHW pump(s) (if enabled), secondary CHW pump(s), CW pump(s), and cooling tower(s) per 5.20.6, 5.20.7, 5.20.9, and 5.20.12 respectively.

Retain the following sentence for primary-only plants. Delete otherwise.

e. Disable the operating primary CHW pump(s), CW pump(s), and cooling tower(s) per 5.20.6, 5.20.9, and 5.20.12 respectively.

Retain the following two clauses (5.20.2.6 and 5.20.2.7) if the plant does not have a waterside economizer. Delete otherwise.

5.20.2.6. When the plant is enabled:

Retain the following sentence for plants with parallel chillers and headered primary CHW pumps. Delete otherwise.

a. Open the CHW isolation valve of the lead chiller.

Retain the following sentence for plants with series chillers and headered primary CHW pumps. Delete otherwise.

b. Close the CHW isolation valve of the lead chiller.

Retain the following sentence for water-cooled plants with headered CW pumps. Delete otherwise.

c. Open the CW isolation valve of the lead chiller.

Retain the following sentence for water-cooled primary-secondary plants. Delete otherwise.

d. Stage on lead primary CHW pump, secondary CHW pump, CW pump, and cooling towers per 5.20.6, 5.20.7, 5.20.9, and 5.20.12 respectively.

Retain the following sentence for air-cooled primary-secondary plants. Delete otherwise.

e. Stage on lead primary CHW pump and secondary CHW pump per 5.20.6 and 5.20.7 respectively.

Retain the following sentence for water-cooled primary-only plants. Delete otherwise.

f. Stage on lead primary CHW pump, CW pump, and cooling towers per 5.20.6, 5.20.9, and 5.20.12 respectively.

Retain the following sentence (g) for air-cooled primary-only plants. Delete otherwise.

g. Stage on lead primary CHW pump per 5.20.6.

h. Once the lead pumps are proven on, enable the lead chiller.

5.20.2.7. When the plant is disabled:

a. Shut off the enabled chiller(s).

Retain the following sentence for plants with parallel chillers and headered primary CHW pumps. Delete otherwise.

Where chillers have a CHW request network point, consider increasing the delay to 10 minutes to ensure that flow is not cut off too soon. Where chillers do not have this point (e.g., older chillers without network interfaces), the default delay is appropriate.

b. For each enabled chiller, close the CHW isolation valve after 3 minutes or the chiller is not requesting CHW flow.

Retain the following sentence for plants with series chillers and headered primary CHW pumps. Delete otherwise.

Where chillers have a CHW request network point, consider increasing the delay to 10 minutes to ensure that flow is not cut off too soon. Where chillers do not have this point (e.g., older chillers without network interfaces), the default delay is appropriate.

c. For each enabled chiller, open the CHW isolation valve after 3 minutes or the chiller is not requesting CHW flow.

Retain the following sentence for water-cooled plants with headered CW pumps. Delete otherwise.

Where chillers have a CW request network point, consider increasing the delay to 10 minutes to ensure that flow is not cut off too soon. Where chillers do not have this point (e.g., older chillers without network interfaces), the default delay is appropriate.

d. For each enabled chiller, close the CW isolation valve after 3 minutes or the chiller is not requesting CW flow.

Retain the following sentence for water-cooled primary-secondary plants. Delete otherwise.

e. Disable the operating primary CHW pump(s), secondary CHW pump(s), CW pump(s), and cooling tower(s) per 5.20.6, 5.20.7, 5.20.9, and 5.20.12 respectively.

Retain the following sentence for air-cooled primary-secondary plants. Delete otherwise.

f. Disable the operating primary CHW pump(s) and secondary CHW pump(s) per 5.20.6, 5.20.7 respectively.

Retain the following sentence for water-cooled primary-only plants. Delete otherwise.

g. Disable the operating primary CHW pump(s), CW pump(s), and cooling tower(s) per 5.20.6, 5.20.9, and 5.20.12 respectively.

Retain the following sentence for air-cooled primary-only plants. Delete otherwise.

h. Disable the operating primary CHW pump(s) per 5.20.6.

Retain Section 5.20.3 if the plant has a waterside economizer. Delete otherwise.

5.20.3. Waterside Economizer Control

5.20.3.1. Enable waterside economizer (WSE) if it has been disabled for at least 20 minutes and CHWRT upstream of HX is greater than the predicted heat exchanger leaving water temperature (PHXLWT) plus 2°F. PHXLWT is:

$$PHXLWT = T_{WB} + PA_{HX} + PA_{CT}$$
$$PA_{HX} = DA_{HX} * PLR_{HX}$$
$$PA_{CT} = m * (DT_{WB} - T_{WB}) + DA_{CT}$$

where
T_{WB}= current wetbulb temperature
PA_{HX}= predicted heat exchanger approach
PA_{CT} = predicted cooling tower approach
DA_{HX} = design heat exchanger approach

Retain the following PLR_{HX} definition for primary-only plants. Delete otherwise.

PLR_{HX}= the lesser of 1 and predicted heat exchanger part load ratio (current chilled water flow rate divided by design HX chilled water flow rate)

Retain the following PLR_{HX} definition for primary-secondary plants. Delete otherwise.

PLR_{HX}= the lesser of 1 and predicted heat exchanger part load ratio (current secondary chilled water flow rate divided by design HX chilled water flow rate)
DT_{WB}= design wetbulb temperature
DA_{CT} = design cooling tower approach
m = output of logic in Section 5.20.3.3 below.

This algorithm predicts the achievable HXLWT based on current plant load conditions, as estimated by PLRHX, and ambient wet bulb relative to design conditions. The logic is tuned based on the "m" parameter, which accounts for whether cooling *tower approach tends to worsen or improve with decreasing ambient wet bulb. Tower psychrometrics are such that for a given condenser water flow rate and range, approach will worsen as wetbulb temperature decreases, which drives "m" positive. However, for most plant, plant load (and thus either range or flowrate) tends to decrease as ambient wetbulb decreases, so closer approaches are achievable at lower wetbulbs, which drives "m" negative. "m" is therefore tuned on a plant specific basis per subsequent logic.*

5.20.3.2. Disable WSE when it has run for at least 20 minutes and CHW temp downstream of HX is greater than CHWRT upstream of HX less 1ºF for 2 minutes (i.e., if the HX is not reducing the CHW temp by at least 1°F).

5.20.3.3. PHXLWT Tuning

a. Decrease "m" by 0.02 when the economizer is disabled if the economizer remained enabled for greater than 60 minutes.

b. Increase "m" by 0.02 when the economizer is disabled if the economizer remained enabled for less than 30 minutes and WseTower-MaxSpeed did not decrease below 100% speed while the WSE was enabled. See xxxviii for definition and use of WseTower-MaxSpeed.

c. "m" shall be limited to the range of -0.2 to 0.5.

d. "m" shall initialize at 0 upon first plant start up and shall not be reinitialized every time the plant is disabled/enabled. Rather, "m" holds its value when the plant is disabled and tuning resumes from that value when the plant is re-enabled.

Use the following three clauses for plants where CHW flow through the WSE is controlled using a modulating heat exchanger bypass valve. See schematics in Informative Appendix A for examples.

5.20.3.4. When economizer is enabled, start next CW pump and/or adjust CW pump speed per 5.20.9.6, open CW isolation valve to the HX, and enable the WSE in-line CHW return line valve.

5.20.3.5. When the WSE in-line CHW return line valve is enabled, it shall be modulated by a direct-acting PID loop to maintain the DP across the CHW side of the HX at $HX_{DP\text{-}Design}$. Map the loop output from 0% open at 0% output to 100% open at 100% output. Bias the loop to launch from 100% output. The valve shall be fully open when loop is disabled.

This loop ensures that flow through the heat exchanger does not exceed design, which has the potential to cause chilled water loop DP to rise above design and starve loads of flow. Biasing the loop output to 100% when the loop is enabled ensures that the valve does not immediately modulate closed upon WSE startup.

5.20.3.6. When economizer is disabled, WSE in-line CHW return line valve shall be disabled (opened), HX CW isolation valve fully closed, and the last lag CW pump disabled and/or CW pump speed changed per 5.20.9.6.

Use the following four clauses for plants where CHW flow through the WSE is controlled by a variable speed HX pump. Delete otherwise. See schematics in Informative Appendix A for examples.

5.20.3.7. When economizer is enabled, start next CW pump and/or adjust CW pump speed per 5.20.9.6, open CW isolation valve to the HX and enable the CHW HX Pump.

5.20.3.8. WSE HX Pump Speed Reset Requests shall be generated based on the difference (" T) between chilled water return temperature upstream of the WSE and WSE HX entering CHW temperature.

a. If " T exceeds 2°F, send 2 requests until " T is less than 1.2°F.

b. Else if " T exceeds 1°F, send 1 request until " T is less than 0.2°F.

c. Else send 0 requests.

5.20.3.9. When the WSE HX pump is proven on, WSE HX pump speed shall be reset using Trim & Respond logic with the following parameters:

Variable	Value
Device	WSE HX pump proven on
SP_0	HxPumpDesSpd
SP_{min}	Minimum Speed
SP_{max}	HxPumpDesSpd
T_d	15 minutes
T	2 minutes
I	0
R	WSE HX Pump Speed Reset Requests
SP_{trim}	+2%
SP_{res}	-3%
$SP_{res\text{-}max}$	-6%

This trim and respond loop resets pump speed to avoid wasting pump energy by recirculating water through the heat exchanger. Recirculating water also decreases heat transfer by degrading heat exchanger log mean temperature difference (LMTD), reducing economizer capacity.

5.20.3.10. When economizer is disabled, CHW HX Pump shall be disabled, HX CW isolation valve fully closed, and the last lag CW pump disabled and/or CW pump speed changed per 5.20.9.6.

Retain the following clause where a chiller bypass valve is needed to operate the WSE without flowing water through any of the chillers. This is typically true of primary-only parallel chiller plants. Delete otherwise.

5.20.3.11. When economizer is enabled and all chiller isolation valves are commanded closed, open the economizer-only CHW bypass valve. Close bypass valve when any chiller isolation valve is commanded open and exceeds 25% open (as determined by valve position (if provided), or either nominal valve timing or valve ramp rate, whichever is slower).

In atypical primary-only applications where waterside economizer flow exceeds the design flow of one chiller, it may prove necessary to modify sequences to utilize this bypass for trim capacity control. As an example, suppose a plant has (3) 500 tons chillers and a waterside economizer sized for the whole load; this is typical of some data centers. Suppose the waterside economizer is meeting the whole plant load of 1200 tons at some point. If ambient wet bulb temperature increases such that the waterside economizer can only meet 1150 tons of plant load, then a chiller needs to start. But 1200 tons of flow cannot be sent through one 500 ton chiller, so either (2) chillers need to start and will cycle under low load, or one chiller needs to start with the remaining plant flow sent through the bypass. In such a case, the chiller supplies water at a temperature below plant supply temperature setpoint, which is then blended with the remaining WSE flow not sent through the chiller to achieve plant setpoint. Sequences for this application, which is typical of a data center, are outside the purview of the RP.

5.20.4. Chiller Staging

5.20.4.1. Chiller stages shall be defined as follows:

The following table is project specific and must indicate the chillers that are required to run in each stage. Where chillers are interchangeable and should be lead/lag alternated, that must be indicated with an "or" in the enabled chillers column.

For instance in the example table below, if there is a swing chiller (CH-1) and two identical larger chillers (CH-2, CH-3), there are 5 possible chiller capacity stages.

The waterside economizer-only stage and column should be deleted if there is no waterside economizer.

Chiller Stage	**Enabled Chillers**	**Waterside Economizer Status**
0	None	Off
0+WSE	None	On
1	CH-1	On or Off

2	CH-2 or CH-3	On or Off
3	CH-1 and (CH-2 or CH-3)	On or Off
4	CH-2 and CH-3	On or Off
5	CH-1, CH-2, and CH-3	On or Off

Interchangeable chillers are generally those considered to be equal in capacity and type (positive displacement, constant speed or variable speed centrifugal), or are otherwise deemed equally suitable to meet the same load by the Designer.

Retain the following clause for water-cooled plants with parallel chillers. Delete otherwise.

5.20.4.2. Interchangeable chillers indicated with "or" in the table above shall be lead/lag controlled per 5.1.15.3. If a chiller is in alarm per 5.1.15.5.b, its CHW and CW isolation valves shall be closed.

Retain the following clause for water-cooled plants with series chillers. Delete otherwise.

5.20.4.3. Interchangeable chillers indicated with "or" in the table above shall be lead/lag controlled per 5.1.15.3. If a chiller is in alarm per 5.1.15.5.b, its CHW valve shall be opened and CW isolation valve shall be closed.

Retain the following clause for air-cooled plants with parallel chillers. Delete otherwise.

5.20.4.4. Interchangeable chillers indicated with "or" in the table above shall be lead/lag controlled per 5.1.15.3. If a chiller is in alarm per 5.1.15.5.b, its CHW isolation valve shall be closed.

Retain the following clause for air-cooled plants with series chillers. Delete otherwise.

5.20.4.5. Interchangeable chillers indicated with "or" in the table above shall be lead/lag controlled per 5.1.15.3. If a chiller is in alarm per 5.1.15.5.b, its CHW valve shall be opened.

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

Retain the following clause for primary-only plants and primary-secondary plants without flow meters in all secondary loops (if more than one). Delete otherwise.

5.20.4.7. $Q_{required}$ is calculated based on chilled water return temperature (*CHWRT*) entering the chillers, active chilled water supply temperature setpoint ($CHWST_{SP}$), and measured flow through the primary circuit flow meter ($FLOW_P$), 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.

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

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. Note that using entering return temperature, as opposed to temperature upstream of waterside economizers or chilled water minimum flow bypasses as applicable, is critical for calculations to be executed properly.

Retain the following clause for primary-secondary plants with flow meters in all secondary loops (if more than one). Delete otherwise.

5.20.4.8. $Q_{required}$ is calculated based on secondary chilled water return temperature (*SCHWRT*), active chilled water supply temperature setpoint ($CHWST_{SP}$), and measured flow through the secondary circuit flow meter ($FLOW_S$), 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.

$$Q_{required} = \frac{FLOW_S(SCHWRT - CHWST_{SP})}{24}\ [tons]$$

5.20.4.9. 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 chiller 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.

5.20.4.10. *OPLR* shall be calculated as follows:

$$OPLR = \frac{Q_{required}[tons]}{Sum\ of\ QchX\ for\ Chillers\ in\ stage}$$

5.20.4.11. Minimum cycling part load ratio, $OPLR_{MIN}$, shall be calculated as:

$$OPLR_{MIN,stage} = \frac{Sum\ of\ MinUnloadTonsX\ for\ Chillers\ in\ stage}{Sum\ of\ QchX\ for\ Chillers\ in\ stage}$$

5.20.4.12. Stage up events are initiated in part based on current stage *OPLR* exceeding a stage up part load ratio, $SPLR_{UP}$; stage down events are initiated in part based on *OPLR* for the next lower stage falling below a stage down part load ratio, $SPLR_{DN}$.

5.20.4.13. Staging events require that a chiller stage be available. A stage shall be deemed *unavailable* if the stage cannot be achieved because a chiller required to operate in the stage is faulted per ii or a chilled water or condenser water pump dedicated to that chiller is faulted per i; otherwise, the stage shall be deemed available.

5.20.4.14. $SPLR_{UP}$ and $SPLR_{DN}$ reset based on the types of chillers operating in the current stage and the types of chillers operating in the next higher and lower *available* stages per the subsequent logic. The rules below are organized in order of precedence from most important to least important; more important rules supersede less important rules.

The above clause effectively means the rules for staging constant speed centrifugal chillers supersede the rules for staging positive displacement chillers, and the rules for staging positive displacement chillers supersede the rules for staging variable speed centrifugal chillers.

These rules assume the following staging hierarchy applies globally across chiller plants based on current industry best practice:
(1) If the plant has any positive displacement machines, those are staged on first since they are generally sized to handle low load conditions.
(2) Variable speed centrifugal machines are staged on next.
(3) Constant speed centrifugal machines are staged on last.

---

a. Set $SPLR_{UP}$ as follows:

Retain the next clause for plants with any constant speed centrifugal chillers. Delete otherwise.

---

1. When any chillers in the next higher stage are constant speed centrifugal, $SPLR_{UP}$ shall be 90%.

Fixed speed chillers are only able to unload using throttling devices, e.g., inlet guide vanes. As a result, chiller efficiency worsens significantly at low loads. Efficiency is optimized by staging once the operating chillers are fully loaded. The staging *point is therefore selected to be just slightly less than full load to avoid losing CHWST setpoint briefly as would occur if staging were delayed until full load for the current stage were achieved.*

Where used, constant speed centrifugal machines are typically the largest (and last stage) chillers in the plant and their efficiency is most sensitive to load. Therefore, the rules for staging these machines takes precedence.

Retain the next clause if the plant has any stage with all positive displacement (screw or scroll) chillers. Delete otherwise.

2. When all chillers operating in the current stage are positive displacement, $SPLR_{UP}$ shall be 80%.

Positive displacement chillers utilize a fixed staging PLR because screw and scroll compressors have a fixed compression ratio (most commercial screw chillers typically do not employ variable volume ratio technology, though some are coming to market). Positive displacement chiller efficiency at a given load is therefore not as sensitive to changes in lift as centrifugal chiller efficiency, and the relative efficiencies at different chiller load percentages (e.g., 30% for two chiller operation vs. 60% for one chiller operation) hold reasonably constant as lift changes. As such, resetting staging PLR with lift is not necessary to optimize screw chiller plant performance. This is in contrast to variable speed centrifugal chiller reset logic described below.

Positive displacement machines are typically used as low load chillers in larger plants. It therefore makes sense to load them nearly fully prior to staging on larger variable speed centrifugal machines (where used). As such, positive displacement machine staging criteria take precedence over variable speed centrifugal machine staging criteria.

Retain the next clause for plants with any variable speed centrifugal chillers. Delete otherwise.

3. When any chillers in the current operating stage are variable speed centrifugal, $SPLR_{UP}$ shall be calculated as the 5 minute rolling average of the following equation sampled at least every 30 seconds:

$$SPLR_{UP} = Min(Max(0.45, E * LIFT + F), 0.9)$$

$$LIFT = CWRT - CHWST_{SP}$$

$$E = \frac{0.9}{(LIFT_{MAX} - LIFT_{MIN})}$$

$$F = E * (0.4 * LIFT_{MAX} - 1.4 * LIFT_{MIN})$$

viii. LIFTmin and LIFTmax shall be calculated as the averages of LIFTminX and LIFTmaxX for all variable speed centrifugal chillers operating in the current stage respectively.

Centrifugal chiller efficiency varies significantly with lift. As lift increases for a given load, centrifugal compressors must run faster to avoid surge. Capacity trimming under such conditions is accomplished using inlet guide vanes or variable geometry diffusers, which reduces chiller efficiency. The above equation resets the centrifugal staging point up when lift is high to minimize throttling of surge control devices and keep chillers operating near to their optimal efficiency. Engineers should consult with the chiller manufacturer to obtain part load efficiency data and adjust the optimal staging bounds for each application. See the ASHRAE Fundamentals of Design and Control of Central Chilled-Water Plants Self-Directed Learning Course for how E and F can be optimally determined. The E and F values above are the simplified coefficients from this SDL, Appendix A normalized for a plant with any number of chillers.

Upper and lower limits of 0.45 and 0.9 are placed on SPLR to ensure stable plant staging irrespective of the optimal staging point indicated by the lift reset curve. Using a two chiller plant with equally sized machines as the simplest example, bounding SPLR to a minimum of 0.45 ensures that the logic does not stage on the second machine if doing so would cause the chillers to be less than 22.5% loaded (0.45 OPLR divided by 2). Bounding SPLR to a maximum of 0.9 ensures that the logic does not delay staging once the operating chiller is more than 90% loaded (OPLR > 0.9) since doing so could risk losing the load.

b. Set $SPLR_{DN}$ as follows:

In the paragraphs below, the stage down SPLR values appear identical to the stage up values. It is important to remember, per 5.20.4.12, that these values are applied against the OPLR values of different plant stages, so they yield different tonnage thresholds.

Note also that the stage down conditions below do not yield a hysteresis band. I.e., if the positive displacement chiller rules were applied to a plant with only two screw chillers sized at 200 tons each, the plant stage up and stage down points would both be 160 tons. This is acceptable because the stages have minimum run times to prevent cycling. Furthermore, plant load for most applications generally trends in one direction for multiple hours before beginning to trend the opposite direction. As such, there is little risk of repeated stage cycling.

Retain the next clause for plants with any constant speed centrifugal chillers. Delete otherwise.

1. When any chillers in the current stage are constant speed centrifugal, $SPLR_{DN}$ shall be 90%.

Retain the next clause if the plant has any stage with all positive displacement (screw or scroll) chillers. Delete otherwise.

2. When all chillers operating in the next lower stage are positive displacement, $SPLR_{DN}$ shall be 80%.

Retain the next clause for plants with any variable speed centrifugal chillers. Delete otherwise.

3. When a variable speed centrifugal chiller operates in the next lower stage, $SPLR_{DN}$ shall be calculated as the 5 minute rolling average of the following equation sampled at least every 30 seconds:

$$SPLR_{DN} = Min(Max(0.45, E * LIFT + F), 0.9)$$

$$LIFT = CWRT - CHWST_{SP}$$

$$E = \frac{0.9}{(LIFT_{MAX} - LIFT_{MIN})}$$

$$F = E * (0.4 * LIFT_{MAX} - 1.4 * LIFT_{MIN})$$

ix. LIFTmin and LIFTmax shall be calculated as the averages of LIFTminX and LIFTmaxX for all variable speed centrifugal chillers operating in the next lower stage respectively.

5.20.4.15. Staging shall be executed per the conditions below subject to the following requirements.

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

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

c. Any unavailable stage (see 5.20.4.13) shall be skipped during staging events, but staging conditionals in the current stage shall be evaluated as per usual.

Retain the following paragraph for plants with waterside economizers. Delete otherwise.

1. Exception: If Stage 1 is unavailable, then the stage down conditionals used while the next higher available Stage is operating shall be those normally applied to Stage 1.

This exception is necessary because the Stage down conditionals for Stage 1 are unique relative to the other stages. They evaluate whether the waterside economizer can run alone without any chillers. If Stage 1 is unavailable, the same evaluation must be conducted for the next higher available stage.

d. Chilled water supply and return temperatures used in staging logic shall be those located in common supply and return mains hardwired to plant controllers.

Retain the following clause for primary-secondary chiller plants with CHW isolation valves where the primary loop does not have a single CHWST sensor that measures the combined supply flow of all chillers. See schematics in Informative Appendix A for examples. Delete otherwise.

e. Where a primary CHW supply temperature sensor is not provided, primary CHW supply temperature used in staging logic shall be the weighted average supply temperature of all chillers with open CHW isolation valves. Temperatures shall be weighted by design chiller flowrates.

Retain the following clause for primary-secondary chiller plants with dedicated primary CHW pumps where the primary loop does not have a single CHWST sensor that measures the combined supply flow of all chillers. See schematics in Informative Appendix A for examples. Delete otherwise.

f. Where a primary CHW supply temperature sensor is not provided, primary CHW supply temperature used in staging logic shall be the weighted average supply temperature of all chillers with dedicated CHW pumps proven on. Temperatures shall be weighted by design chiller flowrates.

The above clause assumes that flows through the chillers are balanced proportional to design.

Retain the following two clauses for Primary-only chiller plants without waterside economizers. Delete otherwise.

g. Stage up if any of the following is true:

   1. **Availability Condition:** The equipment necessary to operate the current stage are unavailable. The availability condition is not subject to the minimum stage runtime requirement. Or

   2. **Efficiency Condition**: Current stage $OPLR > SPLR_{UP}$ for 15 minutes and current stage OPLR is not decreasing at a rate greater than 2.5% per minute averaged over 5 minutes; or

   3. Failsafe Condition:

Retain the following condition for parallel chiller plants, delete otherwise.

      x. CHW DP is 2 psi < setpoint for 15 minutes; or

      xi. CHW supply temperature is 2°F > setpoint for 15 minutes.

h. Stage down if both of the following are true:

   1. Next available lower stage $OPLR < SPLR_{DN}$ for 15 minutes and next lower stage OPLR is not increasing at a rate greater than 2.5% per minute averaged over 5 minutes; and

   2. The failsafe stage up condition is not true.

The first stage up condition stages the chillers at the optimum load point, SPLR, to maximize chiller efficiency. The second stage up condition acts as a failsafe bringing on the lag chiller if one or more coils is starved because chilled water differential pressure is below setpoint or chilled water supply temperature is above setpoint for an extended period. The former may occur if chilled water delta-T is degraded from design or one pump is down for maintenance and the pump(s) are unable to drive additional flow through the operating chiller; the latter may occur if the lead chiller has an active fault condition that is not *generating a failure alarm. It is also possible that the OPLR calculation could go out of calibration due to a failed flow meter and/or return temperature sensor, thus necessitating fallback on the failsafe conditions.*

Note that the DP failsafe condition does not apply to series chiller plants since bringing on an additional chiller would only increase pressure drop in a series chiller plant.

Retain the following five clauses for Primary-only chiller plants with waterside economizers. Delete otherwise.

i. When enabling the plant, skip the Waterside Economizer Only Stage (lowest stage) if PHXLWT with PLR_{HX} set equal to 1 is not 1°F < CHWST setpoint.

j. When only the Waterside Economizer is enabled, stage up if either of the following is true:

1. CHW supply temperature is 2°F > setpoint for 20 minutes; or
2. CHW supply temperature is 4°F > setpoint for 10 minutes.

k. In all other stages, stage up if any of the following is true:

1. **Availability Condition:** The equipment necessary to operate the current stage are unavailable. The availability condition is not subject to the minimum stage runtime requirement. Or
2. **Efficiency Condition**: Current stage $OPLR > SPLR_{UP}$ for 15 minutes and current stage OPLR is not decreasing at a rate greater than 2.5% per minute averaged over 5 minutes; or
3. Failsafe Condition:

Retain the following condition for parallel chiller plants. Delete otherwise.

xii. CHW DP is 2 psi < setpoint for 15 minutes; or

xiii. CHW supply temperature is 2°F > setpoint for 15 minutes.

l. When only the Waterside Economizer is enabled in the next lower stage, stage down if all of the following are true:

1. WseTower-MaxSpeed is less than 100%; and
2. WSE is enabled; and
3. PHXLWT is 1°F < CHW supply temp setpoint.

m. In all other stages, stage down if both of the following are true:

1. Next available lower stage $OPLR < SPLR_{DN}$ for 15 minutes and next lower stage OPLR is not increasing at a rate greater than 2.5% per minute averaged over 5 minutes; and
2. The failsafe stage up condition is not true.

Chiller staging for a Primary-only plant with a WSE mirrors staging for a standard Primary-only plant with the only complications being deciding (1) whether the plant can start with just the waterside economizer and (2) when chillers can be staged off leaving the WSE to meet the load alone. For (1), the logic conservatively estimates the CHWST that the WSE will be able to achieve assuming the WSE HX is fully loaded at startup. If the WSE is projected to be able to provide water at least 1°F colder than the CHWST setpoint, then the plant starts in WSE mode. For (2), the logic similarly verifies that the WSE is predicted to be able to provide water at least 1°F colder than the CHWST setpoint and cross-validates that prediction by ensuring that WseTower-MaxSpeed, which is reset to false load the chillers to prevent cycling with the WSE on, is less than

100%. In other words, the logic checks that the WSE is currently throttling its capacity at current plant conditions with a chiller on; if it is not, then clearly the WSE cannot meet the CHWST setpoint alone.

Retain the following two clauses for Primary-secondary chiller plants without waterside economizers. Delete otherwise.

n. Stage up if any of the following is true:

1. **Availability Condition:** The equipment necessary to operate the current stage are unavailable. The availability condition is not subject to the minimum stage runtime requirement. Or
2. **Efficiency Condition:** Current stage $OPLR > SPLR_{UP}$ for 15 minutes and current stage OPLR is not decreasing at a rate greater than 2.5% per minute averaged over 5 minutes; or
3. Failsafe Condition:

    xiv. Secondary CHW supply temperature > primary CHW supply temperature + 2°F for 10 minutes and the enabled primary pumps are at maximum speed; or

    xv. Primary CHW supply temperature is 2°F > setpoint for 15 minutes.

o. Stage down if both of the following are true:

1. Next available lower stage $OPLR < SPLR_{DN}$ for 15 minutes and next lower stage OPLR is not increasing at a rate greater than 2.5% per minute averaged over 5 minutes; and
2. The failsafe stage up 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 when the presence of secondary recirculation has been confirmed by secondary CHWST exceeding primary by 2°F. The conditional also requires that primary pumps be at maximum speed to ensure that, for variable primary flow applications, the primary pumps are already providing maximum primary flow before staging.

The high primary CHW supply temperature conditional ensures that the plant will stage up in the event that secondary recirculation is not occurring (e.g., because the primary pumps have sufficient head to deliver in excess of design chiller flow), the operating chiller(s) cannot make supply temperature setpoint, and the efficiency condition is not being triggered due to a failed sensor(s).

Retain the following five clauses for Primary-secondary chiller plants with waterside economizers. Delete otherwise.

p. When enabling the plant, skip the Waterside Economizer Only Stage (lowest stage) if PHXLWT with PLR_{HX} set equal to 1 is not 1°F < CHWST setpoint.

q. When only the Waterside Economizer is operating, stage up if either of the following is true:

1. Secondary CHW supply temperature is 2°F > setpoint for 20 minutes; or
2. Secondary CHW supply temperature is 4°F > setpoint for 10 minutes.

r. In all other stages, stage up if any of the following is true:

1. **Availability Condition:** The equipment necessary to operate the current stage are unavailable. The availability condition is not subject to the minimum stage runtime requirement. Or
2. **Efficiency Condition**: Current stage $OPLR > SPLR_{UP}$ for 15 minutes and current stage OPLR is not decreasing at a rate greater than 2.5% per minute averaged over 5 minutes; or

3. Failsafe Condition:

xvi. Secondary CHW supply temperature > primary CHW supply temperature + 2°F for 10 minutes and the enabled primary pumps are at maximum speed; or

xvii. Primary CHW supply temperature is 2°F > setpoint for 15 minutes.

s. When only the Waterside Economizer is enabled in the next lower stage, stage down if all of the following are true:

1. WseTower-MaxSpeed is less than 100%; and
2. WSE is enabled; and
3. PHXLWT is 1°F < CHW supply temp setpoint.

t. In all other stages, stage down if both of the following are true:

1. Next available lower stage $OPLR < SPLR_{DN}$ for 15 minutes and next lower stage OPLR is not increasing at a rate greater than 2.5% per minute averaged over 5 minutes; and
2. The failsafe stage up condition is not true.

The added complications for staging with a WSE are the same for a primary-secondary plant as they are for a primary only plant, so the necessary additional staging logic is identical.

Clauses 5.20.4.16 through 5.20.4.35 present 10 pairs (2 clauses each) of mutually exclusive options for steps to take when a stage change is initiated. Staging steps vary based on: (1) whether the plant is primary-only parallel piped, primary-secondary piped, or primary-only series piped, and (2) whether the primary CHW and CW pumps are headered or dedicated.

Retain all references to condenser water pumps and head pressure control in the selected pair of clauses for water-cooled chiller plants. Delete otherwise.

Retain Clauses 5.20.4.16 and 5.20.4.17 for water-cooled primary-only parallel chiller plants with headered chilled water pumps and headered condenser water pumps or air-cooled primary-only parallel chiller plants with headered chilled water pumps. Delete otherwise.

At various points in all of the staging sequences, there is a requirement to wait for requests for CHW and CW flow to clear, or 3 minutes to elapse, before moving on to the next step in staging. Where chillers have CHW and CW request network points, consider increasing the delay to 10 minutes to ensure that flow is not cut off too soon. Where chillers do not have these points (e.g., older chillers without network interfaces), the default delay is appropriate.

5.20.4.16. Whenever there is a stage-up command:

a. Command operating chillers to reduce demand to 75% of their current load. Wait until actual demand <80% of current load up to a maximum of 5 minutes before proceeding.

The above clause is recommended for applications where a sudden change in load may induce a chiller trip. This was commonly true of older chillers but has often proven unnecessary for modern machines with more robust capacity controls. Leave it if unsure.

Retain the following paragraph if a smaller chiller is staged off while a larger chiller is staged on during any stage change (e.g., for plants with swing chillers). Delete otherwise.

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b. For any stage change during which a smaller chiller is disabled and a larger chiller is enabled, slowly change the minimum flow bypass setpoint to that appropriate for the stage transition as indicated in 5.20.8.3. After new setpoint is achieved, wait 1 minute to allow loop to stabilize.

c. For any other stage change, reset the minimum flow bypass setpoint to that appropriate for the new stage as indicated in 5.20.8.1. After new setpoint is achieved, wait 1 minute to allow loop to stabilize.

If the bypass valve opens quickly, then the chiller load will suddenly drop and the chiller(s) could trip. Suddenly opening a chilled water isolation valve will also destabilize the chilled water DP control loop.

For stage up transitions during which one chiller is enabled while another is disabled, it is necessary to temporarily set the minimum flow bypass setpoint to that necessary to satisfy both the chiller to be enabled and the chiller to be disabled because the newly enabled chiller is brought online prior to disabling a currently operating chiller to avoid dropping the load.

Retain the following paragraph for water-cooled plants. Delete otherwise.

d. Start the next CW pump and/or change CW pump speed to that required of the new stage per 5.20.9 and after 10 seconds enable head pressure control for the chiller being enabled. Wait 30 seconds.

e. Slowly open CHW isolation valve of the chiller being enabled. Determine valve timing in the field as that required to prevent nuisance trips.

Slowly opening the chilled water isolation valve prevents a sudden disruption in flow through the active chiller.

f. Start the next stage chiller after the CHW isolation valve is fully open (as determined by end switch status, or nominal valve timing if end switches are not provided).

Retain the following paragraph if a smaller chiller is staged off while a larger chiller is staged on during any stage change (e.g., for plants with swing chillers).Delete otherwise.

g. For any stage change during which a smaller chiller is disabled and a larger chiller is enabled:

1. Wait 5 minutes for the newly enabled chiller to prove that is operating correctly (not faulted as defined in 5.1.15.5.b.1.ii), then shut off the smaller chiller.

2. When the controller of the smaller chiller being shut off indicates no request for chilled water flow or 3 minutes has elapsed, slowly close the chiller's CHW isolation valve to avoid a sudden change in flow through other operating chillers.

Retain the following paragraph for water-cooled plants. Delete otherwise.

3. When the controller of the smaller chiller being shut off indicates no request for condenser water flow or 3 minutes has elapsed, disable the chiller's head pressure control loop.

4. Change the minimum flow bypass setpoint to that appropriate for the new stage as indicated in 5.20.8.1.

h. Release the demand limit.

5.20.4.17. Whenever there is a stage-down command:

Retain the following paragraph if a smaller chiller is staged on while a larger chiller is staged off during any stage change (e.g., for plants with swing chillers). Delete otherwise.

a. For any stage change during which a smaller chiller is enabled and a larger chiller is disabled:

1. Command operating chillers to reduce demand to 75% of their current load or a percentage equal to current stage $OPLR_{MIN}$, whichever is greater. Wait until actual demand <80% of current load up to a maximum of 5 minutes before proceeding.

The above clause is recommended for applications where a sudden change in load may induce a chiller trip. This was commonly true of older chillers but has often proven unnecessary for modern machines with more robust capacity controls. Leave it if unsure.

2. Slowly change the minimum flow bypass setpoint to that appropriate for the stage transition as indicated in 5.20.8.3. After new setpoint is achieved, wait 1 minute to allow loop to stabilize.

3. Enable head pressure control for the chiller being enabled. Wait 30 seconds.

4. Slowly open CHW isolation valve of the smaller chiller being enabled. Determine valve timing in the field as that required to prevent nuisance trips.

5. Start the smaller chiller after its CHW isolation valve is fully open (as determined by end switch status, or nominal valve timing if end switches are not provided).

6. Wait 5 minutes for the newly enabled chiller to prove that it is operating correctly (not faulted as defined in 5.1.15.5.b.1.ii), then shut off the larger chiller and release the demand limit.

Stage down transitions during which one chiller is enabled while another is disabled require similar logic to stage up events since the chiller being enabled is brought online prior to disabling a currently operating chiller. This avoids dropping the load during staging transitions.

b. If staging down from any other stage, shut off the last stage chiller.

c. When the controller of the chiller being shut off indicates no request for chilled water flow or 3 minutes has elapsed, slowly close the chiller's CHW isolation valve to avoid a sudden change in flow through other operating chillers.

Retain the following paragraph for water-cooled plants. Delete otherwise.

d. When the controller of the chiller being shut off indicates no request for condenser water flow or 3 minutes has elapsed, disable the chiller's head pressure control loop. When the CW isolation/head pressure control valve is fully closed (as determined by end switch status, or nominal valve timing if end switches are not provided), shut off the last lag CW pump and/or change CW pump speed to that required of the new stage per 5.20.9.

e. Change the chilled water minimum flow bypass control setpoint to that appropriate for the new stage as indicated in 5.20.8.1.

Retain Clauses 5.20.4.18 and 5.20.4.19 for water-cooled primary-only parallel chiller plants with headered chilled water pumps and dedicated condenser water pumps. Delete otherwise.

5.20.4.18. Whenever there is a stage-up command:

a. Command operating chillers to reduce demand to 75% of their current load. Wait until actual demand <80% of current load up to a maximum of 5 minutes before proceeding.

The above clause is recommended for applications where a sudden change in load may induce a chiller trip. This was commonly true of older chillers but has often proven unnecessary for modern machines with more robust capacity controls. Leave it if unsure.

Retain the following paragraph if a smaller chiller is staged off while a larger chiller is staged on during any stage change (e.g., for plants with swing chillers). Delete otherwise.

b. For any stage change during which a smaller chiller is disabled and a larger chiller is enabled, slowly change the minimum flow bypass setpoint to that appropriate for the stage transition as indicated in 5.2.8.3. After new setpoint is achieved, wait 1 minute to allow loop to stabilize.

c. For any other stage change, reset the minimum flow bypass setpoint to that appropriate for the new stage as indicated in 5.20.8.1. After new setpoint is achieved, wait 1 minute to allow loop to stabilize.

If the bypass valve opens quickly, then the chiller load will suddenly drop and the chiller(s) could trip. Suddenly opening a chilled water isolation valve will also destabilize the chilled water DP control loop.

For stage up transitions during which one chiller is enabled while another is disabled, it is necessary to temporarily set the minimum flow bypass setpoint to that necessary to satisfy both the chiller to be enabled and the chiller to be disabled because the newly enabled chiller is brought online prior to disabling a currently operating chiller to avoid dropping the load.

d. Start the CW pump of the chiller to be enabled. Wait 30 seconds.

e. Slowly open CHW isolation valve of the chiller being enabled. Determine valve timing in the field as that required to prevent nuisance trips.

Slowly opening the chilled water isolation valve prevents a sudden disruption in flow through the active chiller.

f. Start the next stage chiller after the CHW isolation valve is fully open (as determined by end switch status, or nominal valve timing if end switches are not provided).

Retain the following paragraph if a smaller chiller is staged off while a larger chiller is staged on during any stage change (e.g., for plants with swing chillers). Delete otherwise.

g. For any stage change during which a smaller chiller is disabled and a larger chiller is enabled:

1. Wait 5 minutes for the newly enabled chiller to prove that is operating correctly (not faulted as defined in 5.1.15.5.b.1.ii), then shut off the smaller chiller.

2. When the controller of the smaller chiller being shut off indicates no request for chilled water flow or 3 minutes has elapsed, slowly close the chiller's CHW isolation valve to avoid a sudden change in flow through other operating chillers.

3. When the controller of the smaller chiller being shut off indicates no request for condenser water flow or 3 minutes has elapsed, shut off the chiller's CW pump.

4. Change the minimum flow bypass setpoint to that appropriate for the new stage as indicated in Paragraph 5.20.8 below.

h. Release the demand limit.

5.20.4.19. Whenever there is a stage-down command:

Retain the following paragraph if a smaller chiller is staged on while a larger chiller is staged off during any stage change (e.g., for plants with swing chillers). Delete otherwise.

a. For any stage change during which a smaller chiller is enabled and a larger chiller is disabled:

1. Command operating chillers to reduce demand to 75% of their current load or a percentage equal to current stage $OPLR_{MIN}$, whichever is greater. Wait until actual demand <80% of current load up to a maximum of 5 minutes before proceeding.

The above clause is recommended for applications where a sudden change in load may induce a chiller trip. This was commonly true of older chillers but has often proven unnecessary for modern machines with more robust capacity controls. Leave it if unsure.

2. Slowly change the minimum flow bypass setpoint to that appropriate for the stage transition as indicated in 5.20.8.3. After new setpoint is achieved, wait 1 minute to allow loop to stabilize.

3. Enable the CW pump of smaller chiller being enabled. Wait 30 seconds.

4. Slowly open CHW isolation valve of the smaller chiller being enabled. Determine valve timing in the field as that required to prevent nuisance trips.

5. Start the smaller chiller after its CHW isolation valve is fully open (as determined by end switch status, or nominal valve timing if end switches are not provided).

6. Wait 5 minutes for the newly enabled chiller to prove that is operating correctly (not faulted as defined in 5.1.15.5.b.1.ii), then shut off the larger chiller and release the demand limit.

Stage down transitions during which one chiller is enabled while another is disabled require similar logic to stage up events since the chiller to be enabled is brought online prior to disabling a currently operating chiller. This avoids dropping the load during staging transitions.

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b. If staging down from any other stage, shut off the last stage chiller.

c. When the controller of the chiller being shut off indicates no request for chilled water flow or 3 minutes has elapsed, slowly close the chiller's CHW isolation valve to avoid a sudden change in flow through other operating chillers.

d. When the controller of the chiller being shut off indicates no request for condenser water flow or 3 minutes has elapsed, shut off the chiller's CW pump.

e. Change the chilled water minimum flow bypass setpoint to that appropriate for the new stage as indicated in 5.20.8.1.

Retain Clauses 5.20.4.20 and 5.20.4.21 for water-cooled primary-only parallel chiller plants with dedicated chilled water pumps and headered condenser water pumps or air-cooled primary-only parallel chiller plants with dedicated chilled water pumps. Delete otherwise.

5.20.4.20. Whenever there is a stage-up command:

a. Command operating chillers to reduce demand to 75% of their current load. Wait until actual demand <80% of current load up to a maximum of 5 minutes before proceeding.

The above clause is recommended for applications where a sudden change in load may induce a chiller trip. This was commonly true of older chillers but has often proven unnecessary for modern machines with more robust capacity controls. Leave it if unsure.

Retain the following paragraph if a smaller chiller is staged off while a larger chiller is staged on during any stage change (e.g., for plants with swing chillers). Delete otherwise.

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b. For any stage change during which a smaller chiller is disabled and a larger chiller is enabled, slowly change the minimum flow bypass setpoint to that appropriate for the stage transition as indicated in 5.2.8.3. Wait 1 minute after setpoint has been achieved or primary CHW pump speed has reached 100%.

c. For any other stage change, reset the minimum flow bypass setpoint to that appropriate for the new stage as indicated in 5.20.8.1. Wait 1 minute after setpoint has been achieved or primary CHW pump speed has reached 100%.

If the bypass valve opens quickly, then the chiller load will suddenly drop and the chiller(s) could trip. Suddenly opening a chilled water isolation valve will also destabilize the chilled water DP control loop.

For stage up transitions during which one chiller is enabled while another is disabled, it is necessary to temporarily set the minimum flow bypass setpoint to that necessary to satisfy both the chiller to be enabled and the chiller to be disabled because the newly enabled chiller is brought online prior to disabling a currently operating chiller to avoid dropping the load.

Retain the following paragraph for water-cooled plants. Delete otherwise.

d. Start the next CW pump and/or change CW pump speed to that required of the new stage per 5.20.9 and after 10 seconds enable head pressure control for the chiller being enabled. Wait 30 seconds.

e. Enable and slowly ramp up the CHW pump of the chiller being enabled to match the other operating CHW pump(s). Determine ramp rate in the field as that required to prevent nuisance trips.

Slowly ramping the CHW pump prevents a sudden disruption in flow through the active chiller(s).

f. Start the next stage chiller after all operating CHW pumps are at the same speed.

Retain the following paragraph if a smaller chiller is staged off while a larger chiller is staged on during any stage change (e.g., for plants with swing chillers). Delete otherwise.

g. For any stage change during which a smaller chiller is disabled and a larger chiller is enabled:

   1. Wait 5 minutes for the newly enabled chiller to prove that is operating correctly (not faulted as defined in 5.1.15.5.b.1.ii), then shut off the smaller chiller.

   2. When the controller of the smaller chiller being disabled indicates no request for chilled water flow or 3 minutes has elapsed, slowly ramp down the chiller's CHW pump to avoid a sudden change in flow through other operating chillers. Turn off the CHW pump once it reaches 25% speed.

Retain the following paragraph for water-cooled plants. Delete otherwise.

   3. When the controller of the smaller chiller being shut off indicates no request for condenser water flow or 3 minutes has elapsed, disable the chiller's head pressure control loop.

   4. Change the minimum flow bypass setpoint to that appropriate for the new stage as indicated in Paragraph 5.20.8.1 below.

h. Release the demand limit.

5.20.4.21. Whenever there is a stage-down command:

Retain the following paragraph if a smaller chiller is staged on while a larger chiller is staged off during any stage change (e.g., for plants with swing chillers). Delete otherwise.

a. For any stage change during which a smaller chiller is enabled and a larger chiller is disabled:

   1. Command operating chillers to reduce demand to 75% of their current load or a percentage equal to current stage $OPLR_{MIN}$, whichever is greater. Wait until actual demand <80% of current load up to a maximum of 5 minutes before proceeding.

The above clause is recommended for applications where a sudden change in load may induce a chiller trip. This was commonly true of older chillers but has often proven unnecessary for modern machines with more robust capacity controls. Leave it if unsure.

2. Slowly change the minimum flow bypass setpoint to that appropriate for the stage transition as indicated in 5.20.8.3. Wait 1 minute after setpoint has been achieved or primary CHW pump speed has reached 100%.

Retain the following paragraph for water-cooled plants. Delete otherwise.

3. Enable head pressure control for the chiller being enabled. Wait 30 seconds.

4. Enable and slowly ramp up the CHW pump of the smaller chiller being enabled to match the other operating CHW pump(s). Determine ramp rate in the field as that required to prevent nuisance trips.

5. Start the smaller chiller after all operating CHW pumps are at the same speed.

6. Wait 5 minutes for the newly enabled chiller to prove that is operating correctly (not faulted as defined in 5.1.15.5.b.1.ii), then shut off the larger chiller and release the demand limit.

Stage down transitions during which one chiller is enabled while another is disabled require similar logic to stage up events since the chiller to be enabled is brought online prior to disabling a currently operating chiller. This avoids dropping the load during staging transitions.

b. If staging down from any other stage, shut off the last stage chiller.

c. When the controller of the chiller being disabled indicates no request for chilled water flow or 3 minutes has elapsed, slowly ramp down the chiller’s CHW pump to avoid a sudden change in flow through other operating chillers. Turn off the CHW pump once it reaches 25% speed.

Retain the following paragraph for water-cooled plants. Delete otherwise.

d. When the controller of the chiller being shut off indicates no request for condenser water flow or 3 minutes has elapsed, disable the chiller's head pressure control loop. When the CW isolation/head pressure control valve is fully closed (as determined by end switch status, or nominal valve timing if end switches are not provided), shut off the last lag CW pump and/or change CW pump speed to that required of the new stage per 5.20.9.

e. Change the chilled water minimum flow bypass setpoint to that appropriate for the new stage as indicated in 5.20.8.1.

Retain Clauses 5.20.4.22 and 5.20.4.23 for water-cooled primary-only parallel chiller plants with dedicated chilled water pumps and dedicated condenser water pumps. Delete otherwise.

5.20.4.22. Whenever there is a stage-up command:

a. Command operating chillers to reduce demand to 75% of their current load. Wait until actual demand <80% of current load up to a maximum of 5 minutes before proceeding.

The above clause is recommended for applications where a sudden change in load may induce a chiller trip. This was commonly true of older chillers but has often proven unnecessary for modern machines with more robust capacity controls. Leave it if unsure.

Retain the following paragraph if a smaller chiller is staged off while a larger chiller is staged on during any stage change (e.g., for plants with swing chillers). Delete otherwise.

b. For any stage change during which a smaller chiller is disabled and a larger chiller is enabled, slowly change the minimum flow bypass setpoint to that appropriate for the stage transition as indicated in 5.2.8.3. Wait 1 minute after setpoint has been achieved or primary CHW pump speed has reached 100%.

c. For any other stage change, reset the minimum flow bypass setpoint to that appropriate for the new stage as indicated in 5.20.8.1. Wait 1 minute after setpoint has been achieved or primary CHW pump speed has reached 100%.

If the bypass valve opens quickly, then the chiller load will suddenly drop and the chiller(s) could trip. Suddenly opening a chilled water isolation valve will also destabilize the chilled water DP control loop.

For stage up transitions during which one chiller is enabled while another is disabled, it is necessary to temporarily set the minimum flow bypass setpoint to that necessary to satisfy both the chiller to be enabled and the chiller to be disabled because the newly enabled chiller is brought online prior to disabling a currently operating chiller to avoid dropping the load.

d. Start the CW pump of the chiller to be enabled. Wait 30 seconds.

e. Enable and slowly ramp up the CHW pump of the chiller to be enabled to match the other operating CHW pump(s). Determine ramp rate in the field as that required to prevent nuisance trips.

Slowly ramping the CHW pump prevents a sudden disruption in flow through the active chiller(s).

f. Start the next stage chiller after all operating CHW pumps are at the same speed.

Retain the following paragraph if a smaller chiller is staged off while a larger chiller is staged on during any stage change (e.g., for plants with swing chillers). Delete otherwise.

g. For any stage change during which a smaller chiller is disabled and a larger chiller is enabled:

   1. Wait 5 minutes for the newly enabled chiller to prove that is operating correctly (not faulted as defined in 5.1.15.5.b.1.ii), then shut off the smaller chiller.

   2. When the controller of the smaller chiller being disabled indicates no request for chilled water flow or 3 minutes has elapsed, slowly ramp down the chiller's CHW pump to avoid a sudden change in flow through other operating chillers. Turn off the CHW pump once it reaches 25% speed.

   3. When the controller of the smaller chiller being shut off indicates no request for condenser water flow or 3 minutes has elapsed, shut off the chiller's CW pump.

   4. Change the minimum flow bypass setpoint to that appropriate for the new stage as indicated in Paragraph 0 below.

h. Release the demand limit.

5.20.4.23. Whenever there is a stage-down command:

Retain the following paragraph if a smaller chiller is staged on while a larger chiller is staged off during any stage change (e.g., for plants with swing chillers). Delete otherwise.

a. For any stage change during which a smaller chiller is enabled and a larger chiller is disabled:

1. Command operating chillers to reduce demand to 75% of their current load or a percentage equal to current stage $OPLR_{MIN}$, whichever is greater. Wait until actual demand <80% of current load up to a maximum of 5 minutes before proceeding.

The above clause is recommended for applications where a sudden change in load may induce a chiller trip. This was commonly true of older chillers but has often proven unnecessary for modern machines with more robust capacity controls. Leave it if unsure.

2. Slowly change the minimum flow bypass setpoint to that appropriate for the stage transition as indicated in 5.20.8.3. Wait 1 minute after setpoint has been achieved or primary CHW pump speed has reached 100%.

3. Enable the CW pump of smaller chiller being enabled. Wait 30 seconds.

4. Enable and slowly ramp up the CHW pump of the smaller chiller being enabled to match the other operating CHW pump(s). Determine ramp rate in the field as that required to prevent nuisance trips.

5. Start the smaller chiller after all operating CHW pumps are at the same speed.

6. Wait 5 minutes for the newly enabled chiller to prove that is operating correctly (not faulted as defined in 5.1.15.5.b.1.ii), then shut off the larger chiller and release the demand limit.

Stage down transitions during which one chiller is enabled while another is disabled require similar logic to stage up events since the chiller to be enabled is brought online prior to disabling a currently operating chiller. This avoids dropping the load during staging transitions.

b. If staging down from any other stage, shut off the last stage chiller.

c. When the controller of the chiller being disabled indicates no request for chilled water flow or 3 minutes has elapsed, slowly ramp down the chiller's CHW pump to avoid a sudden change in flow through other operating chillers. Turn off the CHW pump once it reaches 25% speed.

d. When the controller of the chiller being shut off indicates no request for condenser water flow or 3 minutes has elapsed, shut off the chiller's CW pump.

e. Change the chilled water minimum flow bypass setpoint to that appropriate for the new stage as indicated in 5.20.8.1.

Retain Clauses 5.20.4.24 and 5.20.4.25 for water-cooled primary-secondary parallel chiller plants with headered primary CHW pumps and headered CW pumps or air-cooled primary-secondary parallel plants with headered CHW pumps. Delete otherwise.

5.20.4.24. Whenever there is a stage-up command:

Retain the following paragraph for water-cooled plants. Delete otherwise.

a. Start the next CW pump and/or change CW pump speed to that required of the new stage per Section 5.20.9 and after 10 seconds enable head pressure control for the chiller being enabled. Wait 30 seconds.

b. Start the next primary CHW pump and after 10 seconds open the CHW isolation valve of the chiller being enabled.

c. Start the next stage chiller after the CHW isolation valve is fully open (as determined by end switch status, or nominal valve timing if end switches are not provided).

Retain the following paragraph if a smaller chiller is staged off while a larger chiller is staged on during any stage change (e.g., for plants with swing chillers). Delete otherwise.

d. For any stage change during which a smaller chiller is disabled and a larger chiller is enabled:

1. Wait 5 minutes for the newly enabled chiller to prove that is operating correctly (not faulted as defined in 5.1.15.5.b.1.ii), then shut off the smaller chiller.

2. When the controller of the smaller chiller being shut off indicates no request for chilled water flow or 3 minutes has elapsed, close the chiller's CHW isolation valve. Wait 15 seconds then shut off the last stage primary CHW pump.

Retain the following paragraph for water-cooled plants. Delete otherwise.

3. When the controller of the smaller chiller being shut off indicates no request for condenser water flow or 3 minutes has elapsed, disable the chiller's head pressure control loop.

5.20.4.25. Whenever there is a stage-down command:

Retain the following paragraph if a smaller chiller is staged on while a larger chiller is staged off during any stage change (e.g., for plants with swing chillers). Delete otherwise.

a. For any stage change during which a smaller chiller is enabled and a larger chiller is disabled:

Retain the following paragraph for water-cooled plants. Delete otherwise.

1. Enable head pressure control of the chiller being enabled. Wait 30 seconds.

2. Start the next primary CHW pump and after 10 seconds open the CHW isolation valve of the chiller being enabled.

3. Start the smaller stage chiller after the CHW isolation valve is fully open (as determined by end switch status, or nominal valve timing if end switches are not provided).

4. Wait 5 minutes for the newly enabled chiller to prove that is operating correctly (not faulted as defined in 5.1.15.5.b.1.ii), then shut off the larger chiller.

b. For any other stage change, shut off the last stage chiller.

c. When the controller of the chiller being shut off indicates no request for chilled water flow or 3 minutes has elapsed, close the chiller's CHW isolation valve. Wait 15 seconds then shut off the last stage primary CHW pump.

Retain the following paragraph for water-cooled plants. Delete otherwise.

d. When the controller of the chiller being shut off indicates no request for condenser water flow or 3 minutes has elapsed, disable the chiller's head pressure control loop. When the CW isolation/head pressure control valve is fully closed (as determined by end switch status, or nominal valve timing if end switches are not provided), shut off the last lag CW pump and/or change CW pump speed to that required of the new stage per 5.20.9.

Retain clause 5.20.4.26 and 5.20.4.27 for water-cooled primary-secondary parallel chiller plants with headered primary CHW pumps and dedicated CW pumps. Delete otherwise.

5.20.4.26. Whenever there is a stage-up command:

a. Start the CW pump of the chiller being enabled. Wait 30 seconds.

b. Start the next primary CHW pump and after 10 seconds open the CHW isolation valve of the chiller being enabled.

c. Start the next stage chiller after the CHW isolation valve is fully open (as determined by end switch status, or nominal valve timing if end switches are not provided).

Retain the following paragraph if a smaller chiller is staged off while a larger chiller is staged on during any stage change (e.g., for plants with swing chillers). Delete otherwise.

d. For any stage change during which a smaller chiller is disabled and a larger chiller is enabled:

1. Wait 5 minutes for the newly enabled chiller to prove that is operating correctly (not faulted as defined in 5.1.15.5.b.1.ii), then shut off the smaller chiller.

2. When the controller of the smaller chiller being shut off indicates no request for chilled water flow or 3 minutes has elapsed, close the chiller's CHW isolation valve. Wait 15 seconds then shut off the last stage primary CHW pump.

3. When the controller of the smaller chiller being shut off indicates no request for condenser water flow or 3 minutes has elapsed, shut off the chiller's CW pump.

5.20.4.27. Whenever there is a stage-down command:

Retain the following paragraph if a smaller chiller is staged on while a larger chiller is staged off during any stage change (e.g., for plants with swing chillers). Delete otherwise.

a. For any stage change during which a smaller chiller is enabled and a larger chiller is disabled:

1. Enable the CW pump of the smaller chiller being enabled. Wait 30 seconds.

2. Start the next primary CHW pump and after 10 seconds open the CHW isolation valve of the chiller being enabled.

3. Start the smaller stage chiller after the CHW isolation valve is fully open (as determined by end switch status, or nominal valve timing if end switches are not provided).

4. Wait 5 minutes for the newly enabled chiller to prove that is operating correctly (not faulted as defined in 5.1.15.5.b.1.ii), then shut off the larger chiller.

b. For any other stage change, shut off the last stage chiller.

c. When the controller of the chiller being shut off indicates no request for chilled water flow or 3 minutes has elapsed, close the chiller's CHW isolation valve. Wait 15 seconds then shut off the last stage primary CHW pump.

d. When the controller of the chiller being shut off indicates no request for condenser water flow or 3 minutes has elapsed, shut off the chiller's CW pump.

Retain Clause 5.20.4.28 and 5.20.4.29 for water-cooled primary-secondary parallel chiller plants with dedicated primary CHW pumps and headered CW pumps or air-cooled primary-secondary parallel chiller plants with dedicated primary CHW pumps. Delete otherwise.

5.20.4.28. Whenever there is a stage-up command:

Retain the following paragraph for water-cooled plants. Delete otherwise.

a. Start the next CW pump and/or change CW pump speed to that required of the new stage per 5.20.9 and after 10 seconds enable head pressure control for the chiller being enabled. Wait 30 seconds.

b. Start the primary CHW pump of the chiller being enabled. Wait 30 seconds.

c. Start the next stage chiller.

Retain the following paragraph if a smaller chiller is staged off while a larger chiller is staged on during any stage change (e.g., for plants with swing chillers). Delete otherwise.

d. For any stage change during which a smaller chiller is disabled and a larger chiller is enabled:

1. Wait 5 minutes for the newly enabled chiller to prove that is operating correctly (not faulted as defined in 5.1.15.5.b.1.ii), then shut off the smaller chiller.

2. When the controller of the chiller being shut off indicates no request for chilled water flow or 3 minutes has elapsed, shut off the chiller's primary CHW pump.

Retain the following paragraph for water-cooled plants. Delete otherwise.

3. When the controller of the smaller chiller being shut off indicates no request for condenser water flow or 3 minutes has elapsed, disable the chiller's head pressure control loop.

5.20.4.29. Whenever there is a stage-down command:

Retain the following paragraph if a smaller chiller is staged on while a larger chiller is staged off during any stage change (e.g., for plants with swing chillers). Delete otherwise.

a. For any stage change during which a smaller chiller is enabled and a larger chiller is disabled:

Retain the following paragraph for water-cooled plants. Delete otherwise.

1. Enable head pressure control of the chiller being enabled. Wait 30 seconds.

2. Start the primary CHW pump of the chiller being enabled. Wait 30 seconds.

3. Start the smaller chiller.

4. Wait 5 minutes for the newly enabled chiller to prove that is operating correctly (not faulted as defined in 5.1.15.5.b.1.ii), then shut off the larger chiller.

b. For any other stage change, shut off the last stage chiller.

c. When the controller of the chiller being shut off indicates no request for chilled water flow or 3 minutes has elapsed, shut off the chiller's primary CHW pump.

Retain the following paragraph for water-cooled plants. Delete otherwise.

d. When the controller of the chiller being shut off indicates no request for condenser water flow or 3 minutes has elapsed, disable the chiller's head pressure control loop. When the CW isolation/head pressure control valve is fully closed (as determined by end switch status, or nominal valve timing if end switches are not provided), shut off the last lag CW pump and/or change CW pump speed to that required of the new stage per 5.20.9.

Retain Clause 5.20.4.30 and 5.20.4.31 for water-cooled primary-secondary parallel chiller plants with dedicated primary CHW pumps and dedicated CW pumps. Delete otherwise.

5.20.4.30. Whenever there is a stage-up command:

a. Start the CW pump of the chiller being enabled. Wait 30 seconds.

b. Start the primary CHW pump of the chiller being enabled. Wait 30 seconds.

c. Start the next stage chiller.

Retain the following paragraph if a smaller chiller is staged off while a larger chiller is staged on during any stage change (e.g., for plants with swing chillers). Delete otherwise.

d. For any stage change during which a smaller chiller is disabled and a larger chiller is enabled:

1. Wait 5 minutes for the newly enabled chiller to prove that is operating correctly (not faulted as defined in 5.1.15.5.b.1.ii), then shut off the smaller chiller.

2. When the controller of the chiller being shut off indicates no request for chilled water flow or 3 minutes has elapsed, shut off the chiller's primary CHW pump.

3. When the controller of the smaller chiller being shut off indicates no request for condenser water flow or 3 minutes has elapsed, shut off the chiller's CW pump.

5.20.4.31. Whenever there is a stage-down command:

Retain the following paragraph if a smaller chiller is staged on while a larger chiller is staged off during any stage change (e.g., for plants with swing chillers). Delete otherwise.

a. For any stage change during which a smaller chiller is enabled and a larger chiller is disabled:

1. Enable the CW pump of the smaller chiller being enabled. Wait 30 seconds.

2. Start the primary CHW pump of the chiller being enabled. Wait 30 seconds.

3. Start the smaller chiller.

4. Wait 5 minutes for the newly enabled chiller to prove that is operating correctly (not faulted as defined in 5.1.15.5.b.1.ii), then shut off the larger chiller.

b. For any other stage change, shut off the last stage chiller.

c. When the controller of the chiller being shut off indicates no request for chilled water flow or 3 minutes has elapsed, shut off the chiller's primary CHW pump.

d. When the controller of the chiller being shut off indicates no request for condenser water flow or 3 minutes has elapsed, shut off the chiller's CW pump.

Retain Clauses 5.20.4.32 and 5.20.4.33 for water-cooled primary-only series chiller plants with headered CW pumps or air-cooled primary-only series chiller plants. Delete otherwise.

5.20.4.32. Whenever there is a stage-up command:

a. If the chiller to be started is the upstream chiller, command the operating chiller to reduce demand to 75% of its current load. Wait until actual demand <80% of current load up to a maximum of 5 minutes before proceeding.

b. If the chiller to be started is the downstream chiller, ramp the CHWST setpoint of the operating chiller from the current plant CHWST setpoint to the average of the current plant CHWST setpoint and the current CHW return temperature over 5 minutes.

Retain the following paragraph for water-cooled plants. Delete otherwise.

c. Start the next CW pump and/or change CW pump speed to that required of the new stage per 5.20.9 and after 10 seconds enable head pressure control for the chiller being enabled. Wait 30 seconds.

d. Slowly close CHW bypass valve of the chiller that is to be started. Determine valve timing in the field as that required to prevent nuisance trips.

e. Start the next stage chiller after the CHW bypass valve is fully shut (as determined by end switch status, or nominal valve timing if end switches are not provided).

1. If the newly enabled chiller is the upstream chiller, set its CHWST setpoint to the average of the current plant CHWST setpoint and current CHW return temperature.

2. If the newly enabled chiller is the downstream chiller, set its CHWST setpoint equal to the plant CHWST setpoint.

f. Release the demand limit on the lead chiller (if enabled).

5.20.4.33. Whenever there is a stage-down command:

a. Shut off the last stage chiller.

b. If the disabled chiller is the downstream chiller, reset the upstream chiller's CHWST setpoint to the current plant CHWST setpoint (do not ramp).

c. When the controller of the chiller being shut off indicates no request for chilled water flow or 3 minutes has elapsed, slowly open the chiller's CHW bypass valve to avoid a sudden change in flow through the other operating chiller.

Retain the following paragraph for water-cooled plants. Delete otherwise.

d. When the controller of the chiller being shut off indicates no request for condenser water flow or 3 minutes has elapsed, disable the chiller's head pressure control loop. When the CW isolation/head pressure control valve is fully closed (as determined by end switch status, or nominal valve timing if end switches are not provided), shut off the last lag CW pump and/or change CW pump speed to that required of the new stage per 5.20.9.

Retain Clauses 5.20.4.34 and 5.20.4.35 for water-cooled primary-only series chiller plants with dedicated CW pumps. Delete otherwise.

5.20.4.34. Whenever there is a stage-up command:

a. If the chiller to be started is the upstream chiller, command the operating chiller to reduce demand to 75% of its current load. Wait until actual demand <80% of current load up to a maximum of 5 minutes before proceeding.

b. If the chiller to be started is the downstream chiller, ramp the CHWST setpoint of the operating chiller from the current plant CHWST setpoint to the average of the current plant CHWST setpoint and the current CHW return temperature over 5 minutes.

c. Start the CW pump of the chiller to be enabled. Wait 30 seconds.

d. Slowly close CHW bypass valve of the chiller that is to be started. Determine valve timing in the field as that required to prevent nuisance trips.

e. Start the next stage chiller after the CHW bypass valve is fully shut (as determined by end switch status, or nominal valve timing if end switches are not provided).

1. If the newly enabled chiller is the upstream chiller, set its CHWST setpoint to the average of the current plant CHWST setpoint and current CHW return temperature per 5.20.5.7.

2. If the newly enabled chiller is the downstream chiller, set its CHWST setpoint equal to the plant CHWST setpoint.

f. Release the demand limit on the lead chiller (if enabled).

5.20.4.35. Whenever there is a stage-down command:

a. Shut of the last stage chiller.

b. If the disabled chiller is the downstream chiller, reset the upstream chiller's CHWST setpoint to the current plant CHWST setpoint (do not ramp).

c. When the controller of the chiller being shut off indicates no request for chilled water flow or 3 minutes has elapsed, slowly open the chiller's CHW bypass valve to avoid a sudden change in flow through the other operating chiller.

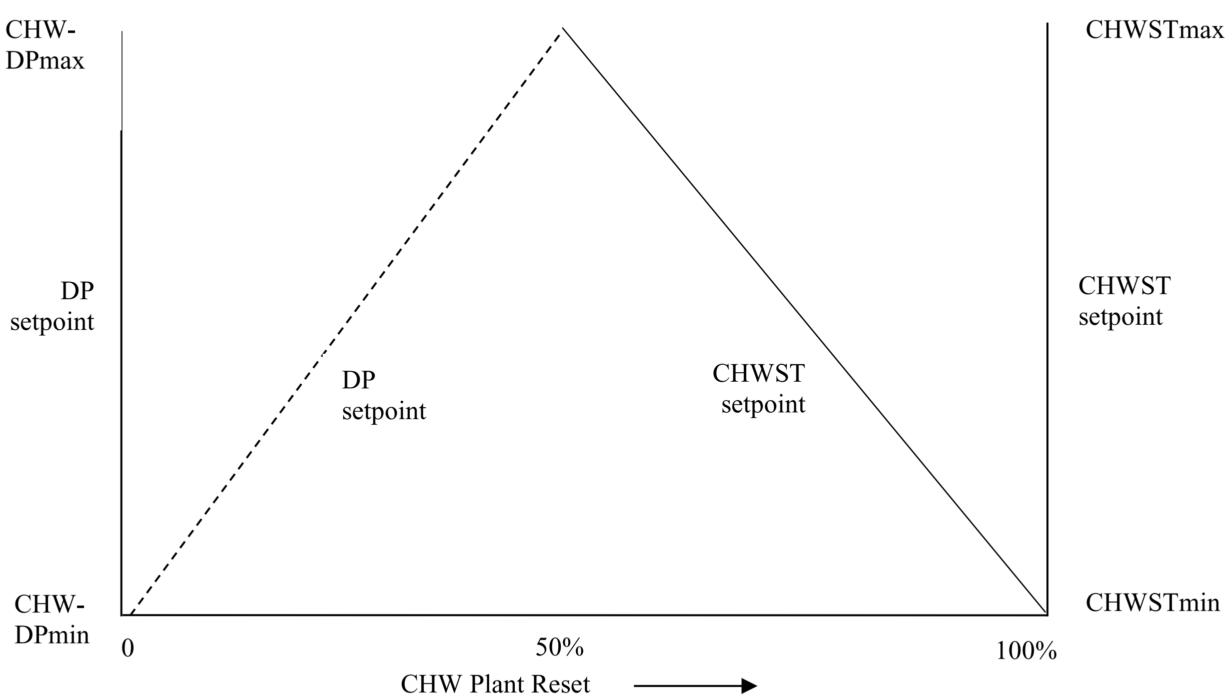
d. When the controller of the chiller being shut off indicates no request for condenser water flow or 3 minutes has elapsed, shut off the chiller's CW pump.

5.20.5. Chilled Water Plant Reset

5.20.5.1. CHWSTmin in the following logic shall be the lowest CHWSTminX of chillers in the plant.

Retain the following clause for primary-only and primary-secondary systems serving differential pressure controlled pumps. Delete otherwise.

5.20.5.2. Differential Pressure Controlled Loops: Chilled water supply temperature setpoint CHWSTsp and pump 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.

Engineers may nonetheless adjust the CHW Plant Reset loop mapping based on unique project constraints. For plants with very low design CHW delta-Ts (<12°F) and high pump heads (>120 ft) it may be advisable to overlap the resets—e.g., reset DP setpoint from 0% to 75% loop output and CHWST setpoint from 25% to 100% loop output—instead of fully resetting CHWST setpoint up before beginning to lower resetting pump DP setpoint down.

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

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

c. CHW Plant Reset variable shall be reset using Trim & Respond logic with the following parameters:

Variable	Value
Device	Any CHW Pump Distribution Loop
SP_0	100%
SP_{min}	0%
SP_{max}	100%
T_d	15 minutes
T	5 minutes
I	2
R	Cooling CHWST Reset Requests
SP_{trim}	-2%
SP_{res}	+3%
$SP_{res\text{-}max}$	+7%

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.

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

e. 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.

Retain the following paragraph for primary-secondary plants serving more than one set of differential pressure controlled pumps. Delete otherwise.

f. A unique instance of the above reset shall be used for each set of differential pressure controlled secondary pumps.

1. Chilled Water Reset Requests from all loads served by a set of pumps shall be directed to those pumps' reset loop only.

2. The DP setpoint output from each reset shall be used in the DP control loop for the associated set of pumps only (i.e., the DP setpoint will not change for any other DP control loops).

Retain the following paragraph for plants where more than one remote DP sensor serves a given set of primary or secondary pumps.

g. Where more than one remote DP sensor serves a given set of primary or secondary pumps, remote DP setpoints for all remote sensors serving those pumps shall increase in unison. Note: if remote sensors have different CHW-DPmax values, then the amount each DP setpoint changes per percent loop output will differ.

Retain the following clause for Primary-only CHW plants serving a single large load (typically a very large air handler). Delete otherwise.

5.20.5.3. CHWST setpoint shall be reset as a function of the air handler SAT control loop output. Refer to air handler sequences.

When a chilled water plant serves a single very large load, such as a massive custom air handler, SAT is often controlled by directly resetting CHWST setpoint. No DP reset is needed since there are no control valves in the system.

Retain the following two clauses for primary-secondary systems where there are any coil pumps. Delete otherwise.

5.20.5.4. Coil Pumped Loops: Chilled water supply temperature setpoint, CHWSTsp, shall be reset using Trim & Respond logic with the following parameters:

Variable	Value
Device	Any CHW Pump
SP_0	CHWSTmin
SP_{min}	CHWSTmin
SP_{max}	60°F
T_d	15 minutes
T	5 minutes
I	2
R	Cooling CHWST Reset Requests
SP_{trim}	+0.75°F
SP_{res}	-1°F
$SP_{res\text{-}max}$	-2.5°F

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.

5.20.5.5. A unique instance of the above reset shall be used for each set of coil pumps.

Retain the following clause if the plant has multiple reset loops. Delete otherwise.

5.20.5.6. The CHWST setpoint used at the plant shall be the lowest value output from each of the active reset loops.

Retain the following two clauses for series chiller plants. Delete otherwise.

5.20.5.7. When only one chiller is enabled, CHWST setpoint shall be the setpoint resulting from the plant reset loop(s).

5.20.5.8. When the upstream and downstream machines are enabled:

a. Downstream chiller CHWST setpoint shall be the setpoint resulting from the plant reset loop(s).

b. Upstream chiller CHWST setpoint shall be the 5-minute rolling average of the following calculation:

$$\mathrm{CWHST}_{\mathrm{upstream}} = CHWRT - (CHWRT - CHWSTsp_{downstream}) * \frac{QchX_{upstream}}{QchX_{upstream} + QchX_{downstream}}$$

Using a rolling average avoids sudden fluctuations in chiller setpoint that may induce plant instability. Weighting the setpoint by the design capacity ratio of the series chillers improves efficiency when the upstream chiller is selected to provide more of the load. The efficiency of even identical chillers in series can be optimized by shifting load to the upstream chiller which is more efficient due to the warmer CHWST. This is usually determined by iteratively varying this setpoint to minimize combined chiller power using chiller selection software.

5.20.6. Primary Chilled Water Pumps

Retain the following clause for plants with headered primary chilled water pumps. Delete otherwise.

5.20.6.1. Primary CHW pumps shall be lead/lag controlled per Paragraph 5.1.15.3.

Retain the following clause for plants with parallel chillers, headered primary chilled water pumps, and without a waterside economizer. Delete otherwise.

5.20.6.2. Enable lead primary CHW pump when any chiller CHW isolation valve is commanded open. Disable the lead primary CHW pump when all chiller CHW isolation valves are commanded closed.

Retain the following clause for plants with parallel chillers, headered primary chilled water pumps, and a waterside economizer. Delete otherwise.

5.20.6.3. Enable lead primary CHW pump when any chiller CHW isolation valve is commanded open or WSE is enabled. Disable the lead primary CHW pump when all chiller CHW isolation valves are commanded closed and WSE is disabled.

Retain the following clause for plants with series chillers and without a waterside economizer. Delete otherwise.

5.20.6.4. Enable lead primary CHW pump when any chiller CHW isolation valve is commanded closed. Disable the lead primary CHW pump when all chiller CHW isolation valves are commanded open.

Retain the following clause for plants with series chillers and a waterside economizer. Delete otherwise.

5.20.6.5. Enable lead primary CHW pump when any chiller CHW isolation valve is commanded closed or WSE is enabled. Disable the lead primary CHW pump when all chiller CHW isolation valves are commanded open and WSE is disabled.

Retain the following clause for plants with dedicated primary chilled water pumps. Delete otherwise.

Where chillers have a CHW request network point, consider increasing the pump disable delay to 10 minutes to ensure that flow is not cut off too soon. Where chillers do not have this point (e.g., older chillers without network interfaces), the default delay is appropriate.

5.20.6.6. Enable lead primary CHW pump when the lead chiller is required to run, but prior to the chiller being enabled. Disable the lead CHW pump when the lead chiller is disabled and either the lead chiller has been proven off for 3 minutes or is not requesting chilled water flow.

Retain the following clause for primary-only plants with headered variable speed primary pumps using differential pressure pump speed control. Delete otherwise.

5.20.6.7. CHW pumps shall be staged as a function of CHWFR, the ratio of current chilled water flow, $FLOW_P$, to design primary pump flow, PCHWF_{design}. and the number of pumps, N-PCHWP, that operate at design conditions. Pumps are assumed to be equally sized.

$$\text{CHWFR} = \frac{FLOW_P}{PCHWF_{design}}$$

Flow is used, as opposed to speed, to keep the chilled water pumps operating near 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 curves). If desired, the stage down flow point can be offset slightly below the stage up point to prevent cycling between pump stages in applications with highly variable loads.

a. Start the next lag pump whenever the following is true for 10 minutes:

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

b. Shut off the last lag pump whenever the following is true for 10 minutes:

$$\text{CHWFR} \leq \frac{Number\ of\ Operating\ Pumps - 1}{N} - .03$$

Retain the following two clauses for primary-only plants where the remote DP sensor(s) is hardwired to the plant controller. Delete otherwise.

5.20.6.8. 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.

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

Retain the following three clauses for primary-only plants 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.

5.20.6.10. Remote 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 primary loop DP sensor hardwired to the plant controller. Reset local DP from CHW-DPmin psi at 0% loop output to LocalCHW-DPmax at 100% loop output.

5.20.6.11. When any pump is proven on, pump speed will be controlled by a reverse acting PID loop maintaining the local primary DP signal at the DP setpoint output from the remote sensor control loop. All pumps receive the same speed signal.

5.20.6.12. 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 the 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 CHW 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 two clauses for primary-secondary plants and primary-only plants where primary pump speed is not controlled to maintain differential pressure. Delete otherwise.

5.20.6.13. The number of operating primary chilled water pumps shall match the number of operating chillers.

5.20.6.14. See 5.20.4 for primary chilled water pump staging sequence relative to chiller stage-up and stage-down events.

Retain the following clause for primary-only plants and primary-secondary plants with variable speed primary pumps that are intended to operate at a fixed speed. Delete otherwise.

5.20.6.15. Pump speed shall be Ch-MaxPriPumpSpdStage as determined by the balancer as that necessary to provide design flow, CHW-DesFlowX through all chillers operating in the stage.

The above scenario—variable speed pumps operated at a constant speed—most commonly applies to constant flow primary-only plants. For example, a plant serving only one or two very large air handlers may use this scheme.

Retain the following clause for variable primary-variable secondary plants with primary and secondary loop flow meters. Delete otherwise.

5.20.6.16. Primary pump speed shall be reset by a reverse acting PID loop maintaining flow through the decoupler, as measured by the primary flowrate less secondary flowrate, at 5% of PCHWFdesign. Loop output shall be mapped from CH-MinPriPumpSpdStage to 100% speed in proportion to loop output from 0% to 100%.

Maintaining slightly more than 0 gpm through the bypass avoids the risk of secondary recirculation caused by any control loop instability.

Retain the following clause for variable primary-variable secondary plants with a flow meter in the decoupler. Delete otherwise.

5.20.6.17. Primary pump speed shall be reset by a reverse acting PID loop maintaining flow through the decoupler flow meter at 5% of PCHWFdesign, where positive flow indicates flow from the supply to the return. Loop output shall be mapped from CH-MinPriPumpSpdStage to 100% speed in proportion to loop output from 0% to 100%.

Maintaining slightly more than 0 gpm through the bypass avoids the risk of secondary recirculation caused by any control loop instability.

Retain the following two clauses for variable primary-variable secondary plants without flow meters from which to deduce decoupler flow. Delete otherwise.

5.20.6.18. Primary Pump Speed Reset Requests shall be generated based on the difference (” T) between secondary CHW supply temperature and primary CHW supply temperature upstream of the decoupler.

a. If ” T exceeds 2°F, send 2 requests until ” T is less than 1.2°F.

b. Else if ” T exceeds 1°F, send 1 request until ” T is less than 0.2°F.

c. Else send 0 requests.

Using supply temperature sensors to generate requests is preferable to using return temperature sensors because it allows for a quick response to a sudden change in secondary flow (i.e., secondary supply temperature exceeding primary supply temperature by a large margin). If return temperature sensors are used, it is only possible to know that secondary recirculation is occurring when primary and secondary return temperatures match, but the degree of recirculation is unknown.

Where dynamic changes in secondary flow are expected, e.g., for plants with only a few large coils or pumped coils, then more request levels can be defined as needed, but control using one of the preceding flow matching strategies is preferred.

Retain the following paragraph where the primary loop does not have a single CHWST sensor that measures the combined supply flow of all chillers. See schematics in Informative Appendix A for examples.

d. Primary CHW supply temperature used in the request logic shall be the weighted average supply temperature of all chillers proven on. Temperatures shall be weighted by design chiller flowrates.

The above clause assumes that flows through the chillers are balanced proportional to design.

5.20.6.19. Pump speed of all primary CHW pumps proven on shall be reset using Trim & Respond logic with the following parameters:

Variable	**Value**
Device	Any primary pump proven on
SP_0	100%
SP_{min}	CH-MinPriPumpSpdStage
SP_{max}	100%
T_d	15 minutes
T	2 minutes
I	0
R	Primary Pump Speed Reset Requests
SP_{trim}	-2%
SP_{res}	+3%
$SP_{res-max}$	+6%

Delete Section 5.20.7. for Primary-only plants. Where multiple secondary loops with differing configurations exist, create a unique copy of 5.20.7 for each.

5.20.7. Secondary Chilled Water Pumps

5.20.7.1. Secondary CHW pumps shall be lead/lag controlled per Paragraph 5.1.15.3.

5.20.7.2. Enable lead secondary CHW pump when plant is enabled and any load served by the pump(s) is generating a Chiller Plant Request. Disable the lead pump otherwise.

Keep the following clause if the plant has one or more sets of secondary loop pumps serving downstream control valves. Delete if all secondary loop loads are served by coil pumps.

5.20.7.3. Pumps serving multiple coils

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

$$\text{SCHWFR} = \frac{FLOW_S}{SCHWF_{design}}$$

Flow is used, as opposed to speed, to keep the chilled water pumps operatingnear 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). If desired, the stage down flow point can be offset slightly below the stage up point to prevent cycling between pump stages in applications with highly variable loads.

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

$$\text{SCHWFR} > \frac{Number\ of\ Operating\ Pumps}{N} - .03$$

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

$$\text{SCHWFR} < \frac{Number\ of\ Operating\ Pumps - 1}{N} - .03$$

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

b. When any secondary CHW 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.

c. 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.

Keep the following three paragraphs 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.

d. 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.

e. 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.

f. 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 DP sensor all the way back to the CHW 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.

Keep the following clause for plants with coil pumps. Delete otherwise.

5.20.7.4. Coil Pumps

Retain the following clause where coil pumps can turn down to 20% of design speed or less. This is true of all variable speed drive driven pumps. Delete otherwise.

a. Enable the coil pump(s) when plant is enabled and the coil pump speed command exceeds 30% for 5 minutes continuously. Disable the pump(s) when either the plant is disabled or the pump speed command drops to minimum speed for 5 minutes continuously.

Retain the following two clauses where coil pumps cannot turn down to 20% of design speed or less. This is true of some ECM driven pumps, though not all. Delete otherwise.

b. Enable the lead coil pump when plant is enabled and the coil pump speed command exceeds 30% for 5 minutes continuously. Disable the lead pump when either the plant is disabled or the pump speed command drops to minimum speed for 5 minutes continuously.

c. Coil pumps shall be staged based on minimum speed, PumpSpeedMin, and the number of pumps that operate at design coil flow, *N*.

   1. Enable the next lag pump if less than *N* pumps are operating and pump speed exceeds the following for 1 minute:

$$PumpSpeedMin * \frac{(Number\ of\ operating\ pumps + 1)}{Number\ of\ operating\ pumps} + 10\%$$

2. Disable the last lag pump if pump speed falls below PumpSpeedMin for 1 minute.

Coil pumps with good turndown are not staged since coil pumps operate on a nearly fixed system curve (ignoring variations in differential pressure across the primary loop points of connection). As such, coil pump speed generally tracks linearly with flow and pump efficiency varies minimally along the fixed system curve. This means efficiency is optimized by running the design quantity of pumps at all times if the pumps are selected near their best efficiency point at design. This approach also avoids running pumps to the right of their choke line.

In rare applications, typically limited to those involving smaller coils served by ECM driven pumps, speed turndown may be insufficient with multiple pumps running for stable supply air temperature control. In such cases, pumps should instead be staged. The above logic stages additional pumps on as soon as possible to maximize efficiency and minimize operation to the right of the choke line.

d. Refer to air handler system control sequence for pump speed control logic.

Coil pumps are generally controlled to maintain supply air temperature setpoint as part of a control loop running on an air handler controller, e.g., increase pump speed via a direct acting control loop to maintain supply air temperature at setpoint. Coil pump speed control sequences therefore cannot be generalized as part of the plant logic.

When the request logic below is inserted in Guideline 36, it will live in the Air Handler sequences.

e. Chilled Water Reset Requests

1. If any coil pump is proven on, pump speed exceeds 99% for 2 minutes, and the supply air temperature exceeds the supply air temperature setpoint by 5°F for 2 minutes, send 3 Requests,

2. Else if any coil pump is proven on, pump speed exceeds 99% for 2 minutes, and the supply air temperature exceeds the supply air temperature setpoint by 3°F for 2 minutes, send 2 Requests,

3. Else if any coil pump is proven on and pump speed exceeds 95%, send 1 Request until pump speed is less than 85% or no coil pumps serving the coil are proven on.

4. Else if the coil pump speed is less than 95%, send 0 Requests.

f. Chiller Plant Requests. Send the chiller plant that serves the coil pump a Chiller Plant Request as follows:

1. If the pump speed command is greater than 95%, send 1 Request until the speed command is minimum for 5 minutes.

2. Else if the pump speed command is less than 95%, send 0 Requests.

Keep the following section for Primary-only chilled water plants with a minimum flow bypass valve. Delete otherwise.

5.20.8. Chilled Water Minimum Flow Bypass Valve

Retain the following clause for Primary-only plants with parallel chillers.

5.20.8.1. Bypass valve shall modulate to maintain minimum flow as measured by the chilled water flow meter at a setpoint that provides minimum flow through all operating chillers, determined as follows:

a. For the chillers operating in the stage, identify the chiller with the highest ratio, MinFlowRatio, of CHW-MinFlowX to CHW-DesFlowX.

b. Calculate the minimum flow setpoint as MinFlowRatio multiplied by the sum of CHW-DesFlowX for the operating chillers.

If the chillers have different minimum flow to design flow ratios, just maintaining the sum of the minimum flows will not satisfy the chiller(s) with the highest relative minimum flows. Note that this also requires that chillers be balanced to distribute flow proportional to their design flow.

Retain the following clause for Primary-only plants with series chillers.

5.20.8.2. Bypass valve shall modulate to maintain minimum flow as measured by the chilled water flow meter at a setpoint equal to the largest CHW-MinFlowX of the operating series chillers.

Retain the following clause for plants that stage a chiller on while staging another off during any stage change.

5.20.8.3. During stage changes that require one chiller to be enabled while another is disabled, the minimum flow setpoint shall temporarily change to account for the CHW-MinFlowX of both the chiller to be enabled and to be disabled prior to starting the newly enabled chiller. See staging events in 5.20.4 for timing of setpoint change to this transitionary value.

5.20.8.4. When any CHW pump is proven on, the bypass valve PID loop shall be enabled. The valve shall be opened 100% otherwise. When enabled, the bypass valve loop shall be biased to start with the valve 100% open.

Biasing the loop to 100% upon start up ensures that the valve does not slam shut upon enabling the loop. Starting with the valve fully open is appropriate because flows are often very low when the plant is first turned on.

Delete Section 5.20.9. for air-cooled plants. Retain otherwise.

5.20.9. Condenser Water Pumps

Retain the following clause for plants with headered condenser water pumps. Delete otherwise.

5.20.9.1. Condenser water pumps shall be lead/lag controlled per Paragraph 5.1.15.3.

Retain the following clause for plants with headered condenser water pumps and a waterside economizer. Delete otherwise.

5.20.9.2. Enable lead CW pump when any chiller or WSE CW isolation valve is commanded open. Disable the lead CW pump when all chiller and WSE CW isolation valves are commanded closed.

Retain the following clause for plants with headered condenser water pumps and no waterside economizer. Delete otherwise.

5.20.9.3. Enable lead CW pump when any chiller CW isolation valve is commanded open. Disable the lead CW pump when all chiller CW isolation valves are commanded closed.

Retain the following clause for plants with dedicated condenser water pumps. Delete otherwise.

Where chillers have a CW request network point, consider increasing the pump disable delay to 10 minutes to ensure that flow is not cut off too soon. Where chillers do not have this point (e.g., older chillers without network interfaces), the default delay is appropriate.

5.20.9.4. Enable lead CW pump when the lead chiller is required to run, but prior to the chiller being enabled. Disable the lead CW pump when the lead chiller is disabled and either the lead chiller has been proven off for 3 minutes or is not requesting CW flow.

Delete the following clause if the plant has variable speed condenser water pumps or a waterside economizer. Retain otherwise.

5.20.9.5. The number of operating condenser water pumps shall match the number of operating chillers.

Delete the following two clauses if the plant does not have variable speed condenser water pumps. Retain otherwise.

Where headered condenser water pumps are unequally sized, list the pump tags of the required pumps for each stage in the "CWPs On" column below.

5.20.9.6. The number of operating condenser water pumps and design condenser water pump speed for the stage, Cw-DesPumpSpdStage, shall be set per the table below.

Chiller Stage	CWPs On	Cw-DesPumpSpdStage
0	0	N/A, Off
0+WSE	1	Per TAB to provide design flow through HX
1	1	Per TAB to provide design flow through chiller
1+WSE	2	Per TAB to provide at least design flow through both chiller and WSE
2	2	Per TAB to provide at least design flow through both chillers
2+WSE	2	Per TAB to provide at least design flow through both chillers and WSE, or 100% speed if design flow cannot be achieved.

The above table would be expanded with additional stages if the plant includes more chiller stages. Note that for plants with more chillers, it is unlikely that the WSE will be enabled with >2 chillers enabled, so defining unique pump quantity and speed combinations to account for WSE operation is typically unnecessary. I.e., for a 3 chiller plant, the same CWP quantity and speed would be applicable to Chiller Stage 3 and Chiller Stage 3 + WSE.
Note that unless chillers and the WSE HX are dynamically balanced with head pressure control valves based on chiller stage (complexity not recommended), design balance will only be achieved in one stage (typically all chillers operating and WSE HX disabled). The staging table therefore calls for determining speeds in all stages such that at least design flow is achieved through all operating equipment, which means all but one piece of equipment will exceed design flow.

5.20.9.7. Condenser water pump speed setpoint for a given stage shall be Cw-DesPumpSpdStage unless reset per Head Pressure Control logic in 0.

5.20.9.8. See 5.20.4 for lag condenser water pump on/off staging timing.

Delete Section 0 for air-cooled plants or water-cooled plants where head pressure control is not required. Retain otherwise.

Most water-cooled chillers require a minimum refrigerant head (lift) between the evaporator and condenser to ensure trouble-free chiller starts and to maintain oil circulation. However, centrifugal chillers serving air handlers with air-side economizers (and without waterside economizers) often are not provided with head pressure control, and some oil-free chillers with magnetic or ceramic bearings, can operate with zero or even negative lift (as measured by water temperatures).

5.20.10. Head Pressure Control

5.20.10.1. Head pressure control signal shall be that output from the chiller controller whenever available. Otherwise, if a head pressure control signal is not available from the chiller controller, a reverse acting PID loop shall maintain the temperature differential between the chiller's condenser water return temperature and chilled water supply temperature at LIFTminX.

Subsequent sequences assume that the head pressure control signal, where output from the chiller controller is not wired directly to the head pressure control valve, but rather hardwired to an AI on the plant BAS controller. This allows monitoring of the head pressure control signal for stability, as well as remapping the signal as specified herein to avoid fighting between the head pressure control and tower speed control loops.

Note that the above BAS loop maintaining LIFTminX, if required, relies on the chiller's sensors, not common loop sensors. If hardwired sensors are available, they should be used; otherwise use network points through the chiller interface.

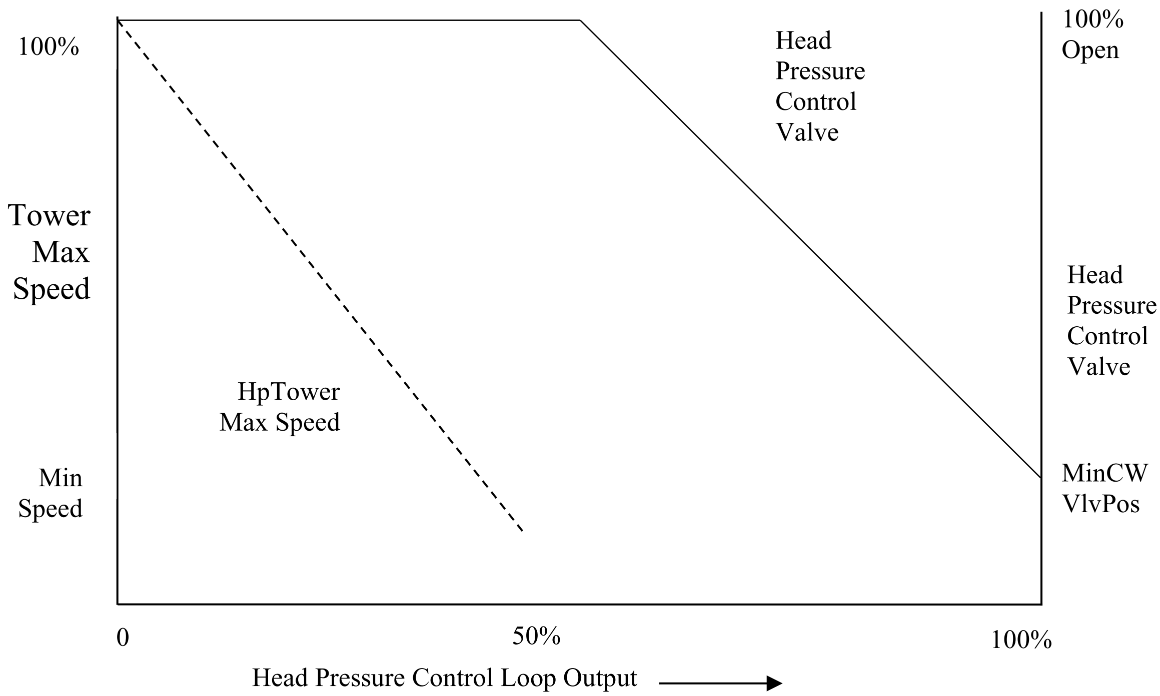
5.20.10.2. Each operating chiller shall have its own head pressure control loop. Head pressure control loop is enabled and disabled per chiller staging logic in 5.20.4.

Retain the following clause for plants with fixed speed condenser water pumps. Delete otherwise. Note: Such plants are assumed not to have a waterside economizer.

5.20.10.3. For each chiller, map loop output as follows:

a. From 0-50%, the loop output shall reset maximum cooling tower speed point, HpTowerMaxSpd, from 100% to minimum speed.

b. From 50-100%, the loop output shall reset head pressure control valve position from 100% open to MinCWVlvPos.

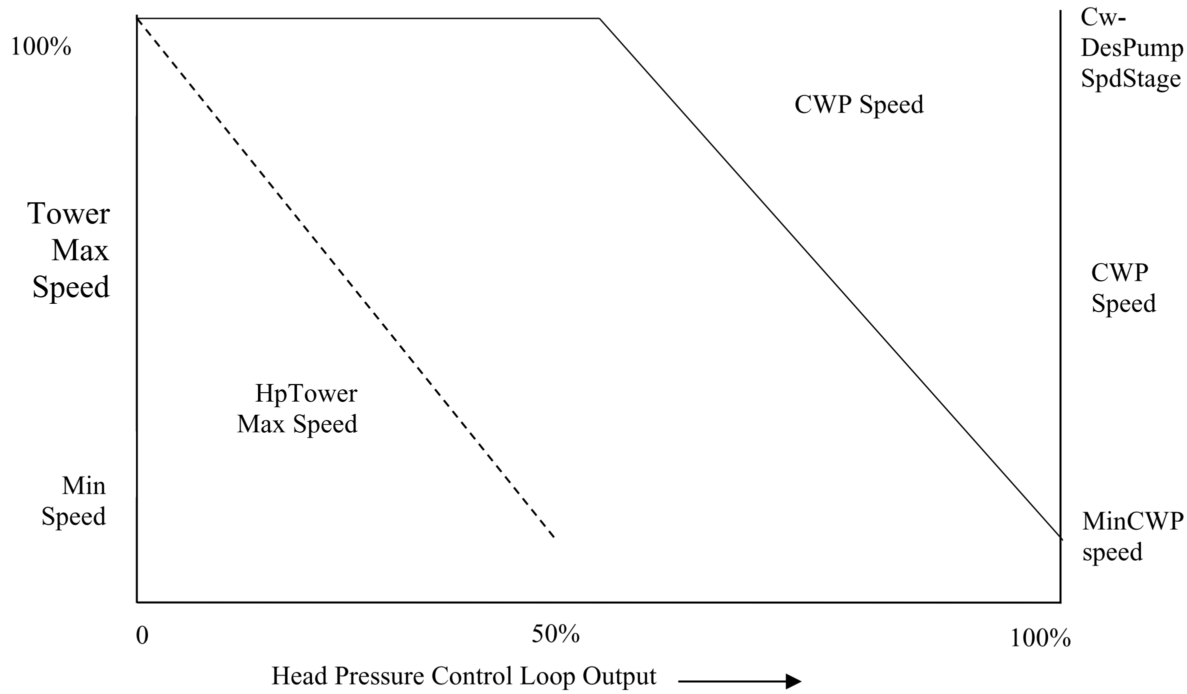


Retain the following clause if the plant has variable speed condenser water pumps and no waterside economizer. Delete otherwise.

5.20.10.4. For each chiller, map loop output as follows:

a. From 0-50%, the loop output shall reset maximum cooling tower speed point, HpTowerMaxSpd, from 100% to minimum speed.

b. From 50-100%, the loop output shall reset condenser water pump speed from Cw-DesPumpSpdStage to MinCWPspeed. Where condenser water pumps are dedicated, speed reset shall be independent for each chiller.

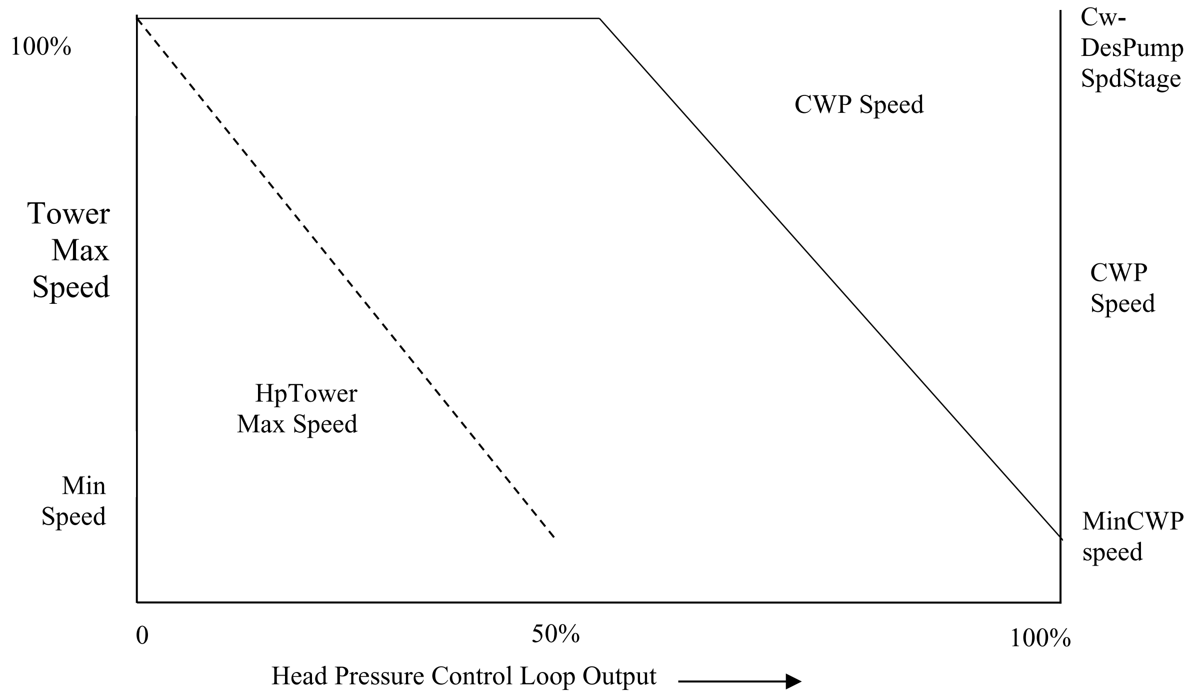


Retain the following two clauses if the plant has a waterside economizer. Delete otherwise. Note: Such plants are assumed to have headered condenser water pumps.

5.20.10.5. For each chiller, when the WSE is disabled, map loop output as follows:

a. From 0-50%, the loop output shall reset maximum cooling tower speed point, HpTowerMaxSpd, from 100% to minimum speed.

b. From 50-100%, the loop output shall reset condenser water pump speed from Cw-DesPumpSpdStage to MinCWPspeed.



c. Note: Each enabled chiller's head pressure control valve shall be 100% open irrespective of loop output.

5.20.10.6. When the WSE is enabled, map loop outputs as follows:

a. Maximum cooling tower speed point, HpTowerMaxSpeed, shall be 100% irrespective of loop output.

b. Condenser water pump speed shall be equal to the design speed for the stage irrespective of loop output.

c. Each enabled chiller's head pressure control loop output shall reset head pressure control valve position from 100% open at 0% loop output to MinCWVlvPos at 100% loop output.

Retain the following clause for plants with headered condenser water pumps. Delete otherwise.

5.20.10.7. When the head pressure control loop is disabled per Paragraph 5.20.4.17, the CW isolation/head pressure control valve shall be closed.

The following section is required for most non-chemical water treatment systems, and recommended for some chemical treatment systems, to ensure condenser water is properly treated. Delete if not required. Always delete for air-cooled plants.

5.20.11. Water Treatment Override

5.20.11.1. Every night at 1:00 am, if all condenser water pumps are off and the condenser water pumps have not accumulated at least 20 minutes of runtime in the last 36 hours then:

Retain the following sentence if there are chiller condenser isolation valves. Delete otherwise.

a. Open all chiller condenser isolation valves.

Retain the following if there are tower isolation valves. Delete otherwise.

b. Open all tower isolation valves.

c. Start lead condenser water pump.

d. After 20 minutes, or if the plant is enabled, release back to normal control.

Retain Section 5.20.12 for water-cooled plants. Delete otherwise.

5.20.12. Cooling Towers

Retain the following clause for plants that have tower isolation valves. Delete otherwise.

For a two chiller/two tower plant, ASHRAE Standard 90.1 requires that the tower minimum flow on each tower be above 50% so tower isolation valves are neither needed nor desired. The sequences below are configured to allow for plants with 3 or more CW pumps and towers where staging is needed to maintain minimum flow. The tower isolation valves can be on the tower inlet only provided the equalizer (or flume gate) is large enough to allow water to flow from the enabled cell to the disabled cell(s) with the small head between the high-water-level point of the enabled cell to the low-water-level point of the disabled cells. If not, valves are required on both inlet and outlet.

5.20.12.1. Tower Staging

a. Tower cells shall be lead/lag controlled per Paragraph 5.1.15.3.

The table needs to be edited for each plant based on the condenser water flow per stage, number of towers in the plant, and tower minimum flow requirements.

b. Quantity of enabled cooling tower cells shall map to Plant Stage.

Plant Stage	Enabled Tower Cells
0	0
0 + WSE	2
1	2
1 + WSE	4
2	4
2 + WSE	4

Quantity of enabled cells per pump stage should be the maximum that provides at least minimum tower flow through each cell as required by the tower manufacturer. Maximizing the quantity of operating towers minimizes fan power because fans have variable speed drives. For instance, one tower at full speed uses approximately four times as much power as two towers at half speed.

c. Lead cell(s) shall be enabled when the lead CW pump is enabled. Lead cell(s) shall be disabled when all CW pumps are proven off.

d. Tower stage changes shall be initiated concurrently with condenser water pump stage and/or condenser water pump speed changes per plant staging logic in 5.20.4.

e. When enabling a tower cell, open its supply isolation valve, and outlet isolation valve if provided. Once proven open as determined by end switch status, or nominal valve timing if end switches are not provided, enable tower fan.

f. When disabling a tower cell, command the fan off and shut its supply isolation valve, and outlet isolation valves if provided.

5.20.12.2. Fan Control

Use the following CWRT Control Sequence for plants with dynamic load profiles, i.e., those for which PLR may change by more than approximately 25% in any hour. Examples include plants primarily serving a few large air handlers with similar schedules and plants serving intermittent process loads. Delete otherwise.

a. Condenser Water Return Temperature (CWRT) Control

1. Tower fan control is in part dictated by plant part load ratio, PLR_{plant}, which is the ratio of current plant required capacity, $Q_{required}$, to plant design capacity:

$$PLR_{plant} = \frac{Q_{required}}{Q_{design}}$$

2. CWRTdes in the subsequent logic shall be the lowest CWRTdesX of all chillers.

Retain the following qualifier for plants with waterside economizers. Delete otherwise.

3. When any chillers are enabled and the waterside economizer is disabled, the following logic shall apply.

This sequence controls condenser water return temperature, as opposed to supply, since CWRT more closely correlates to chiller lift, which drives chiller efficiency and surge conditions.

4. Maximum tower speed shall be limited based on *OPLR*. Reset the variable PlrTowerMaxSpd linearly from 100% at 50% *OPLR* down to 70% at 0% *OPLR*.

Maximum tower speed is limited at low plant part load ratios to prevent tower energy waste when either (1) CHWST is reset low at low PLRs or (2) wet bulb is elevated at low PLRs. Both conditions can cause the CWRT setpoint output from the following equation to be unachievable.

5. CWRT setpoint, CWRTsp, shall be the output of the following equation.

$$CWRTsp = CHWSTsp + LIFTtarget$$

$$LIFTtarget = Max\big(LIFTmin, Min(LIFTmax, A * PLR_{Plant} + B)\big)$$

$$A = 1.1 * (LIFTmax - LIFTmin)$$

$$B = LIFTmax - A$$

xviii. Where chillers have different LIFTminX values, LIFTmin in the above equation shall reset dynamically to equal the highest LIFTminX of enabled chillers.

Retain the following sentence for parallel chiller plants only. Delete otherwise.

xix. Where chillers have different LIFTmaxX values, LIFTmax in the above equations shall reset dynamically to equal the lowest LIFTmaxX of enabled chillers.

Retain the following sentence for series chiller plants only. Delete otherwise.

xx. LIFTmax shall be calculated based on the downstream chiller(s) on the chilled water side. Where downstream chillers have different LIFTmaxX values, LIFTmax shall be calculated for each downstream machine and the lowest value used in the above logic.

The above equation resets desired chiller lift (as approximated by CWRT and CHWST setpoint) as a function of load. This heuristic relationship is based on modeling indicating that, for plants with constant condenser water flow, optimal combined chiller and tower efficiency is most closely approximated with such a reset. See the ASHRAE Fundamentals of Design and Control of Central Chilled-Water Plants

Self-Directed Learning Course for more information. The values of A and B are the simplified values from the SDL, Appendix A.

This implementation puts an upper bound on lift to prevent the setpoint from resetting too high (and causing surge for centrifugal machines).

Use the following two paragraphs when the plant is close coupled, i.e., the pipe length from the chillers to cooling towers does not exceed approximately 100 feet. Delete otherwise.

6. When any condenser water pump is proven on, CWRT shall be maintained at setpoint by a direct acting PID loop. The loop output shall be mapped to the variable CWRTTowerSpd. Map CWRTTowerSpd from minimum tower speed at 0% loop output to 100% speed at 100% loop output.

7. Tower speed command signal shall be the lowest value of CWRTTowerSpd, HpTowerMaxSpd from each chiller head pressure control loop, and PlrTowerMaxSpd. All operating fans shall receive the same speed signal.

Use the following three paragraphs when the plant is not close coupled, i.e., the pipe length from the chillers to cooling towers exceeds approximately 100 feet. Delete otherwise.

8. When any condenser water pump is proven on, CWRT shall be controlled to CWRTsp by setting CWST setpoint, CWSTsp, equal to CWRTsp minus CWdt, where CWdt is the 5 minute rolling average of common condenser water return temperature less condenser water supply temperature, sampled at minimum once every 30 seconds. When the plant is first enabled CWdt shall be held fixed equal to 50% of CWRTdesX less CWSTdesX of the enabled chiller for 5 minutes to populate the rolling average queue before populating with actual data.

9. When any condenser water pump is proven on, CWST shall be maintained at setpoint by a direct acting PID loop. The loop output shall be mapped to the variable CWSTTowerSpd. Reset CWSTTowerSpd from minimum tower speed at 0% loop output to 100% speed at 100% loop output.

10. Tower speed command signal shall be the lowest value of CWSTTowerSpd, HpTowerMaxSpd from each chiller head pressure control loop, and PlrTowerMaxSpd. All operating fans shall receive the same speed signal.

The above cascading loop logic improves control stability when there is significant thermal mass in the loop. Thermal mass slows the response of CWRT to changes in setpoint.

11. Disable the tower fans if either

    xxi. Any enabled chiller's HpTowerMaxSpd has equaled tower minimum speed for 5 minutes, or

Retain the following sentence if tower speed is controlled to maintain CWRT at setpoint. Delete otherwise.

    xxii. Tower fans have been at minimum speed for 5 minutes and CWRT drops below setpoint minus 1°F.

Retain the following sentence if tower speed is controlled to maintain CWST at setpoint. Delete otherwise.

    xxiii. Tower fans have been at minimum speed for 5 minutes and CWST drops below setpoint minus 1°F.

12. Enable the tower fans if

    xxiv. They have been off for at least 1 minute, and

Retain the following sentence if tower speed is controlled to maintain CWRT at setpoint. Delete otherwise.

xxv. CWRT rises above setpoint by 1°F, and

Retain the following sentence if tower speed is controlled to maintain CWST at setpoint. Delete otherwise.

xxvi. CWST rises above setpoint by 1°F, and

xxvii. All enabled chillers' HpTowerMaxSpd are greater than tower minimum speed.

13. When all condenser water pumps are commanded off, disable the PID loop and stop all tower fans.

14. Upon plant startup, hold CWRTsp at 10°F degrees less than CWRTdes for 10 minutes before ramping the setpoint to the calculated value above over 10 minutes.

This logic gives plant load an opportunity to stabilize prior to releasing control to the reset logic.

Use the following CWST Control Sequence for plants with stable load profiles (i.e., those for which PLR_{plant} is expected to change by less than approximately 25% during any hour) and where network interfaces or power meters are available to read equipment power. Examples include campus central plants, plants serving buildings with many air systems and a variety of schedules and load profiles, and plants with a large, stable base load. Delete otherwise.

b. Condenser Water Supply Temperature (CWST) Control

1. CWSTdes in the subsequent logic shall be the lowest CWSTdesX of all chillers.

Retain the following qualifier for plants with waterside economizers. Delete otherwise.

2. When any chillers are enabled and the waterside economizer is disabled, the following logic shall apply.

3. When the plant is first enabled, initialize CWST setpoint, CWSTsp, to 10°F less than CWSTdes.

4. Instantaneous plant output, Q_{actual}, is calculated based on chilled water return temperature (*CHWRT*) entering the chillers, current chilled water supply temperature leaving the plant, and measured flow through the primary circuit flow meter ($FLOW_P$), as shown in the equation below.

$$Q_{actual} = \frac{FLOW_P(CHWRT - CHWST)}{24}\ [tons]$$

5. Combined chiller and tower fan efficiency, Eff_{Ch+T}, is calculated based on the combined power draw of all tower fans as read from tower VFD interfaces (kW_{Towers}), the combined power draw of all chillers as read from the chiller interfaces or power meters (kW_{Ch}), and instantaneous plant output (Q_{actual}). Eff_{Ch+T} used in logic shall be a 5-minute rolling average of instantaneous values sampled at a minimum of every 30 seconds.

$$Eff_{Ch+T} = \frac{kW_{Towers} + kW_{Ch}}{Q_{actual}}$$

6. At the end of every time interval, equal in length to the Chilled Water Plant Reset time step (see Paragraph 5.20.5.2.a) plus 5 minutes, execute the following reset:

xxviii. After the initial time interval, reset CWSTsp down 1°F.

There is no history when the plant is first enabled, so a direction to reset must be picked arbitrarily.

xxix. For each subsequent time interval, reset CWSTsp down by 1°F if CWST is no more than 0.5°F above present setpoint, tower fan speed command is less than 95%, CHWST setpoint has not increased relative to the setpoint at the end of the previous interval, and either:

(y) CWSTsp had reset down in the previous time interval and EffCh+T is now less than at the previous setpoint change.

(z) CWSTsp had reset up in the previous time interval and EffCh+T is now greater than at the previous setpoint change.

xxx. Else, if CWST is no more than 0.5°F below present setpoint, reset CWSTsp up by 1°F.

xxxi. Else, do not change CWSTsp.

This logic attempts to optimize total chiller and tower efficiency. Since CW pump speed is fixed except when modulated for head pressure control (as applicable), CW pump power is not included in the optimization logic.

Two varying parameters can cofound this stepwise efficiency optimization routine: (1) varying plant load and (2) chilled water supply temperature setpoint reset. Both factors independently impact chiller efficiency and tower efficiency, making attribution of increases and decreases in efficiency to CWST setpoint reset alone impossible. As such, this approach is not recommended for plants with dynamic load profiles. Additionally, note that CWST setpoint is not allowed to reset down concurrently with CHWST setpoint resetting up since the latter typically outweighs the impact of the former making it impossible to tell whether the CWST reset did any good. A similar restriction is not placed on the CWST reset when CHWST setpoint is resetting down since chiller efficiency should continuously get worse in such a scenario, meaning the CWST setpoint will be self-correcting by repeatedly alternating setpoints within a 1°F range as efficiency continues to worsen until CHWST setpoint stabilizes.

7. Maximum CWST-setpoint shall be limited to CWSTdes from contract documents.

8. Minimum CWST-setpoint shall reset dynamically and equal the active chilled water supply temperature setpoint plus *LIFTminX* – 2°F. Where chillers have different *LIFTminX* values, *LIFTminX* in the above equation shall reset dynamically to equal the highest *LIFTminX* of enabled chillers.

Set the temperature offset (2°F) in the above sentence equal to the minimum temperature rise across a single chiller's condenser when operating at minimum load and design condenser water flow.

9. When any condenser water pump is proven on, CWST shall be maintained at setpoint by a direct acting PID loop. The loop output shall be mapped to the variable CWSTTowerSpd. Reset CWSTTowerSpd from minimum tower speed at 0% loop output to 100% speed at 100% loop output.

10. Tower speed command signal shall be the lower value of CWSTTowerSpd and HpTowerMaxSpd from each chiller head pressure control loop. All operating fans shall receive the same speed signal.

11. Disable the tower fans if either

xxxii. Any enabled chiller's HpTowerMaxSpd has equaled tower minimum speed for 5 minutes, or

xxxiii. Tower fans have been at minimum speed for 5 minutes and the CWST drops below setpoint minus 1°F.

12. Enable the tower fans if

xxxiv. They have been off for at least 1 minute, and

xxxv. CWST rises above setpoint by 1°F, and

xxxvi. All enabled chillers' HpTowerMaxSpd are greater than tower minimum speed.

13. When all condenser water pumps are commanded off, disable the PID loop and stop all tower fans.

Retain the following section for plants with a waterside economizer. Delete otherwise.

c. WSE Mode

1. When the WSE is enabled and chiller(s) are running (i.e., integrated operation):

xxxvii. Fan speed shall be equal to WseTower-MaxSpeed.

xxxviii. WseTower-MaxSpeed shall be reset by a direct acting PID loop maintaining the chiller load at 110% of the sum of MinUnloadCapX values for the operating chillers. Map WseTower-MaxSpeed from minimum speed at 0% loop output to 100% speed at 100% loop output. Bias the loop to launch from 100% output.

xxxix. When starting integrated operation after previously operating with only the WSE, hold WseTower-MaxSpeed at 100% for 10 minutes to give the chiller time to get up to speed and produce at least MinUnloadCapX, then enable the loop.

2. When the WSE is running alone:

Waterside economizer only mode sequences herein presume a plant where the WSE flowrate is does not exceed the design flow of one chiller in WSE only mode as is typical of most commercial applications. For applications where WSE only mode CHW flow is likely to exceed the design flow of one chiller, e.g., a data center, additional logic is warranted for tower and CWP staging not included within the scope of this RP. For such plants, tower speed is typically controlled to maintain a leaving temperature setpoint and CWP speed is modulated to maintain CHWST at setpoint.

xl. Fan speed shall be modulated to maintain CHWST at setpoint by a direct acting PID loop that resets fan speed from minimum at 0% loop output to maximum at 100% loop output.

xli. If CHWST drops below setpoint and fans have been at minimum fan speed for 5 minutes, fans shall cycle off for at least 3 minutes and until CHWST rises above setpoint by 1°F.

Keep the following clause where 2-position tower bypass control valves are needed to prevent tower freezing if the plant needs to operate in freezing weather. Delete otherwise.

5.20.12.3. Cooling Tower Bypass Valves

a. If any condenser water pump is on, all tower fans are off, and CWST from the tower falls below 40°F for 5 minutes, fully open the tower bypass valve to the tower basins.

Modulating a tower bypass valve in freezing weather runs the risk of icing towers. Manufacturer guidance is either to run in full bypass, or no bypass.

b. Close the valve to the tower basins when any of the following are true:

1. The WSE is disabled, the valve has been open for at least 5 minutes, and CWST rises LIFTminX – 2°F above CHWST setpoint. Where chillers have different *LIFTminX* values, *LIFTminX* in the above equation shall reset dynamically to equal the highest *LIFTminX* of enabled chillers.

2. The WSE is enabled, the valve has been open for at least 5 minutes, and CHWST rises to within 1°F of CHWST setpoint.

3. Tower fans are commanded on (valve shall never be open when fans are on).

Retain the following section for water-cooled plants. Delete otherwise.

5.20.13. Tower Make-up Water

5.20.13.1. Make-up water valve shall cycle based on tower water fill level sensor. The valve shall open when water level falls below T-level-min-fill. It shall close when the water level goes above T-level-max-fill.

5.20.14. Emergency Chiller Off

Retain the following clause for plants with waterside economizers. Delete otherwise.

5.20.14.1. Chillers shall be locked off (start/stop points overridden to off at highest protocol priority) upon closing of emergency chiller off switch located at chiller room entry. Remaining equipment shall remain enabled and be indexed to Stage 0 + WSE until the plant is either disabled or the emergency power off switch is released, at which point staging shall resume from Stage 0 + WSE.

Retain the following clause for plants without waterside economizers. Delete otherwise.

5.20.14.2. Chillers shall be locked off (start/stop points overridden to off at highest protocol priority) upon closing of emergency chiller off switch located at chiller room entry. After 5 minutes, shut off all pumps and towers.

Keep the following Paragraph for water-cooled plants where basin heaters and heat trace are used in freezing climates. Delete otherwise.

5.20.15. Freeze Protection

Retain the following two clauses for cold climate water-cooled plants with tower basin heaters and basin temperature sensors. Delete otherwise.

5.20.15.1. Tower Basin Heaters

a. Enable basin heater whenever basin temperature drops below 38°F.

b. Disable basin heater whenever basin temperature rises above 40°F.

Retain the following two clauses for cold climate water-cooled plants with outdoor piping and piping heat trace. Delete otherwise.

5.20.15.2. Piping Heat Trace

a. Enable heat trace whenever outdoor air temperature drops below 34°F.

b. Disable heat trace whenever outdoor air temperature rises above 40°F.

5.20.16. Performance Monitoring

5.20.16.1. 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.

5.20.16.2. Total plant power. Calculate total plant power as the sum of chiller power, pump power, and cooling tower fan power. For motors with VFDs, power shall be actual power as read through the VFD network interface. For fixed speed motors (e.g., CW pumps without VFDs), power shall be assumed to be fixed at BHP (from equipment schedule) * 0.746 / 0.93 (approximate motor efficiency).

Retain the following calculation for primary-only plants and primary-secondary plants with both a primary circuit flow meter and primary loop CHWST and CHWRT sensors. Delete otherwise.

5.20.16.3. Total Plant Load. Calculate plant load using flowrate through the primary circuit, $FLOW_P$; chilled water return temperature upstream of the first HX or chiller, *CHWRT*; and primary loop chilled water supply temperature leaving the plant, *CHWST*.

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

Retain the following calculation for primary-secondary plants without both a primary circuit flow meter and primary loop CHWST and CHWRT sensors. Delete otherwise.

5.20.16.4. Total Plant Load. Calculate plant load using flowrate through the secondary circuit, $FLOW_S$; secondary chilled water return temperature, *SCHWRT*; and secondary chilled water supply temperature, *SCHWST*.

$$Q_{Plant} = \frac{FLOW_S\ (SCHWRT - SCHWST)}{24}\ [tons]$$

5.20.16.5. Equipment Load. Calculate load for each operating chiller and WSE heat exchanger (as applicable) using flowrate through the equipment, $FLOW_D$; chilled water return temperature entering the equipment, $CHWRT_D$; and chilled water supply temperature leaving the equipment, $CHWST_D$. Inputs to the below equation shall be determined per the following rules.

$$Q_D = \frac{FLOW_D\ (\mathrm{CHWRT}_D - \mathrm{CHWST}_D)}{24}\ [tons]$$

1. Where flow through each chiller is individually measured using a flow meter, $FLOW_D$ shall be the flow measured by the chiller's associated flow meter.

2. For parallel chillers where flowrate through each chiller is not measured, but flowrate through the primary circuit is measured, $FLOW_D$ shall be assumed proportional to design flow through all operating chillers in the circuit.

3. For constant flow primary loops where neither flowrate through the chillers nor flowrate through the primary loop is measured, $FLOW_D$ shall be assumed equal to the design flowrate through the chiller for the current stage as determined during balancing.

4. For variable flow primary loops without flow meters, use chiller evaporator barrel differential pressure if available through the network interface to determine $FLOW_D$ per manufacturer's pressure versus flow curves; otherwise, do not execute the above calculation for individual chillers.

Retain the following clause for plants with waterside economizers where CHW flowrate through the heat exchanger is controlled by a modulating bypass valve. Delete otherwise.

5. For WSE heat exchangers controlled to differential pressure, heat exchanger flow rate shall be estimated based on design heat exchanger flowrate, *HXFdesign*; design heat exchanger pressure drop, $HX_{DP\text{-}Design}$, and current HX pressure drop, $HX_{DP\text{-}D}$:

$$GPM_D = HXFdesign\left(\frac{HX_{DP-D}}{HX_{DP-Design}}\right)^{0.5}$$

Retain the following clause for plants with a waterside economizer where CHW flowrate through the heat exchanger is controlled by a variable speed heat exchanger pump. Delete otherwise.

6. For WSE heat exchangers with side stream CHW pumps, heat exchanger flow rate shall be estimated based on design heat exchanger flowrate, *HXFdesign*; design heat exchanger pump speed, HxPumpDesSpd; and current HX pump speed, $HX_{Sp\text{-}D}$.

$$GPM_D = HXFdesign\left(\frac{HX_{Sp-D}}{HxPumpDesSpd}\right)$$

7. $CHWRT_D$ shall be the return temperature entering the equipment as read by a hardwired sensor if available. If a hardwired sensor is unavailable for a chiller, temperature shall be read from a sensor internal to the chiller through its network interface.

8. $CHWST_D$ shall be a hardwired temperature sensor at the outlet of the equipment if available. If a hardwired sensor is unavailable for a chiller, temperature shall be read from a sensor internal to the chiller through its network interface. Only if neither of the above is available shall a common supply temperature sensor (i.e., one measuring the output from multiple chillers), be used.

5.20.16.6. Calculate plant efficiency as total plant power divided by plant load. Calculate efficiency for each chiller as chiller power divided by chiller load.

5.20.16.7. Summary Data. For each chiller, and for the total plant, statistics shall be calculated for runtime, kWh, average actual efficiency (kW/ton), 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 (kW/ton)	Runtime (hours)	Avg Daily Energy Use (kWh)	Avg Daily CHW Load (ton-hr)	Avg CHW Demand (ton)	Peak CHW Demand (ton)	Avg Efficiency (kW/ton)	Runtime (hours)	Avg Daily Energy Use (kWh)	Avg Daily CHW Load (ton-hr)	Avg CHW Demand (ton)	Peak CHW Demand (ton)	Avg Efficiency (kW/ton)
CH-1																
CH-2																
Total Plant																

5.20.17. Alarms

5.20.17.1. Maintenance interval alarm when pump has operated for more than 3000 hours as indicated by the Staging Runtime: Level 4. Reset the Staging Runtime interval counter when alarm is acknowledged.

5.20.17.2. Maintenance interval alarm when chiller has operated for more than 1000 hours as indicated by the Staging Runtime: Level 4. Reset the Staging Runtime interval counter when alarm is acknowledged.

5.20.17.3. Chiller alarm: level 2

5.20.17.4. Emergency off switch: Level 1

Retain the following alarm for water-cooled plants. Delete otherwise.

5.20.17.5. Tower level

a. If tower water level sensor indicates water level below T-level-low-alarm, generate a Level 2 alarm.

b. If tower water level sensor indicates water level above T-level-high-alarm, generate a Level 3 alarm.

5.20.17.6. Pump or tower fan 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 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.

Retain the following two alarms for cold climate water-cooled plants with tower basin heaters and basin temperature sensors. Delete otherwise.

5.20.17.7. Tower basin heater alarm is indicated by the status being different from the output command for 15 seconds.

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

b. Commanded off, status on: Level 4. Do not evaluate alarm until the equipment has been commanded off for 15 seconds.

Retain the following two alarms for cold climate water-cooled plants with outdoor piping and heat trace. Delete otherwise.

5.20.17.8. Piping heat trace alarm indicated by the status being different from the output command for 15 seconds.

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

b. Commanded off, status on: Level 4. Do not evaluate alarm until the equipment has been commanded off for 15 seconds.

Retain the following two alarms for plants with two-position valves with end switch status monitoring. Delete otherwise.

5.20.17.9. Valve alarm is indicated by the end switch status being different from the output command for 90 seconds.

a. Commanded open, status not open: Level 2. Do not evaluate alarm until the equipment has been commanded open for 90 seconds.

b. Commanded closed, status not closed: Level 4. Do not evaluate alarm until the equipment has been commanded closed for 90 seconds.

Retain the following alarm for plants with modulating valves with analog position feedback. Delete otherwise.

5.20.17.10. Valve alarm is indicated by the analog position feedback being different from the output command by more than 10% for 90 seconds: Level 2

Retain the following alarm for water-cooled plants with cooling tower basin heaters. Delete otherwise.

5.20.17.11. Tower basin temperature alarm

a. Basin temperature is below 38°F for 5 minutes continuously: Level 3

b. Basin temperature is below 36°F for 5 minutes continuously: Level 2

5.20.17.12. Sensor Failure:

a. Sensor shall be deemed outside of its widest possible operating range if any of the following are true:

   1. Feedback less than 2 mA from any 4 to 20 mA transducer; or

   2. Temperature reading less than 0°F from any temperature sensor.

b. Any sensor that goes outside of its widest possible operating range.

   1. If the sensor is used for monitoring only: Level 3.

   2. If the sensor is used for control: Level 2.

5.20.18. Automatic Fault Detection and Diagnostics

The Automatic Fault Detection and Diagnostics (AFDD) routines for chilled water plants continually assess plant performance by comparing the values of BAS inputs and outputs to a subset of potential fault conditions. The subset of potential fault conditions that is assessed at any point depends on the Operating State of the plant, as determined by the positions of the isolation valves and statuses of pumps. Time delays are applied to the evaluation and reporting of fault conditions, to suppress

false alarms. Fault conditions that pass these filters are reported to the building operator as alarms along with a series of possible causes.
These equations assume that the plant is equipped with isolation valves, as well as a pump status monitoring. If any of these components are not present, the associated tests, and variables should be omitted from the programming.
Note that these faults rely on reasonably accurate measurement of water temperature. Extra precision sensors installed in thermowells with thermal paste are strongly recommended for best accuracy.

5.20.18.1. AFDD conditions are evaluated continuously for the plant.

5.20.18.2. The Operating State (OS) of the plant shall be defined by the commanded positions of the valves and status feedback from the pumps in accordance with the following table.

The Operating State is distinct from and should not be confused with the chilled water plant stage.
OS#1 – OS#5 represent normal operating states during which a fault may nevertheless occur if so determined by the fault condition tests below.

Edit the table below. Delete rows and columns that do not apply.

Operating State	**Chiller CHW Isolation Valves (if Series Chillers)**	**Chiller CHW Isolation Valves or Dedicated PCHWPs (if Parallel Chillers)**	**Chiller CW Isolation Valves or Dedicated CWPs (if water-cooled)**	**CHW Pump Status**	**CW Pump Status (if water-cooled and headered)**	**WSE CHW Pump Status (if WSE with HX Pump)**	**WSE CHW Diverting Valve (if WSE with HX diverting valve)**	**WSE CW Isolation Valve (if WSE)**	**Chiller Bypass Valve (if primary-only or WSE)**
#1: Disabled	All Open	All Closed/Off	All Closed/Off	All Off	All Off	Off	Open	Closed	Closed
#2: One Chiller Enabled	One Closed, All Others Open	One Open/On, All Others Closed/Off	One Modulating, All Others Closed/Off	Any On	Any On	Off	100% Open	Closed	Closed
#3: More than one Chiller Enabled	Both Closed	More than one Open/On	More than one modulating	Any On	Any On	Off	100% Open	Closed	Closed
#4: Waterside Economizer-only	All Open	All Closed/Off	All Closed/Off	Any On	Any On	On	< 100% Open	Open	Open
#5: Integrated Waterside Economizer	Any Open or Any Closed	Any Open/On or Any Closed/Off	Any Modulating or Any Closed/Off	Any On	Any On	On	< 100% Open	Open	Closed

5.20.18.3. The following points must be available to the AFDD routines for the chilled water plant:

Retain the following two variables for primary-secondary plants and primary-only plants where pump speed is controlled to maintain differential pressure. Delete otherwise.

a. DP = Chilled water loop differential pressure (each loop, where applicable)

b. DPSP = Chilled water loop differential pressure setpoint (each loop, where applicable)

Retain the following variable if there is a flow meter in the primary loop. Delete otherwise.

c. $FLOW_P$ = Primary chilled water flow

Retain the following variable if there is a flow meter in the secondary loop. Delete otherwise.

d. FLOW_{S} = Secondary chilled water flow

Retain the following two variables for Primary-only chilled water plants with a minimum flow bypass valve. Delete otherwise.

e. MFBPV = Chilled water minimum flow bypass valve command; 0% d MFBPV d 100%

f. CHW-MinFlowSP = Effective minimum chilled water flow setpoint (MinFlowRatio multiplied by the sum of CHW-DesFlowX of enabled chillers).

Retain the following two variables for water-cooled plants. Delete otherwise.

g. SpeedCT = Cooling tower speed command; 0% d SpeedCT d 100%

h. $\text{Status}_{\text{CWP}}$ = Lead condenser water pump status

i. $\text{Status}_{\text{PCHWP}}$ = Lead primary chilled water pump status

Retain the following variable for primary-secondary plants. Delete otherwise.

j. $\text{Status}_{\text{SCHWP}}$ = Lead secondary chilled water pump status

Retain the following variable for plants with waterside economizers where CHW flow through the WSE is controlled by a variable speed HX pump. Delete otherwise.

k. $\text{Status}_{\text{WSEHXP}}$ = Waterside economizer heat exchanger pump status

l. CHWST = Common chilled water supply temperature leaving the chillers

m. CHWSTSP = Chilled water supply temperature setpoint

n. CHWRT = Common chilled water return temperature entering the chillers

Retain the following two variables for water-cooled plants. Delete otherwise.

o. CWST = Condenser water supply temperature

p. CWSTdes = Lowest condenser water supply temperature at chiller selection conditions for chillers; CWSTdes shall be the lowest CWSTdesX of all chillers

Retain the following two variables for plants with waterside economizers. Delete otherwise.

q. $\text{CHWRT}_{\text{BeforeWSE}}$ = Chilled water return temperature before the waterside economizer

r. $\text{CHWRT}_{\text{AfterWSE}}$ = Chilled water return temperature after the waterside economizer

s. $\text{CHWST}_{\text{CH-x}}$ = CH-x chilled water supply temperature (each chiller)

t. $\text{CHWRT}_{\text{CH-x}}$ = CH-x chilled water return temperature (each chiller)

Retain the following two variables for water-cooled plants. Delete otherwise.

u. CWSTCH-x = CH-x condenser water supply temperature (each chiller)

v. CWRTCH-x = CH-x condenser water return temperature (each chiller)

Retain the following two variables for plants with waterside economizers. Delete otherwise.

w. $CWRT_{HX}$ = Waterside economizer condenser water return temperature

x. DAHX = Design heat exchanger approach

y. RefrigEvapTempCH-x = CH-x refrigerant evaporating temperature (each chiller)

Retain the following variable for water-cooled plants. Delete otherwise.

z. RefrigCondTempCH-x = CH-x refrigerant condensing temperature (each chiller)

aa. CHW-ISOCH-x = CH-x chilled water isolation valve commanded position (each chiller)

Retain the following variable for water-cooled plants with headered CW pumps. Delete otherwise.

bb. CW-ISOCH-x = CH-x condenser water isolation valve commanded position; 0% d CW-ISOCH-x d 100% if modulating, open/closed if two-position (each chiller)

Retain the following variable for plants with waterside economizers where CHW flow through the WSE is controlled by a modulating diverting valve. Delete otherwise.

cc. WSE-HX-CHW-DIV = Waterside economizer chilled water diverting valve commanded position; 0% d WSE-HX-CHW-DIV d 100%

Retain the following variable for plants with waterside economizers. Delete otherwise.

dd. WSE-HX-CW-ISO = Waterside economizer condenser water isolation valve commanded position; open/closed

Retain the following variable for plants where system gauge pressure is monitored. Delete otherwise.

ee. PGAUGE = Chilled water system gauge pressure

The chiller chilled water supply temperature, chiller condenser water return temperature, refrigerant evaporating and condensing temperature points are listed as optional in 4.10.1 because they are typically networked points that are read via a chiller network interface rather than through hardwired connections. Where a chiller network interface or specific points are not available, omit the associated fault conditions.

5.20.18.4. The following values must be continuously calculated by the AFDD routines:

a. 5-minute rolling averages with 1-minute sampling time of the following point values; operator shall have the ability to adjust the averaging window and sampling period for each point independently

1. $CHWST_{AVG}$ = rolling average of the common chilled water supply temperature

2. $CHWRT_{AVG}$ = rolling average of the common chilled water return temperature

Retain the following two variables for plants with waterside economizers. Delete otherwise.

3. $CHWRT_{BEFOREWSE, AVG}$ = rolling average of the chilled water return temperature before the waterside economizer

4. $CHWRT_{AFTERWSE, AVG}$ = rolling average of the chilled water return temperature after the waterside economizer

Retain the following four variables for water-cooled plants. Delete otherwise.

5. $CWST_{AVG}$ = rolling average of the common condenser water supply temperature
6. $CWRT_{AVG}$ = rolling average of the common condenser water return temperature
7. $CWST_{CH-x, AVG}$ = rolling average of CH-x condenser water supply temperature (each chiller)
8. $CWRT_{CH-x, AVG}$ = rolling average of CH-x condenser water return temperature (each chiller)
9. $CHWST_{CH-x, AVG}$ = rolling average of CH-x chilled water supply temperature (each chiller)
10. $CHWRT_{CH-x, AVG}$ = rolling average of CH-x chilled water return temperature (each chiller)

Retain the following variable for plants with waterside economizers. Delete otherwise.

11. $CWRT_{HX, AVG}$ = rolling average of the waterside economizer heat exchanger condenser water return temperature

Retain the following variable for plants where system gauge pressure is monitored. Delete otherwise.

12. $P_{GAUGE, AVG}$ = rolling average of chilled water system gauge pressure

Retain the following variable for primary-secondary plants and primary-only plants where pump speed is controlled to maintain differential pressure. Delete otherwise.

13. DP_{AVG} = rolling average of loop differential pressure (each loop, where applicable)

Retain the following variable if there is a flow meter in the primary loop. Delete otherwise.

14. $FLOW_{P, AVG}$ = rolling average of primary chilled water flow

Retain the following variable if there is a flow meter in the secondary loop. Delete otherwise.

15. $FLOW_{S, AVG}$ = rolling average of secondary chilled water flow

Retain the following variable for water-cooled plants. Delete otherwise.

16. RefrigCondTempCH-x, AVG = rolling average of CH-x refrigerant condensing temperature (each chiller)
17. RefrigEvapTempCH-x, AVG = rolling average of CH-x refrigerant evaporating temperature (each chiller)

b. CHW-FlowCH-X (each chiller)

Retain the following clause for plants with parallel chillers and headered primary chilled water pumps. Delete otherwise.

1. For plants with parallel chillers and headered primary chilled water pumps: 1 if $CHW\text{-}ISO_{CH-x} > 0$, 0 if $CHW\text{-}ISO_{CH-X} = 0$

Retain the following clause for plants with parallel chillers and dedicated primary chilled water pumps. Delete otherwise.

2. For plants with parallel chillers and dedicated primary chilled water pumps: 1 if $Status_{PCHWP}$ = On, 0 if $Status_{PCHWP}$ = Off.

Retain the following clause for plants with series chillers. Delete otherwise.

3. For plants with series chillers: 1 if $CHW\text{-}ISO_{CH\text{-}x}$ <100, 0 if $CHW\text{-}ISO_{CH\text{-}X}$ = 100 (each chiller)

Retain the following variable for water-cooled plants. Delete otherwise.

c. CW-FlowCH-X (each chiller)

Retain the following clause for plants with headered condenser water pumps and modulating condenser water isolation valves. Delete otherwise.

1. For plants with headered condenser water pumps and if condenser water isolation valve is modulating: 1 if $CW\text{-}ISO_{CH\text{-}x}$ > 0% open, 0 if $CW\text{-}ISO_{CH\text{-}X}$ = 0% open (each chiller)

Retain the following clause for plants with headered condenser water pumps and two-position condenser water isolation valves. Delete otherwise.

2. For plants with headered condenser water pumps and if condenser water isolation valve is two-position: 1 if $CW\text{-}ISO_{CH\text{-}X}$ = open, 0 if $CW\text{-}ISO_{CH\text{-}X}$ = closed (each chiller)

Retain the following clause for plants with dedicated condenser water pumps. Delete otherwise.

3. For plants with dedicated condenser pumps: 1 if $Status_{CWP}$ = on, 0 if $Status_{CWP}$ = off

d. ΔOS = number of changes in Operating State during the previous 60 minutes (moving window)

e. ΔStage = number of chilled water plant stage changes during the previous 60 minutes (moving window)

f. StartsCH-x = number of CH-x starts in the last 60 mins (each chiller)

5.20.18.5. The following internal variables shall be defined. All parameters are adjustable by the operator, with initial values as given below:

The default values have been intentionally biased towards minimizing false alarms at the expense of missing real alarms. This avoids excessive false alarms that will erode user confidence and responsiveness. However, if the goal is to achieve the best possible energy performance and system operation, these values should be adjusted based on field measurement and operational experience.

Values for physical factors such as pump heat and sensor error can be measured in the field or derived from trend logs and hardware submittals. Likewise, the switch delays can be refined by observing the time required to achieve quasi steady state operation in trend data.

Other factors can be tuned by observing false positives and false negatives (i.e., unreported faults). If transient conditions or noise cause false alarms, increase the alarm delay. Likewise, failure to report real faults can be addressed by adjusting the temperature, pressure or flow thresholds.

Variable Name	Description	Default Value
$_{CHWT}$	Temperature error threshold for chilled water temperature sensors	2°F
Retain the following variable for water-cooled plants. Delete otherwise.		

Variable Name	Description	Default Value
$_{CWT}$	Temperature error threshold for condenser water temperature sensors	2°F
Retain the following variable for primary-secondary and primary-only plants where pump speed is controlled to maintain differential pressure. Delete otherwise.		
$_{DP}$	Differential pressure error threshold for DP sensor	2 psi
Retain the following variable for plants with a flow meter. Delete otherwise.		
$_{FM}$	Flow error threshold for flow meter	20 gpm
$_{VFDSPD}$	VFD speed error threshold	5%
Retain the following variable for primary-only plants with a minimum flow bypass valve. Delete otherwise.		
$_{MFBVP}$	Minimum flow bypass valve position error threshold	5%
Retain the following variable for plants where system gauge pressure is monitored. Delete otherwise.		
CHW-ETPreChargePress	Chilled water system expansion tank pre-charge pressure	See mechanical schedule (psig)
Retain the following variable for water-cooled plants. Delete otherwise.		
$Approach_{COND}$	Condenser approach threshold	4°F
$Approach_{EVAP}$	Evaporator approach threshold	3°F
$CHStarts_{MAX}$	Maximum number of chiller starts during the previous 60 minutes (moving window)	2
ΔOS_{MAX}	Maximum number of changes in Operating State during the previous 60 minutes (moving window)	2
$\Delta Stage_{MAX}$	Maximum number of chilled water plant stage changes during the previous 60 minutes (moving window)	2
StageDelay	Time in minutes to suspend Fault Condition evaluation after a change in stage	30
AlarmDelay	Time in minutes that a Fault Condition must persist before triggering an alarm	30
TestModeDelay	Time in minutes that Test Mode is enabled	120

TestModeDelay ensures that normal fault reporting occurs after the testing and commissioning process is completed as prescribed in 5.20.18.12.

5.20.18.6. The following are potential Fault Conditions that can be evaluated by the AFDD routines. If the equation statement is true, then the specified fault condition exists. The Fault Conditions to be evaluated at any given time will depend on the Operating State of the chilled water plant.

Edit the table below. Remove fault conditions that do not apply.

Retain the following fault condition for plants with any chilled water pumps controlled to maintain differential pressure. Delete otherwise. Duplicate the following fault condition for each differential pressure sensor.

FC#1	**Equation**	$DP_{AVG} > {}_{DSP}$ and $Status_{CHWP} = Off$	**Applies to OS #1**
	Description	Differential pressure is too high with the chilled water pumps off	
	Possible Diagnosis	DP sensor error	
Retain the following fault condition if there is a flow meter in the primary loop. Delete otherwise.			
FC#2	**Equation**	$FLOW_{P,\ AVG} > {}_{FM}$ and $Status_{PCHWP} = Off$	**Applies to OS #1**
	Description	Primary chilled water flow is too high with the chilled water pumps off	
	Possible Diagnosis	Flow meter error	
Retain the following fault condition for primary-secondary plants with a flow meter in the secondary loop. Delete otherwise. Duplicate the following fault condition for each secondary loop flow meter.			
FC#3	**Equation**	$FLOW_{S,\ AVG} > {}_{FM}$ and $Status_{SCHWP} = Off$	**Applies to OS #1**
	Description	Secondary chilled water flow is too high with the chilled water pumps off	
	Possible Diagnosis	Flow meter error	
Retain the following fault condition for primary-secondary plants and primary-only plants where pump speed is controlled to maintain differential pressure. Delete otherwise. Duplicate the following fault condition for each differential pressure sensor and/or each secondary loop where pump speed is controlled to maintain differential pressure.			
FC#4	**Equation**	$DP_{AVG} < DPSP - {}_{DP}$ and $Speed_{CHWP}$ e $99\% - {}_{VFDSPD}$	**Applies to OS #2 – #5**
	Description	Chilled water loop differential pressure is too low with chilled water pump(s) at full speed.	
	Possible Diagnosis	Problem with VFD Mechanical problem with pump(s) Pump(s) are undersized Differential pressure setpoint is too high CHWST is too high Primary flow is higher than the design evaporator flow of the operating chillers	

Retain the following fault condition for primary-only plants with a minimum flow bypass valve. Delete otherwise.			
FC#5	**Equation**	$\text{FLOW}_{P,\ AVG} < \text{CHW-MinFlowSp} - {}_{FM}$ and $\text{MFBPV e } 99\% - {}_{MFBPV}$	**Applies to OS #2, #3, #5**
	Description	Primary chilled water flow is too low with the minimum flow bypass valve fully open.	
	Possible Diagnosis	Problem with minimum flow bypass valve Problem with chiller CHW isolation valves Minimum loop differential pressure setpoint too low	
FC#6	**Equation**	$\text{CHWST}_{AVG} - {}_{CHWT} \text{ e CHWSTSP}$	**Applies to OS #2 – #5**
	Description	Chilled water supply temperature is too high	
	Possible Diagnosis	Mechanical problem with chillers Primary flow is higher than the design evaporator flow of the operating chillers	
Retain the following fault condition for plants where system gauge pressure is monitored. Delete otherwise.			
FC#7	**Equation**	$\text{CHW-P}_{GAUGE,\ AVG} < 0.9 * \text{CHW-ETPreChargePress}$	**Applies to OS #1 – #5**
	Description	Chilled water system gauge pressure is too low	
	Possible Diagnosis	Possible chilled water system leak	
Retain the following fault condition for water-cooled plants with chiller network interfaces. Delete otherwise.			
FC#8	**Equation**	$\text{Approach}_{COND} \text{ e RefrigCondTemp}_{CH\text{-}x,\ AVG} - \text{CWRT}_{CH\text{-}x,\ AVG}$	**Applies to OS #2, #3, #5**
	Description	Condenser approach is too high	
	Possible Diagnosis	Possible condenser fouling or blocked condenser tubes Low condenser water temperature Low condenser water flow	
Retain the following fault condition for plants with chiller network interfaces. Delete otherwise.			
FC#9	**Equation**	$\text{Approach}_{EVAP} \text{ e CHWST}_{CH\text{-}x,\ AVG} - \text{RefrigEvapTemp}_{CH\text{-}x,\ AVG}$	**Applies to OS #2, #3, #5**
	Description	Evaporator approach is too high	
	Possible Diagnosis	Possible evaporator fouling or blocked evaporator tubes Low refrigeration charge Contaminated refrigeration charge	

Retain the following fault condition for parallel chilled water plants with chiller network interfaces. Delete otherwise.			
FC#10	**Equation**	$\lvert(\ (CHW\text{-}Flow_{CH\text{-}X} * CHWST_{CH\text{-}X}) /\ \ CHW\text{-}Flow_{CH\text{-}X}) - CHWST_{AVG}\rvert > {}_{CHWT}$ and $\ CHW\text{-}Flow_{CH\text{-}X} = 1$	**Applies to OS #2, #5**
	Description	Deviation between the active chiller chilled water supply temperature and the common chilled water supply temperature is too high.	
	Possible Diagnosis	A chilled water supply temperature sensor is out of calibration	
Retain the following fault condition for parallel chilled water plants with chiller network interfaces. Delete otherwise.			
FC#11	**Equation**	$\lvert(\ (CHW\text{-}Flow_{CH\text{-}X} * CHWRT_{CH\text{-}X}) /\ \ CHW\text{-}Flow_{CH\text{-}X}) - CHWRT_{AVG}\rvert > {}_{CHWT}$ and $\ CHW\text{-}Flow_{CH\text{-}X} = 1$	**Applies to OS #2, #5**
	Description	Deviation between the active chiller chilled water return temperature and the common chilled water return temperature is too high.	
	Possible Diagnosis	A chilled water return temperature sensor is out of calibration	
Retain the following two fault conditions for water-cooled plants with chiller network interfaces. Delete otherwise.			
FC#12	**Equation**	$\lvert(\ (CW\text{-}Flow_{CH\text{-}X} * CWST_{CH\text{-}X}) /\ \ CW\text{-}Flow_{CH\text{-}X}) - CWST_{AVG}\rvert > {}_{CWT}$ and $\ CW\text{-}Flow_{CH\text{-}X} = 1$	**Applies to OS #2**
	Description	Deviation between the active chiller condenser water supply temperature and the common condenser water supply temperature is too high.	
	Possible Diagnosis	A condenser water supply temperature sensor is out of calibration	
FC#13	**Equation**	$\lvert(\ (CW\text{-}Flow_{CH\text{-}X} * CWRT_{CH\text{-}X}) /\ \ CW\text{-}Flow_{CH\text{-}X}) - CWRT_{AVG}\rvert > {}_{CWT}$ and $\ CW\text{-}Flow_{CH\text{-}X} = 1$	**Applies to OS #2**
	Description	Deviation between the active chiller condenser water return temperature and the common condenser water return temperature is too high.	
	Possible Diagnosis	A condenser water return temperature sensor is out of calibration	
Retain the following fault condition for water-cooled plants. Delete otherwise.			

FC#14	**Equation**	$CWST_{AVG}$ - $_{CWT}$ e DesCWSTdes and SpeedCT e 99% - $_{VFDSPD}$	**Applies to OS #2, #3**
	Description	Condenser water supply temperature is too high with cooling tower(s) at full speed.	
	Possible Diagnosis	Problem with cooling tower VFD Mechanical problem with cooling tower(s) Cooling tower(s) undersized	
Retain the following three fault conditions for plants with a waterside economizer. Delete otherwise.			
FC#15	**Equation**	$\lvert CWRT_{HX, AVG} - CWRT_{AVG} \rvert >$ $_{CWT}$ and $CW\text{-}Flow_{CH\text{-}X} = 0$ and WSE-HX-CW-ISO = 1	**Applies to OS #4**
	Description	Deviation between the active waterside economizer condenser water return temperature and the common condenser water return temperature is too high.	
	Possible Diagnosis	A condenser water return temperature sensor is out of calibration	
FC#16	**Equation**	$CWST_{AVG} - CHWRT_{AFTERWSE, AVG} > (1.5 * DA_{HX}) +$ $_{CHWRT}$	**Applies to OS #4, #5**
	Description	Heat exchanger approach is high	
	Possible Diagnosis	Possible heat exchanger fouling or blocked heat exchanger tubes	
FC#17	**Equation**	$\lvert$ CHWRTBeforeWSE - CHWRTAfterWSE $\rvert >$ $_{CHWT}$ and $Status_{WSE\text{-}HX\text{-}P}$ = Off (if HX Pump) or WSE-HX-CHW-DIV = 100% (if diverting valve)	**Applies to OS #4, #5**
	Description	Deviation between the chilled water return temperature before and after the waterside economizer is too high.	
	Possible Diagnosis	A chilled water return temperature sensor is out of calibration	
FC#18	**Equation**	$\Delta OS > \Delta OS_{MAX}$	**Applies to OS #1 – #5**
	Description	Too many changes in Operating State	
	Possible Diagnosis	Unstable control due to poorly tuned loop or mechanical problem	
FC#19	**Equation**	$\Delta StartsCH\text{-}x > \Delta CHStart_{MAX}$	**Applies to OS #2, #3, #5**
	Description	Too many chiller starts	
	Possible Diagnosis	Chiller is cycling due to load loads. Chiller is oversized and/or has insufficient turndown capability. Chiller stage-up threshold may be set too low.	
FC#20	**Equation**	$\Delta Stage > \Delta Stage_{MAX}$	**Applies to OS #1 – #5**
	Description	Too many stage changes	
	Possible Diagnosis	Staging thresholds and/or delays need to be adjusted	

5.20.18.7. A subset of all potential fault conditions is evaluated by the AFDD routines. The set of applicable fault conditions depends on the Operating State of the plant:

Edit the list of operating states and associated fault conditions to match those in the operating state and fault condition tables above.

a. In OS #1 (Disabled), the following Fault Conditions shall be evaluated:

1. FC#1: Differential pressure is too high with the chilled water pumps off
2. FC#2: Primary chilled water flow is too high with the primary chilled water pumps off
3. FC#3: Secondary chilled water flow is too high with the secondary chilled water pumps off
4. FC#7: Chilled water system gauge pressure is too low
5. FC#18: Too many changes in operating state
6. FC#20: Too many stage changes

b. In OS#2 (One chiller enabled without WSE), the following Fault Conditions shall be evaluated:

1. FC#4: Chilled water loop differential pressure is too low with chilled water pump(s) at full speed.
2. FC#5: Primary chilled water flow is too low with the minimum flow bypass valve fully open.
3. FC#6: Chilled water supply temperature is too high
4. FC#7: Chilled water system gauge pressure is too low
5. FC#8: Condenser approach is too high
6. FC#9: Evaporator approach is too high
7. FC#10: A chilled water supply temperature sensor is out of calibration
8. FC#11: A chilled water return temperature sensor is out of calibration
9. FC#12: A condenser water supply temperature sensor is out of calibration
10. FC#13: A condenser water return temperature sensor is out of calibration
11. FC#14: Condenser water supply temperature is too high with cooling tower(s) at full speed
12. FC#18: Too many changes in Operating State
13. FC#19: Too many chiller starts
14. FC#20: Too many stage changes

c. In OS#3 (More than one chiller enabled), the following Fault Conditions shall be evaluated:

1. FC#4: Chilled water loop differential pressure is too low with chilled water pump(s) at full speed.
2. FC#5: Primary chilled water flow is too low with the minimum flow bypass valve fully open.

3. FC#6: Chilled water supply temperature is too high
4. FC#7: Chilled water system gauge pressure is too low
5. FC#8: Condenser approach is too high
6. FC#9: Evaporator approach is too high
7. FC#14: Condenser water supply temperature is too high with cooling tower(s) at full speed
8. FC#18: Too many changes in Operating State
9. FC#19: Too many chiller starts
10. FC#20: Too many stage changes

d. In OS#4 (Waterside Economizer-only), the following Fault Conditions shall be evaluated:

1. FC#4: Chilled water loop differential pressure is too low with chilled water pump(s) at full speed.
2. FC#6: Chilled water supply temperature is too high
3. FC#7: Chilled water system gauge pressure is too low
4. FC#15: A condenser water return temperature sensor is out of calibration
5. FC#16: Heat exchanger approach is high
6. FC#17: Deviation between the chilled water return temperature before and after the waterside economizer is too high
7. FC#18: Too many changes in Operating State
8. FC#20: Too many stage changes

e. In OS#5 (Integrated waterside economizer), the following Fault Conditions shall be evaluated:

1. FC#4: Chilled water loop differential pressure is too low with chilled water pump(s) at full speed.
2. FC#5: Primary chilled water flow is too low with the minimum flow bypass valve fully open.
3. FC#6: Chilled water supply temperature is too high
4. FC#7: Chilled water system gauge pressure is too low
5. FC#8: Condenser approach is too high
6. FC#9: Evaporator approach is too high
7. FC#10: A chilled water supply temperature sensor is out of calibration
8. FC#11: A chilled water return temperature sensor is out of calibration
9. FC#16: Heat exchanger approach is high
10. FC#17: Deviation between the chilled water return temperature before and after the waterside economizer is too high

11. FC#18: Too many changes in Operating State

12. FC#19: Too many chiller starts

13. FC#20: Too many stage changes

5.20.18.8. For each chiller, the operator shall be able to suppress the alarm for any Fault Condition.

5.20.18.9. Evaluation of Fault Conditions shall be suspended under the following conditions:

a. When no pumps are operating.

b. For a period of StageDelay minutes following a change in plant stage.

5.20.18.10. Fault Conditions that are not applicable to the current Operating State shall not be evaluated.

5.20.18.11. A Fault Condition that evaluates as true must do so continuously for AlarmDelay minutes before it is reported to the operator.

5.20.18.12. Test Mode shall temporarily set StageDelay and AlarmDelay to 0 minutes for a period of TestModeDelay minutes to allow instant testing of the AFDD system and to ensure normal fault detection occurs after testing is complete.

5.20.18.13. When a Fault Condition is reported to the operator, it shall be a Level 3 alarm and shall include the description of the fault and the list of possible diagnoses from the table in 5.20.18.6.

Add the following figures to Informative Appendix A:

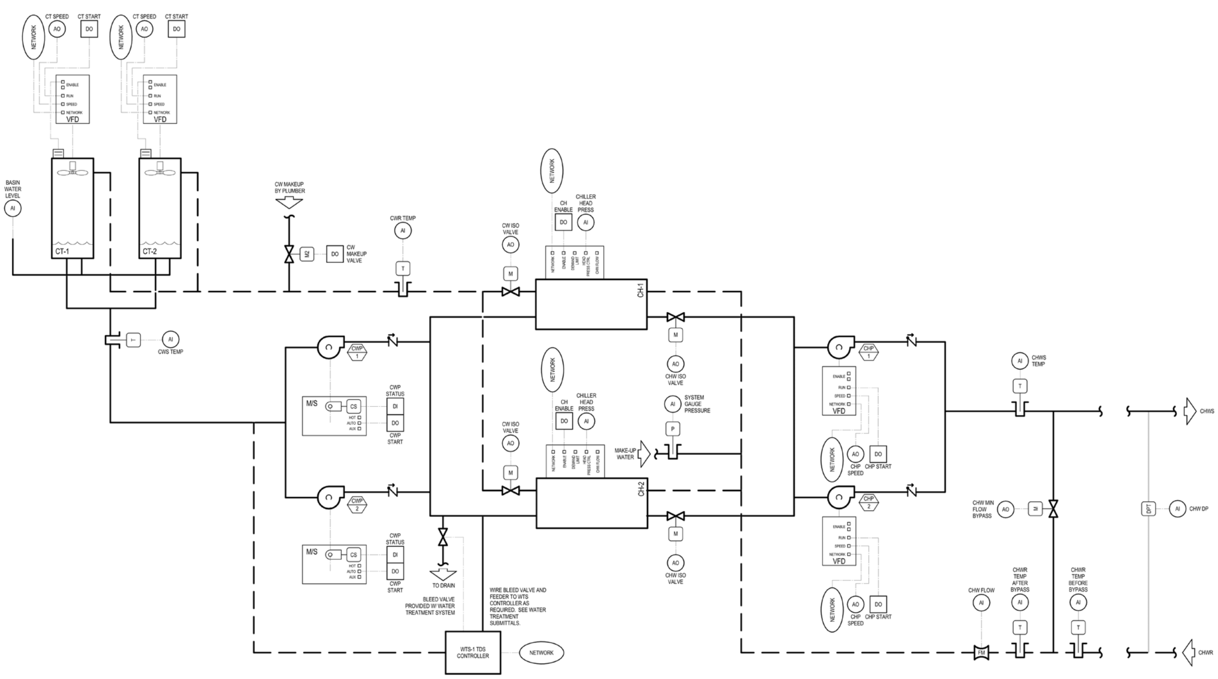


Figure A-14 Chilled water plant with parallel chillers, variable primary distribution, constant speed CW pumps, and headered pumps

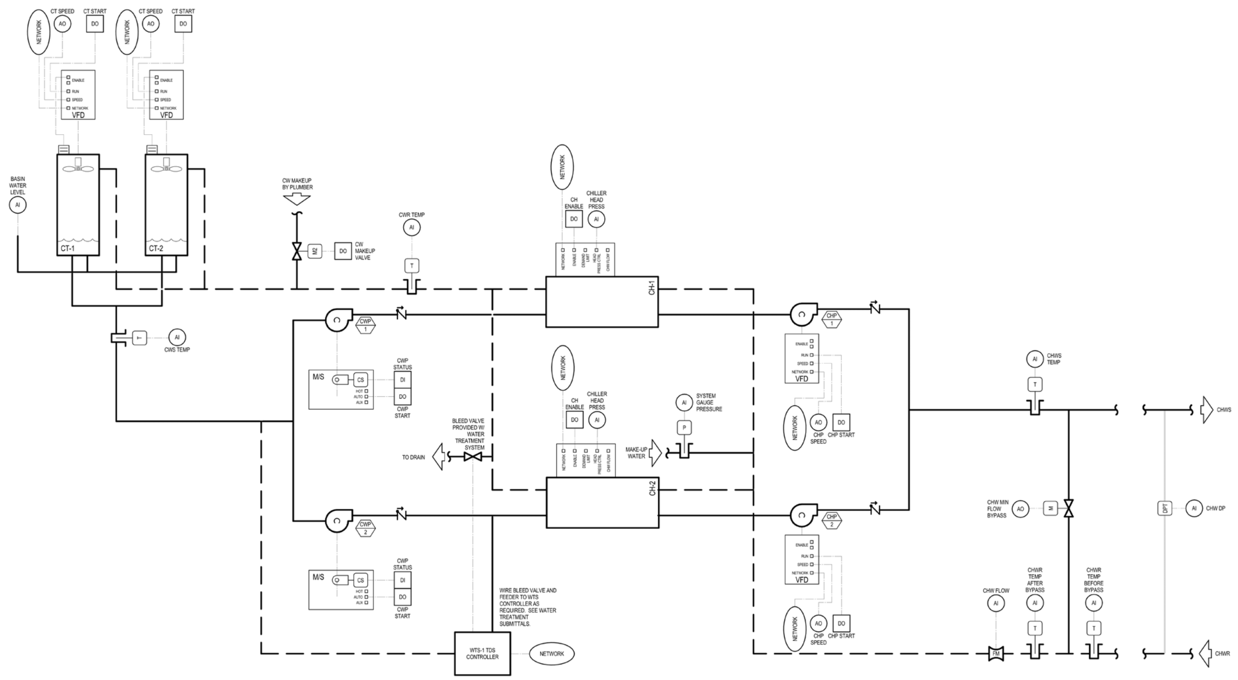


Figure A-15 Chilled water plant with parallel chillers, variable primary distribution, constant speed CW pumps, and dedicated pumps

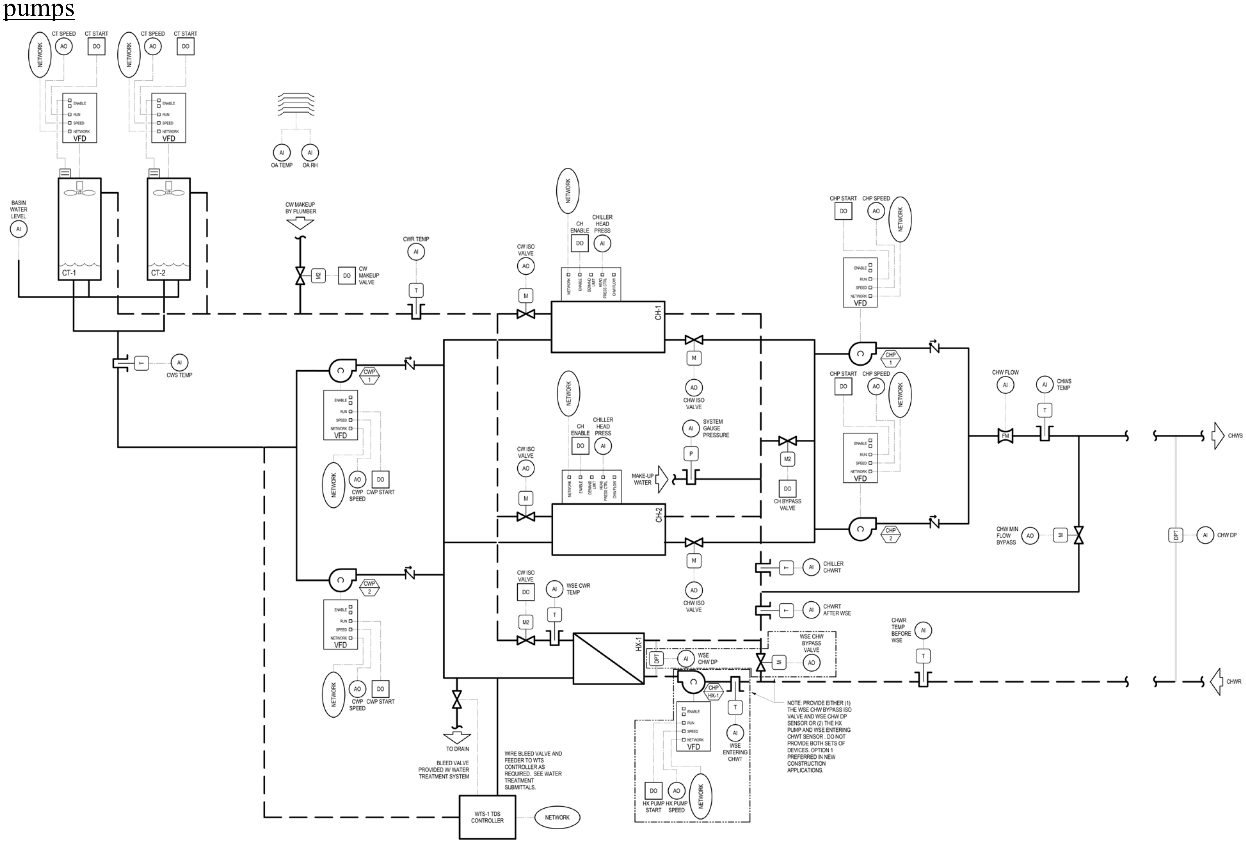


Figure A-16 Chilled water plant with parallel chillers and WSE, variable primary distribution, variable speed CW pumps, and headered pumps

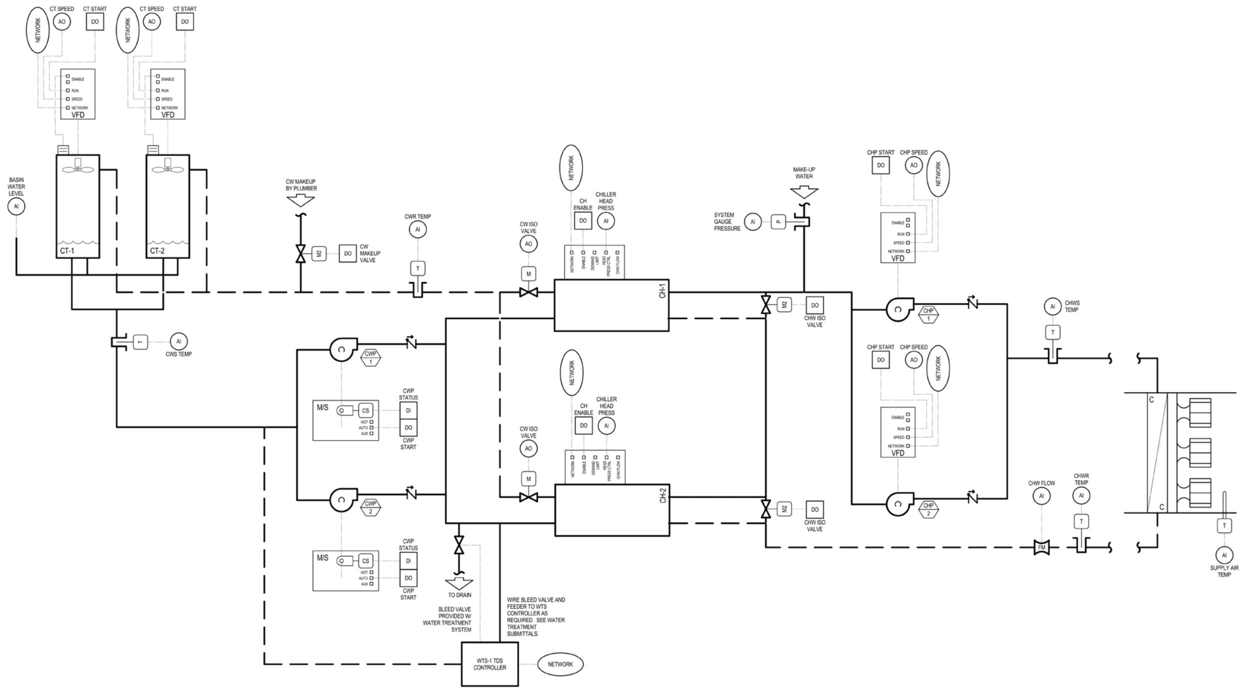


Figure A-17 Chilled water plant with series chillers, constant primary distribution, constant speed CW pumps, and headered pumps

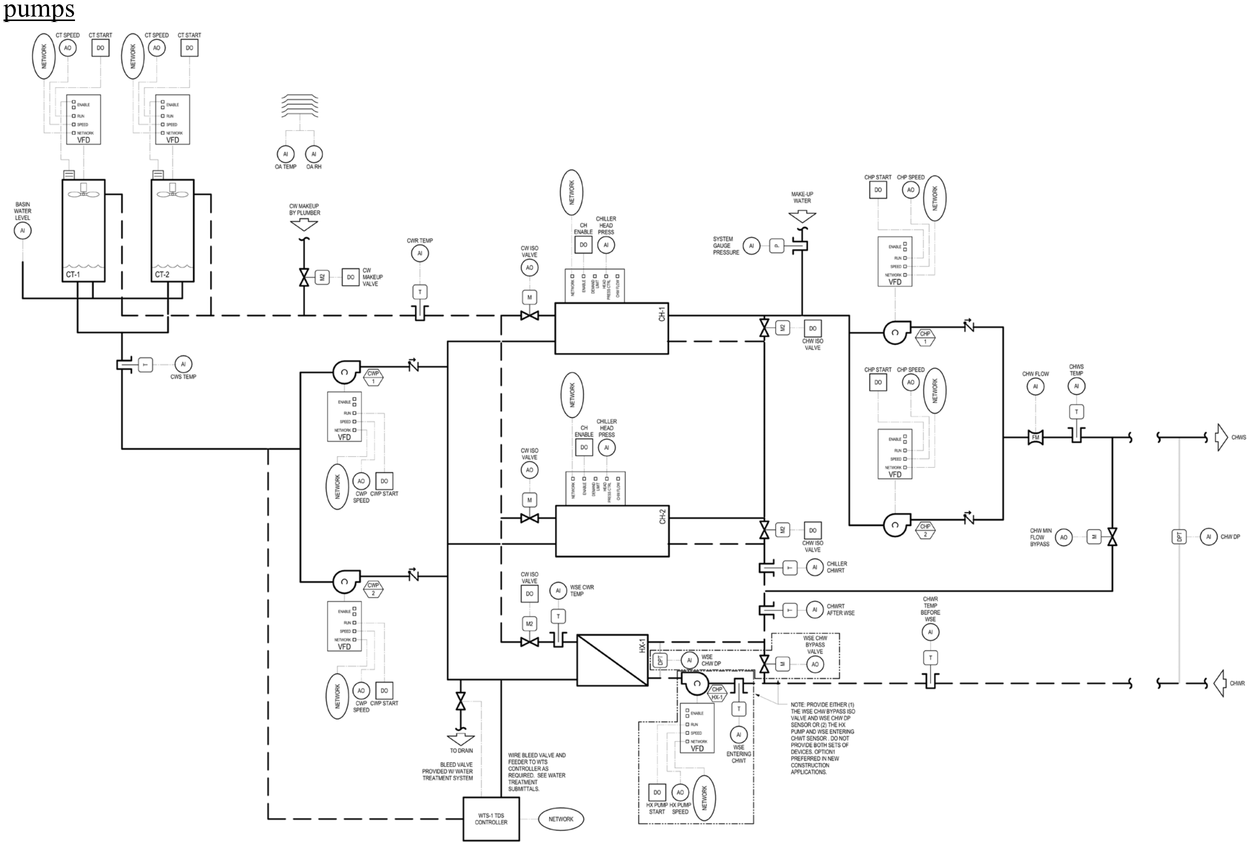


Figure A-18 Chilled water plant with series chillers and WSE, variable primary distribution, variable speed CW pumps, and headered pumps

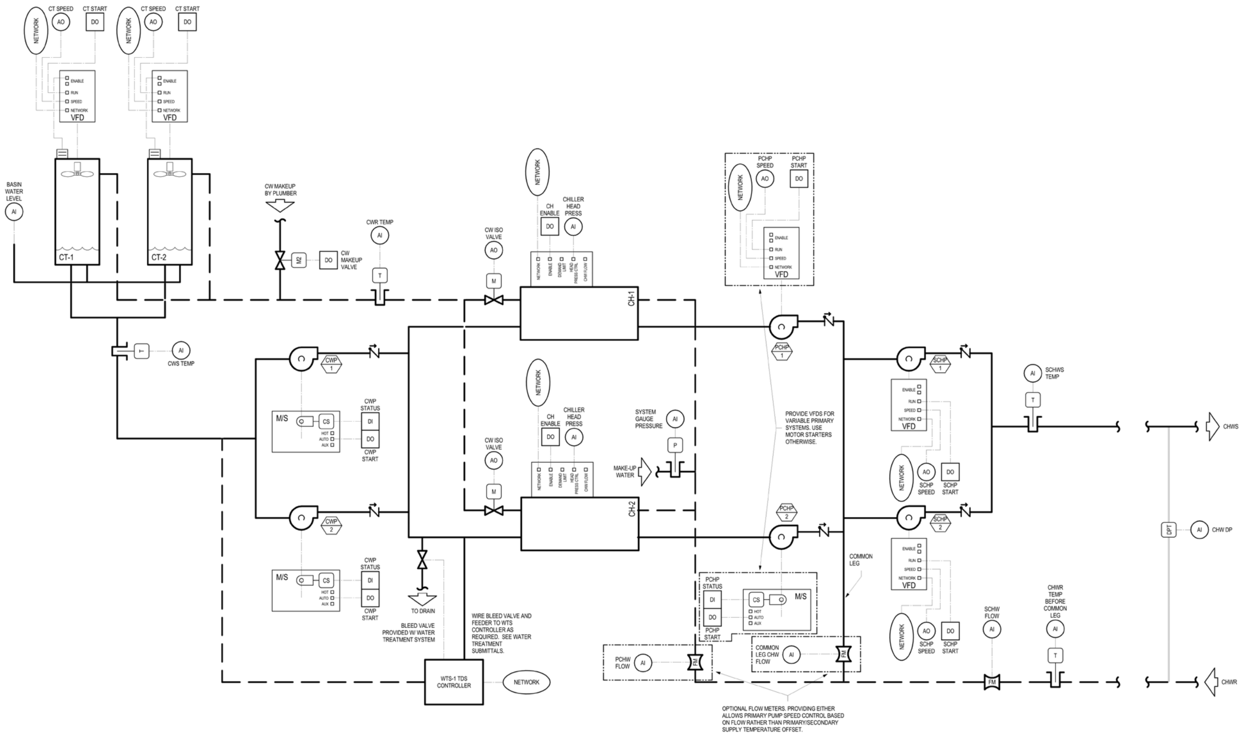


Figure A-19 Chilled water plant with parallel chillers, primary-secondary distribution, constant speed CW pumps, dedicated primary CHW pumps, and headered CW pumps

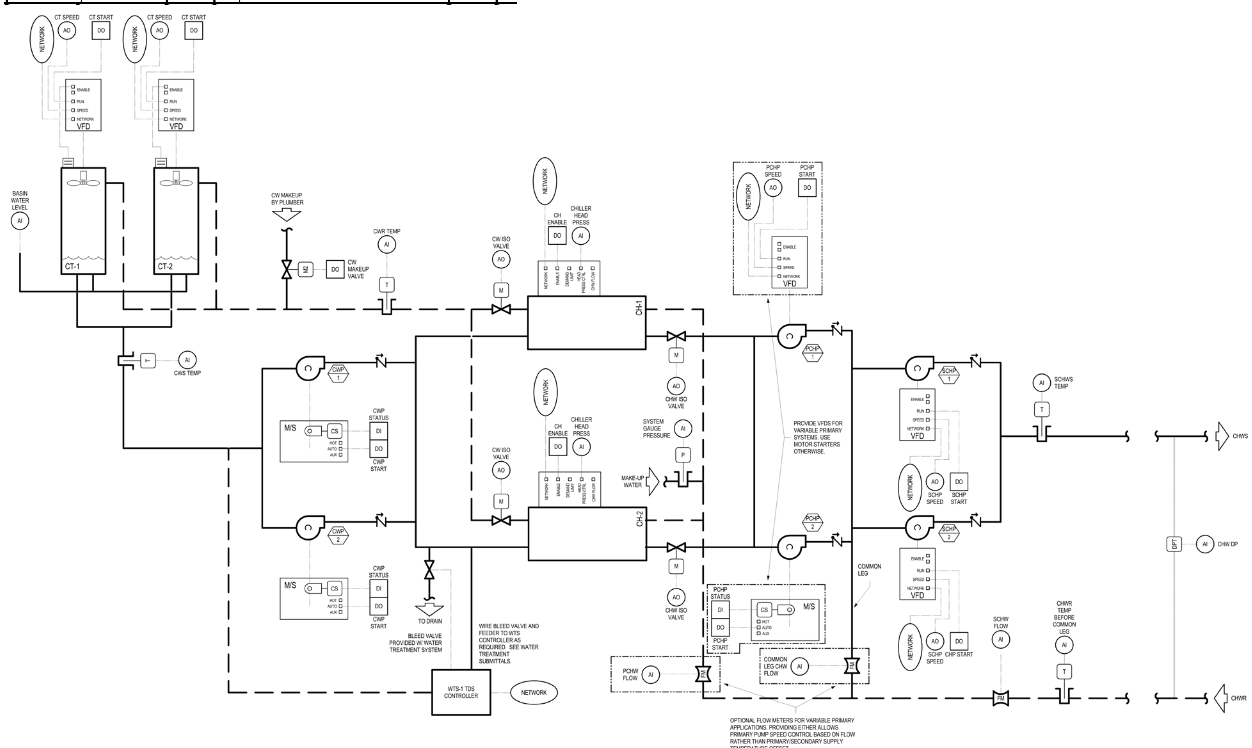


Figure A-20 Chilled water plant with parallel chillers, primary-secondary distribution, constant speed CW pumps, and headered pumps

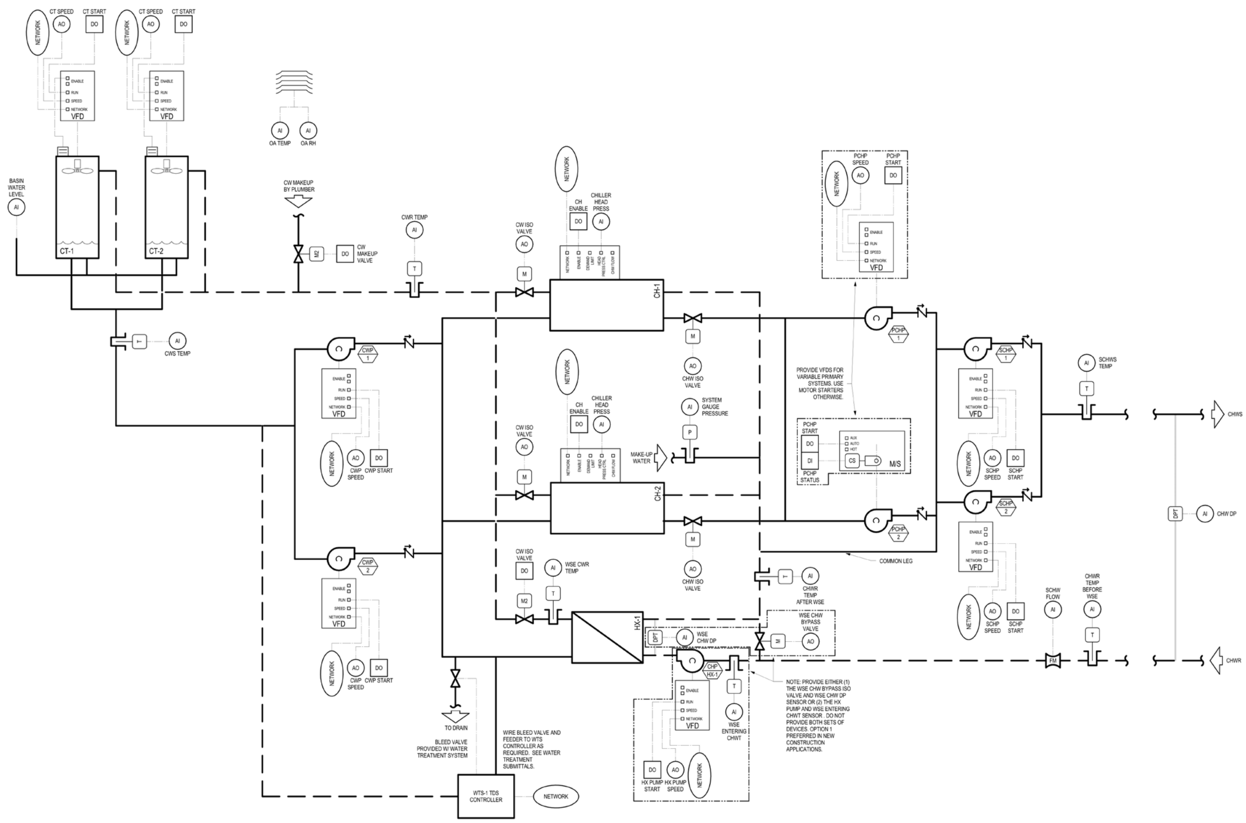


Figure A-21 Chilled water plant with parallel chillers and WSE, primary-secondary distribution, variable speed CW pumps, and headered pumps

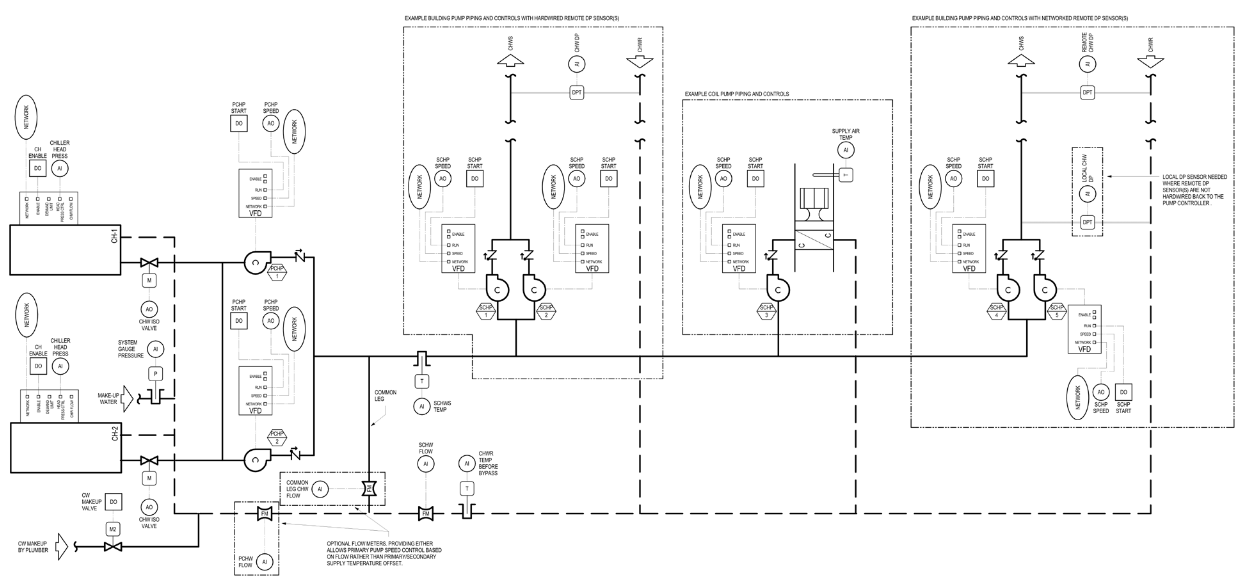


Figure A-22 Chilled water plant with parallel chillers, primary-distributed secondary distribution (CHW side only)

POLICY STATEMENT DEFINING ASHRAE'S CONCERN FOR THE ENVIRONMENTAL IMPACT OF ITS ACTIVITIES

ASHRAE is concerned with the impact of its members' activities on both the indoor and outdoor environment. ASHRAE's members will strive to minimize any possible deleterious effect on the indoor and outdoor environment of the systems and components in their responsibility while maximizing the beneficial effects these systems provide, consistent with accepted Standards and the practical state of the art.

ASHRAE's short-range goal is to ensure that the systems and components within its scope do not impact the indoor and outdoor environment to a greater extent than specified by the Standards and Guidelines as established by itself and other responsible bodies.

As an ongoing goal, ASHRAE will, through its Standards Committee and extensive Technical Committee structure, continue to generate up-to-date Standards and Guidelines where appropriate and adopt, recommend, and promote those new and revised Standards developed by other responsible organizations.

Through its *Handbook*, appropriate chapters will contain up-to-date Standards and design considerations as the material is systematically revised.

ASHRAE will take the lead with respect to dissemination of environmental information of its primary interest and will seek out and disseminate information from other responsible organizations that is pertinent, as guides to updating Standards and Guidelines.

The effects of the design and selection of equipment and systems will be considered within the scope of the system's intended use and expected misuse. The disposal of hazardous materials, if any, will also be considered.

ASHRAE's primary concern for environmental impact will be at the site where equipment within ASHRAE's scope operates. However, energy source selection and the possible environmental impact due to the energy source and energy transportation will be considered where possible. Recommendations concerning energy source selection should be made by its members.

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As an industry leader in research, standards writing, publishing, certification, and continuing education, ASHRAE and its members are dedicated to promoting a healthy and sustainable built environment for all, through strategic partnerships with organizations in the HVAC&R community and across related industries.

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