ASHRAE

ADDENDA

ASHRAE Addendum y 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 HW 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 y to Guideline 36-2018

Add Section 3.1.8. as follows:

3.1.8. Hot Water Plant

3.1.8.1. Temperature Setpoints

a. HWSTmax, the highest hot water supply temperature setpoint

Retain the following parameter for hybrid systems. Delete otherwise

b. HWSTmax-cond, the design hot water supply temperature of the condensing boilers.

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

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

3.1.8.2. Boiler Flow Setpoints

a. HW-MinFlowX, the design minimum Boiler water flowrate as recommended by the manufacturer for Boiler X, in gpm.

Retain the following parameter for primary-only hot water plants with a minimum flow bypass valve. Delete otherwise.

b. HW-DesFlowX, the design boiler hot water flowrate for Boiler X, in gpm.

Retain the following parameter for plants with condensing boilers. Delete otherwise.

3.1.8.3. Minimum Boiler Firing Rate

a. B-FiringMinX, the lowest %-firing rate of Boiler X before cycling, e.g. 20% for a boiler with 5 to 1 turndown.

3.1.8.4. Capacity

a. QbX, design output capacity of Boiler X, in KBtu/h.

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

b. PHWFdesign, design primary loop flow, in gpm (each loop)

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

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

3.1.8.5. Headered Pump Design Quantities

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

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

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

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

Add Section 3.2.4. as follows:

3.2.4. Hot Water Plant

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

3.2.4.1. HW-DPmax, the maximum hot water differential pressure setpoint, in psi

Instructions for establishing HW-DPmax should be provided in the Test and Balance Specification. For example:
1) Fully open all control valves serving coils that are located downstream of the differential pressure sensor.
2) Fully close all control valves serving coils that are located upstream of the differential pressure sensor.
3) 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.
4) 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.

3.2.4.2. LocalHW-DPmax, the maximum hot water differential pressure setpoint local to the plant, in psi

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

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

3.2.4.3. B-MinPriPumpSpdStage, the primary hot water pump speed necessary to deliver minimum hot water flow, HW-MinFlowX, through the operating boiler(s) in the stage.

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

1. *Open isolation valves of all boilers.*
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 boiler, as measured by either heat exchanger differential pressure or a flow meter, decreases to 110% of HW-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.

3.2.4.4. 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 for hot water pumps in accordance with the test and balance specifications.

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.*
3. *Observe 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 4.11. as follows:

4.11 **Hot Water Plant**

4.11.1. Boilers

Required?	**Description**	**Type**	**Device**
R	Boiler enable	DO	Connect to boiler enable contact; typ. each boiler
R	HW supply temperature setpoint	AO	AI to boiler control panels or AI through boiler network interfaces.
Optional point for monitoring boiler firing rate.			
O	Boiler firing rate	AI	Firing rate from boiler controller (may be via network connection rather than hardwired). Use gas valve position if firing rate is not known. Typ. each boiler.
Required for boiler plants with headered primary pumps. Delete otherwise.			
A	Boiler isolation valve	DO	2-position line sized valve; typ. each boiler
Retain the following two points for optional valve end switch status feedback.			
O	Boiler isolation valve closed end switch	DI	Valve end switch contact; typ. each boiler
O	Boiler isolation valve open end switch	DI	Valve end switch contact; typ. each boiler
O	Boiler natural gas flow	DI (pulse)	Flow meter serving all boilers

4.11.2. HW Pumps

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

4.11.3. Primary HW Loop

Required?	Description	Type	Device
HW flow required for primary-only plants; the flow meter must be located on the plant side of the HW minimum flow bypass where provided. Optional for variable primary-variable secondary plants. Not required nor recommended for constant primary-variable secondary plants.			
A	HW supply or return flow	AI	Flow meter
HW bypass valve is required for variable flow primary-only plants with boilers with non-zero minimum flow. Delete otherwise.			
A	HW Min flow bypass valve	AO	Modulating valve sized for minimum flow of one boiler
HW supply temperature sensor required for primary-only plants. Optional for primary-secondary plants.			
A	HW supply temperature	AI	Temperature sensor
HW return temperature is required for primary-only plants and primary-secondary plants with non-condensing boilers. For primary-only plants, locate on plant side of the HW minimum flow bypass to allow for correct load calculations.			
A	Plant HW return temperature	AI	Temperature sensor
Optional sensor for monitoring temperature coming back from coils in primary-only plants with a HW bypass. Delete for all other plant configurations.			
O	Loop HW return temperature	AI	Temperature sensor
O	HW 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.

4.11.4. Secondary HW Loop

Re-quired?	Description	Type	Device
R	Secondary HW supply temperature	AI	Temperature sensor
R	Secondary HW return temperature	AI	Temperature sensor
A	Secondary HW supply or return flow	AI	Flow meter
Retain the following sensor for hybrid boiler plants. Delete otherwise. Sensor is to be located in the secondary loop downstream of the condensing boiler primary loop decoupler but upstream of the non-condensing boiler primary loop decoupler.			
A	Intermediate HW supply temperature	AI	Temperature sensor

Add Section 5.21. as follows:

5.21 **Hot Water Plant**

Retain the applicable variables from Section 3.1.8 and 3.2.4. Delete variables that are not applicable.

5.21.1. See Paragraph 3.1.8 for HWSTmax, HW-LOT, HW-MinFlowX, HW-DesFlowX, QbX, B-FiringMinX, PHWFdesign, and SHWFdesign. See Paragraph 3.2.4 for HW-DPmax, LocalHW-DPmax, and B-MinPriPumpSpdStage.

5.21.2. Plant Enable/Disable

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

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

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

b. OAT<HW-LOT, and

c. The Boiler plant enable schedule is active.

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

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

b. OAT>HW-LOT + 1°F, or

c. The Boiler plant enable schedule is inactive.

Heating Hot-Water 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 Heating Hot-Water 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.

Importance multipliers (IM) shall be added to Heating Hot-Water Plant Requests in a future addendum to Guideline 36 to ensure that critical coils can independently cause the plant to start. For example, setting the importance multiplier of a large air handler's Heating Hot-Water 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.

5.21.2.4. When the plant is enabled:

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

---

a. Open the HW isolation valve of the lead boiler.

Retain the following two sentences for primary-secondary plants. Delete otherwise.

---

b. Stage on lead primary HW pump and secondary HW pump per 5.21.6 and 5.21.7 respectively.

c. Once the lead pumps have proven on, enable the lead boiler.

Retain the following two sentences for primary-only plants. Delete otherwise.

---

d. Stage on lead primary HW pump per 5.21.6.

e. Once the lead pump has proven on, enable the lead boiler.

5.21.2.5. When the plant is disabled:

a. Shut off the enabled boiler(s).

Retain the following sentence for primary-only and primary-secondary plants with headered primary HW pumps. Delete otherwise.

---

b. For each enabled boiler with headered primary HW pumps, close the HW isolation valve(s) after 3 minutes and disable the operating HW pump(s) per 5.21.6.

Retain the following sentence for primary-only and primary-secondary plants with dedicated primary HW pumps. Delete otherwise.

c. For each enabled boiler with dedicated primary HW pumps, disable the operating primary HW pump(s) per 5.21.6.

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

d. Disable the operating secondary HW pump(s) per 5.21.7.

5.21.3. Boiler Staging

5.21.3.1. Boiler stages shall be defined as follows:

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

For instance, in the example table below, if there is a pony boiler (B-1) and two identical larger boilers (B-2, B-3), there are 5 possible boiler capacity stages.

Boiler Stage	Enabled Boilers
0	None
1	B-1
2	B-2 or B-3
3	B-1 and (B-2 or B-3)
4	B-2 and B-3
5	B-1, B-2, and B-3

Retain the following clause for plants with equally sized condensing or non-condensing boilers. Delete otherwise.

5.21.3.2. Interchangeable boilers indicated with "or" in the table above shall be lead/lag controlled per Section 5.1.15.3.

Retain the following clause for plants with headered primary pumps and HW isolation valves. Delete otherwise.

5.21.3.3. If a boiler is in alarm, the boiler shall be disabled and after 3 minutes, its HW isolation valve shall be closed.

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

5.21.3.4. If a boiler is in alarm, the boiler shall be disabled and after 3 minutes, its dedicated primary pump shall be disabled.

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.

5.21.3.5. Boilers are staged in part based on required capacity, $Q_{required}$. $Q_{required}$ is calculated based on hot water return temperature ($HWRT$), active hot water supply temperature setpoint ($HWST_{SP}$), 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.

$$Q_{required} = 0.49 * FLOW_P(HWST_{SP} - HWRT)\ [\frac{\text{kbtu}}{\text{h}}]$$

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

5.21.3.6. Boilers are staged in part based on required capacity, $Q_{required}$. $Q_{required}$ is calculated based on secondary hot water return temperature (*SHWRT*), active hot water supply temperature setpoint ($HWST_{SP}$), 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.

$$Q_{required} = 0.49 * FLOW_S(HWST_{SP} - SHWRT)\ [\frac{\mathrm{kbtu}}{\mathrm{h}}]$$

Retain the following clause for plants with condensing boilers. Delete otherwise.

5.21.3.7. Boilers are staged in part based on the minimum output of a given stage, $B\text{-}STAGE_{MIN}$. Calculate $B\text{-}STAGE_{MIN}$ as the largest B-FiringMinX of all boilers in the stage times design capacity of all boilers in the stage. Note that B-FiringMin and capacity may vary for each boiler, e.g. for unequally sized boilers with different minimum turndowns.

B-STAGEMIN defines the minimum load boilers can operate at in a given stage without any of them cycling. If minimum capacities of all boilers (e.g. B-FiringMinX for a given boiler times its design capacity) were summed directly instead of correcting for the highest B-FiringMinX among all enabled boilers in a stage, boilers with a higher B-FiringMinX would still cycle.

5.21.3.8. Staging events require that a boiler stage be available. A stage shall be deemed *unavailable* if the stage cannot be achieved because a boiler required to operate in the stage is faulted per5.1.15.5.b.1.iii or a hot water pump dedicated to that boiler is faulted per 5.1.15.5.b.1.i; otherwise the stage shall be deemed available.

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

a. Each stage shall have a minimum runtime of 10 minutes.

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

c. Any unavailable stage (see 5.21.3.8) shall be skipped during staging events, but staging conditionals in the current stage shall be evaluated as per usual.

Retain the following paragraph for hybrid plants. Delete otherwise.

1. Exceptions:

   i. If the highest condensing boiler stage is unavailable, the stage up conditionals in the next lower condensing boiler stage shall be those from the highest condensing boiler stage.

   ii. If the lowest non-condensing boiler stage is unavailable, the stage down conditionals of the next higher non-condensing boiler stage shall be those from the lowest non-condensing boiler stage.

d. Hot 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 boiler plants where the primary loop does not have a single HWST sensor that measures the common supply temperature. Delete otherwise.

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

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

Retain the following two clauses for primary only condensing boiler plants. Delete otherwise.

f. 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:** Both of the following are true:

   i. $Q_{required}$ exceeds 200% of *B-STAGE*$_{MIN}$ of the next available stage for 10 minutes

   ii. Hot water flowrate exceeds the minimum flow setpoint of the next available stage (see 5.21.8).

3. **Failsafe Condition:** HW supply temperature is 10°F < setpoint for 15 minutes.

g. Stage down if all of the following are true:

1. Either:

   i. $Q_{required}$ falls below 110% of *B-STAGE*$_{MIN}$ of the current stage for 5 minutes; or

   ii. The minimum flow bypass valve, if provided, is greater than 0% open for 5 minutes.

2. The failsafe stage up condition is not true.

3. $Q_{required}$ is less than 80% of the design capacity, QbX, of the boilers in the next available lower stage for 5 minutes.

Condensing boilers are generally more efficient at low load since the ratio of heat transfer surface area to thermal mass flowrate is maximized, increasing flue gas condensation. Staging on boilers at low load therefore maximizes plant efficiency. However, the energy penalty from cycling losses due to staging on lag equipment prematurely, only to have them cycle off, may more than offset the part load efficiency gains.

Staging is delayed until the current stage output exceeds the minimum output of the next stage by 100% to avoid boiler short cycling following stage up, which dramatically decreases plant efficiency. The default stage up threshold for the efficiency condition is set to ensure sufficient load to prevent boilers from short cycling and to create an adequate hysteresis to prevent unnecessary boiler staging, but the optimal threshold will depend in part on the boiler turndown. The designer should consider adjusting this threshold based on plant attributes: higher for boilers with more turndown, lower for boilers with less turndown.

Staging is also dependent on minimum flow requirements. If minimum flowrate of the next stage is not satisfied under current operating conditions, then supply water will need to be bypassed to the return following a stage up, which raises return temperature. Elevated return temperature decreases condensation and boiler efficiency as a result, so staging up is inhibited under these conditions. For the same reason, a stage down is triggered if the minimum flow bypass valve is opened with more than one boiler in operation.

Retain the following two clauses for variable primary/variable secondary condensing boiler plants. Delete otherwise.

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

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

2. **Efficiency Condition:** Both of the following are true:

   i. $Q_{required}$ exceeds 150% of *B-STAGE*$_{MIN}$ of the next available stage for 10 minutes

   ii. Primary hot water flowrate exceeds the minimum flow setpoint of the next available stage (see 5.21.8).

3. **Failsafe Condition:** HW supply temperature is 10°F < setpoint for 15 minutes.

i. Stage down if all of the following are true:

1. Either:

   i. $Q_{required}$ falls below 110% of $B\text{-}STAGE_{MIN}$ of the current stage for 5 minutes; or

   ii. For 5 minutes, Primary HW pumps are at B-MinPriPumpSpdStage and primary HWRT exceeds secondary HWRT by 3°F.

2. The failsafe stage up condition is not true.

3. $Q_{required}$ is less than 80% of the design capacity, QbX, of the boilers in the next available lower stage for 5 minutes.

Staging conditions are identical for variable primary/variable secondary condensing boiler plants to those used for primary only condensing boiler plants, except that slightly different logic must be used for the minimum flow based stage down conditional since there is no minimum flow bypass valve. Primary hot water return temperature exceeding secondary hot water return temperature indicates primary recirculation, which limits condensing boiler plant efficiency as described previously. This conditional only applies when primary hot water pumps are at minimum speed since minimum speed indicates (1) low load for the stage and that (2) primary pump speed cannot be reduced further to mitigate return temperature degradation.

Retain the following two clauses for non-condensing boiler plants. Delete otherwise.

---

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

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

2. **Efficiency Condition:** $Q_{required}$ exceeds 90% of the design capacity, QbX, of the boilers in the current stage for 10 minutes; or

3. **Failsafe Condition:** HW supply temperature is 10°F < setpoint for 15 minutes.

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

1. $Q_{required}$ is less than 80% of the design capacity of the next lower available stage for 10 minutes; and

2. The failsafe stage up condition is not true.

Non-condensing boilers do not benefit significantly from operating at low turndowns since the primary benefit of doing so is to maximize condensing, which is not permissible with non-condensing boiler heat exchangers. Logic is therefore simplified by running boilers to near full output prior to staging.

Retain the following four clauses for hybrid boiler plants. Delete otherwise.

The following logic is written with the intent that the designer first enables all condensing boiler stages before any non-condensing boiler stages. The logic will still work if this rule is not followed, but some of the efficiency afforded by the condensing boilers may be lost in the process.

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l. If all boilers enabled in the next higher stage are condensing, stage up if any of the following is true:

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

2. **Efficiency Condition:** Both of the following are true:

   iii. $Q_{required}$ exceeds 150% of $B\text{-}STAGE_{MIN}$ of the next available stage for 10 minutes

iv. Primary hot water flowrate exceeds the minimum flow setpoint of the next available stage (see 5.21.8).

3. **Failsafe Condition:** HW supply temperature is 10°F < setpoint for 15 minutes.

m. If all boilers enabled in the current stage are condensing, stage down if all of the following are true:

1. Either:

   v. $Q_{required}$ falls below 110% of $B\text{-}STAGE_{MIN}$ of the current stage for 5 minutes; or

   vi. For 5 minutes, Primary HW pumps are at B-MinPriPumpSpdStage and primary HWRT exceeds secondary HWRT by 3°F.

2. The failsafe stage up condition is not true.

3. $Q_{required}$ is less than 80% of the design capacity, QbX, of the boilers in the next available lower stage for 5 minutes.

n. If any boiler enabled in the next higher stage is non-condensing, stage up if any of the following is true:

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

2. **Efficiency Condition:** $Q_{required}$ exceeds 90% of the design capacity, QbX, of the boilers in the current stage for 10 minutes; or

3. **Failsafe Condition:** HW supply temperature is 10°F < setpoint for 15 minutes.

o. If any boiler enabled in the current stage is non-condensing, stage down if all of the following are true:

1. $Q_{required}$ is less than 80% of the design capacity of the next available lower stage for 10 minutes.

2. The failsafe stage up condition is not true.

Retain the following two clauses for plants with only condensing or only non-condensing boilers. Delete the following two clauses for hybrid plants.

5.21.3.10. Whenever a lag boiler is enabled:

Retain the following paragraph if a smaller boiler is staged off while a larger boiler is staged on during any stage change (e.g. for plants with pony boilers) and the plant has a minimum flow bypass valve. Delete otherwise.

a. For any stage change during which a smaller boiler is disabled and a larger boiler is enabled, slowly change the minimum flow bypass setpoint to that appropriate for the stage transition as indicated in 5.21.8.2. After new setpoint is achieved, wait 1 minute to allow loop to stabilize.

Retain the following paragraph if the plant has a minimum flow bypass valve. Delete otherwise. Delete the words "For any other stage change, " if the preceding paragraph is deleted.

b. For any other stage change, reset the minimum flow bypass setpoint to that appropriate for the new stage as indicated in 5.21.8.1.

A stabilization delay does not apply in this case since flowrate will already be at least the stage minimum per staging logic.

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

c. Start the next lag boiler's primary pump.

Retain the following sentence for primary-only plants with headered variable speed primary pumps. Delete otherwise.

d. Open the next lag boiler's isolation valve.

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

e. Start the next lag primary pump and simultaneously open the next lag boiler's isolation valve.

f. After 30 seconds, enable the lag boiler.

Retain the following paragraph if a smaller boiler is staged off while a large boiler is staged on during any stage change (e.g. for plants with pony boilers). Delete otherwise.

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

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

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

2. After 3 minutes, turn off the smaller boiler's primary pump.

Retain the following sentence for primary-only plants with headered variable speed primary pumps. Delete otherwise.

3. After 3 minutes, close the smaller boiler's isolation valve.

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

4. After 3 minutes, turn off the last lag primary pump and simultaneously close the smaller boiler's isolation valve.

Retain the following sentence if the plant has a minimum flow bypass valve. Delete otherwise.

5. Change the minimum flow bypass setpoint to that appropriate for the new stage as indicated in 5.21.8.1.

5.21.3.11. Whenever a lag boiler is disabled:

Retain the following paragraph if a smaller boiler is staged on while a larger boiler is staged off during any stage change (e.g. for plants with pony boilers) and the plant has a minimum flow bypass valve. Delete otherwise. If deleting, remove the words "If staging down from any other stage," from 5.21.3.11.b below.

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

Retain the following sentence if the plant has a minimum flow bypass valve. Delete otherwise.

1. Slowly change the minimum flow bypass setpoint to that appropriate for the stage transition as indicated in 5.21.8.2. After new setpoint is achieved, wait 1 minute to allow loop to stabilize.

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

2. Enable the smaller boiler's primary pump.

Retain the following sentence for primary-only plants with headered variable speed primary pumps. Delete otherwise.

3. Open the smaller boiler's isolation valve.

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

4. Start the next lag primary pump and simultaneously open the smaller boiler's isolation valve.

5. After 30 seconds, enable the smaller boiler.

6. Wait 5 minutes for the newly enabled boiler to prove that it is operating correctly (not faulted as defined in 5.1.15.5.b.1.iii, then shut off the larger boiler.

b. If staging down from any other stage, disable the last stage boiler.

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

c. After 3 minutes, turn off the disabled boiler's primary pump.

Retain the following sentence for primary-only plants with headered variable speed primary pumps. Delete otherwise.

d. After 3 minutes, close the disabled boiler's isolation valve.

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

e. After 3 minutes, turn off the last lag primary pump and simultaneously close the disabled boiler's isolation valve.

Retain the following sentence if the plant has a minimum flow bypass valve. Delete otherwise.

f. Change the minimum flow bypass setpoint to that appropriate for the new stage as indicated in 5.21.8.1.

Retain clauses 5.21.3.12 through 5.21.3.17 for hybrid boiler plants. Delete otherwise.

Note: Staging logic below assumes no unequally sized boilers within either the condensing boiler group or non-condensing boiler group, though the condensing boilers may be smaller than the non-condensing boilers or vice versa.

5.21.3.12. Whenever a lag condensing boiler is enabled:

Retain the following sentence for plants with dedicated primary pumps in the condensing boiler loop. Delete otherwise.

a. Start the next lag condensing boiler's primary pump.

Retain the following sentence for plants with headered primary pumps in the condensing boiler loop. Delete otherwise.

b. Start the next lag condensing loop primary pump and simultaneously open the next lag boiler's isolation valve.

c. After 30 seconds, enable the lag boiler.

5.21.3.13. Whenever the first non-condensing boiler is enabled:

a. Reset the non-condensing boiler hot water supply temperature setpoint per 5.21.4.3.

Retain the following sentence for plants with dedicated primary pumps in the non-condensing boiler loop. Delete otherwise.

b. Whenever the hot water supply temperature upstream of the non-condensing loop return pipe connection exceeds 140°F, or 5 minutes have elapsed, start the first non-condensing boiler's primary pump.

Retain the following sentence for plants with headered primary pumps in the non-condensing boiler loop. Delete otherwise.

---

c. Whenever the hot water supply temperature upstream of the non-condensing loop return pipe connection exceeds 140°F, or 5 minutes have elapsed, start the first non-condensing loop primary pump and simultaneously open the first non-condensing boiler's isolation valve.

d. After 30 seconds, enable the lag boiler.

5.21.3.14. Whenever any other non-condensing boiler is enabled:

Retain the following sentence for plants with dedicated primary pumps in the non-condensing boiler loop. Delete otherwise.

---

a. Start the next lag non-condensing boiler's primary pump.

Retain the following sentence for plants with headered primary pumps in the non-condensing boiler loop. Delete otherwise.

---

b. Start the next lag non-condensing loop primary pump and simultaneously open the next lag boiler's isolation valve.

c. After 30 seconds, enable the lag non-condensing boiler.

5.21.3.15. Whenever any non-condensing boiler other than the lead non-condensing boiler is disabled:

a. Disable the non-condensing boiler.

Retain the following sentence for plants with dedicated primary pumps in the non-condensing boiler loop. Delete otherwise.

---

b. After 3 minutes, turn off the lag non-condensing boiler's primary pump.

Retain the following sentence for plants with headered primary pumps in the non-condensing boiler loop. Delete otherwise.

---

c. After 3 minutes, turn off the last lag non-condensing loop primary pump and simultaneously close the boiler's isolation valve.

5.21.3.16. Whenever the lead non-condensing boiler is disabled:

a. Disable the non-condensing boiler and reset the condensing boiler hot water supply temperature setpoint per 5.21.4.2.

Retain the following sentence for plants with dedicated primary pumps in the non-condensing boiler loop. Delete otherwise.

---

b. After 3 minutes, turn off the lag non-condensing boiler's primary pump.

Retain the following sentence for plants with headered primary pumps in the non-condensing boiler loop. Delete otherwise.

---

c. After 3 minutes, turn off the last lag non-condensing loop primary pump and simultaneously close the boiler's isolation valve.

5.21.3.17. Whenever a lag condensing boiler is disabled:

a. Disable the condensing boiler.

Retain the following sentence for plants with dedicated primary pumps in the condensing boiler loop. Delete otherwise.

b. After 3 minutes, turn off the lag boiler's primary pump.

Retain the following sentence for plants with headered primary pumps in the condensing boiler loop. Delete otherwise.

c. After 3 minutes, turn off the last lag primary pump and simultaneously close the boiler's isolation valve.

5.21.4. Hot Water Supply Temperature Reset

5.21.4.1. Plant hot water supply temperature setpoint shall be reset using Trim & Respond logic with the following parameters:

Variable	**Value**
Device	Any HW Pump Distribution Loop
SP_0	SP_{max}
SP_{min}	90ºF for condensing and hybrid boiler plants; 155°F for non-condensing plants
SP_{max}	HWSTmax
T_d	10 minutes
T	5 minutes
I	2
R	Hot-Water Reset Requests
SP_{trim}	-2ºF
SP_{res}	+3ºF
$SP_{res-max}$	+7ºF

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

SPmin must be higher for non-condensing boiler plants to avoid condensing operation. 155°F should be sufficient for most plants, though SPmin will vary as a function of coil selections and the nature of loads served. Engineers may therefore need to adjust this limit on a project specific basis.

Note that for hybrid boiler plants SPmin is reset from 90°F to 155°F based on whether non-condensing boilers are in operation or not in subsequent logic.

Retain the following two clauses for hybrid boiler plants. Delete otherwise.

5.21.4.2. When only condensing boilers are enabled, condensing boiler setpoint shall be the Plant hot water supply temperature setpoint.

5.21.4.3. Whenever any non-condensing boilers are enabled:

a. Non-condensing boiler setpoint shall be the Plant hot water supply temperature setpoint.

b. SPmin in the Plant hot water supply temperature trim and respond loop shall be reset to 155°F while any non-condensing boilers are in operation.

c. Condensing boiler setpoint shall be the lesser of the design condensing boiler supply temperature, HWSTmax-cond, and current Plant hot water supply temperature setpoint less an offset of 10°F.

Maintaining the condensing boiler setpoint 10°F below the non-condensing boiler setpoint ensures the non-condensing boilers are sufficiently loaded to avoid cycling.

Note that leaving condensing boiler supply tempera ture must be at least 135°F to protect non-condensing boilers from condensing operation. Since SPmin is 155°F when any non-condensing boilers are enabled, the 10°F offset yields an effective minimum condensing boiler supply temperature of 145°F. This provides a 10°F buffer between allowable non-condensing boiler entering temperature and condensing boiler setpoint, which allows for some instability in the condensing boiler HWST control loop and minimizes control loop interaction with the condensation control sequences below.

Note that if the design condensing boiler flow is less than the design plant flow (not recommended), the effective minimum condensing boiler temperature setpoint of 145°F may need to be elevated to protect the non-condensing boilers by raising SPmin. Reducing the 10°F offset instead would not be appropriate since it may lead to non-condensing boiler cycling under moderate load conditions when the condensing boiler flow can match secondary loop flow.

Retain Section 5.21.5 for plants with non-condensing boilers. Delete otherwise.

5.21.5. Non-Condensing Boiler Condensation Control

Retain the following two clauses for Primary-only plants. Delete otherwise.

5.21.5.1. A reverse acting condensation control P-only loop shall reset a required minimum flow bypass valve position variable, MinCondVlvPos, from 0% at 140°F boiler entering temperature to 100% at 135°F boiler entering temperature.

5.21.5.2. Minimum bypass valve condensation control loop shall be enabled whenever any non-condensing boiler is enabled. Loop shall be disabled otherwise.

Retain the following two clauses for Primary-secondary plants with constant speed primary pumps and variable speed secondary pumps. Delete otherwise.

5.21.5.3. A reverse acting condensation control P-only loop shall reset an allowable maximum secondary pump speed variable, MaxSecCondSpd, from 100% at 140°F boiler entering temperature to minimum pump speed at 135°F boiler entering temperature.

5.21.5.4. Secondary pump speed condensation control loop shall be enabled whenever any secondary pump is enabled and any non-condensing boiler is enabled. Loop shall be disabled and MaxSecCondSpd set to 100% otherwise.

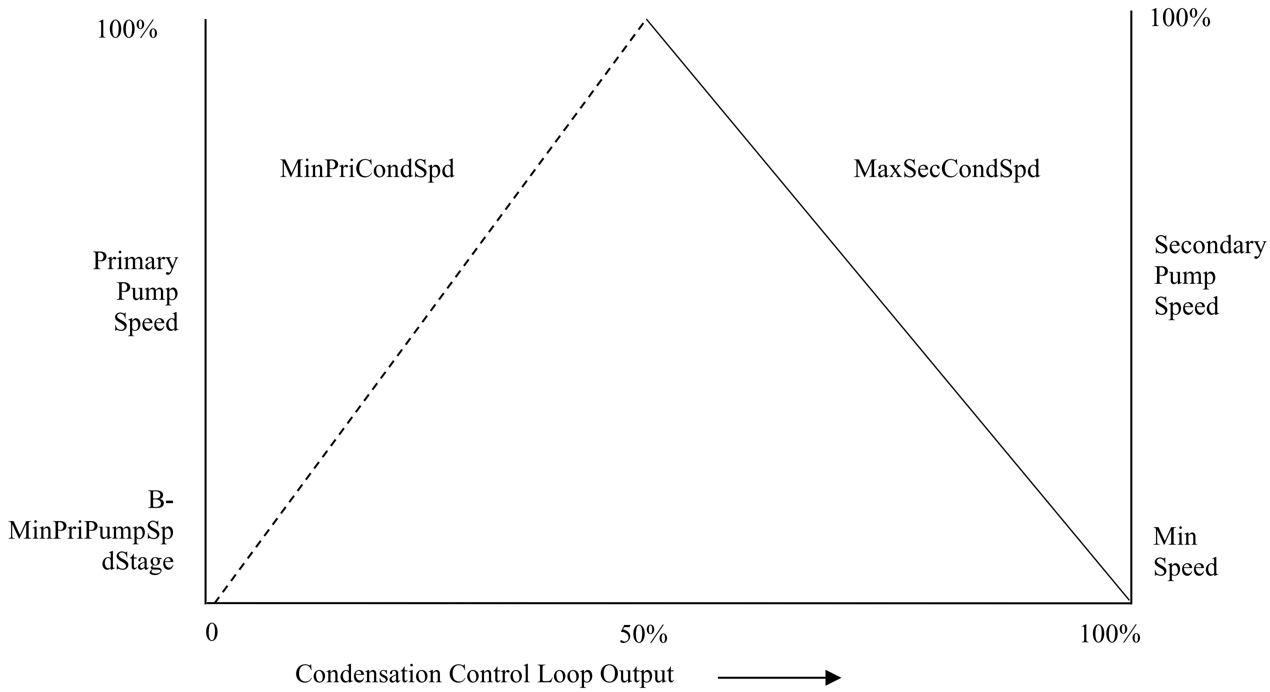
The above two clauses assume that secondary pump VFDs are provided for condensation control instead of 3-way thermostatic mixing valves. Limiting secondary pump speed increases the ratio of primary recirculation to secondary return entering the boiler(s), which elevates boiler entering temperature much the same as a 3-way mixing valve does.

VFDs cost less than thermostatic mixing valves and the associated piping, reduce pump energy use, and allow for improved valve controllability via differential pressure pump speed control.

A P-only limiting loop is specified to ensure that once boiler entering temperature dips to 135°F, maximum recirculation is provided to avoid condensation.

Retain the following two clauses for Primary-secondary plants with variable speed primary pumps. Delete otherwise.

5.21.5.5. A reverse acting condensation control P-only loop shall maintain boiler entering temperature at 140°F. Loop output shall vary from 0% at 140°F boiler entering temperature to 100% at 135°F boiler entering temperature. Loop output shall be mapped as shown below and described subsequently.



a. From 0% to 50% loop output, reset an allowable minimum primary pump speed variable, MinPriCondSpd, from B-MinPriPumpSpdStage to 100%.

b. From 50% to 100% loop output, reset an allowable maximum secondary pump speed variable, MaxSecCondSpd, from 100% to minimum pump speed.

5.21.5.6. Condensation control loop shall be enabled whenever any non-condensing boiler is enabled. Loop shall be disabled, MinPriConSpd set to B-MinPriPumpSpd, and MaxSecCondSpd set to 100%, otherwise.

Where variable speed primary pumps are provided, they should be used first to provide condensation protection since increasing primary pump speed to increase boiler entering temperature does not starve loads like limiting secondary pump speed (or using thermostatic mixing valves for that matter) does. A slow PID loop is used for this purpose in the interest of minimizing control interaction with the secondary pump speed P-only limiting loop. The loop is biased to launch from 100% as a startup protection mechanism.

5.21.5.7. Refer to pump speed control logic for use of condensation control variables.

Retain the following clause for Primary-secondary plants with constant speed primary pumps and constant speed secondary pumps. Delete otherwise.

5.21.5.8. A thermostatic mixing valve shall maintain boiler entering temperature above 135°F.

Where multiple primary loops with differing configurations exist, e.g. in a hybrid plant, create a unique copy of 5.21.6 for each.

5.21.6. Primary Hot Water Pumps

Retain the following two clauses for plants with headered primary hot water pumps. Delete otherwise.

5.21.6.1. Primary hot water pumps shall be lead/lag controlled per Section 5.1.15.3.

5.21.6.2. Enable lead primary hot water pump when any boiler isolation valve is commanded open. Disable the lead hot water pump when all boiler isolation valves are commanded closed.

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

5.21.6.3. Enable lead primary hot water pump when plant is enabled. Disable the lead primary hot water pump when the lead boiler is disabled and the lead boiler has been proven off for 3 minutes.

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

5.21.6.4. HW pumps shall be staged as a function of the ratio of current hot water flow, $FLOW_P$, to design flow, $PHWF_{design}$, and the number of pumps, N-PHWP, that operate at design conditions. Pumps are assumed to be equally sized.

$$\text{HWFR} = \frac{FLOW_P}{PHWF_{design}}$$

Flow is used, as opposed to speed, to keep the hot 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 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.

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

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

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

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

Retain the following two clauses for Primary-only plants with variable speed primary pumps where the control DP sensor(s) is hardwired to the plant controller. Delete otherwise.

Note: VFDs are not required on HW pumps by Title 24 and only required on large HW pumps used in fossil fuel boiler plants by Standard 90.1. These provisions exist because pump energy is converted to heat through friction losses at the pump and in pipe, coils, valves; reductions in HW pump energy are made up by the boilers. Energy costs are reduced because fossil fuel costs less per BTU than electricity, but savings are minor. However, constant speed pumps are not recommended on pumps with design head greater than about 50 feet due to increased noise from control valves, reduced controllability, and increased valve and pump wear.

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

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

HW pump DP setpoint is not reset by valve position because valve position is already used to reset HWST, which saves much more energy than DP reset. As noted above, pump energy is ultimately turned into heat so reductions in HW pump energy are made up by the boilers.

Retain the following three clauses for primary-only plants with variable speed primary pumps 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.

5.21.6.7. Remote loop DP shall be maintained at a setpoint of HW-DPmax. HW-DPmax 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 5 psi at 0% loop output to LocalHW-DPmax at 100% loop output.

5.21.6.8. 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. PID loop output shall be mapped from minimum pump speed at 0% to maximum pump speed at 100%.

5.21.6.9. 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 all plants other than primary-only plants with headered variable speed primary pumps. Delete otherwise.

5.21.6.10. Primary pumps shall be staged with the boilers, i.e. the number of pumps shall match the number of boilers.

5.21.6.11. See 5.21.3 for primary hot water pump staging sequence relative to boiler stage-up and stage-down events.

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

5.21.6.12. 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 0 gpm. Loop output shall be mapped from B-MinPriPumpSpdStage to 100% speed in proportion to loop output from 0% to 100%.

An offset of 0 gpm maximizes condensing operation for plants with condensing boilers at the risk of some secondary recirculation (and thus HWST degradation) due to control loop hunting. This risk is warranted to maximize condensing boiler efficiency. For non-condensing boiler plants, a small positive offset can be used to minimize the risk of secondary recirculation.

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

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

Retain the following three clauses for primary-secondary plants with variable speed primary pumps and a secondary loop supply temperature sensor, but no flow meters from which to deduce decoupler flow. Delete otherwise.

5.21.6.14. Primary Pump Speed Reset Requests shall be generated based on the difference (” T) between primary HW supply temperature and secondary loop temperature immediately downstream 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 dropping below 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 clause where the primary loop does not have a single HWST sensor that measures the common supply temperature of all boilers. Delete otherwise.

5.21.6.15. Primary HW supply temperature used in the request logic shall be the weighted average supply temperature of all boilers that are proven on. Temperatures shall be weighted by design boiler flowrates.

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

5.21.6.16. Primary HW pump speed of all Primary HW 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}	B-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%

Retain the following clause for plants with non-condensing boilers served by variable speed primary pumps. Delete otherwise.

5.21.6.17. Whenever MinPriCondSpd is greater than the current flow control loop speed command, the pump speed setpoint shall be MinPriCondSpd.

Condensation protection takes precedence over all other flow control logic to avoid damaging non-condensing boilers.

Retain the following section for primary-secondary boiler plants. Delete otherwise. Where multiple secondary loops with differing configurations exist, create a unique copy of 5.21.7 for each.

5.21.7. Secondary Hot Water Pumps

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

5.21.7.2. Enable lead secondary HW pump when plant is enabled and any load served by the pump(s) is generating a Heating Hot-Water Plant Request. Disable the lead pump otherwise.

Retain the following clause for variable speed secondary pumps serving a secondary loop with a flow meter. Delete otherwise.

5.21.7.3. Secondary HW pumps shall be staged as a function of SHWFR, the ratio of current hot water flow, $FLOW_S$, to design flow, and the number of pumps, N-SHWP, that operate at design conditions. Pumps are assumed to be equally sized.

$$\text{SHWFR} = \frac{FLOW_s}{SHWF_{design}}$$

Flow is used, as opposed to speed, to keep the hot 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 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.

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

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

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

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

Retain the following clause for variable speed secondary pumps serving a secondary loop without a flow meter. Delete otherwise.

5.21.7.4. Secondary HW pumps shall be staged as a function of speed.

a. Stage up when speed exceeds 90% for 5 minutes or 99% for 1 minutes.

b. Stage down when speed falls below 40% for 10 minutes.

When staging based on speed, the stage down point must be selected judiciously to minimize the possibility of repeat cycling (stage down point too high) and avoid getting "stuck" in a higher stage (stage down point too low). The stage up point must also be carefully selected to avoid running to the right of the operating pump's choke line before staging up, which can lead to excess vibration. For large systems with 3 or more secondary pumps, this is a particularly critical consideration and may warrant using a lower stage up speed for Stage 1 to Stage 2 than for higher stage transitions.

The above setpoints are general guidelines, but each project warrants inspection of the pump curve(s) relative to the estimated system curve to identify the proper staging points.

Note that none of these considerations are critical when staging on flow, which is preferred.

Retain the following two clauses for DP controlled variable speed pumps if the remote DP sensor(s) is hardwired to the secondary pump controller. Delete otherwise.

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

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

HW pump DP setpoint is not reset by valve position because valve position is already used to reset HWST, which saves much more energy that DP reset. As noted above, pump energy is converted to heat so reductions in HW pump energy are made up by the boilers.

Retain the following three clauses for DP controlled variable speed pumps if the remote DP sensor is not hardwired to the secondary pump controller, but a local DP sensor is hardwired to the secondary pump controller. Delete otherwise.

5.21.7.7. Remote loop DP shall be maintained at a setpoint of HW-DPmax. HW-DPmax 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 5 psi at 0% loop output to LocalHW-DPmax at 100% loop output.

5.21.7.8. 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. PID loop output shall be mapped from minimum pump speed at 0% to maximum pump speed at 100%.

5.21.7.9. 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.

Retain the following clause for plants with variable speed secondary pumps and non-condensing boilers. Delete otherwise.

5.21.7.10. Whenever MaxSecCondSpd is less than the current DP loop speed command signal, the pump speed setpoint shall be MaxSecCondSpd.

Condensation protection takes precedence over DP control to avoid damaging non-condensing boilers.

Retain the following clause for constant speed secondary pumps. Delete otherwise.

5.21.7.11. Secondary HW pumps shall be staged with primary pumps.

Constant speed secondary pumps are generally not advisable on any boiler system. For non-condensing boiler systems, secondary pump VFDs are a more cost-effective means of providing condensation protection than 3-way thermostatic mixing valves and provide energy benefits as discussed in 5.21.5.

For condensing boiler systems, constant speed secondary pumps could in theory be provided in conjunction with variable speed primary pumps to still allow for condensing operation at low loads, but a better option would be to simply provide a variable-primary system with either variable speed or constant speed pumps. The controls are simpler and as good or better energy performance will result.

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

5.21.8. Minimum Flow Bypass Valve

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

a. For the boilers operating in the stage, identify the boiler with the highest ratio, MinFlowRatio, of HW-MinFlowX to HW-DesFlowX.

b. Calculate the minimum flow setpoint, HW-MinFlowSP as MinFlowRatio multiplied by the sum of HW-DesFlowX for the operating boilers.

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

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

5.21.8.2. During stage changes that require one boiler to be enabled while another is disabled, the minimum flow setpoint, HW-MinFlowSP shall temporarily change to include the HW-MinFlowX of both the boiler to be enabled and the boiler to be disabled prior to starting the newly enabled boiler. See staging events in 5.21.2.4 for timing of setpoint change to this transitionary value.

Retain the following clause if the primary loop contains only condensing boilers. Delete otherwise.

5.21.8.3. A reverse acting PID loop shall maintain minimum flow as measured by the hot water flow meter at setpoint. Reset valve position from 0% open at 0% loop output to 100% open at 100% loop output.

Retain the following two clauses if the primary loop contains any non-condensing boilers. Delete otherwise.

5.21.8.4. A reverse acting PID loop shall maintain minimum flow as measured by the hot water flow meter at setpoint. Reset the variable MinFlowVlvPos from 0% open at 0% loop output to 100% open at 100% loop output.

5.21.8.5. Minimum flow bypass valve position shall be the larger of MinFlowVlvPos and MinCondVlvPos defined in the Condensation Control Section.

5.21.8.6. When any HW pump is proven on, the bypass valve control loop shall be enabled. The valve shall be opened otherwise. When enabled, the bypass valve minimum flow PID loop shall be biased 100% (valve 100% open).

Biasing the minimum flow PID 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.

5.21.9. Performance Monitoring

5.21.9.1. 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.

5.21.9.2. Total Plant Gas Use. Convert measured gas usage to Btu/h by a user adjustable conversion factor (default value = 1000 Btu/h per ft^3 of gas; actual value set by user from utility bill).

Retain the following calculation for primary-only plants and primary-secondary plants with both a primary circuit flow meter and primary loop HWST and HWRT sensors. Delete otherwise.

5.21.9.3. Total Plant Load. Calculate plant load using flowrate through the primary circuit, $FLOW_P$; primary hot water return temperature, *PHWRT*; and primary hot water supply temperature, *PHWST*.

$$Q_{actual} = 0.49 * FLOW_P(PHWST - PHWRT)\ \left[\frac{\text{kbtu}}{\text{h}}\right]$$

Retain the following calculation for primary-secondary plants without both a primary circuit flow meter and primary loop HWST and HWRT sensors. Delete otherwise.

5.21.9.4. Total Plant Load. Calculate plant load using flowrate through the secondary circuit, $FLOW_S$; secondary hot water return temperature, *SHWRT*; and secondary hot water supply temperature leaving the plant, *SHWST*.

$$Q_{actual} = 0.49 * FLOW_S(SHWST - SHWRT)[\frac{\text{kbtu}}{\text{h}}]$$

Retain the following paragraph for all plants other than those with variable flow primary loops without flow meters. Delete otherwise.

5.21.9.5. Boiler Load. Calculate load for each operating boiler (as applicable) using flowrate through the boiler, $FLOW_B$; hot water return temperature entering the boiler, $HWRT_B$; and hot water supply temperature leaving the boiler, $HWST_B$. Inputs to the below equation shall be determined per the following rules.

$$Q_B = 0.49 * FLOW_B(HWST_B - HWRT_B)[\frac{kbtu}{h}]$$

Where flow through each boiler is individually measured using a flow meter, $FLOW_B$ shall be the flow measured by the boiler's associated flow meter.

Retain the following paragraph for plants with parallel boilers where flowrate through each boiler is not measured, but flowrate through the primary circuit is measured. Delete otherwise.

a. $FLOW_B$ shall be assumed proportional to design flow through all operating boilers in the circuit.

Retain the following paragraph for plants with constant primary loop where neither flowrate through the boiler nor flowrate through the primary loop is measured. Delete otherwise.

b. $FLOW_B$ shall be assumed equal to the design flowrate through the boiler for the current stage as determined during balancing.

c. $HWRT_B$ shall be the return temperature entering the boiler as read by a hardwired BAS sensor if available. If a hardwired sensor is unavailable, temperature shall be read from a sensor internal to the boiler through its network interface. If multiple boilers are enabled, the temperature shall be the average return temperature read from the operating boilers through the network interface.

d. $HWST_B$ shall be a hardwired temperature sensor at the outlet of the equipment if available. If a hardwired sensor is unavailable, temperature shall be read from a sensor internal to the boiler 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 boilers), be used.

5.21.9.6. Calculate plant thermal efficiency as equal to measured plant load divided by measured gas consumption.

5.21.9.7. Summary Data

a. For each boiler, statistics shall be calculated for runtime, cumulative load (btu), average demand (btu/h), and peak demand (btu/h). All statistics shall be presented on an instantaneous, year-to-date, and previous year basis.

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

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

	Instantaneous				Year-to-date						Previous Year					
	Lifetime Runtime (hours)	Gas Demand (kBtu/h)	HW Demand (kBtu/h)	Efficiency	Runtime (hours)	Gas Use (MMBtu)	HW Load (MMBtu)	Avg HW Demand (kBtu/h)	Peak HW Demand (kBtu/h)	Avg Efficiency	Runtime (hours)	Gas Use (MMBtu)	HW Load (MMBtu)	Avg HW Demand (kBtu/h)	Peak HW Demand (kBtu/h)	Avg Efficiency
B-1																
B-2																
Total Plant																

5.21.10. Alarms

5.21.10.1. 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.

5.21.10.2. Maintenance interval alarm when boiler has operated for more than 2000 hours as indicated by the Staging Runtime: Level 4. Reset the Staging Runtime interval counter when alarm is acknowledged.

5.21.10.3. Boiler alarm: Level 2

5.21.10.4. Low boiler leaving hot water temperature (more than 15°F below setpoint) for more than 15 minutes when boiler has been enabled for longer than 15 minutes: Level 3

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

a. Commanded on, status off: Level 2. Do not evaluate alarm until the 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 60 seconds.

Retain the following two alarms for plants with two-position valves with end switch status monitoring. Delete otherwise.

5.21.10.6. 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.

5.21.10.7. Valve alarm is indicated by the analog position feedback being different from the output command by more than 10% for 90 seconds: Level 2

5.21.10.8. 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.

5.21.11. Automatic Fault Detection and Diagnostics

The Automatic Fault Detection and Diagnostics (AFDD) routines for hot 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 recommended for best accuracy.

5.21.11.1. AFDD conditions are evaluated continuously for the plant.

5.21.11.2. 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. For hybrid plants, determine the Operating State for each primary loop.

The Operating State is distinct from and should not be confused with the hot water plant stage.
OS#1 – OS#3 represent normal operation during which a fault may nevertheless occur, if so determined by the fault condition tests below.

Operating State	**Boiler Isolation Valve or Dedicated Primary HW Pump Status**	**PHW Pump Status (if primary-only) or SHW Pump Status (if primary-secondary)**
#1: Disabled	All Closed/Off	All Off
#2: One boiler enabled	One Open/On, All Others Closed/Off	Any On
#3: More than one boiler enabled	Any Open/On	Any On

5.21.11.3. The following points must be available to the AFDD routines for the hot 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 = Hot water loop differential pressure (each loop, where applicable)

b. DPSP = Hot 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 hot water flow (each primary loop, where applicable)

Retain the following variable if there is a flow meter in the secondary loop. Delete otherwise.

d. $FLOW_S$ = Secondary hot water flow (each secondary loop, where applicable)

Retain the following two variables for primary-only plants with a minimum flow bypass valve. Delete otherwise.

e. MFBPV = Hot water minimum flow bypass valve command; 0% d MFBPV d 100%

f. HW-MinFlowSP = Effective minimum hot water flow setpoint (equal to MinFlowRatio multiplied by the sum of HW-MinFlowX of operating boilers)

Retain the following variable for primary-secondary plants where pump speed is controlled to maintain differential pressure. Delete otherwise.

g. $Speed_{HWP}$ = Secondary hot water pump speed command; 0% d SpeedHWP d 100%

Retain the following variable for primary-only plants where pump speed is controlled to maintain differential pressure. Delete otherwise.

h. $Speed_{HWP}$ = Hot water pump speed command; 0% d SpeedHWP d 100%

i. $Status_{PHWP}$ = Lead primary hot water pump status (each primary loop, where applicable)

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

j. $Status_{SHWP}$ = Lead secondary hot water pump status (each secondary loop, where applicable)

k. HWST = Common hot water supply temperature

l. HWSTSP = Hot water supply temperature setpoint

m. HWRT = Average boiler entering water temperature (each loop)

Retain the following variable for plants headered primary pumps. Delete otherwise.

n. $HWISO_{B\text{-}x}$ = B-x hot water isolation valve commanded position (each boiler)

Retain the following variable for plants where system gauge pressure is monitored. Delete otherwise.

o. P_{GAUGE} = Hot water system gauge pressure

5.21.11.4. 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. $HWST_{AVG}$ = rolling average of the common hot water supply temperature (each primary loop, where applicable)

2. $HWRT_{AVG}$ = rolling average of the average boiler entering water return temperature.

Retain the following variable for plants where system gauge pressure is monitored. Delete otherwise.

3. $P_{GAUGE, AVG}$ = rolling average of hot 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.

4. 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.

5. $FLOW_{P, AVG}$ = rolling average of primary hot water flow (each loop, where applicable)

Retain the following variable if there is a flow meter in the secondary loop. Delete otherwise.

6. $FLOW_{S, AVG}$ = rolling average of secondary hot water flow (each loop, where applicable)

7. $HWST_{B\text{-}x}$ = rolling average of B-x hot water supply temperature (each boiler)

8. $HWRT_{B\text{-}x}$ = rolling average of B-x hot water return temperature (each boiler)

b. $HWFlow_{B\text{-}X}$ (each boiler)

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

1. For plants with headered primary hot water pumps: 1 if $HWISO_{B\text{-}X}$ = open, 0 if $HWISO_{B\text{-}X}$ = closed

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

2. For plants with dedicated primary hot water pumps: 1 if $Status_{PHWP}$ = on, 0 if $Status_{PHWP}$ = off

c. ΔOS = number of changes in Operating State during the previous 60 minutes (moving window)

d. ΔStage = number of hot water plant stage changes during the previous 60 minutes (moving window)

e. $Starts_{B\text{-}x}$ = number of B-x starts in the last 60 mins (each boiler)

5.21.11.5. 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
$_{HWT}$	Temperature error threshold for hot water temperature sensors	5°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
$_{FM}$	Flow error threshold for flow meter	20 gpm
Retain the following variable for plants with variable speed pumps. Delete otherwise.		
$_{VFDSPD}$	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%

Variable Name	Description	Default Value
Retain the following variable for plants where system gauge pressure is monitored. Delete otherwise.		
ETPreChargePress	Hot water system expansion tank pre-charge pressure	See mechanical schedule (psig)
CondTemp	Boiler condensing temperature threshold	135°F
$BStarts_{MAX}$	Maximum number of boiler 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 hot 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 5.21.11.12.

5.21.11.6. 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 hot water plant.

Edit the table below. Remove fault conditions that do not apply.

<table>
<tr><td colspan="4">Retain the following fault condition for plants with any hot water pumps controlled to maintain differential pressure. Delete otherwise. Duplicate the following fault condition for each differential pressure sensor.</td></tr>
<tr><td rowspan="3">FC#1</td><td>Equation</td><td>$DP_{AVG} > \ _{DSP}$
and
$Status_{HWP} = Off$</td><td rowspan="3">Applies to OS #1</td></tr>
<tr><td>Description</td><td>Differential pressure is too high with the hot water pumps off</td></tr>
<tr><td>Possible Diagnosis</td><td>DP sensor error</td></tr>
<tr><td colspan="4">Retain the following fault condition if there is a flow meter in the primary loop. Delete otherwise. Duplicate the following fault condition for each primary loop with a flow meter.</td></tr>
<tr><td rowspan="3">FC#2</td><td>Equation</td><td>$FLOW_{P, AVG} > \ _{FM}$
and
$Status_{PHWP} = Off$</td><td rowspan="3">Applies to OS #1</td></tr>
<tr><td>Description</td><td>Primary hot water flow is too high with the hot water pumps off</td></tr>
<tr><td>Possible Diagnosis</td><td>Flow meter error</td></tr>
</table>

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 $Status_{SHWP} = Off$	**Applies to OS #1**
	Description	Secondary hot water flow is too high with the associated hot 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 $Speed_{HWP}$ e 99% - ${}_{VFDSPD}$	**Applies to OS #2, #3**
	Description	Hot water loop differential pressure is too low with hot 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 HWST is too low Primary flow is higher than the design flow of the operating boilers	
Retain the following fault condition for primary-only plants with a minimum flow bypass valve. Delete otherwise.			
FC#5	**Equation**	$FLOW_{P,\ AVG} < HW\text{-}MinFlowSp - {}_{FM}$ and MFBPV e 99% - ${}_{MFBPV}$	**Applies to OS #2, #3**
	Description	Primary hot water flow is too low with the minimum flow bypass valve fully open.	
	Possible Diagnosis	Problem with minimum flow bypass valve Problem with boiler isolation valves Minimum loop differential pressure setpoint too low	
For hybrid plants, duplicate the following fault condition for each primary loop.			
FC#6	**Equation**	$HWST_{AVG} + {}_{HWT} < HWSTSP$	**Applies to OS #2, #3**
	Description	Hot water supply temperature is too low.	
	Possible Diagnosis	Mechanical problem with boilers Primary flow is higher than the design flow of the operating boilers Deviation between the internal boiler hot water supply temperature sensor and the plant hot water supply temperature is too high (i.e. boiler sensor is out of calibration).	
Retain the following fault condition for plants where system gauge pressure is monitored. Delete otherwise.			

FC#7	**Equation**	$P_{GAUGE,\ AVG} < 0.9 * ETPreChargePress$	**Applies to OS #1 – #3**
	Description	Hot water system gauge pressure is too low	
	Possible Diagnosis	Possible hot water system leak	
Retain the following fault condition for plants with a condensing boiler. Delete otherwise.			
FC#8	**Equation**	$HWRT_{AVG} - \ _{HWT} > CondTemp$	**Applies to OS #2, #3**
	Description	Hot water return temperature is too high for condensing to occur.	
	Possible Diagnosis	Hot water supply temperature setpoint is too high. Hot water load is too low. High bypass flow is raising the entering water temperature. Hot water coils are not designed for condensing at current loads.	
Retain the following fault condition for plants with a non-condensing boiler. Delete otherwise.			
FC#9	**Equation**	$HWRT_{AVG} + \ _{HWT} < CondTemp$	**Applies to OS #2, #3**
	Description	Hot water return temperature is too low. Condensing is likely to occur.	
	Possible Diagnosis	Hot water supply temperature setpoint is too low.	
Retain the following fault condition if any boiler has a network interface and the plant has a common hot water supply temperature sensor at the discharge of the boiler(s). Delete otherwise. For hybrid plants, duplicate the following fault condition for each primary loop.			
FC#10	**Equation**	$\lvert(\ (HW\text{-}Flow_{B\text{-}X} * HWST_{B\text{-}X}) / \ HW\text{-}Flow_{B\text{-}X}) - HWST_{AVG} \rvert > \ _{HWT}$	**Applies to OS #2**
	Description	Deviation between the active boiler hot water supply temperature and the common hot water supply temperature is too high.	
	Possible Diagnosis	A hot water supply temperature sensor is out of calibration	
Retain the following fault condition if any boiler has a network interface and the plant has a common hot water return temperature sensor at the inlet of the boiler(s). Delete otherwise. For hybrid plants, duplicate the following two fault condition for each primary loop.			
FC#11	**Equation**	$\lvert(\ (HW\text{-}Flow_{B\text{-}X} * HWRT_{B\text{-}X}) / \ HW\text{-}Flow_{B\text{-}X}) - HWRT_{AVG} \rvert > \ _{HWT}$	**Applies to OS #2**
	Description	Deviation between the active boiler hot water return temperature and the common boiler entering water temperature is too high.	
	Possible Diagnosis	A hot water return temperature sensor is out of calibration	
FC#12	**Equation**	$\Delta OS > \Delta OS_{MAX}$	**Applies to OS #1 – #3**
	Description	Too many changes in Operating State	
	Possible Diagnosis	Unstable control due to poorly tuned loop or mechanical problem	
FC#13	**Equation**	$\Delta StartsB\text{-}x > \Delta BStart_{MAX}$	

	Description	Too many boiler starts	**Applies to OS #2, #3**
	Possible Diagnosis	Boiler is cycling due to load loads Boiler is oversized and/or has insufficient turndown. Boiler stage-up threshold may be set too low.	
FC#14	**Equation**	$\Delta Stage > \Delta Stage_{MAX}$	**Applies to OS #1 – #3**
	Description	Too many stage changes	
	Possible Diagnosis	Staging thresholds and/or delays need to be adjusted	

5.21.11.7. 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 hot water pumps off
2. FC#2: Primary hot water flow is too high with the primary hot water pumps off
3. FC#3: Secondary hot water flow is too high with the associated secondary hot water pumps off
4. FC#7: Hot water system gauge pressure is too low
5. FC#10: Too many changes in operating state
6. FC#12: Too many stage changes

b. In OS#2 (One boiler enabled), the following Fault Conditions shall be evaluated:

1. FC#4: Hot water loop differential pressure is too low with hot water pump(s) at full speed.
2. FC#5: Primary hot water flow is too low with the minimum flow bypass valve fully open.
3. FC#6: Hot water supply temperature is too low
4. FC#7: Hot water system gauge pressure is too low
5. FC#8: Hot water return temperature is too high for condensing to occur
6. FC#9: Hot water return temperature is too low. Condensing is likely to occur
7. FC#10: Deviation between the active boiler hot water supply temperature and the common hot water supply temperature is too high.
8. FC#11: Deviation between the active boiler hot water return temperature and the common boiler entering water temperature is too high.
9. FC#12: Too many changes in Operating State
10. FC#13: Too many boiler starts
11. FC#14: Too many stage changes

c. In OS#3 (More than one boiler enabled), the following Fault Conditions shall be evaluated:

1. FC#4: Hot water loop differential pressure is too low with hot water pump(s) at full speed.
2. FC#5: Primary hot water flow is too low with the minimum flow bypass valve fully open.
3. FC#6: Hot water supply temperature is too low
4. FC#7: Hot water system gauge pressure is too low
5. FC#8: Hot water return temperature is too high for condensing to occur
6. FC#9: Hot water return temperature is too low. Condensing is likely to occur
7. FC#12: Too many changes in Operating State
8. FC#13: Too many boiler starts
9. FC#14: Too many stage changes

5.21.11.8. For each boiler, the operator shall be able to suppress the alarm for any Fault Condition.

5.21.11.9. Evaluation of Fault Conditions shall be suspended under the following conditions:

a. When no pumps are operating.

b. When all equipment associated with a fault condition in maintenance mode.

c. For a period of StageDelay minutes following a change in plant stage.

5.21.11.10. Fault Conditions that are not applicable to the current Operating State shall not be evaluated.

5.21.11.11. A Fault Condition that evaluates as true must do so continuously for AlarmDelay minutes before it is reported to the operator.

5.21.11.12. 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.

5.21.11.13. 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 5.21.11.6.

Add the following figures to the end of Informative Appendix A:

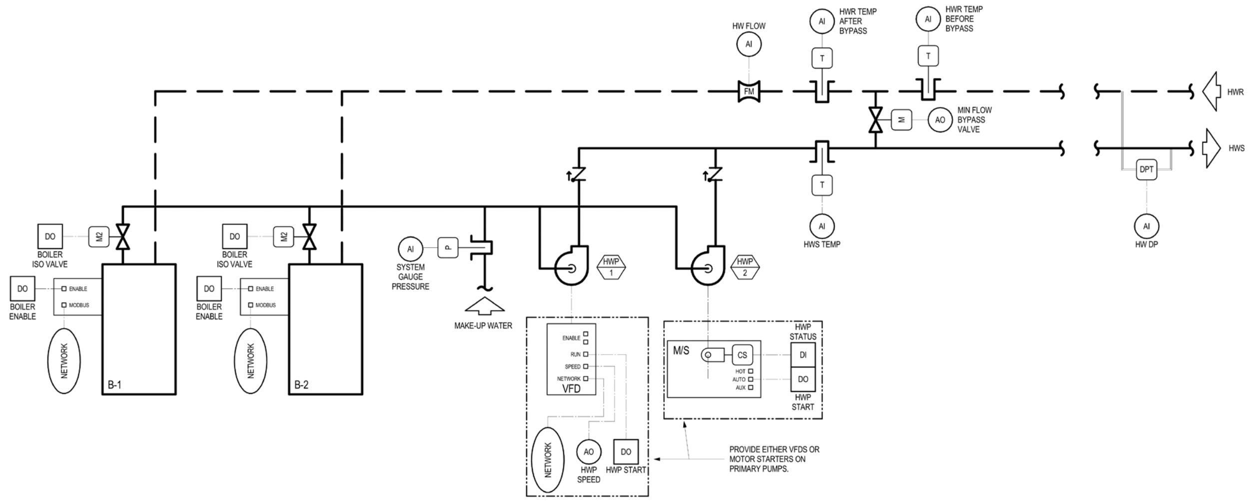


Figure A-23 Hot water plant with condensing boilers, variable primary distribution, and headered pumps

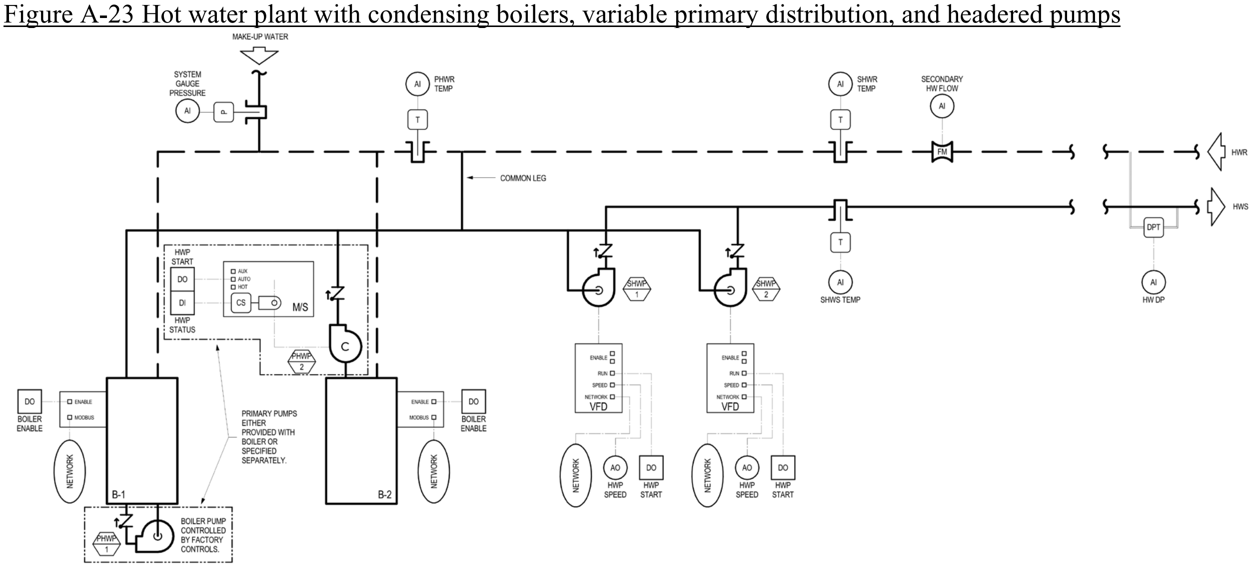


Figure A-24 Hot water plant with non-condensing boilers, primary-secondary distribution, and dedicated primary pumps

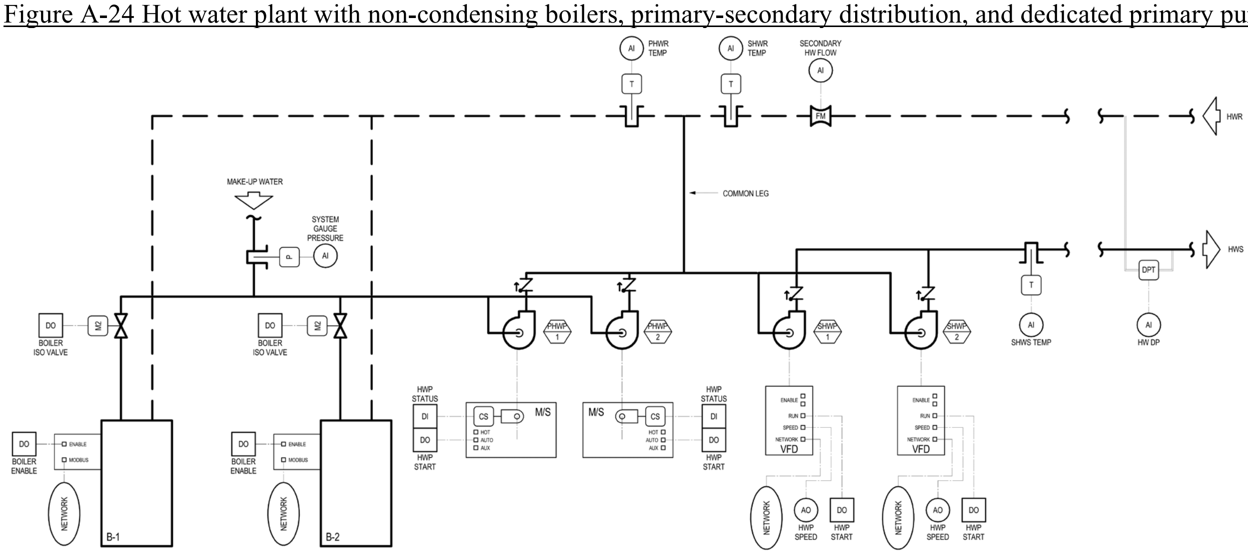


Figure A-25 Hot water plant with non-condensing boilers, primary-secondary distribution, and headered primary pumps

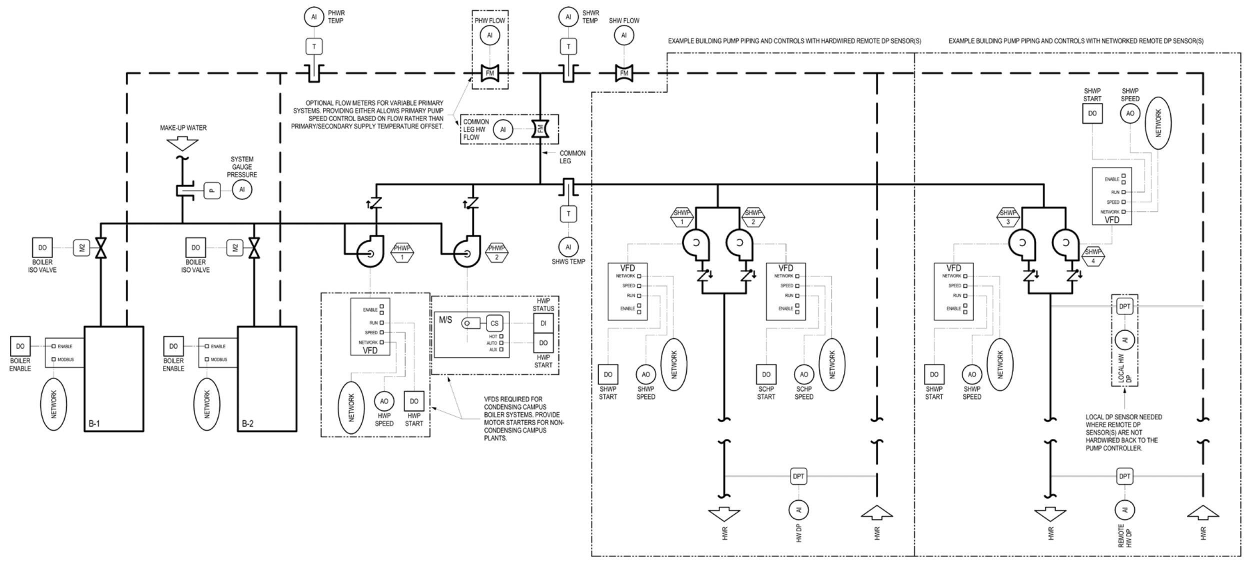


Figure A-26 Hot water plant with non-condensing or condensing boilers, primary-distributed secondary distribution, and headered primary pumps

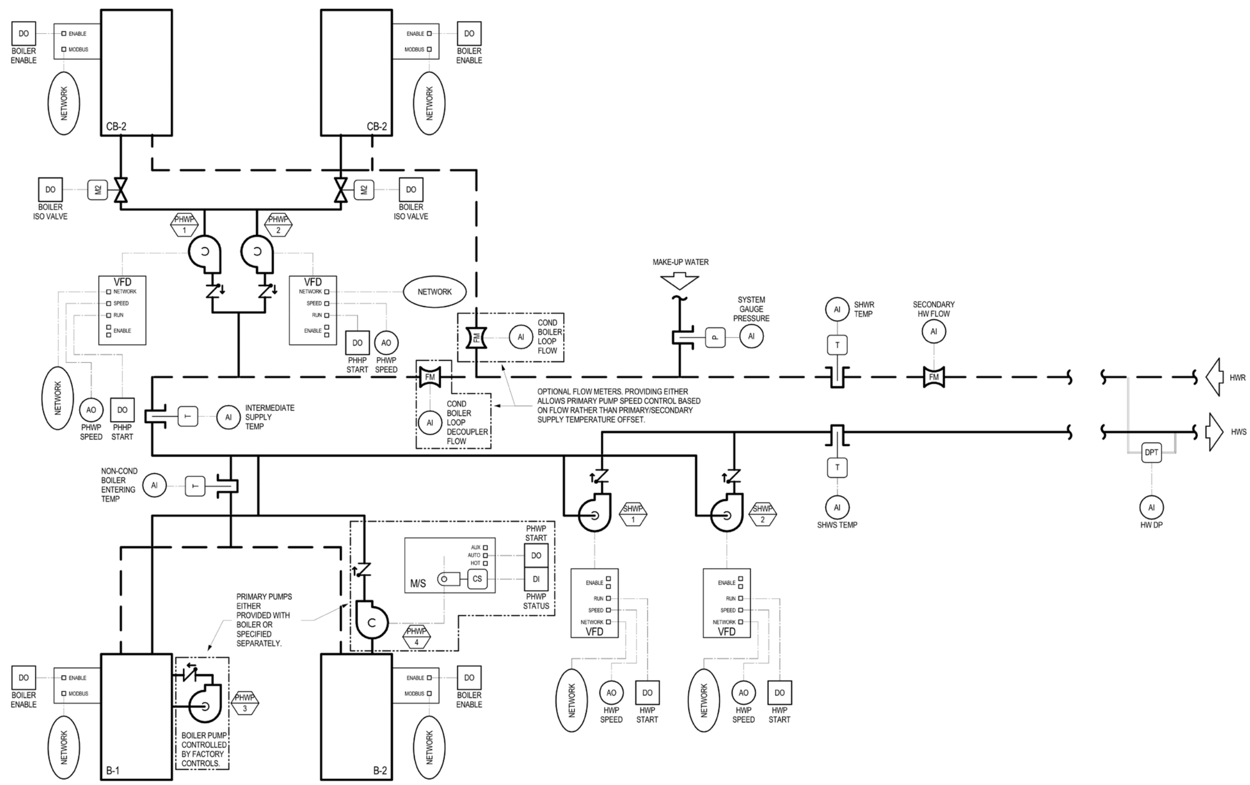


Figure A-27 Hot water plant with non-condensing and condensing boilers (hybrid plant) and separate non-condensing and condensing primary loops

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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About ASHRAE

Founded in 1894, ASHRAE is a global professional society committed to serve humanity by advancing the arts and sciences of heating, ventilation, air conditioning, refrigeration, and their allied fields.

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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7/21