Addendum x to
ASHRAE Guideline 36-2018

Public Review Draft

Proposed Addendum x to Guideline 36-2018, High-Performance Sequences of Operation for HVAC Systems

Second Public Review (April 2021)
(Draft shows Proposed Independent Substantive Changes to Previous Public Review Draft)

This draft has been recommended for public review by the responsible project committee. To submit a comment on this proposed standard, go to the ASHRAE website at www.ashrae.org/standards-research--technology/public-review-drafts and access the online comment database. The draft is subject to modification until it is approved for publication by the Board of Directors and ANSI. Until this time, the current edition of the standard (as modified by any published addenda on the ASHRAE website) remains in effect. The current edition of any standard may be purchased from the ASHRAE Online Store at www.ashrae.org/bookstore or by calling 404-636-8400 or 1-800-727-4723 (for orders in the U.S. or Canada).

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ASHRAE, 180 Technology Parkway, Peachtree Corners GA 30092

(This foreword is not part of this guideline. It is merely informative and does not contain requirements necessary for conformance to the guideline.)

FOREWORD

This ~~addendum includes the CHW plant sequences and associated logic variables and hardwired control points developed as part of ASHRAE Research Project 1711: Advanced Sequences of Operation for HVAC Systems – Phase II Central Plants and Hydronic Systems. Typos and minor language clarity issues identified since final publication of the RP-1711 sequences on December 31, 2019, have been cleaned up in this version.~~is the second public review of Addendum x addressing control sequences for Chilled Water Plants and includes only substantive changes to the first public review draft. Rationale for each change is shown directly before the change.

~~Cross-references herein refer to content from Addendum r which has been approved in an earlier public review. . Approval of this addendum is therefore predicated on approval of Addendum r.~~

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

Addendum x to Guideline 36-2018

Revise 3.1.7.8 as follows. This creates variables for parameters referenced in tower level controls for clarity.

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

3.1.7.8. Cooling Tower Level Control

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

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

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

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

Add 3.1.7.9 as follows. This creates variables for parameters referenced in pump staging controls for clarity.

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

3.1.7.9. Headered Pump Design Quantities

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

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

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

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

Add following to Section 5.20.4.15 to clarify when these two paragraphs apply:

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

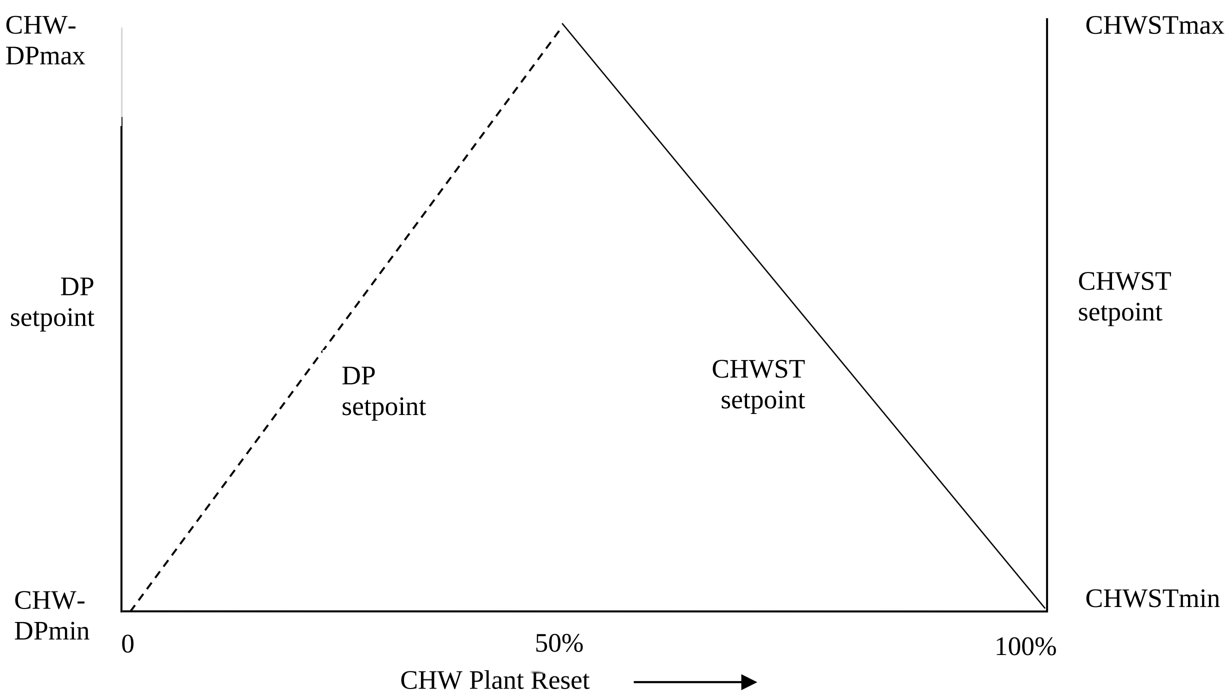
e. Where a primary CHW supply temperature sensor is not provided, primary CHW supply temperature used in staging logic shall be the weighted average supply temperature of all chillers with open CHW isolation valves. Temperatures shall be weighted by design chiller flowrates.

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

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

Add item a. to Section 5.20.5.2 to describe the reset sequence (typo):

5.20.5.2. Differential Pressure Controlled Loops: Chilled water supply temperature setpoint CHWSTsp and pump differential pressure setpoint CHW-DPsp shall be reset based on the current value of the logic variable called "CHW Plant Reset" as shown below and described subsequently.



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

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

Revise Section 5.20.5.7 to improve efficiency of series chillers by using the design capacity ratio to determine upstream chiller setpoint.

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

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

5.20.5.8. When the upstream and downstream machines are enabled:

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

b. Upstream chiller CHWST setpoint shall be the 5-minute rolling average of the mean of the primary CHW return temperature and the plant CHWST setpoint.following calculation:

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

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

Revise Section 5.20.6.7 to reference a variable for the number of pumps, which has been added as a parameter in Section 3.

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

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

Revise Sections 5.20.6.8 and 5.20.6.11 as shown to avoid conflict with Section 5.1.13, which calls for VFD mapping to be 0%-100% so speed signal matches speed.

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

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

Revise Section 5.20.7.3 to reference a variable for the number of pumps, which has been added as a parameter in Section 3.

5.20.7.3. Pumps serving multiple coils

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

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

Revise Section 5.20.7.3 b. and e. as shown to avoid conflict with Section 5.1.13 which calls for VFD mapping to be 0%-100% so speed signal matches speed.

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

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

Revise Section 5.20.10. advisory text to address other cases where head pressure control might not be provided.

Delete Section 0~~5.20.10~~ for air-cooled plants or water-cooled plants where head pressure control is not required. Retain otherwise.

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

Move Section 5.20.12.2 a to be a subsection of what is currently numbered as b. since it only applies to the first tower fan control sequence. Subsequent subsections are renumbered accordingly.

5.20.12.2. Fan Speed Control

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

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

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

~~b.~~a. Condenser Water Return Temperature (CWRT) Control

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

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

Clarify Section 5.20.12.2.a.8 to 11 that use cascading loops to indirectly control CWRT:

~~7.~~8. When any condenser water pump is proven on, CWRT shall be controlled to CWRTsp by setting CWST setpoint, CWSTsp, ~~shall be set~~ equal to CWRTsp minus CWdt, where CWdt is the 5 minute rolling average of common condenser water return temperature less condenser water supply temperature, sampled at minimum once every 30 seconds. When the plant is first enabled CWdt shall be held fixed equal to 50% of CWRTdesX less CWSTdesX of the enabled chiller for 5 minutes to populate the rolling average queue before populating with actual data.

~~8.~~9. When any condenser water pump is proven on, CWST shall be maintained at setpoint by a direct acting PID loop. The loop output shall be mapped to the variable CWSTTowerSpd. Reset CWSTTowerSpd from minimum tower speed at 0% loop output to 100% speed at 100% loop output.

~~9.~~10. Tower speed command signal shall be the lowest value of CWSTTowerSpd, HpTowerMaxSpd from each chiller head pressure control loop, and PlrTowerMaxSpd. All operating fans shall receive the same speed signal.

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

~~10.~~11. Disable the tower fans if either

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

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

ii. Tower fans have been at minimum speed for 5 minutes and ~~temperature towers are controlled to~~CWRT drops below setpoint minus 1°F.

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

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

Clarify Section 5.20.12.2.b tower fan control logic.

~~c.~~b. Condenser Water Supply Temperature (CWST) Control

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

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

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

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

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

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

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

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

~~4. Calculate combined chiller and tower efficiency, Eff_{Ch+T}. Eff_{Ch+T} is calculated based on the combined power draw of all tower fans as read from tower VFD interfaces (kW_{Towers}), the combined power draw of all chillers as read from the chiller interfaces or power meters (kW_{Ch}), and instantaneous plant output ($Q_{actual\ i}$). $Q_{actual\ i}$ differs from $Q_{required}$ only in that it is an instantaneous value instead of a rolling average and is calculated using actual CHWST instead of CHWST setpoint. Eff_{Ch+T} used in logic shall be a 5-minute rolling average of instantaneous values sampled at a minimum of every 30 seconds.~~

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

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

v. ~~For~~After the initial time interval, reset CWSTsp down 1°F.

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

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

(a) CWSTsp ~~CWST setpoint~~ had reset down in the previous time interval and Eff_{Ch+T} is now less than at the previous setpoint change.

(b) CWSTsp ~~CWST setpoint~~ had reset up in the previous time interval and Eff_{Ch+T} is now greater than at the previous setpoint change.

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

~~vii.~~viii. ~~Otherwise~~Else, do not change CWSTsp~~CWST setpoint~~.

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

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

~~6. At the end of the initial time interval, reset CWST setpoint down~~ by 1°F.

~~*There is no history when the plant is first enabled, so a direction to reset must be picked arbitrarily. An initialization setpoint should be chosen that ensures minimum chiller lift at startup.*~~

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

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

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

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

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

11. Disable the tower fans if either

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

    ii. Tower fans have been at minimum speed for 5 minutes and the ~~temperature towers are controlling speed to~~CWST drops below setpoint minus 1°F.

12. Enable the tower fans if

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

    ii. ~~Temperature towers are controlling speed to~~CWST rises above setpoint by 1°F, and

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

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

Revise Section 5.20.13 and 5.20.17.5 to include tower level variables from Section 3 for clarity.

5.20.13. Tower Make-up Water

5.20.13.1. Make-up water valve shall cycle based on tower water fill level sensor. The valve shall open when water level falls below T-level-min-fill~~the minimum fill level recommended by the tower manufacturer~~. It shall close when the water level goes above T-level-max-fill~~the maximum level recommended by the tower manufacturer~~.

5.20.17.5. Tower level

a. If tower water level sensor indicates ~~low~~ water level below T-level-low-alarm, generate a Level 2 alarm.

b. If tower water level sensor indicates ~~high~~ water level above T-level-high-alarm, generate a Level 3 alarm.