A Workflow for Transparent and Replicable Modelica Implementations of ASHRAE Guideline 36 Controls for Chiller Plants with Waterside Economizers

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October 2026

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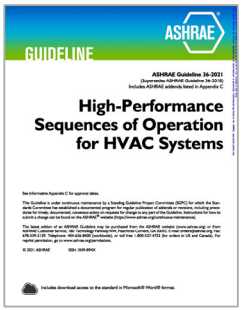
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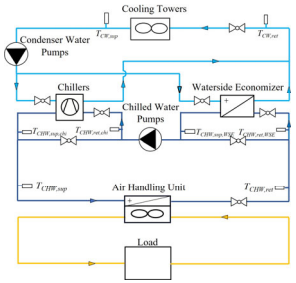
The How and Why:

- Rule-based controls are widely used in industry. However, they can be difficult to implement in Modelica.
- We develop a workflow for transparent, replicable implementation of complex, rule-based controls.
- We use that workflow to apply Guideline 36 chiller plant controls to a case study of a chiller plant with waterside economizer (WSE).

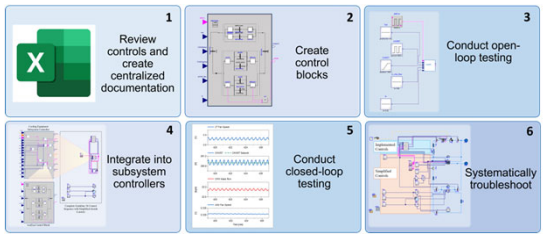
Introduce motivation



Explain case study



Demonstrate workflow



Conclude

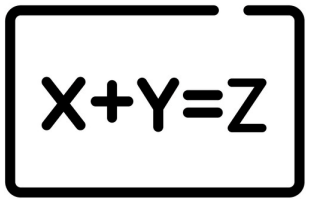


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Modelica is uniquely able to evaluate complex controls in cooling systems.

JH1

Equation-Based and Declarative



Describes physical relationships acausally and can handle large systems of equations.

Modelica Language



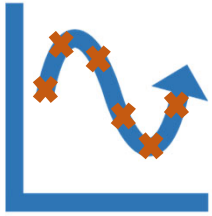
Object-Oriented

Can build large systems out of repeatable components.

Dynamic



Captures fast dynamics caused by controls through changing time steps.



Handles Continuous and Discrete Behavior

Can simulate physical systems and controls together.

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Slide 3

JH1 Switch with 2nd slide? Delete?
Ho, Julia Lien, 2026-09-30T19:21:07.345

Implementing controls is still difficult to do.

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

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

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

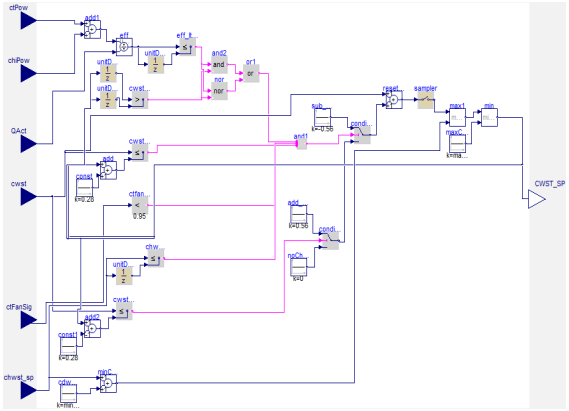
iii. Else, if CWST is no more than 0.5°F below present setpoint, reset CWSTsp up by 1°F.

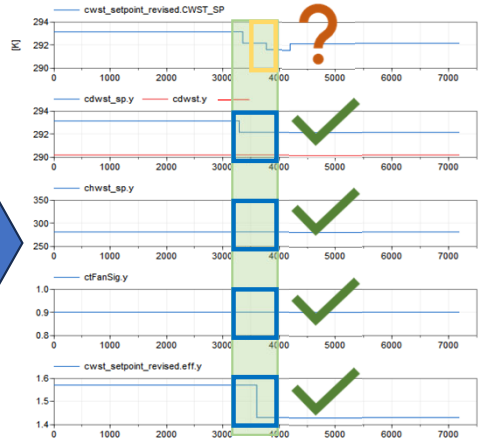
iv. Else, do not change CWSTsp.

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.







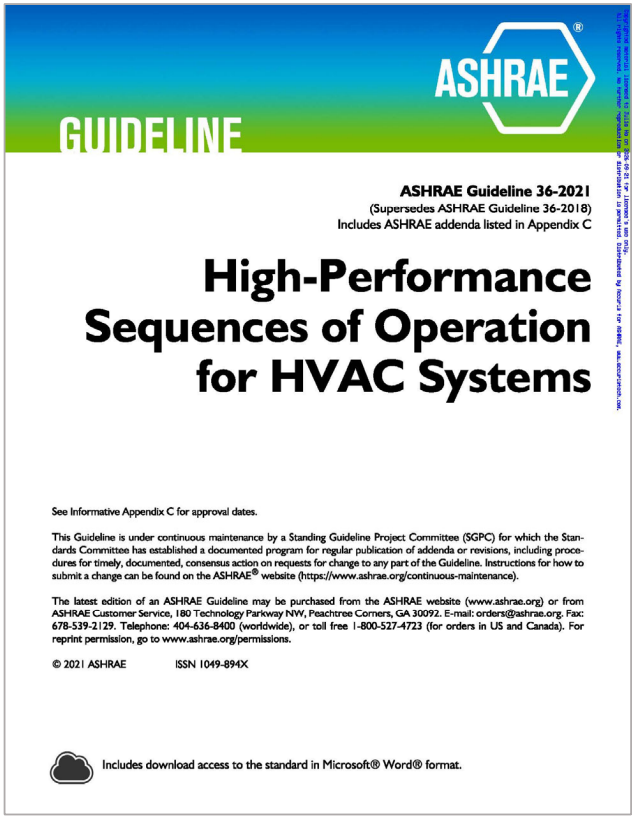
Challenges include:

- Correctly interpreting plain-English control sequences
- Implementing faithfully in Modelica
- Testing and integrating controls
- Documenting implementation, ambiguities, and potential issues
- Making this process replicable for others

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ASHRAE Guideline 36 – What Is It?

Key:
HVAC – Heating, Ventilation, and Air Conditioning
ASHRAE – American Society of Heating, Refrigerating, and Air-Conditioning Engineers



GUIDELINE

ASHRAE

ASHRAE Guideline 36-2021
(Supersedes ASHRAE Guideline 36-2018)
Includes ASHRAE addenda listed in Appendix C

High-Performance Sequences of Operation for HVAC Systems

See Informative Appendix C for approval dates.

This Guideline is under continuous maintenance 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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Includes download access to the standard in Microsoft® Word® format.

Title page of ASHRAE Guideline 36-2021 [2]

- Sophisticated rule-based control sequences for airside and hydronic HVAC systems.
- Developed by ASHRAE-affiliated engineers.
- Goal is to reduce engineering time, commissioning time, and energy use [1].
- Airside sequences are widely studied and consistently save energy.
- Chiller plant sequences were first included in 2021 version [2] and have not been studied as thoroughly.
  - Current studies include Grahovac 2024 [3], Lu 2021 [4].

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Modeling Testbed

Key:
CHW – chilled water
CDW – condenser water
WSE – waterside economizer

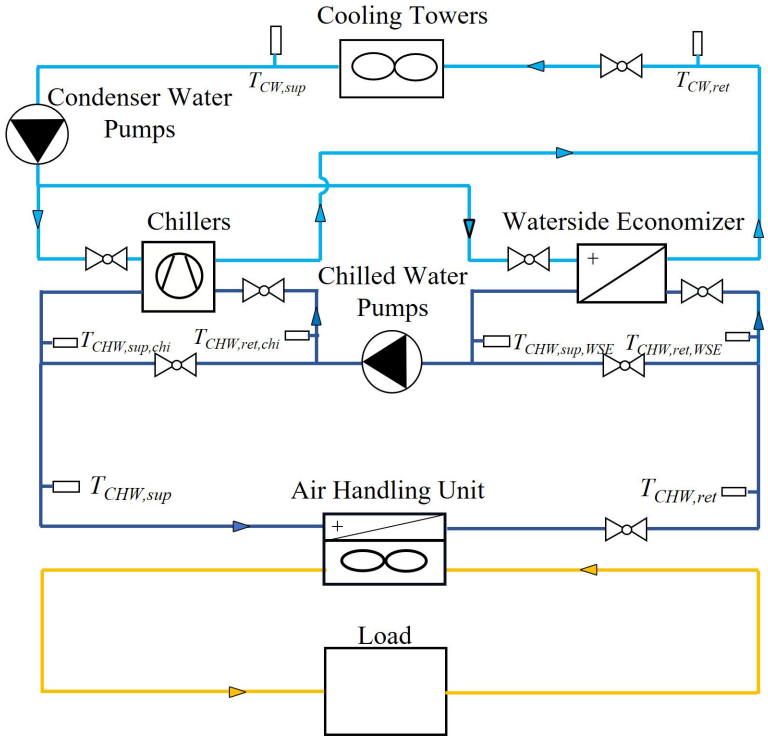
From previous literature [5].

Chiller plant supplies an office building with conventional (constant load) data center.

- EnergyPlus is used for prescribed office building loads.
- Data center is 40% of peak load (864 kW)

Chiller plant is sized for peak load (2160 kW).

- Two 1294 kW parallel chillers
- One 2588 kW WSE
- Two headered CHW pumps
- Two headered CDW pumps
- Two parallel cooling towers



Case study schematic, from Faulkner (2025) [5]

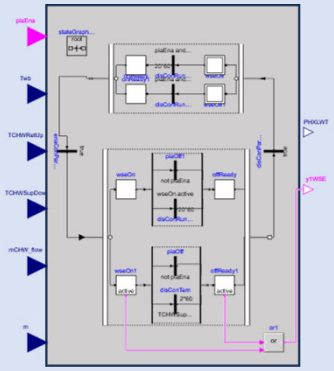
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The Workflow

1

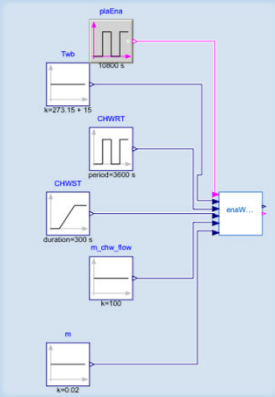
Review controls and create centralized documentation

2



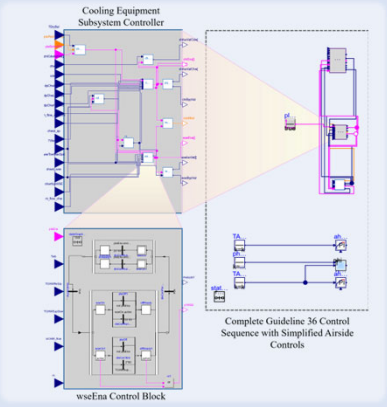
Create control blocks

3



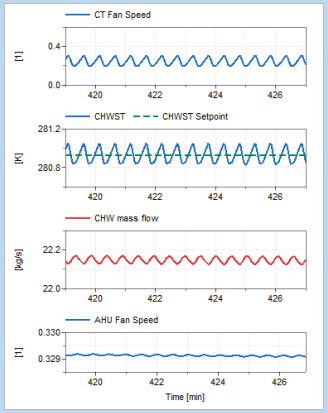
Conduct open-loop testing

4



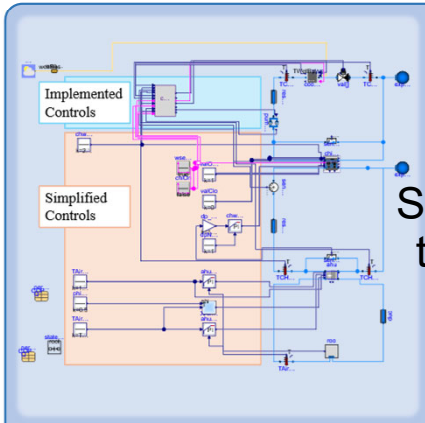
Integrate into subsystem controllers

5



Conduct closed-loop testing

6



Systematically troubleshoot

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Example: WSE Enable/Disable Control

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

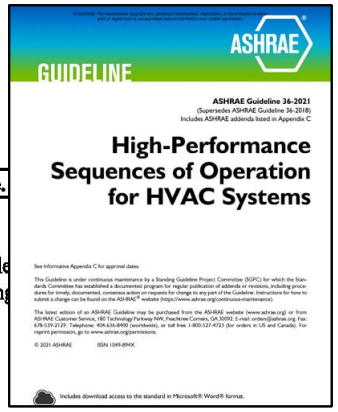
5.20.3. Waterside Economizer Control

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

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

o
o
o

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



Screenshots from ASHRAE Guideline 36-2021 [2]

These are **two** of around **100** Guideline 36 chiller plant control actions implemented in this project.

JH1

This project spans 50 pages of controls.

Copied from ASHRAE Guideline 36-2021:

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

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Slide 8

JH1 Add number of pages from G36

Ho, Julia Lien, 2026-09-30T19:20:48.846

Step 1: Documentation

Key:
G36 – Guideline 36

- Create a central tracking document (CTD)
- Store with models

Written control sequences				Modelica Implementation	Testing protocol			
Control Sequence	Applicable System	G36 Section	Testable Control Action	Equivalent Modelica Control Component	Simulation Script	Modelica Example Using Simulation Script	Passed Test?	Notes
Waterside Economizer Control Enable/Disable	Plants with wse	5.20.3.1	Enable WSE if it has been disabled for >=20 min and CHWRT upstream of HX is > predicted HX leaving water temp (PHXLWT) + 2F.	WSEControlLogics.Controls.Guideline36.Chiller.enaWSE	g36_5.20.3.1.mos	WSEControlLogics.Controls.Guideline36.Validation.WSEStaging.g36_5_20_3_1	y	Calculated PHXLWT by hand - calculations are correct.

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Naming that references original control sequence

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Naming that references original control sequence
Full paths for Modelica models and components

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Naming that references original control sequence
Full paths for Modelica models and components
Testing feedback to document ambiguities, uncertainty, changes from written control

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Step 2: Control Block Implementation

- Identify closely related control actions.
- If needed, create visual representations.
- Implement in Modelica.

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- **Identify closely related control actions.**
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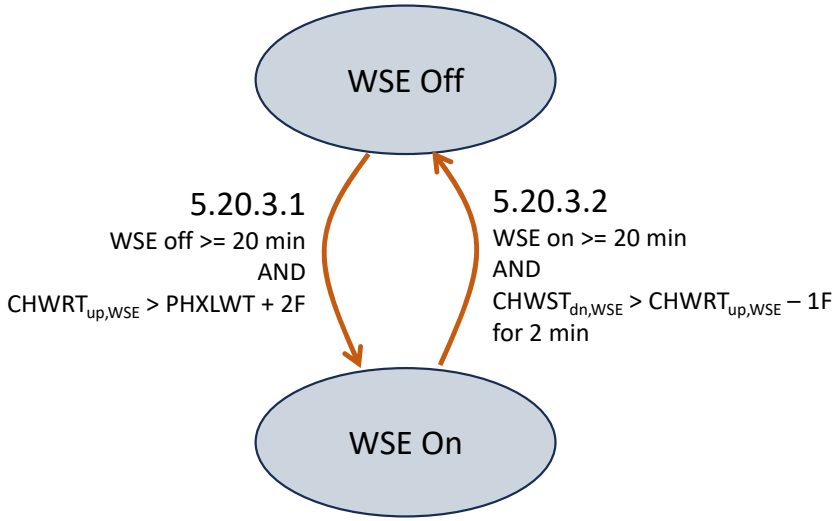
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Selected control actions, copied from ASHRAE G36 [2].

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State graph representing as-written controls.

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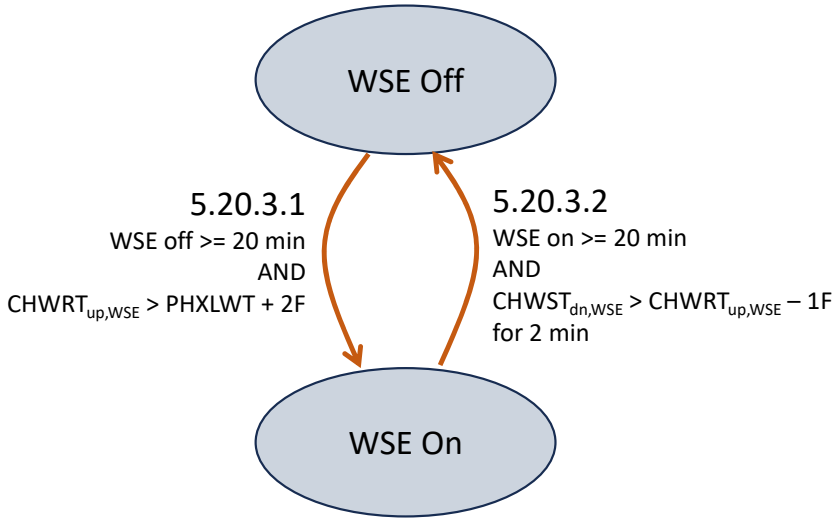
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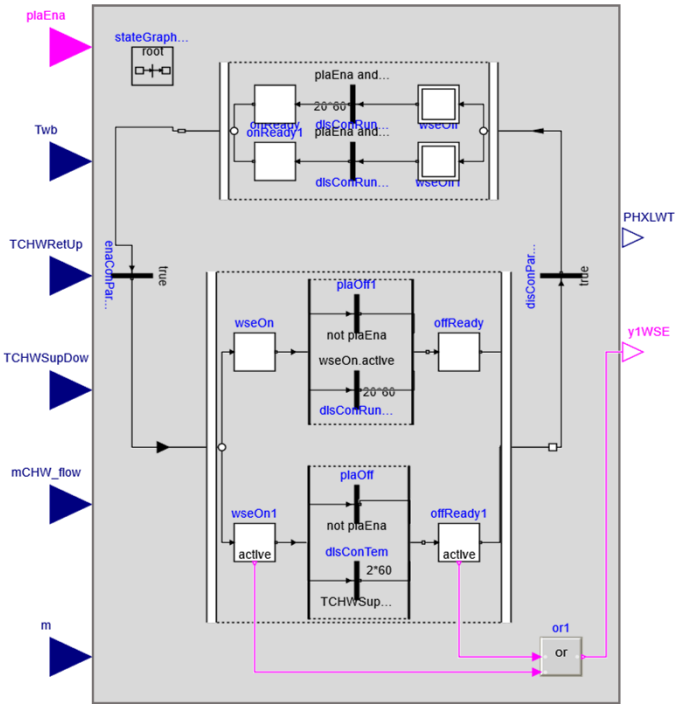
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State graph representing as-written controls.

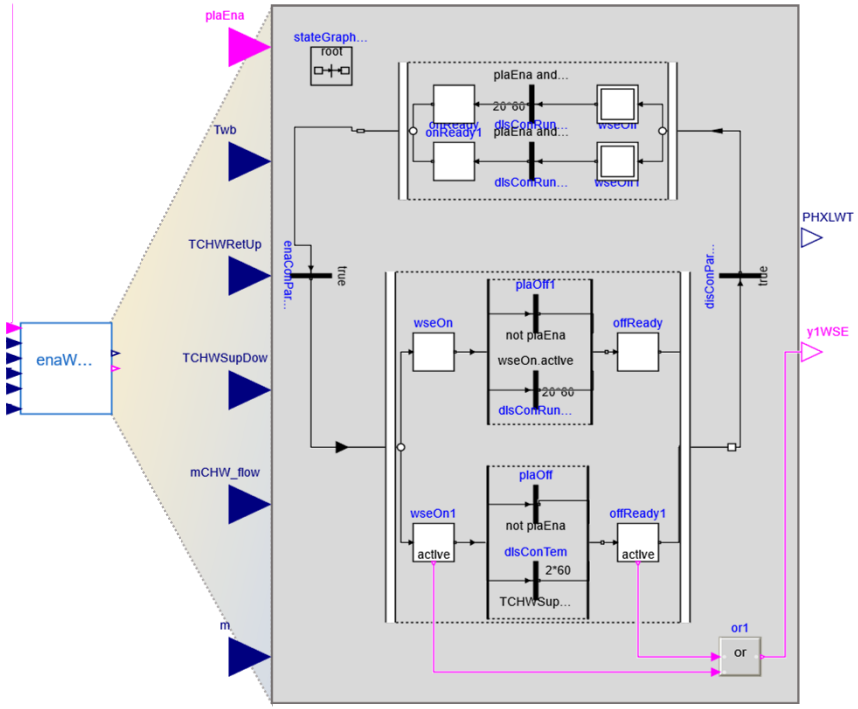


Modelica control sequence implementation

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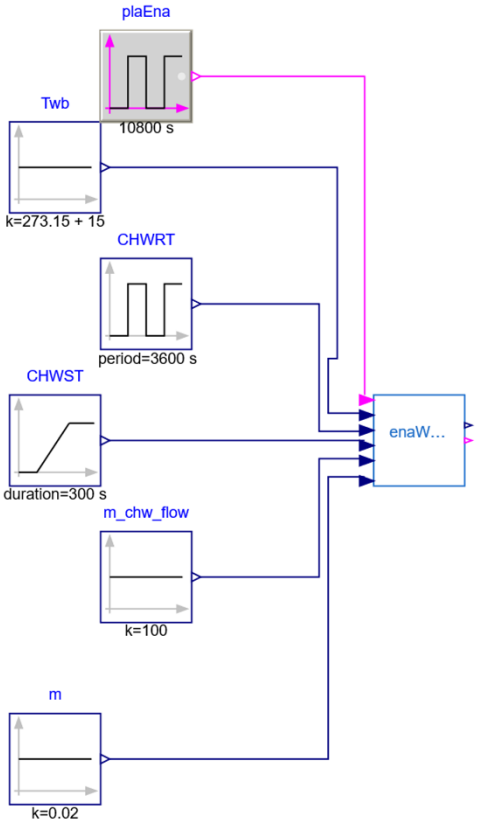
Modelica control sequence implementation

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Step 3: Open Loop Testing

- Prescribe inputs to the control block to output an expected behavior.

- The names of these models and simulation/plotting scripts should reference the control action:
  - Model: g36_5_20_3_2.mo
  - Script: g36.5.20.3.2.mos



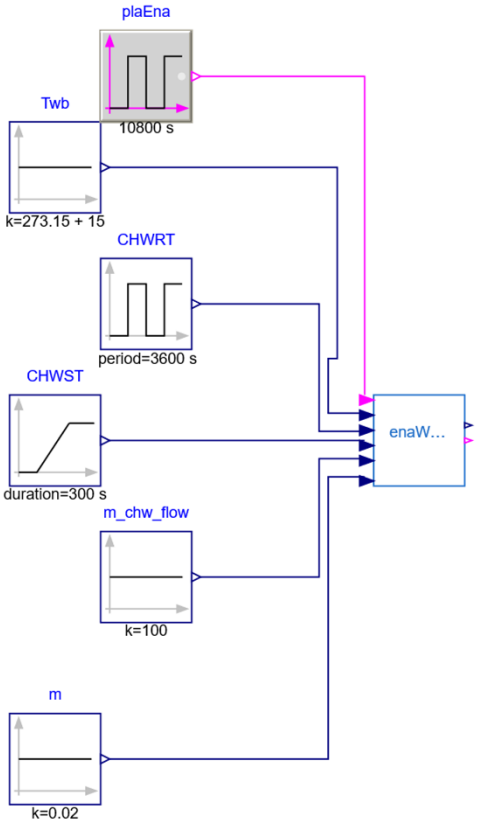
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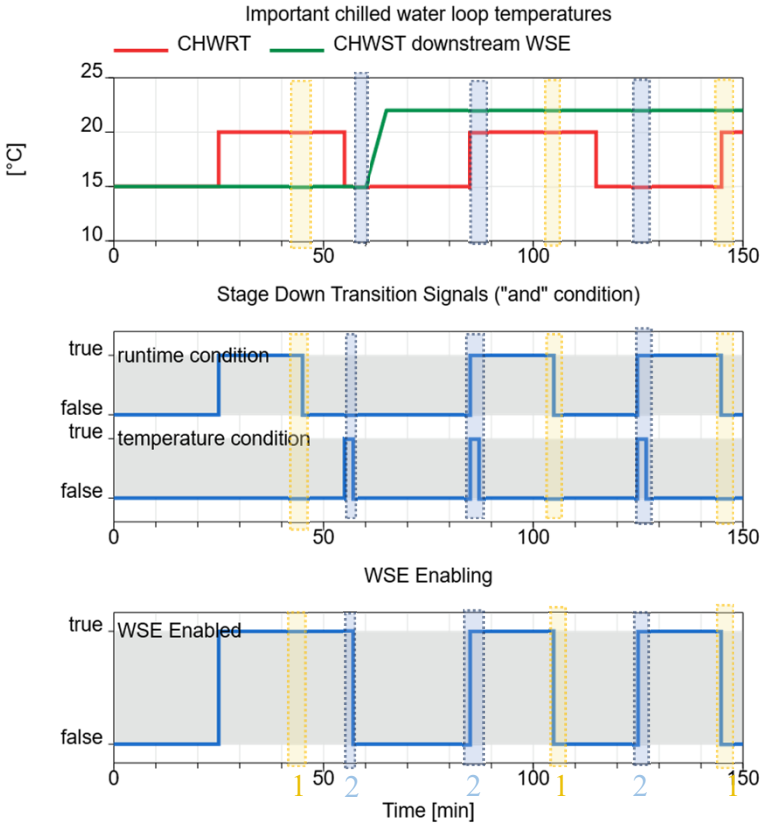
Step 3: Open Loop Testing

Key:
CHW– chilled water
HX – heat exchanger (WSE)
WSE – waterside economizer

5.20.3.2. Disable WSE when:

- (1) it has run for at least 20 minutes *[runtime]*
- (2) and CHW temp downstream of HX is greater than CHWRT upstream of HX less 1 degF for 2 minutes *[temperature]*





Here, all transition signals become false when the condition is met and their associated state has changed.

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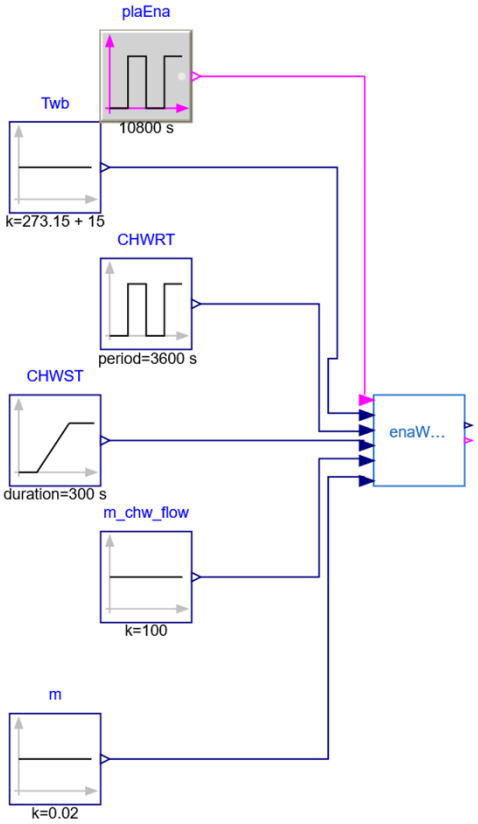
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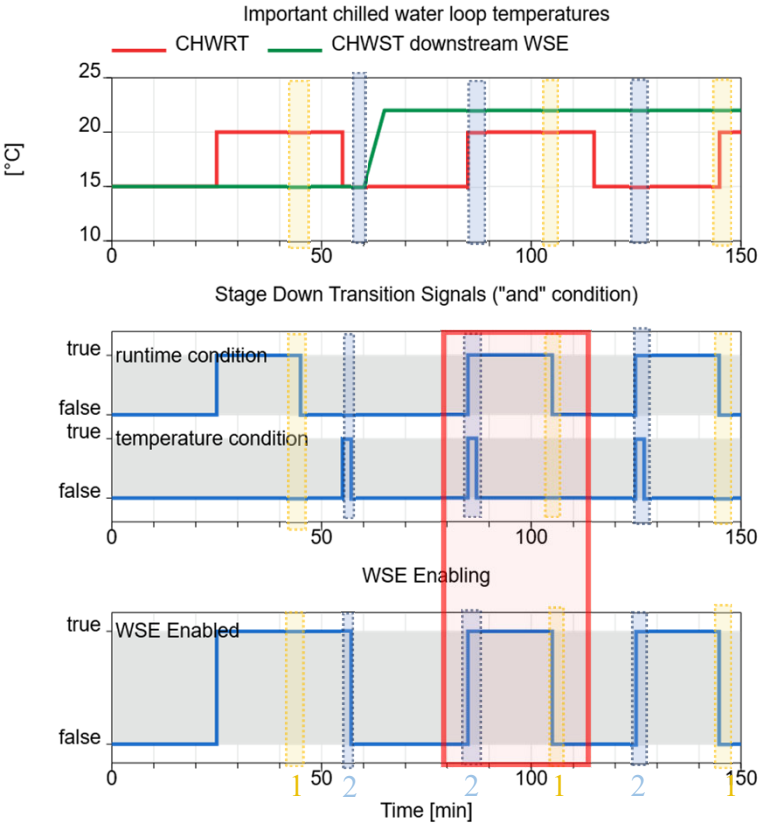
Implementation error here: can you find it?

Answer: condition (2) can be met any time before condition (1) is met.

If this happens, the WSE will disable at 20 minutes even if condition (2) is not true at that time.

This was not initially caught during open loop testing.





Here, all transition signals become false when the condition is met and their associated state has changed.

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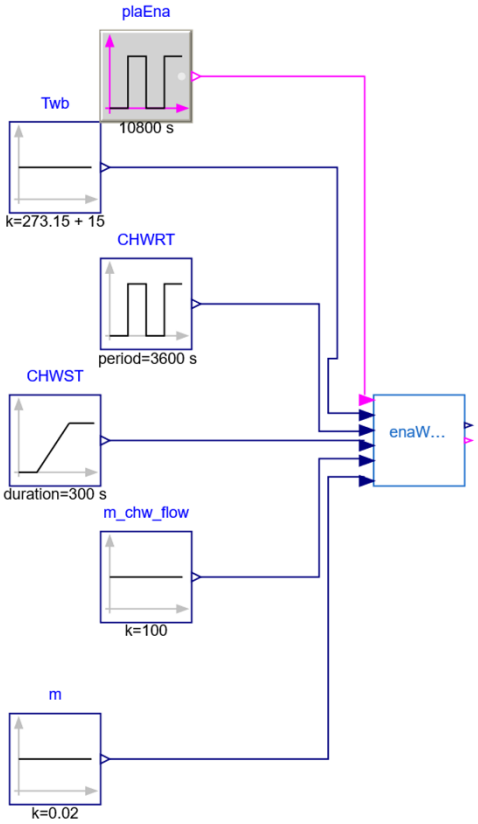
Step 3: Open Loop Testing

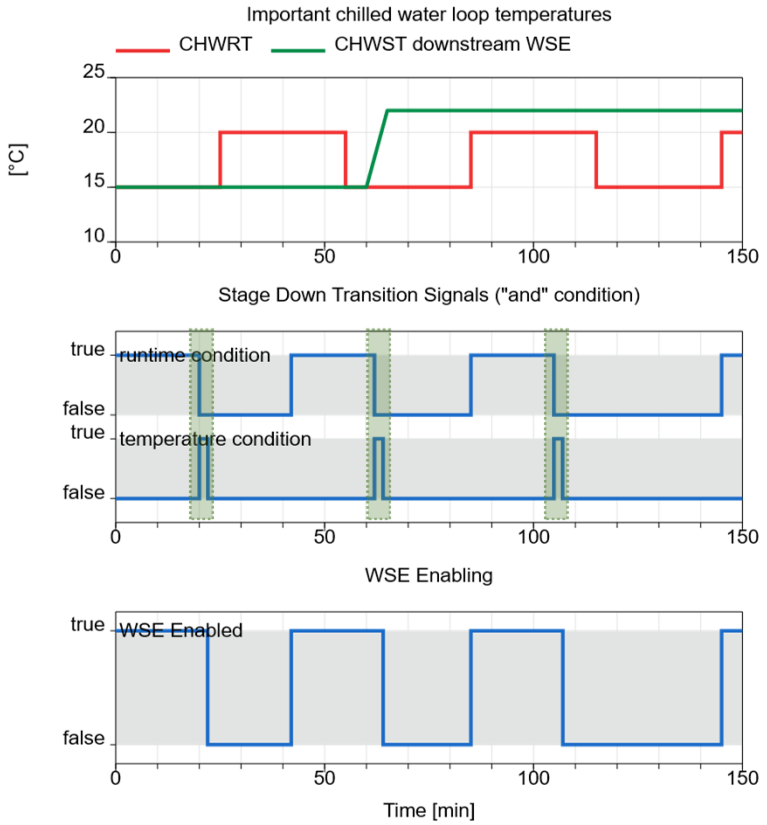
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- (1) it has run for at least 20 minutes *[runtime]*
- (2) and CHW temp downstream of HX is greater than CHWRT upstream of HX less 1 degF for 2 minutes *[temperature]*

This was fixed after finding the issue in Step 5 (closed loop testing).





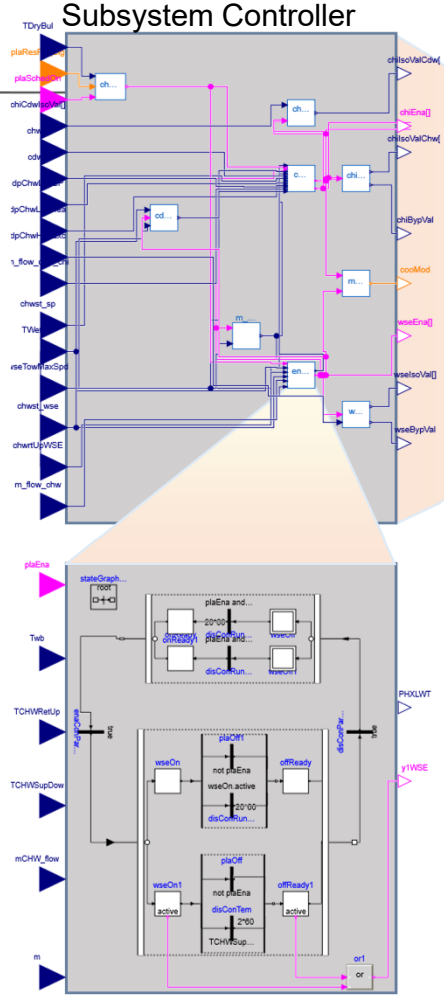
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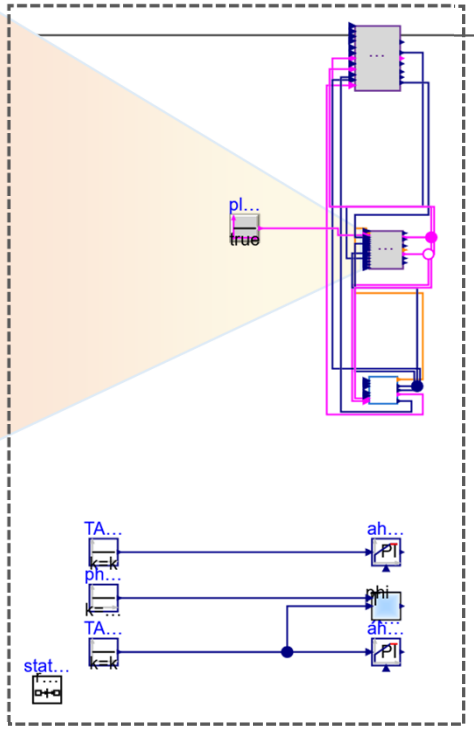
Step 4: Control Integration

- Determine how control sequences should be grouped
  - i.e., CDW Loop, Cooling Equipment, CHW Loop
- Combine relevant controls and propagate parameters
- Create a partial model that can be extended with physical systems.

Cooling Equipment Subsystem Controller



wseEna Control Block



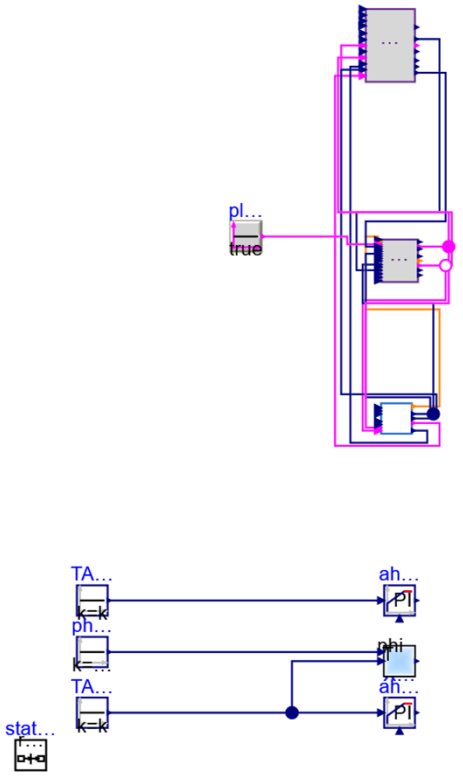
Complete Guideline 36 Control Sequence with Simplified Airside Controls

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Slide 22

JH1 Is it a partial model?
Ho, Julia Lien, 2026-09-24T16:16:42.981

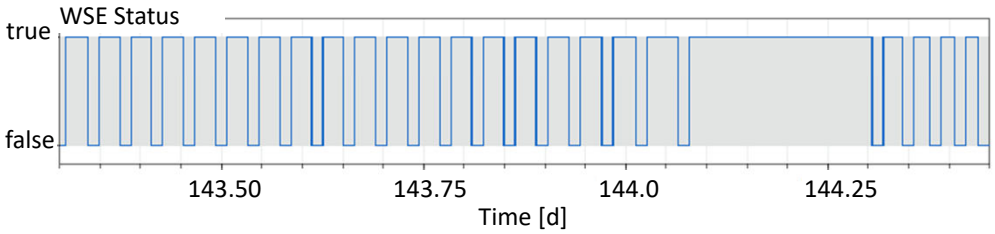
Step 5: Closed Loop Testing

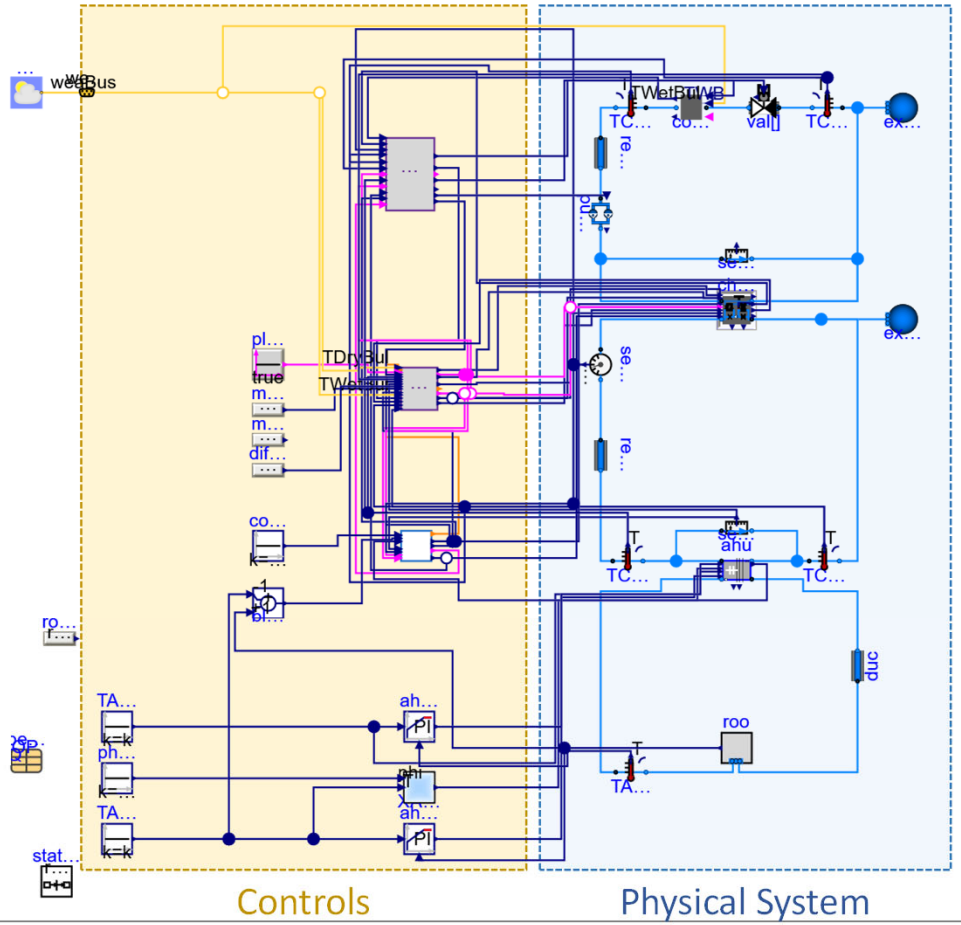


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Step 5: Closed Loop Testing

- Integrate the partial control model with the physical system model.
- Simulate and correct any control issues.
- If control issues are found that are clearly related to a specific control block, iterate through steps 2-5 of the workflow.

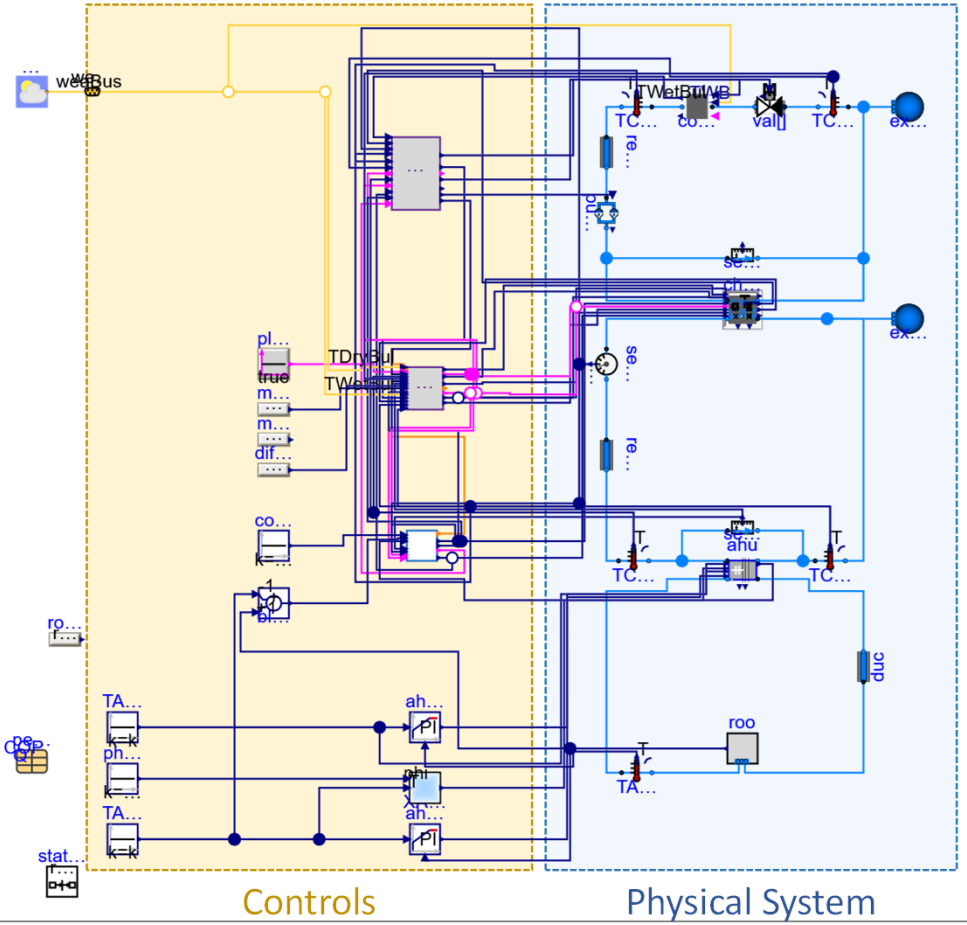




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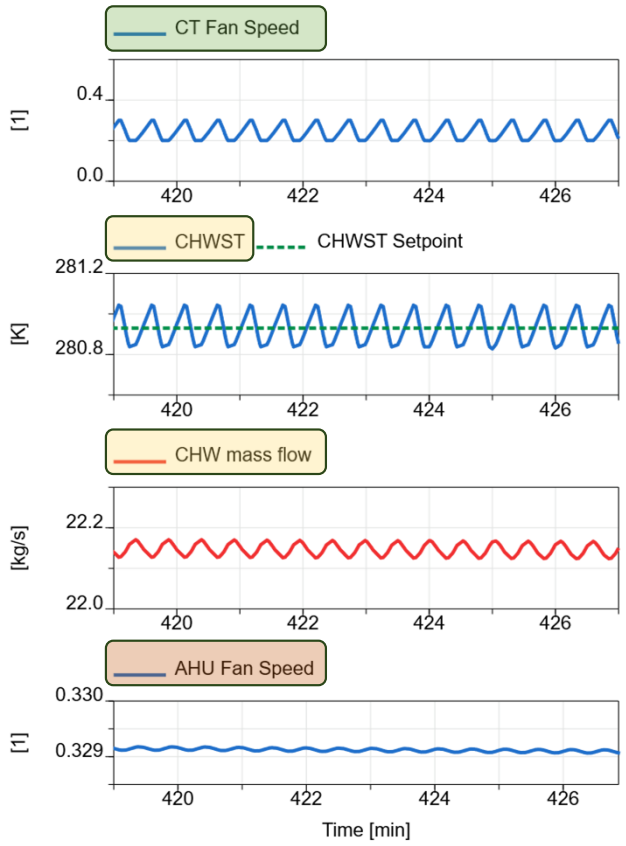
Step 5: Closed Loop Testing

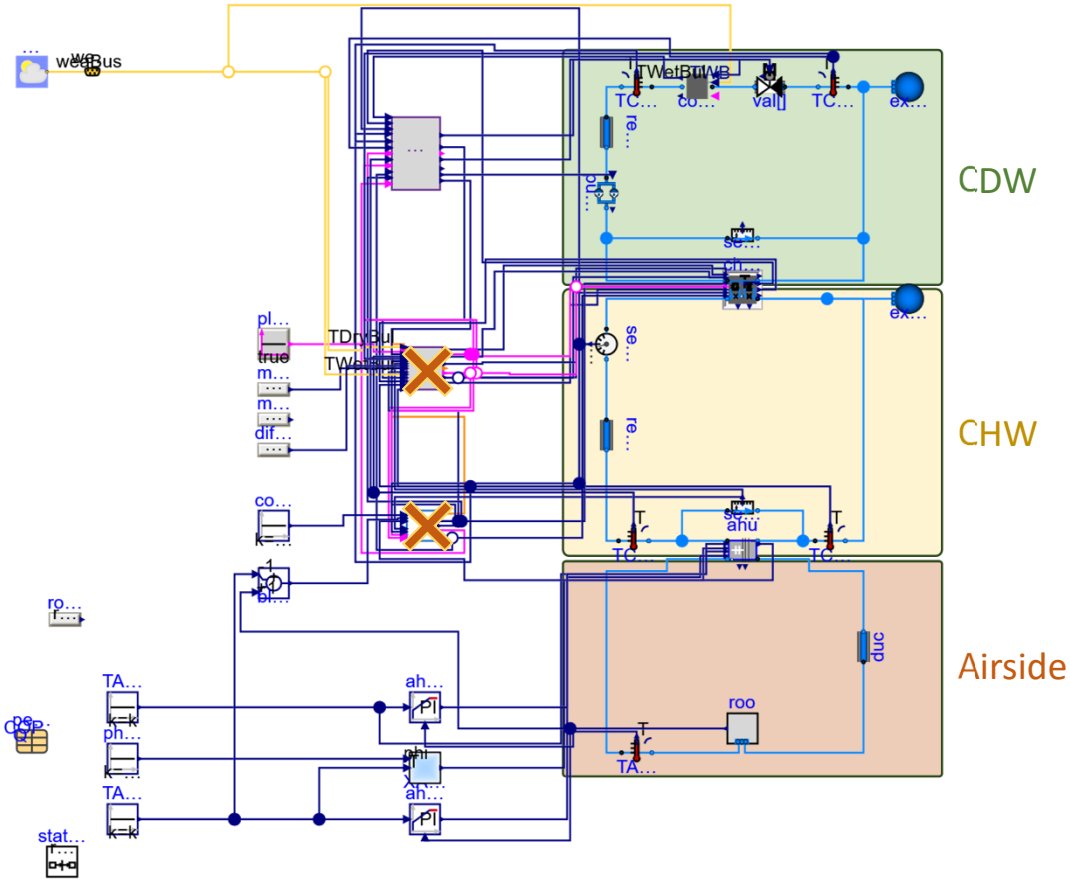
- Integrate the partial control model with the physical system model.
- Simulate and correct any control issues.
- If control issues are found that are clearly related to a specific control block, iterate through steps 2-5 of the workflow.
- If control issues with no clear source are found, use step 6 of the workflow.



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Step 6: Systematic Troubleshooting

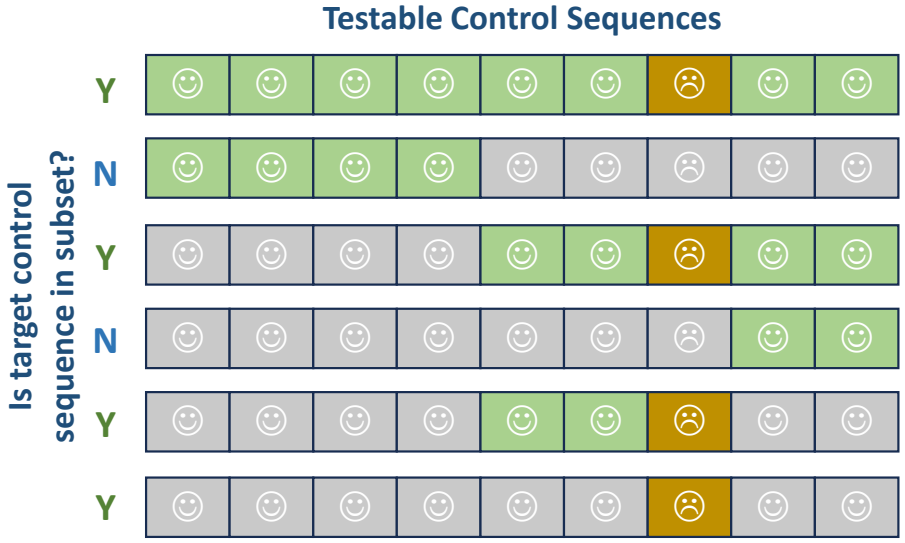


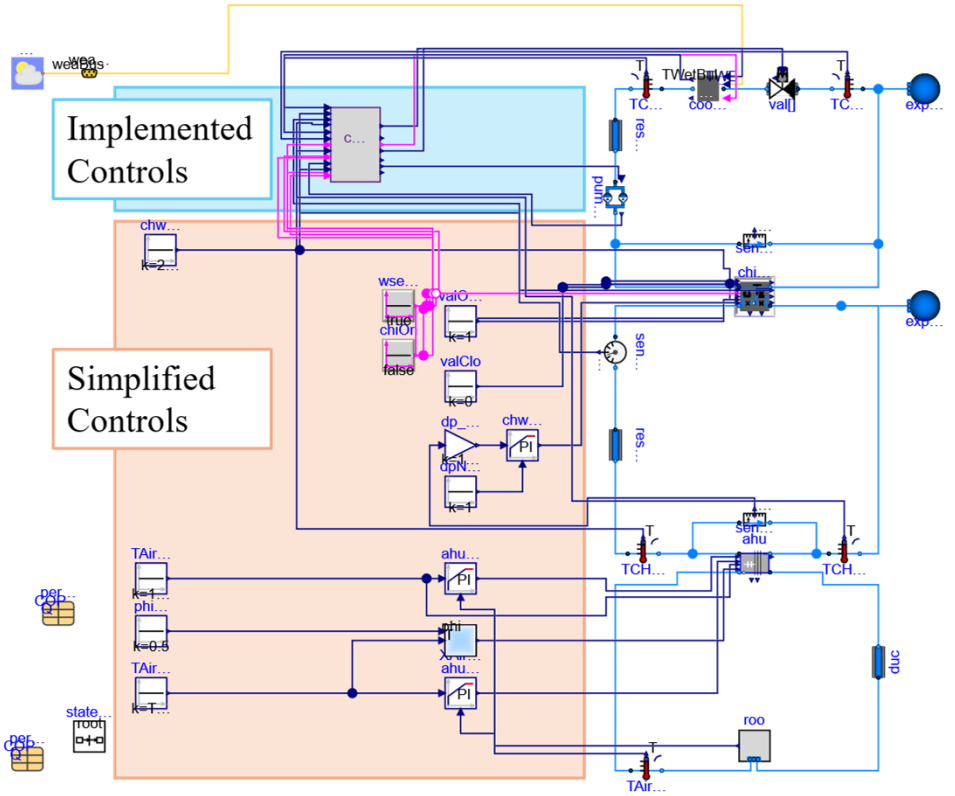


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Step 6: Systematic Troubleshooting

- Replace your controls one half at a time until you find the problematic control block
- Similar philosophy to binary search algorithm





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Step 6: Systematic Troubleshooting JH1

Issue:

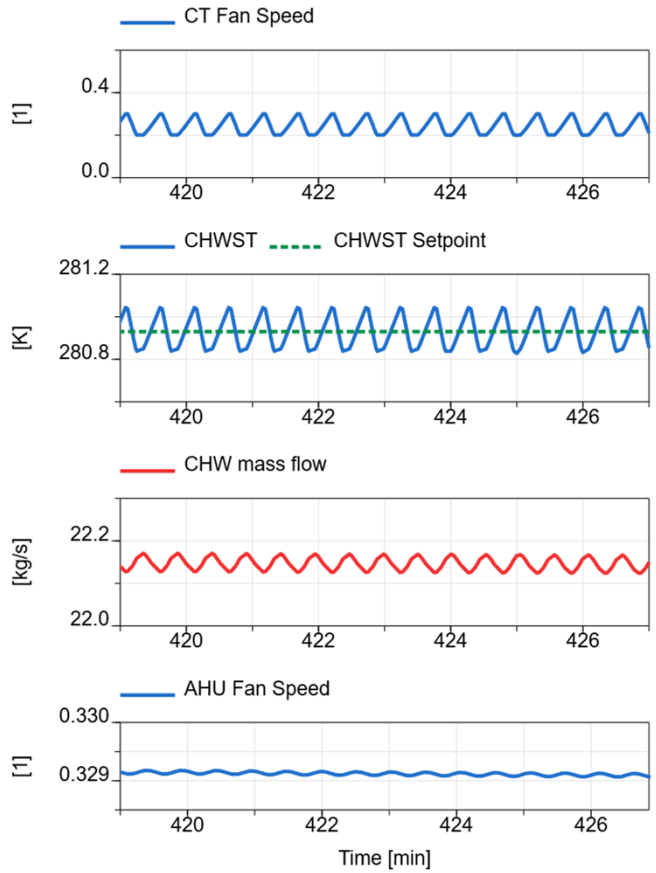
1. PI control proportional gain was too large.
2. Fan enabling control caused many events even though it was correct.

Solution:

1. Reduce k from 0.5 to 0.1.
2. Revise fan enable control.

Table 1. Simulation Results of Days 0-17.7

	Simulation Time (min)	State Events
Original	5.53	13527
Corrected	0.42	803



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JH1 Show corrected figure too

Ho, Julia Lien, 2026-09-30T19:20:17.558

Step 6: Systematic Troubleshooting

Issue:

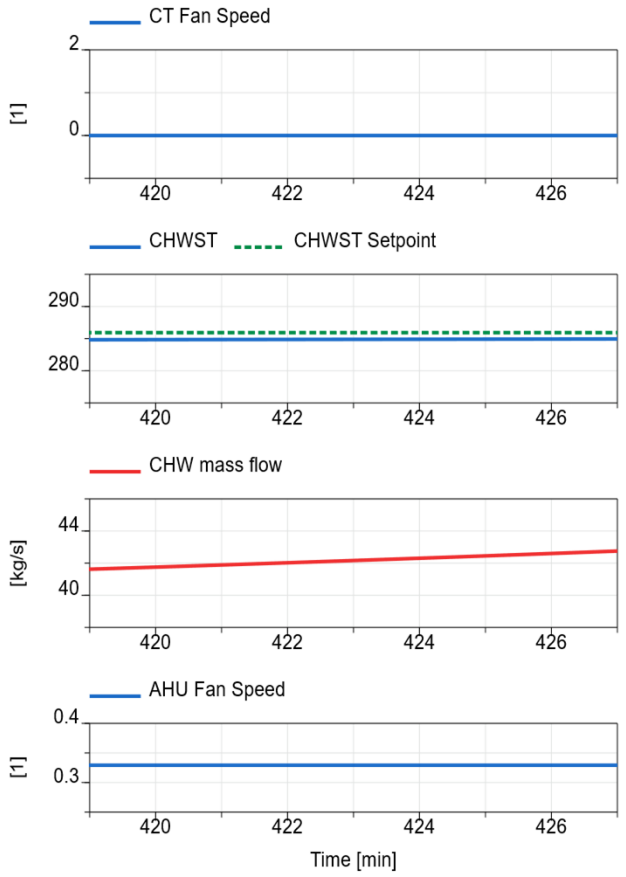
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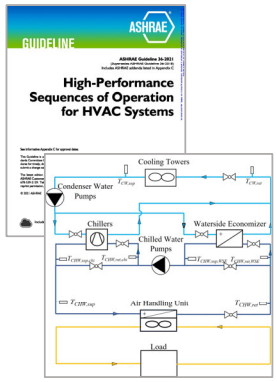


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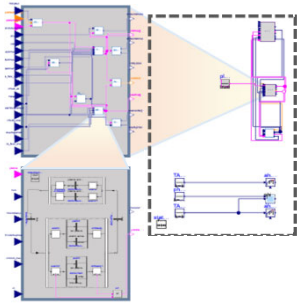
In summary, we…

1. Review controls and create centralized documentation
2. Create control blocks
3. Conduct open-loop testing
4. Integrate into subsystem controllers
5. Conduct closed-loop testing
6. Systematically troubleshoot

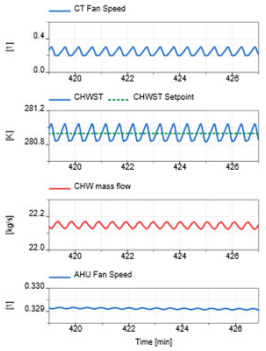
Created a workflow to help implement complex rule-based controls in Modelica



Implemented ~100 Guideline 36 [2] control actions in Modelica with a case study



Explained each step with WSE enable/disable controls



Demonstrated the iterative troubleshooting process with preliminary results

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Thank you! Questions?

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Contact

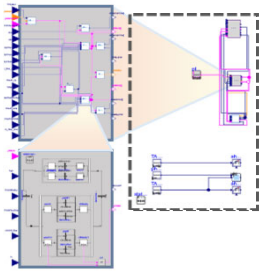
Julia Ho
SBS Lab, Penn State
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Acknowledgements

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This work was also authored in part by the National Laboratory of the Rockies for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. The views expressed herein do not necessarily represent the views of the U.S. Department of Energy or the United States Government.

Papers



Ho, J., Faulkner, C., & Zuo, W. (2026). **A Workflow for Transparent and Replicable Modelica Implementations of ASHRAE Guideline 36 Controls for Chiller Plants with Waterside Economizers.** *Proceedings of the 2026 American Modelica and FMI Conference*.

ScienceDirect Link

Ho, J., & Zuo, W. (2026). **Simulation-Assisted Evaluation and Improvement of Guideline 36 for District Cooling Systems.** *Energy and Buildings*, 118238. https://doi.org/10.1016/j.enbuild.2026.118238

This paper includes a proposed improvement to G36 that was developed with this presentation's workflow.

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JH1 Mention CDWST fix

Ho, Julia Lien, 2026-09-30T20:01:20.842

References

1. ASHRAE. (2021). *ASHRAE Guideline 36-2021: High-Performance Sequences of Operation for HVAC Systems*. ASHRAE.

2. *Guideline 36-2021: What's New and Why It's Important*. (2021, September 14). ASHRAE Journal Newsletter. https://www.ashrae.org/news/ashraejournal/guideline-36-2021-what-s-new-and-why-it-s-important

3. Grahovac, M., Ehrlich, P., Hu, J., & Wetter, M. (2024). Model-based data center cooling controls comparative co-design. *Science and Technology for the Built Environment*, *30*(4), 394–414. https://doi.org/10.1080/23744731.2023.2276011

4. Lu, X., Fu, Y., O'Neill, Z., & Wen, J. (2021). A holistic fault impact analysis of the high-performance sequences of operation for HVAC systems: Modelica-based case study in a medium-office building. *Energy and Buildings*, *252*. https://doi.org/10.1016/j.enbuild.2021.111448

5. Faulkner, C. A., Ho, J., Shi, C., Fan, C., Ildiri, N., & Zuo, W. (2025). Development of Near-Optimal Advanced Control Sequences for Chiller Plants with Water-Side Economizers in U.S. Climates (ASHRAE RP-1661). *Science and Technology for the Built Environment*, *31*(1), 18–35. https://doi.org/10.1080/23744731.2024.2404814

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Step 1: Documentation

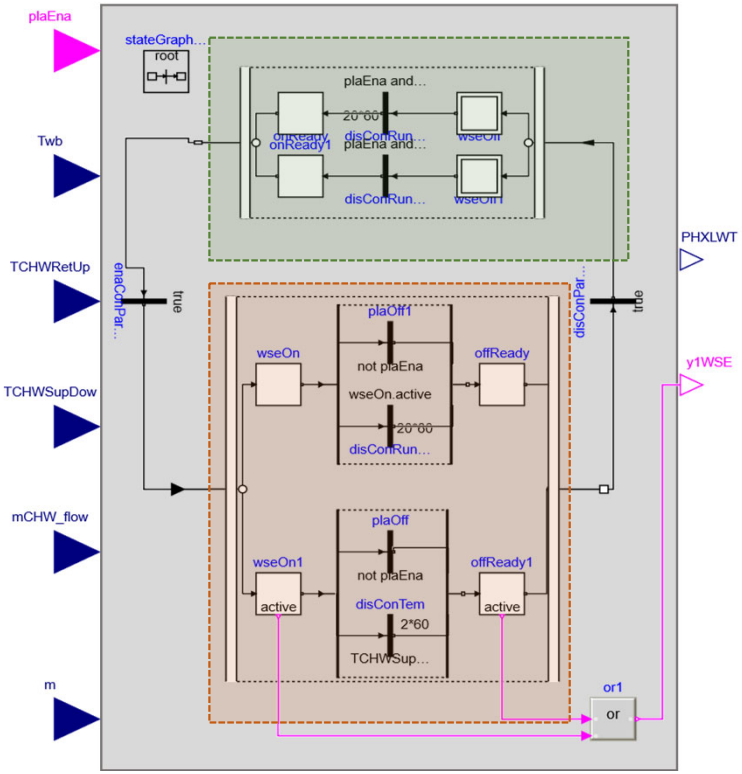
Control Sequence	Equivalent Modelica Control Component	G36 Section	Applicable System	Testable Control Action	Simulation Script	Modelica Example Using Simulation Script	Passed Test?	Notes
Waterside Economizer Control Enable/Disable	WSEControlLogics.Controls.Guideline36.Chiller.enaWSE	5.20.3.1	Plants with wse	Enable WSE if it has been disabled for >=20 min and CHWRT upstream of HX is > predicted HX leaving water temp (PHXLWT) + 2F.	g36_5.20.3.1.mos	WSEControlLogics.Controls.Guideline36.Validation.WSEStaging.g36_5_20_3_1	y	PCalculated by hand - calculations are correct.
		5.20.3.1	Plants with wse and primary-only plants	PLR_HX = min(1, pred HX PLR (m_current / design HX CHW flow rate)	g36_5.20.3.1.mos	WSEControlLogics.Controls.Guideline36.Validation.WSEStaging.g36_5_20_3_1	y	Not explicitly tested, but can be seen in code.
		5.20.3.2	Plants with wse	Disable WSE when it has run for >= 20 min and CHW temp downstream of HX > CHWRT upstream HX - 1F for 2 min. "(ie, if the HX is not reducing the CHW temp by at least 1degF)"	g36_5.20.3.2.mos	WSEControlLogics.Controls.Guideline36.Validation.WSEStaging.g36_5_20_3_2	y	

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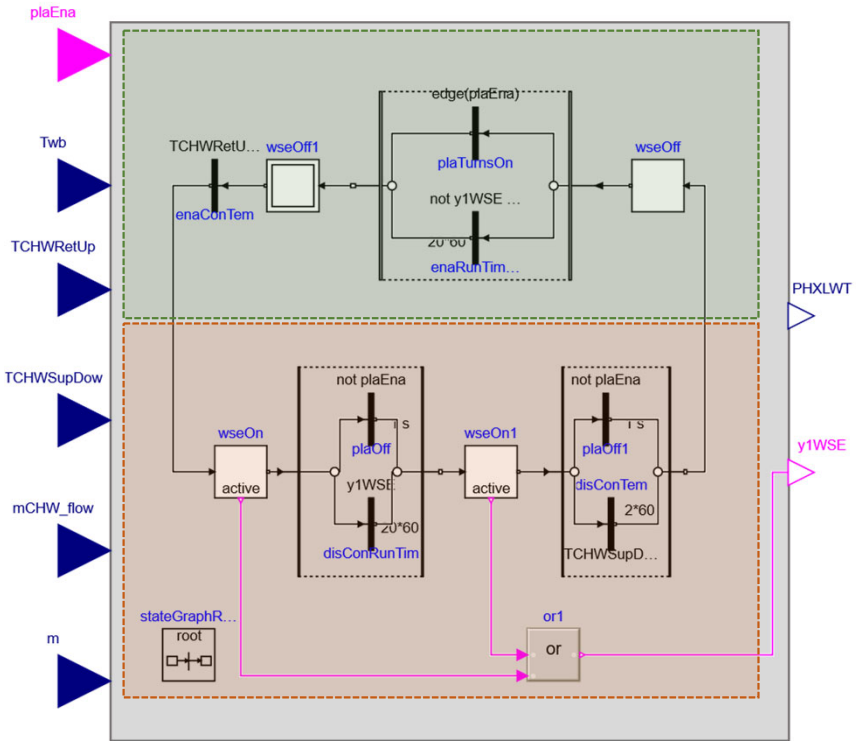
Model Corrections JH1

Enable

Disable



Original wseEna Control Block (conditions executed in parallel)



Revised wseEna Control Block (conditions executed in series)

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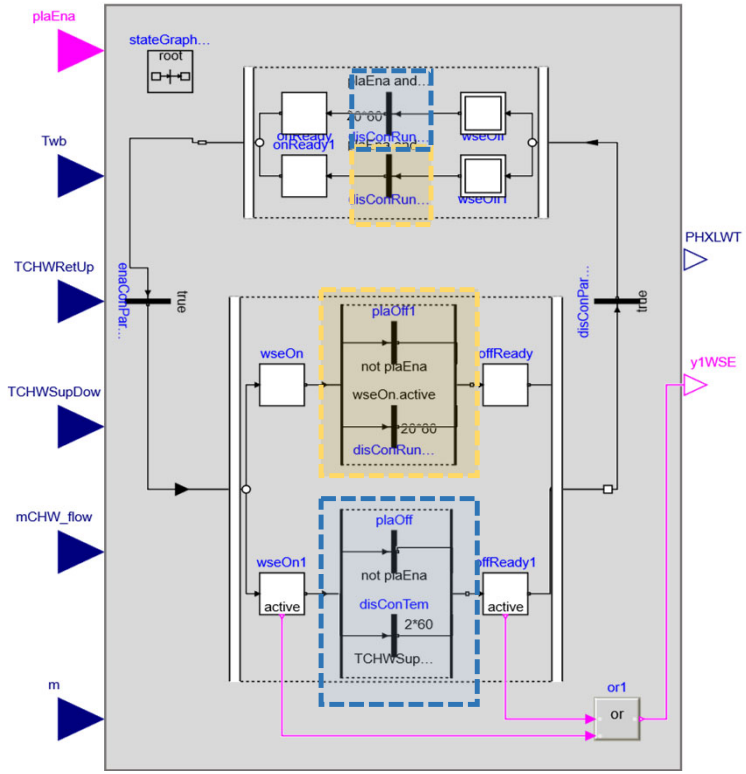
JH1 Add this slide

Ho, Julia Lien, 2026-09-30T19:20:02.816

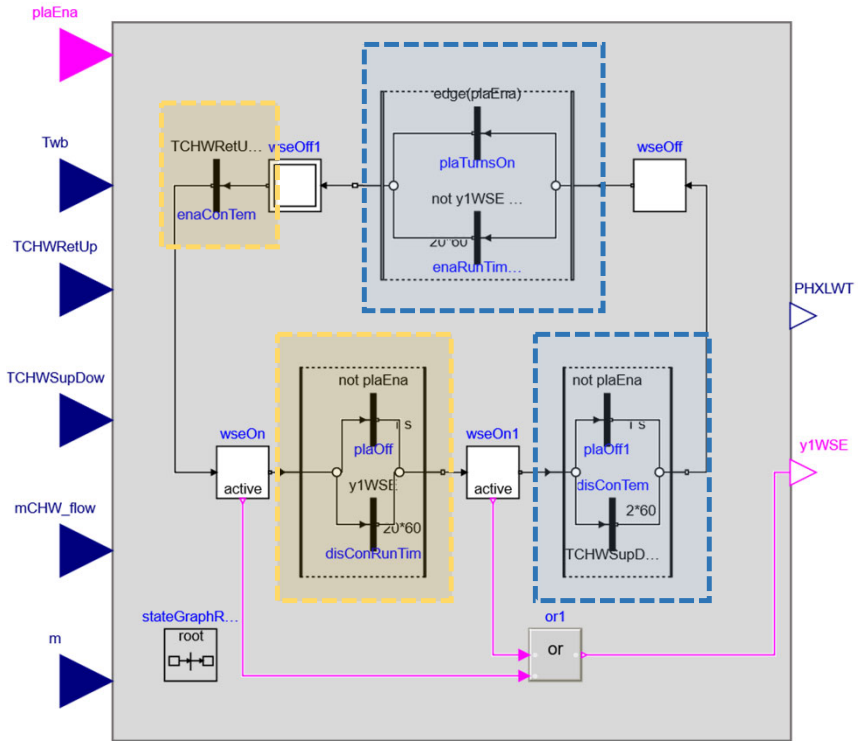
Model Corrections

Runtime

Temperature



Original wseEna Control Block (conditions executed in parallel)



Revised wseEna Control Block (conditions executed in series)

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