OpenBuildingControl

Michael Wetter
Philip Haves
Jianjun Hu
Milica Grahovac

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Lawrence Berkeley National Laboratory

Presentation Contents

- Guideline 36 implementation
- Case study:
  See https://github.com/lbl-srg/obc/tree/master/meetings/2017-11-tag for report
- Updates to CDL
- Verification of requirements
- Feedback/discussions

Control Description Language

CDL library

Compared CDL library with industrial control library.

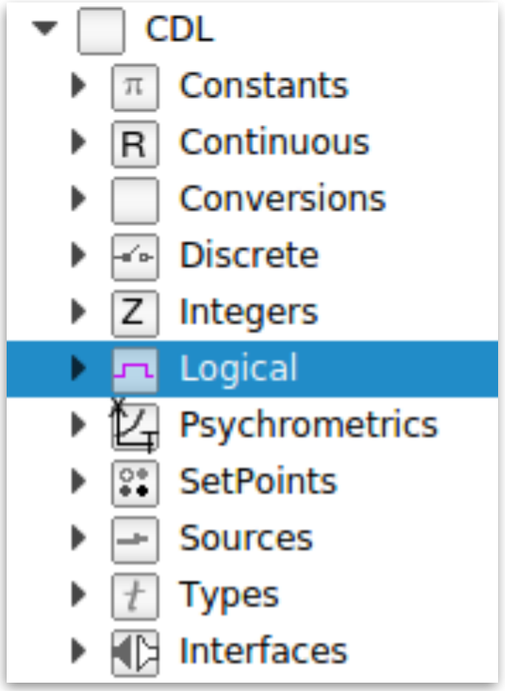
Validated blocks to ensure expected functionalities

- against known results
- across independent two independent simulators (Dymola and JModelica)

Package name	Description
Constants	Library of constants
Continuous	Library with elementary mathematical functions for continuous variables
Conversions	Library with blocks for type conversion
Discrete	Library of discrete input/output blocks with fixed sample period
Integers	Library with elementary mathematical functions for integer variables
Logical	Library with logical blocks
Psychrometrics	Library with psychrometric blocks
Routing	Package of blocks to combine and extract signals
SetPoints	Package with models for control set points
Types	Package with type definitions
Interfaces	Library with connectors for input and output signals

In CDL library:

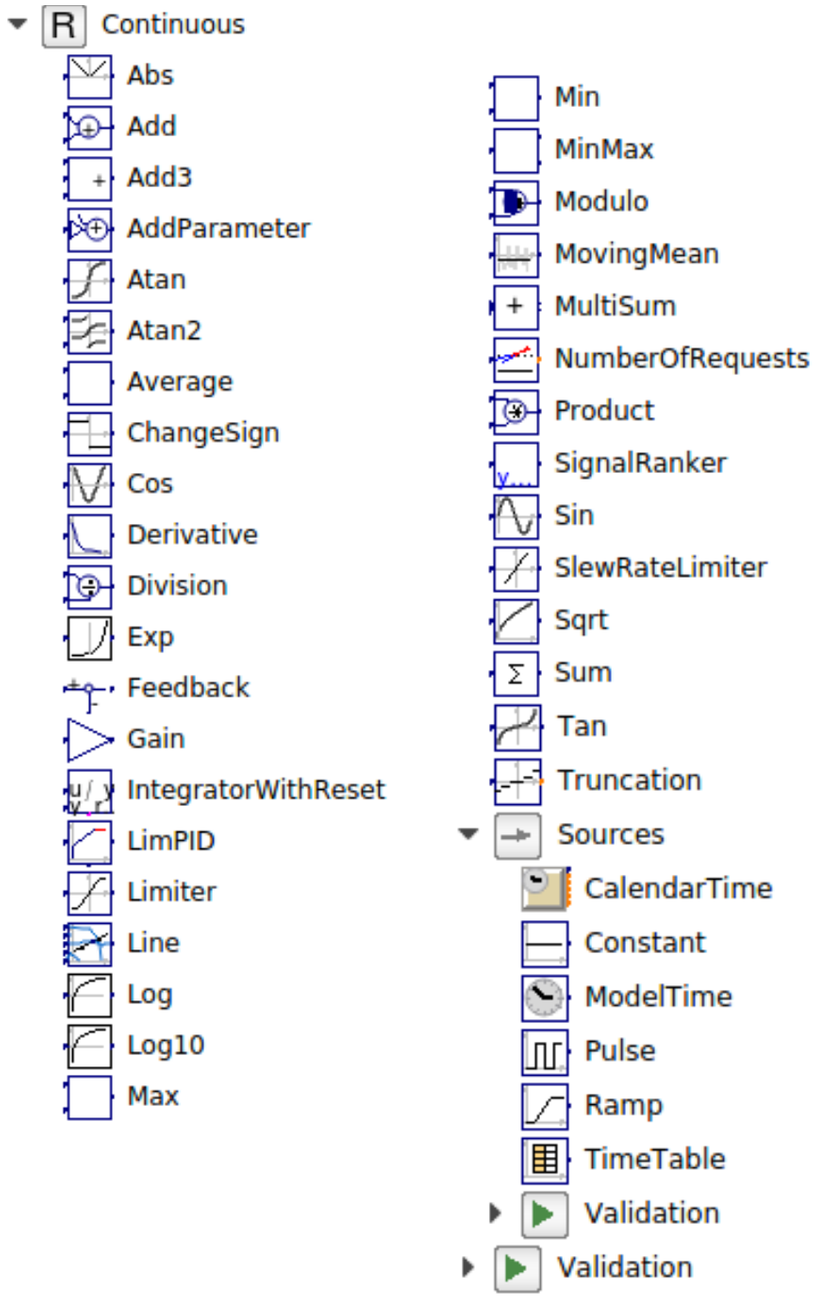
- 11 packages
- 117 basic blocks



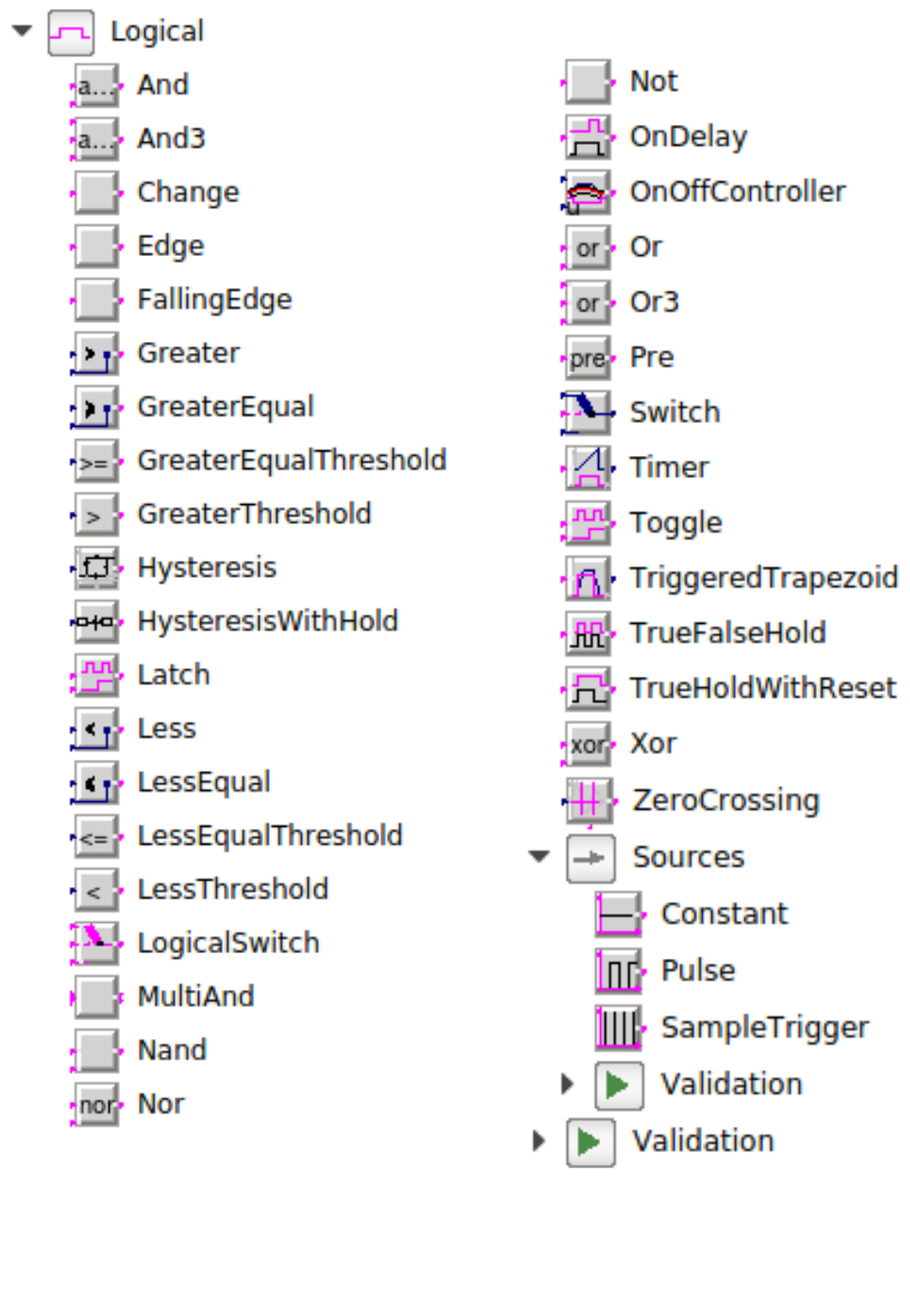
Browse CDL library at
http://simulationresearch.lbl.gov/modelica/releases/v5.0.0/help/Buildings_Controls_OBC_CDL.html

CDL library: Packages

`CDL.Continuous`:
elementary mathematical functions for continuous variables

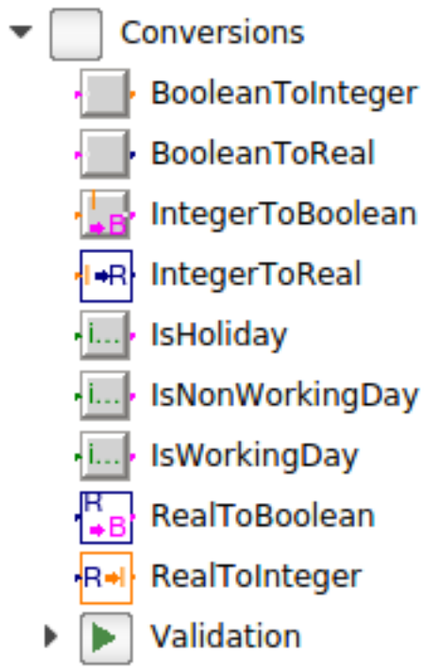


`CDL.Logical`:
elementary mathematical functions for boolean variables

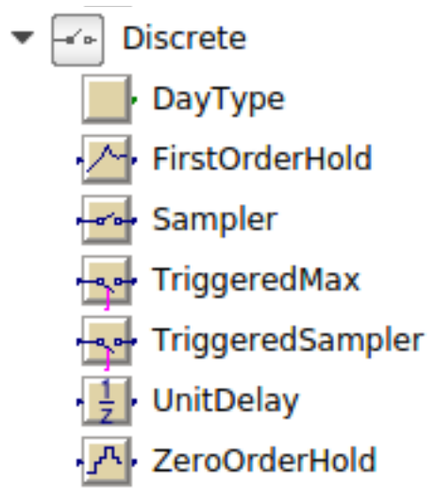


CDL library: Packages

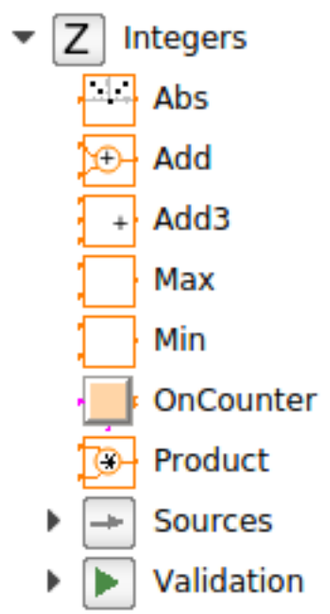
`CDL.Conversions`:
type conversions



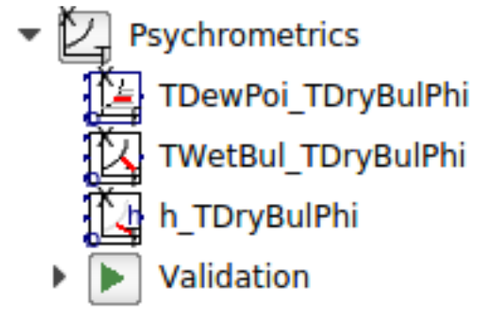
`CDL.Discrete`:
daytype, sample, delay, hold



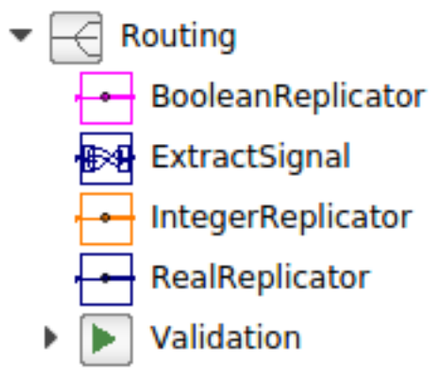
`CDL.Integers`:
mathematical functions for integer variables



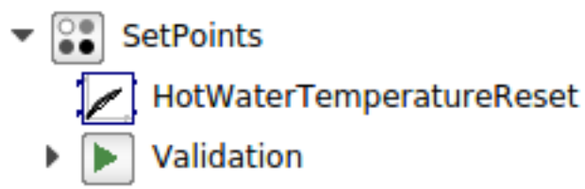
`CDL.Psychrometrics`:
psychrometric calculations



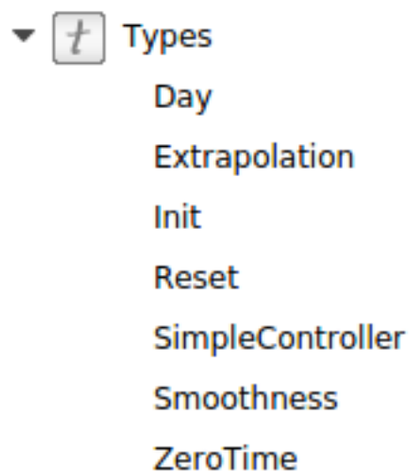
`CDL.Routing`:
combine and extract signals



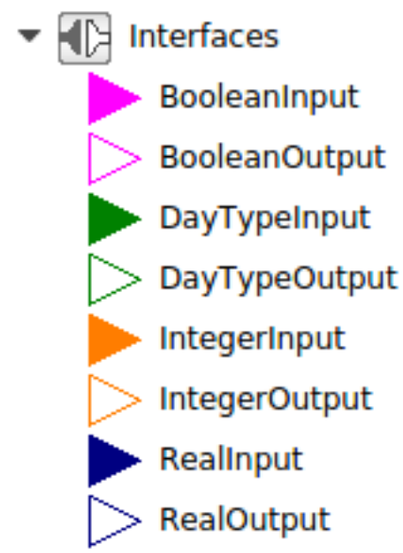
`CDL.Setpoints`:
setpoints for control systems



`CDL.Types`:
type definitions



`CDL.Interfaces`:
connectors for input and output signals



CDL is used to implement open and proprietary sequences

The standard to be supported by vendors

- CDL
- ASHRAE
- G36

Sequences that come out of ASHRAE projects and can be shared with community.

Custom implementations that are built using the CDL language, and CDL blocks

- GSA
- ARUP
- ALC

GSA preferred sequences, made available through a CDL-complaint implementation.

Design firms can share their own (proprietary) implementation across their offices.

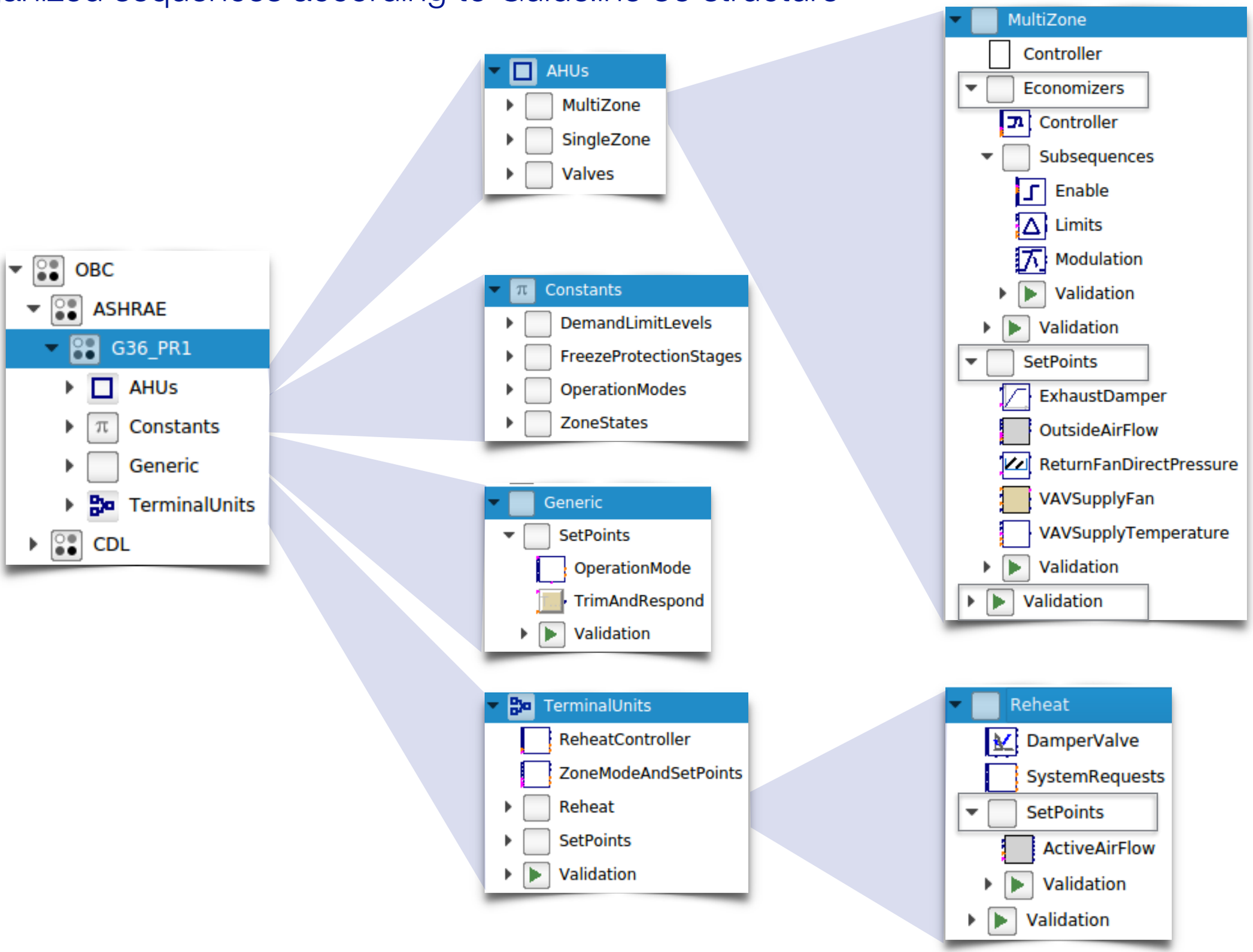
Control vendors can provide their own specialized sequences, either as open-source, or as compiled (proprietary) I/O blocks.

Companies are illustrative

Implementation of ASHRAE Guideline 36 control sequences

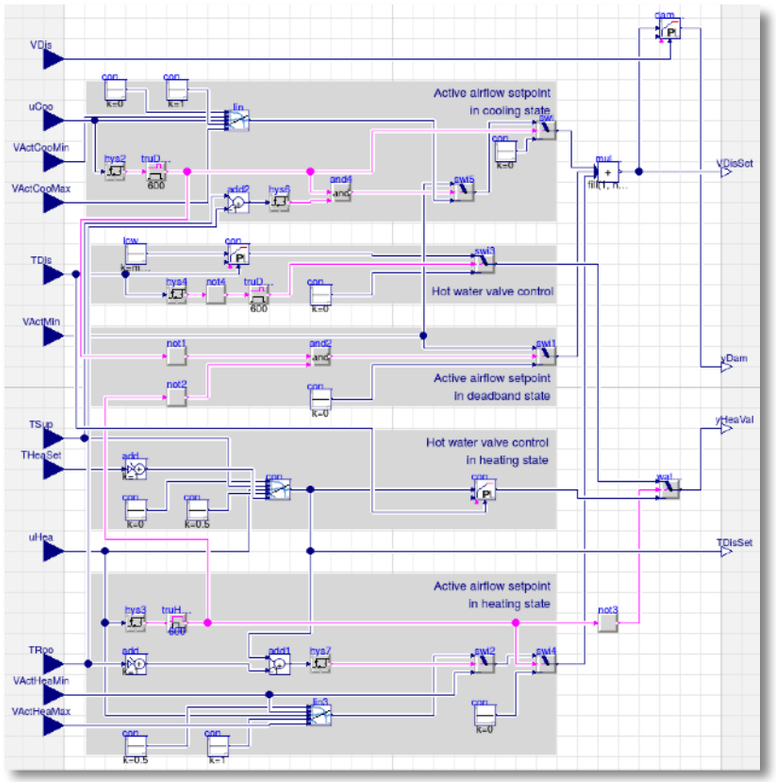
Implement sequences with CDL

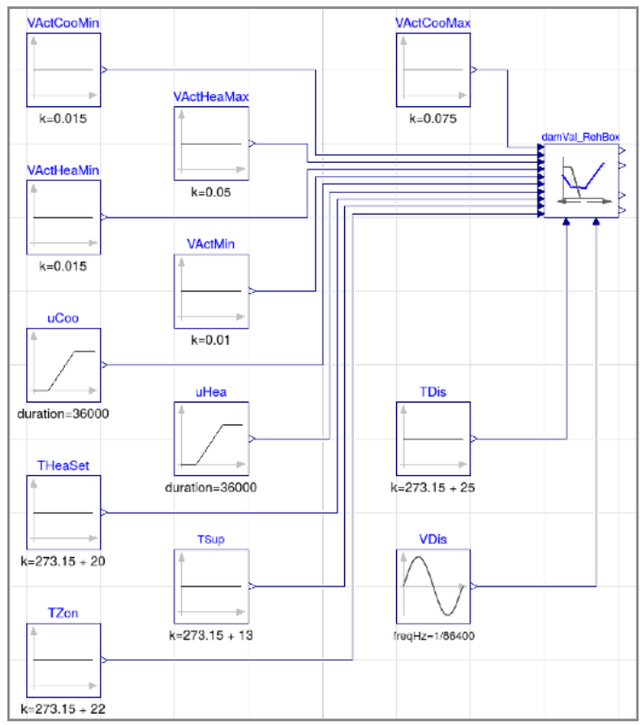
Organized sequences according to Guideline 36 structure

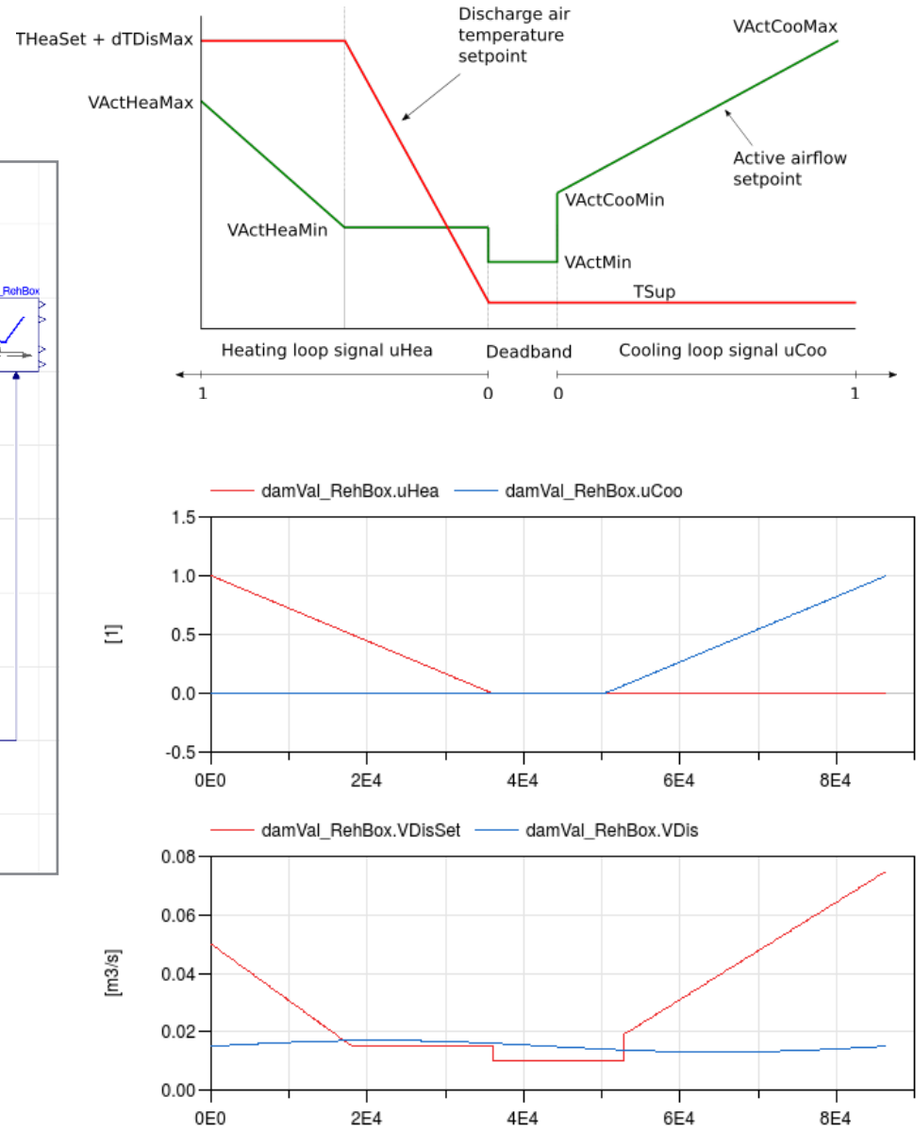


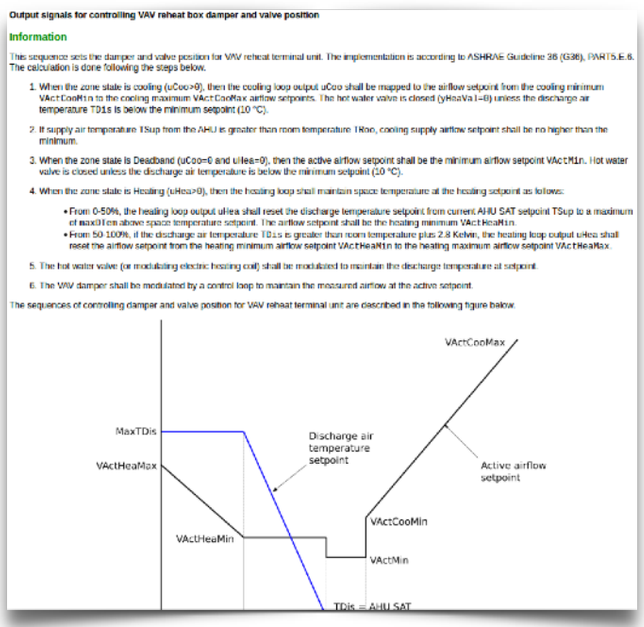
Implement sequences with CDL

Documented and validated sequences









Output signals for controlling VAV reheat box damper and valve position

Information

This sequence sets the damper and valve position for VAV reheat terminal unit. The implementation is according to ASHRAE Guideline 36 (G36), PART5.E.6. The calculation is done following the steps below.

1. When the zone state is cooling (uCoo>0), then the cooling loop output uCoo shall be mapped to the airflow setpoint from the cooling minimum VActCooMin to the cooling maximum VActCooMax airflow setpoints. The hot water valve is closed (yHeaVal=0) unless the discharge air temperature TDis is below the minimum setpoint (10 °C).
2. If supply air temperature TSup from the AHU is greater than room temperature TRoo, cooling supply airflow setpoint shall be no higher than the minimum.
3. When the zone state is Deadband (uCoo=0 and uHea=0), then the active airflow setpoint shall be the minimum airflow setpoint VActMin. Hot water valve is closed unless the discharge air temperature is below the minimum setpoint (10 °C).
4. When the zone state is Heating (uHea>0), then the heating loop shall maintain space temperature at the heating setpoint as follows:
   - From 0-50%, the heating loop output uHea shall reset the discharge temperature setpoint from current AHU SAT setpoint TSup to a maximum of maxDTemp above space temperature setpoint. The airflow setpoint shall be the heating minimum VActHeaMin.
   - From 50-100%, if the discharge air temperature TDis is greater than room temperature plus 2.8 Kelvin, the heating loop output uHea shall reset the airflow setpoint from the heating minimum airflow setpoint VActHeaMin to the heating maximum airflow setpoint VActHeaMax.
5. The hot water valve (or modulating electric heating coil) shall be modulated to maintain the discharge temperature at setpoint.
6. The VAV damper shall be modulated by a control loop to maintain the measured airflow at the active setpoint.

The sequences of controlling damper and valve position for VAV reheat terminal unit are described in the following figure below.

Buildings.Controls.OBC.ASHRAE.G36_PR1.TerminalUnits.Reheat.DamperValve

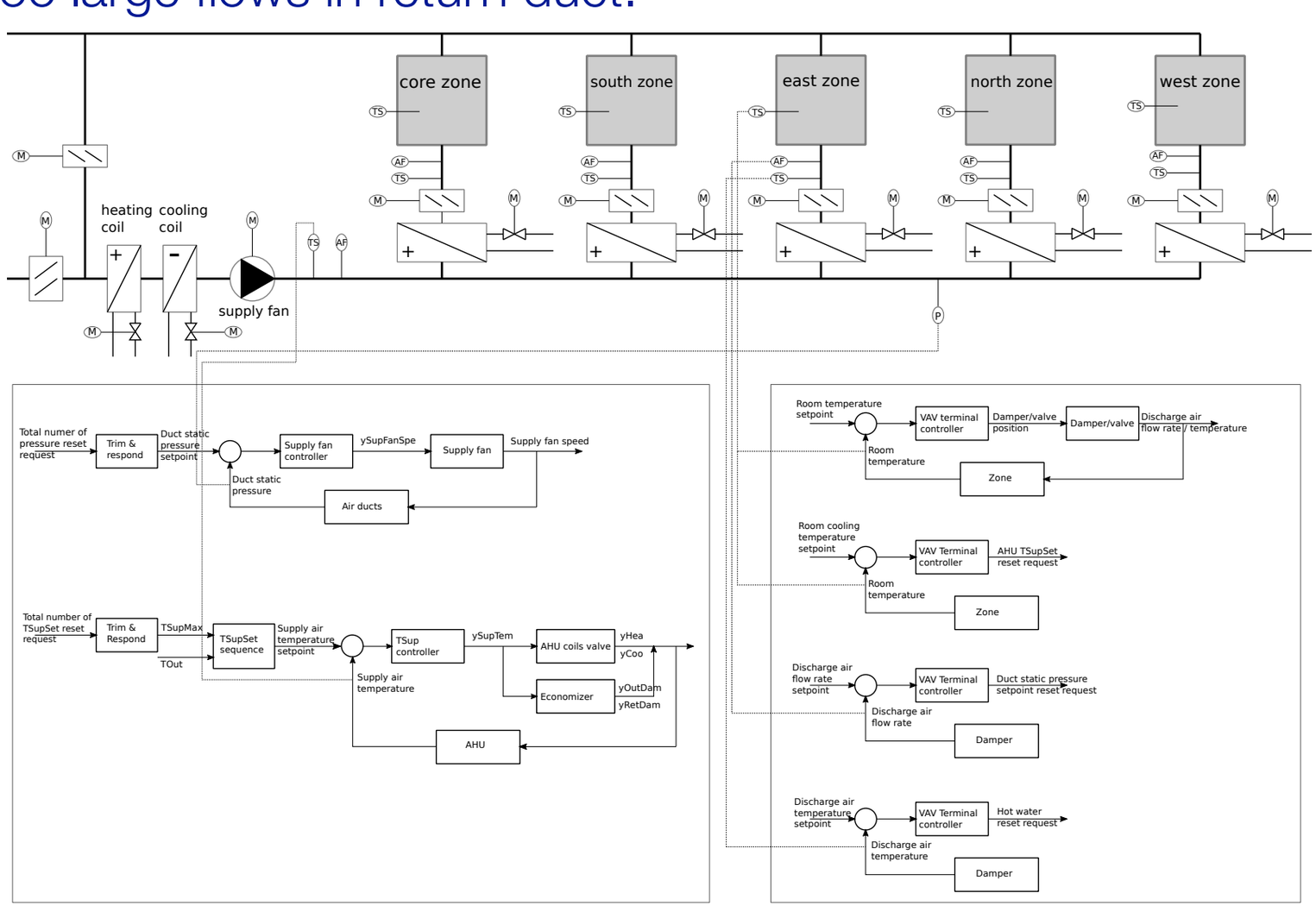
Case study

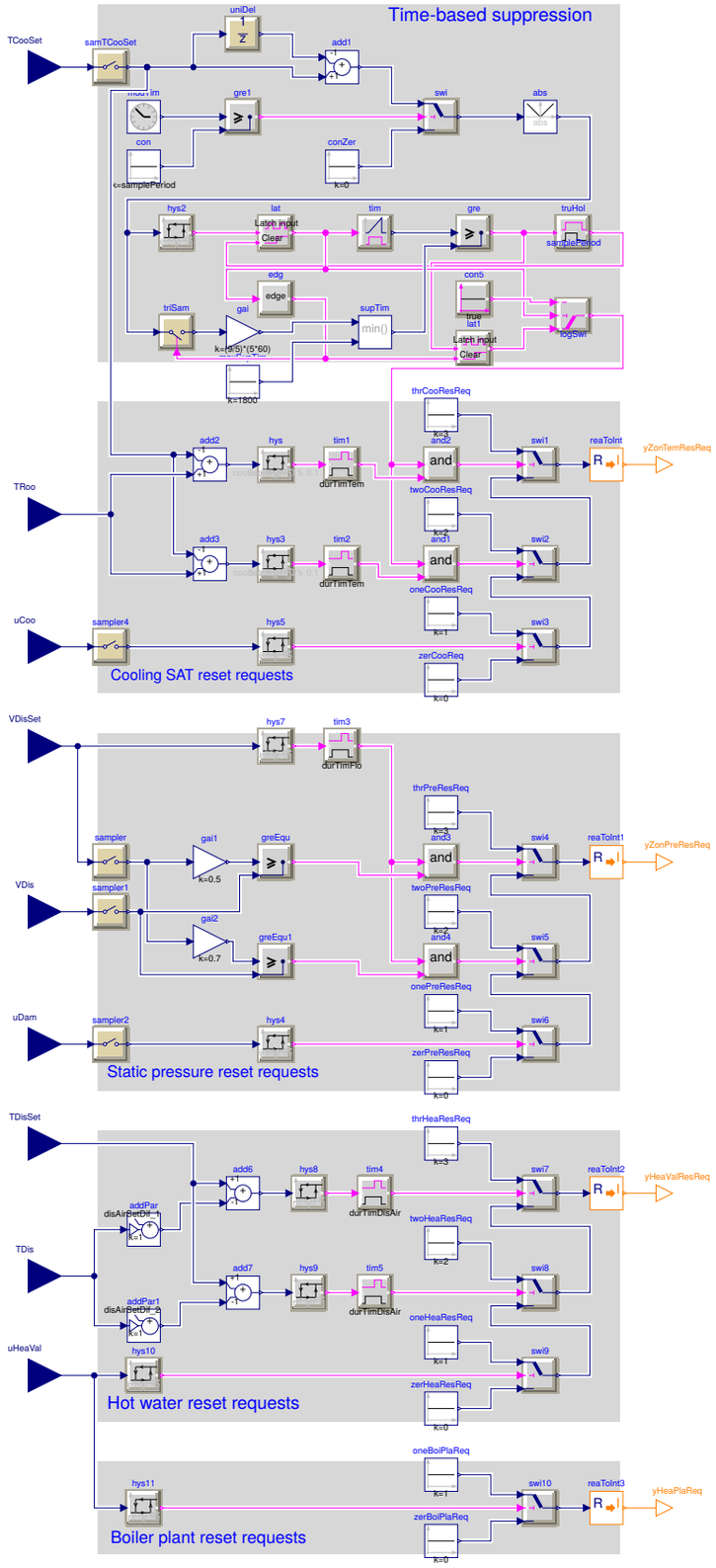
For report, see
http://obc.lbl.gov/specification/example.html or
https://github.com/lbl-srg/obc/tree/master/meetings/2017-11-tag

Physics and dynamics

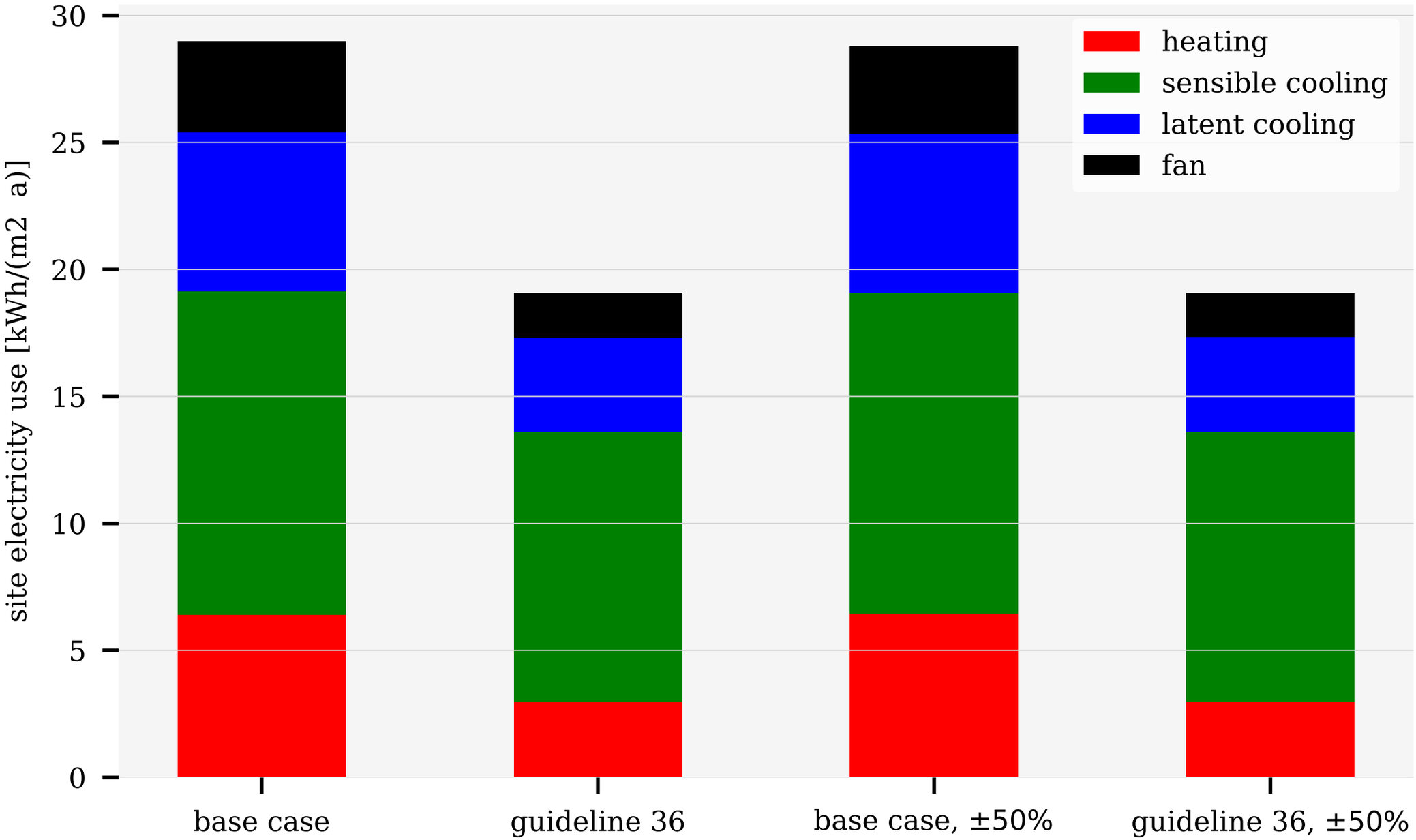
Wind pressure driven infiltration.
Full airflow network.
All flows based on flow friction, damper positions and fan curve.
4,000 component, 40,000 variables, adaptive time step, state/ time events.

Early idealizations, such as forcing fan mass flow, gave unrealistic behavior (such as 4000 Pa fan head), while forcing fan head gave too large flows in return duct.



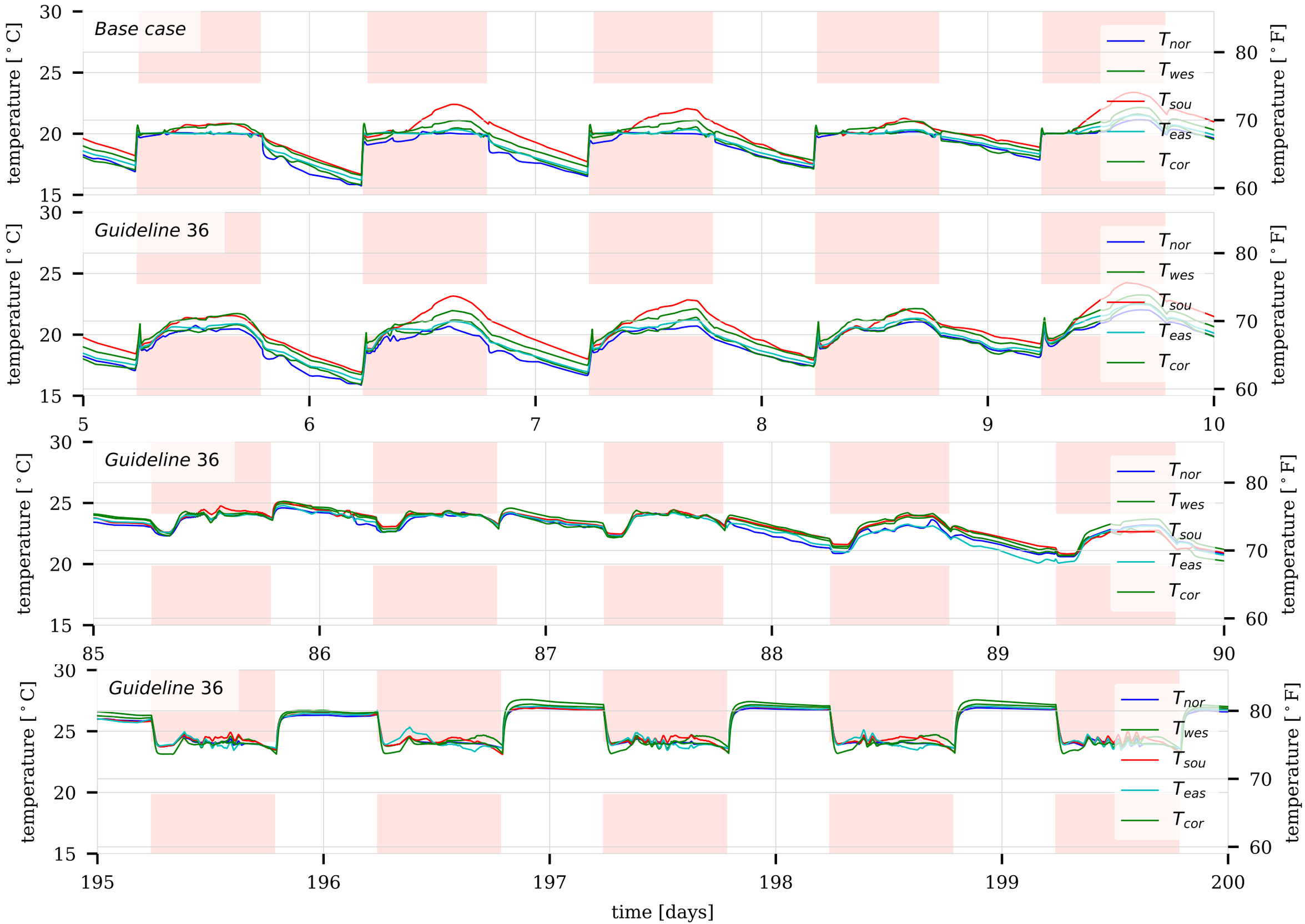


Main results



Example output

See http://obc.lbl.gov/specification/example.html for more trajectories and discussion



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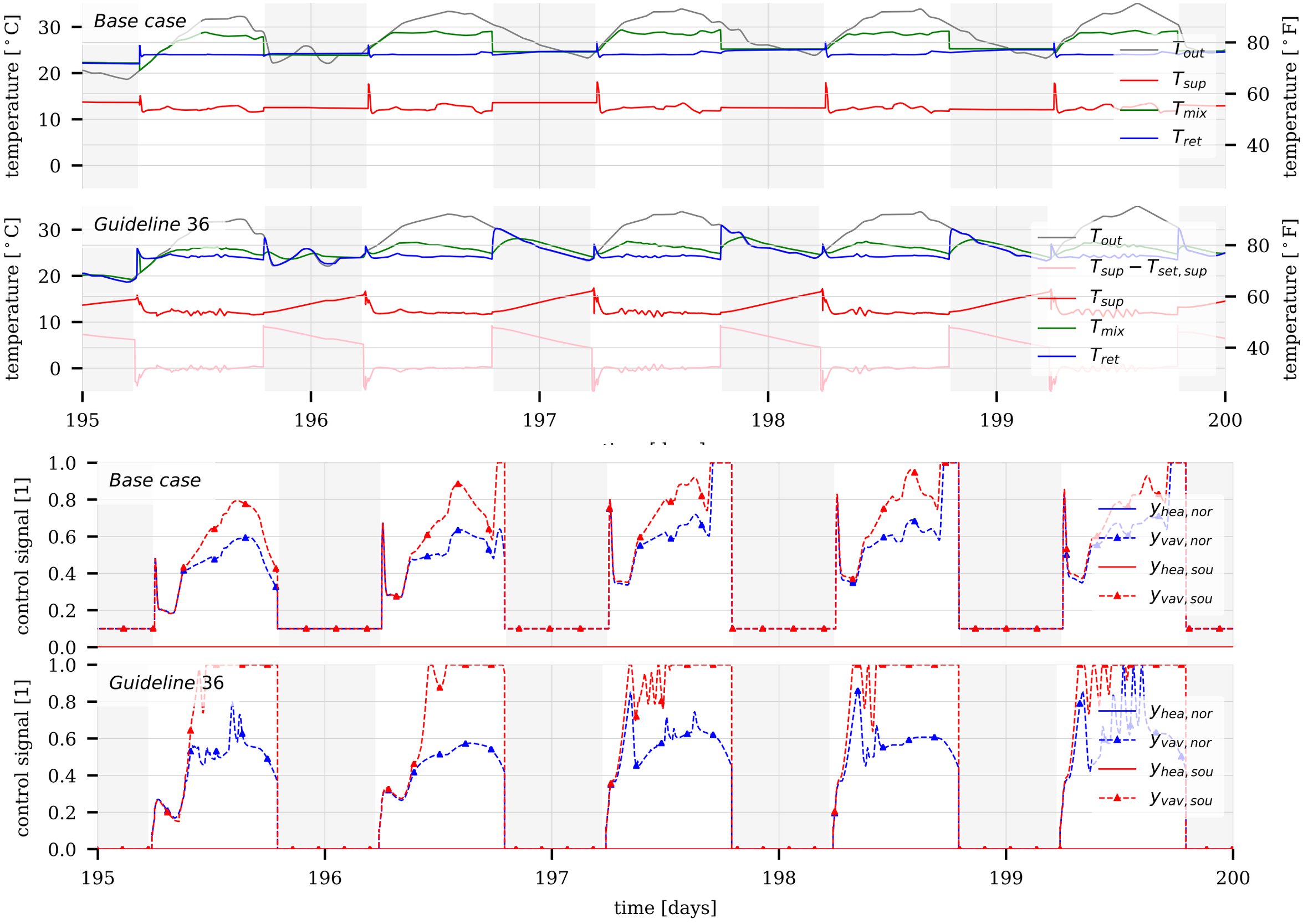

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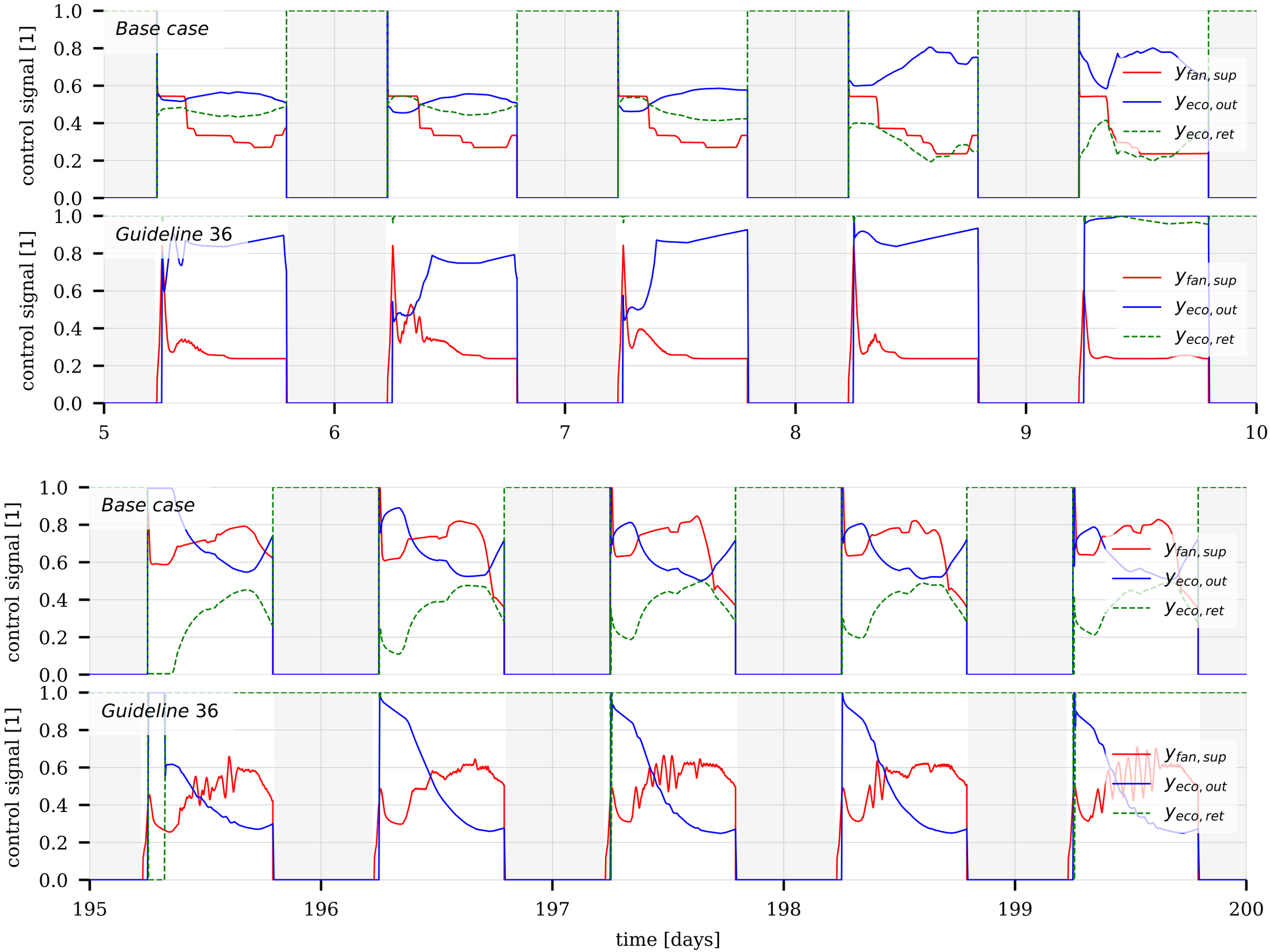


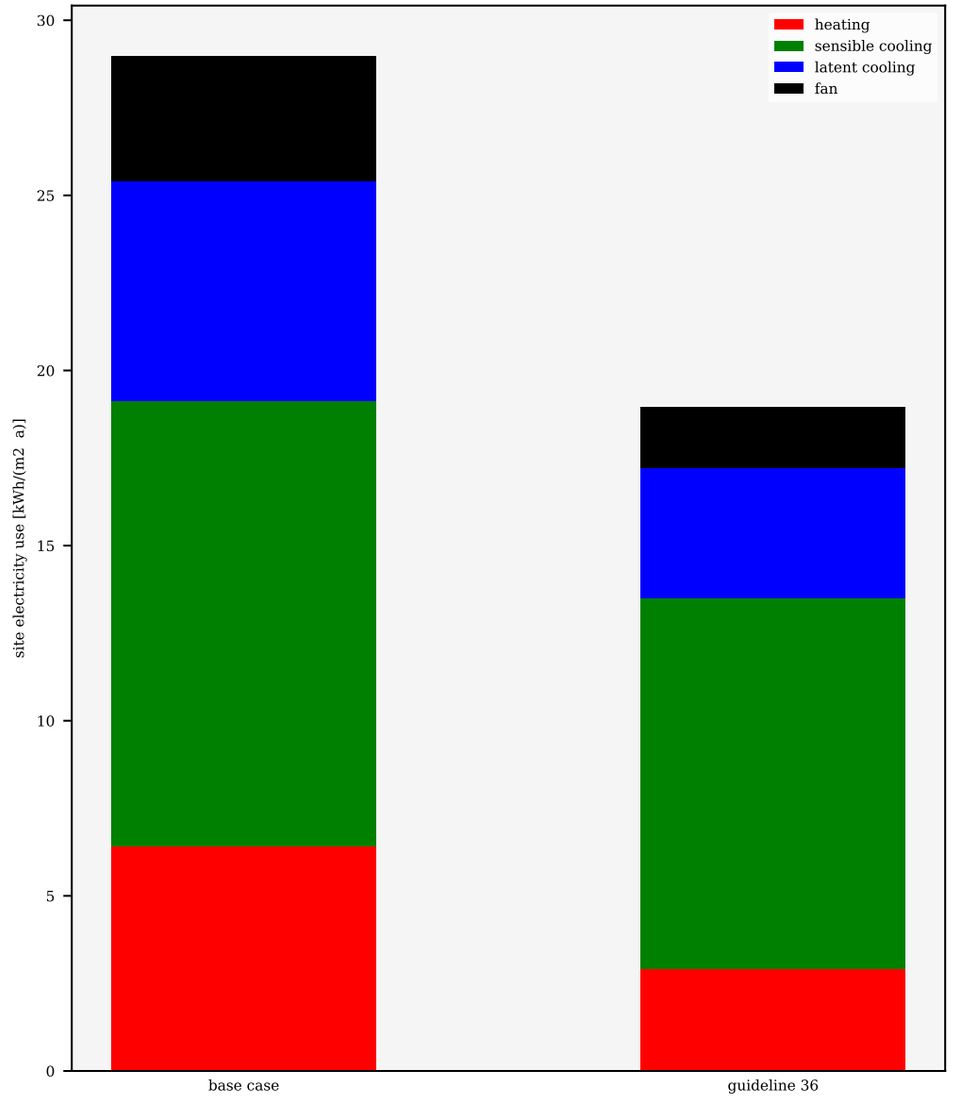
Key take-aways

About 30% annual site energy savings for Chicago, solely due to controls [close to zero capital needed].

Can simulate actual control sequences, with dynamic response.

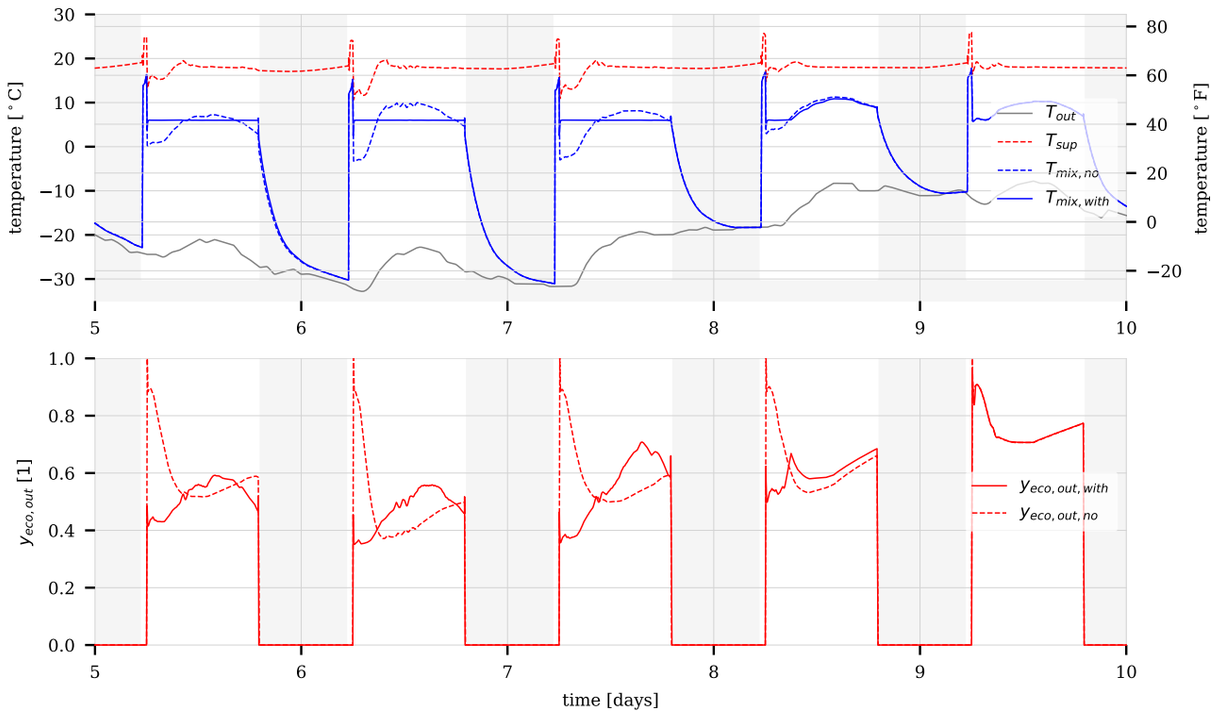
Simulation detected issues with control, and was used to verify recommendation for better

- frost protection at heating coil http://obc.lbl.gov/specification/example.html#freeze-protection-for-mixed-air-temperature
- short-cycling



Packaging of sequences is important, because interpretation and implementation of the sequences was more time-consuming and error-prone than anticipated.

- Sequences are written to convey control intent, and not to guide implementation.
- There was no reference against which we could test our implementation.
- There were some gaps, ambiguities and errors in the specification. Simulation showed short-cycling and potential to freeze the heating coil.



Possible future uses (beyond this project)

Make ready-to-use sequences accessible to energy modelers through Spawn of EnergyPlus.

Publish sequences as reference implementations against which vendor implementations can be compared.

Verify savings are robust through performance assessment across different climates.

Use as benchmark for comparing/rating advanced control sequences such as MPC.

Use to test FDD algorithms, in particular at the system level where control may compensate for faults.

Use for operator training and/or educational tools such as community colleges.

Possible future R&DD:

Guideline 36 is for public review #1. Should be updated to approved final version (now in 3rd public review).

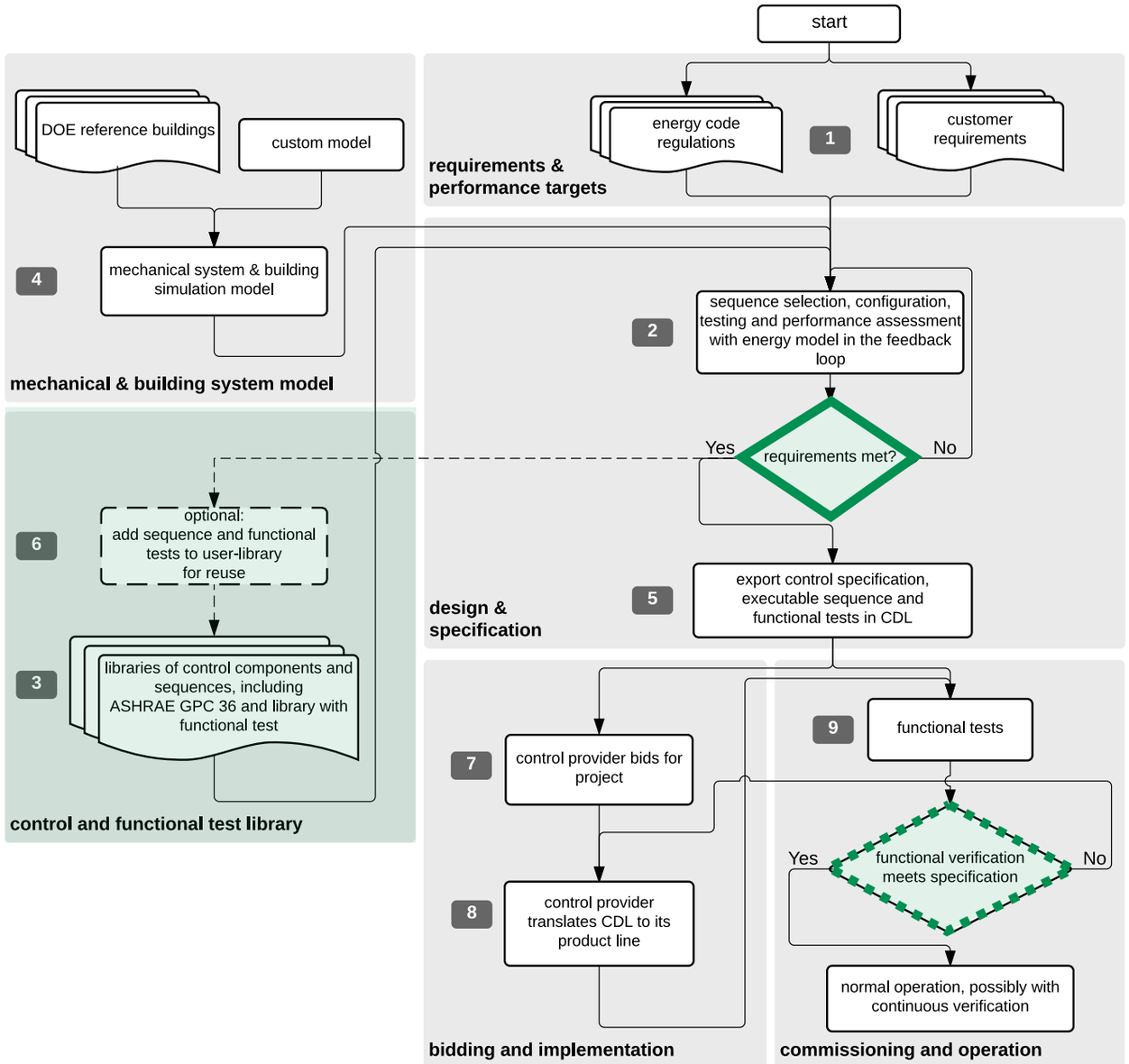
We implemented about 50% of the Guideline 36. Various economizer variants, dual-fan dual-duct, and Title 24 sequences are not implemented and beyond the project resources.

Field testing of sequences would be desirable.

Requirements verification

Goal is to (semi-)automatically test requirements during design and commissioning, and possibly also during continuous operation

- M3.1 By Q5, demonstrate with an *emulated control response* that the controls verification can signal satisfied, undecided, and violated test results.
- M3.2 By Q6, demonstrate with an *actual measured control response* that the controls verification can signal satisfied, undecided, and violated test results.



81.2 % of Guideline36 requirements are satisfied at time = 1.8144e+07 s

Requirements violated (3 of 16)

Observation	Requirement	First violation at	Description
VAV terminal box	conVAVEas.reqTRooCoo	1.74868e+07 s	Room air temperature maintains cooling setpoint
VAV terminal box	conVAVSou.reqTRooCoo	1.75913e+07 s	Room air temperature maintains cooling setpoint
VAV terminal box	conVAVWes.reqTRooCoo	1.77736e+07 s	Room air temperature maintains cooling setpoint

Requirements untested (0 of 16)

None

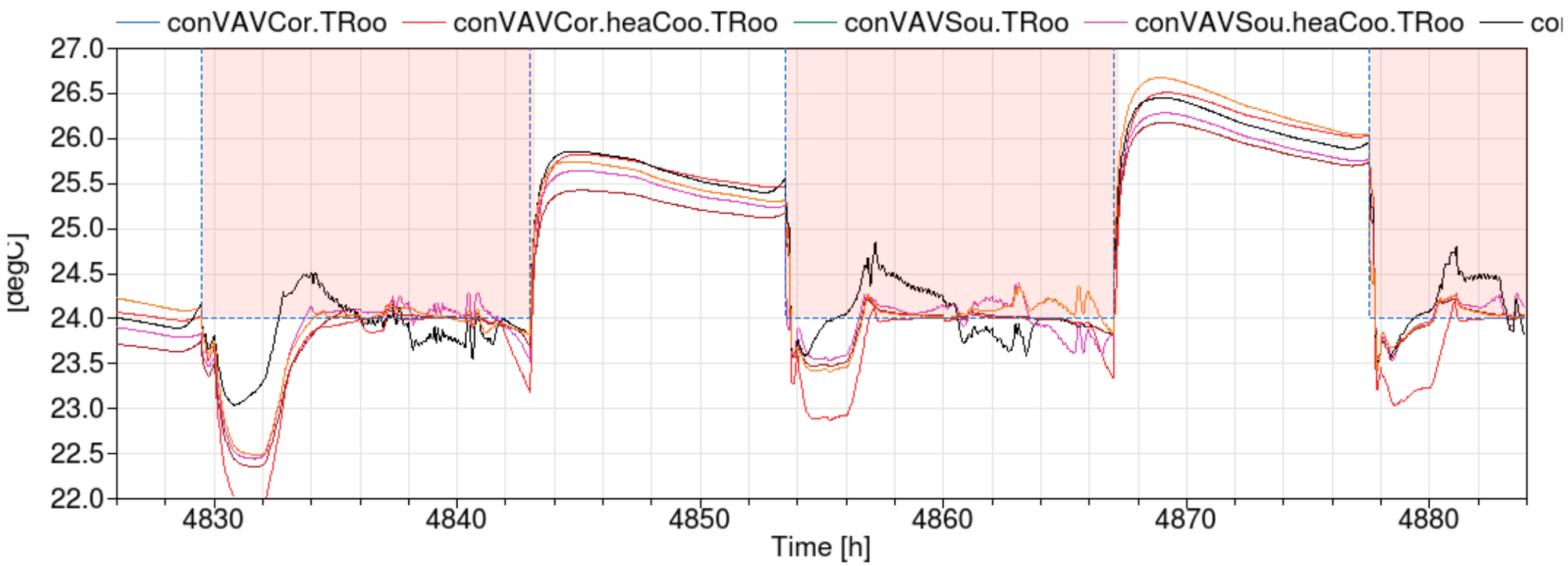
Requirements satisfied (13 of 16)

Observation	Requirement	Description
VAV terminal box	conVAVCor.reqTRooCoo	Room air temperature maintains cooling setpoint
VAV terminal box	conVAVCor.reqTRooHea	Room air temperature maintains heating setpoint
VAV terminal box	conVAVCor.reqYDam	VAV damper signal stable
VAV terminal box	conVAVEas.reqTRooHea	Room air temperature maintains heating setpoint
VAV terminal box	conVAVEas.reqYDam	VAV damper signal stable
VAV terminal box	conVAVNor.reqTRooCoo	Room air temperature maintains cooling setpoint
VAV terminal box	conVAVNor.reqTRooHea	Room air temperature maintains heating setpoint
VAV terminal box	conVAVNor.reqYDam	VAV damper signal stable
VAV terminal box	conVAVSou.reqTRooHea	Room air temperature maintains heating setpoint
VAV terminal box	conVAVSou.reqYDam	VAV damper signal stable
VAV terminal box	conVAVWes.reqTRooHea	Room air temperature maintains heating setpoint
VAV terminal box	conVAVWes.reqYDam	VAV damper signal stable
AHU	reqTFre	Mixed air temperature above freezing

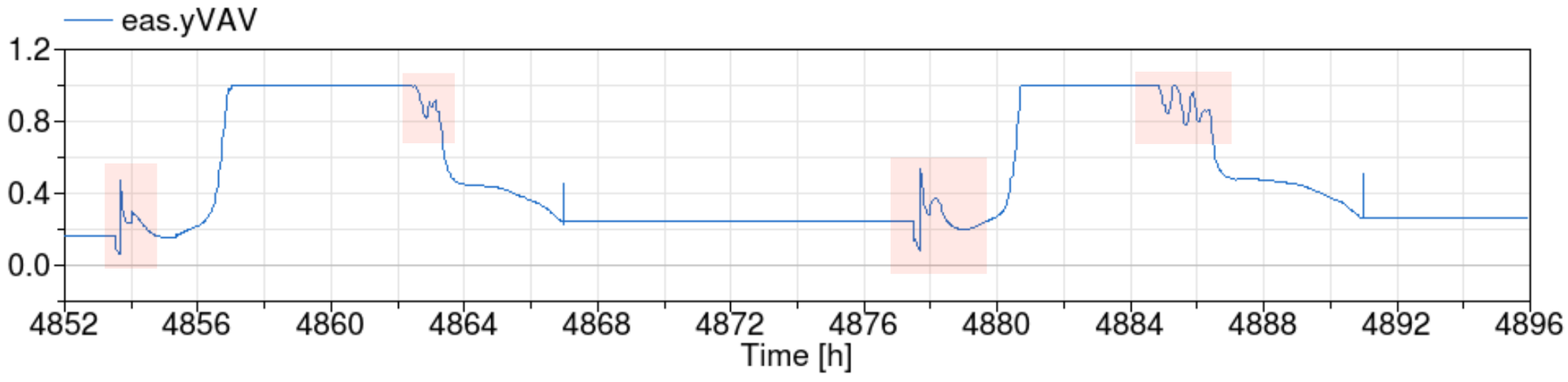
Example output

Problem: How do we verify 100s to 1000s of trajectories, and identify which one(s) cause (first) a problem?

Are these room temperatures satisfactory?

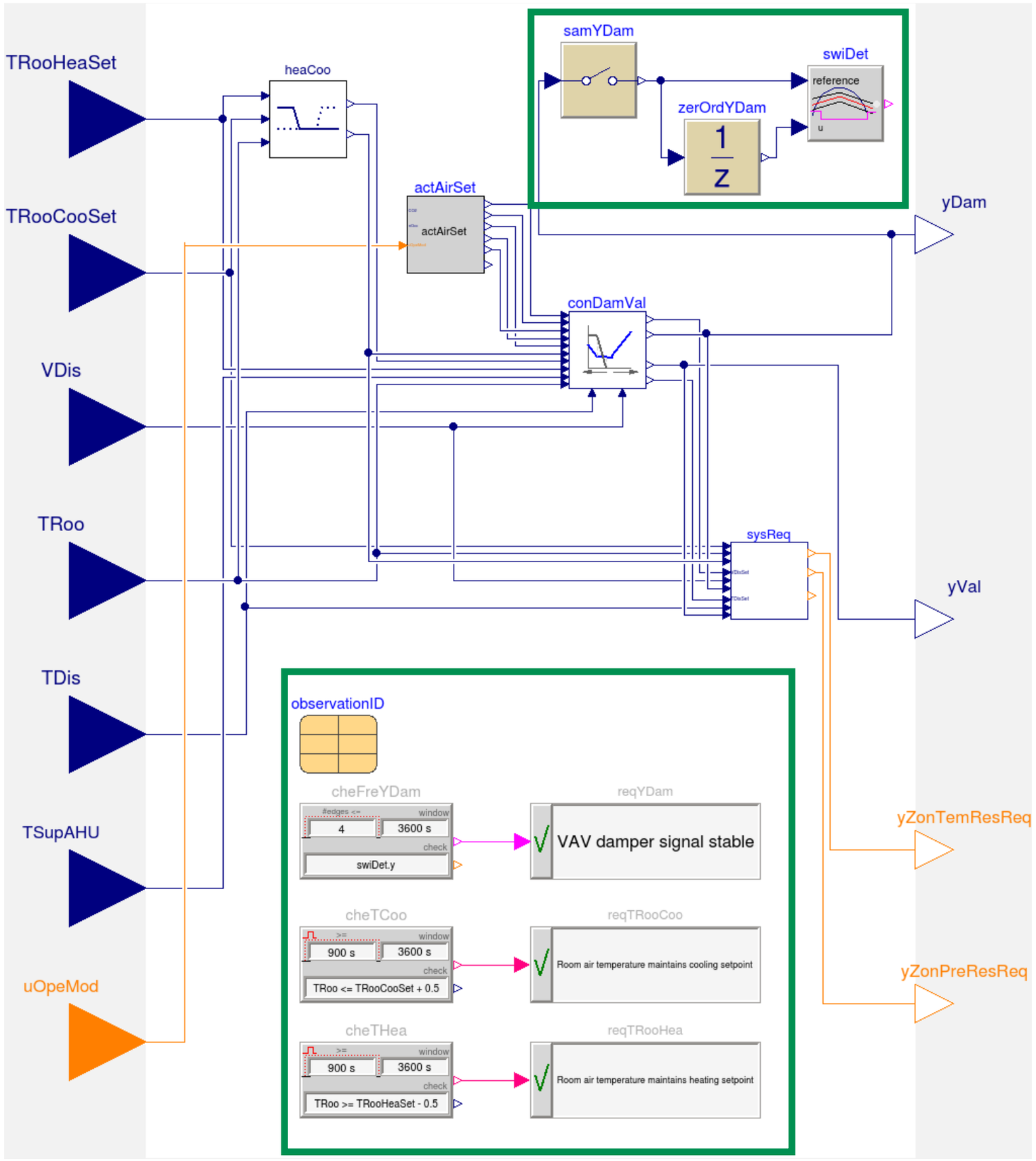


Is this damper control signal stable?



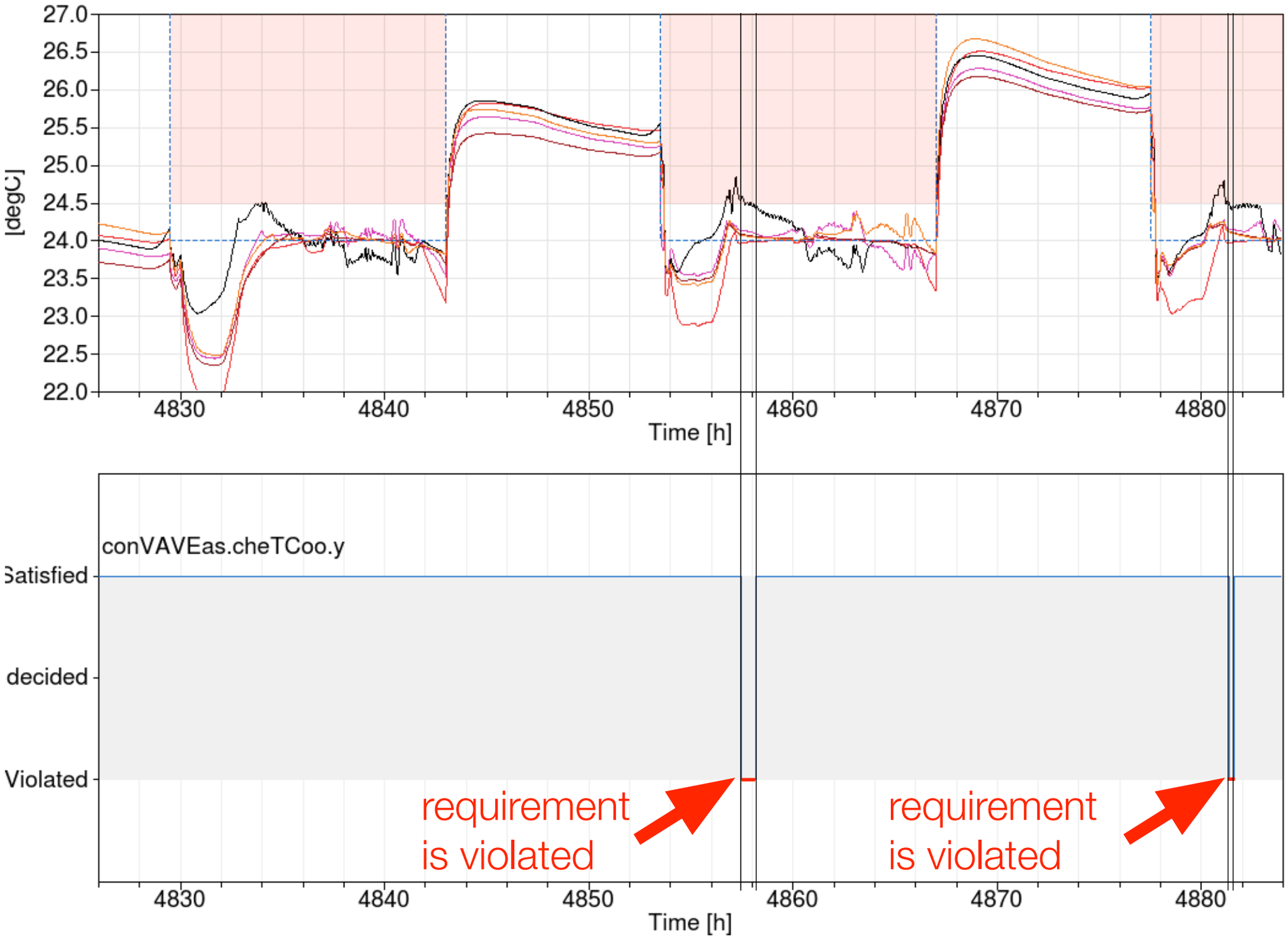
Simulations based on branch issue846_verification, commit 454cc7521

Approach: Instrument the control with verification tests



Verification of room air temperature of east zone

Requirement: Room air temperature shall be within (TSet + 0.5 K) for at least 45 min within each 60 min window.

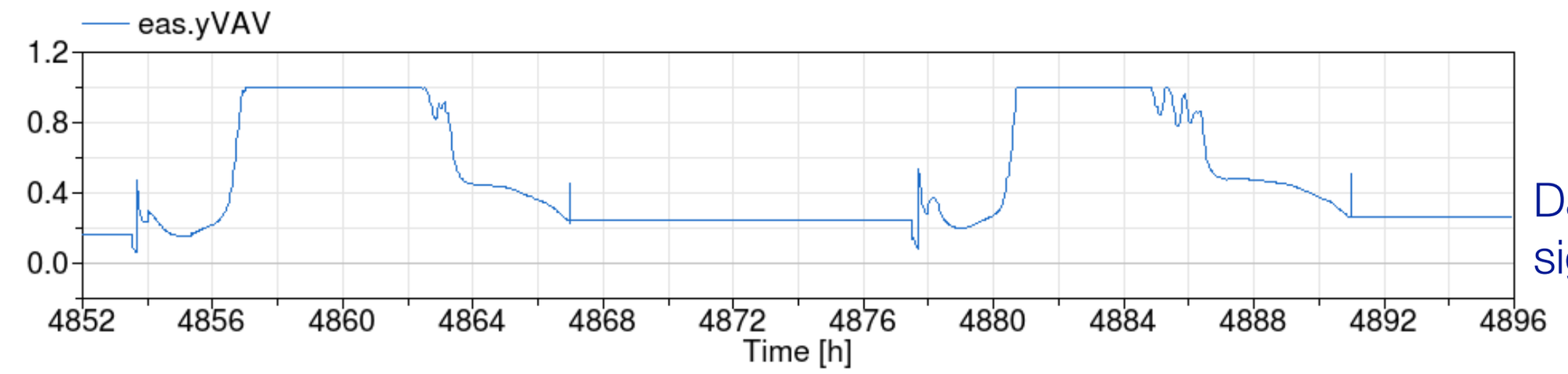


dashed:
cooling set point

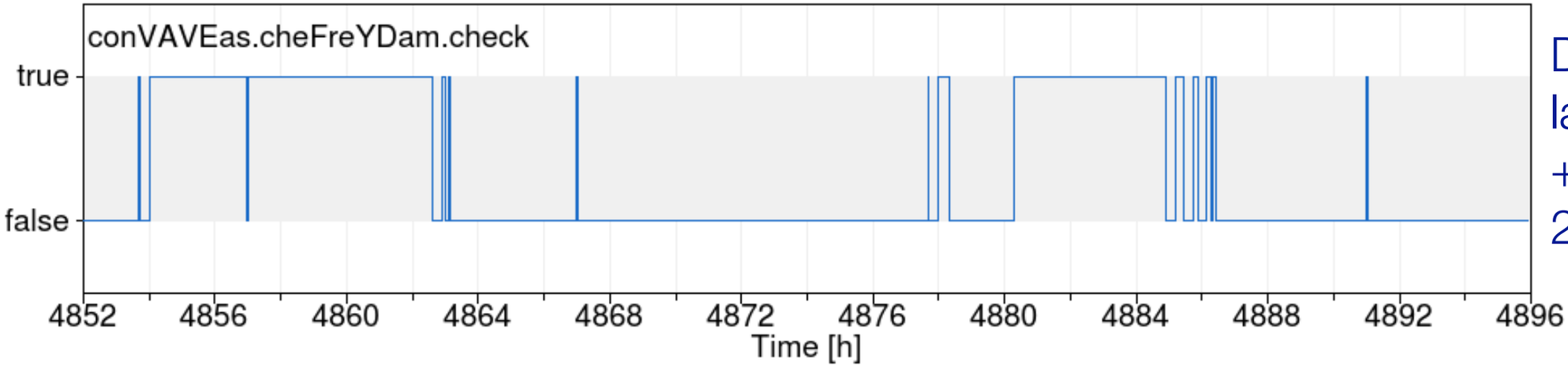
black:
east room
air temperature

Verification of east zone damper signal

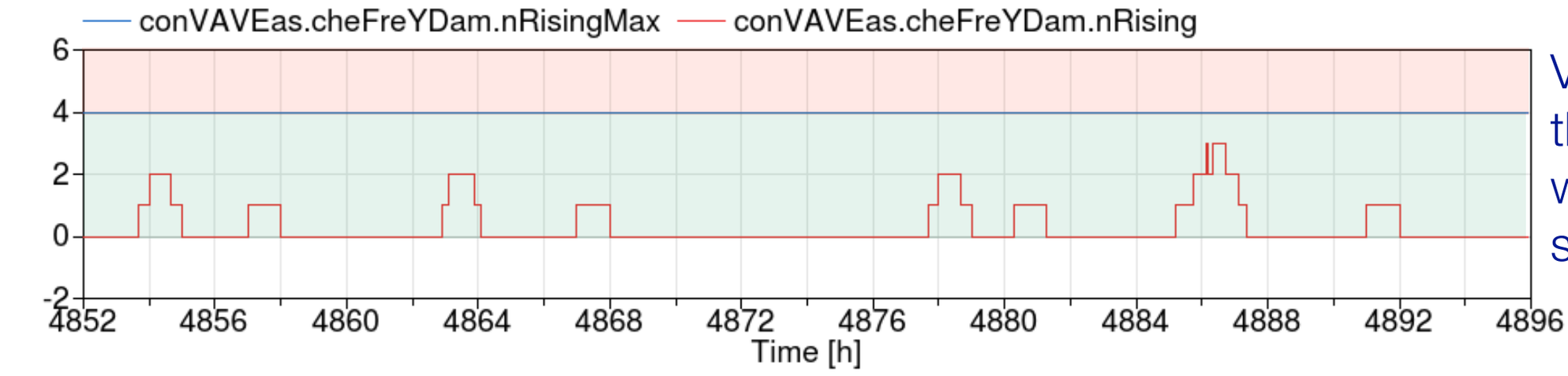
Requirement: Damper signal shall not oscillate more than 4 times per hour between +/- 0.025 (for a 2 minute sample period)



Damper control signal



Detect changes larger than +/- 0.025 between 2 minute samples



Verify no more than 4 changes within 1 hour sliding window

Verification tests

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- M3.2 By Q6, demonstrate with an *actual measured control response* that the controls verification can signal satisfied, undecided, and violated test results.

Need input from team and TAG for what requirements shall be verified. For example

- how well shall set points be tracked?
- when shall cycling equipment be flagged?
- when shall control signals be flagged as oscillatory?
- …

Then, can build a requirements library for use in projects.

81.2 % of Guideline36 requirements are satisfied at time = 1.8144e+07 s

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Controls and verification in real buildings

Controls design tool and functional verification tools

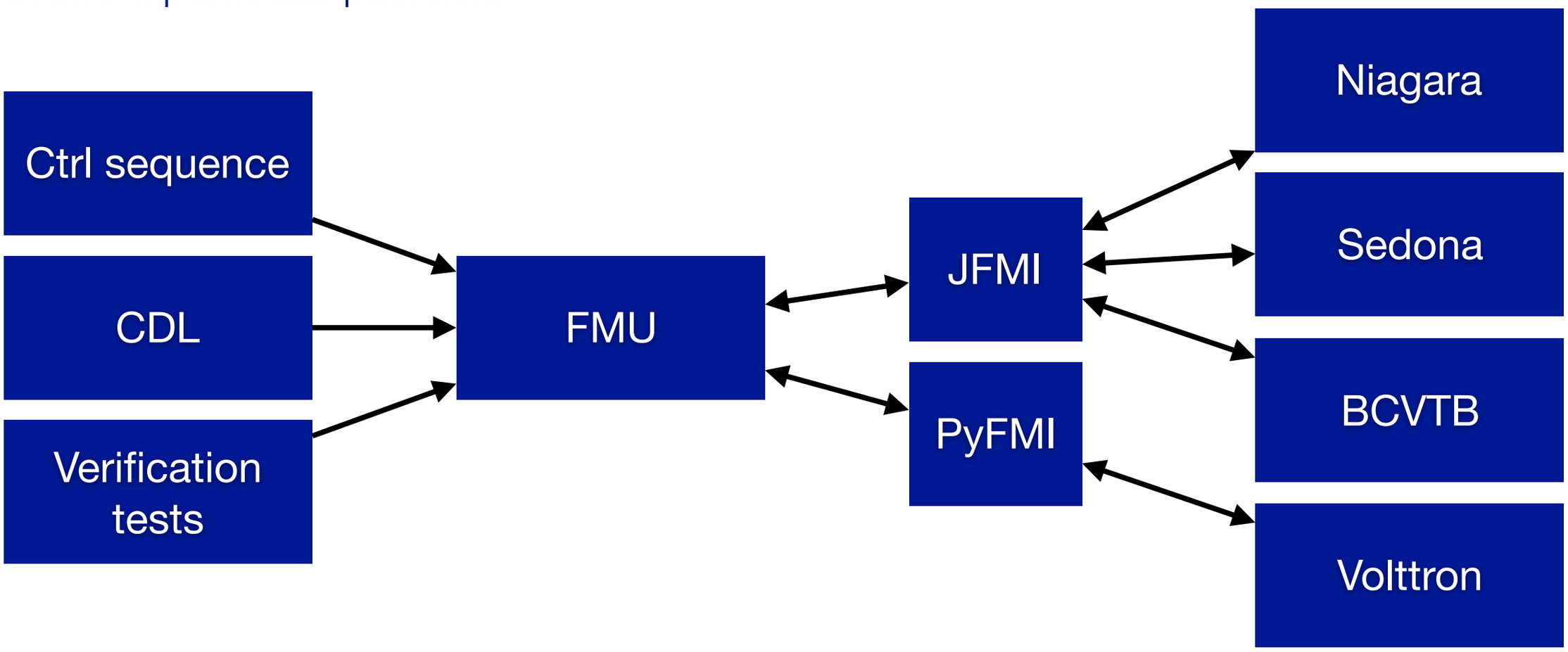
Controls design tool:

Started looking into schema driven GUI.

Work ongoing on parsing CDL to JSON.

Functional verification tool:

Tending toward FMU for run-time, with file that has information about I/O mapping, to avoid lock-in into a particular platform.



Functional verification tools

Sedona vs. Volttron vs. BCVTB

Sedona:

Based on Tridium Niagara, a commercial product.

Need to add FMI interface or develop code generation.

Commercial companies use it (AnkaLabs, http://www.eac.io/; Contemporary Controls, https://www.ccontrols.com/; others?) .

Chance to find a building that has Sedona (which could then be used as a control platform too).

Volttron:

Transformative Wave (https://transformativewave.com/) uses it, not (yet) clear who else.

Deployment path of OBC towards grid modernization?

Need to add FMI interface.

No license costs.

Easily deployed for a case study.

BCVTB:

Easy to connect to BACNet or RESTful services.

Know what its limits are (no surprises about unforeseen gaps in functionality).

Can run FMI as-is.

Easily deployed for a case study *if* building owner allows it.

Milestone and progress

	Year 1												Year 2											
	Q1			Q2			Q3			Q4			Q5		Q6				Q7					
1 Specification			M1.1						M1.2															
2 Controls design tool																								
2.1 Requirements and software architecture						M2.1																		
2.2 Impl. of ctrl seq. (secondary sys.)											M2.2													
2.3 Impl. of ctrl seq. (primary sys., facade & lighting)																								
2.4 Impl. of GUI																								
2.5 CDL export to English language and a product line																								
2.6 OpenStudio integration																			M2.5					
3 Functional verification tool																								
3.1 Requirements and software architecture																								
3.2 Impl. of hardware interface																								
3.3 Impl. of verification test module														M3.1				M3.2						
3.4 Impl. of GUI																								
4 Case studies																								
5 Com. and market transformation plan																								

Discussion

Feedback

- What else should be considered in the project or in new related projects/case studies?

Input from team and TAG needed for:

Control sequence library

- Need well documented sequences for
  - primary systems
  - facade

Verification test

- Need test criteria to implement library that can be used during modeling, commissioning and real-time operation.

Controls export & verification module

- Need to decide on target platform, and depending on platform, need assistance in integration/code generation.