OpenBuildingControl

Digitizing the control delivery process

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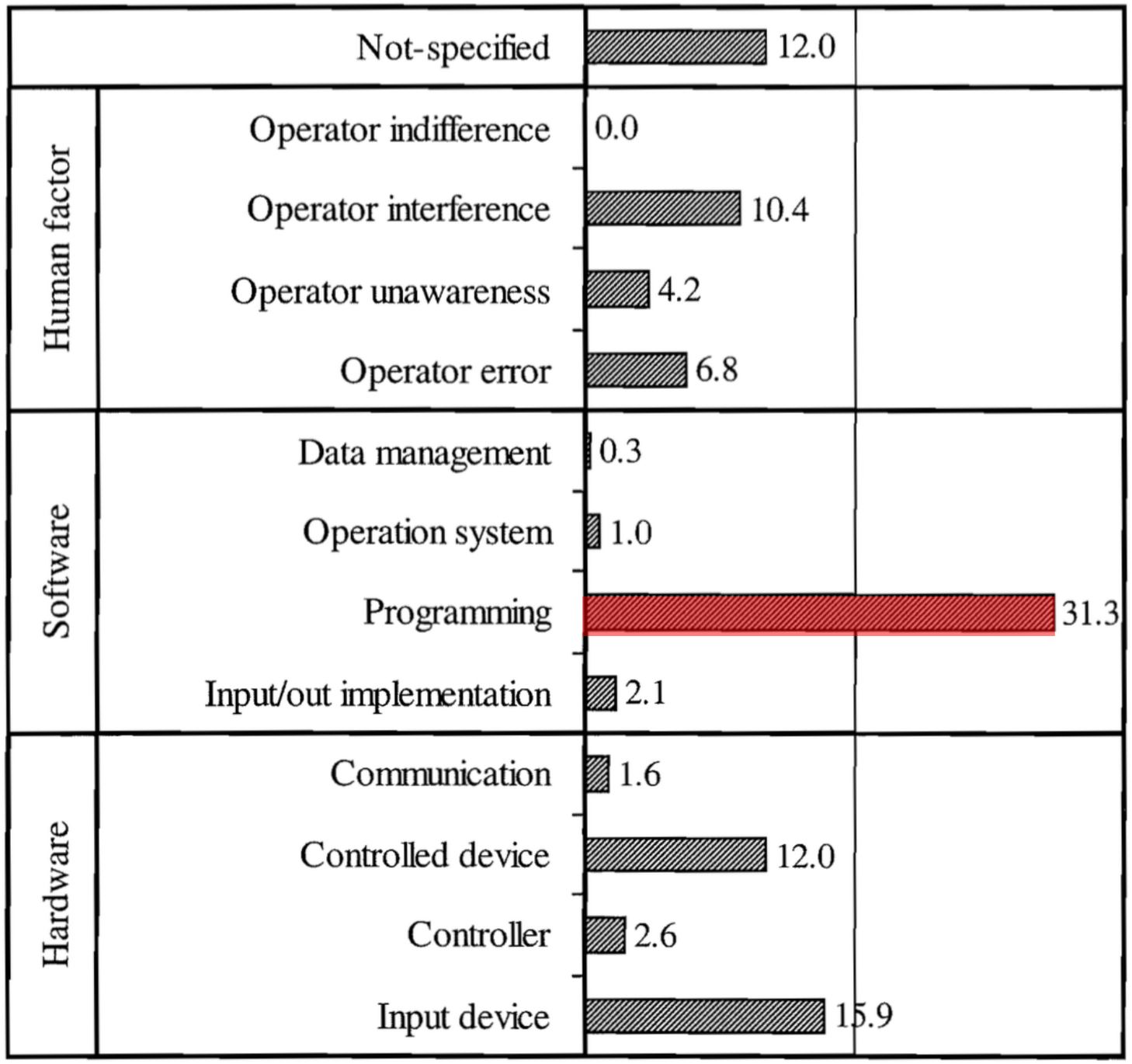
Presentation Contents

- Overview
- Sequence implementations
- CDL -> ALC EIKON
- Verification
- Collaboration with ASHRAE
- Discussions

Overview

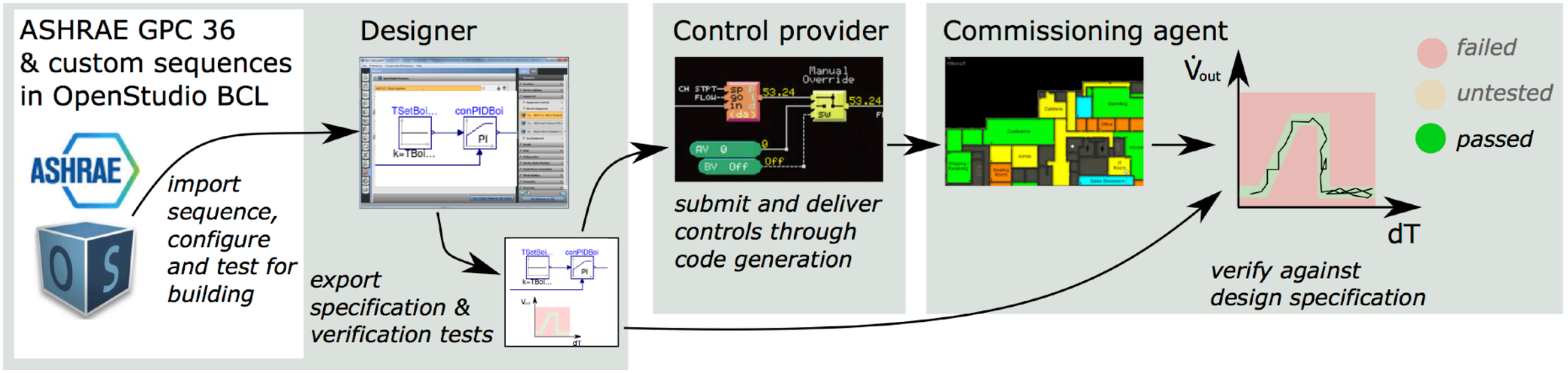
Challenge

Controls are the Achilles heel of commercial buildings, because there is no end-to-end quality control, and no standardization for control logic.



Control-related problems (Ardehali, Smith 2002).

Goal: Bridge silos between design and operation through digitized process that realizes energy savings of advanced control sequences

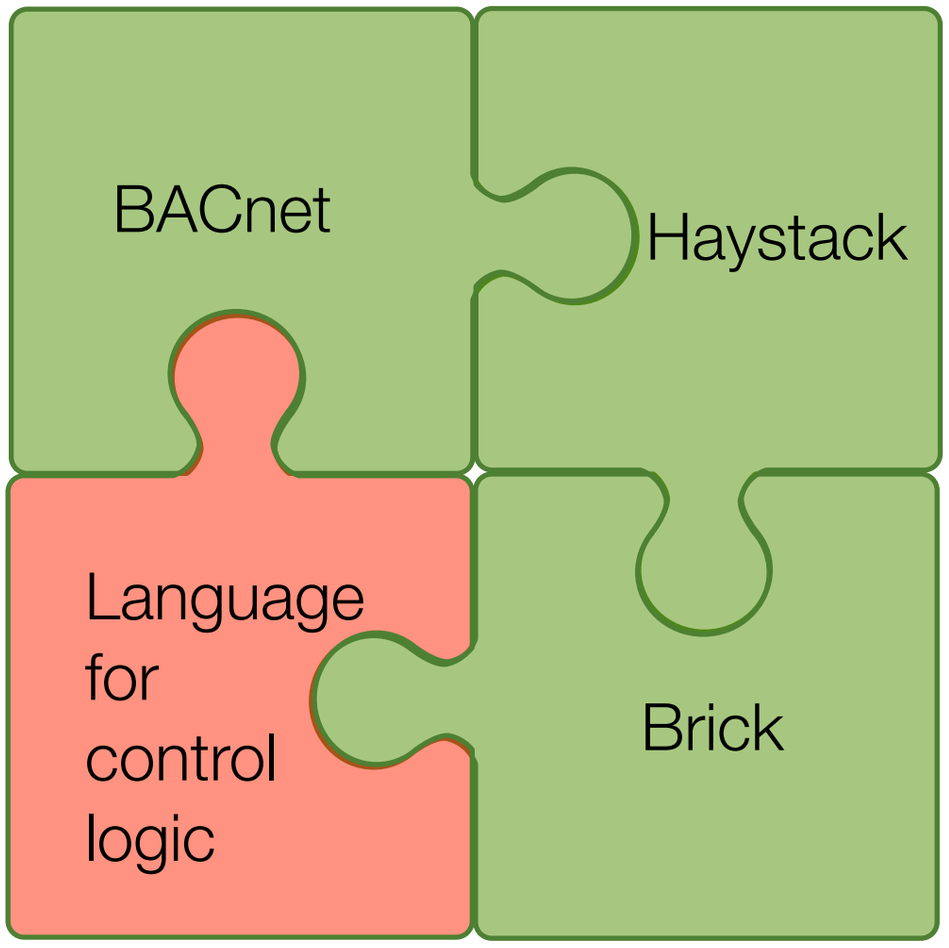


Codify best practice | Design | Implement | Verify against original design intent

We are developing a standardized language to express the control sequences and transmit them through the whole process in machine-readable format.

https://obc.lbl.gov

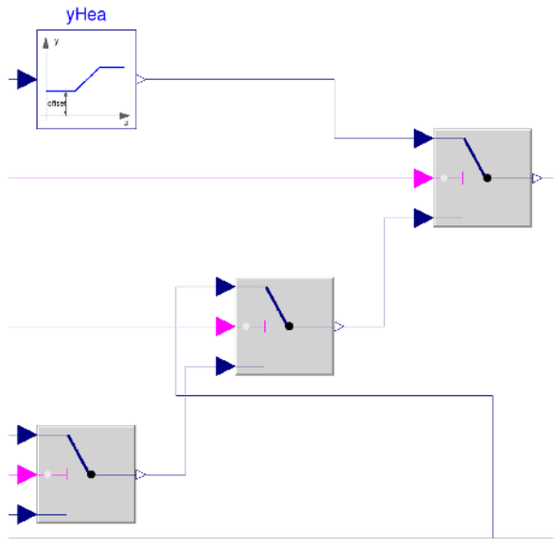
A key goal is to standardize a language for expression control logic, complementary to standards for communication and for semantic modeling



What is the Control Description Language?

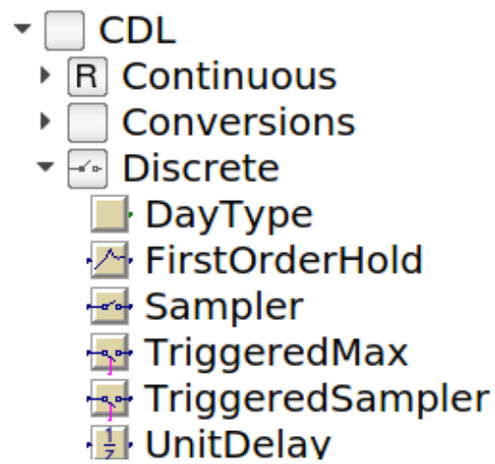
A declarative language for expressing block-diagrams for controls (and requirements)

A graphical language for rendering these diagrams.

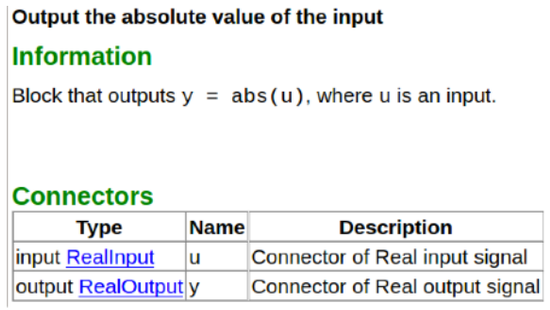


A library with elementary input/output blocks that should be supported [through a translator] by CDL-compliant control providers

Example: CDL has an adder with inputs `u1` and `u2`, gains `k1` and `k2`, and output
`y = k1*u1 + k2*u2`.



A syntax for documenting the control blocks and diagrams.



Output the absolute value of the input

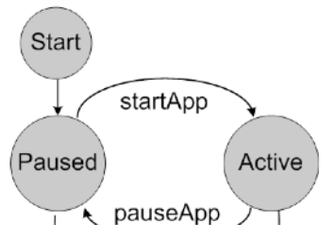
Information

Block that outputs `y = abs(u)`, where u is an input.

Connectors

Type	Name	Description
input RealInput	u	Connector of Real input signal
output RealOutput	y	Connector of Real output signal

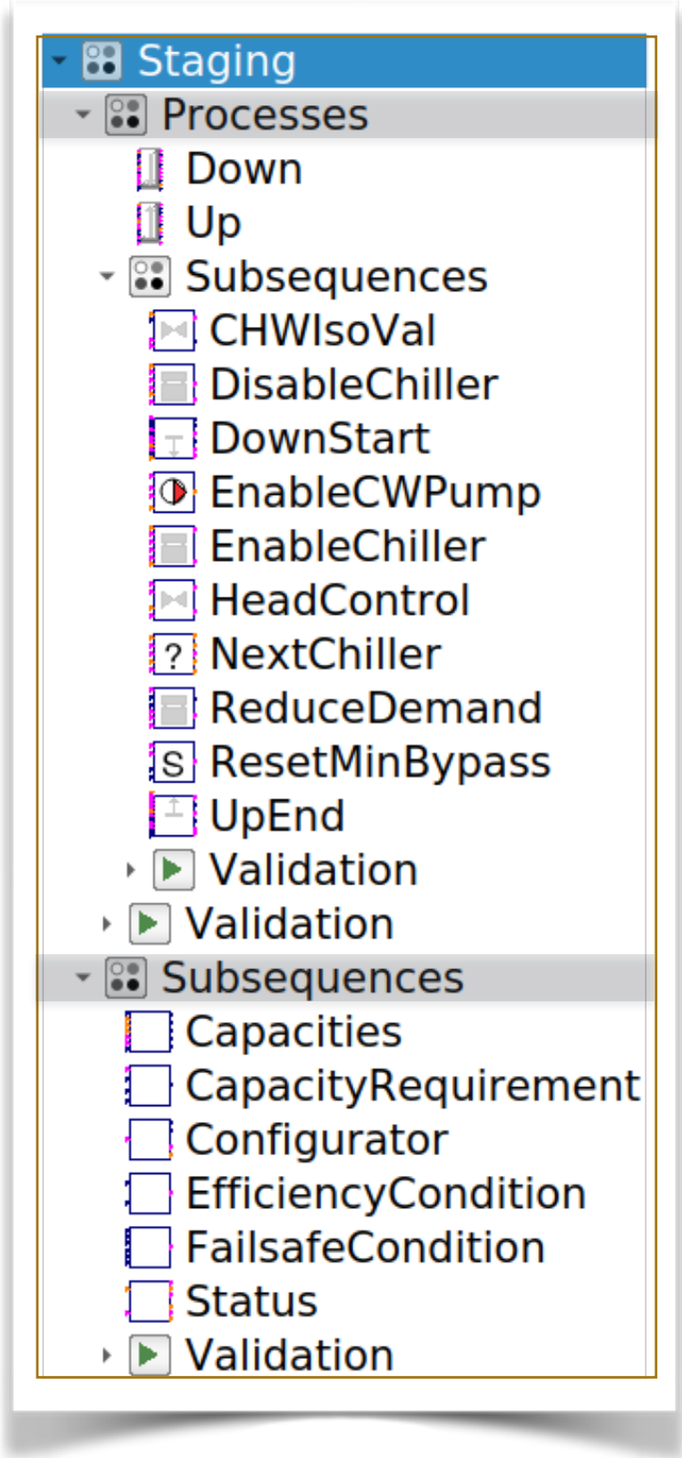
A model of computation that describes the interaction among the blocks.



Sequence implementations

Status of Sequence Implementation

- Completed
  - Specified Control Description Language CDL (http://obc.lbl.gov/specification/cdl.html)
  - Implemented & released VAV sequences from Guideline 36 (public review draft 1).
  - Multi-zone VAV: Demonstrated 30% HVAC site energy reduction compared to sequences published by ASHRAE 10 years ago.
  - Single-zone VAV: Demonstrated 17% savings compared to conventional control sequence
  - Released translator from CDL to json intermediate format, to html and MS Word.
- Spring 2020:
  - Demonstrated automatic translation of multi-zone VAV G36 sequence from CDL to ALC EIKON (with translator from Dave Robin)
  - Chiller plant sequences based on ASHRAE RP-1711 implemented by Spring 2020.
  - VAV sequence from Guideline 36 official release implemented by Summer 2020
- Until October 2022
  - Phase II of OpenBuildingControl (LBNL, PNNL, Paul Ehrlich, Taylor Engineering, software contractor TBD)



Where do we need contributions in sequence implementation?

- Chiller plant sequences based on ASHRAE RP-1711 implemented by Spring 2020.
  - review and testing
- Boiler plants
- Completion of Guideline 36 (e.g, dual-fan dual-duct)
- Other sequences (e.g., alternate to G36, roof top units, radiant systems, facade)
- Basic building blocks (e.g., recovery wheel, room thermostat with overwrite and window switch, …)
- Specifying, and adding, information that allows export of BRICK model

This is not a "programming task" but rather requires knowledge in

How to partition a sequence.

Determine what functionality should be in one control block.

What configuration parameters need to be exposed to users.

How do you test for correctness
- open loop tests
- closed loop tests
- robust to sensor noise
- good default values for tunable parameters

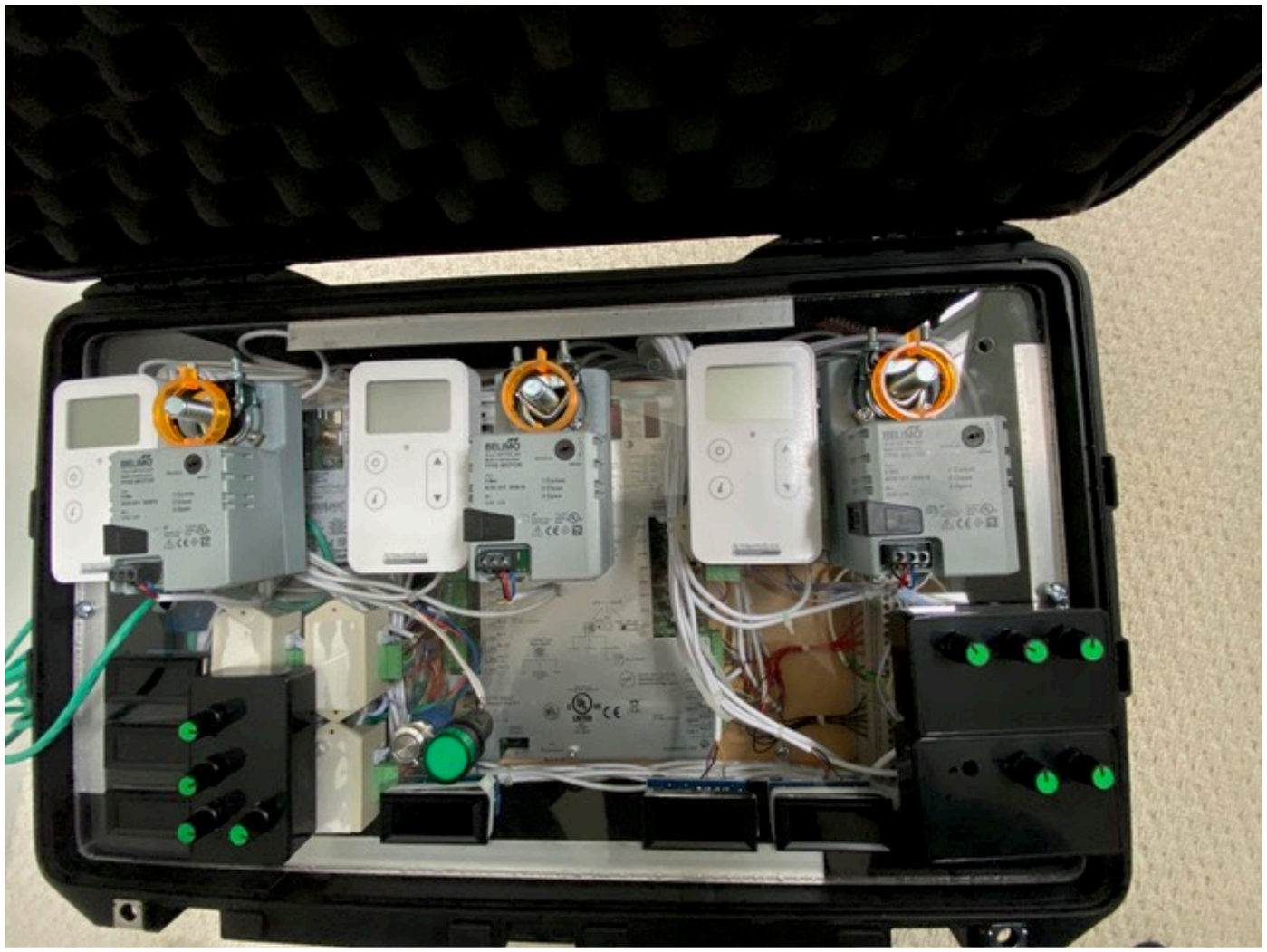
How to explain the sequence in easy to understand English language.

Export of CDL to ALC EIKON

Prototype translator CDL to EIKON of Automated Logic Control (ALC)

Status:

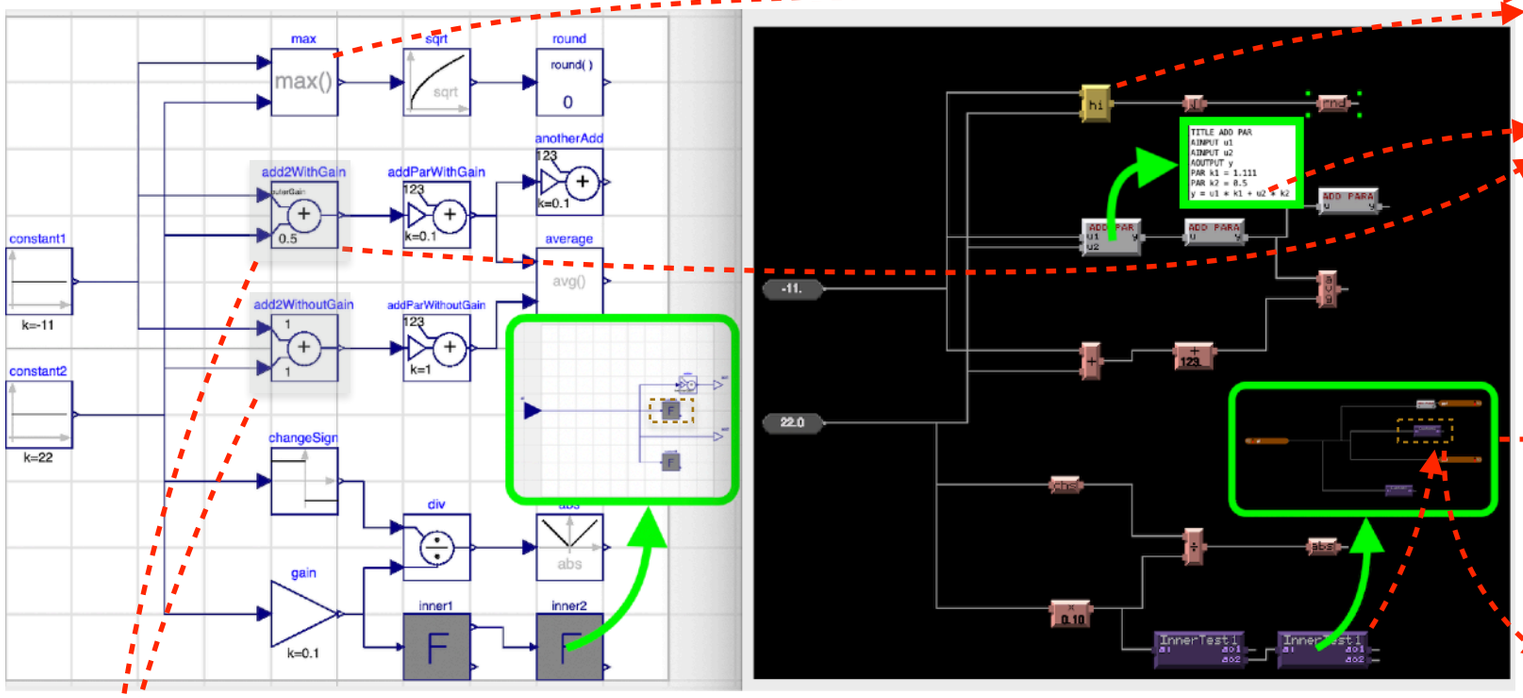
- Built demonstration kit for demonstrating Eikon sequences translated from CDL
- Prepared tools for testing with actual control programs:
    - parameter reference, block conditional removal, graphical mapping
- Currently work on demonstration of VAV multi-zone sequence for DOE Peer Review



Prototype translator CDL to EIKON of Automated Logic Control (ALC)

Capabilities:

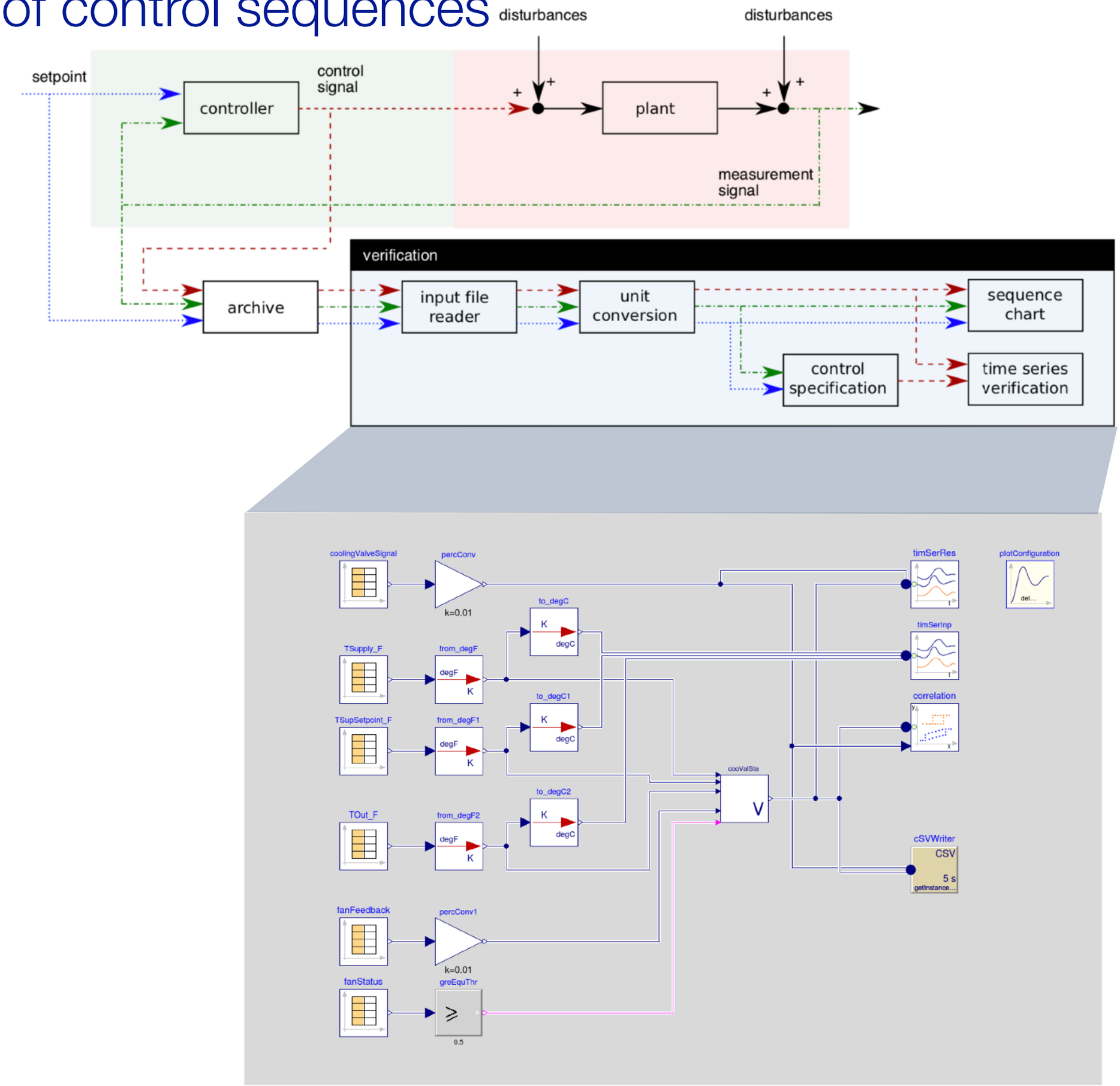
- Converts non-elementary Modelica model to a top-level Eikon program



- map 1-to-1 to Eikon primitives (pink/ yellow)
- map to custom line-code blocks (gray)
- convert inner model to custom blocks (purple) containing inner logic.
- map to pre-made graphical logic
- Dynamically maps based on parameter values (`add2WithGain` vs `add2WithoutGain`)
- Assigns parameters inside line-code and pre-made logic blocks
- Propagates Modelica parameter values to inner logic

Verification

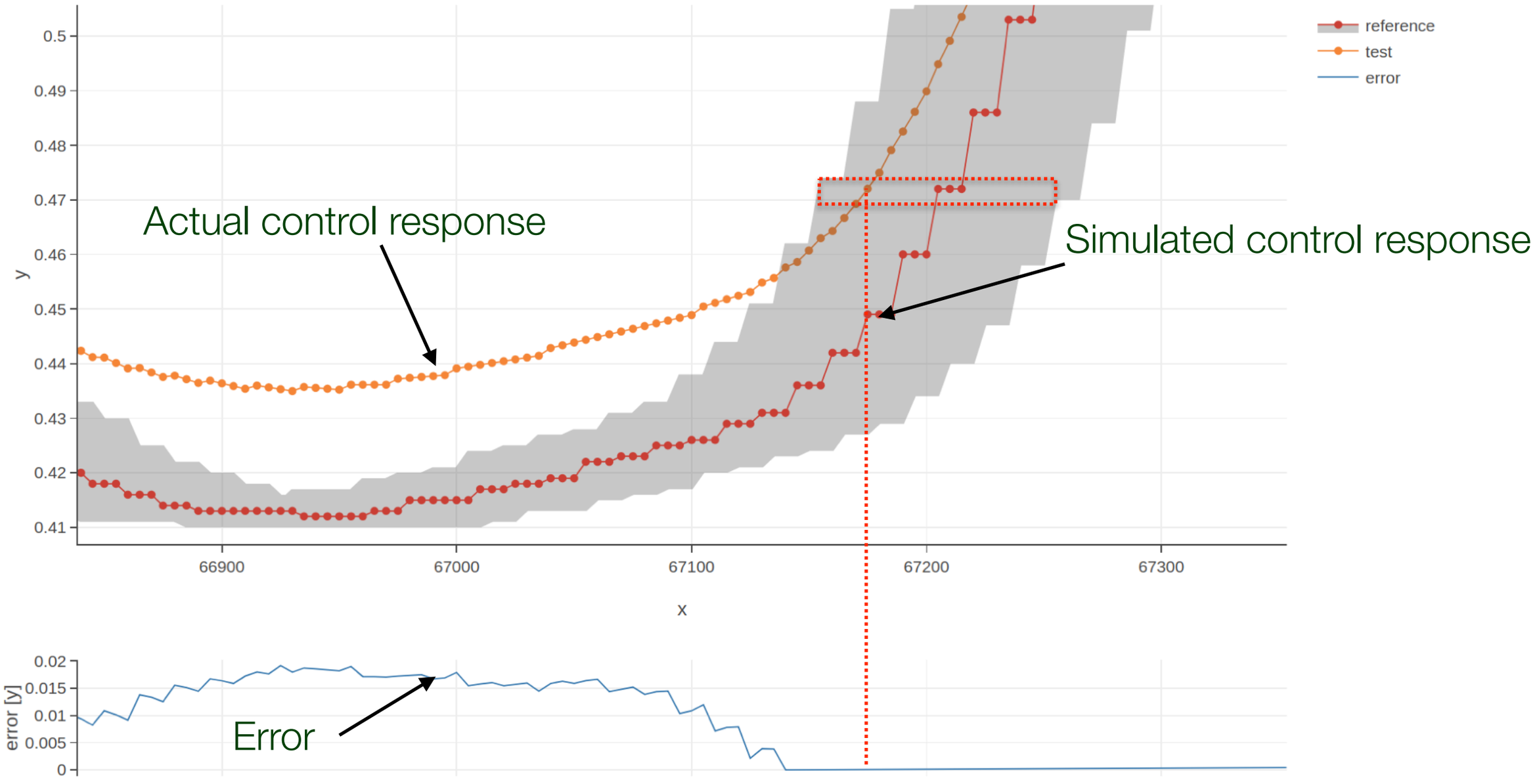
Verification of control sequences



Are time series between simulated and implemented control within a certain error band?

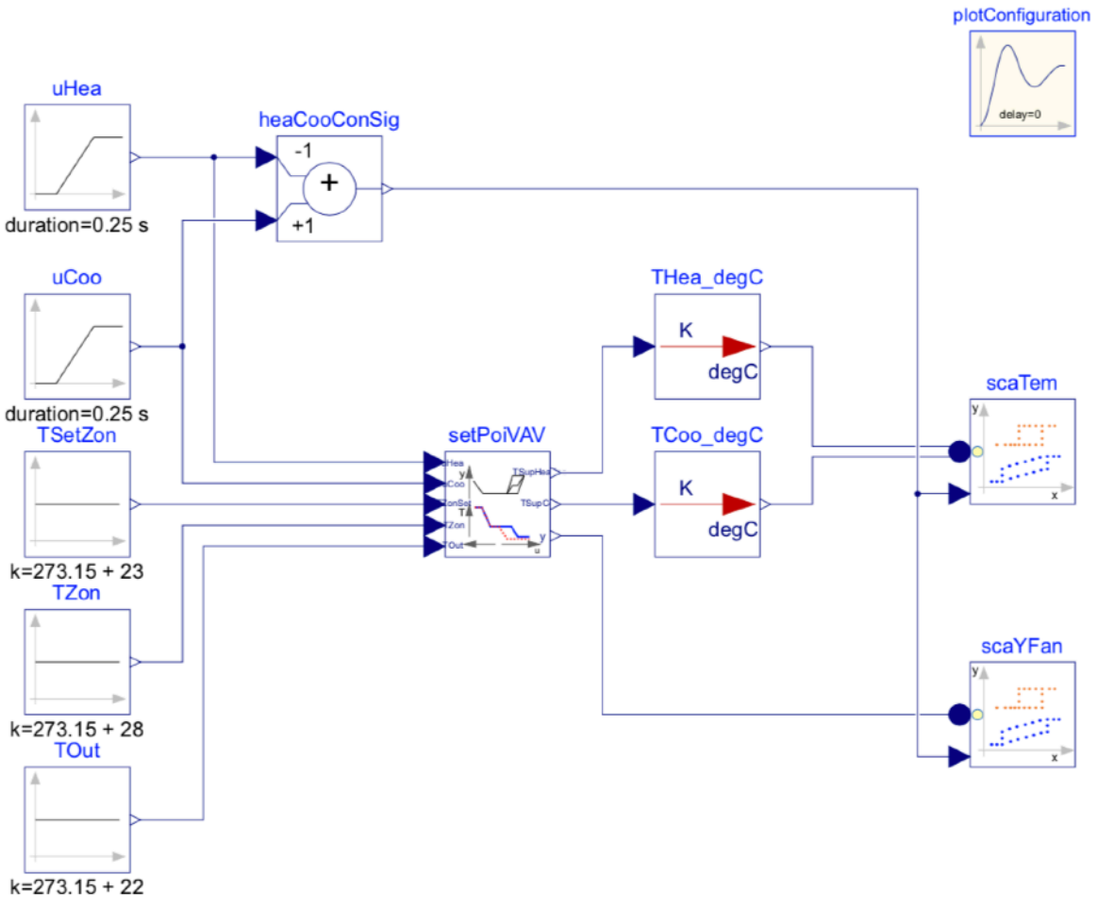
Detailed principles

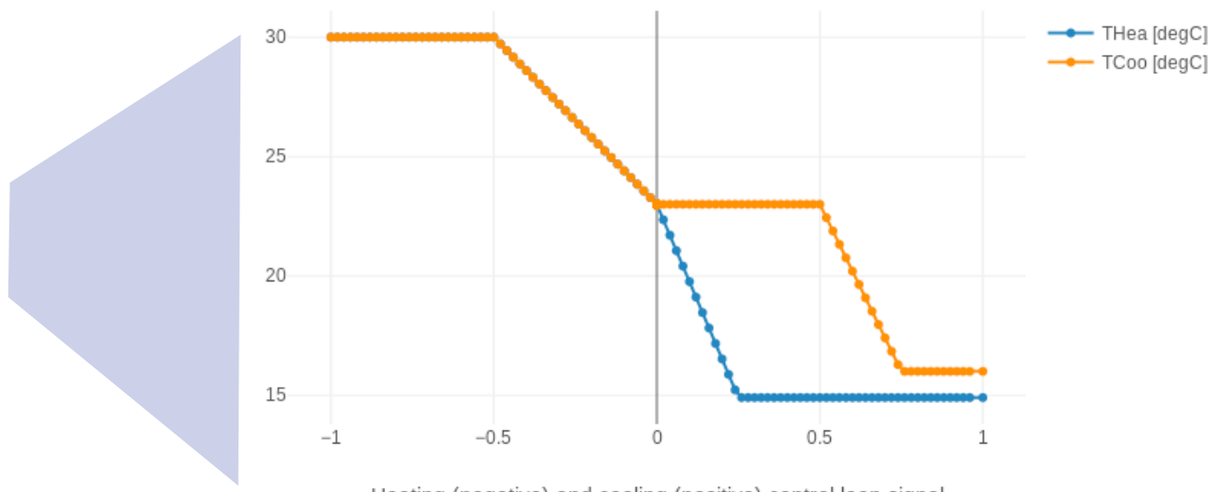
- L1-norm based comparison
- Trajectory comparison (as opposed to point-to-point): handles time events & different time scales

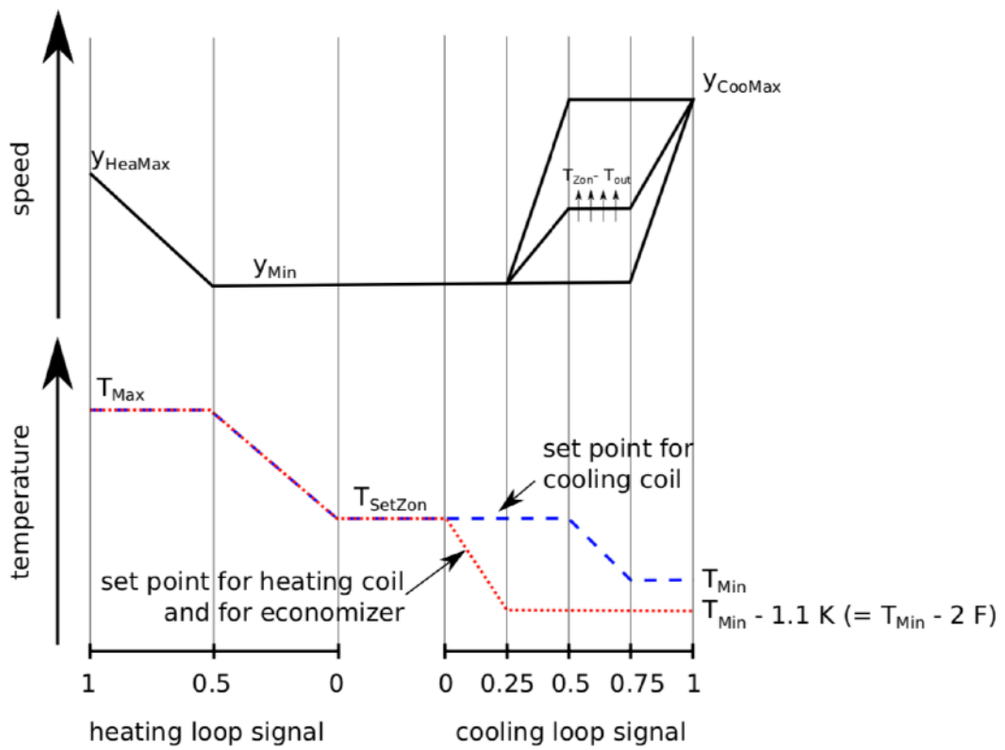


Example output generated using funnel *software, https://github.com/lbl-srg/funnel*

Optional: Generate sequence charts



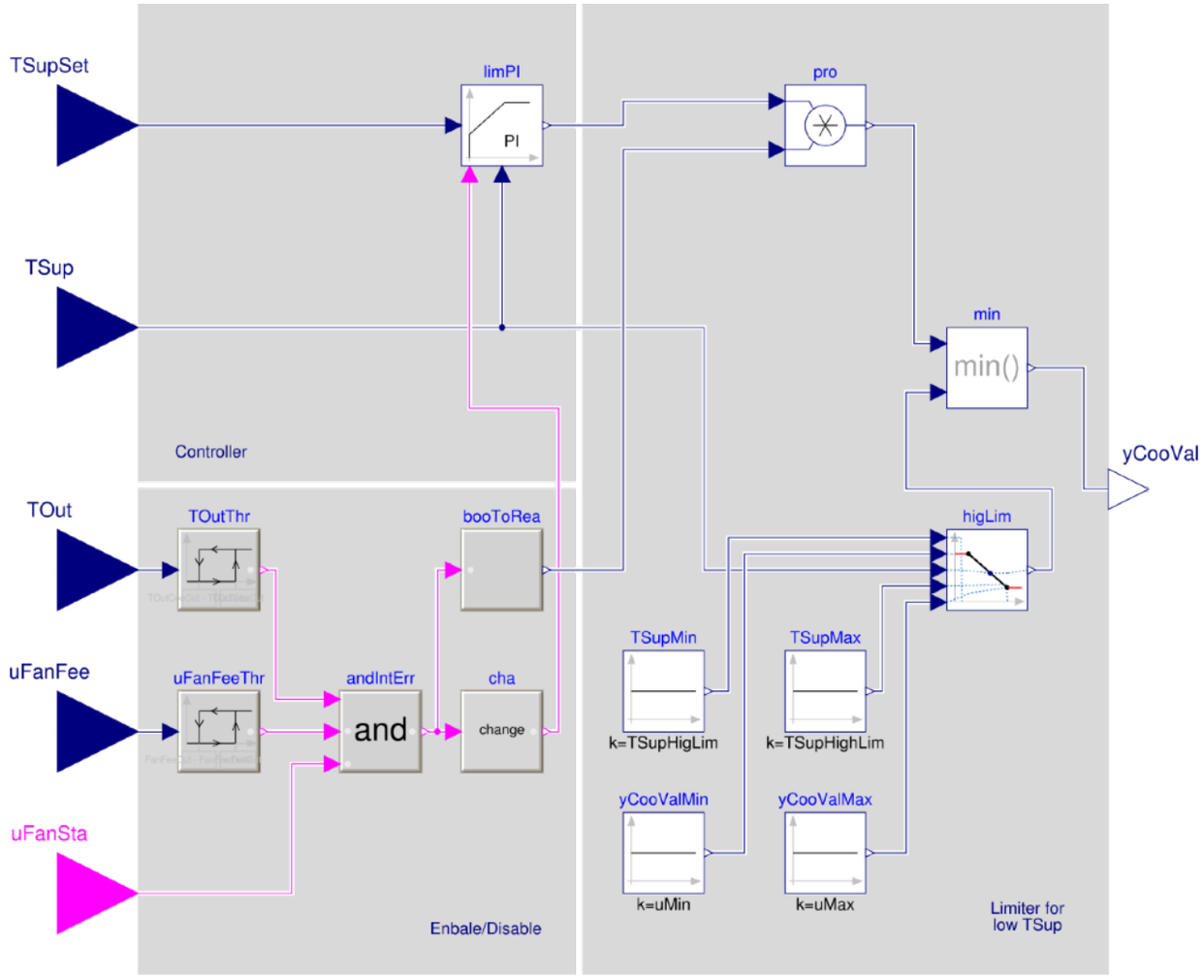




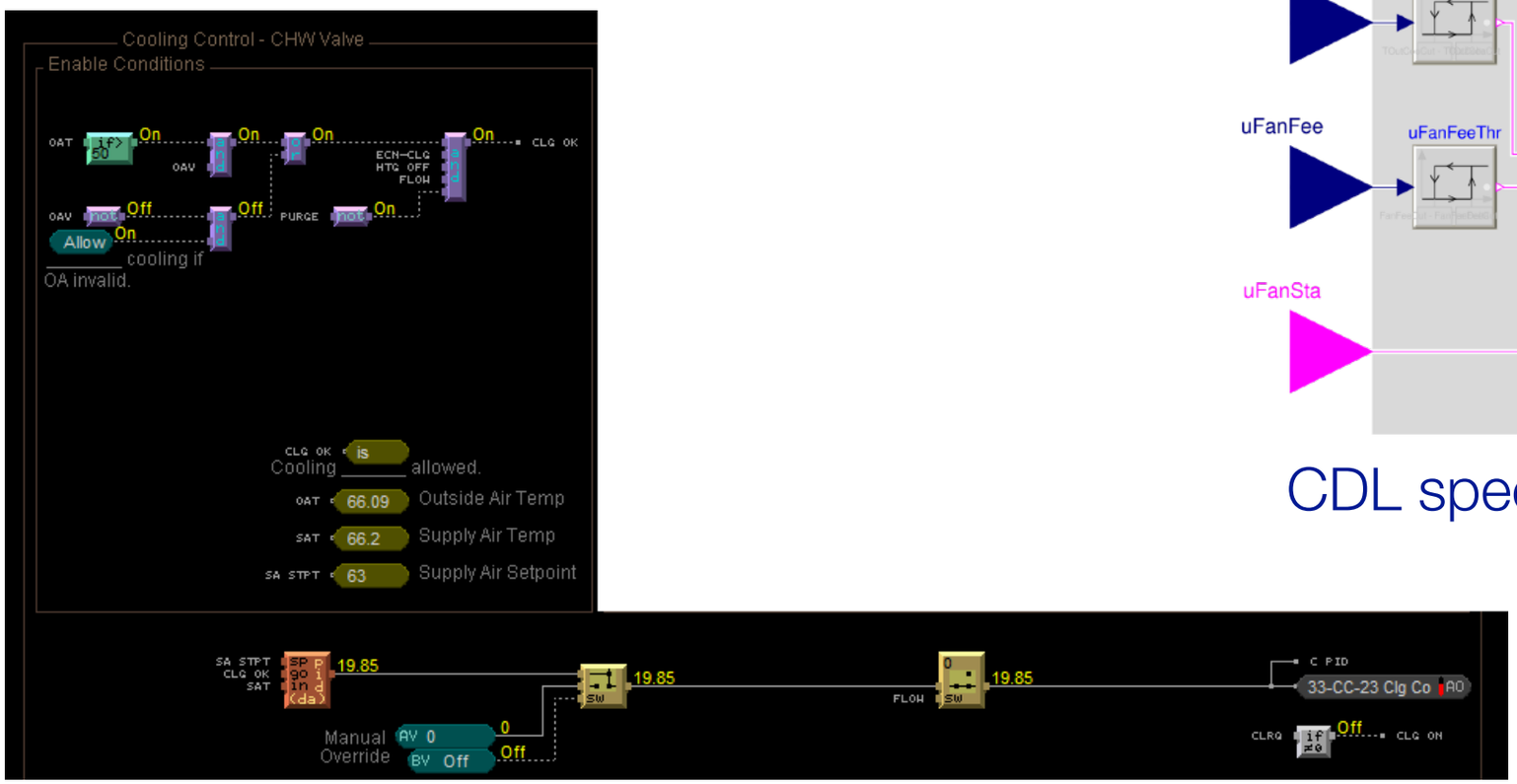
Verification test with a measured control response - Sequence specification

We validated a **trended output** of a control sequence that defines the **cooling coil valve** position.

The cooling coil valve sequence is a part of the ALC EIKON control logic implemented in building 33 at LBNL.

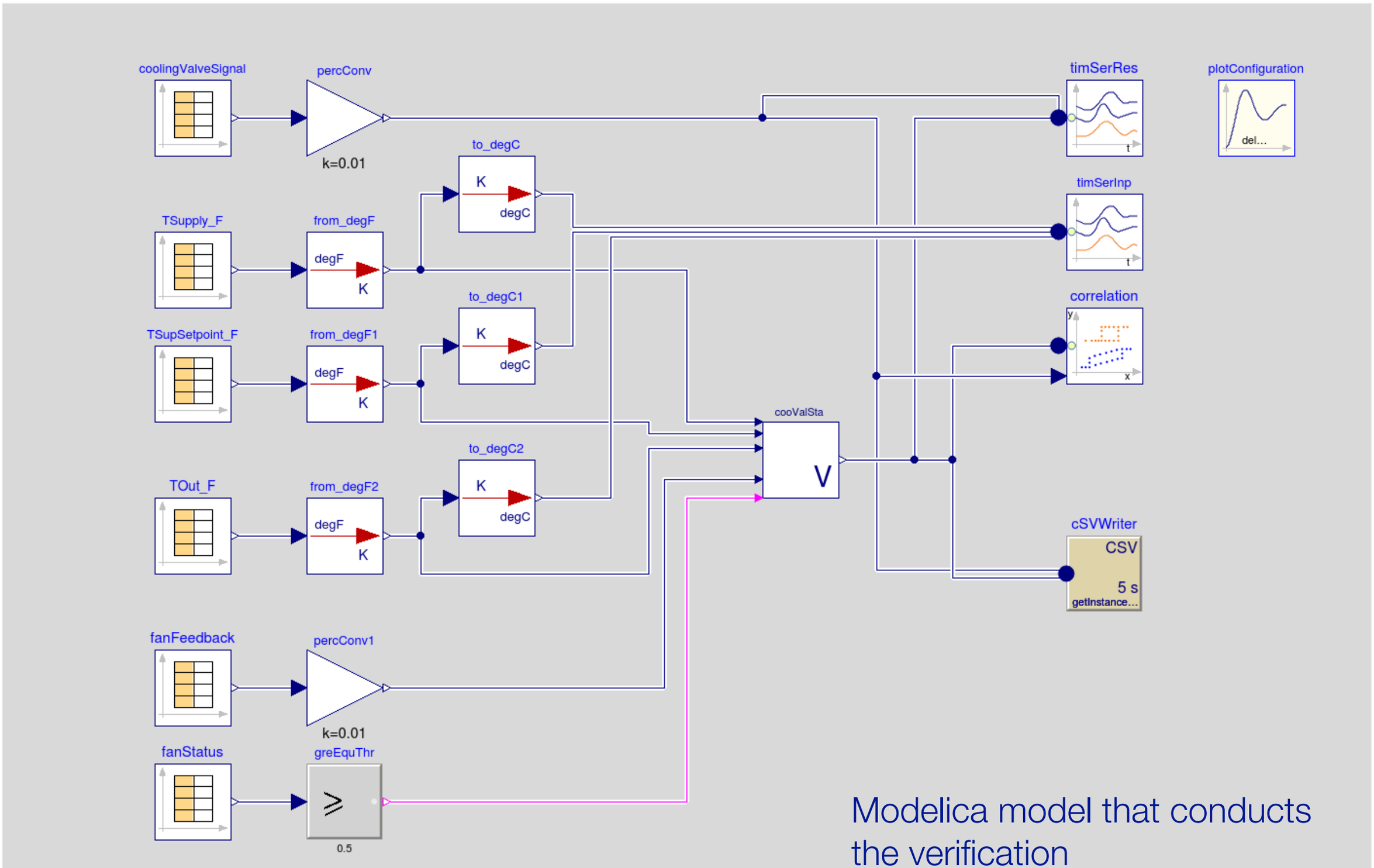


CDL specification



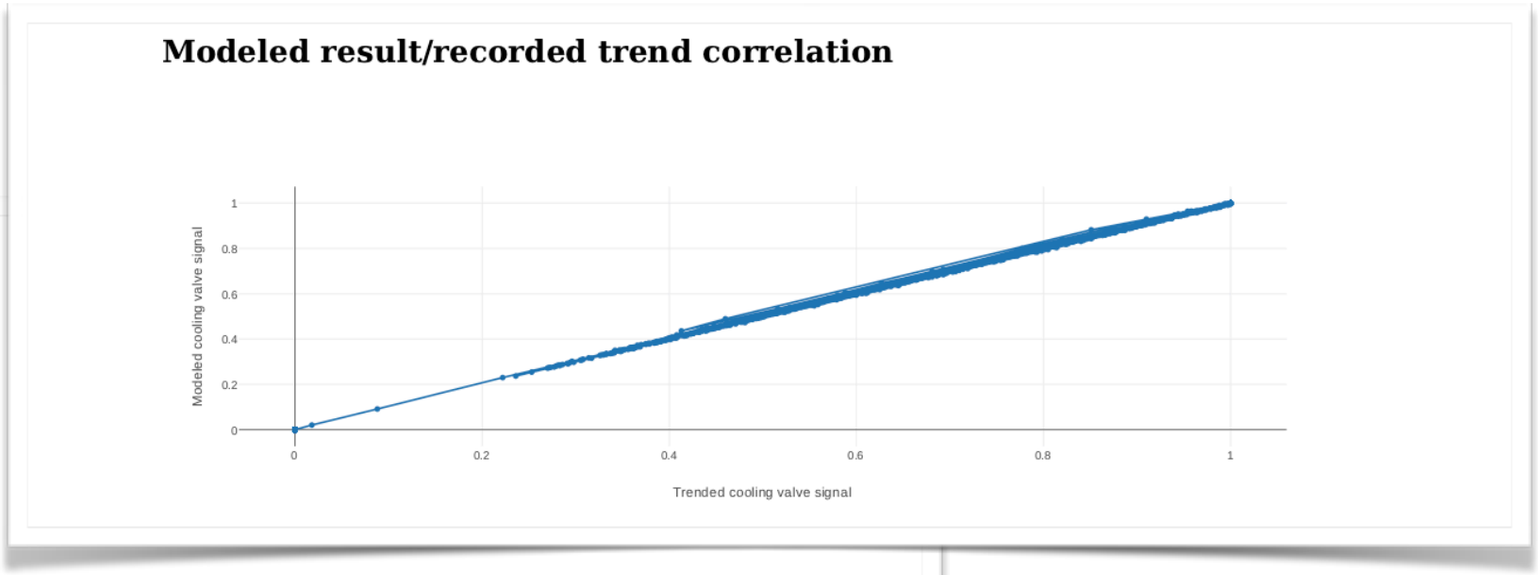
ALC EIKON specification

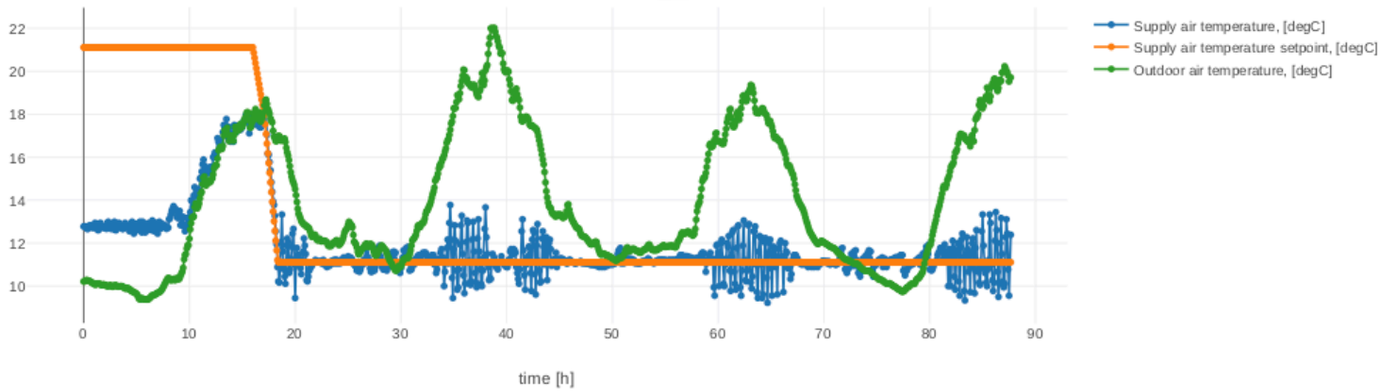
Verification test with a measured control response - Conducting the verification

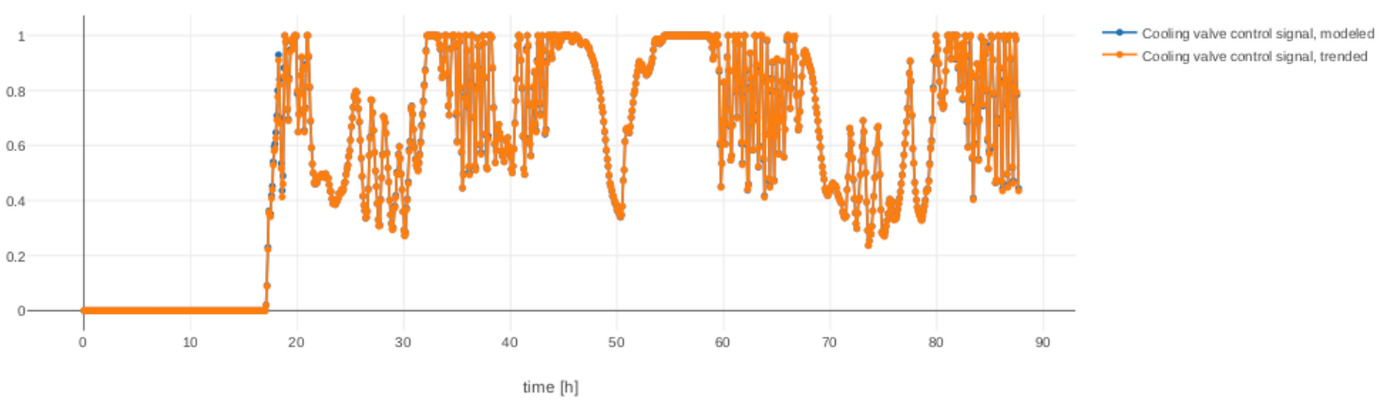


Modelica model that conducts the verification

Verification test with a measured control response - verification results







Where do we need contributions?

- Determine how close tolerance should be based on larger control sequence.
- Facilitate mapping of actual, trended control sequences with model to reduce setup time.

Collaboration with ASHRAE

Make CDL an ANSI/ISO Standard via ASHRAE

Title: CDL - A Control Description Language that enables a Digital Control Delivery Process

Purpose: To standardize a declarative programming language for digitizing the control delivery process, using a human and machine readable format suitable for

- Closed loop performance simulation of the control sequences
- Process to develop and specify sequences
- Machine-to-machine translation, or native use of the sequences for control platforms
- Verification of the correct implementation of the control sequences

Scope: This standard applies to control sequences for mechanical systems, active facades, and lighting systems.

Note: Out of scope is water treatment, security, transportation.

Scope of CDL is driven by expressiveness of block diagram language, need to translate to product lines, and to accommodate heterogeneity in product offerings

In scope	Out of scope
Control logic	Communication (except for I/O tags, e.g., what should be a BACnet point)
	Semantic modeling (except for export of semantic information)
Schedule values are input to logic	Declaration of schedules
Alarms	How alarms are handled (email, GUI, …)
Modularization of logic (I/O blocks)	What blocks runs on what hardware (may allow for optional annotation to restrict what must be on central or local controller)
Annotation declaring what I/O need to be fed to trends, advanced FDD, MPC, AI etc.	Advanced FDD, MPC, AI (as impractical with block diagram modeling)

Guideline 36, generated from CDL Reference Implementation

Outdoor and return air damper modulation

Sequence ID: 4345-0000

Info

Multi zone VAV AHU economizer modulation block. It calculates the outdoor and return air damper positions based on ….

Inputs are damper position limits obtained from `ASHRAE.G36_PR1.AHUs.MultiZone.VAV.Economizers.Subsequences.Enable`.

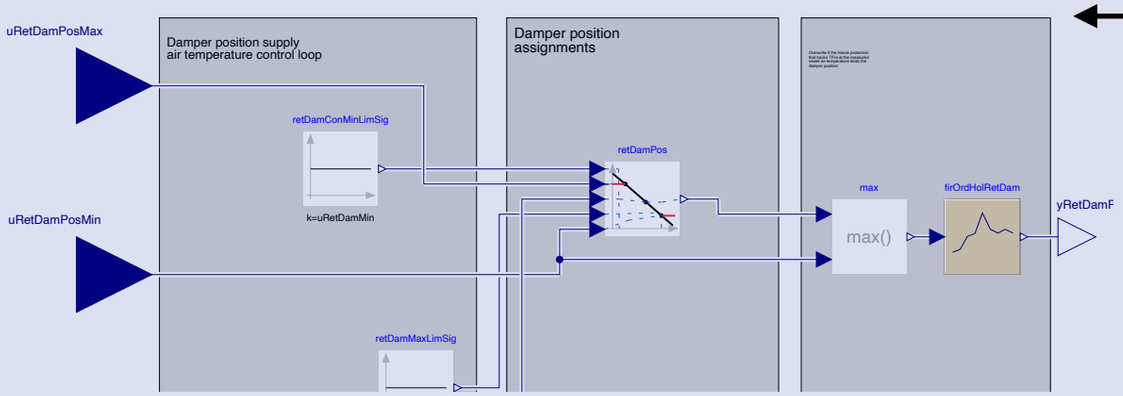
…

The time rate of change of the damper signals is limited by a first order hold, using the sample time `samplePeriod`. This prevents ….

Parameters

It has the following parameters:

Type	Quantity	Name	Default	Unit	Display unit	min	max	Description
Commissioning								
Controller								
Real		uMin	-0.25	1	1		0 (adjustable)	Lower limit of controller input when outdoor damper opens (see diagram)
Real		uMax	+0.25	1	1	0		Upper limit of



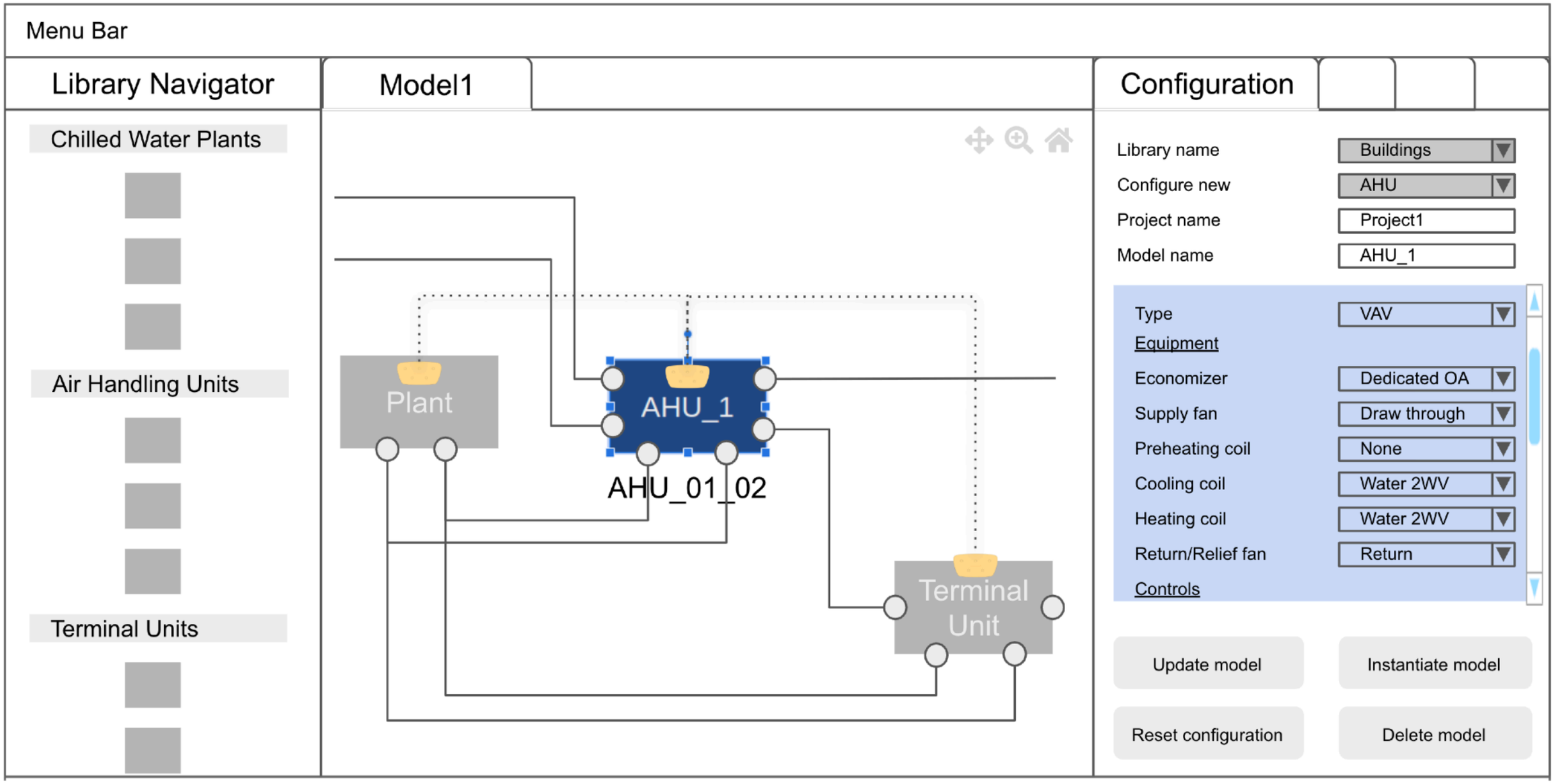
Unique sequence number links to reference implementation that was used to generate this documentation, tables and figures, and that is used in Sequence Configuration Tool.

English language description, with permalink to other sequences and to parameters, inputs and outputs of the sequence

List of parameters, inputs and output

Block diagram

Sequence Selection and Configuration Tool - GUI



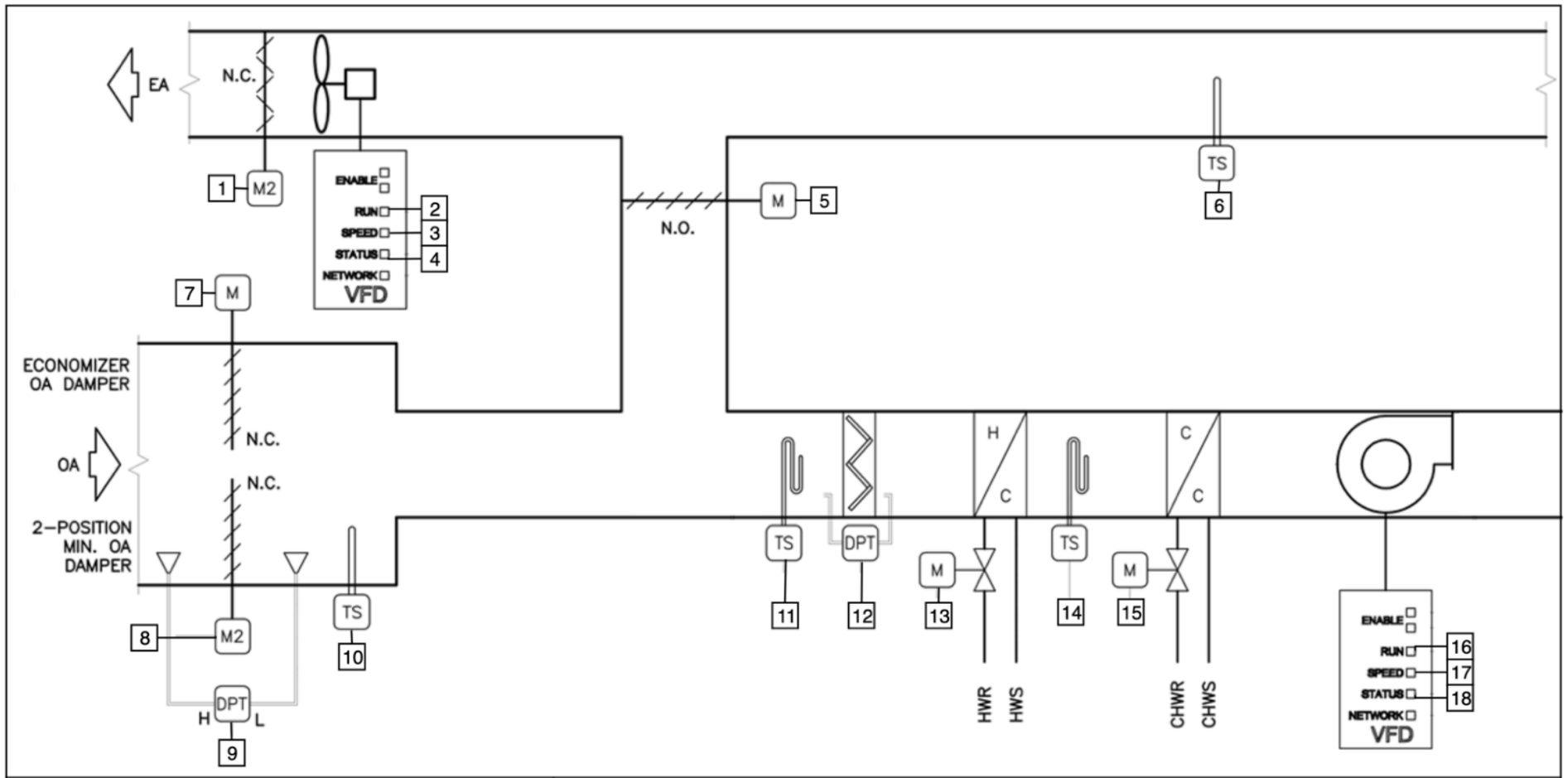
At the “subsystem” level (e.g. AHU, terminal unit):

- Specify the system configuration by filling up a simple HTML input form
- Select compatible control sequences already programmed in CDL
- Configure the control options through the HTML form
- Optionally: further customize the design by editing the block diagram

The configuration widget relies on an open data structure:

- Independent from the software implementation
- That every CDL developer can leverage to develop custom forms for specific systems or applications

Sequence Selection and Configuration Tool Documentation Export



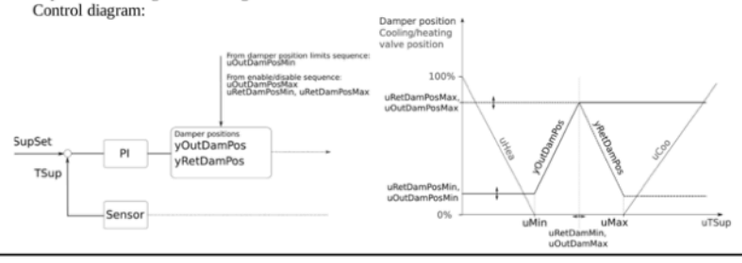
Control Points List

1. Relief damper position	DO
2. Relief fan start	DO
3. Relief fan speed	AO
4. Relief fan status	DI
5. Return air damper position	AO
6. Return air temperature	AI
7. Economizer outdoor air damper position	AO
8. Minimum outdoor air damper position	DO
9. ...	...

Control Sequence Description

The time rate of change of the damper signals is limited by a first order hold, using the sample time samplePeriod. This prevents a quick opening of the outdoor air damper, for example when the outdoor airflow setpoint has a step change. Slowing down the opening of the outdoor air damper allows the freeze protection to componensate with its dynamics that is faster than the opening of the outdoor air damper. To avoid that all dampers are closed, the return air damper has the same time rate of change limitation.

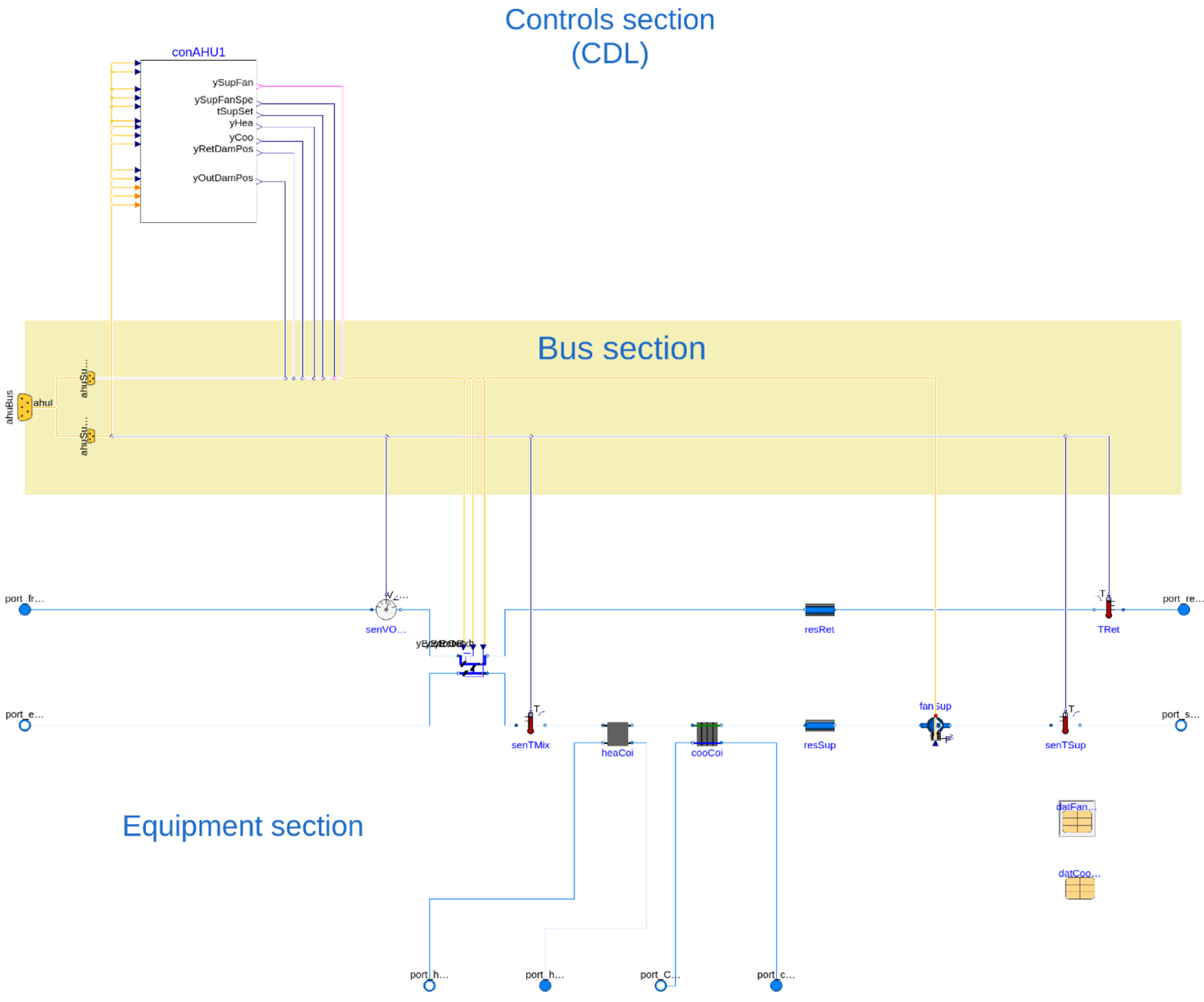
The control charts below show the input-output structure and an economizer damper modulation sequence assuming a well configured controller.
Control diagram:



The documentation generator selects the sections of the guideline corresponding to the actual system configuration and SOO options.

HTML and docx formats are supported.
Cross-references (paragraphs, figures, tables) are maintained.

Sequence Selection and Configuration Tool
Simulation Model Export (Modelica)



Generation of a simulation model:

- Ready to simulate

  All the connections between the CDL, equipment and subsystems components are generated.

- “Graphically readable”

  For further editing the diagram representation of the model (with any third-party Modelica editor)

- Enriched with the metadata allowing further configuration with the HTML input form

Benefit of a reference implementation of control logic

Process	• Move from paper to digitized workflow
Guideline 36 Committee	• Test sequence correctness & performance in simulation • Remove ambiguity • Allow formal testing & certification

Control Providers	• Automatic translation from CDL to their respective product lines
	  • of Guideline 36
	  • of custom configurations
	• Have digital reference to verify that sequences are programmed error free

Control buyers	• ASHRAE Guideline 36 certified sequences
Mechanical engineers	• Can have Control Sequence Selection and Configuration Tool, up-to-date with Guideline
Energy modelers	• Can simulate actual control sequences
New markets	• Digital twins. • Integration with BIM • Integration with semantic modeling (ASHRAE 223P)

Discussions

Project Website: https://obc.lbl.gov

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