Standardization to Digitalize Control Design and Delivery

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Overview

What problem do we solve?

New ASHRAE Standard 231P "Control Description Language"

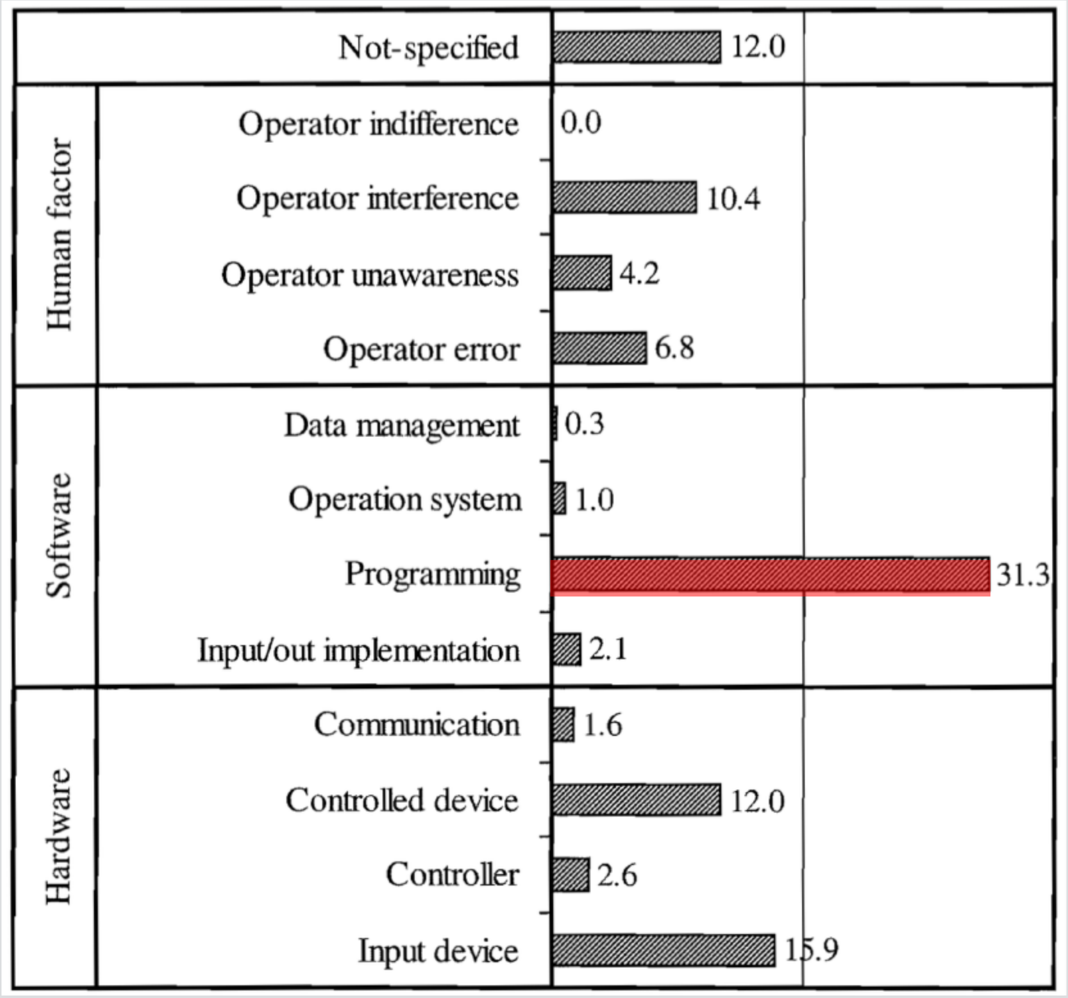
Integrating standards for robust control digitalization

Q&A

What problem do we solve?

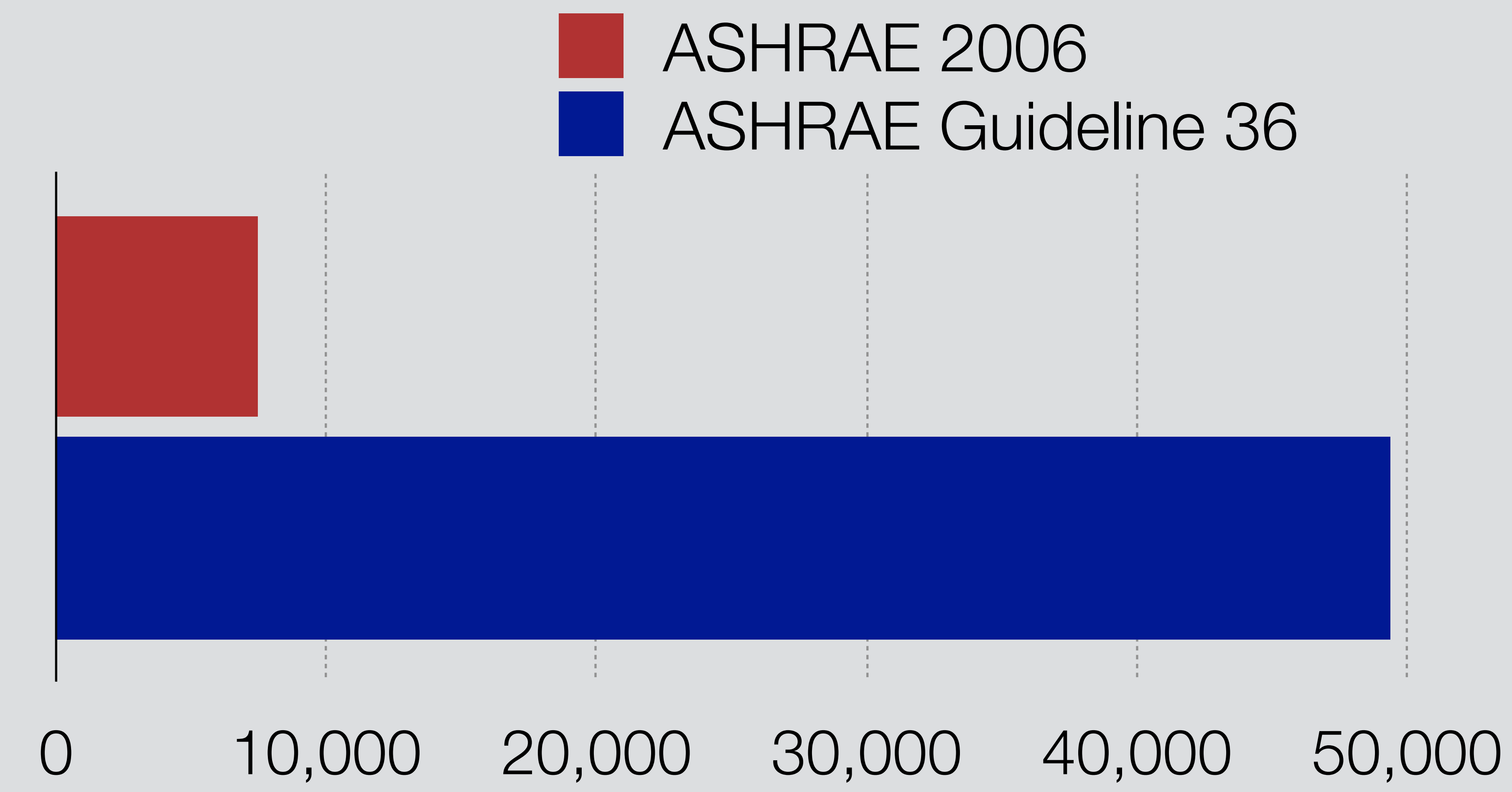
Why do we think we can meet new integration challenges if we even fail to deliver yesterday's energy systems in a robust way?

2000



Control-related problems (Ardehali, Smith 2002).

2020



# of lines of code for a multi-zone VAV control sequence using CDL

2030 ?

Control optimizes across energy carriers.
Digital twin & real-time data integration.
IoT
…

See previous presentation of David Blum for more context.

Controls Delivery Process

Conventional

- Review design documents
- Secure project
  develop controls submittal
- Interpret sequence and
  develop controls programs
- Download to
  controls
- Trouble shoot during
  commissioning, as sequences
  were never tested closed loop

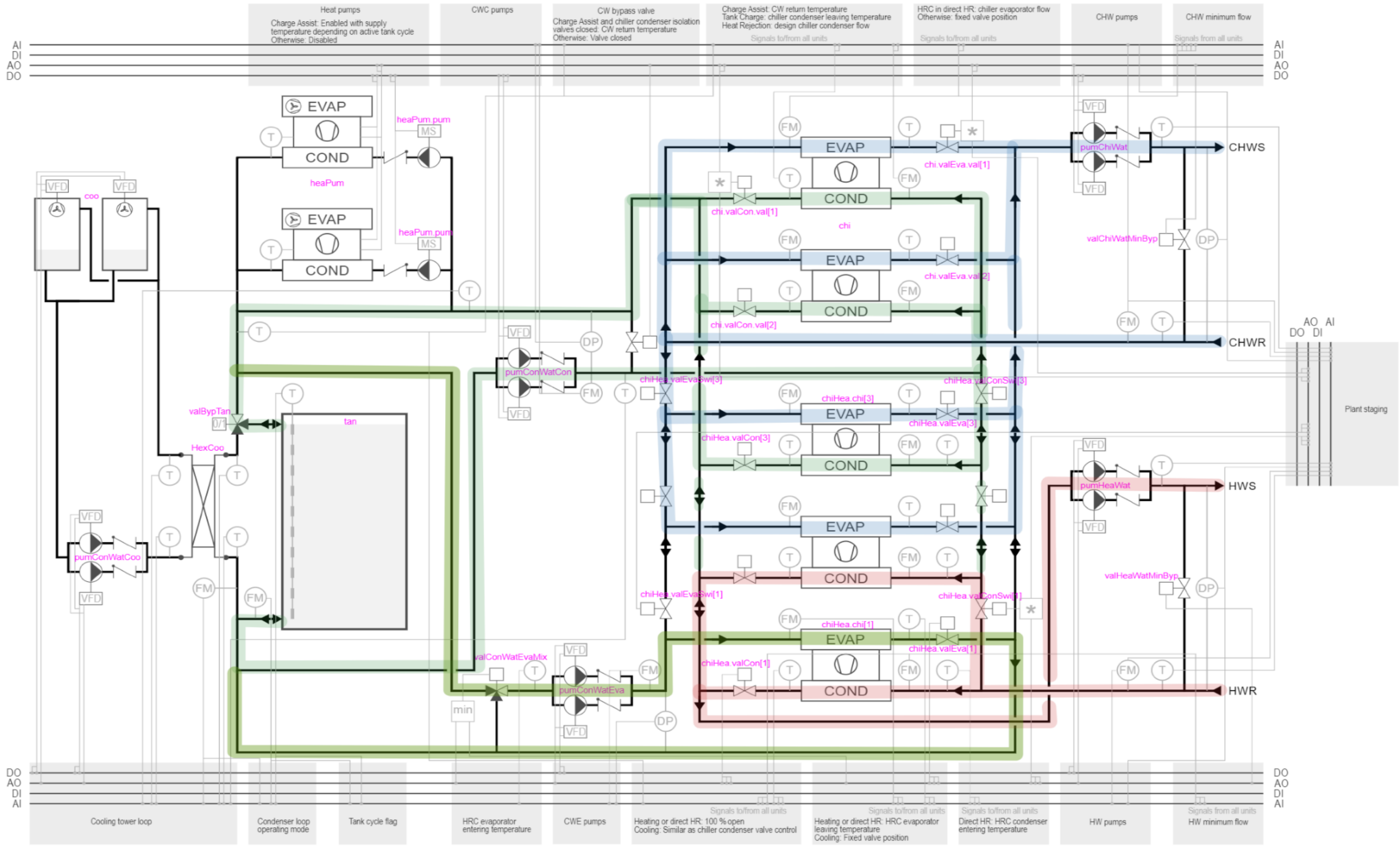
New

CDL from designer

- CDL compliant controller → Review and download to controllers
- Legacy
  - Review and translate to proprietary programming language
  - Download into controllers

Point in case: Heat pump plants

Industry is not ready to deploy complex, untested decarbonized systems – certainly not at scale
High-profile failures (often requiring expensive retrofits) only make the problem worse



HVAC & control complexity

- 20 modes of operation
- multiple heat pumps
- storage with 5 tuning parameters
- multiple cooling towers
- **45 pages of control sequences**

See reports of failed heat pump deployment in Europe.

Cost-effective, high-efficiency HP plant with small footprint needed for dense developments have complexities that stifle large scale deployment
(https://taylorengineers.com/news-1/new-article-in-the-ashrae-journal, implementation in https://simulationresearch.lbl.gov/modelica/releases/v10.0.0/help/Buildings_Experimental_DHC_Plants_Combined.html)

New proposed ASHRAE Standard 231P (draft)

History of CDL/ASHRAE Standard 231P

- **2018**: Michael Wetter, Milica Grahovac and Jianjun Hu.
  Control Description Language.
  1st American Modelica Conference, Cambridge, MA, USA, August 2018.

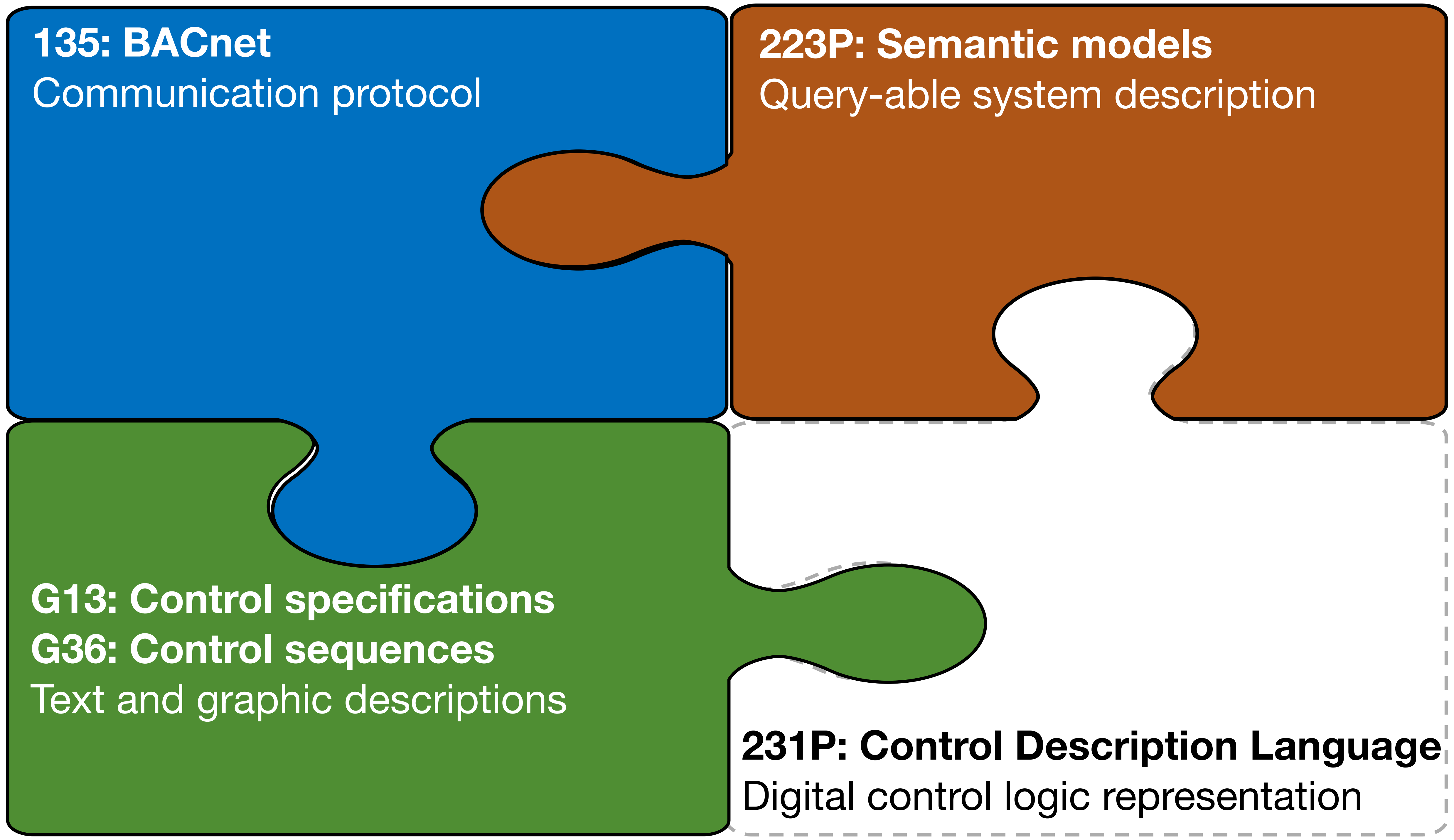
- **2020**: ASHRAE approved formation of Standards Committee 231: Control Description Language

- **2022**: Publication of digitizing control delivery.
  Michael Wetter, Paul Ehrlich, Antoine Gautier, Milica Grahovac, Philip Haves, Jianjun Hu, Anand Prakash, Dave Robin and Kun Zhang.
  OpenBuildingControl: Digitizing the control delivery from building energy modeling to specification, implementation and formal verification.
  Energy, Volume 238, Part A, January 2022.

- **2023**: First release of ctrl-flow.lbl.gov, based on Control Description Language.

- **2024**: Expected public release draft of ASHRAE Standard 231P.

ASHRAE Standard 231P fills a gap by creating a digital control logic representation



Requirements for a digital control logic specification

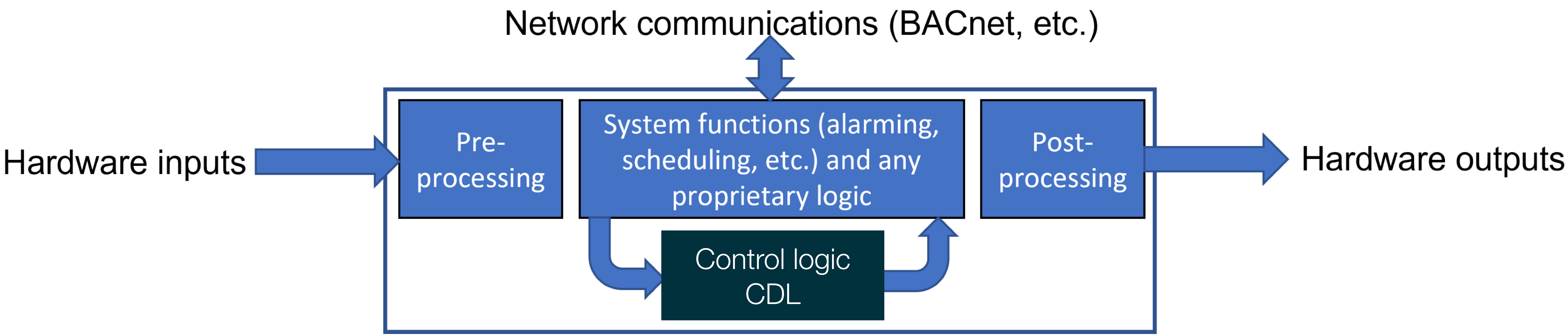
- Deterministic
- Translate-able to physical control platforms
- AND simulate-able ←→ must be both in order to bridge BEM and controls

ASHRAE Standard 231P: “Control Description Language (CDL)” ←→ a subset of another standard called Modelica.

A block diagram for implementing control logic, first described in Wetter et al., 2018.

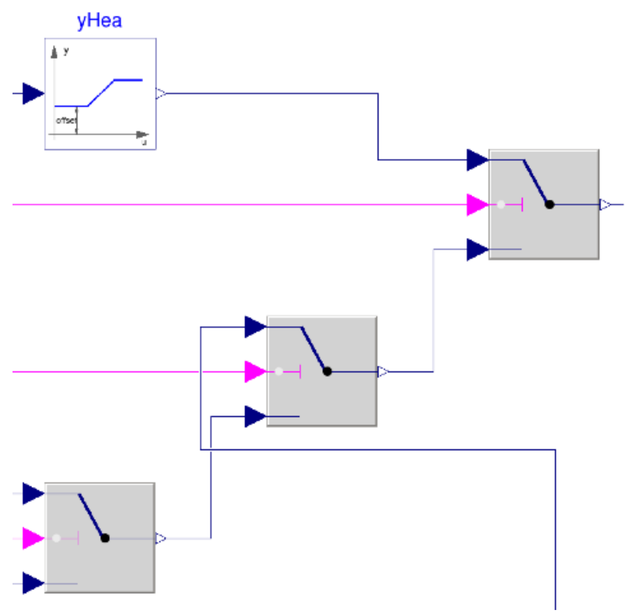
Michael Wetter, Milica Grahovac and Jianjun Hu.
Control Description Language.
1st American Modelica Conference, Cambridge, MA, USA, August 2018.

What is the scope of CDL?



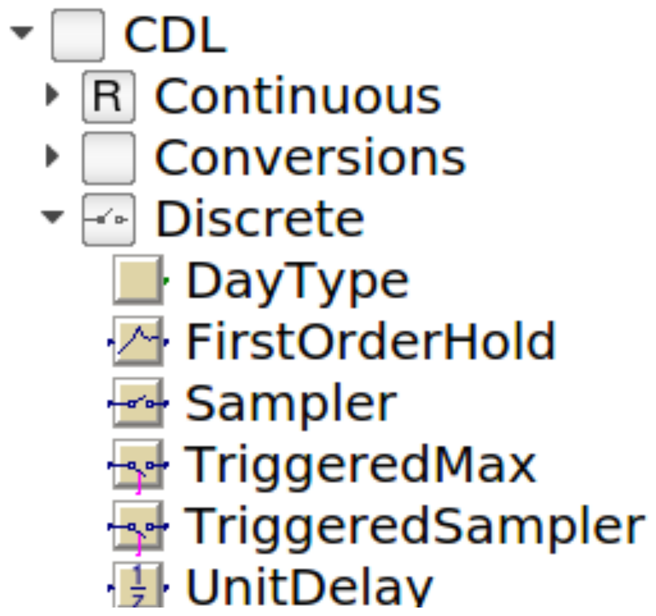
What is the Control Description Language?

A declarative **block diagram language**.

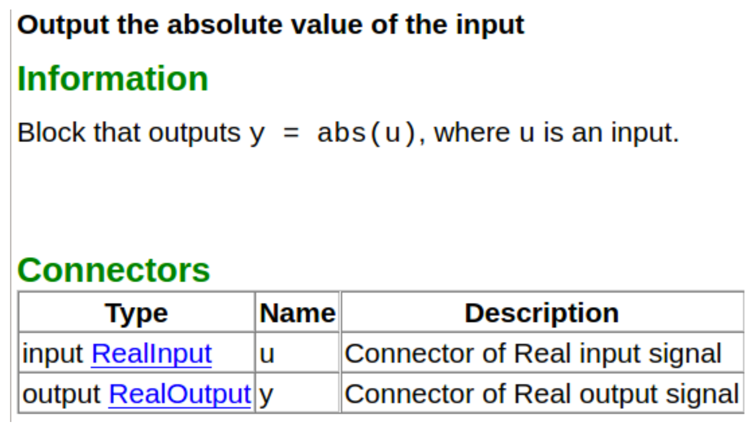


A **library** about about 150 elementary input/output blocks that should be supported, through a translator, by control providers.

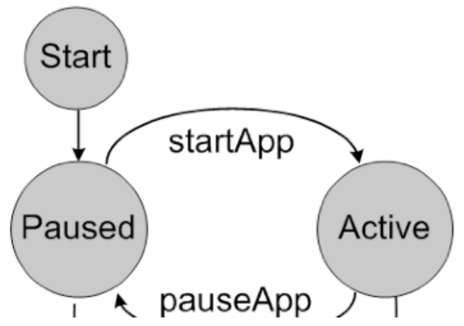
Example:
CDL has a MultiplyByParameter block with input `u`, gain `k`, and output `y = k*u`.



A **documentation syntax** for control blocks and sequences.



A **model of computation** that describes when to update signals.



A language fully compatible with the open Modelica standard, enabling **simulation** and **code generation**.

Basic elementary blocks are defined in a library that is immutable to the users (fixed by the specification).

Behavior is expressed mathematically,

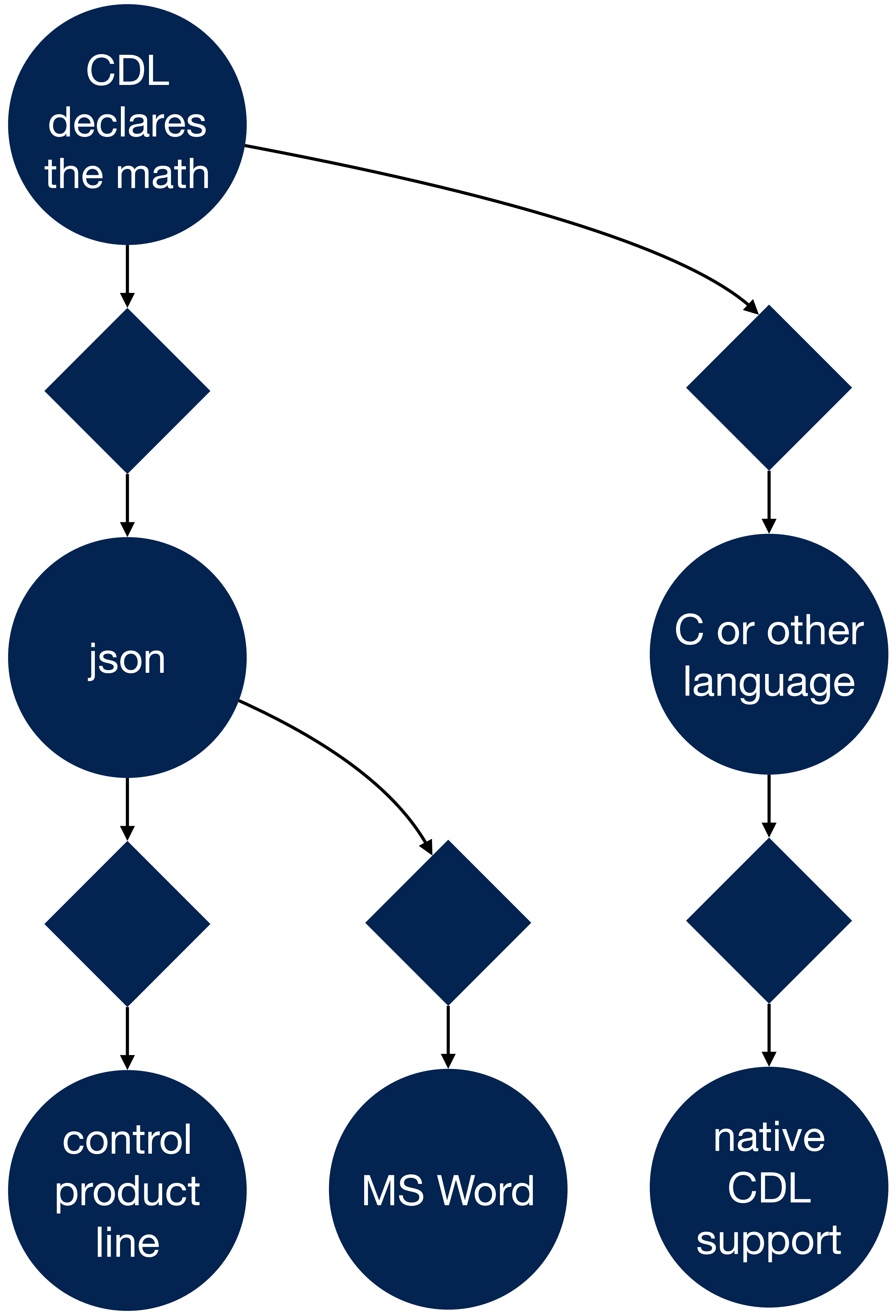
$$(p, t, u(t), x(t)) \mapsto y(t).$$

Software implementation is not part of the specification, as it should not be part of the standard.

Note: This implies that

- the implementation can be graphical or text-based.
- CDL-compliant sequences can be executed as functions (C, Java, Python, Julia, …)
- The controller product line does not need to know anything about CDL.

Control providers who support CDL need to be able to implement the same functionality as is defined by the elementary CDL blocks.



How we specified CDL

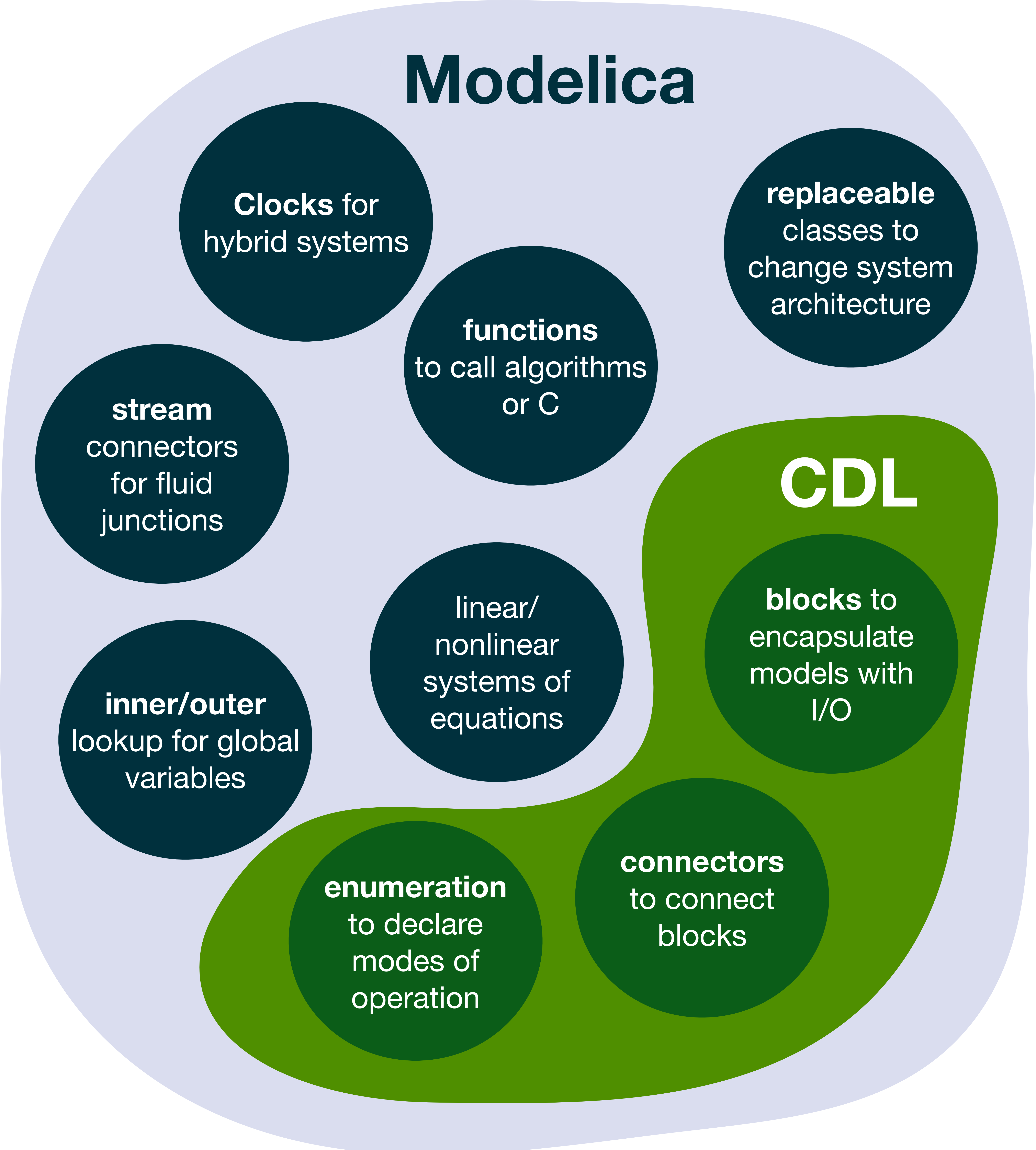
Conform to the Modelica Standard 3.3, ***but*** remove everything that is not needed to practically declare control logic and their English language documentation.

Keep it simple & easy to parse.

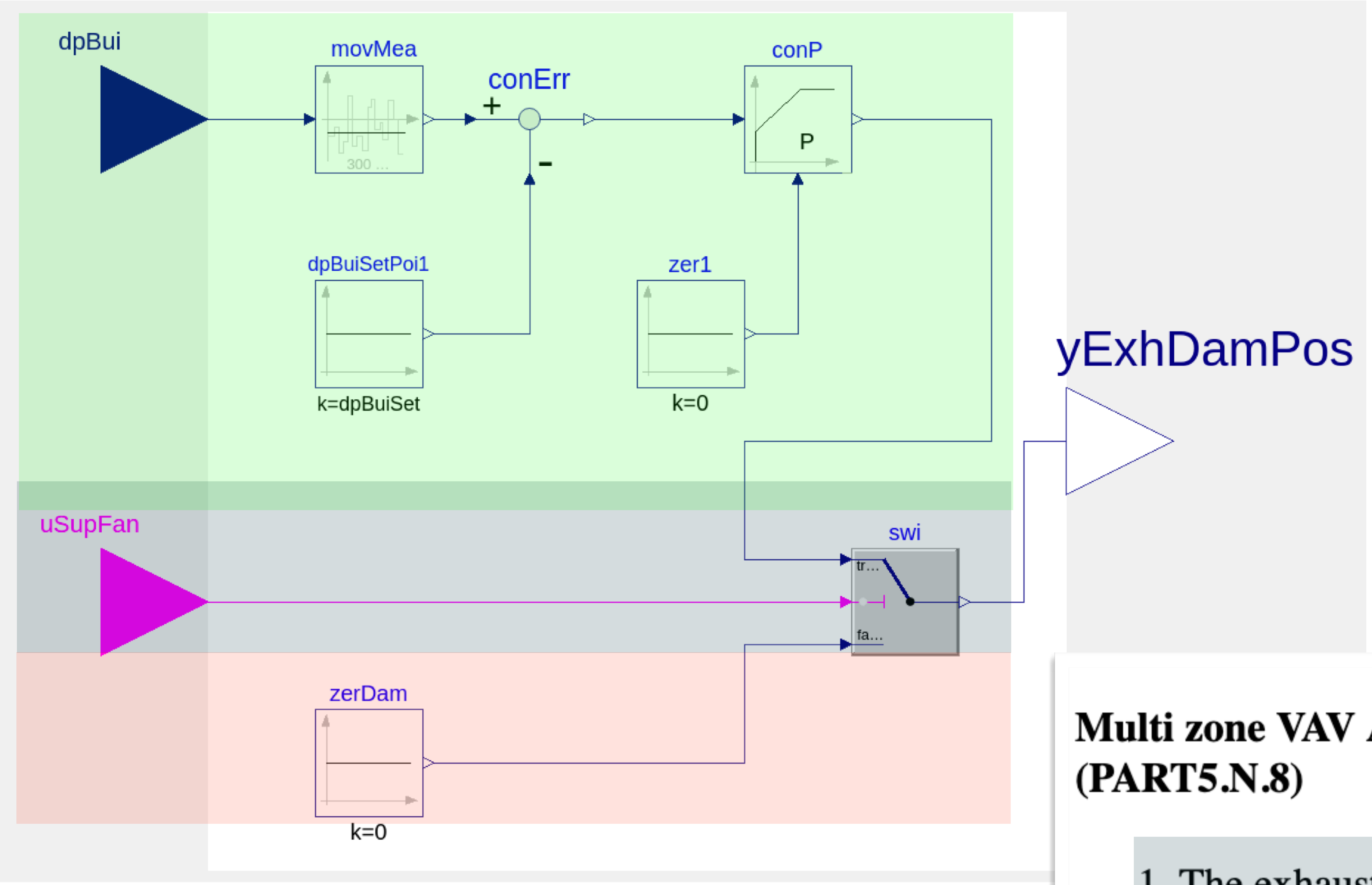
… and allow reuse of technology from the Modelica ecosystem.

Example:

No extends, replaceable, inner/outer, flow, unless all is encapsulated in an Extension Block (https://obc.lbl.gov/specification/cdl.html#extension-blocks)



Example Control Sequence in CDL

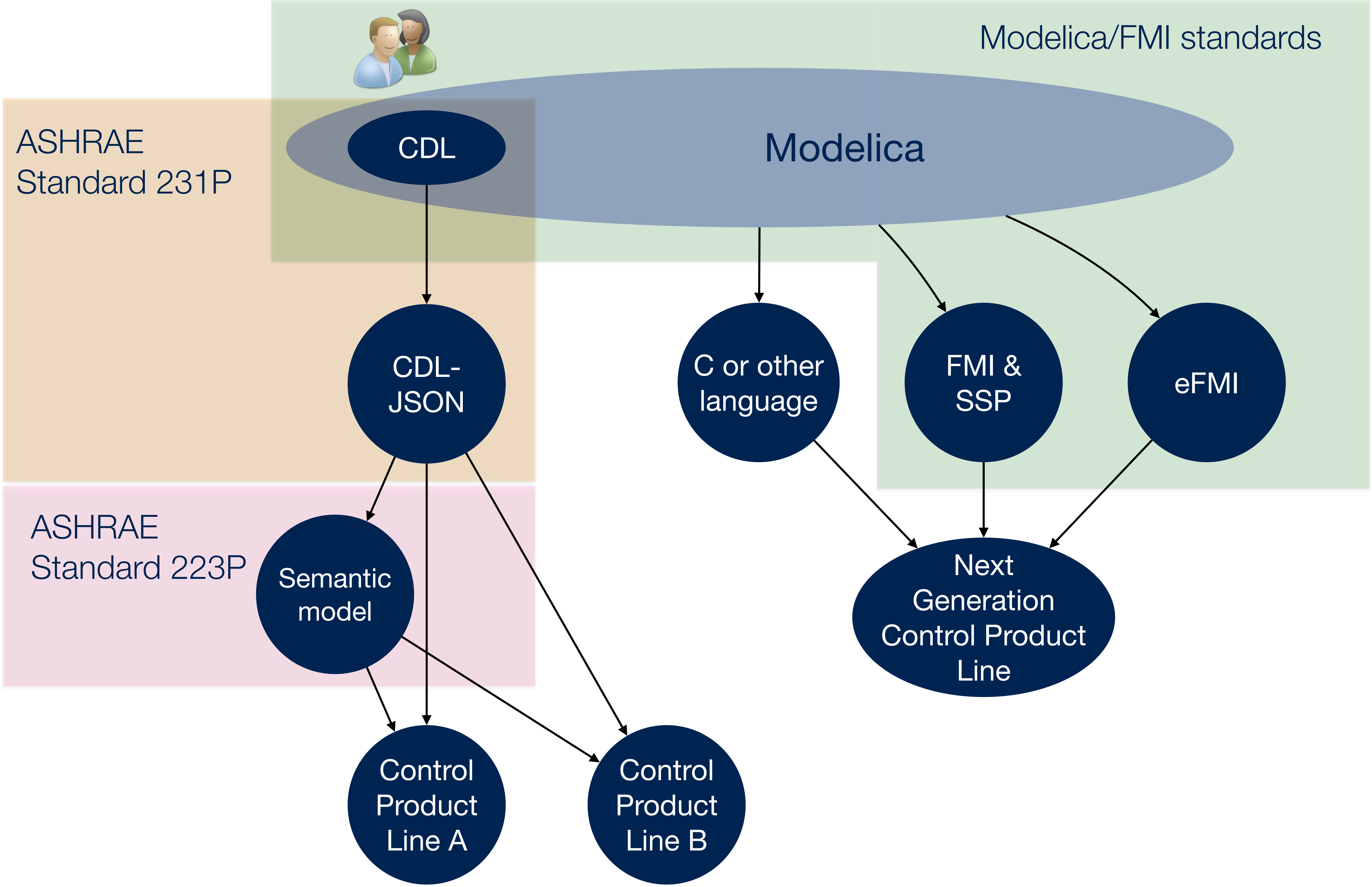


CDL block diagram view

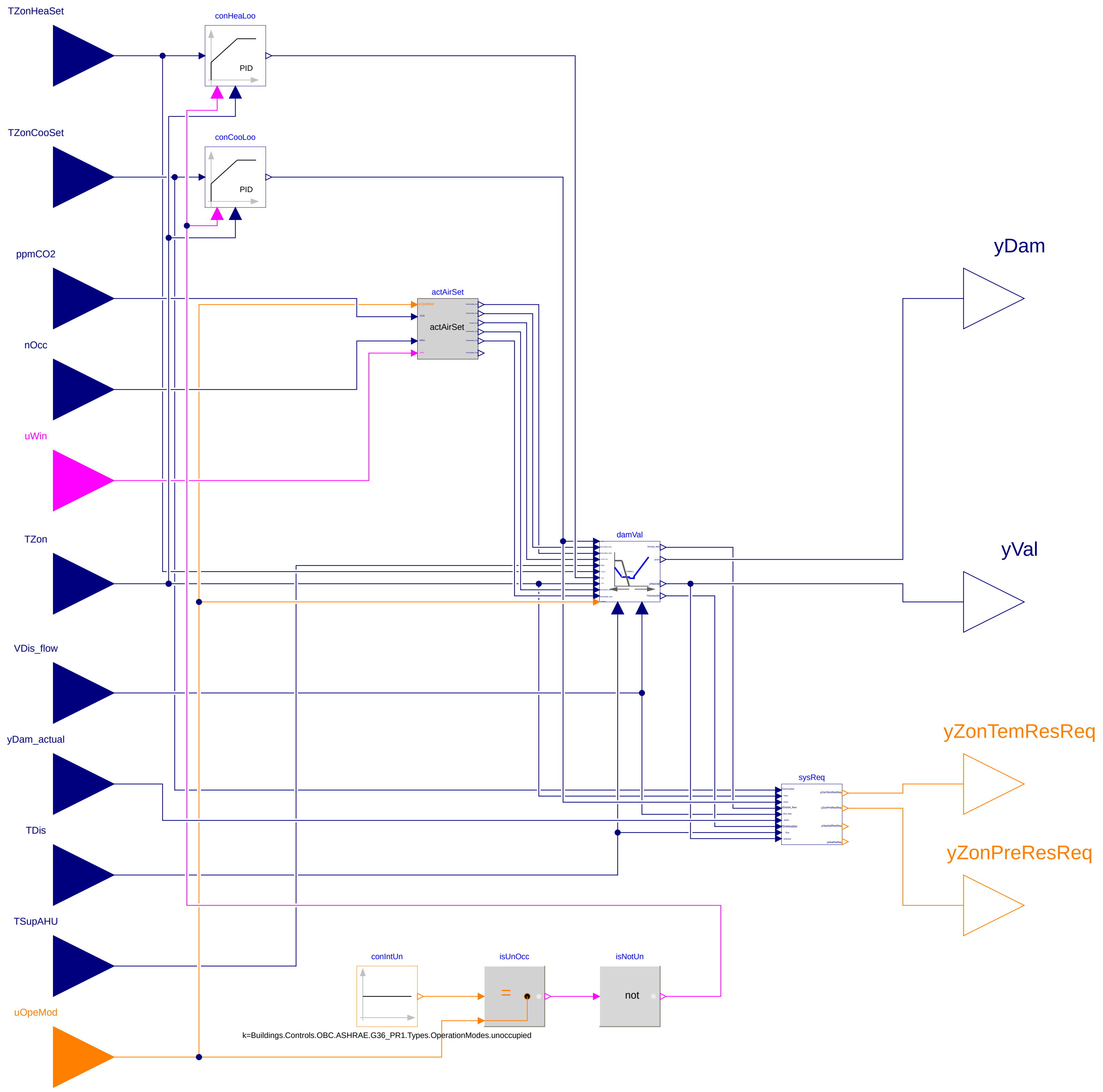
Multi zone VAV AHU: Control of actuated exhaust dampers without fans (PART5.N.8)

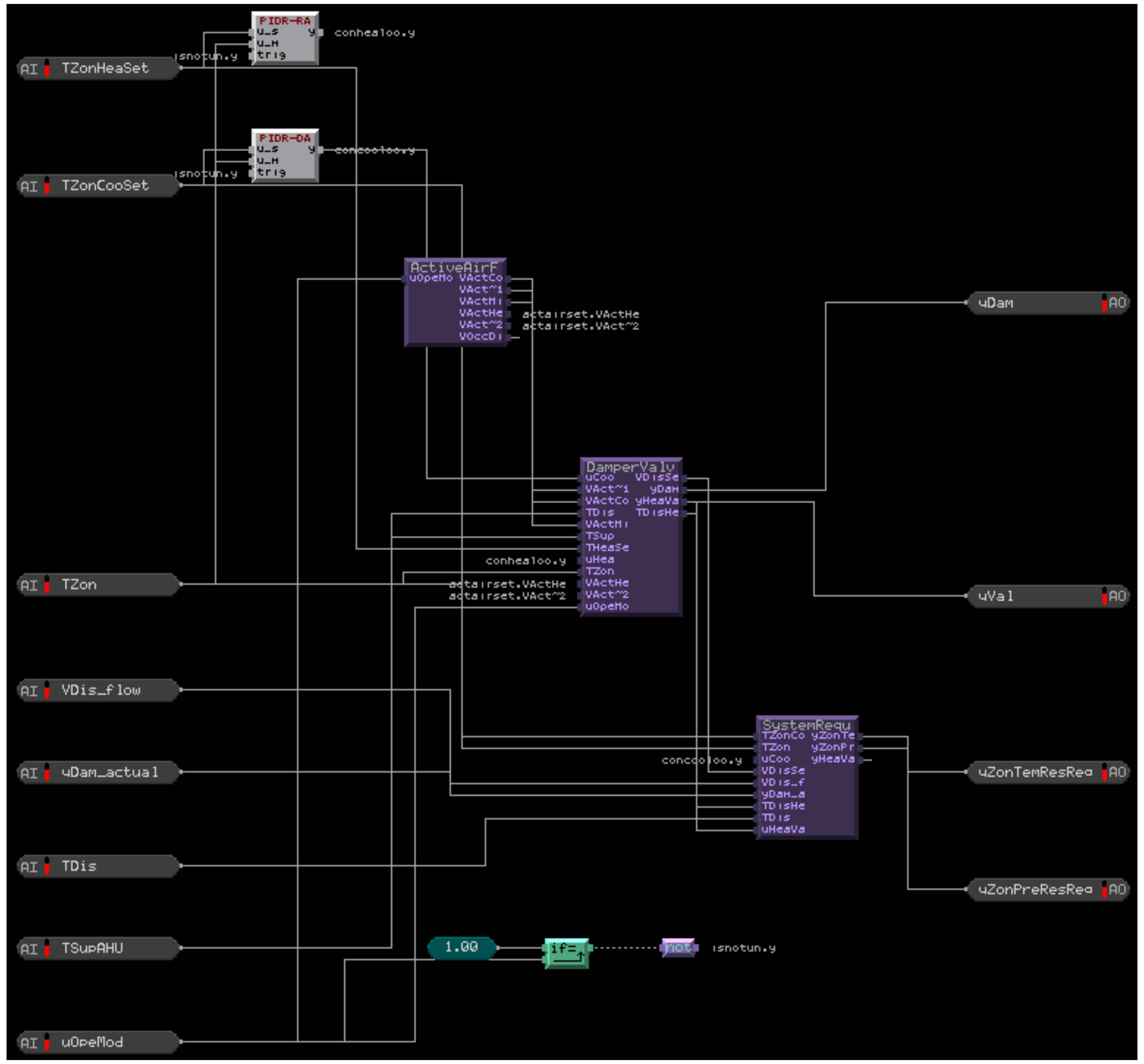
1. The exhaust damper is enabled when the associated supply fan is proven on `uFan = true`, and disabled otherwise.
2. When enabled, a P-only control loop modulates the exhaust damper to maintain a building static pressure of `dpBui`, which is by default *12* Pa (*0.05* inchWC).
3. When `uFan = false`, the damper is closed.

CDL will allow translation to existing building control product lines and use of FMI Standards



Prototyped machine-to-machine translation from simulation model to a native control product line

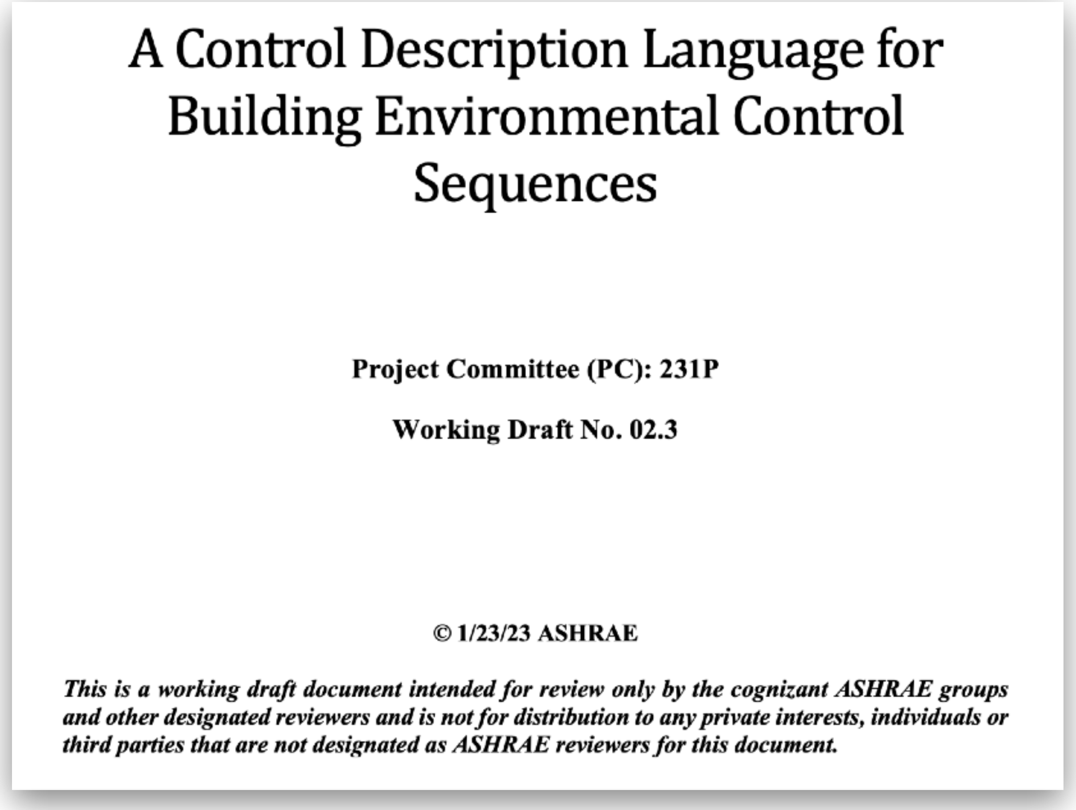




Michael Wetter, Paul Ehrlich, Antoine Gautier, Milica Grahovac, Philip Haves, Jianjun Hu, Anand Prakash, Dave Robin and Kun Zhang.
OpenBuildingControl: Digitizing the control delivery from building energy modeling to specification, implementation and formal verification.
Energy, Volume 238, Part A, January 2022.

How does digitalization of control sequences fit into larger ASHRAE, BEM and commissioning ecosystem?

Standard digital control logic representation


A Control Description Language for Building Environmental Control Sequences

Project Committee (PC): 231P

Working Draft No. 02.3

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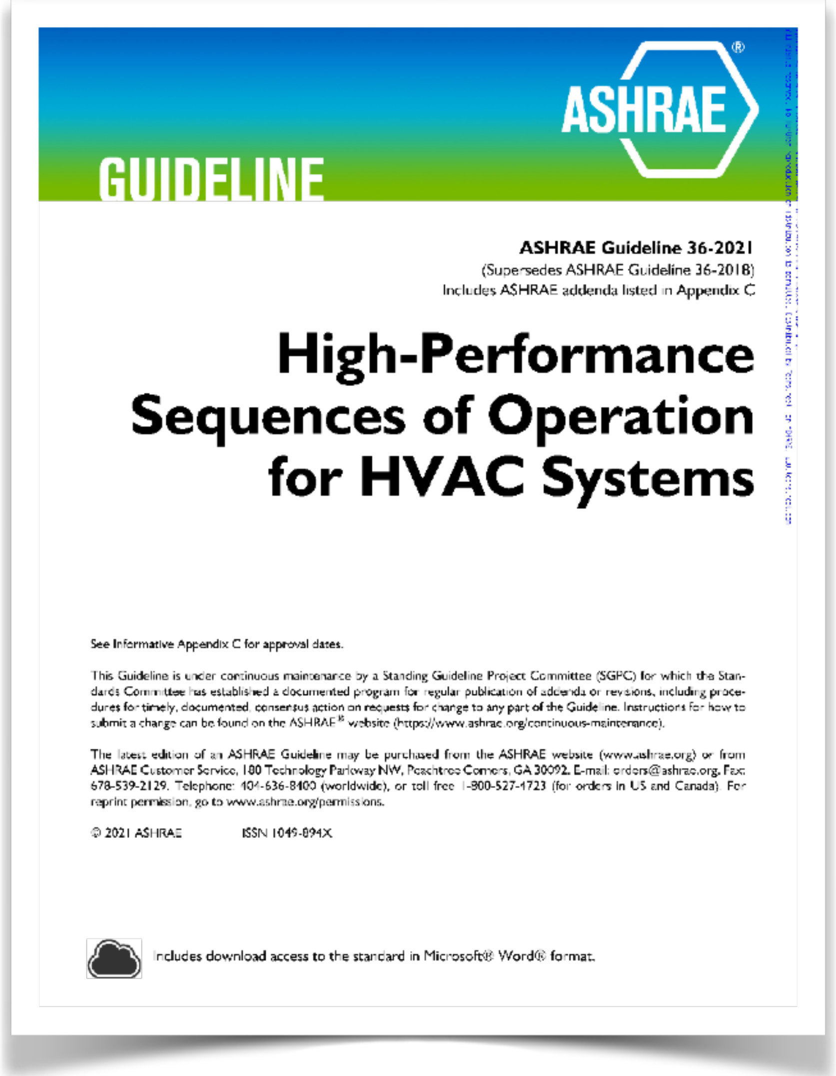
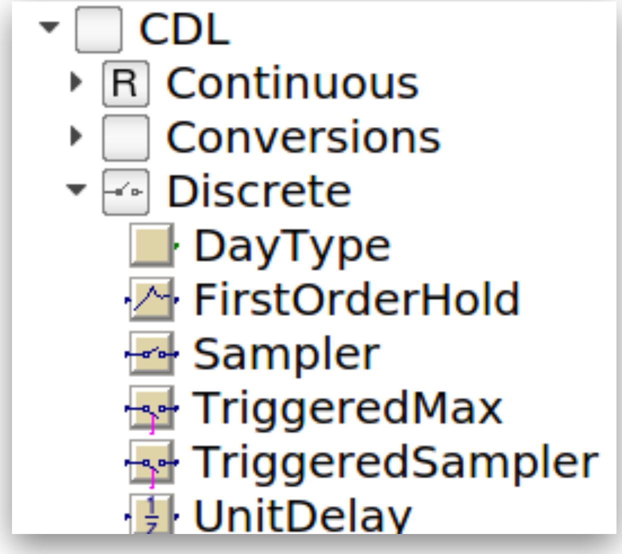
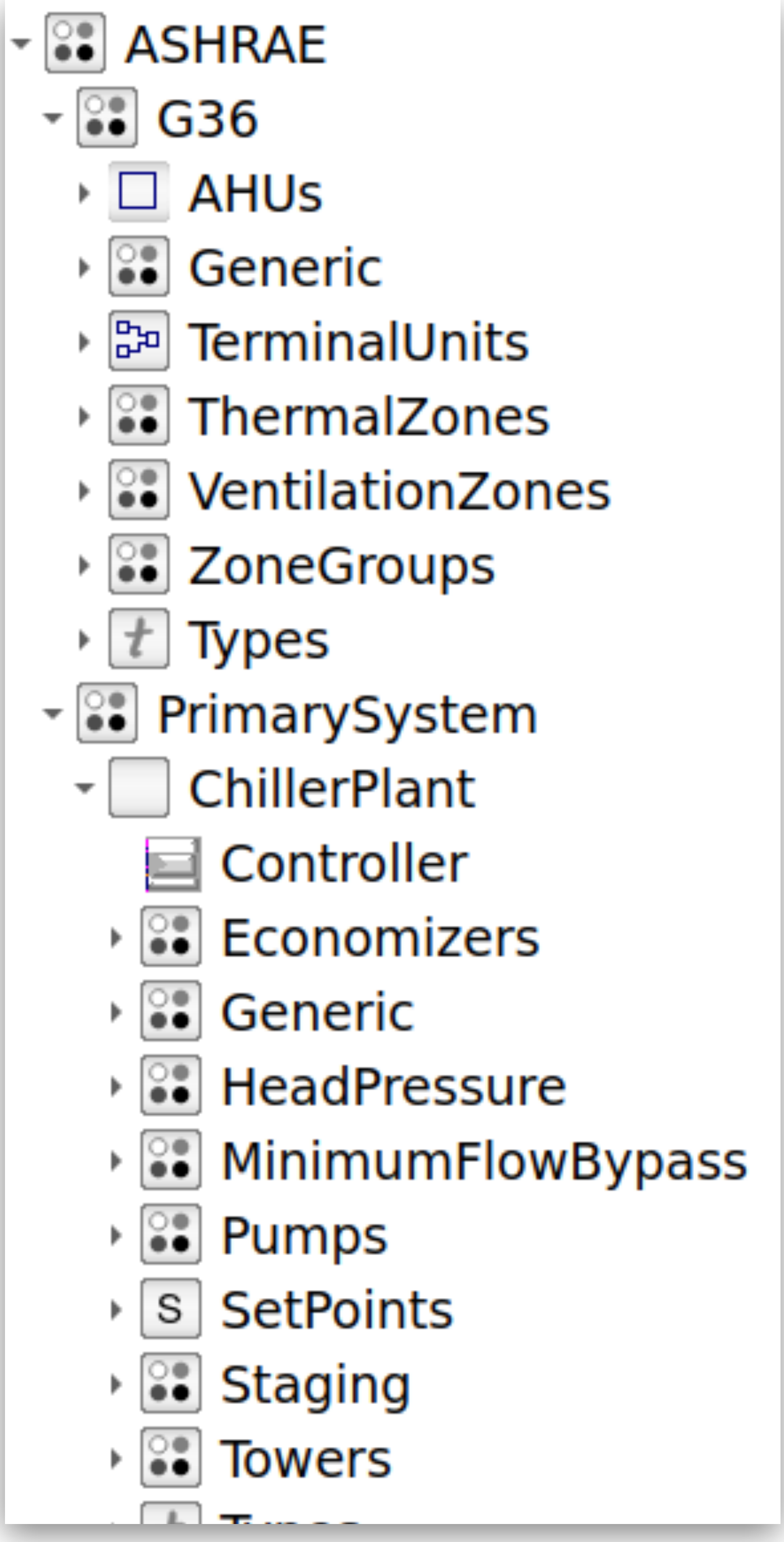
This is a working draft document intended for review only by the cognizant ASHRAE groups and other designated reviewers and is not for distribution to any private interests, individuals or third parties that are not designated as ASHRAE reviewers for this document.



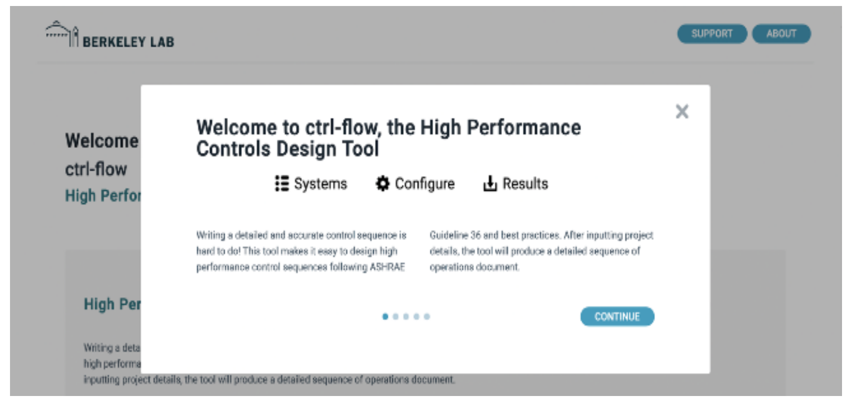
CDL sequence implementations

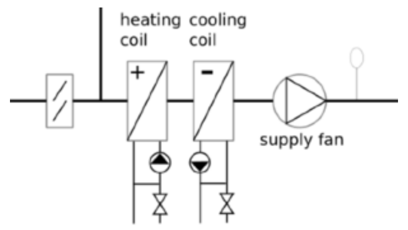




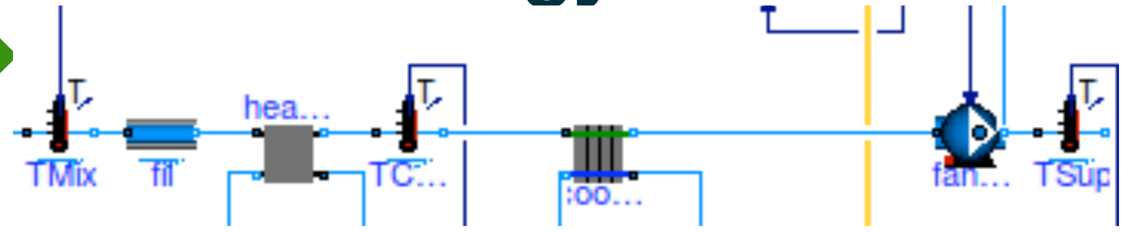
Sequence configuration

ctrl-flow

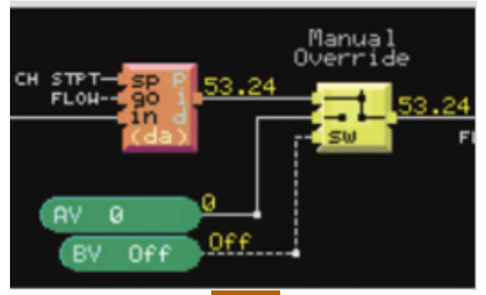




Annual energy simulation

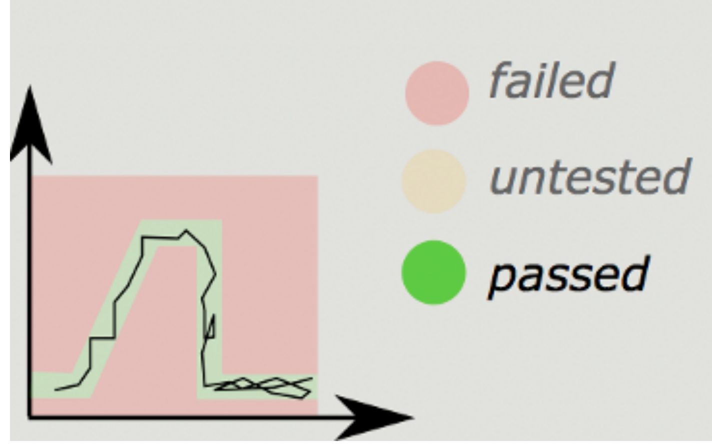


Implementation



+/-

Formal testing and/or commissioning



Sequence description (not limited to ASHRAE G36)

2024-25?: Code generation for cloud offerings or embedded controller

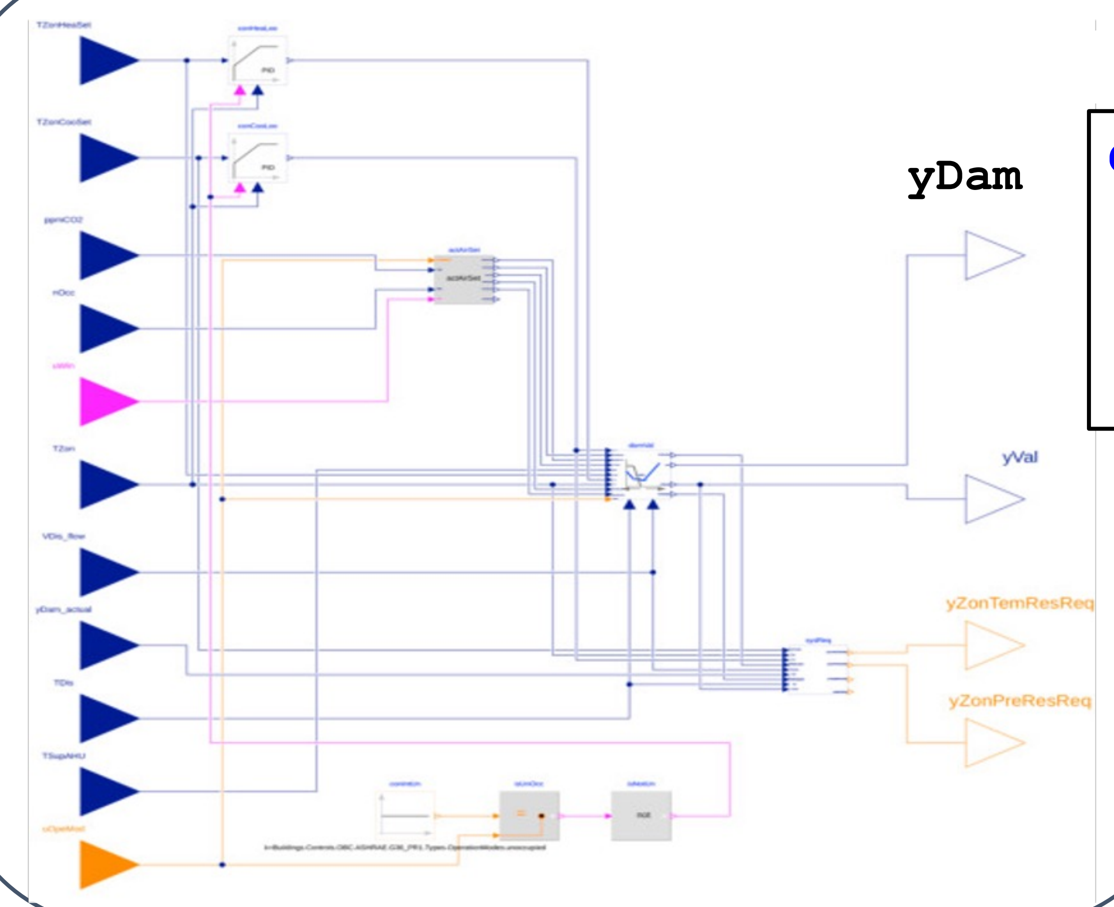
Legend

- Implemented
- Prototyped
- Designed/specified

Integrating standards for robust control digitalization

Combining control logic and semantic models

Generic VAV terminal box control logic (CDL)



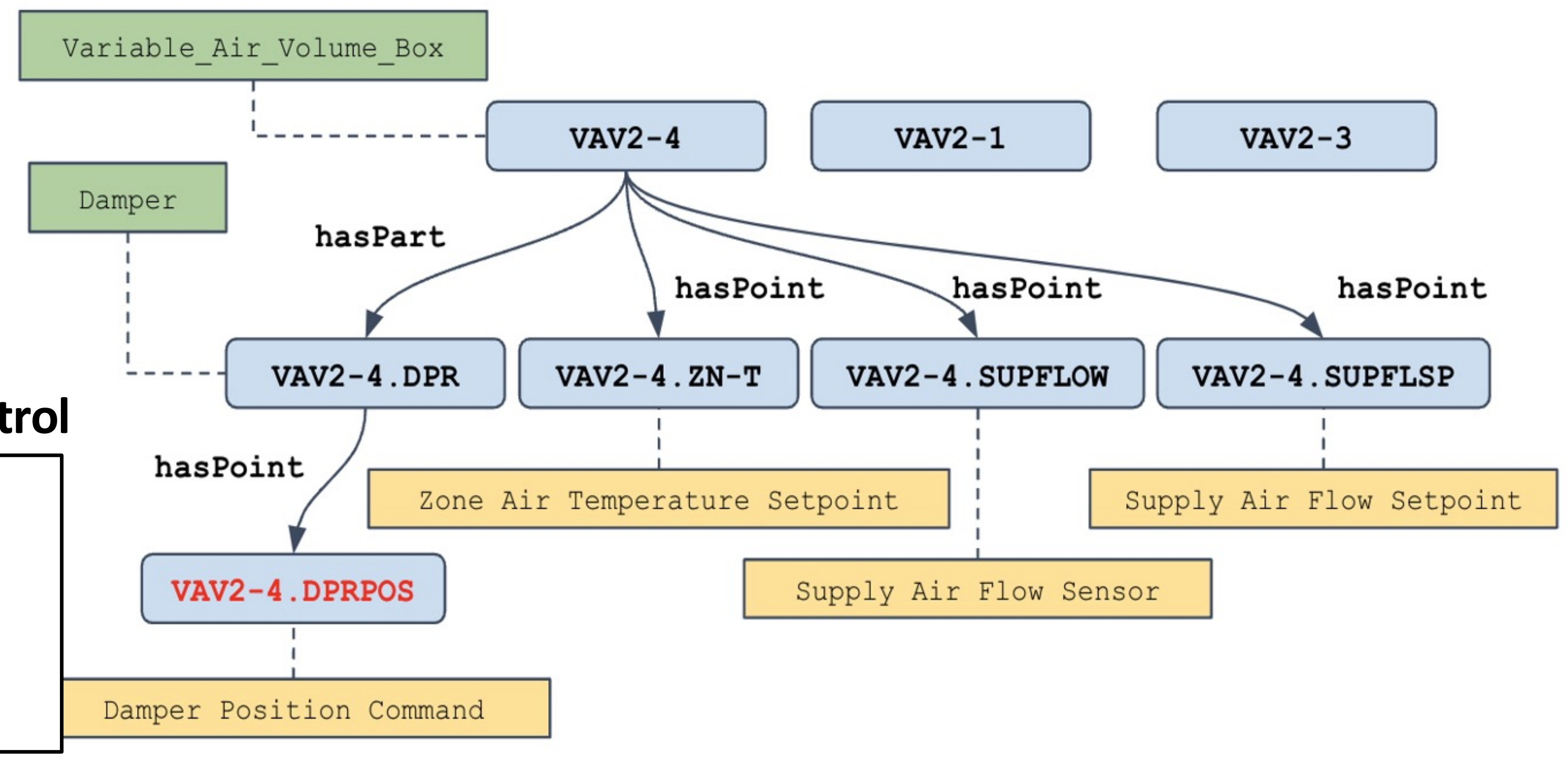
Modelica

CDL for yDam VAV Damper Position Control

```
CDL.Interfaces.RealOutput yDam (
  final min=0, final max=1, final unit="1")
  "Signal for VAV damper"
  annotation (__semantic(standard="brick"
    "a brick:Damper_Command ."));
```

Building-specific semantic model (Brick)

Brick



brick for VAV2-4.DPRPOS Damper Position Control

```
:VAV2-4 a brick:VAV;
   brick:hasPart :VAV2-4.DPR
:VAV2-4.DPRPOS a brick:Damper_Command;
   brick:isPointOf :VAV2-4.DPR
   bacnet:object-name "DMP_CM_2-4" .
```

1

SPARQL query for finding VAV boxes in Brick model

```
SELECT ?vav WHERE {
   ?vav a brick:VAV ;
}
Result: {"VAV2-4", "VAV2-1", "VAV2-3"}
```

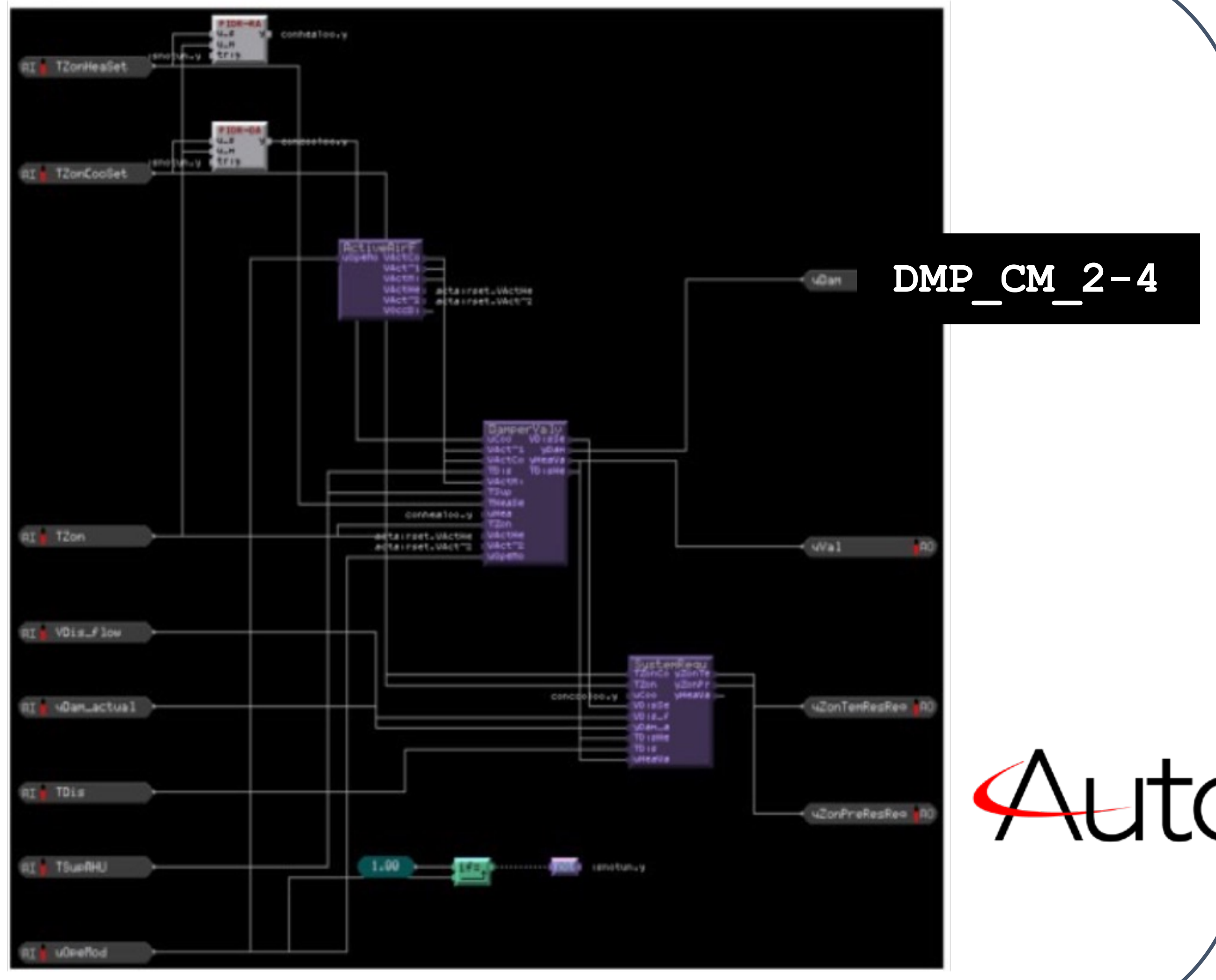
2

SPARQL query for finding BACnet point name of VAV2-4 Damper Position control

```
SELECT ?dprpos ?point WHERE {
   ?dprpos a brick:Damper_Command ;
      brick:isPointOf+ :VAV2-4 ;
      bacnet:object-name ?point .
}
Result: {"VAV2-4.DPRPOS", "DMP_CM_2-4"}
```

3

Building-specific VAV box control logic (ALC)



Automated Logic

Amir Roth, Michael Wetter, Kyle Benne, David Blum, Yan Chen, Gabriel Fierro, Marco Pritoni, Avijit Saha and Draguna Vrabie.
Towards Digital and Performance-Based Supervisory HVAC Control Delivery.
ACEEE Summer Study on Energy Efficiency in Buildings, p. 3-528--3-543, Pacific Grove, CA, August, 2022.

Questions

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References

ctrl-flow.lbl.gov

https://obc.lbl.gov/specification/cdl.html

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