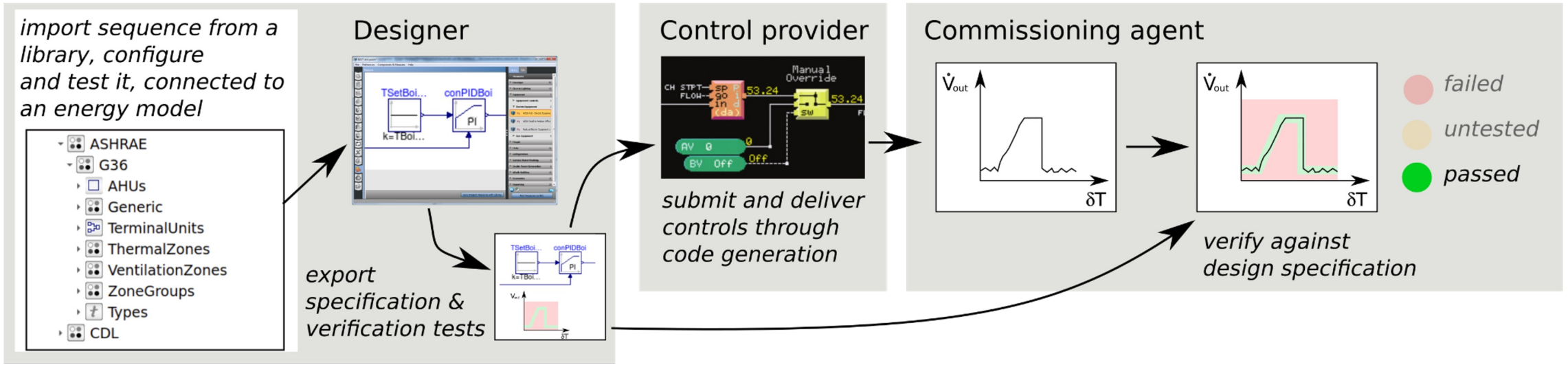
OpenBuildingControl II



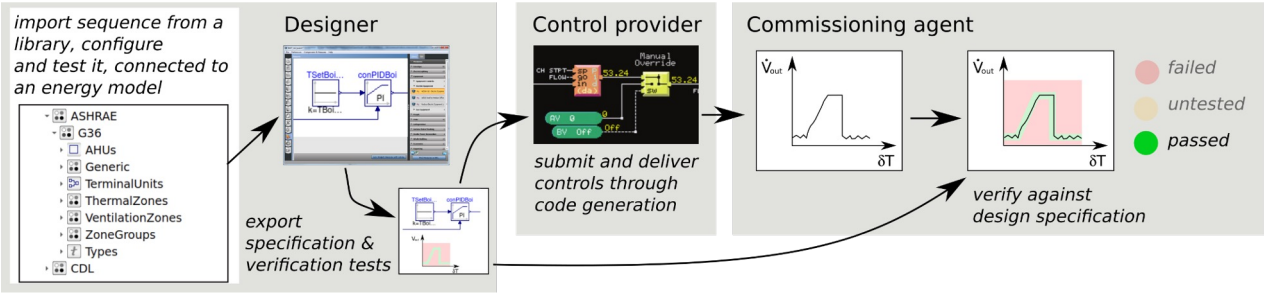
LBNL, PNNL, Building Intelligence Group, Taylor Engineers, Solamen, DEPT
Michael Wetter, PhD
mwetter@lbl.gov
WBS 3.2.6.69

Project Summary

Objective and Outcome

High-performance control sequences like those in ASHRAE G36 can reduce HVAC energy use by 30%, but are rarely implemented because they are complex and today's control delivery process is largely manual.

The Open Building Control project aims to realize the potential of advanced control by establishing a digitized control delivery process, with formal end-to-end quality assurance.



Digitized control delivery with formal end-to-end quality assurance, based on open standards.

Team and Partners

PNNL: Sequence development and verification.

Building Intelligence Group: Industry outreach, chairing ASHRAE Standard 231P.

Taylor Engineers: Industry feedback, control sequence guidance.

Solamen: Sequence dev., tool development.

DEPT: Control sequence selection tool implementation.

Stats

Period: FY23-26 (Phase I 2016-20, Phase II: 20-22)

DOE budget: $625k/yr, Cost Share: Industry via ASHRAE 231P; Phase I: CEC $1.3M (16-20); Carrier $1M via CRADA

Milestone 1: Q1: translator to export sequences in ASHRAE 231P based on BEM templates

Milestone 2: Q2: ctrl-flow sequence selection tool

Milestone 3: Q3: Public review draft ASHRAE 231P

Problem

Today's control design, implementation, and commissioning process is manual, labor-intensive, ambiguous and error-prone. It was not designed for high-performance HVAC, much less for more complex decarbonized HVAC.

Designer

- Producing sequence specs is tedious & error-prone.
- No tools to judge how good a sequence is.
- Copy/paste sequences.

Controls Contractor

- Interpreting verbose sequences is tedious & error-prone.
- Tight schedule & budget.

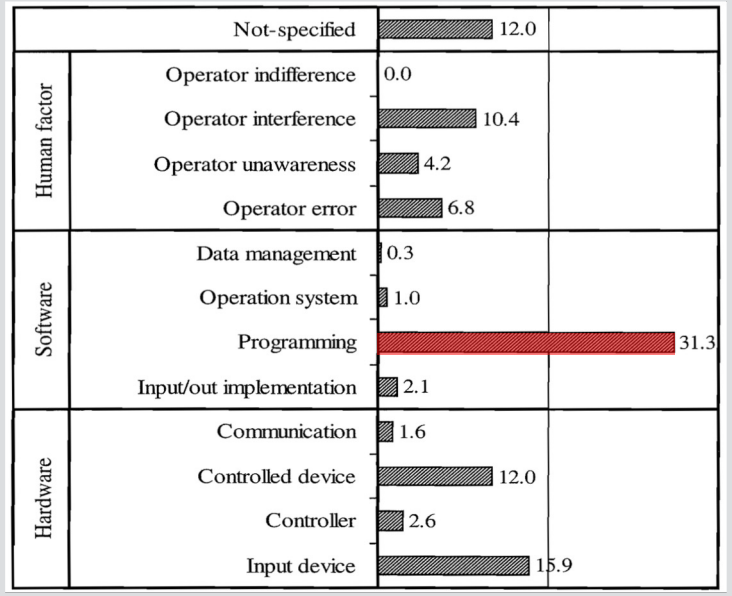
Cx agent & operator

- Verification is slow & limited.
- Poorly documented.

8. When any condenser water pump is proven on, CWRT shall be controlled to CWRTsp by setting CWST setpoint, CWSTsp, 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

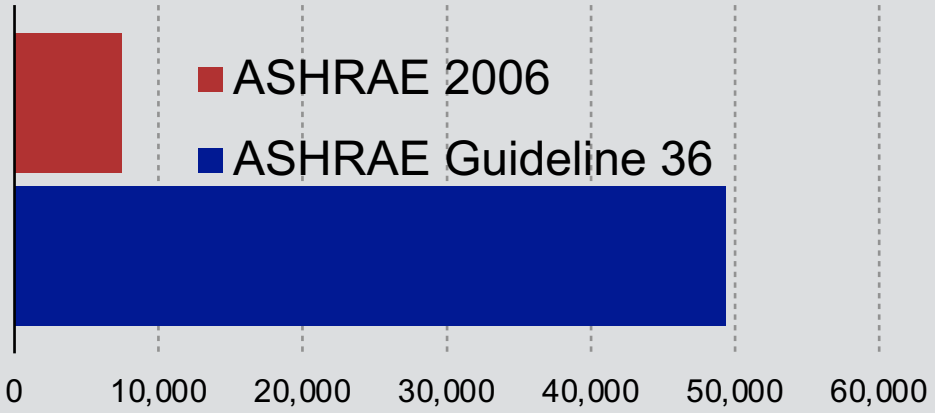
Problem

2002



Control-related problems (Ardehali, Smith 2002).

2018



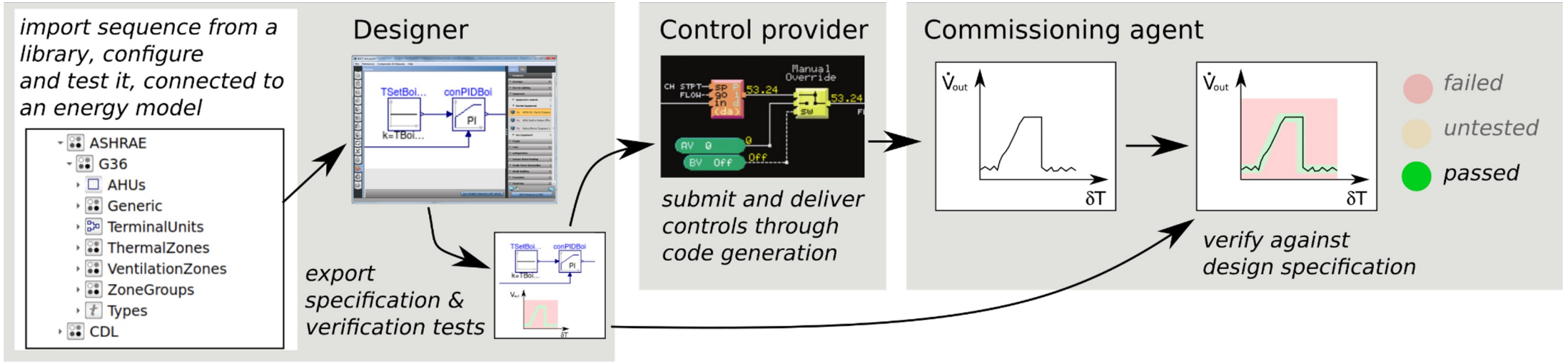
# of lines of code for a multi-zone VAV control sequence using CDL

2025 ?

- Heat pump plants
- Grid responsive predictive control
- Control that optimizes across energy carriers
- Digital twins

We will not be able to control these new, more complex systems using workflows that have shown to not work well even for simpler controls.

Approach – What is novel? Why will it work?



1. Developed a digitized control delivery process with formal end-to-end verification
2. Developed a formal language for control logic, the Control Description Language (CDL) that supports both direct simulation and direct implementation, bridging the worlds of system design and performance evaluation (BEM) and control.
3. Codifying CDL in an ASHRAE standard (231P) to allow broad adoption.
4. Developed an electronic catalog of control sequences, including ASHRAE G36 in CDL.
5. Developed tools to assist designers: ctrl-flow and Modelica Buildings Library.

Alignment – Impact

- **Building owners and operators**
  - **Reduced cost ($9.3bn/yr savings [Wetter+, 2021]) and carbon**
  - **Improved operation and occupant satisfaction**

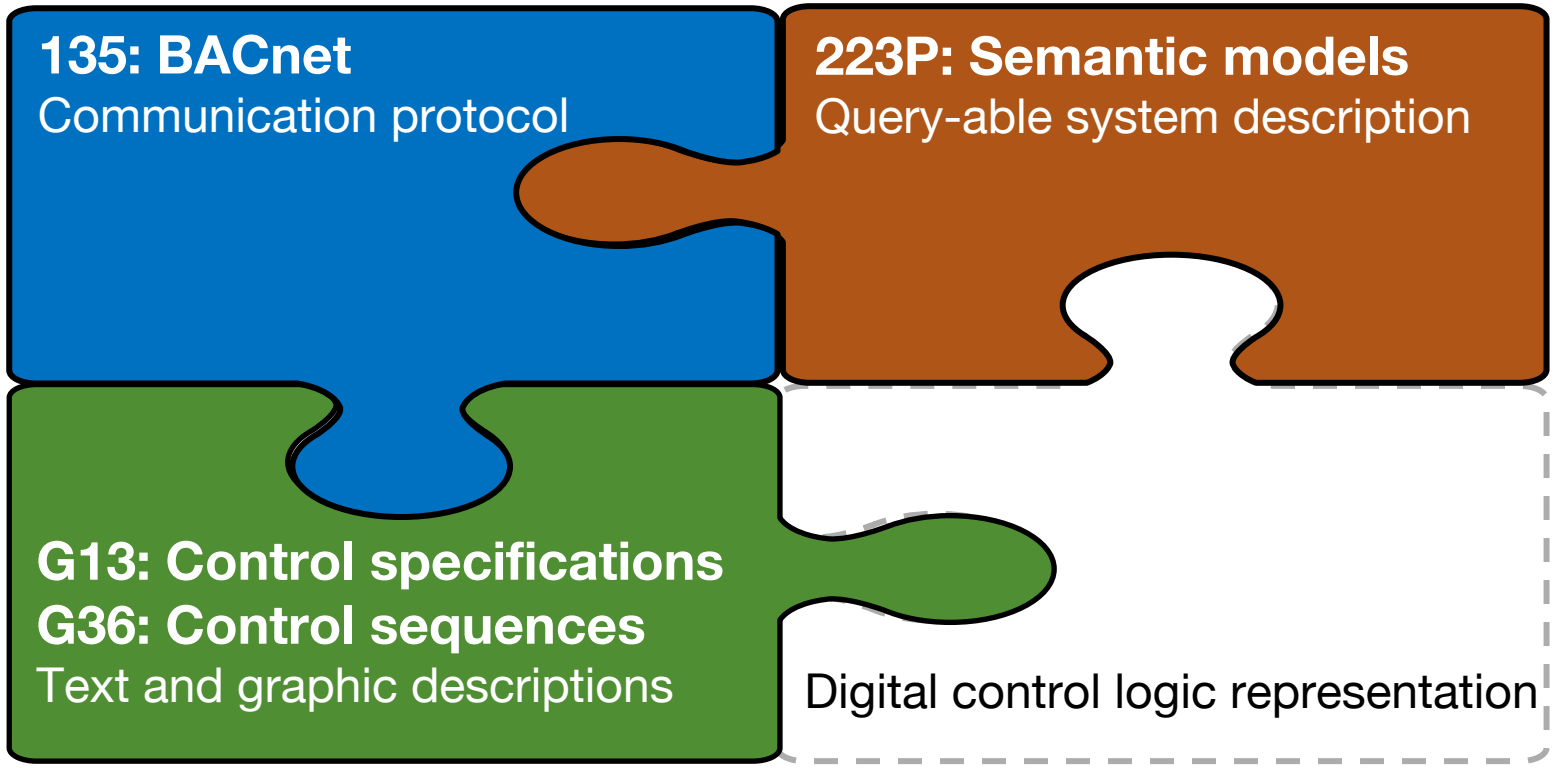
- **Controls industry**
  - **Language** to share, simulate and implement best in class sequences for heat pump plants and GEB
  - **Cheaper, faster** workflow from design to commissioning
  - **De-risked** deployment of high performance controls

- **Mechanical engineers**
  - Reduced time and risk ← configure sequences from vetted catalog

- **Control providers and system integrators**
  - Reduced time and costs ← logic translated from mechanical engineer's specification

- **Commissioning agents**
  - Reduced time and cost ← clear specification for highly automated formal control verification

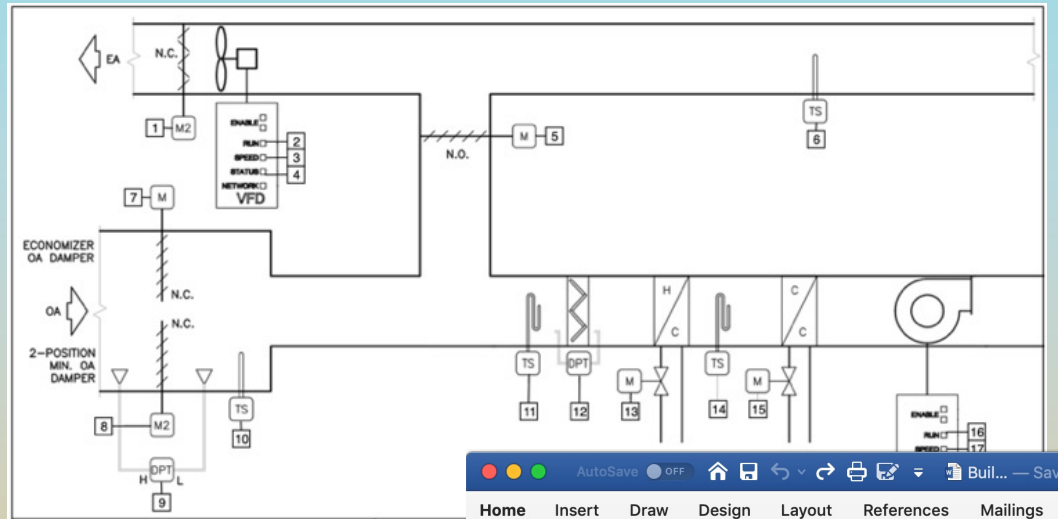
Approach – The missing (ASHRAE standard) piece

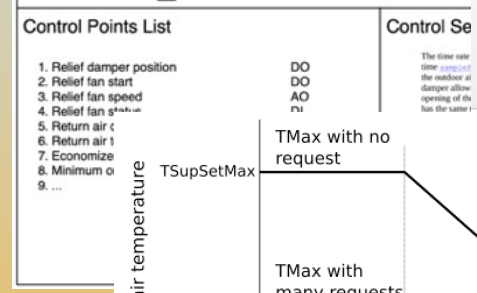


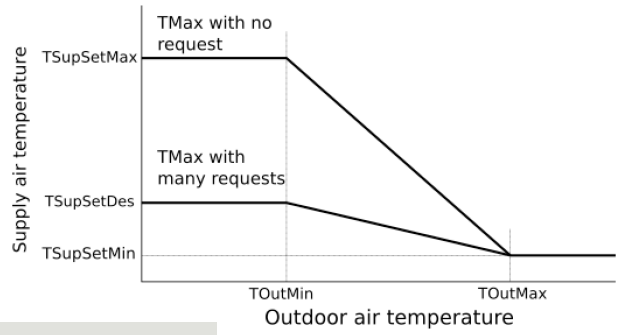
- **Requirements for a digital control logic specification**
  - Deterministic
  - Translate-able to physical control platforms
  - AND simulate-able ← must be both in order to bridge BEM and controls
- **ASHRAE 231P: "Control Description Language (CDL)" ← a subset of Modelica**

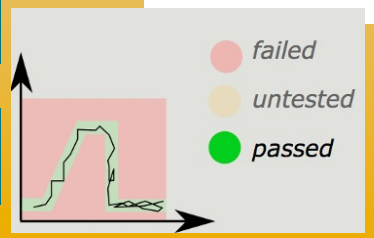
Approach: OBC process will create all necessary products

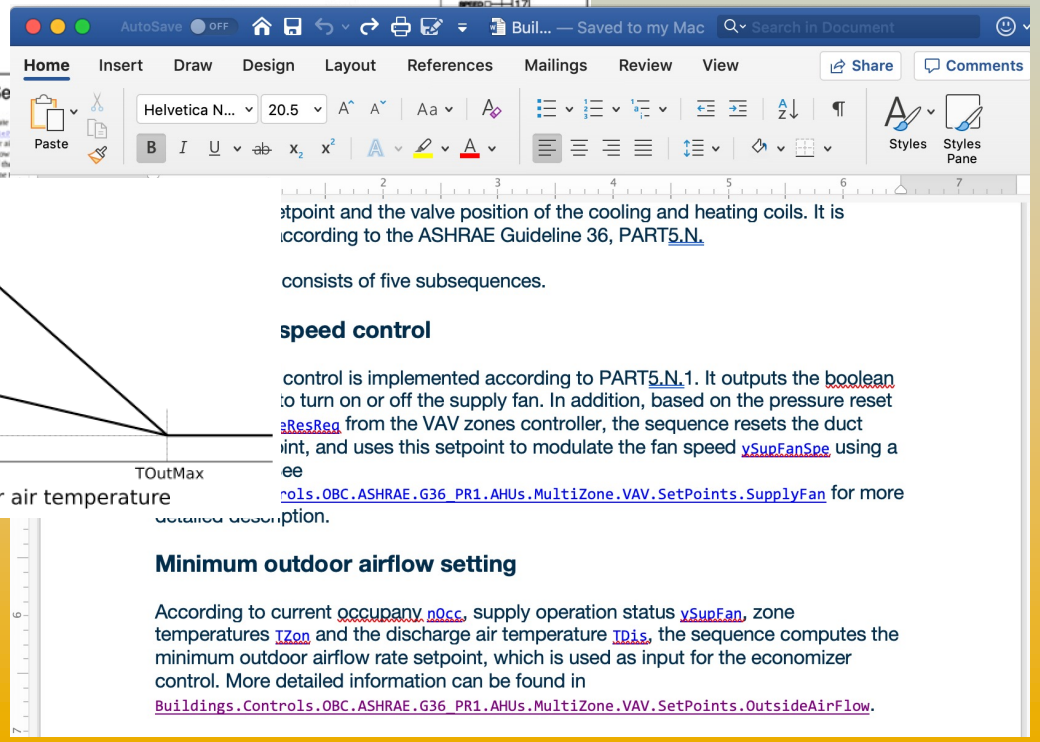
- ASHRAE Standard for control logic
- Catalog of control sequences
- Detailed sequence **description**
- Control **points list**
- **Control diagrams**
- **Plant schematics**
- **Sequence specification for translation to product lines**
- **Test criteria for commissioning**





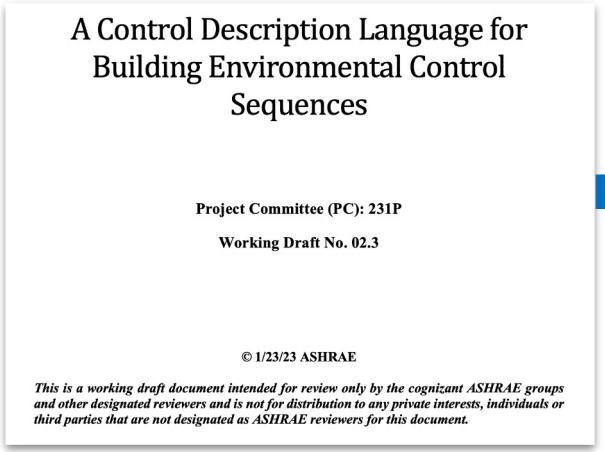






Approach – Digitized ecosystem and workflows

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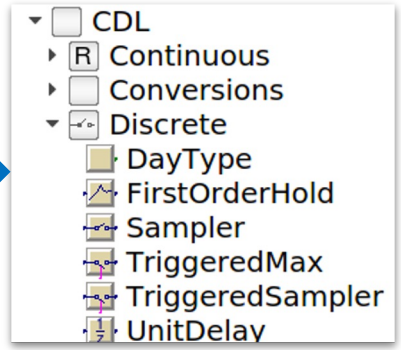
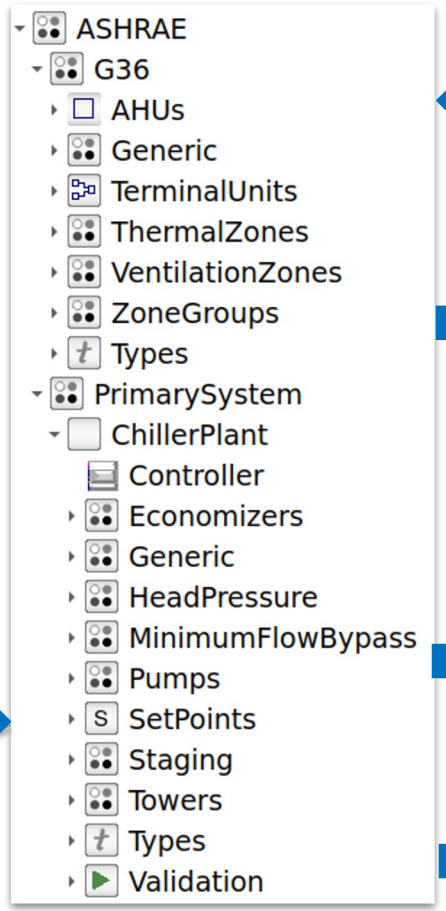
This is a working draft document intended for review only by the cognizant ASHRAE groups and other designated reviewers and is not for distribution to any private interests, individuals or third parties that are not designated as ASHRAE reviewers for this document.

Modelica Buildings Library

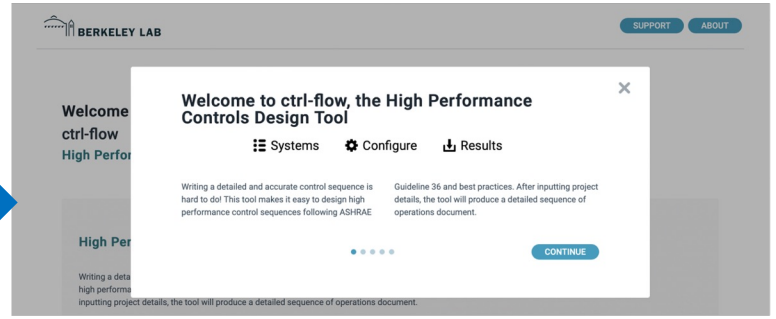
CDL implementations of sequences





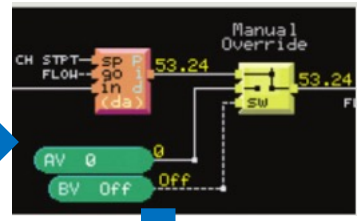
ctrl-flow

Sequence selection and editing

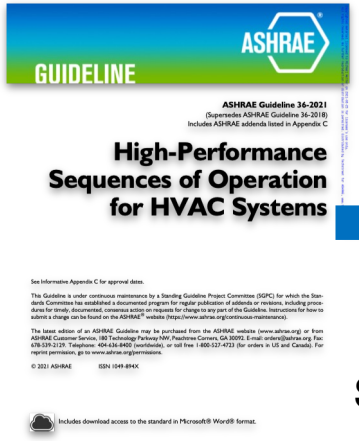


Spawn of EnergyPlus

Annual energy simulation

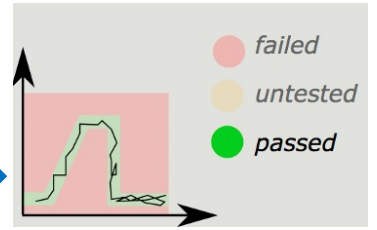


Implementation



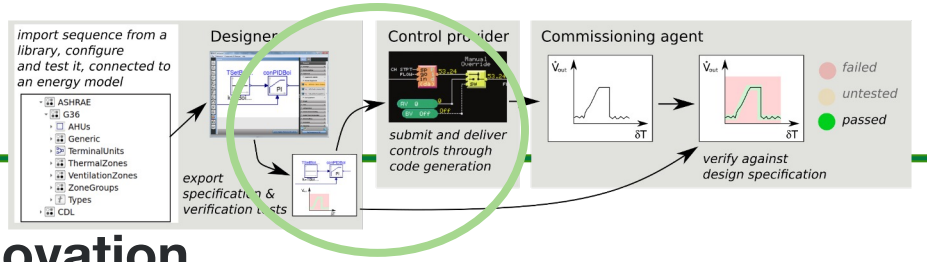
Sequence specs and descriptions

+/-



Commissioning

Approach – Deployment



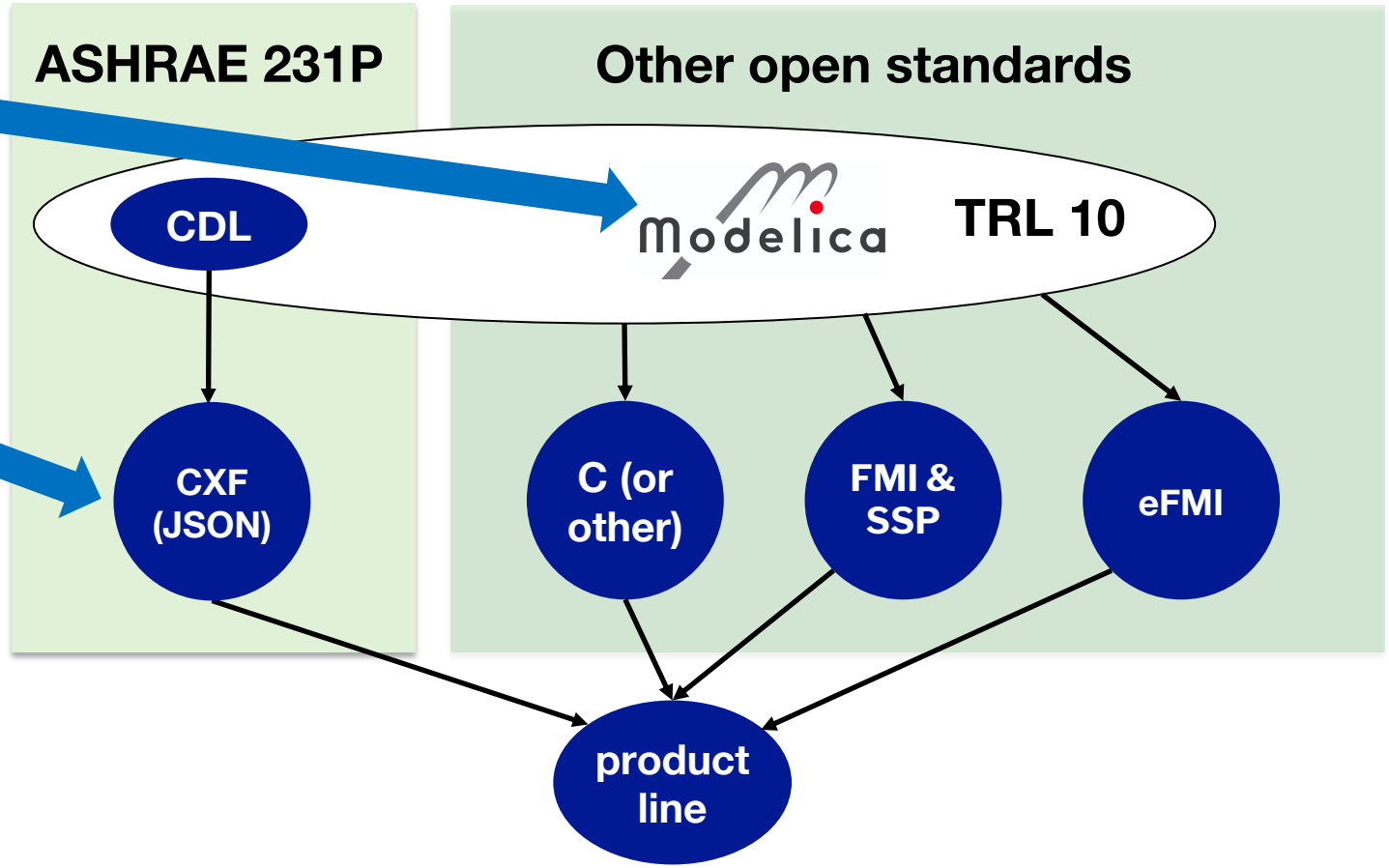
- **Meet control industry where they are while enabling innovation**
  - Accommodates today's building control product lines
  - Enabling model-based design ← requested by some control providers

TRL 6

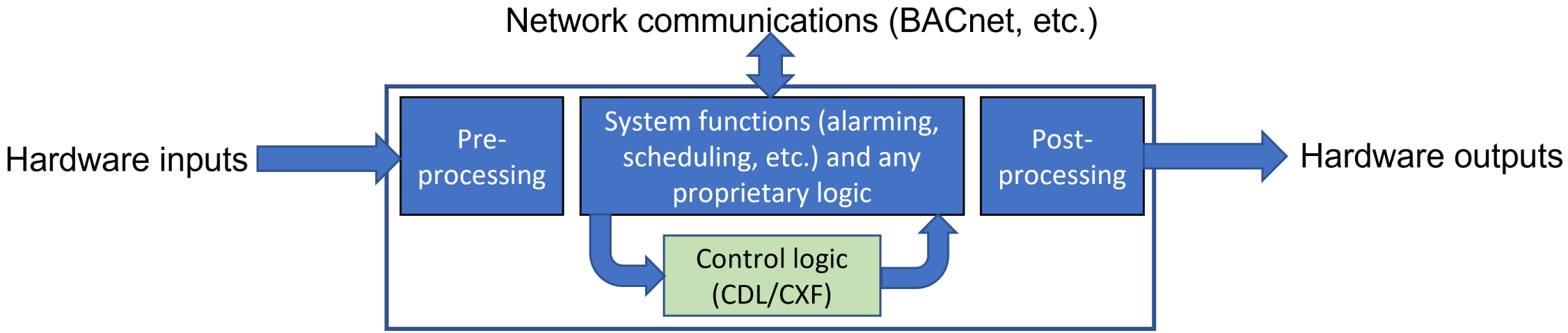
Terminal unit controller:
8,000 lines of CDL

TRL 4

Terminal unit controller:
100,000 lines of CXF (JSON)



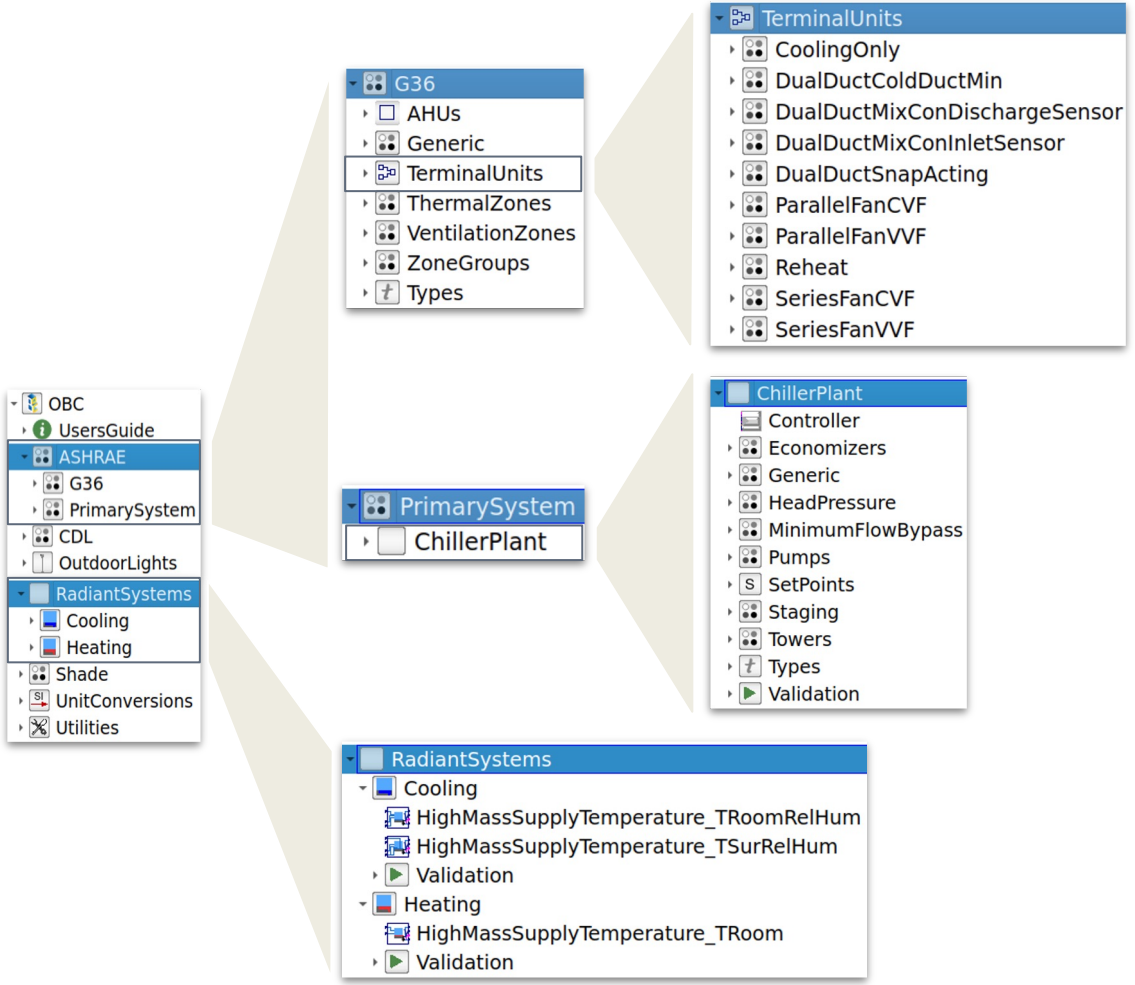
Progress - ASHRAE 231P “Control Description Language”



- **An ASHRAE Standard for interoperable exchange of control programming logic**
- Three main components
  - “Control Description Language” (CDL) in Modelica: for design, simulation and testing
  - “Control eXchange Format” (CXF) in JSON: for import and export in building automation products
  - “Elementary Blocks”: 140 computational blocks used by CDL and CXF
- 24 members (owners/operators, control system designers, system integrators, researchers).
- Draft standard for public review expected in 2023
- Process has been invaluable in surfacing the challenges involved in control system design and exposing the differences between simulation and delivery of control systems

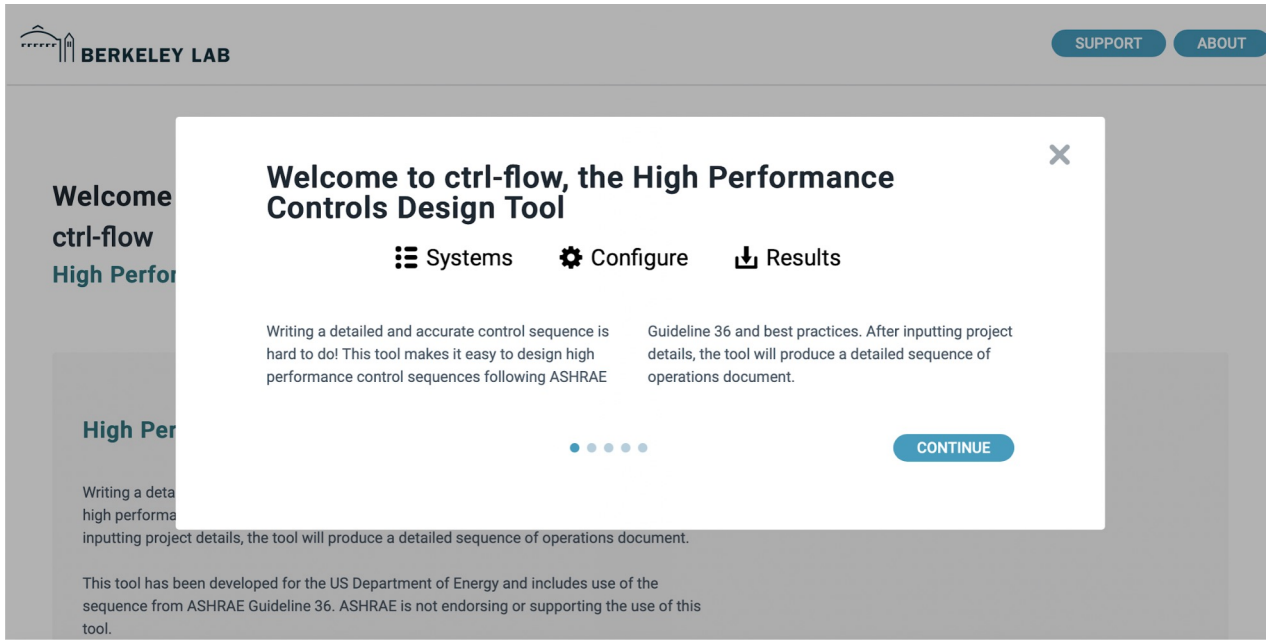
Progress – Expanded library of control sequences

- Sequences for radiant heating and cooling systems
- G36 sequence official version in Modelica Buildings Library, including air side equipment
- G36 sequences for chiller plants (summer 2023)
- 200 tests for all sequences
  - open-loop for each subsequence
  - closed-loop with energy model for system controller
- Detected errors and ambiguities in G36 documentation, leading to improvements:
  - economizer high-limit selection
  - AHU freeze protection sequence
  - hierarchy of zone setpoint adjustments
  - pressure control for AHU system with return fan
  - dual-duct terminal unit using mixing control with discharge airflow sensor



Progress: ctrl-flow – “High Performance Control Design Tool”

- Allows building control systems designers to configure and adapt for their building a vetted control sequence, such as from ASHRAE G36, and export digital design specification
- Designed for easy expansion using Modelica template models
- Initial release
  - Supports air-side of ASHRAE G36
  - Outputs edited control sequence
- Future releases
  - Water-side of G36, heat pump plants, …
  - Outputs
    - CDL, CXF and Modelica HVAC models
    - Points lists and diagrams
- Free, open source (ctrl-flow.lbl.gov)



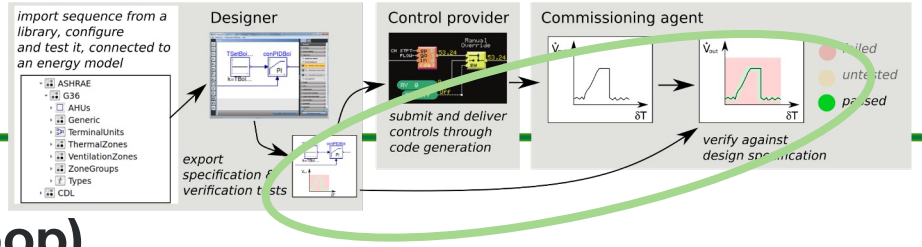
ctrl-flow.lbl.gov

This tool essentially automates editing the, “Retain the following sections for/if…” sections that I do manually when editing and specifying G36. There is value in having a user-friendly interface with selectable options to decipher this!

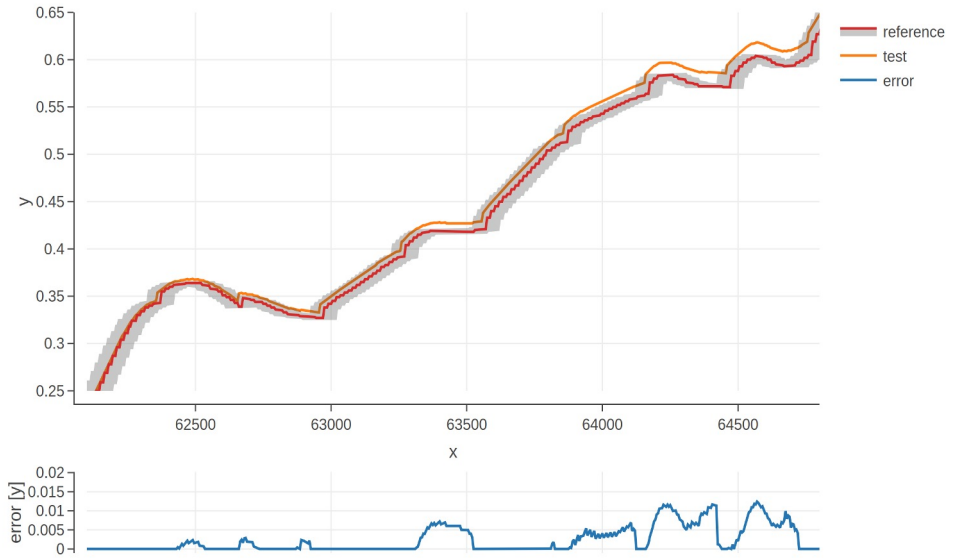
…looking forward to CDL for modeling/calculating energy savings and CXF for controls contractor.

Kyle Wacyra – Capital Efficiency

Progress – End-to-end verification



- **Formal verification of as-installed control logic (open-loop)**
  - Demonstrated prototype implementation
  - Deployment proposed for subsequent years
- **Applicable to**
  - Vendors testing G36 implementations against reference
  - Commissioning agents testing logic against CDL spec
- **Comparison make allowances for**
  - Sensor noise
  - Data discretization
  - Time synchronization



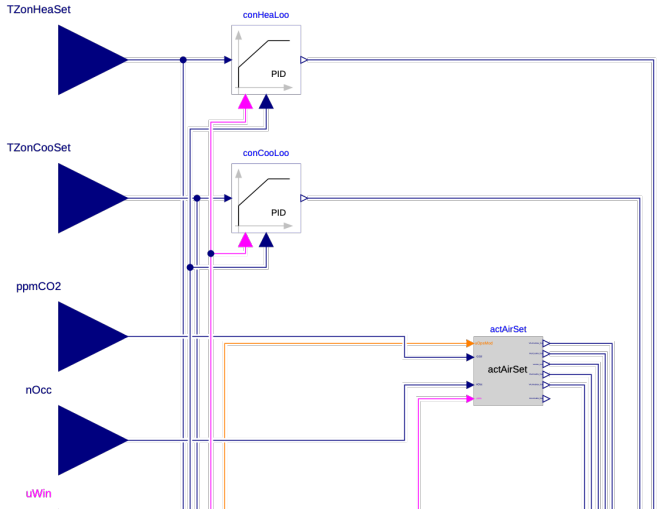
Michael Wetter, Antoine Gautier, Milica Grahovac, Jianjun Hu. Verification of Control Sequences within OpenBuildingControl. Proc. of the 14th IBPSA Conference, p. 885–892, Rome, Italy, September 2019.

Complements closed-loop verification performed by ConStrain (later in this track)

- We conduct open-loop control logic verification against the design specification

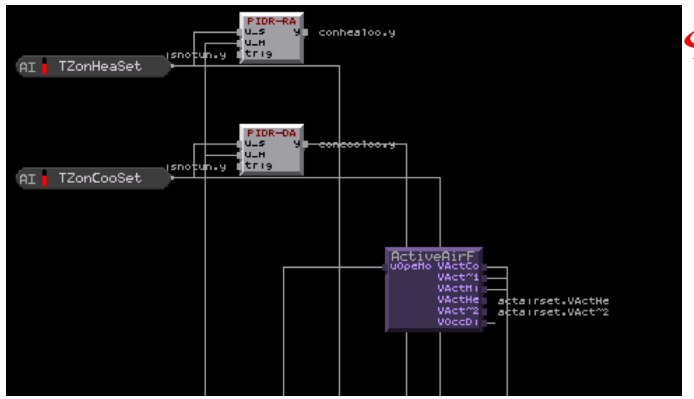
Risks and Mitigations

Risk	Mitigation
Available sequence configuration options lead to **inconsistent specification**	Test permutations of control configurations with simulation
Lack of support of ASHRAE Standard 231P by control providers	Provide tools that lower their costs if standard is supported. Provide commissioning agent with digital control specification and tools for formal verification.
Heterogeneity of control product lines make ASHRAE Standard 231P adoption difficult	Work closely with control providers when developing the standard. Provide proof of concept translations.



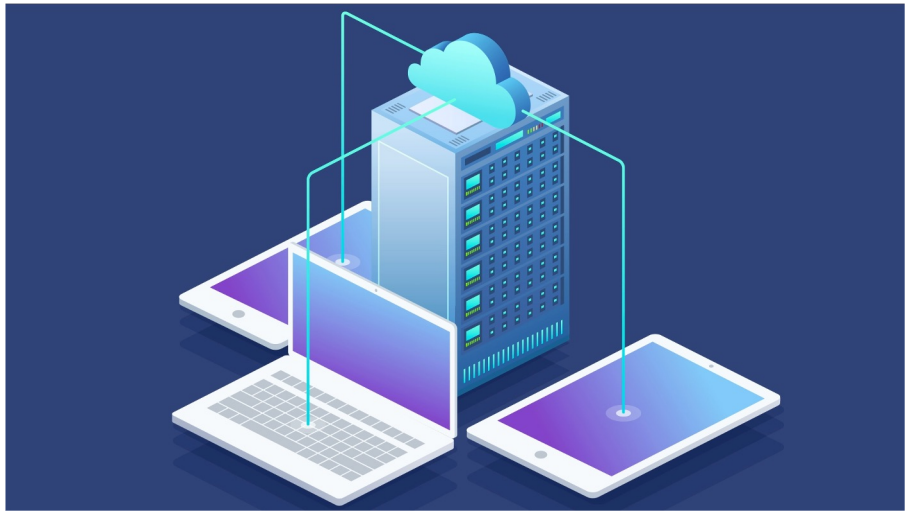
Modelica

Automatically translated.
https://doi.org/10.1016/j.energy.2021.121501



Automated Logic

Success Story – Simulation Helps Optimize Meta's Data Centers



Building a thermal simulator

Our dynamic model combines first-principle physics with building-modeling languages, including Modelica. To simulate a particular data hall, we first need static, site-specific details about the facility's geometry, construction materials, and HVAC, as well as its system configurations and component efficiencies. Then we numerically re-create the control strategies (using the control Description Language) governing the behavior of all the HVAC and water equipment as functions of the indoor and outdoor conditions.

https://engineering.fb.com/2022/09/14/data-center-engineering/data-centers-meta-thermal-simulation-optimization/

Issues recap and lessons learned

- **Deep decarbonization asks industry to deploy novel, unproven, integrated system with high complexity**
- **Industry lacks subject matter expertise and is not prepared to manage complexity and de-risk solutions**
  - MEP and control providers **lack scalable solutions** to decarbonize medium and large commercial buildings (50% gsf)
  - Mechanical designers and manufacturers conceive heat-pump plants with **20+ modes of operation**, but lack design and verification tools and processes
  - Anecdotal evidence shows it can take **3 to 5 years to get complex HVAC systems to work**
  - **Other countries reported failed heat pump deployments** (Switzerland and Italy) for medium and large buildings due to complexity and lack of subject expertise despite their long history in heat pumps.
- **Building automation systems (BAS) are not designed to handle increased complexity**

What we learned

- ***Digitization*** of control delivery enables managing complexity, de-risking novel solutions, and providing end-to-end verification.
- ***Technologies*** that accommodate current product lines yet enable innovative providers to leapfrog current paradigms are possible.
- ***Collaboration*** **with industry** is important for technology transition – from paper-based workflows to cost-effective, robust, digitized workflows.

Progress – Future plans

- Publish **ASHRAE Standard 231P** following 2023 public review
- Work with industry to adopt 231 into their **product lines**
  - Manufacturers (Carrier CRADA, Trane, …)
  - Design firms (Taylor Engineers, ARUP, Southland Industries, …)
  - Large operators (Meta, Penn State Facilities, …)
- Add heat-pump systems and output formats to **ctrl-flow**
  - Provide industry awareness and training
- Expand **control sequences library**, focus on heat-pump systems
- Further integrate rule-based control with **grid-responsive control** approaches (MPC and similar)
- **Bridge gap between energy modeling (BEM) and controls**
  - Control is key to system efficiency
  - BEM is key to dynamic analysis, design, and optimization
  - Spawn and OpenBuildingControl are the bridge between them

OpenBuildingControl

Thank You

LBNL, PNNL, Building Intelligence Group, Taylor Engineers, Solamen, DEPT

Michael Wetter, PhD
mwetter@lbl.gov

WBS 3.2.6.69

REFERENCE SLIDES

Project Execution

	FY2023				FY2024				FY2025			
Planned budget	625k				625k				625k			
Spent budget	360k											
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Past Work												
Q1: Release modelica-json for ASHRAE Std 231P	◆											
Q2: Release ctrl-flow & schedule ASHRAE pres.		◆										
Current/Future Work												
Q3: Release modelica-json for semantic models			◆									
Q3: Release ASHRAE Standard 231P review draft			◆									
Q4: Release sequence repository compliant with Std 231 and present to ASHRAE				◆								
Q1 Release seq. library for heat pumps					◆							
Q2: Release modelica-json 2.0 w. Std 223P & 231P support						◆						
Q3: Release 1st version of ASHRAE Standard 231							◆					
Q4: Establish public-private partnership to host ctrl-flow								◆				
Q1: Release sequence repository with all electric plants									◆			
Q2: Release modelica-json 3.0										◆		
Q3: Release addendum to ASHRAE Standard 231											◆	
Q4: Release sequence repository for HP plants w. storage												◆

Red color indicates go/no-go milestones

Team

LBNL
Workflow design, Control Description Language design, ASHRAE Std 231 technical guidance, tool implementations (sequences, verification, ctrl-flow), semantic models

- Michael Wetter (PI)
- David Blum
- Milica Grahovac
- Jianjun Hu
- Anand Prakash
- Marco Pritoni

PNNL
Tool implementations (sequences, verification)

- Yan Chen
- Karthik Devaprasad
- Draguna Vrabie

Building Intelligence Group
Chairing ASHRAE Standard 231P, industry outreach

- Paul Ehrlich

Solamen
Technical guidance ctrl-flow, sequence implementation.

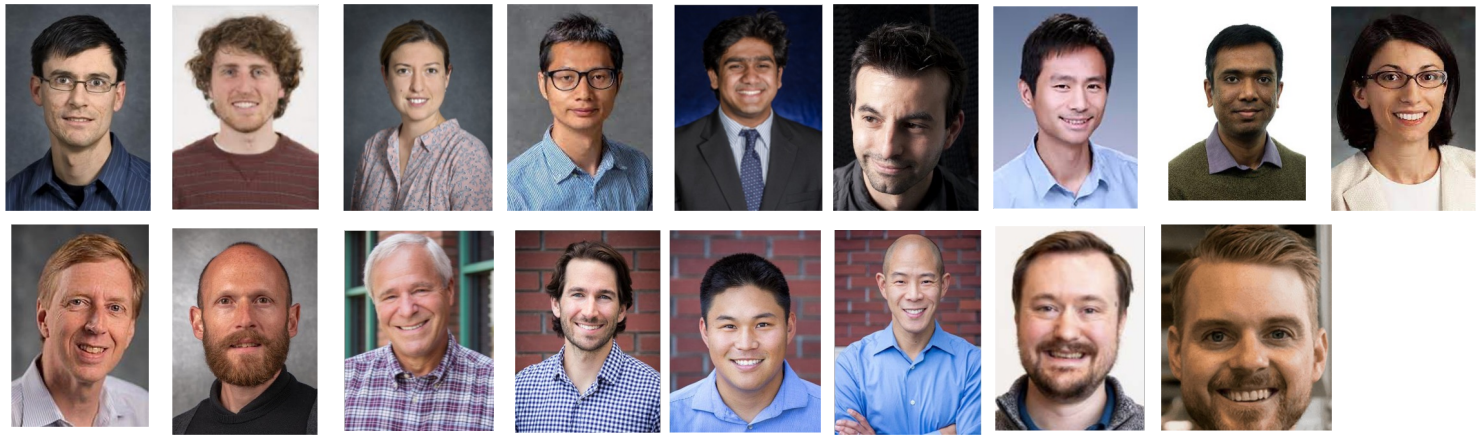
- Antoine Gautier

Taylor Engineers
Technical guidance sequence implementation, industry feedback

- Steven T. Taylor
- Brendon Gill
- Reece Kiriu
- Hwakong Cheng

DEPT
Implementation of ctrl-flow

- Erik Wiffin
- Allan Wintersieck
- Logan Bishop
- Amit Kapoor



Stakeholder engagement through ASHRAE (chairing & driving ASHRAE 231P, coordinating & implementing Guideline 36, coordinating semantics with ASHRAE 223P, workshops), outreach and interviews with designers & owners for process, commercialization and design of control sequence specification tool ctrl-flow.
PI is also PI of DOE's Spawn of EnergyPlus, BOPTEST (control performance benchmark) & skewering the silos (semantic modeling).