U.S. DEPARTMENT OF ENERGY
Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

OpenBuildingControl

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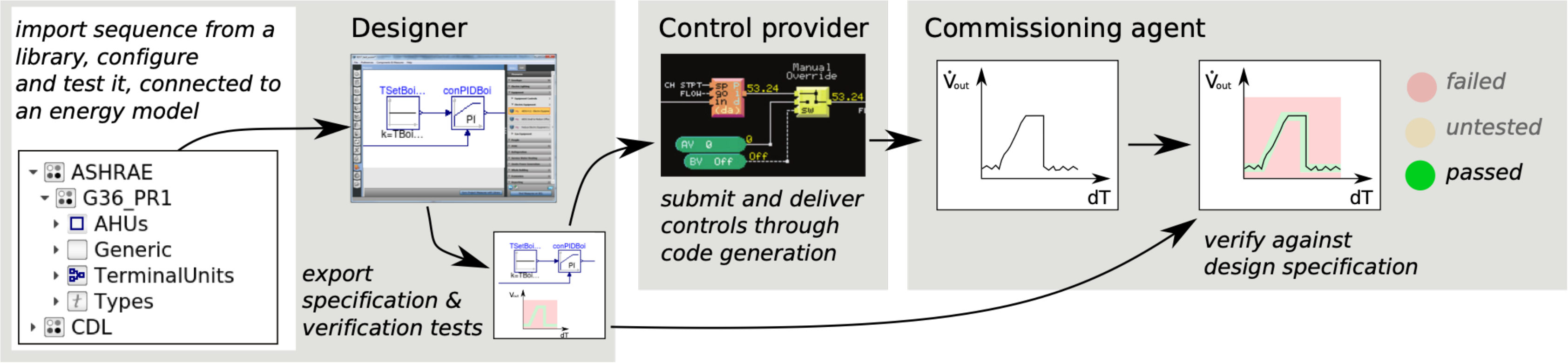

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LBNL, PNNL, Building Intelligence Group, Taylor Engineering

Michael Wetter, LBNL, Staff Scientist
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Project Summary

Timeline:

Start date: Oct. 1, 2019

Planned end date: Sep. 30, 2022

Key Milestones

1. Implemented sequences for primary and secondary systems; 9/20/2021
2. Sequence selection tool for use with Spawn; 9/20/2022

Budget:

Total Project $ to Date:

- DOE: $1,480,000
- Cost Share: Industry via ASHRAE 231P; plus $1.3M during Phase I (2016-2020)

Total Project $:

- DOE: $3,070,00 (FY20-22)
- Cost Share: Industry contributions via ASHRAE 231P;
  plus $1.3M during Phase I (2016-2020)

Key Partners:

PNNL	Sequence dev and verification
Building Intelligence Group	Industry outreach; chairing ASHRAE 231P
Taylor Engineering	Support for sequence implementation
Devetry	Implementation of sequence selection tool

Project Outcome:

Tools and processes for the performance evaluation, specification and verification of building control sequences.

New ASHRAE Standard 231P to express and transmit control logic digitally.

Closing the gap between energy modeling and control delivery process

Team

LBNL
- Michael Wetter (PI)
- David Blum
- Antoine Gautier
- Milica Grahovac
- Jianjun Hu
- Anand Prakash
- Marco Pritoni
- Baptiste Ravache
- Kun Zhang

PNNL
- Yan Chen
- Karthik Devaprasad
- Xuechen Lei
- Jeremy Lerond
- Draguna Vrabie

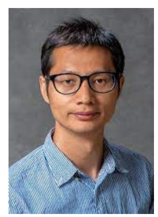
Building Intelligence Group
- Paul Ehrlich

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

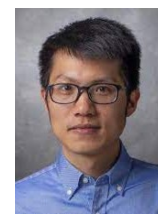
Devetry
- Allan Wintersieck
- Logan Bishop

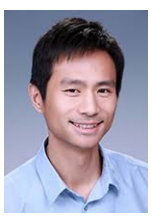






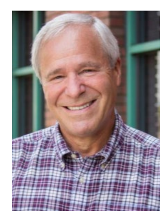











Stakeholder engagement through ASHRAE (chairing & driving ASHRAE 231P, coordinating & implementing Guideline 36 & RP 1711, coordinating semantics with ASHRAE 223P, workshops), outreach and interviews with designers & owners for process, commercialization and design of control sequence specification tool Linkage.
PI is also PI of DOE’s Spawn of EnergyPlus, BOPTEST (control performance benchmark) & skewering the silos (semantic modeling).

Challenges

- ~4 quads/yr is wasted because control sequences are poorly specified & implemented in commercial buildings. Further impact on comfort, safety, & health (PNNL 2017a).
- 50% of installations do not fully meet energy code requirements (PNNL 2017b).

Why? Current process for control design, delivery, operation & maintenance is error-prone, ambiguous & labor intensive. It does not deliver high performance control sequence implementations at the scale needed.

Designer

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

Controls Contractor

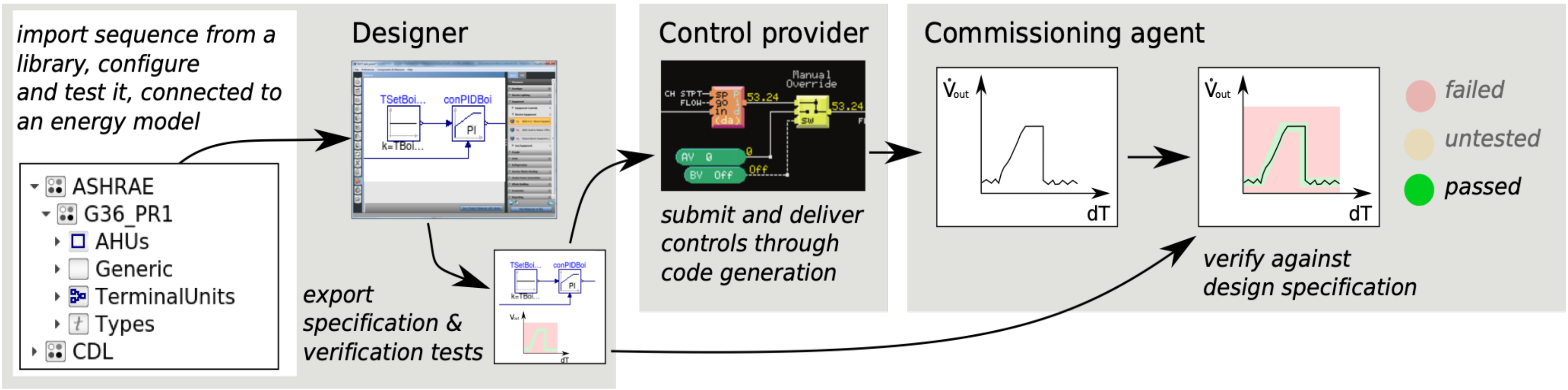
- Interpreting verbose sequences is tedious & error-prone.
- Tight schedule & budget.

Cx agent & operator

- Verification is slow & limited.
- Poorly documented.
- Lack of semantic knowledge.

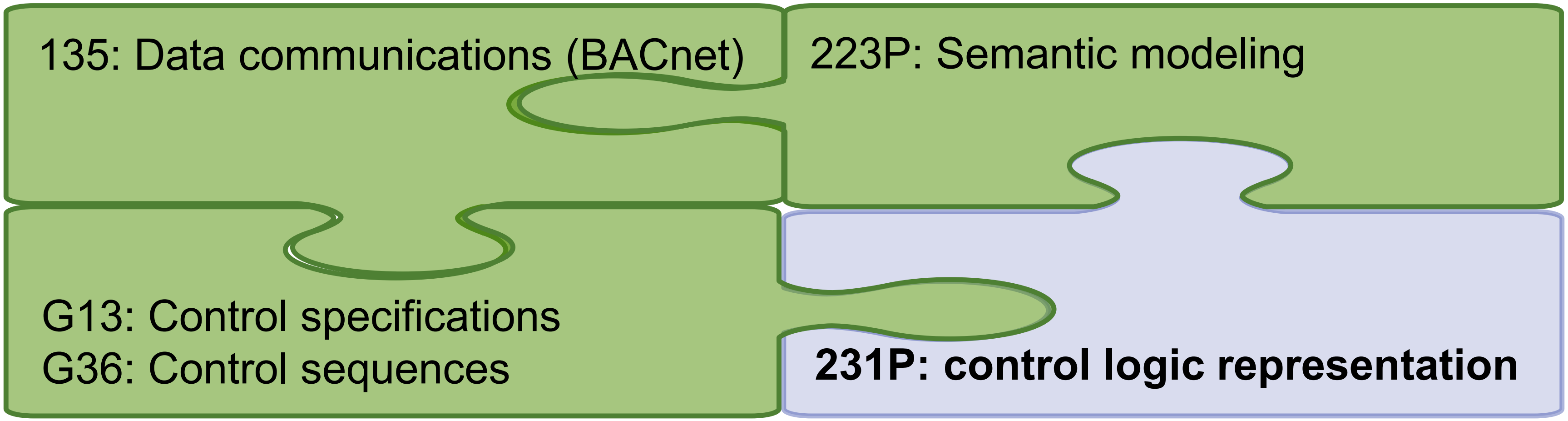
Approach – Digital control delivery process

The Open Building Control (OBC) team is developing a digital control delivery process that links repository of control sequences with tools for design, deployment & verification.



- Process is based on ASHRAE Standard 231P chaired by this team.
- It leverages the Spawn (of EnergyPlus) BEM-controls simulation engine whose development is also led by this team.

Approach – Interoperability via ASHRAE 231P



- **What is in Standard 231P?**
- **Two key representations**
  - CDL: Modelica-based, used primarily for design & simulation
  - CXF: JSON-based, used primarily for control sequence deployment
- **Standardized function blocks**
  - Closely coordinated with industry
  - Collaboration with BACnet and other ASHRAE efforts
  - Common definitions for logic and graphical representation
- **Definition of semantics & syntax**

Process: Current and OBC

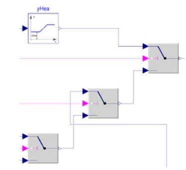
Stage	Current Process	OBC Process
Design	Engineer evaluates control sequences in BEM tool, creates an English document to describe them.	Engineer uses Spawn to evaluate sequences from a library, selects one, and exports both an English document & a digital spec.
Bid	English document is the control spec & contract.	Contract includes both document & digital spec.
Implement	Engineer interprets English spec and implements an apparently similar sequence.	Engineer imports the digital spec into their tools, configures system functions, and downloads sequences into the control system.
Commission	Agent reviews project implementation against English document.	Agent uses the verification tool to formally assure that the programmed sequence is consistent with design.

Anticipated Benefits

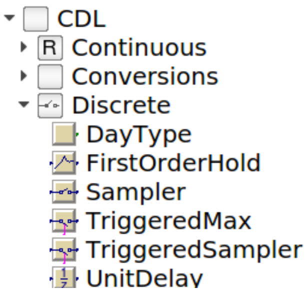
- **Designers**
  - Can easily & accurately specify high performance sequences, such as those ASHRAE Guideline 36
  - Can quantify and improve performance (energy, peak power, load shifting) of control during design
  - Can evaluate building controls for potential upgrades and optimization
- **Control contractors**
  - Have reduced cost & risks, a streamlined process
  - Provide higher quality installations
- **Vendors**
  - Have consistent control approaches
- **Commissioning agents**
  - Have standardized documentation and tools
  - Have non-ambiguous requirement specification

Approach - Control Description Language (CDL)

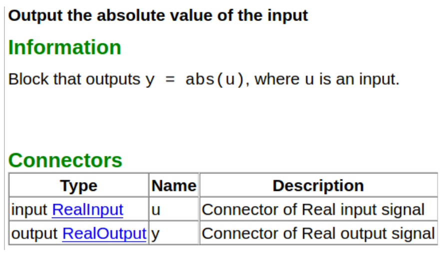
A declarative **block diagram language**.



A **library** with elementary input/output blocks that should be supported, through a translator, by control providers.
Example:
CDL has a gain with input u, gain k, and output y = k*u.



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



Output the absolute value of the input

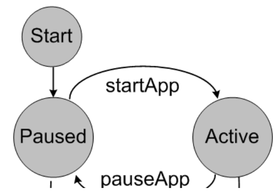
Information

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

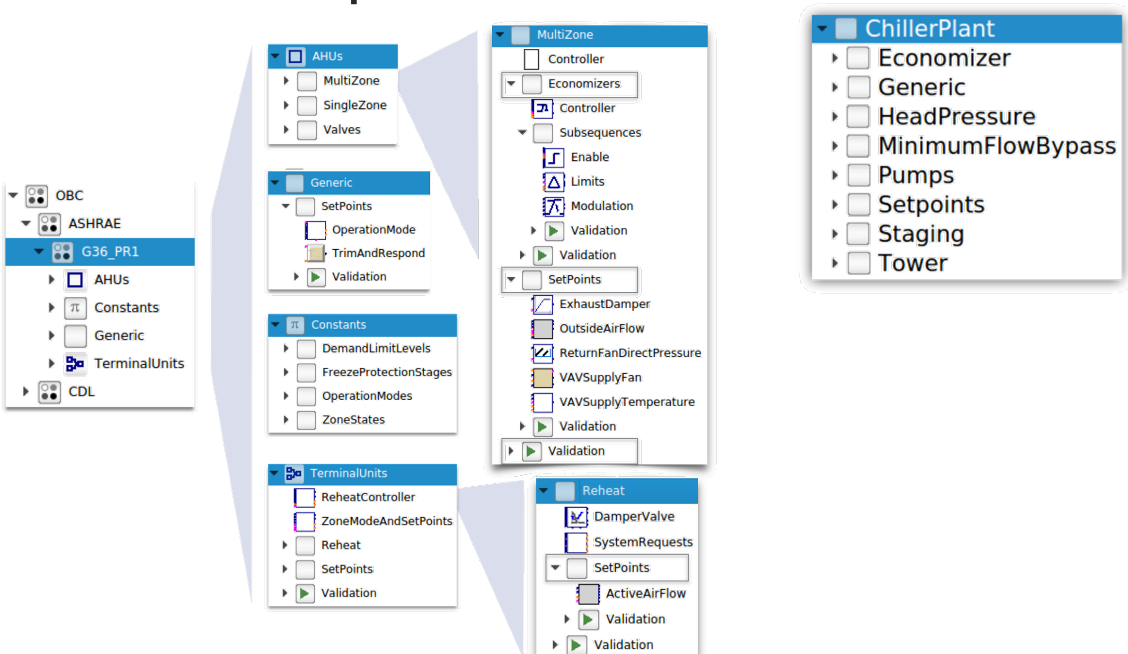
A **model of computation** that describes when to update signals.

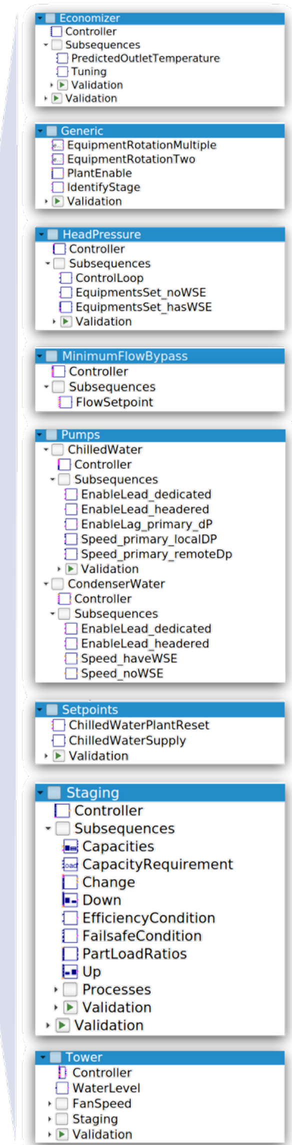


A language fully compatible with the open Modelica standard, enabling **simulation & code generation**.

Approach – Library of customizable sequences

- **ASHRAE Guideline 36**
  - VAV models and 34 test cases/examples
- **ASHRAE RP 1711**
  - Chiller & boiler plant control sequences
- **Packaged rooftop unit & DOAS control sequences**
- **Radiant system control sequences**
- **…**



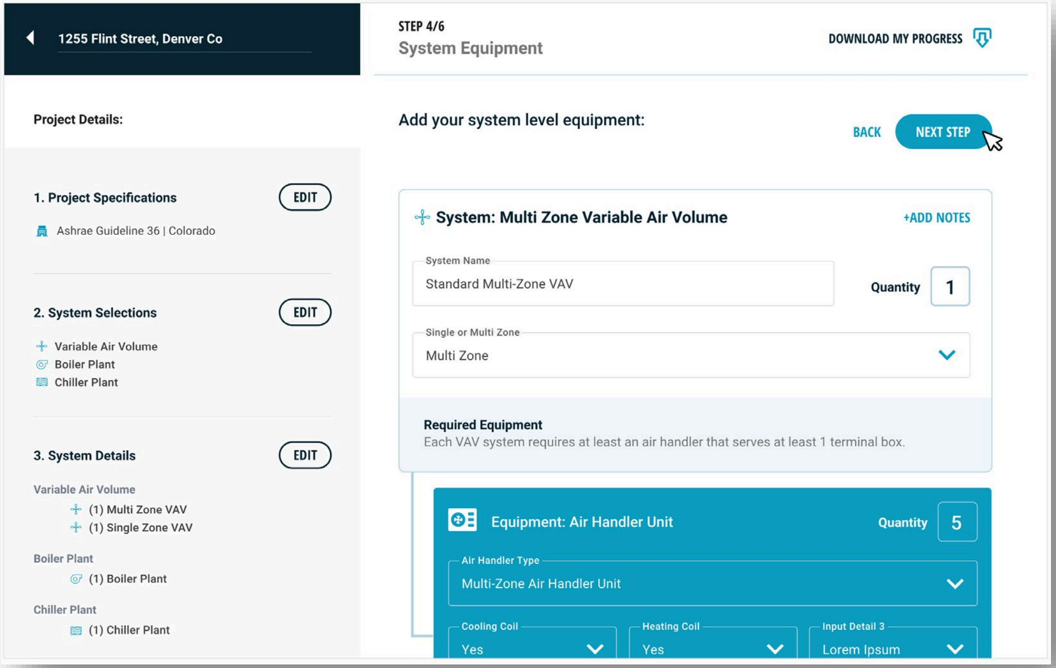


Implementation at https://simulationresearch.lbl.gov/modelica/releases/v8.0.0/help/Buildings_Controls_OBC.html

Approach – Design tool

- Designed & started implementation of HVAC & control sequence selection & configuration tool.

- Allows designers to select & configure HVAC & controls, then export
  - Spawn simulation model
  - Bidding documents
  - 231P control sequence
  - Construction documents

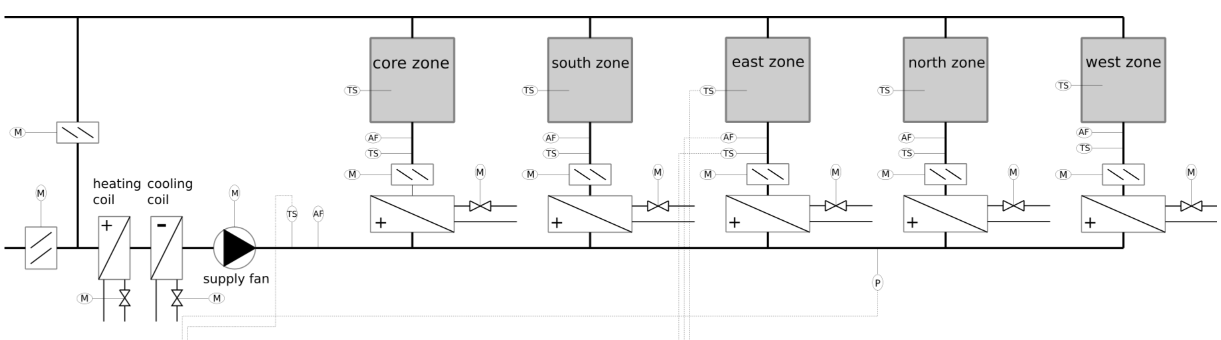


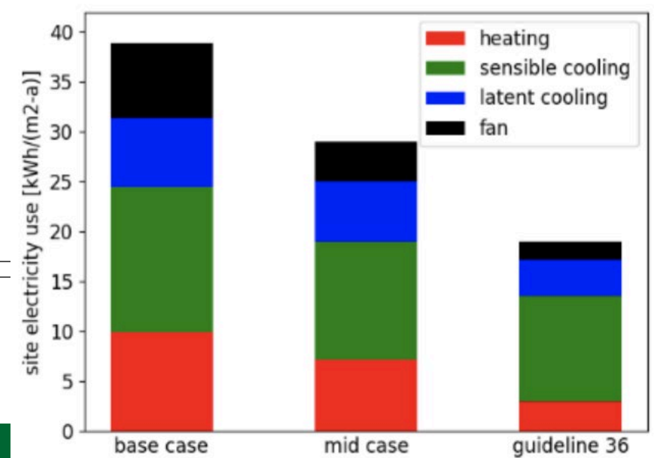
- Menu-driven GUI in early 2022.
- Graphical editing in late 2022.

Specification at https://github.com/lbl-srg/linkage.js

Approach – Performance evaluation

- Two VAV sequences, both in ASHRAE publications, yield <u>15-30% difference</u> in annual HVAC energy (depending on climate, usage, baseline control).
- **Demonstrated closed loop energy performance assessment with Spawn**
- Approach for annual simulation
  - Control simulation coupled to HVAC & envelope.
  - Airflow network.
  - Wind pressure driven infiltration.
  - Flows based on friction, damper positions & fan curves.
  - 4k components, 40k variables (generated from high-level declarations)
  - Adaptive time step based on error control, state- and time-events.



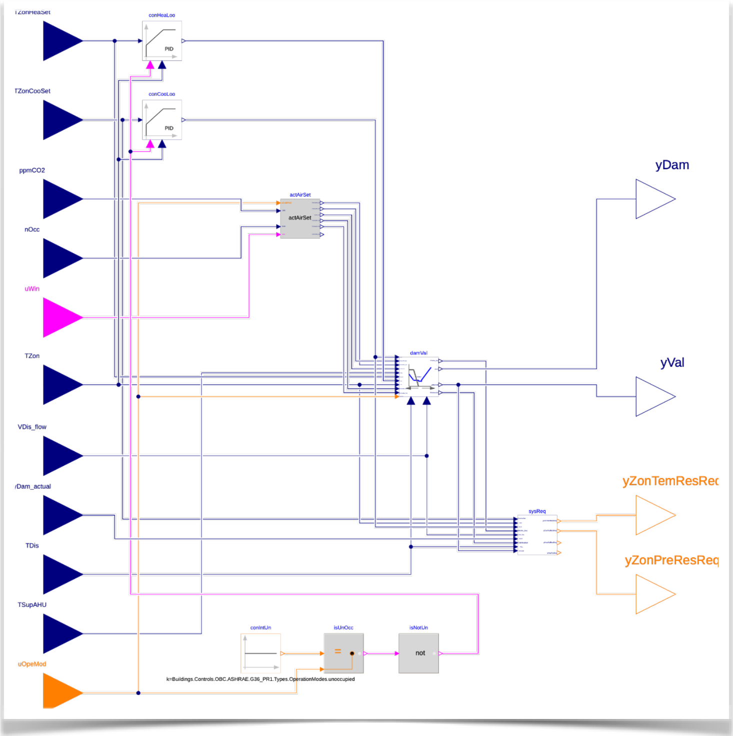


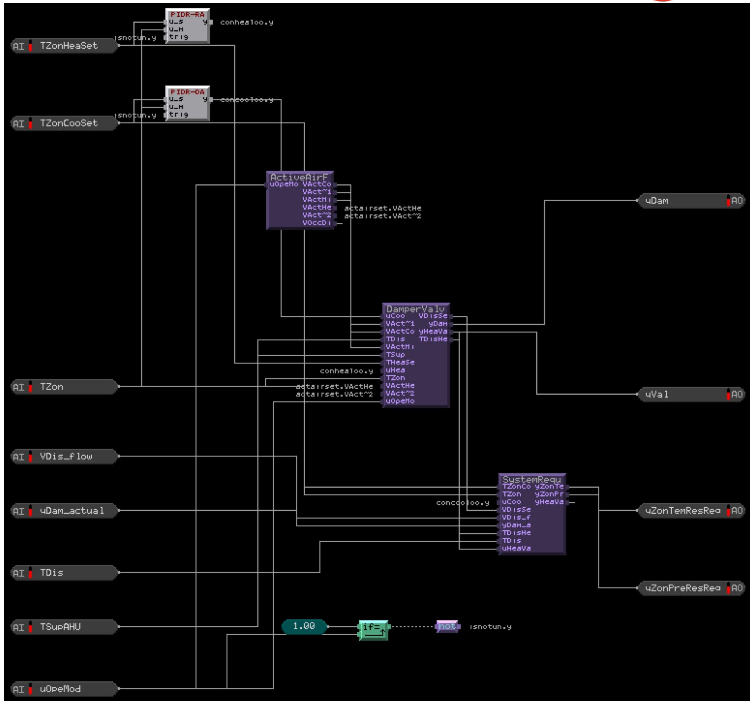
Approach – Translation to control platform

- Demonstrated simulation of sequence in Spawn, and automated translation of the sequence to Automated Logic's EIKON language.

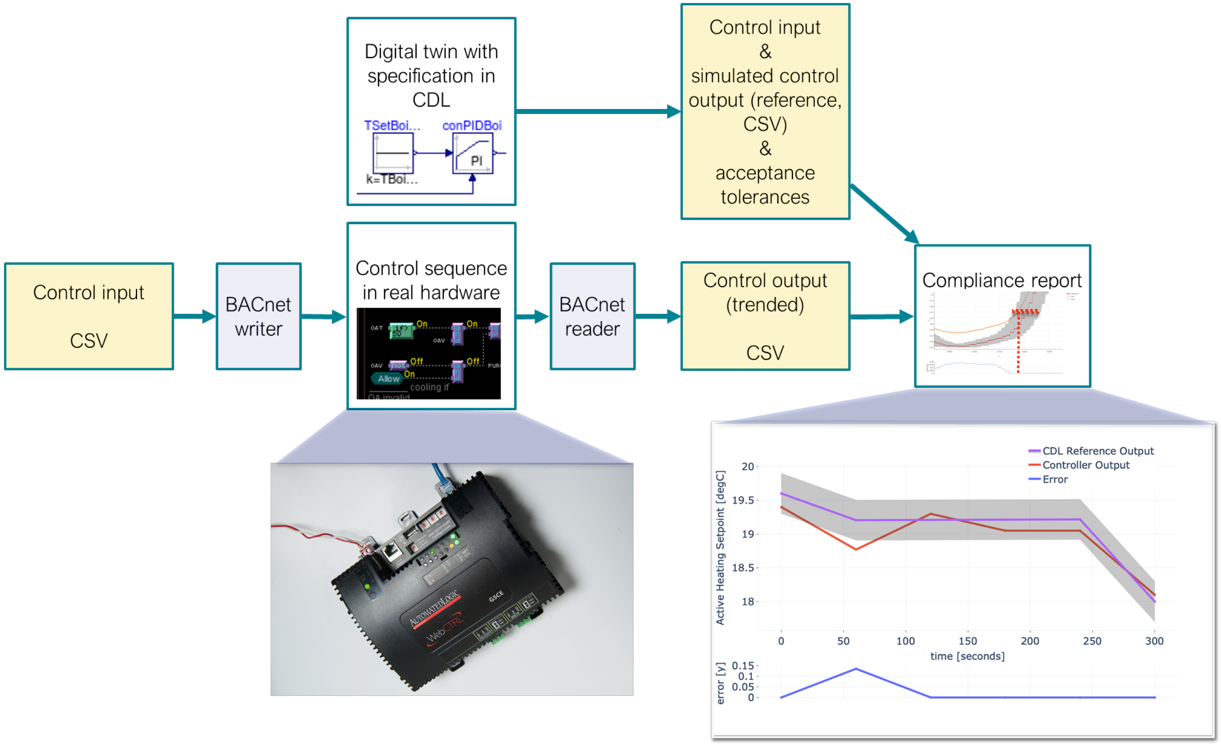
Machine to machine translation

Automated Logic





Approach – Tools for verification



- Demonstrated control sequence verification to ASHRAE (**open loop**)
  - Supports commissioning agents & manufacturers in code development
  - Supports ASHRAE in verifying implementation conformance to G36
- Ongoing: Whole system performance verification (**closed loop**)
  - Supports commissioning agents in verifying that system-level requirements, such as energy codes, are satisfied

Impacts

- **On DOE/BTO**
  - Demonstrated potential to reduce HVAC energy 20-30% via better control
  - Path towards development & publication of control sequences for GEB
- **On Mechanical designers**
  - Tools for delivery of better projects
  - Reduced risk that buildings do not meet energy targets due to control
- **On control providers**
  - Reduced project risk and effort needed for programming
  - More cost-effective delivery of high-performance sequences
  - Reduce the cost and effort to train technicians
- **Commissioning provider**
  - Reduced time and higher quality of verification
- **Building Owners and Operators**
  - Standardized control logic facilitates understanding
  - Improved building efficiency, health and safety

Progress

- CDL specified & reference library implemented
- CDL-compliant G36 sequences released & demonstrated
  - Key 36 members are very positive
- Demonstrated annual energy savings of G36 for a range of configurations
- CDL-based code translation to Building Automation System shared
  - control companies expressed interest in developing translator
  - CRADA with large HVAC manufacturer for product development using OBC + semantic modeling in development.
- In development
  - System design tools
  - Expansion of reference library
  - System verification tool
  - Support for semantic tagging
  - Driving the development of ASHRAE Standard 231
- More information at https://obc.lbl.gov

Remaining Project Work

2021

- 231P
- Library of sequences for Spawn, compliant with 231P

2022

- Control Design Tool
- Control performance verification tool
- Translation tools for 231P

2023

- 231 published
- Vendors start supporting 231 in new and current products
- Design and verification tools released

2024

- Continued expansion of library
- Support and training on tools

Thank You

https://obc.lbl.gov/

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REFERENCE SLIDES

Project Budget

Project Budget:
Phase I: $2M DOE + $1M CEC + $0.3M industry cost-share. All completed.
Phase II: $750k/year planned
Variances:
FY21 had increase of 250k (for PNNL, controls performance) plus 540k (for LBNL/Devetry, Linkage)
Cost to Date: 1,480,000
Additional Funding: For Phase I, $1M from CEC + $0.3M from industry.

Budget History					
Oct. 1, 2019– FY 2020 (past)		FY 2021 (current)		FY 2022 – Sep. 30, 2022 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
750k	0 (plus ASHRAE 231P in-kind)	1,540k	0 (plus ASHRAE 231P in-kind)	750k	0 (plus ASHRAE 231P in-kind)

Project Plan and Schedule