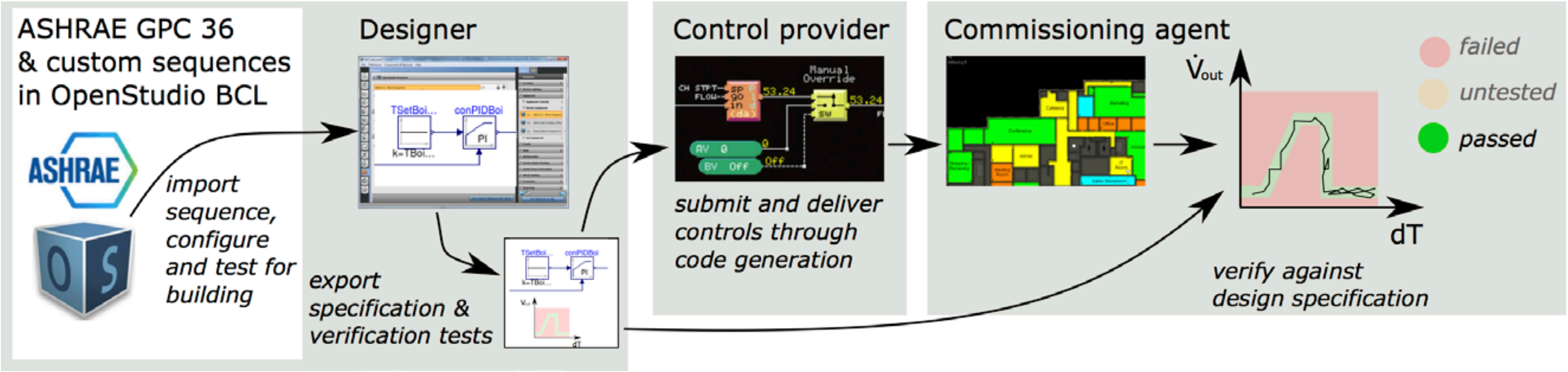
U.S. DEPARTMENT OF ENERGY
Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

OpenBuildingControl



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LBNL, ARUP, Facility Dynamics, Integral Group, PNNL, Taylor Engineering
Controlco, kW Engineering, Oracle, Stanford University

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Project Summary

Timeline:

Start date: 10/1/2016

Planned end date: 11/27/2019

Key Milestones

By 7/2017, post a v1.0 specification of Control Description Language on github.org.

By 10/2017, successfully compared the energy and comfort performance of two ASHRAE-published control sequences.

By 7/2018, release control library for primary and façade systems.

By 4/2019, release CDL to English language export software.

Budget:

Total Project $ to Date:

- DOE: $820,000
- Cost Share: $160,000

Total Project $:

- DOE: $2,000,000
- Cost Share: $1,320,000*
  *$1M cost-share to be signed with CEC soon.

Key Partners:

ARUP	Controlco
Facility Dynamics	kW Engineering
Integral Group	Oracle
PNNL	Stanford University
Taylor Engineering	

Project Outcome:

OpenBuildingControl will develop tools and processes for the performance evaluation, specification and verification of building control sequences.

OpenBuildingControl will close the gap between energy modeling tools, controls specification and verification of correct implementation of control sequences.

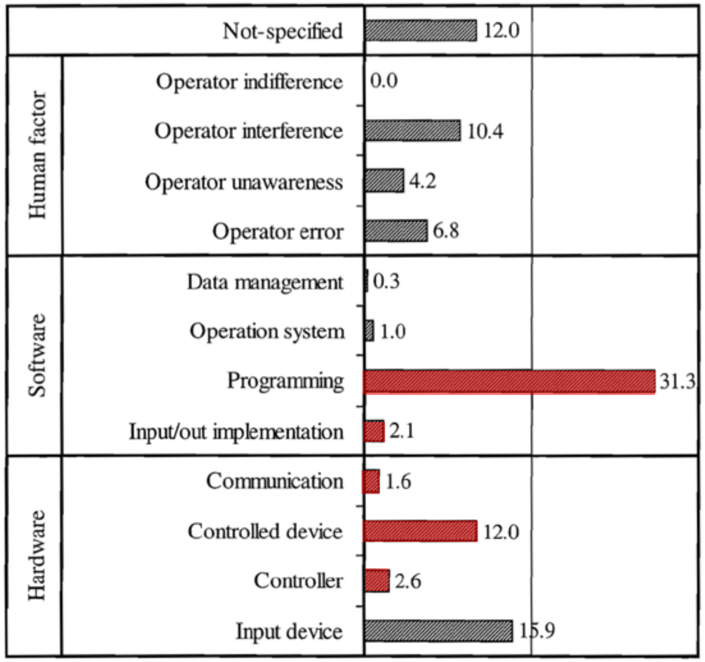
Team

- LBNL: project lead, software development
- Subcontractors:
  - **Integral Group**: specification and testing of standard sequences
  - **Arup**: process definition, testing and demonstration, GUI spec, commercialization plan, international
  - **PNNL**: project organization
  - **Taylor Engineering**: specification and testing review, ASHRAE TC 1.4, RP 1711 and Guideline 36 linkage
  - **Facility Dynamics Engineering**: TAG chair, review

- In-kind cost-share partners:
  - Controlco
  - Integral Group
  - kW Engineering
  - Oracle
  - Stanford University

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). While the study is not recent, discussions with mechanical designers and operators of large buildings confirmed that correct implementation of the control intent remains a problem.

More than 1 quad/yr of energy is wasted in the US because control sequences are poorly specified and implemented in commercial buildings.

The process to specify, implement and verify controls sequences is often only partially successful, with efficiency being the most difficult part to quantify and realize.

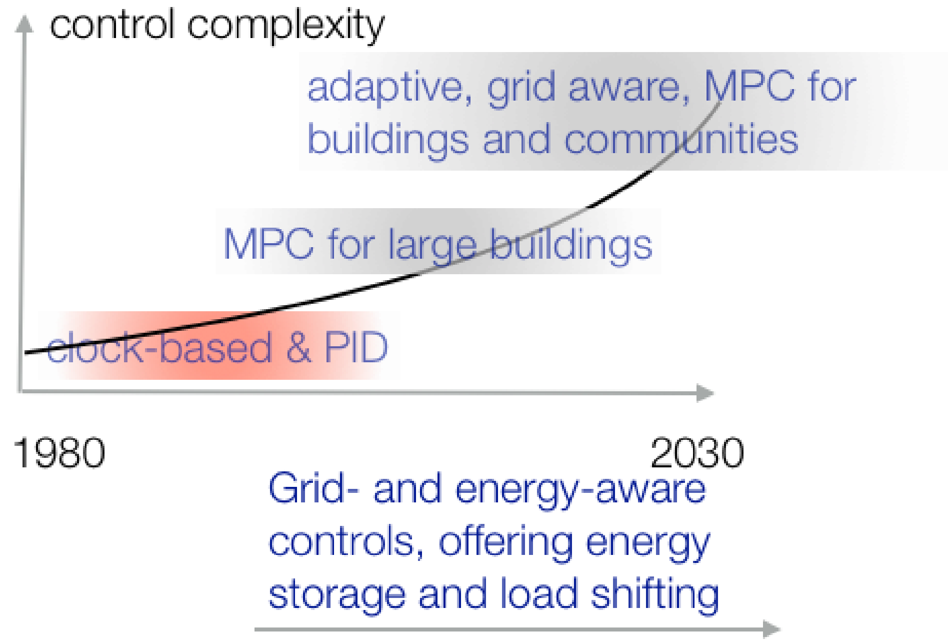
This limits adoption of advanced control sequences as

- anticipated energy savings are not achieved,
- their expected ROI may be missed, and
- engineers are exposed to risk due to malfunctioning system integration, often leading to oversized or overengineered systems.

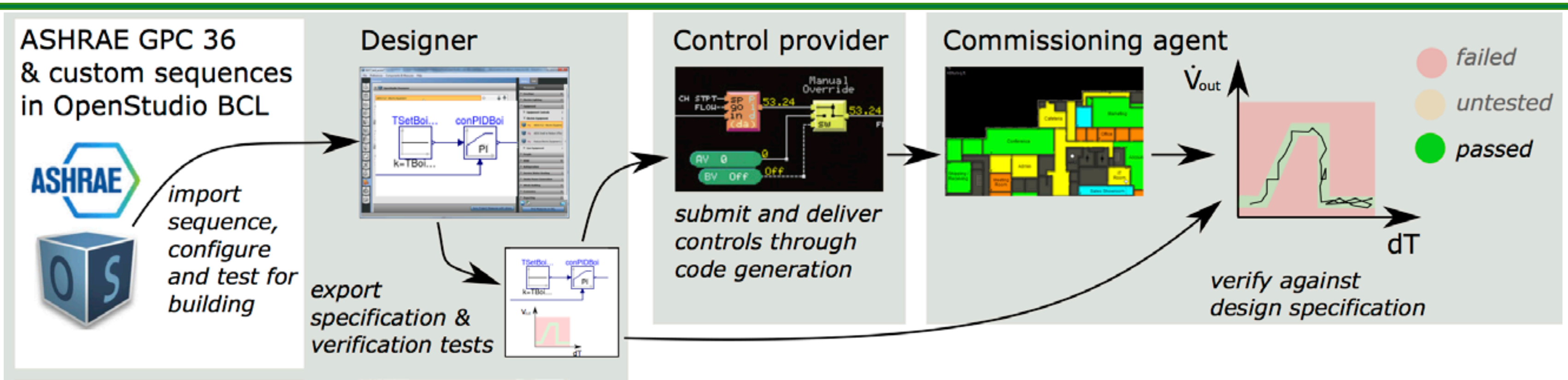
Vision

What if

1. mechanical designers can import in building energy modeling tools best-in-class control sequences from ASHRAE-vetted guidelines?
2. mechanical designers can adapt these sequences to their project, and then exported them digitally for bidding and implementation, together with verification tests?
3. control providers could automatically implement these sequences in their building automation systems?
4. commissioning agents could verify formally that the sequences are implemented as specified?



Approach



Codify best practice Design Implement Verify against original design

BACnet standardizes communication, **OpenBuildingControl** will standardize control sequences & verification tests:

- basic functional building blocks
- composition rules for control sequences, and

for bidding and automatic implementation

- declaration of functional verification tests criteria.

Key Innovations

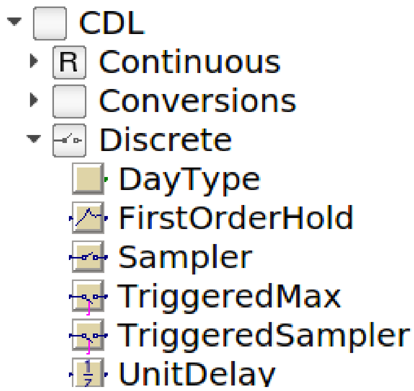
Digital, executable control specification, called Control Description Language (CDL), enabling

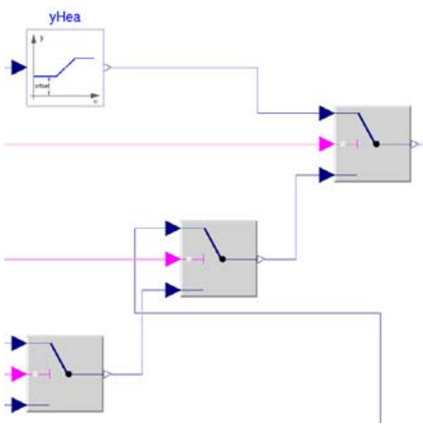
- Sharing of best-practice, e.g., ASHRAE Guideline 36
- Error-free implementation of the specified control sequence
- Formal process that connects design to operation
- Formal verification of design intent

Approach: Control Description Language, connecting formally design, bidding, implementation & operation

The Control Description Language (CDL) consists of

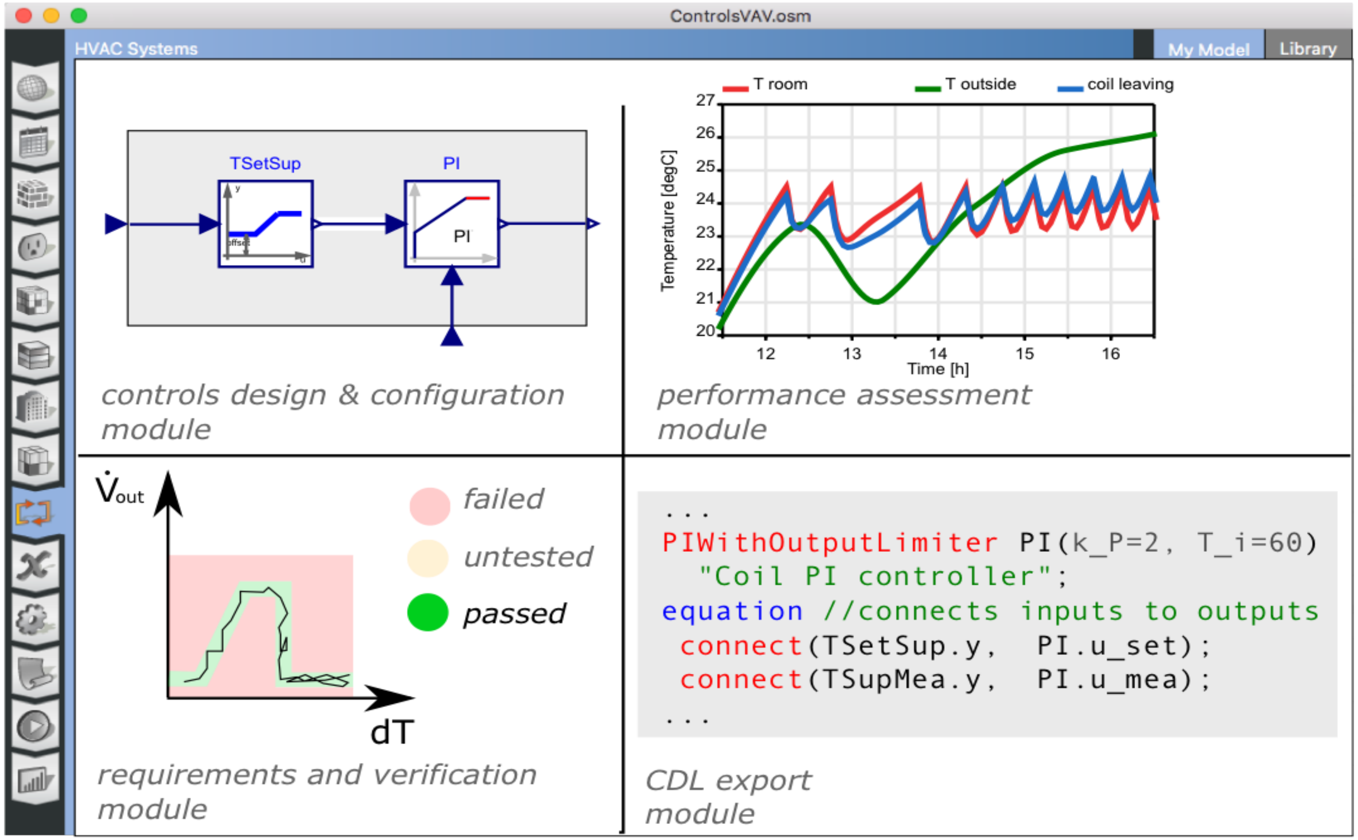
- A library with elementary input/output blocks that should be supported [through a translator] by CDL-compliant control providers.
- A declarative, open-standard, open-source, non-vendor-specific, language for expressing block-diagrams for control sequences.
- A language for rendering these diagrams.
- A syntax for documenting the control blocks and diagrams.
- A model of computation that describes the interaction among the blocks.





Rather than an ambiguous English Word specification against which one cannot test, we now have (i) English language documentation, (ii) block diagram representation, (iii) code that can be executed and that conforms to an open modeling standard (a subset of Modelica)

Approach: Tool for design, test and export



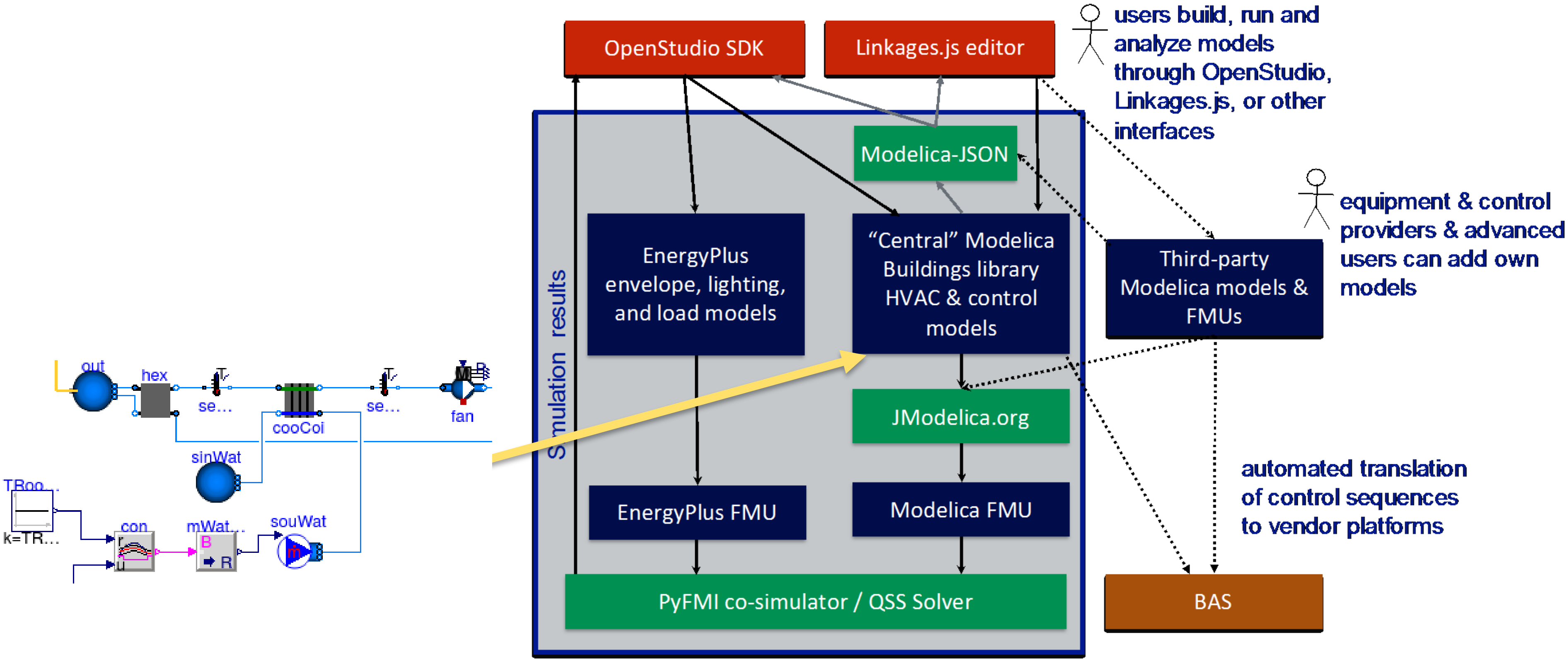
Export of

- Points list
- Bidding documents
- Operator manual
- Sequence specification for machine-to-machine translation to BAS
- Verification tests for commissioning provider

Approach: Performance assessment of control sequence with energy simulation model in the loop

Currently: Simulation using JModelica or Dymola

Final product: Translation and simulation through "Spawn of EnergyPlus"

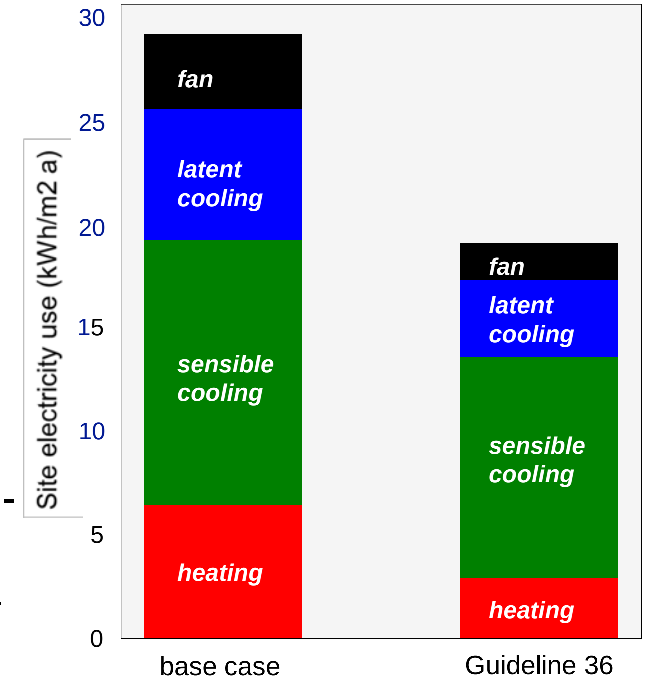


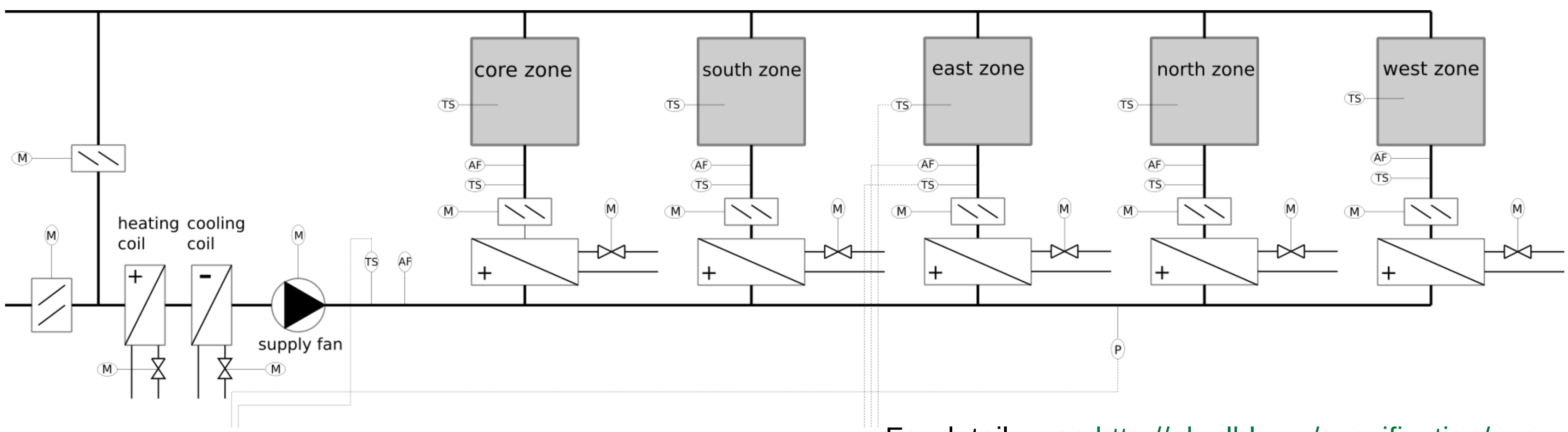
Impacts (demonstrated based on case study)

Two similar VAV sequences, both released in ASHRAE publications, yield <u>30% difference</u> in annual HVAC energy use.

Approach for HVAC & building model:

- Full airflow network.
- Wind pressure driven infiltration.
- All flows based on flow friction, damper positions and fan curves.
- 4,000 components, 40,000 variables (generated from high-level declarations)
- adaptive time step based on error control, state- and time-events.





For details, see http://obc.lbl.gov/specification/example.html

Impacts

DOE/BTO:

- Potential to reduce HVAC energy by 20% to 30%, solely due to better control sequences
- Have tools for dynamic assessment of energy/peak load reduction through integrated systems (HVAC, façade, grid), including path towards hardware-in-the-loop and control deployment
- Path towards development & publication of more sophisticate control sequences, such as for energy-aware, grid-flexible buildings

Mechanical designer:

- Adapt, test and specify control sequences (and verification tests) for particular building
- Reduce risk that building does not meet energy target due to control discrepancies

Control provider:

- Faster, higher quality, error-free automated implementation
- Get non-ambiguous control specification from designer

Commissioning provider:

- Semi-automated verification of compliance with design intent, using formal tests from designer

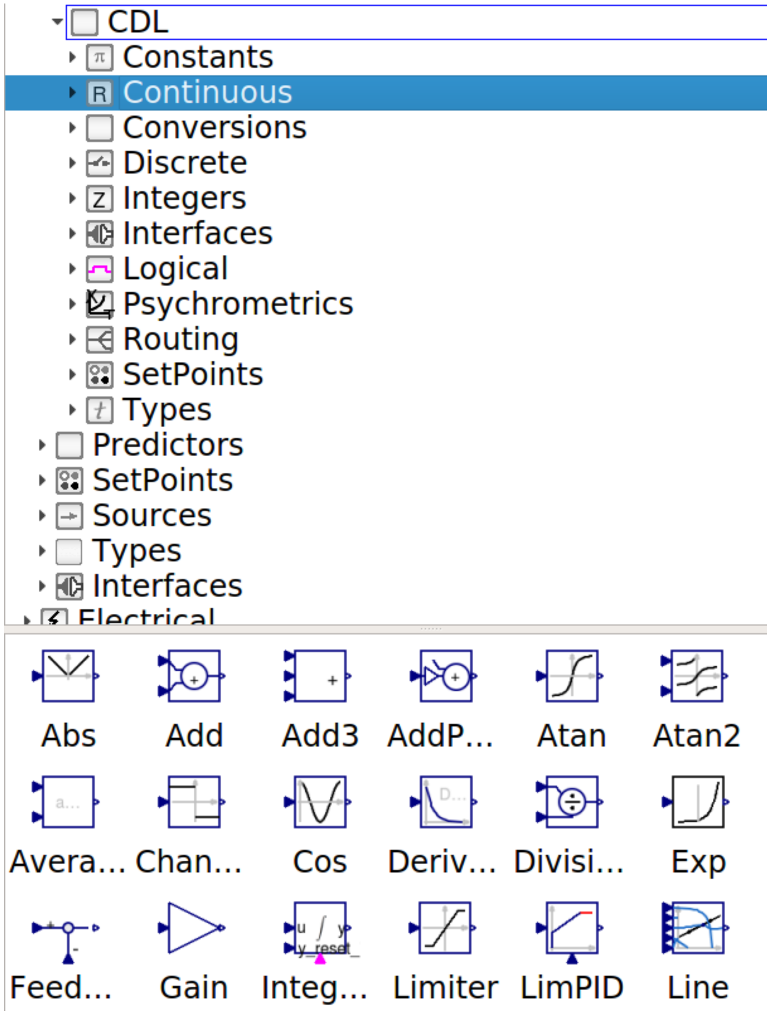
ASHRAE Committee:

- **Guideline 36:** Formal way to test, compare and publish sequences in product-neutral way that can be digitally processed and simulated
- **Advanced Energy Design Guides:** Can include energy-saving sequences in product-neutral way.

Progress

- CDL has been specified
- CDL library has been implemented
- CDL-compliant Guideline 36 sequences have been released and demonstrated; Key Guideline 36 members are very positive
- CDL-based code translation to Building Automation System has been shared; control companies expressed interest in developing translator
- In development:
  - Refine CDL export to JSON and HTML for code generation and English language documentation
  - Verification tool
  - Sequences for primary system

For CDL specification, see http://obc.lbl.gov/specification/cdl.html

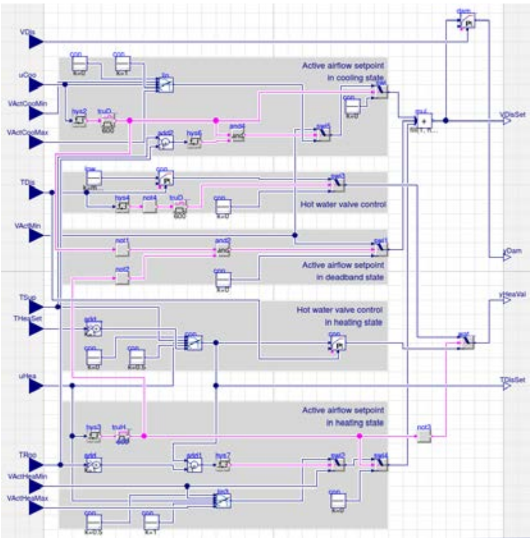


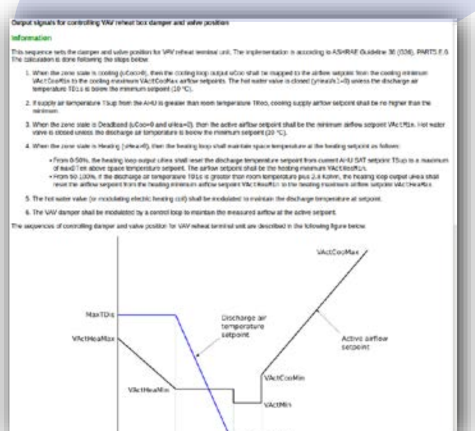
Partial view of CDL library with elementary blocks.

Progress

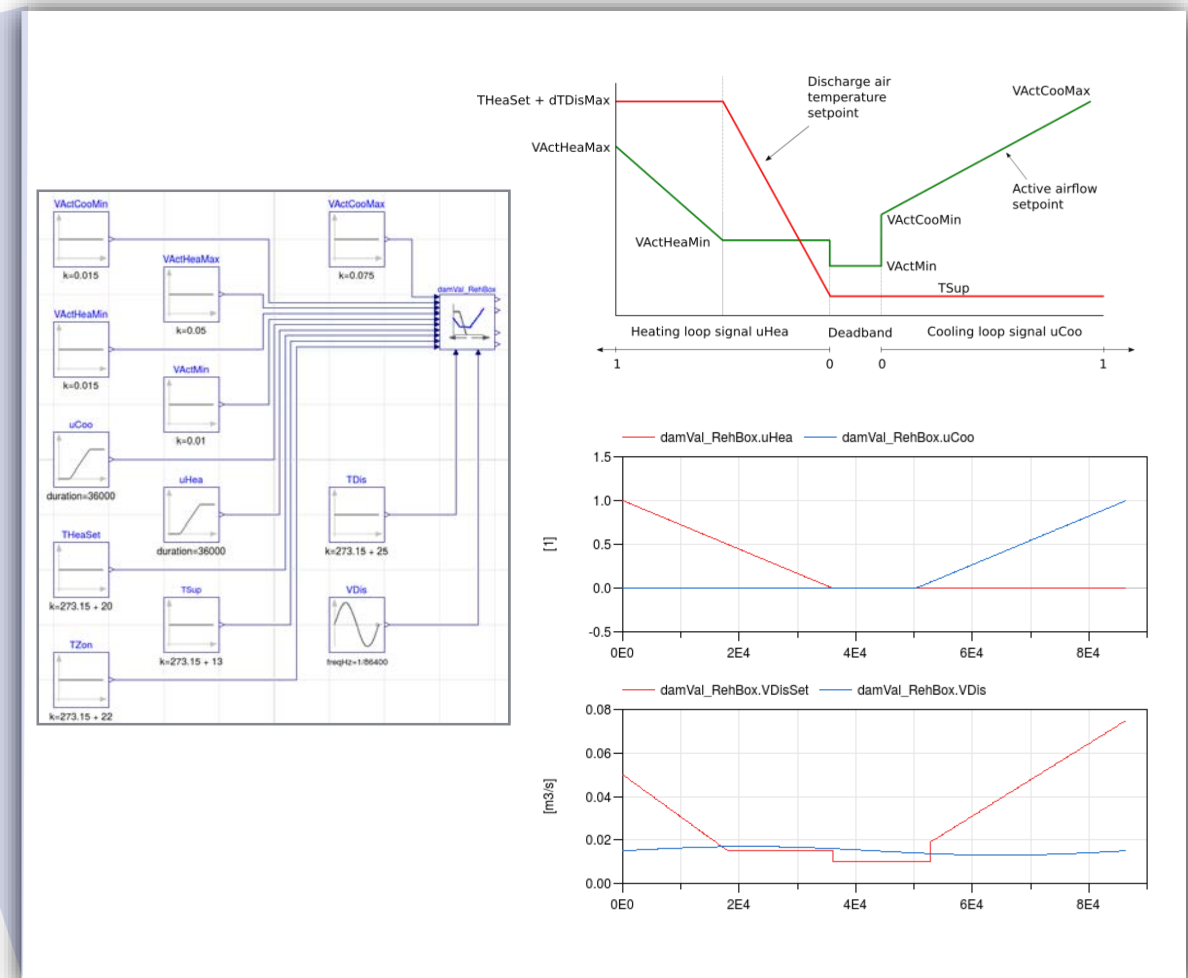
Implemented ASHRAE Guideline 36 Sequences and demonstrated to the committee

Block-diagram view.





Autogenerated documentation.



Examples and validation tests.

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

Stakeholder Engagement

- Building designers:
  Key design firms (ARUP, Integral Group) are part of project team
- ASHRAE:
  - Key guideline 36 and TC 1.4 members are part of project team
    (Steve Taylor, Brent Eubanks, Mark Hydeman)
  - Project presented to ASHRAE Guideline 36 Committee, strong support among key members of Guideline 36 Committee
- Large building owners:
  Oracle and Stanford Facilities are part of project team, and Oracle was selected for case study site.
- Commissioning agents:
  Part of project team (Facility Dynamics)
- Control providers are part of TAG

- Next generation Building Energy Modeling:
  PI also leads “Spawn of EnergyPlus” and coordinates work internationally through IBPSA Project 1 (e.g., with Engie and simulation tool developers)

Remaining Project Work

Near future

- Implementation of verification tool.
- Assist control vendors in developing prototype CDL translators.
- Implementation of sequences for primary systems.
- Specification of control design tools.

Beyond scope of this project

- Deploy through Spawn of EnergyPlus, integrated into OpenStudio.
- Have ASHRAE use OpenBuildingControl to evaluate and prioritize sequences for inclusion in Guidelines, and as reference against which vendors will be certified to be Guideline 36 (or subsequent guidelines) compliant.
- Work with ASHRAE to use CDL as the format for future Guidelines.
- Standardize CDL language for control logic, like BACnet for communication.
- Use for plant and control emulation in BOPTEST (DOE/IBPSA Project 1) and Alfalfa (DOE).

Thank You

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REFERENCE SLIDES

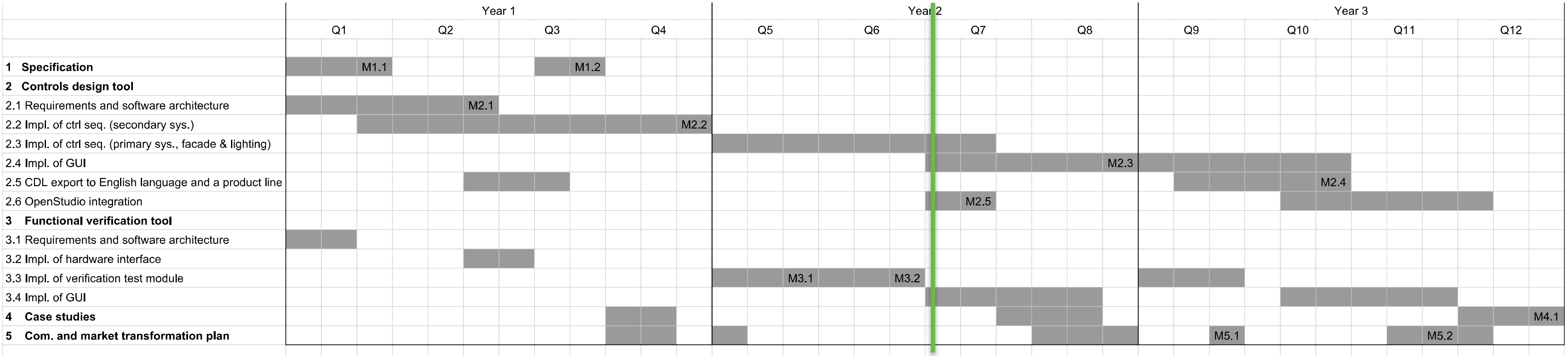
Project Budget

Project Budget: Spending has been conservative due to delays in subcontracting and in signing CEC cost-share agreement of $1M
Additional Funding: Simulation engine development is conducted through DOE "Spawn of EnergyPlus", with substantial contributions through IBPSA Project 1 for model development.

Budget History					
10/1/2016 – FY 2017 (past)		FY 2018 (current)		FY 2019 – 11/30/2019 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
504k (LBL)** +48k (subs)	107k (in-kind)*	773k (LBL)** +160k (subs)	107k (in-kind)*	1023k (LBL) +624k (subs)	107k (in-kind) *

* CEC cost share of $1M not accounted yet as the contract is still in final negotiations between LBL and CEC
** LBNL spending conservative until CEC cost share is signed

Project Plan and Schedule



Project is on track, with minor modifications:

Subtask 2.2: Shifted back by a couple of months as obtaining specifications for control sequences of primary systems took longer than anticipated.

M3.2: Shifted back two months as obtaining control response from actual building took longer than anticipated.

Subtask 2.4: Resources will be focused on specification of GUI for control design rather than on actual implementation. (Actual implementation will be done through OpenStudio/Spawn projects.)

Task 5 had a late start due to negotiations with subcontractor that leads this task.