Adaptive Model-based Predictive Control and Machine Learning

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2019 Haystack Connect
Smart Data. Smart Devices. Smart Buildings. Smart Business.

Modern buildings: connected energy hubs

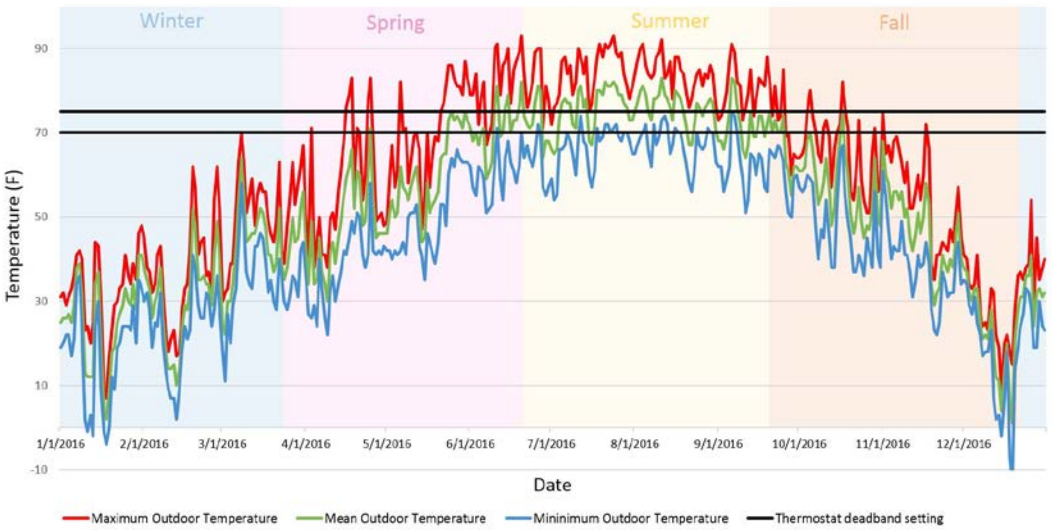
Human Centric, Reliable, Sustainable, Secure

- *Uncertainty*, Diversity,
- Actuation, Sensing,
- Cyber-Physical system
- Many stakeholders
- Bi-directional flow of power
- Energy hub

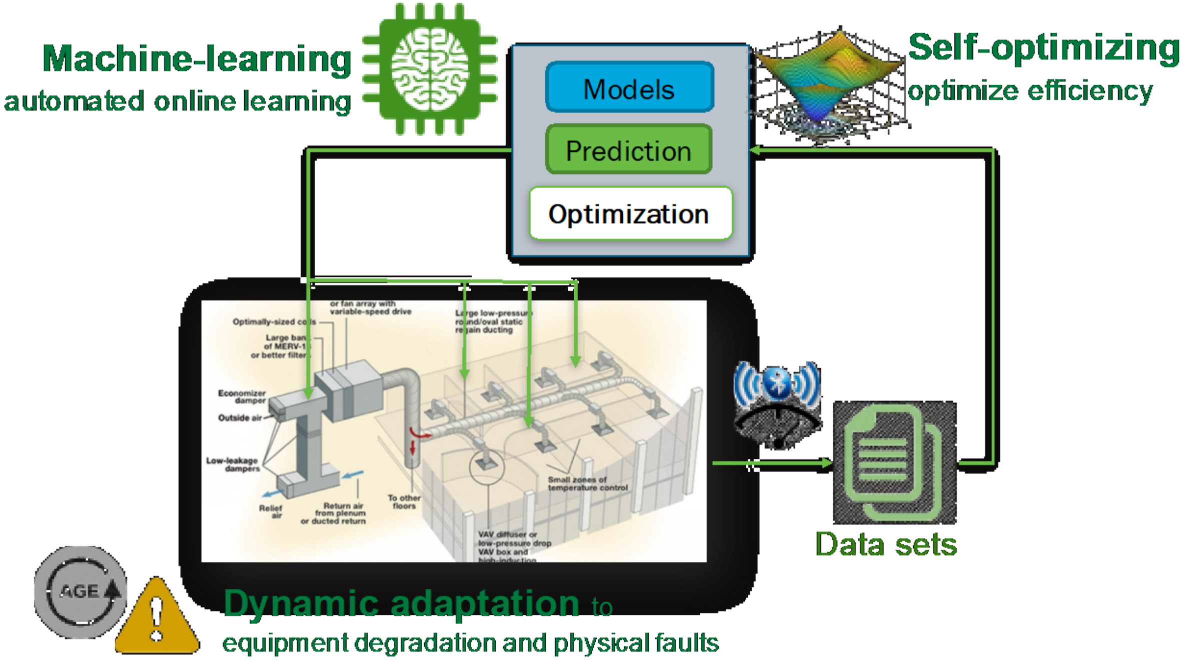
Buildings operate under uncertainty

- Controls are tuned for the worst day
- Seasonal and daily variations of loads driven by weather
- Weekly and daily variations of loads driven by occupancy
- Equipment aging and degradation

Daily mean outdoor air temperature, Chicago 2016



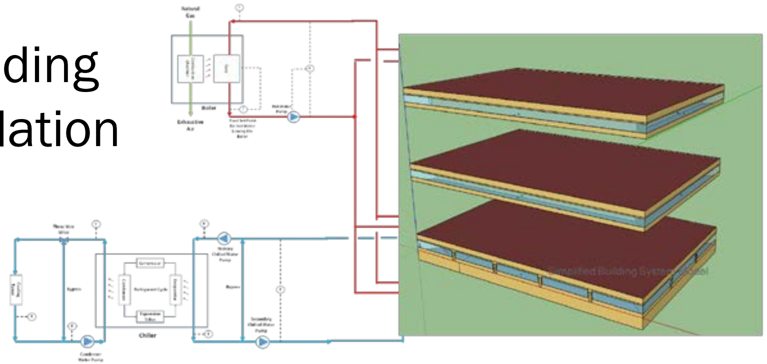
Adaptive Control



- Optimize supervisory control decisions
- Adapt operation to uncertainty

Testing environments

Building Emulation



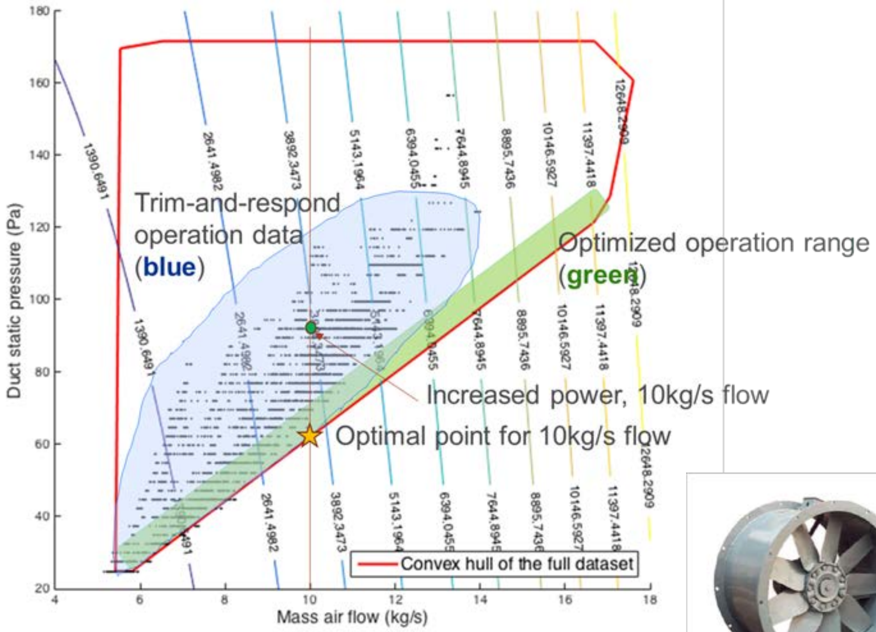
High Throughput Computing

ORNL Test Building

PNNL Living Laboratory

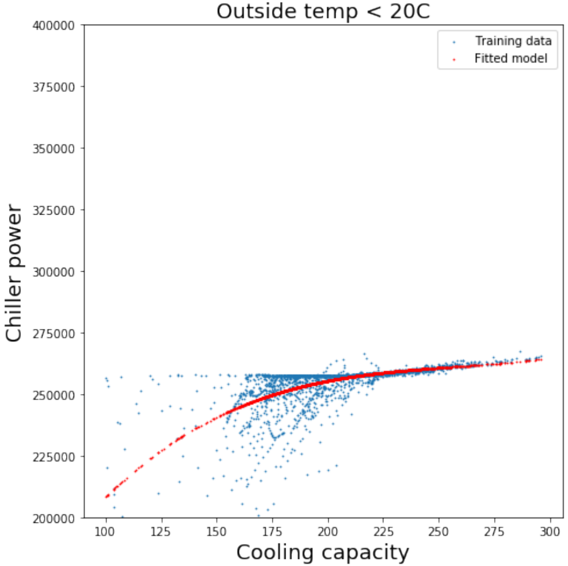
Machine Learning Models

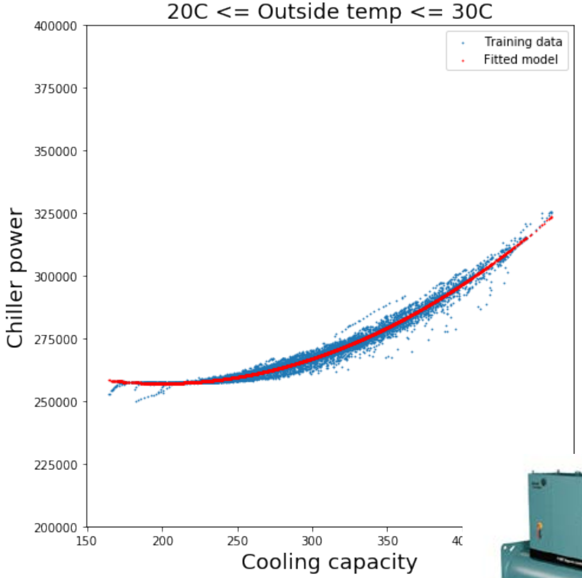
- Learn equipment performance from data
- Online learning algorithms minimize deployment cost

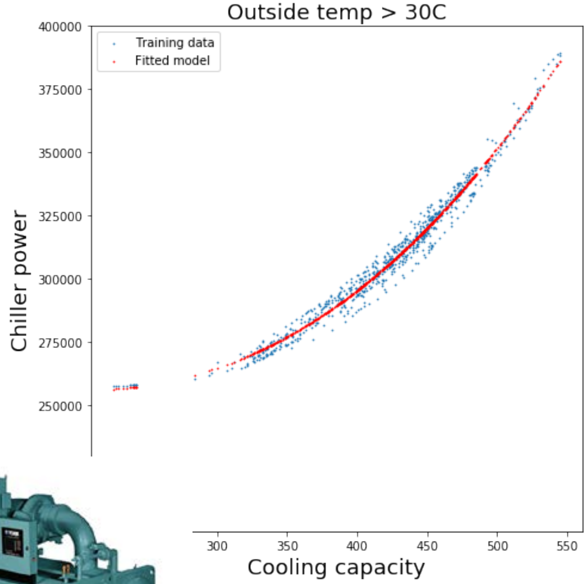


Machine Learning Models

Map chiller delivered cooling capacity to power consumption

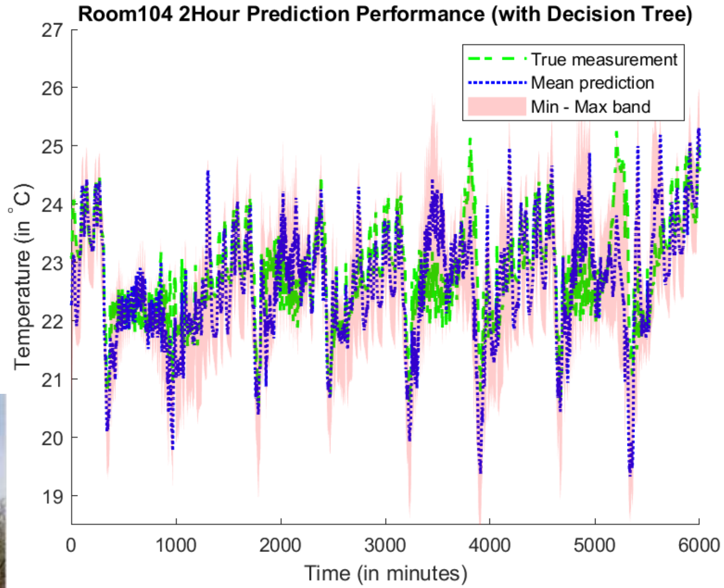




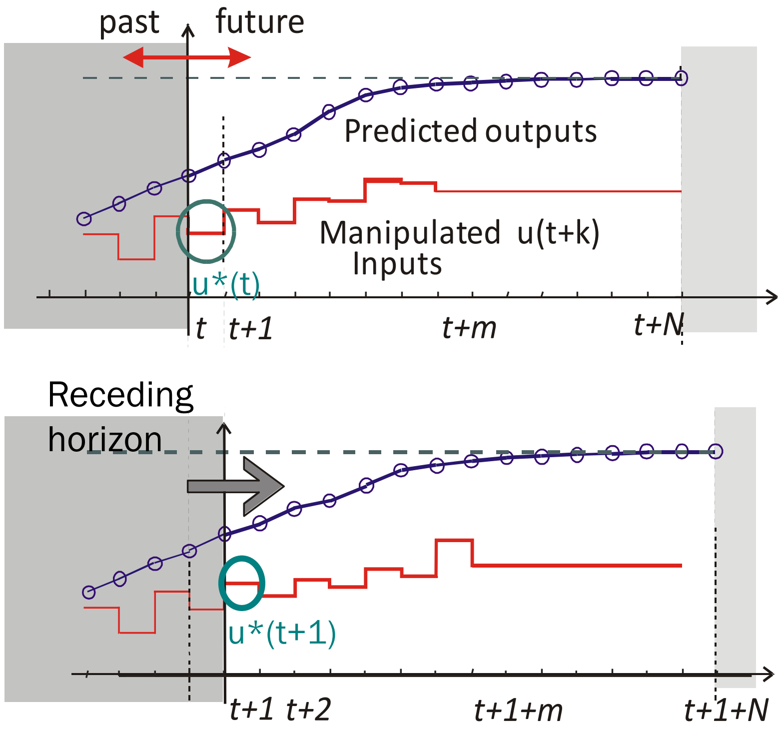


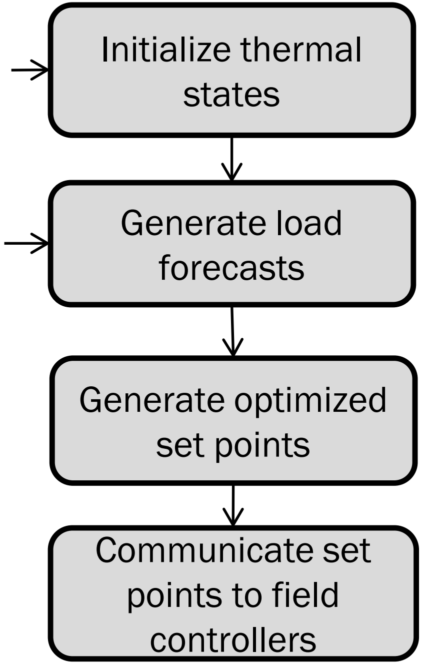
Machine Learning Models

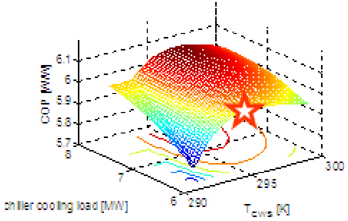
- Learn models that predict zone temperatures with high accuracy
- Trade simplicity vs accuracy



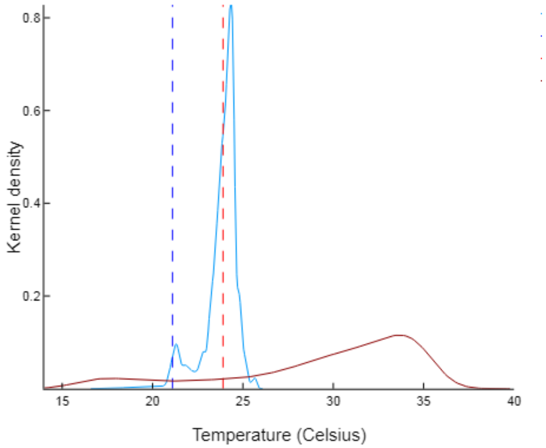
Optimization: Model-based Predictive Control

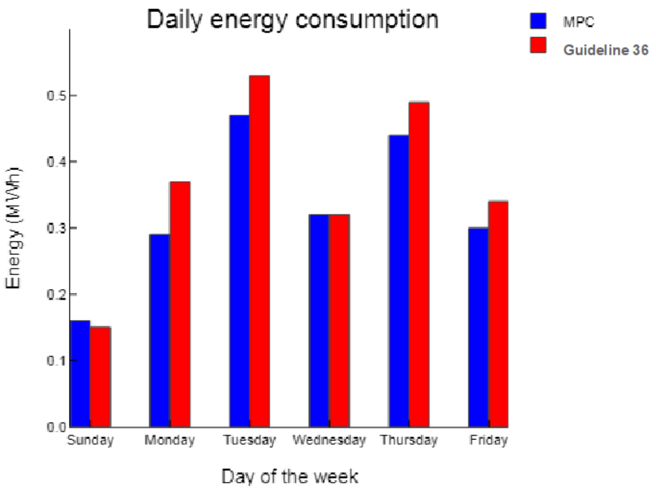


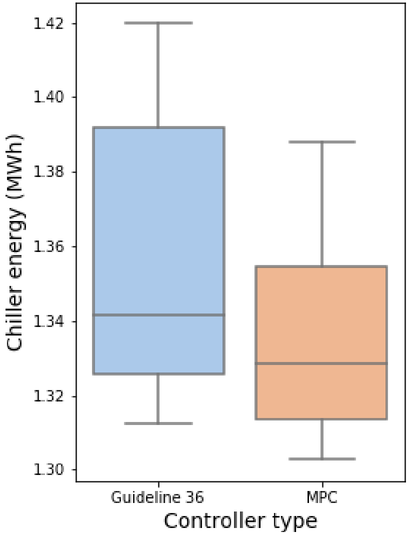




Performance evaluation



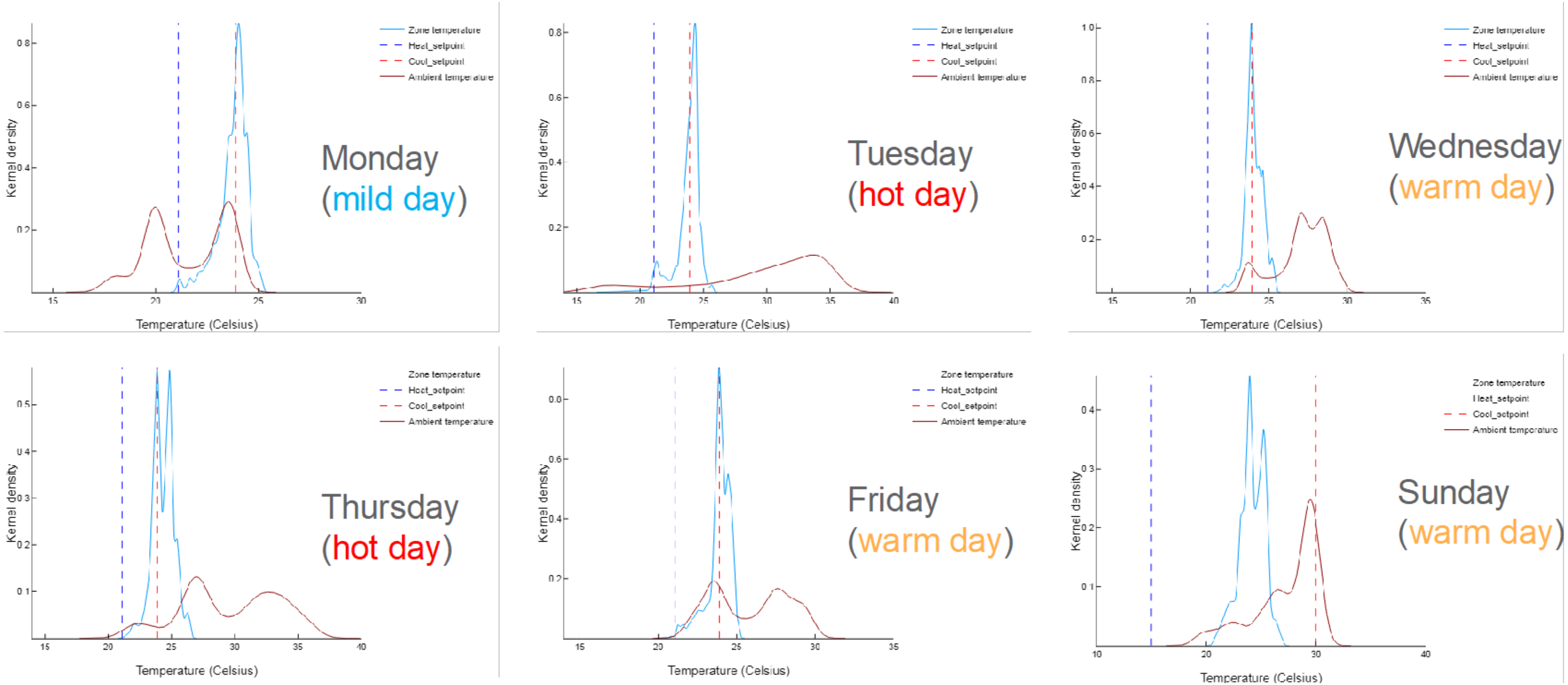




Comfort: distribution of temperature in the zones

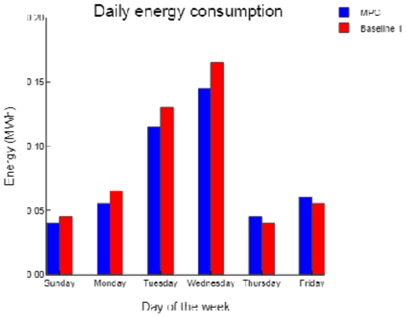
Energy Reduction w.r.t. best in class sequences

Thermal Comfort Performance



Performance evaluation

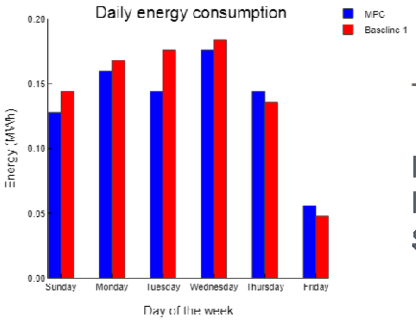
November 12 (Monday) – 17 (Friday)



Total energy consumption

MPC = 0.45 MWh
Baseline1 = 0.52 MWh
Savings (%) = 8.1%

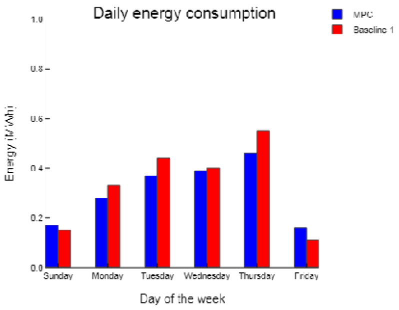
April 31 (Monday) – May 5 (Saturday)



Total energy consumption

MPC = 0.81 MWh
Baseline1 = 0.86 MWh
Savings (%) = 5.8%

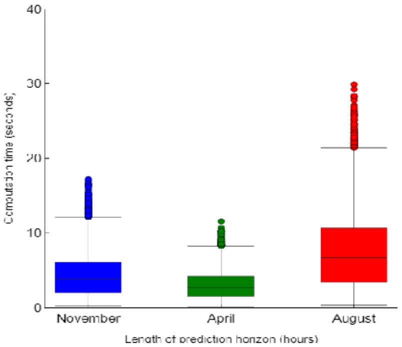
August 6 (Monday) – August 11 (Saturday)



Total energy consumption

MPC = 1.83 MWh
Baseline1 = 1.98 MWh
Savings (%) = 7.5%

Average Computation Time

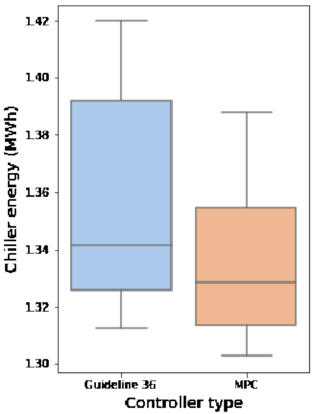


All data in seconds

Week	Avg.	Min	Max
Nov	3.10	0.18	18.65
Apr	2.91	0.11	11.32
Aug	6.97	0.19	31.47

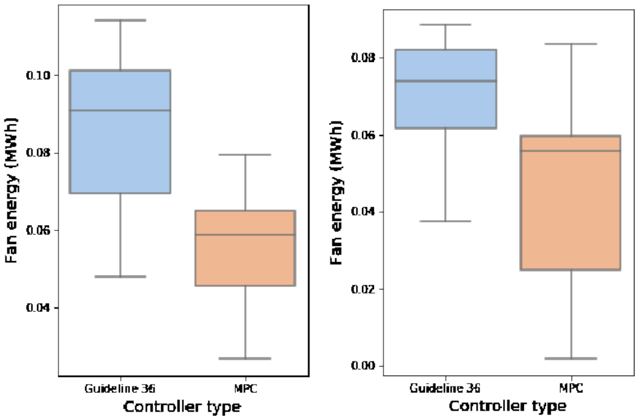
Weekly Energy Savings for Different Seasons

Chiller energy consumption



Summer

Fan energy consumption

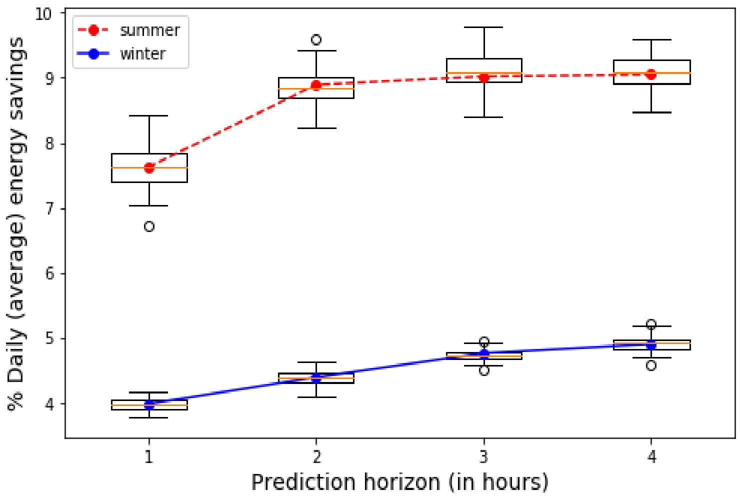


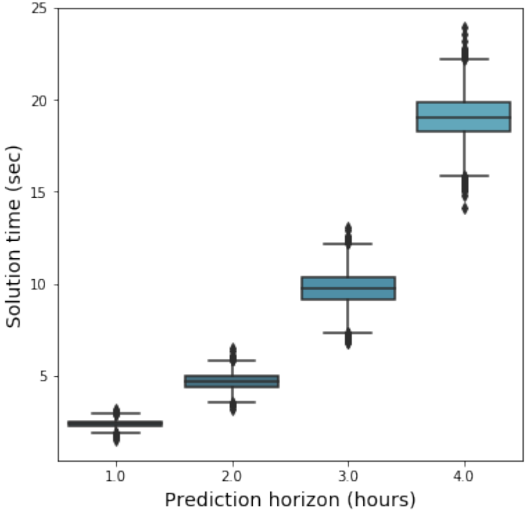
Summer Winter

Average weekly energy consumption (Chiller + Fan)

Season	# Weeks	Guideline 36	MPC	% Savings
Summer	10	1.47 MWh	1.35 MWh	**8.71 %**
Winter	8	0.54 MWh	0.52 MWh	**3.89 %**

Prediction benefit





Energy performance and computation requirements w.r.t. prediction horizon

Contact details

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Thank you

OpenBuildingControl

Michael Wetter
Lawrence Berkeley National Laboratory

BERKELEY LAB

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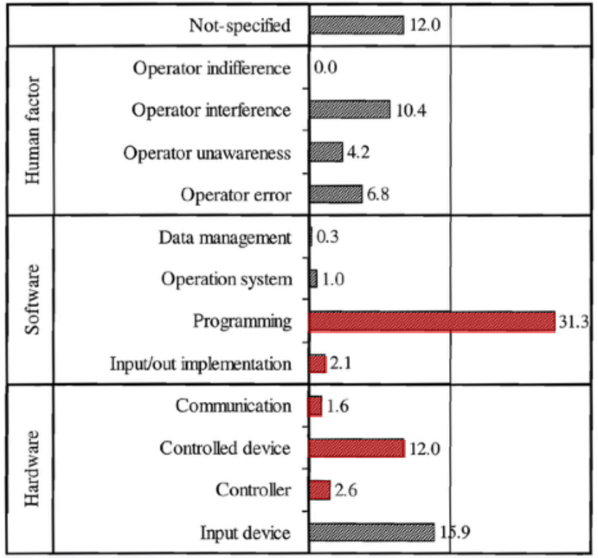
Programming errors are the leading cause of controls-related problems



Control-related problems (Ardehali, Smith 2002).

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

Process: The process to specify, implement and verify controls sequences is expensive and produces low quality implementation.

Performance: Efficiency, occupant- and grid-responsiveness are the most difficult part to quantify and realize.

Risk: ROI of energy savings may not be achieved. Exposure to risk due to malfunctioning system integration.

Vision

What if

1. **Mechanical designer**
    1. selects best-in-class control sequences from ASHRAE-vetted guidelines from a sequence selection tool,
    2. configures them for their project,
    3. exports them digitally for bidding and implementation, together with verification tests.
2. **Control provider** automatically
    1. bids on the project using this electronic specification
    2. implements these sequences in their building automation systems through code translation, and
    3. gets automatically the Haystack and/or BRICK information from the sequences.
3. **Installer** automatically connects hardware, sequences, FDD methods and energy information systems, using Haystack/BRICK.
4. **Commissioning agent** verifies formally that the sequences are implemented as specified, using the Haystack/BRICK information to connect them to a digital twin of the control systems.

Controls

Sense

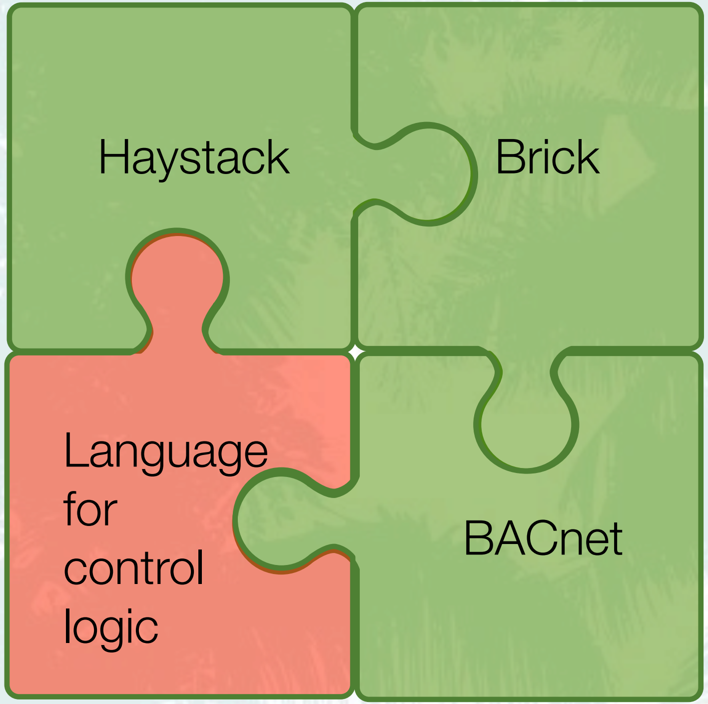
Connect

Communicate

Compute actuation signal

Actuate

What is missing?

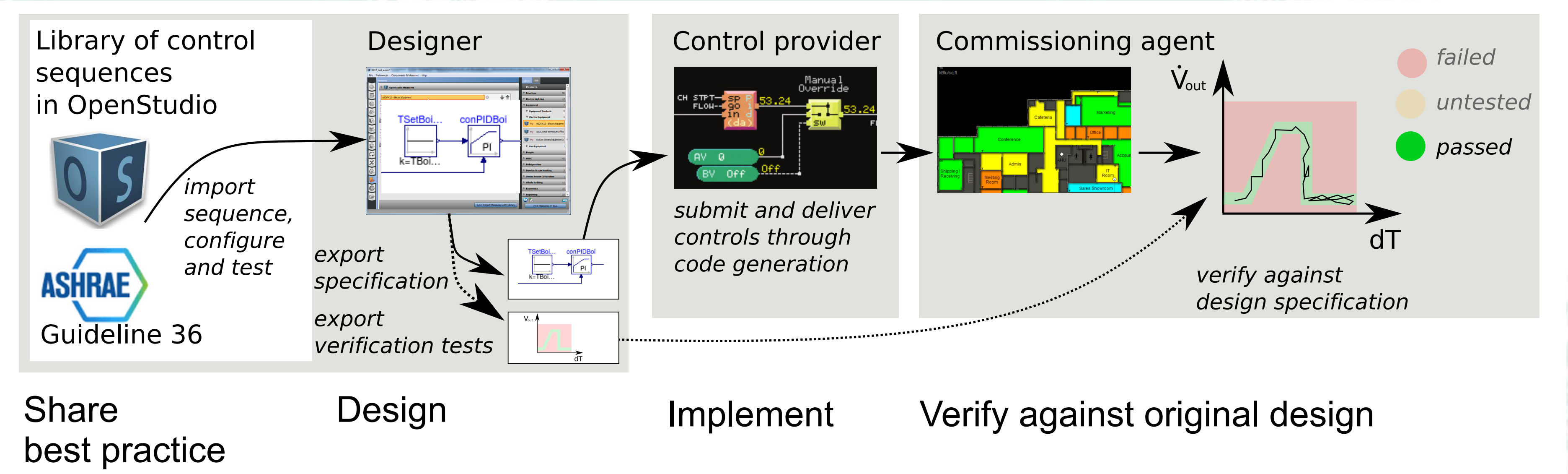


Why now?

Convergence of

- semantic web
- declarative modeling language for building system & control
- collection of best-in-class control sequences
- capability to simulate actual feedback control coupled to energy models
- code generation for machine-to-machine translation
- need for grid-interactive efficient buildings

OpenBuildingControl: Realize energy savings of advanced controls using a formal, highly-automated process



BACnet standardizes communication
OpenBuildingControl standardizes language for sequences

How?

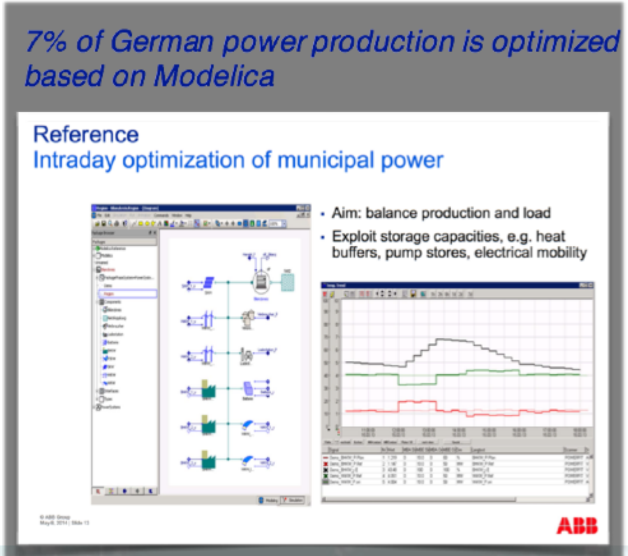
Take the subset of Modelica that is needed for block-diagrams.

Benefits

- Energy performance, e.g., ASHRAE Guideline 36
- Quality: Error-free implementation by construction
- Productivity: Highly automated, elimination of programming errors
- Accountability:
  - Formal process that connects design to operation
  - Formal verification of design intent

MODELICA

Open standard for a language to model dynamic systems. modelica.org

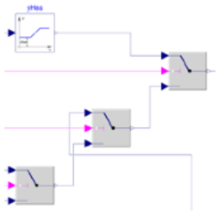


Source: http://new.abb.com/power-generation/power-plant-optimization

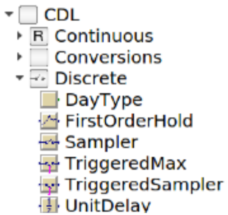
What is the Control Description Language?

A declarative language for expressing block-diagrams for controls.

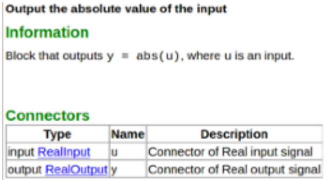
A graphical language for rendering these diagrams.



A library with elementary input/output blocks that should be supported by CDL-compliant control providers.



A syntax for documenting the control blocks and diagrams.



Output the absolute value of the input

Information

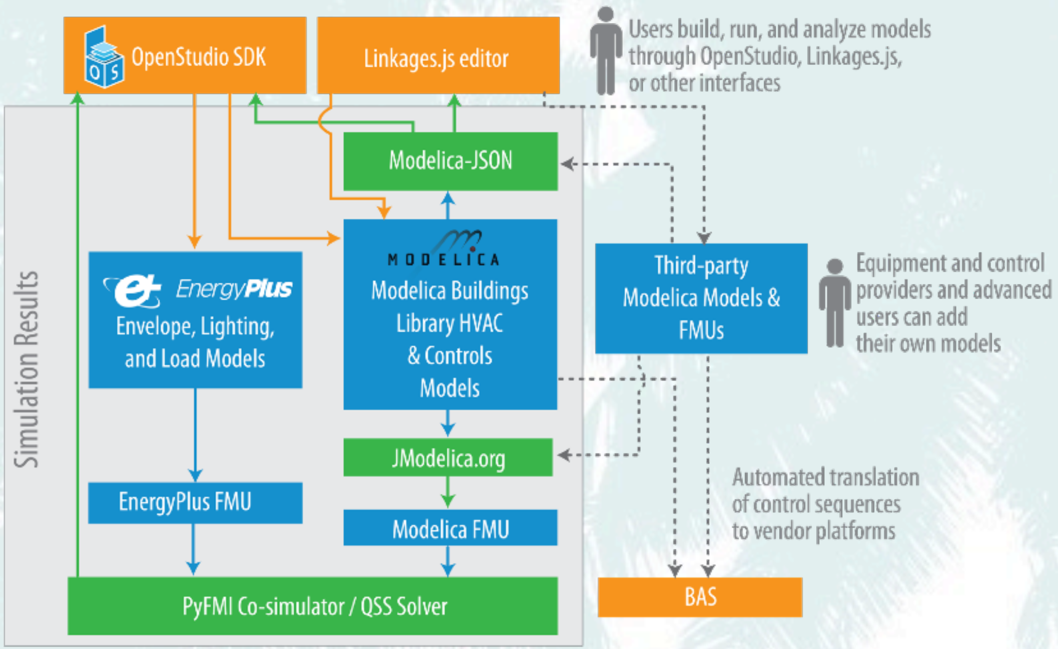
Block that outputs y = abs(u), where u is an input.

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.

How do you test and evaluate the performance of these sequences?



Spawn of EnergyPlus

Allows

- testing of correctness of actual control sequences in simulation coupled to energy model
- assess their energy and demand flexibility

Will

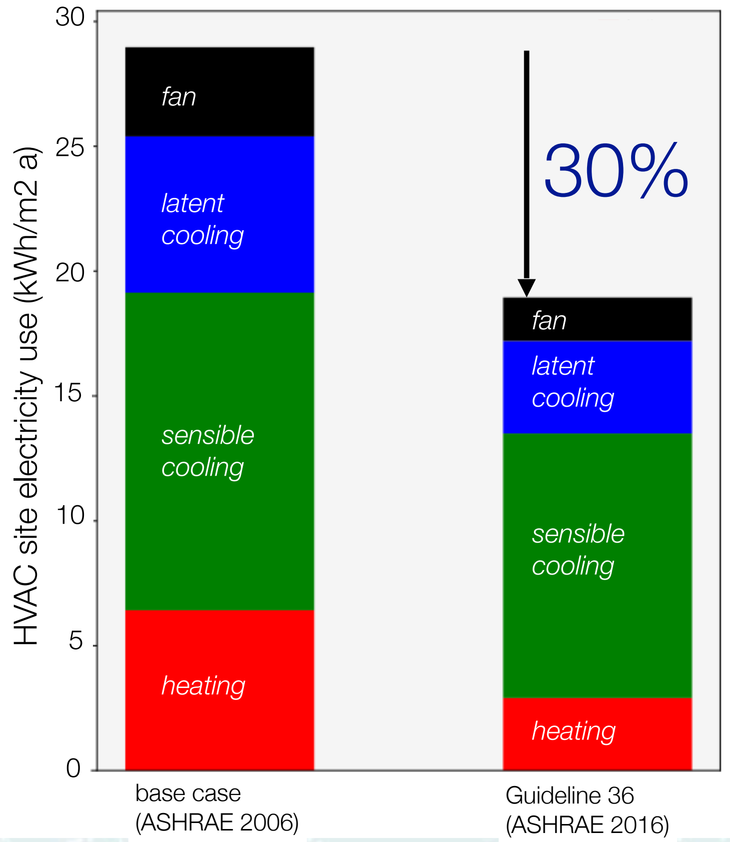
- export control sequences in CDL
- integrate with control delivery process
- export Haystack and BRICK

Why should you care about building energy modeling?

Two similar ASHRAE-published VAV sequences yield 30% different HVAC energy use.

Energy modeling

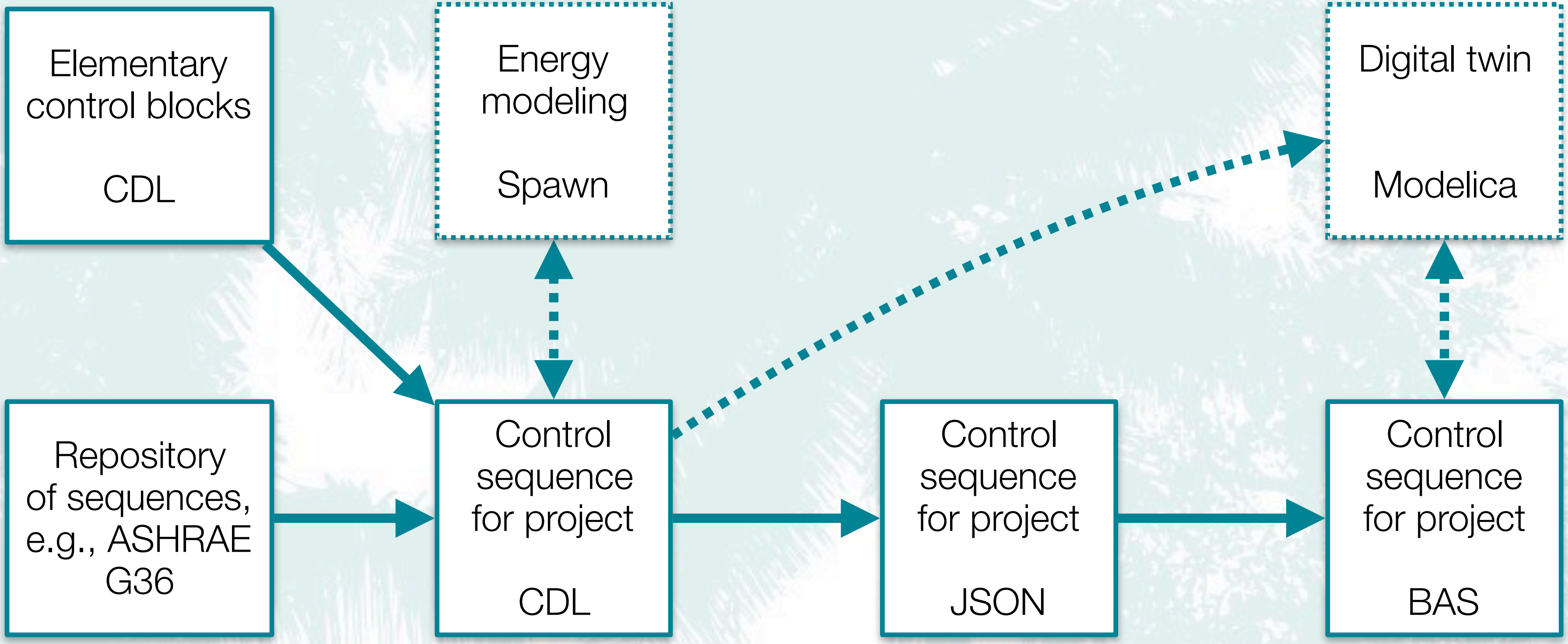
- identifies and helps closing this 30% performance gap,
- yields better control sequences, and
- ensures that savings are realized



See http://obc.lbl.gov/specification/example.html

Michael Wetter, et al.
[OpenBuildingControl: Modeling feedback control as a step towards formal design, specification, deployment and verification of building control sequences.](#)
SimBuild 2018.

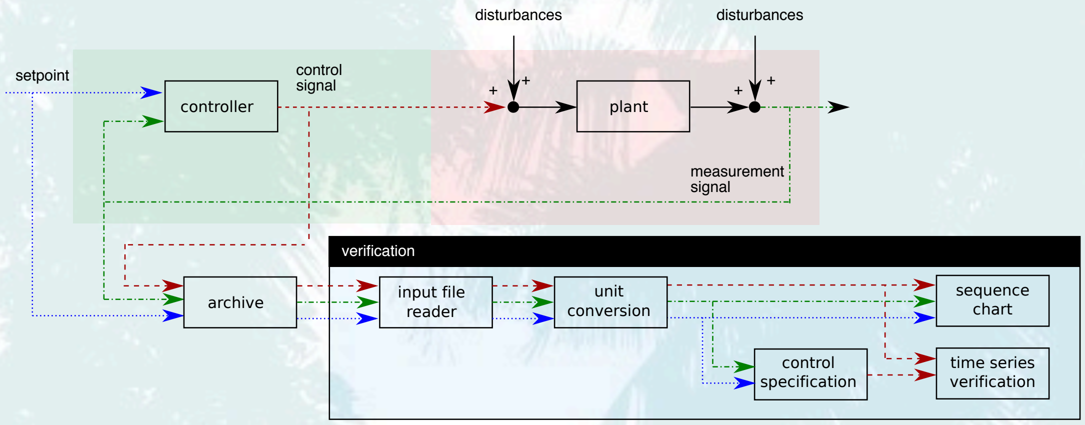
From design to operation

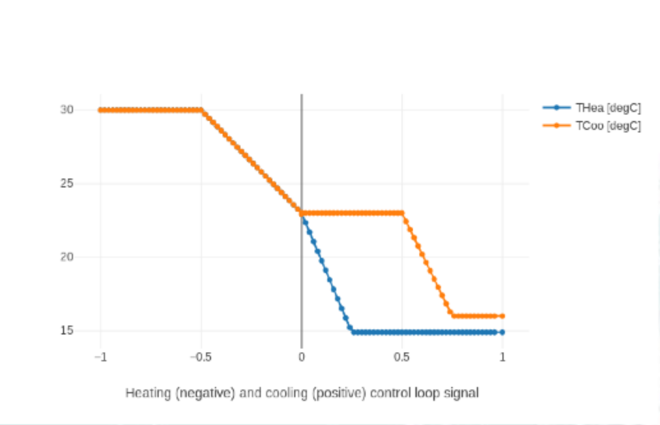


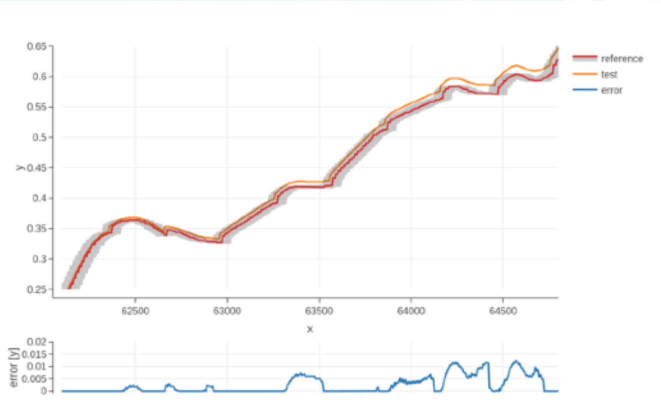
https://obc.lbl.gov/specification/codeGeneration.html

https://github.com/lbl-srg/modelica-json

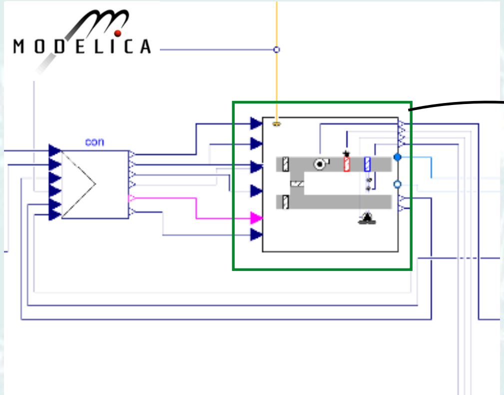
Control verification: Digital twin verifies correct operation

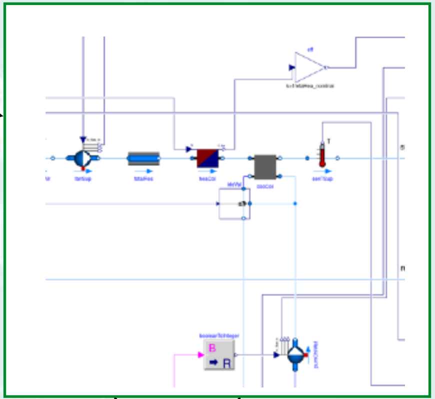




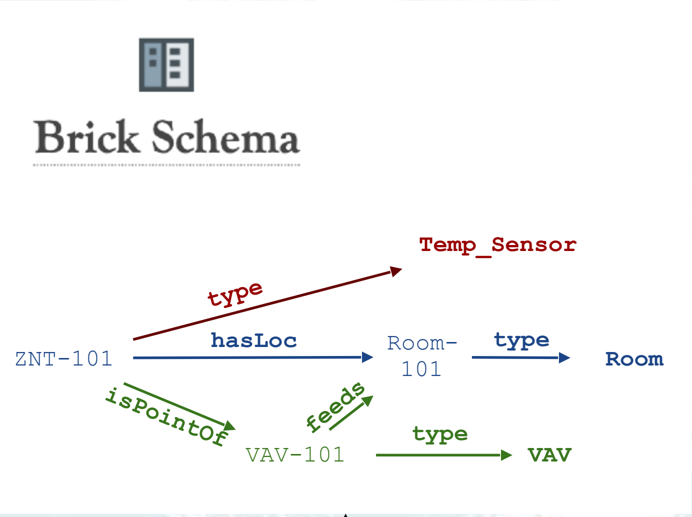


Generate Brick from Spawn (2019-22)





Ontology in json format, as directed graph



Analytics

Digital twin in FMI standard

?

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