Modelica Buildings Library

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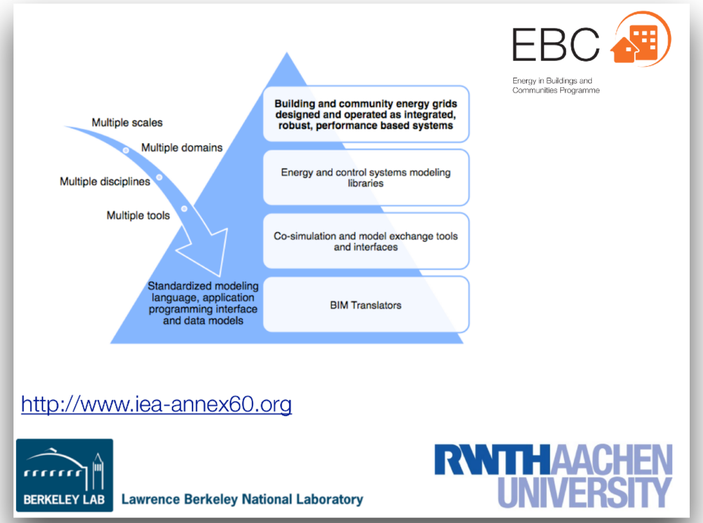
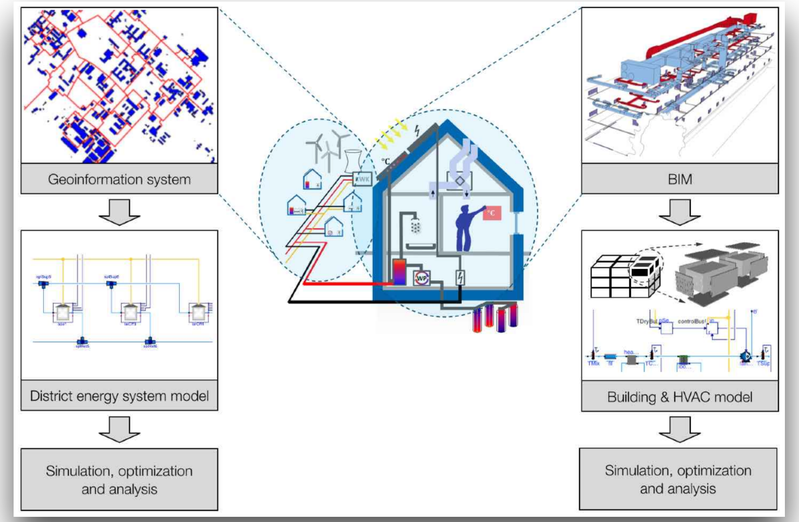
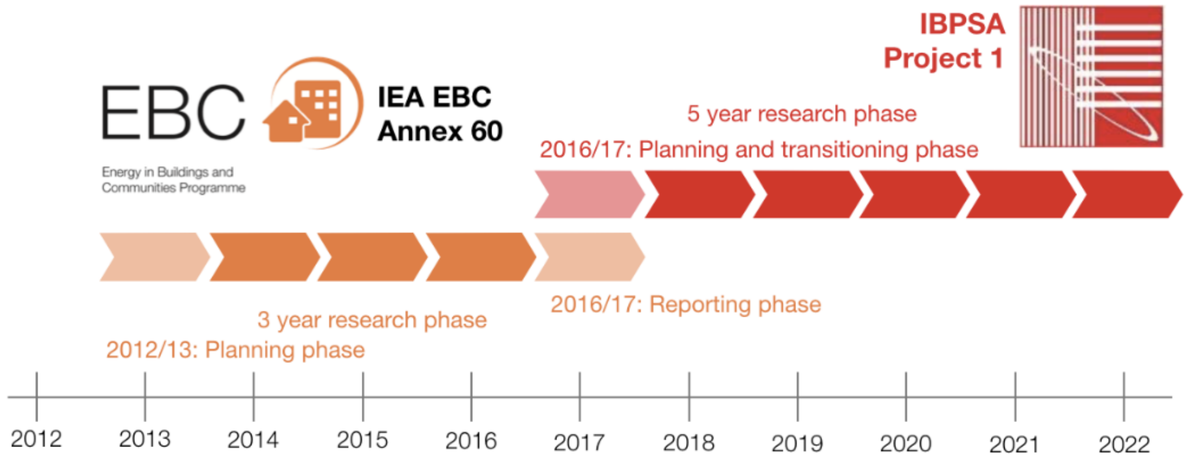
BERKELEY LAB

IEA Annex 60 & IBPSA Project 1 - 50+ institutes collaborating on new generation tools for buildings and districts, now continued as IBPSA Modelica Working Group





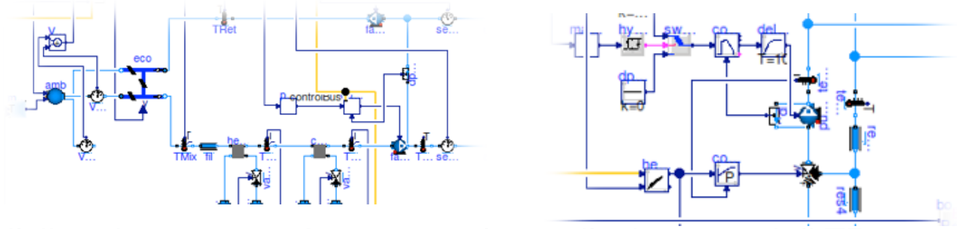


2012-17: iea-annex60.org
2017-22: https://ibpsa.github.io/project1/
2022: https://github.com/ibpsa/modelica-working-group

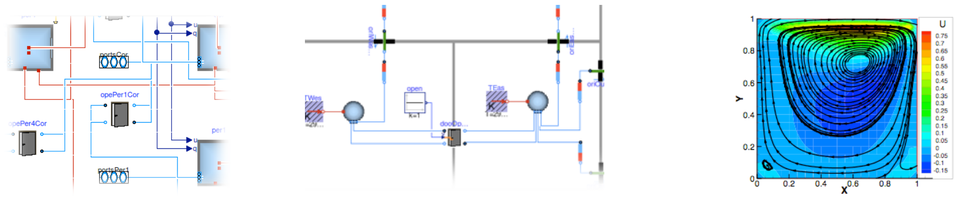
Modelica Buildings Library has 3000+ models and functions

Free open-source repository, 50+ contributors, most cited paper in Journal of Building Performance Simulation since a few years. Co-develop with IBPSA Modelica Library.

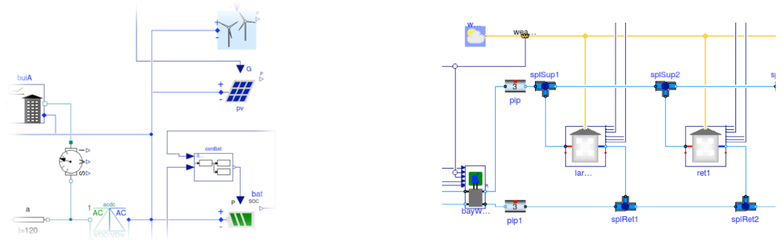
HVAC with realistic supervisory and local loop control

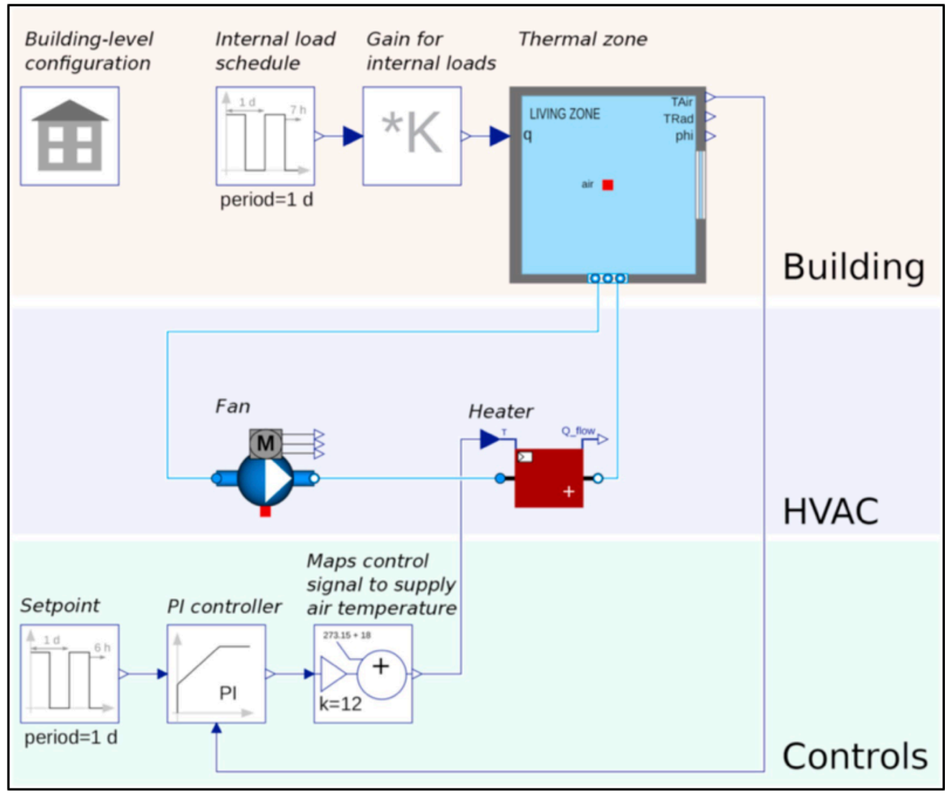


Building heat transfer, natural ventilation, and CFD



Fully coupled thermal, fluid flow, electrical and control simulation





Graphical run-time coupling with Spawn of EnergyPlus

M. Wetter, W. Zuo, T.S. Nouidui, and X. Pang (2014). Modelica Buildings library. *Journal of Building Performance Simulation*, 7(4):253-270.

M. Wetter, K. Benne, A. Gautier, T.S. Nouidui, A. Ramle, A. Roth, H. Tummescheit, S. Mentzer and C. Winther (2020). Lifting the Garage Door on Spawn, an Open-Source BEM-Controls Engine. *Proc. of Building Performance Modeling Conference and SimBuild*, p. 518–525, Chicago, IL, USA, Sep 2020.

Primary use of Buildings library

Main applications

- Model repository for building and district energy simulation, see https://lbl-srg.github.io/soep/
- Development of
  - 5th generation district heating and cooling
  - Data center energy and control systems
  - Heat pump and storage systems
- Controls design and performance evaluation
  - Reference implementation of upcoming ASHRAE Standard 231 “Control Description Language” (obc.lbl.gov)
  - Repository of control sequences in CDL.
- Development and testing of FDD algorithms.

License

- All development is open-source under BSD.

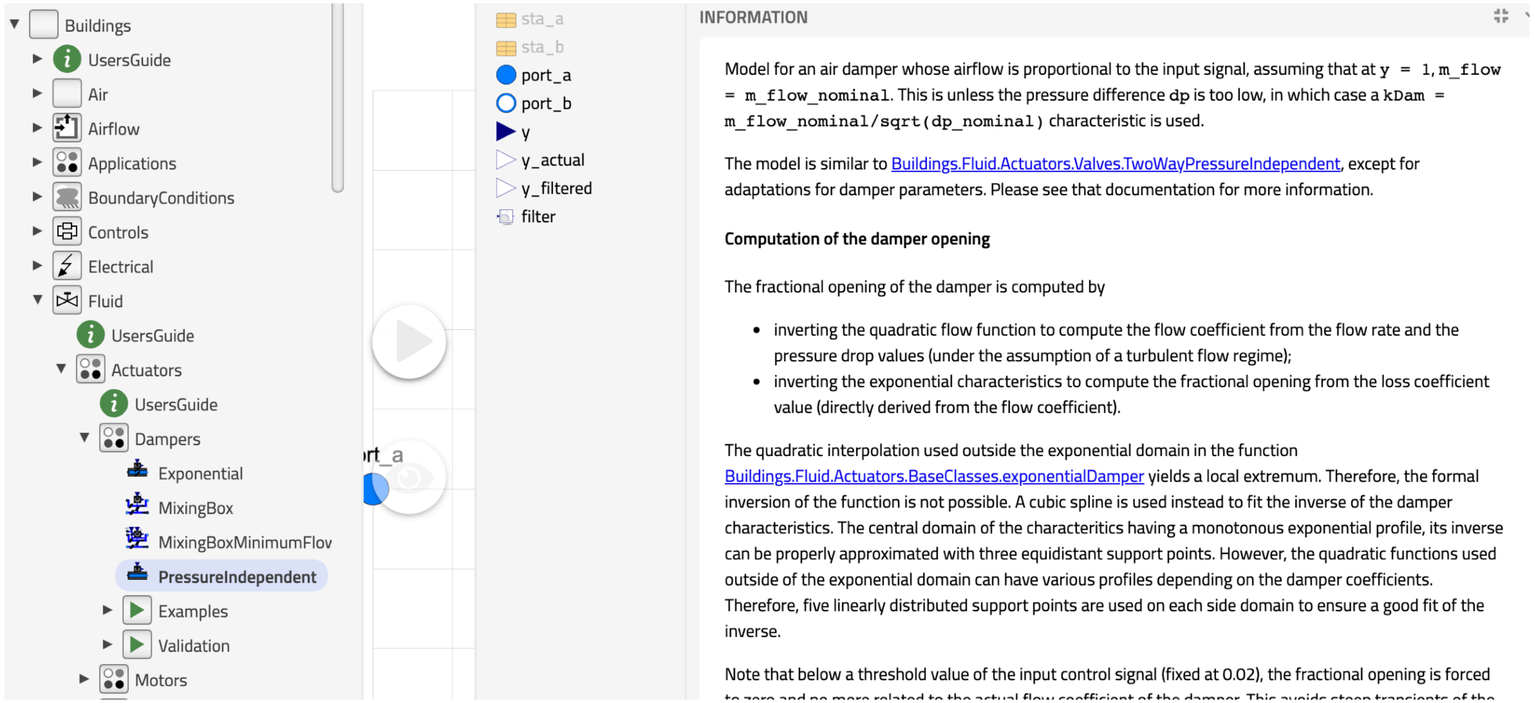
Main modeling assumptions are targeted towards annual simulation

Media	Based on Modelica.Media, but simpler equations for the temperature and pressure range of building HVAC systems. Can track moisture (X) and contaminants (C).
HVAC equipment	Most equipment based on performance curve, or based on nominal conditions and similarity laws. Refrigerant is not modeled. Most equipment optional steady-state or 1st order transient.
Flow resistances	Based on m_flow_nominal and dp_nominal plus similarity law. Optional flag to linearize or to set dp=0.
Room model	- *Detailed*: Any number of constructions are possible. Layer-by-layer window model (similar to Window 6). Optional flag to linearize radiation and/or convection. - *EnergyPlus*: Run-time coupling with EnergyPlus. - *Reduced order*: Two implementations, one for ISO 13790, one for VDI 6007.
Electrical systems	DC. AC 1-phase and 3-phase (dq, dq0). Quasi-stationary or dynamic phase angle (but not frequency).

Documentation and distribution

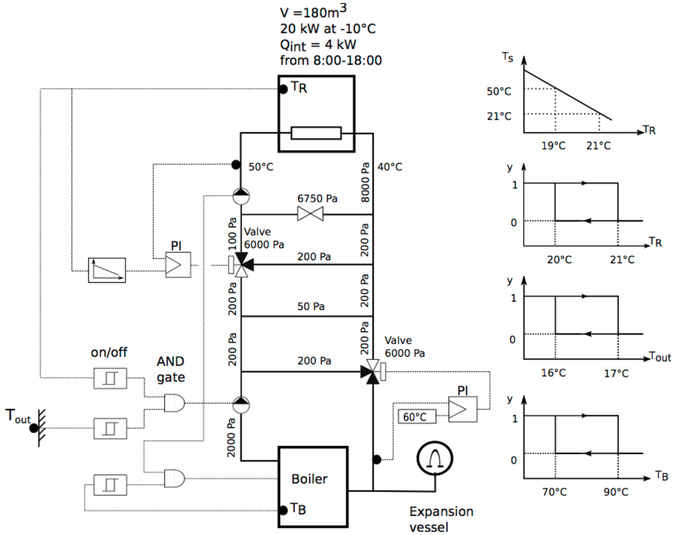
Documentation

- General user guide (getting started, best practice, developer instructions, ...).
- 30 user guides for individual packages.
- 4 tutorials with step-by-step instructions.
- All models contain an “info” section.
- Small test models for all classes, large test cases for “smoke tests,” and various validation cases.
- Papers at http://simulationresearch.lbl.gov/modelica



Distribution

- For users: http://simulationresearch.lbl.gov/modelica
- For developers: https://github.com/lbl-srg/modelica-buildings



Organization of individual packages

Packages are typically structured as shown on the right.

To add a new class, look first at `Interfaces` and `BaseClasses`.

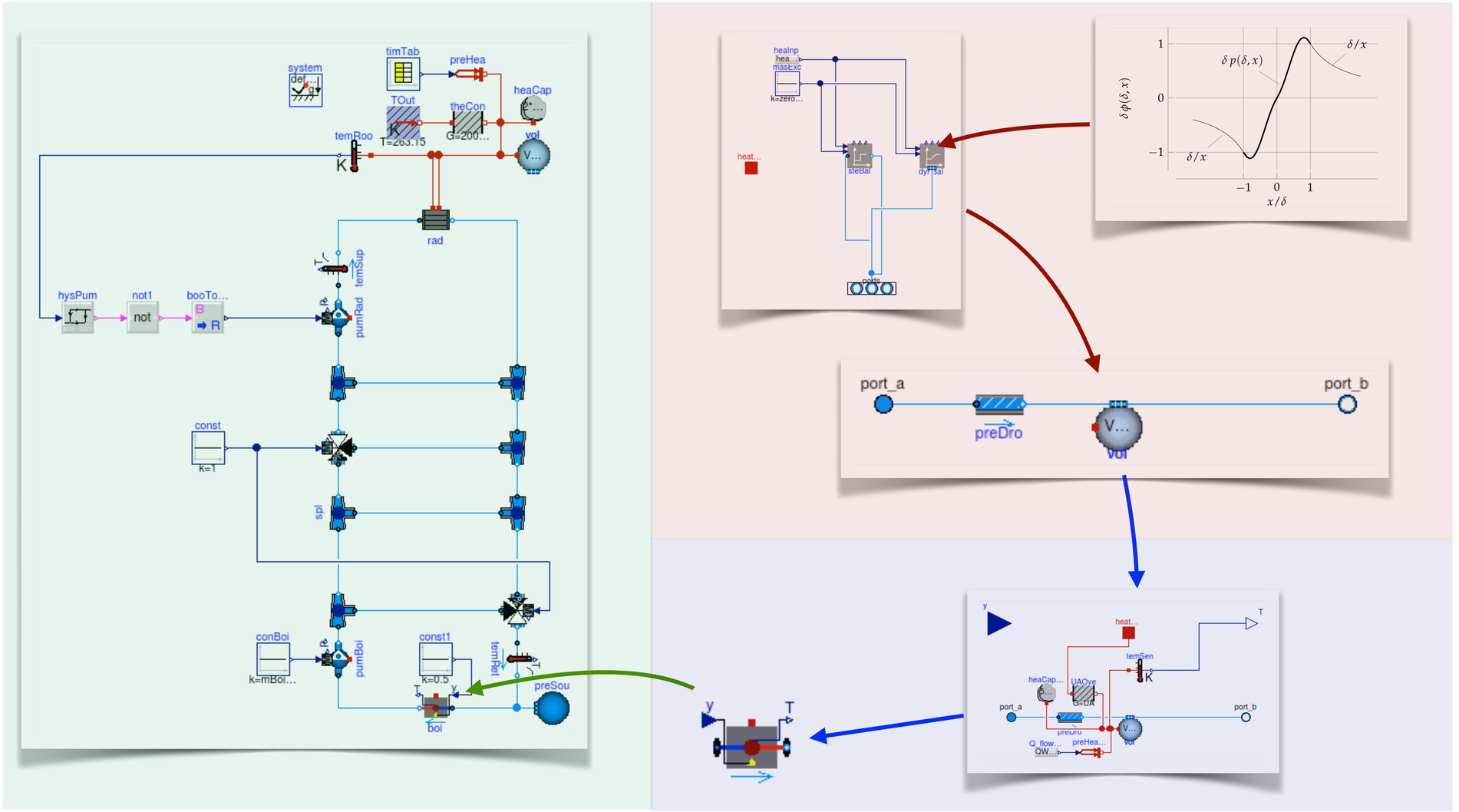
You probably will never implement a component without extending a base class, such as from `Buildings.Fluid.Interfaces`

```
Tutorial
UsersGuide

Any other classes (models,
functions etc.)

Data
Types
Examples
Validation
Benchmarks
Experimental
Interfaces
BaseClasses
Internal
Obsolete
```

Separation between library developer, component developer and end user facilitates model reuse and rapid implementation of new models



Legend:

- Library developer
- Component developer
- End user

Comprehensive set of district energy models enables analysis of 1st to 5th generation DHC

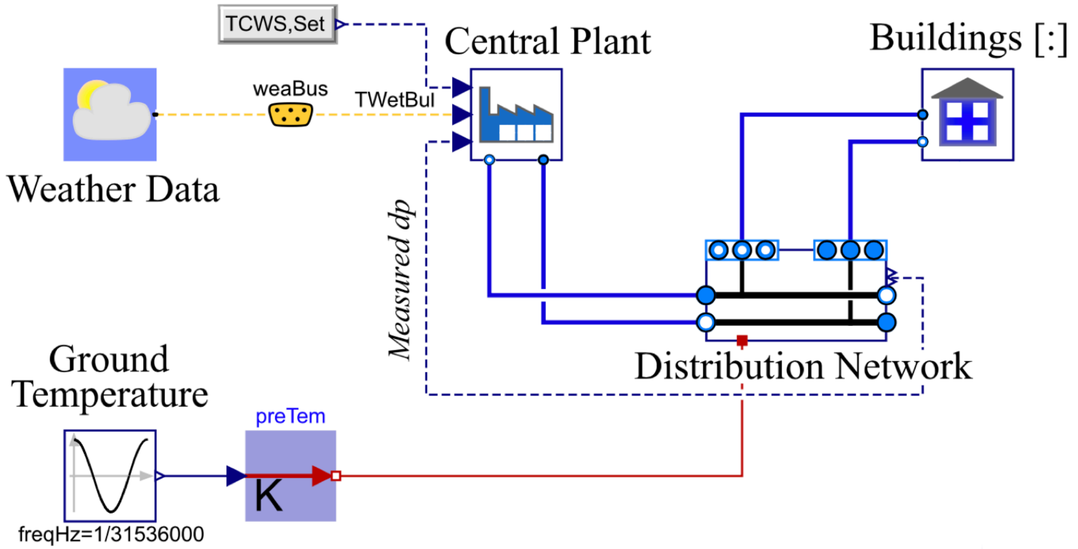
Large variety of thermal and electrical models exists
- 1st to 5th generation district heating and cooling
- AC and DC electrical models

Building Load
- Detailed EnergyPlus models
- Reduced order models
- Time series

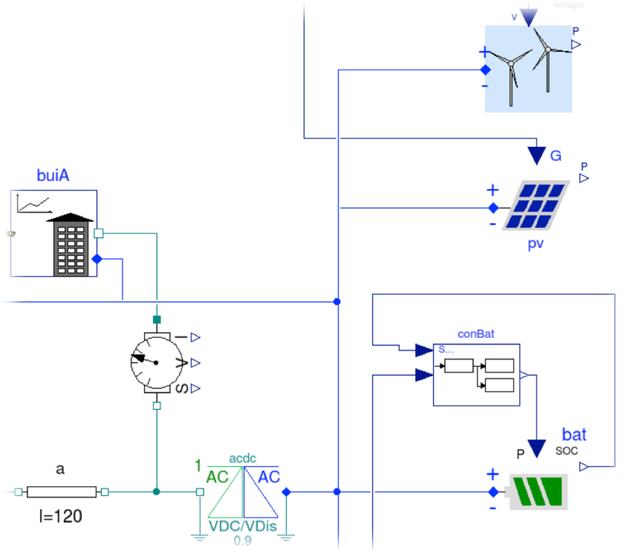
Energy Transfer Stations
- Indirect connection
- Indirect connection with booster heat pump
- Direct connection

Network Topology
- 1-Pipe
- 2-Pipe
- 4-Pipe
- Steam heating

Various storage technologies
- Geothermal (bore fields, zoned bore fields, bore holes and ATES)
- PCM
- Water and ice tanks
- Coupling with detailed geothermal simulators (TOUGH)

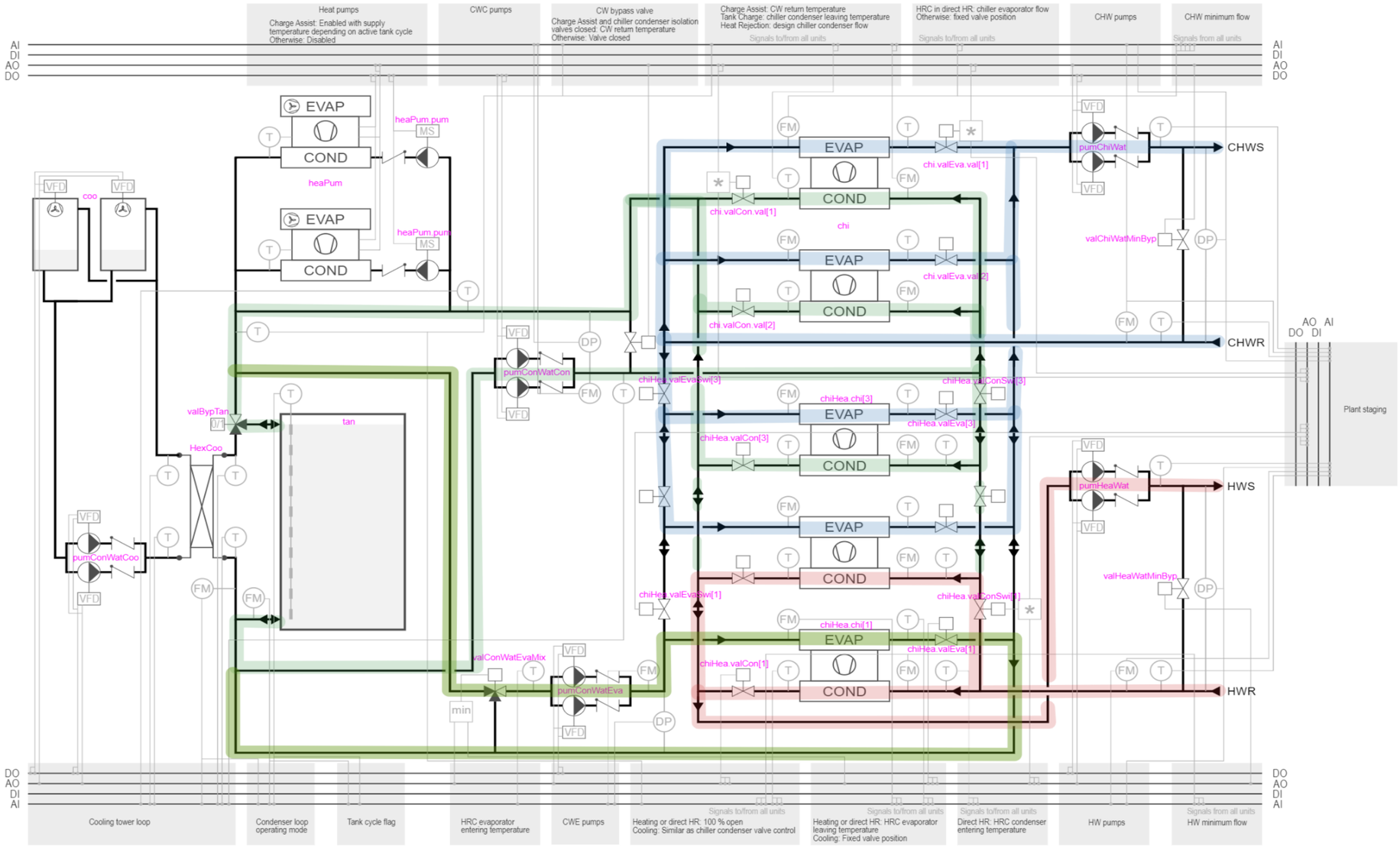


Library has preconfigured district energy systems.



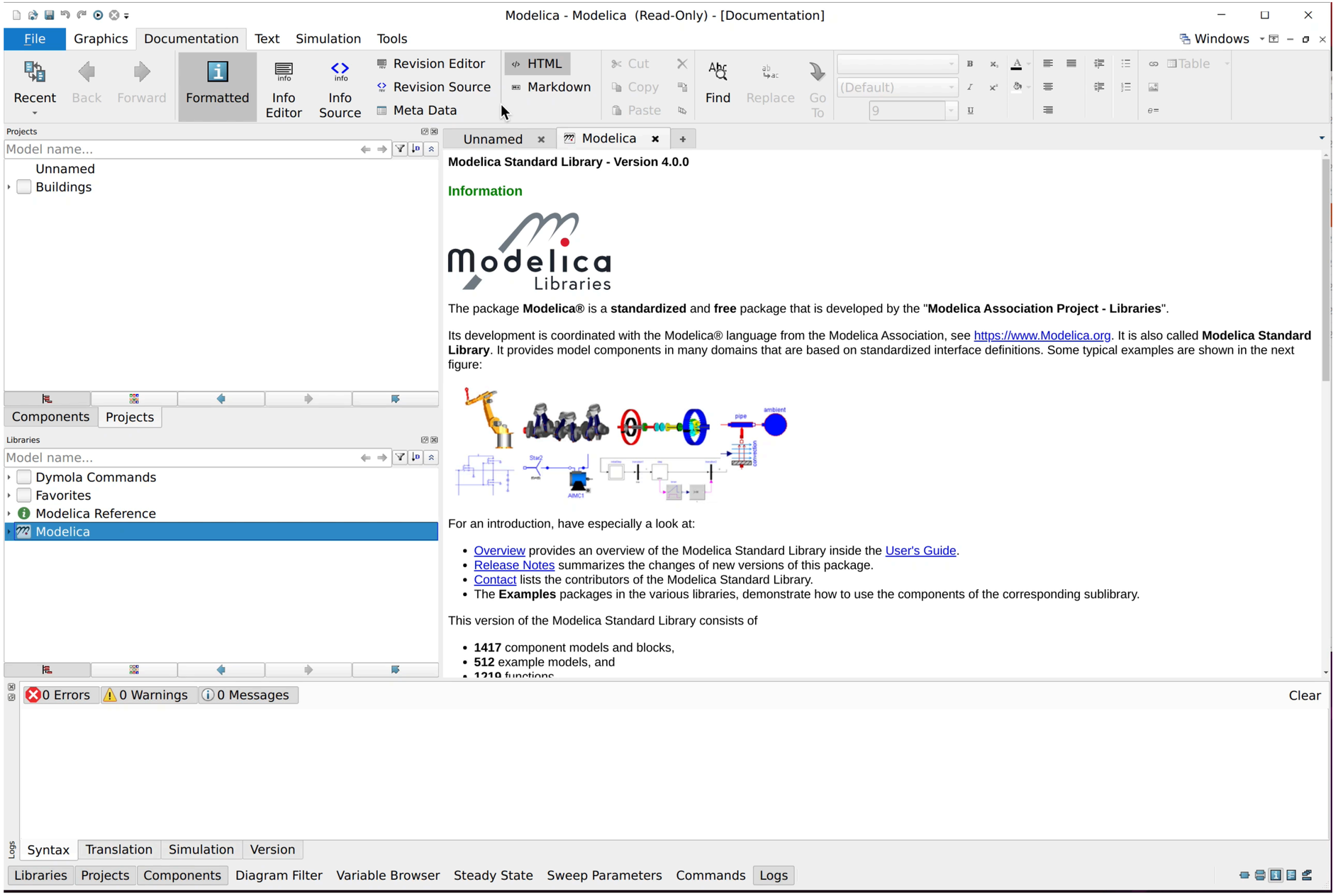
Models for electrical system simulation provide foundation for thermal, electrical, industrial and transportation sector integration.

Example of a heat pump plant



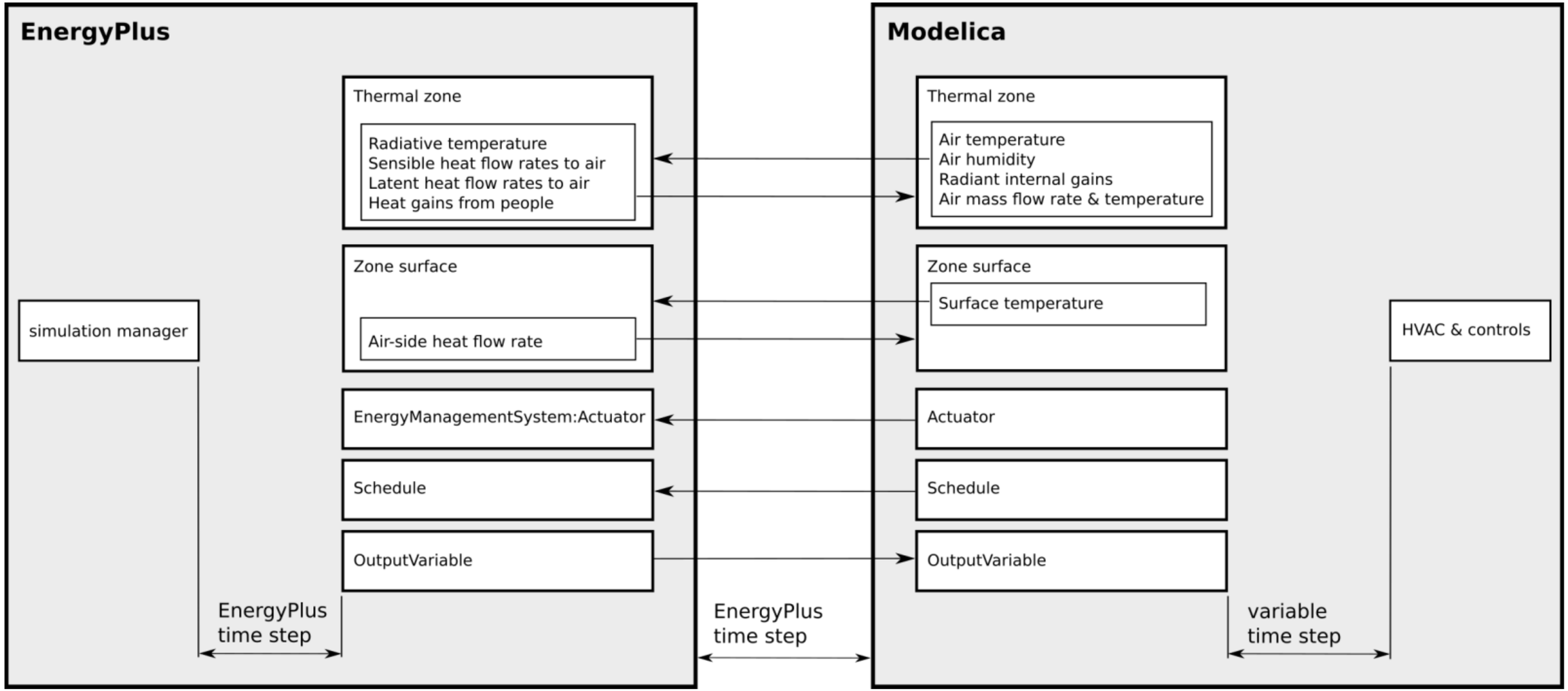
Example for an all-electric plant (model: Buildings.DHC.Plants.Combined.AllElectricCWStorage)

Overview of district energy system implementation



Spawn of EnergyPlus

Spawn allows use of EnergyPlus envelope model with Modelica HVAC and controls



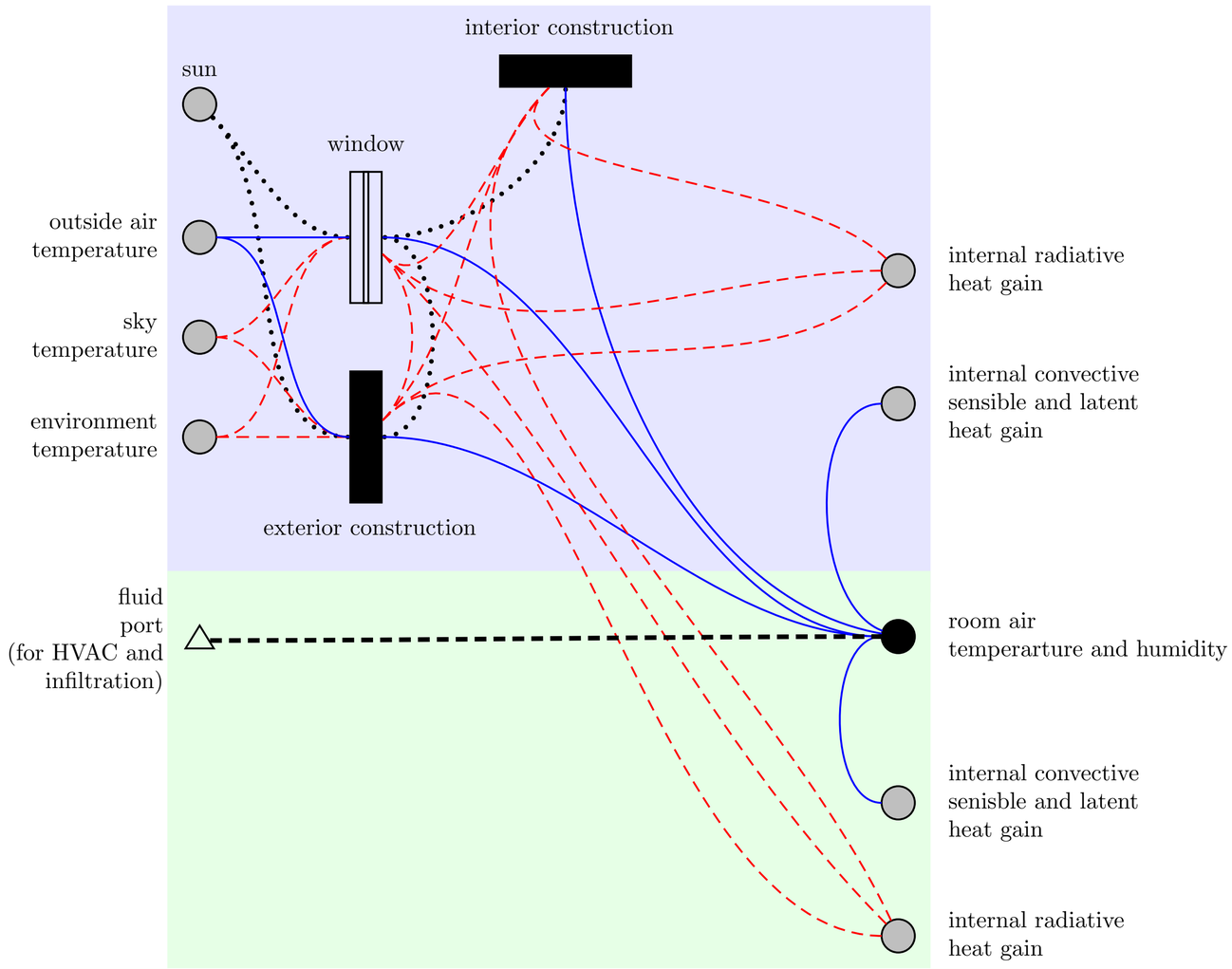
https://simulationresearch.lbl.gov/modelica/releases/latest/help/Buildings_ThermalZones_EnergyPlus_24_2_0_UsersGuide.html

Spawn allows use of EnergyPlus envelope model with Modelica HVAC and controls

Envelope heat transfer (walls, windows) and, optionally, internal loads are simulation in EnergyPlus.
EnergyPlus removes the HVAC system.
EnergyPlus removes any air infiltration.

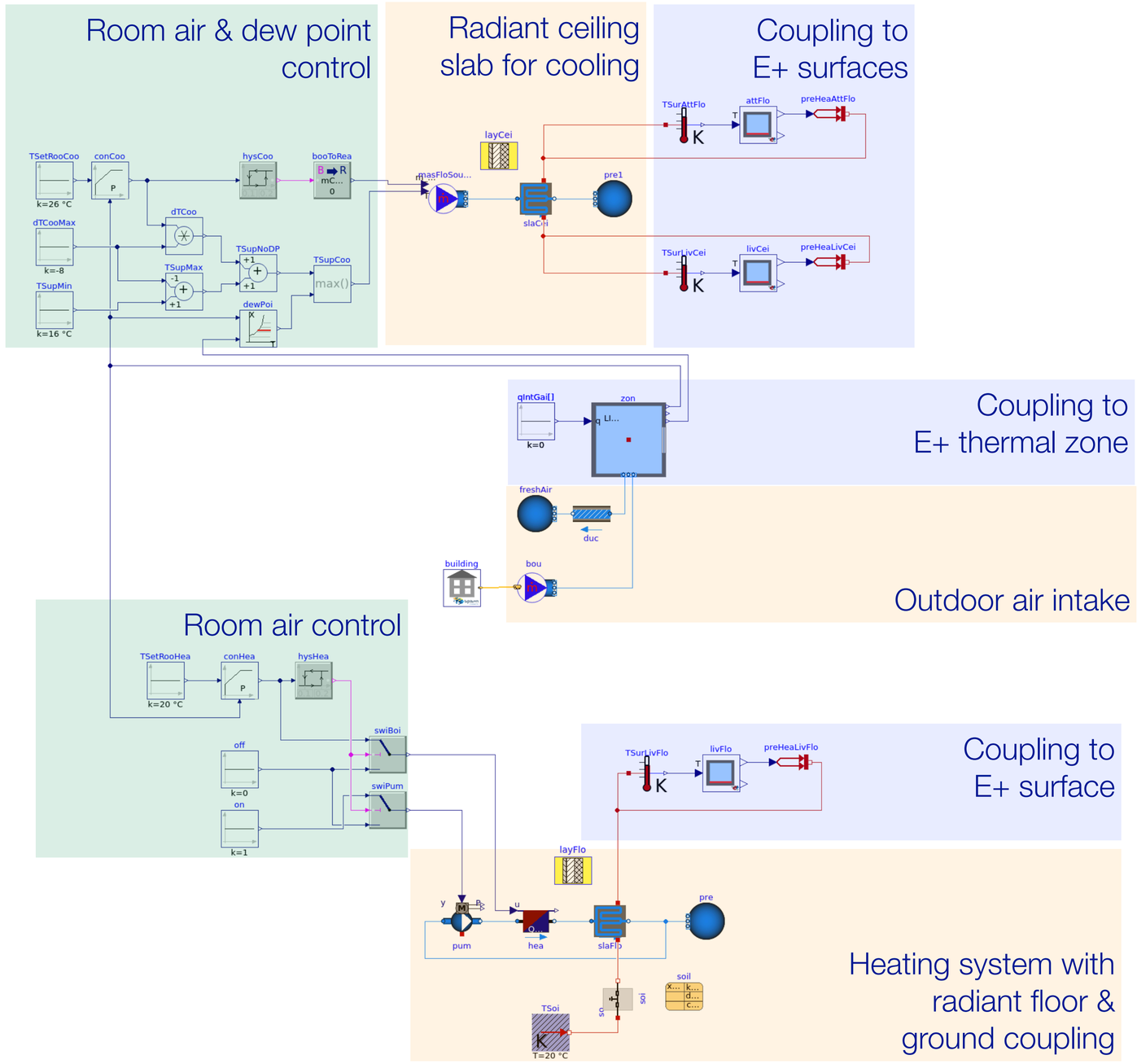
Modelica simulates the room air heat balance.
It also receives radiant, sensible and latent heat gains, and adds them to any heat gains specified in Modelica.

All air flow is modeled in Modelica.

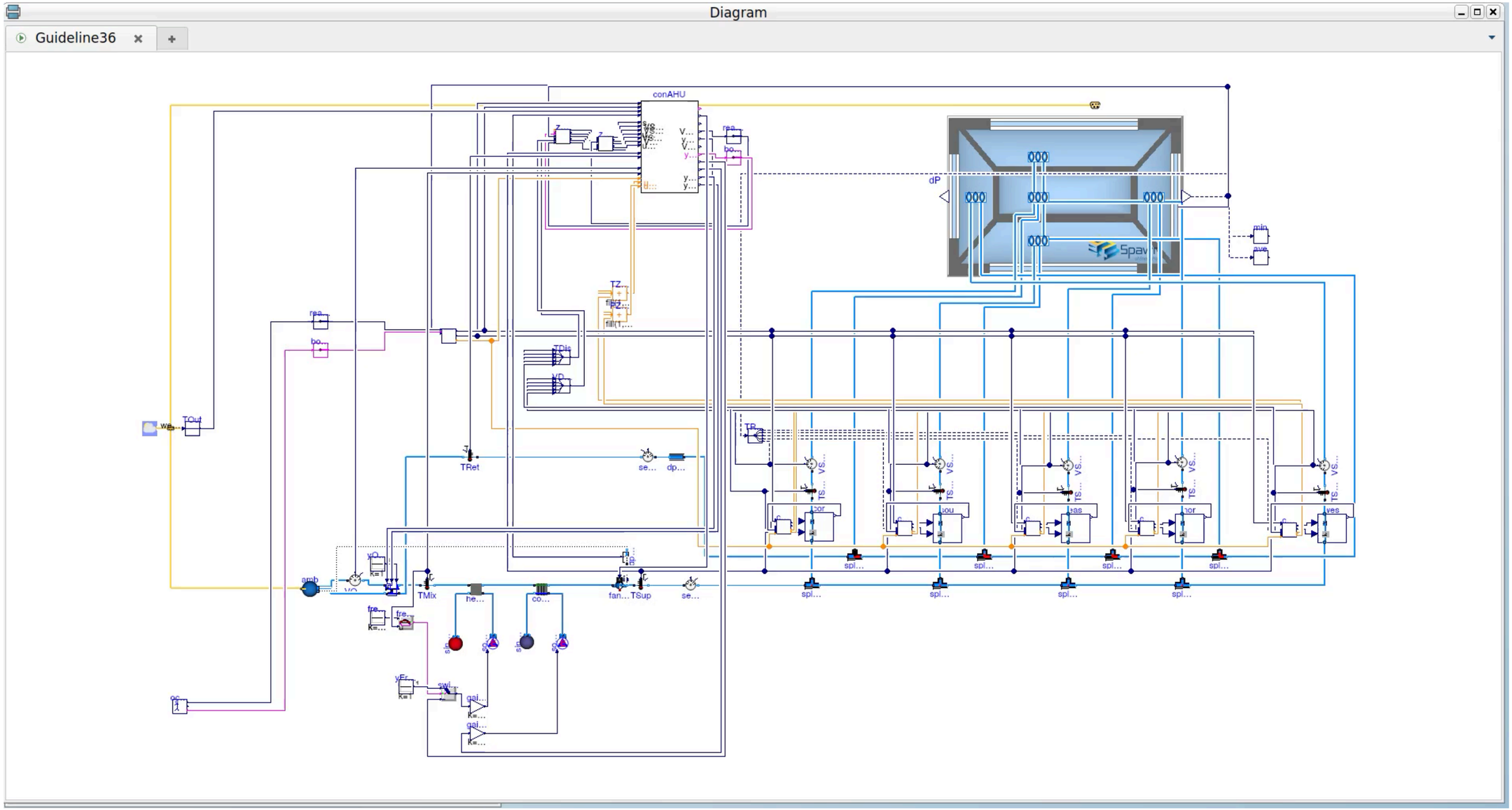


https://simulationresearch.lbl.gov/modelica/releases/latest/help/Buildings_ThermalZones_EnergyPlus_24_2_0_UsersGuide.html

For users, Spawn components can be used like any other Modelica component



Example of CDL within Spawn of EnergyPlus with DOE reference building and ASHRAE G36 control sequence



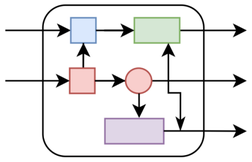
Related projects that build on Modelica Buildings Library

GOES

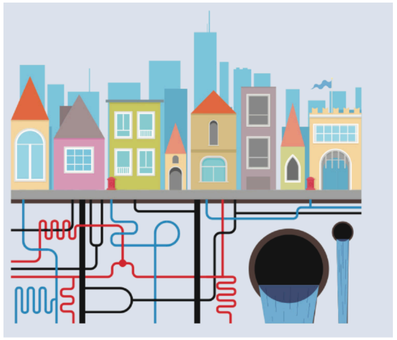
GEOTHERMAL-BASED OPTIMIZED ENERGY SYSTEMS

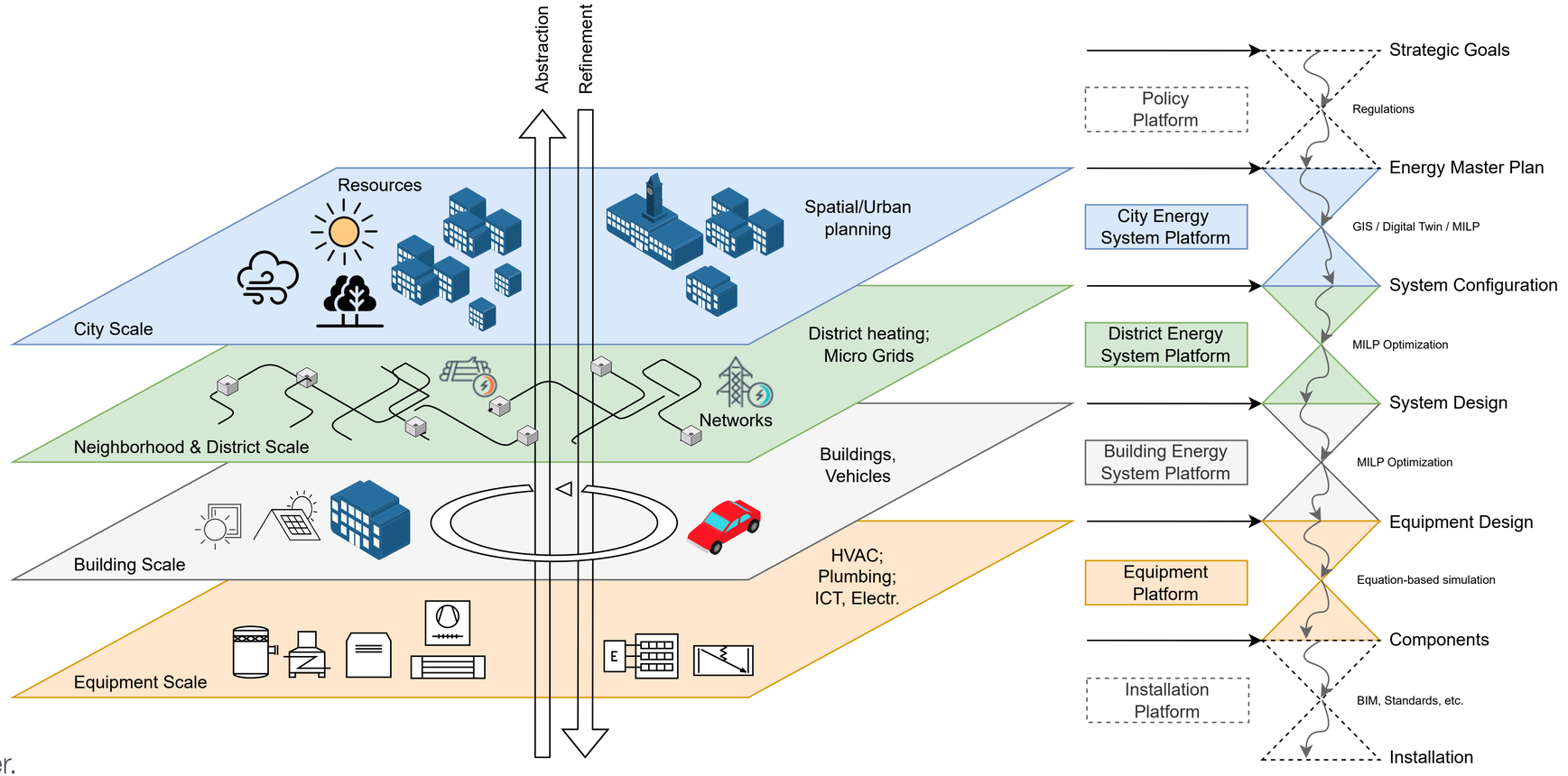
Accelerating scaled deployment of cost-effective, decarbonized energy systems for cities, districts and buildings

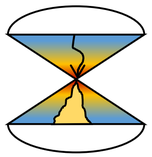
Energy Hub



Energy System







Platform-Based Design

Michael Wetter and Matthias Sulzer.
A call to action for building energy system modelling in the age of decarbonization.
Journal of Building Performance Simulation. P. 1-11. 2023.

Matthias Sulzer, Michael Wetter, Robin Mutschler and Alberto Sangiovanni-Vincentelli.
Platform-based design for energy systems.
Applied Energy, 352, 2023

Empa Materials Science and Technology

BERKELEY LAB

Berkeley

sympheny urban energy. optimized.

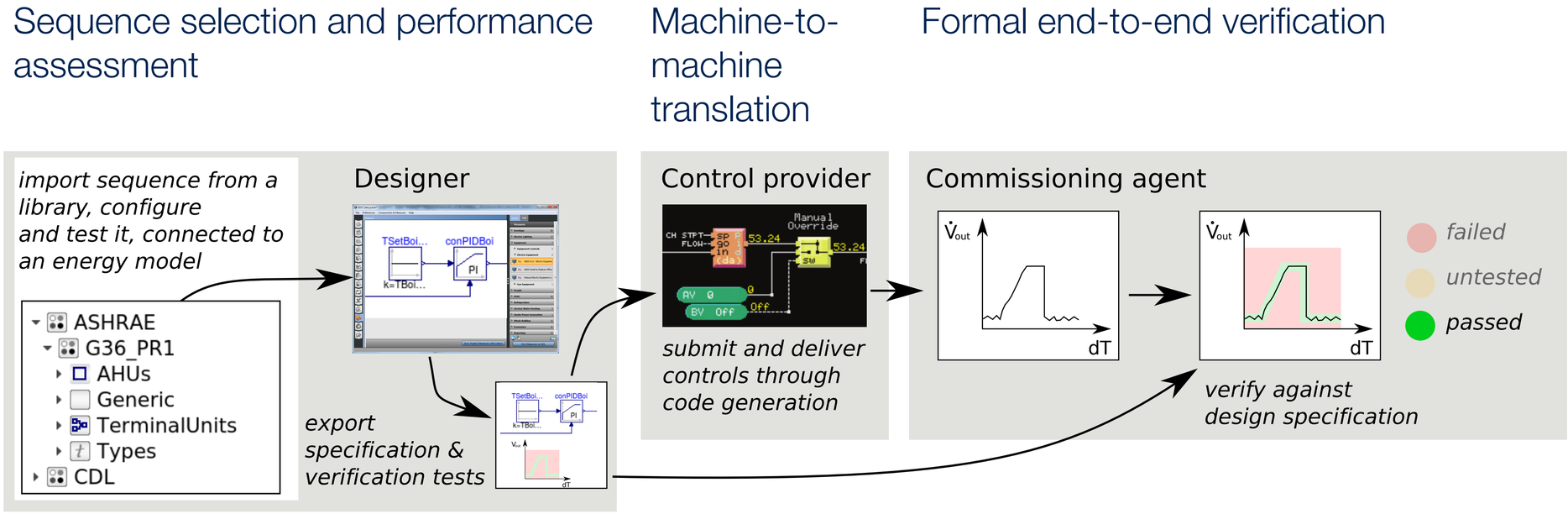
AALBORG UNIVERSITY DENMARK

Karlsruher Institut für Technologie

AIT AUSTRIAN INSTITUTE OF TECHNOLOGY

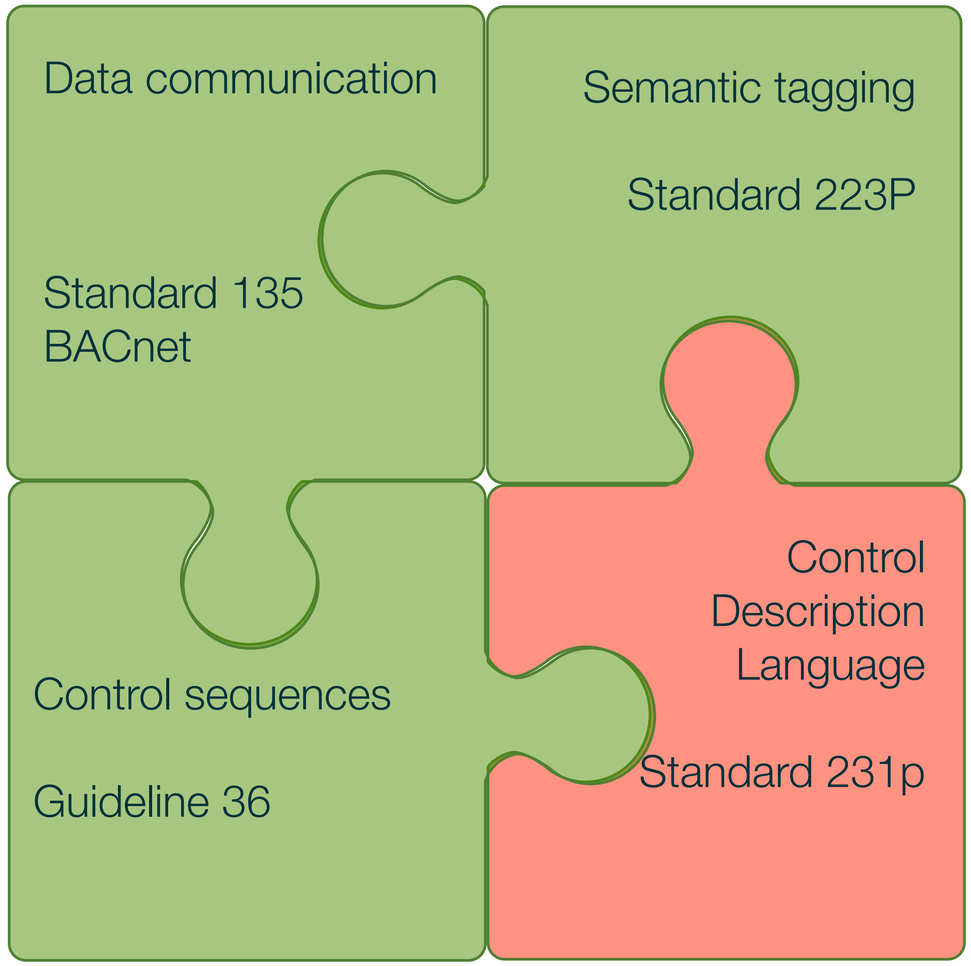
OpenBuildingControl digitalizes the control delivery process based on the ASHRAE Standard 231P. Buildings.Controls.OBC.CDL provides the reference implementation for ASHRAE Standard 231P

ASHRAE Standard 231P is expected for approval vote in 2026.



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.

What gap does CDL address?



Implementation

Name	Description
Constants	Package with constants
Conversions	Package with blocks for type conversion
Discrete	Package with discrete blocks
Integers	Package with blocks for integer variables
Logical	Package with logical blocks
Psychrometrics	Package with psychrometric blocks
Reals	Package with blocks for continuous variables
Routing	Package with blocks that combine and extract signals
Utilities	Package with utility functions
Types	Package with type definitions
Interfaces	Package with connectors for input and output signals

Elementary blocks

Composition rules, see https://obc.lbl.gov/specification/cdl.html

ASHRAE Standard 231P

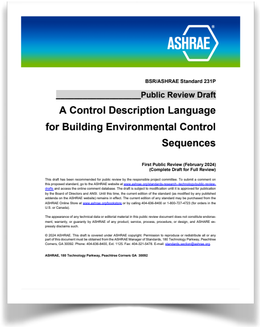
Name	Description
UsersGuide	User's Guide
ASHRAE	Package with control sequences from ASHRAE projects
CDL	Package with blocks, examples and validation tests for control description language
OutdoorLights	Package with controllers for outdoor lights
RadiantSystems	Package with controllers for radiant heating and cooling systems
Shade	Package with controllers for shades
UnitConversions	Package with blocks for unit conversion
Utilities	Package with utility functions

Repository of pre-configured control logic

How does digitalization of control sequences fit with deployment and commissioning?

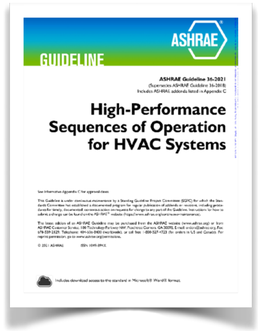
ASHRAE Std 223P (Semantic Data Model)

ASHRAE Std 231P (Control Description Language)

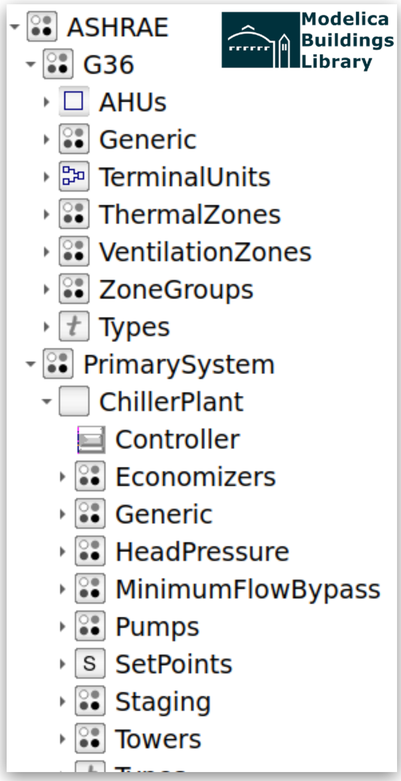


ASHRAE Guideline 36 (Control Sequences)

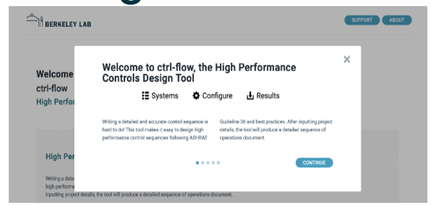
as well as other sources



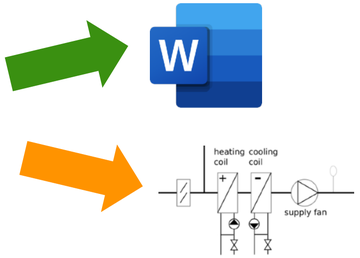
Digitized HVAC & control system templates, compliant with ASHRAE Standards



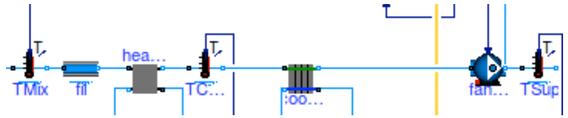
ctrl-flow.lbl.gov: HVAC & control configuration



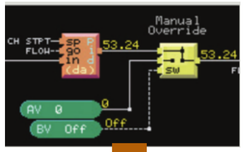
Construction documents



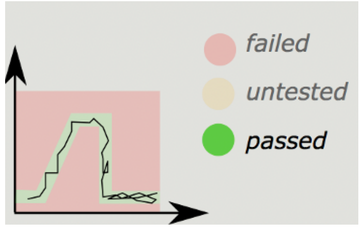
Optional, simulation-based performance



Implementation



Formal testing and/or commissioning



+/-

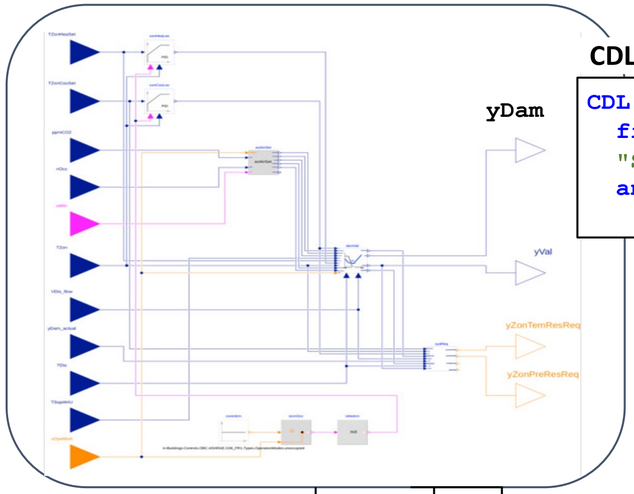
Code generation for cloud, edge computing or embedded controller

Legend

- Implemented
- Prototyped, in development with industry
- ESTCP control design tool project

Combining control logic and semantic models to digitalized control delivery

Generic VAV terminal box control logic (CDL)



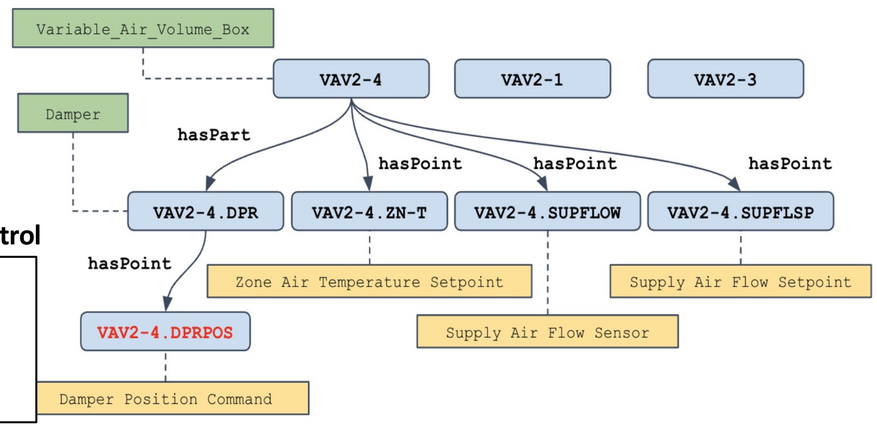
CDL for yDam VAV Damper Position Control

```
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 .\"));
```

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" .
```

Building-specific semantic model (Brick)



Brick

Modelica

1

SPARQL query for finding VAV boxes in Brick model

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

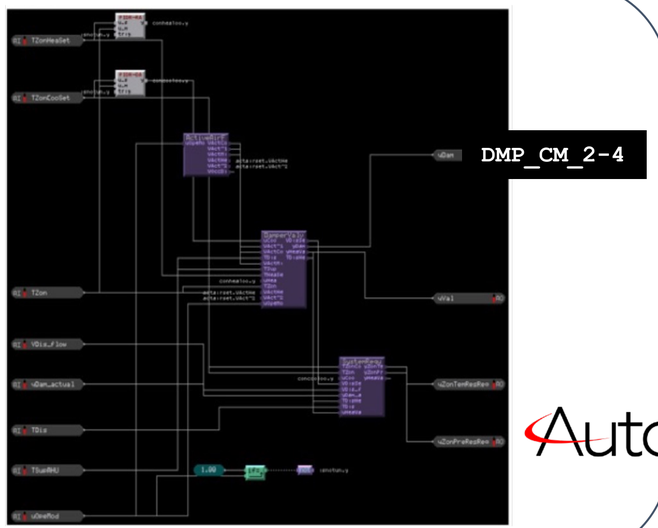
2

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.

Discussion