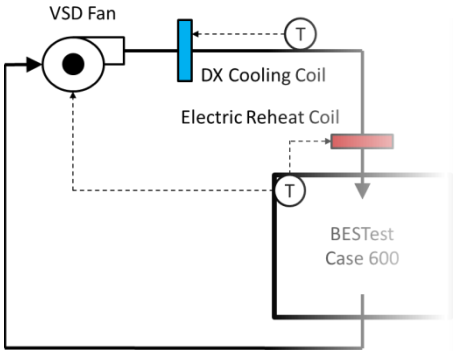
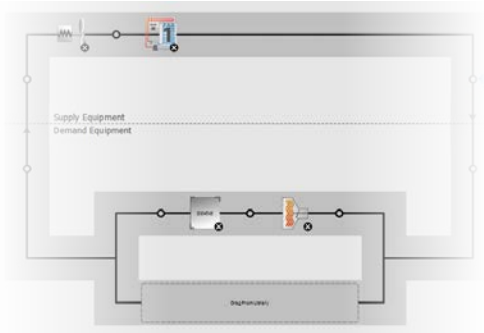
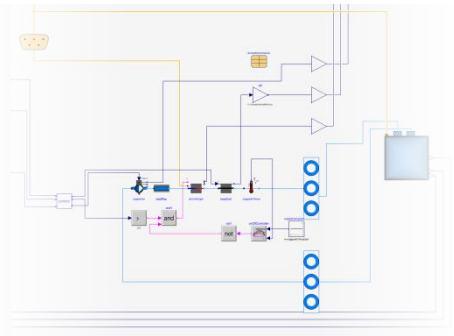
Modelica – Spawn of EnergyPlus

2017 Building Technologies Office Peer Review







Design ***Model*** ***Simulate*** ***Operate***

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Project Summary

Timeline:

Start date: Oct. 2015

Planned end date: Sep. 2019

Key Milestones:

1. Release Modelica Buildings library 4.0; 3/31
2. Prototyped OpenStudio to Modelica HVAC simulation; 8/30/17

Budget:

Total Project $ to Date:

- DOE: $885k (since Oct. 2015)
  $200k (since Oct. 2016)
- Cost Share: no direct, but leverage of >100M investment in Modelica/FMI, IEA EBC Annex 60 (42 institutes) and IBPSA Project 1 (19 institutes)

Total Project $:

- DOE: $2.8M (Oct. 15 to Sep. 19, includes non-SOEP tasks)

Key Partners:

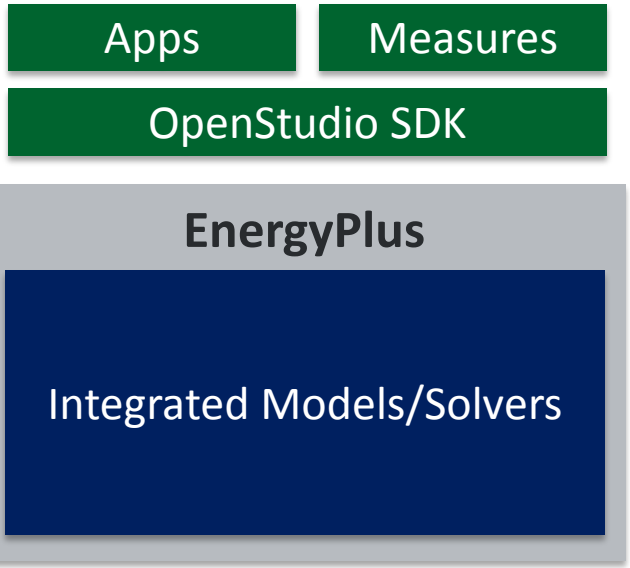
NREL	Plus 41 institutes through IEA EBC Annex 60 that jointly develop Modelica & FMI for buildings
ORNL	
Objexx	
Big Ladder Software	
Modelon	

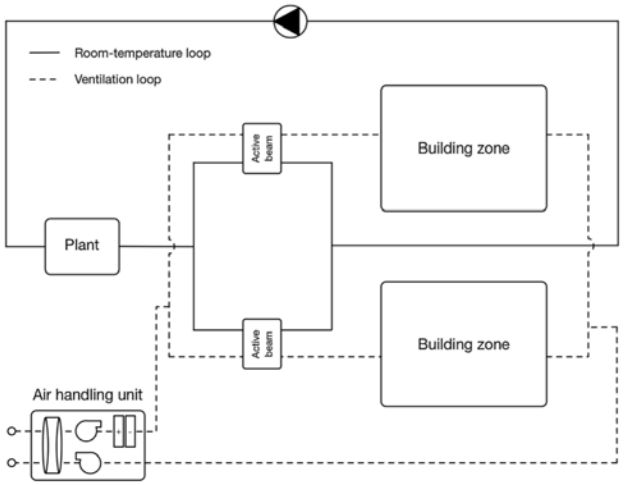
Project Outcome:

Next-generation EnergyPlus that:

- Places EnergyPlus on stable IT platform based on open standards (Modelica and Functional Mockup Interface) and that leverages >$100M in investments.
- Reduces EnergyPlus maintenance effort
- Connects energy simulation with control design, optimization, and implementation
- Closes simulation technology model gap by supporting vendor-defined models

Problem Statement





Novel two-pipe system, reducing energy by 12-18% compared to conventional four-pipe system, to be built based on Modelica virtual prototyping. http://dx.doi.org/10.1016/j.enbuild.2016.10.051

Current-generation BEM engines (like EnergyPlus) are "monolithic"

- Model's "governing" equations are implicit in model-specific solvers

Resulting limitations

- Large, difficult to maintain code bases
- Inability to
  - integrate with external models or analyses
  - extract and reuse models for other use cases (e.g., control implementation)
  - model certain systems with non-conventional flow or control networks
- Poor scalability for large analyses (e.g., district systems)

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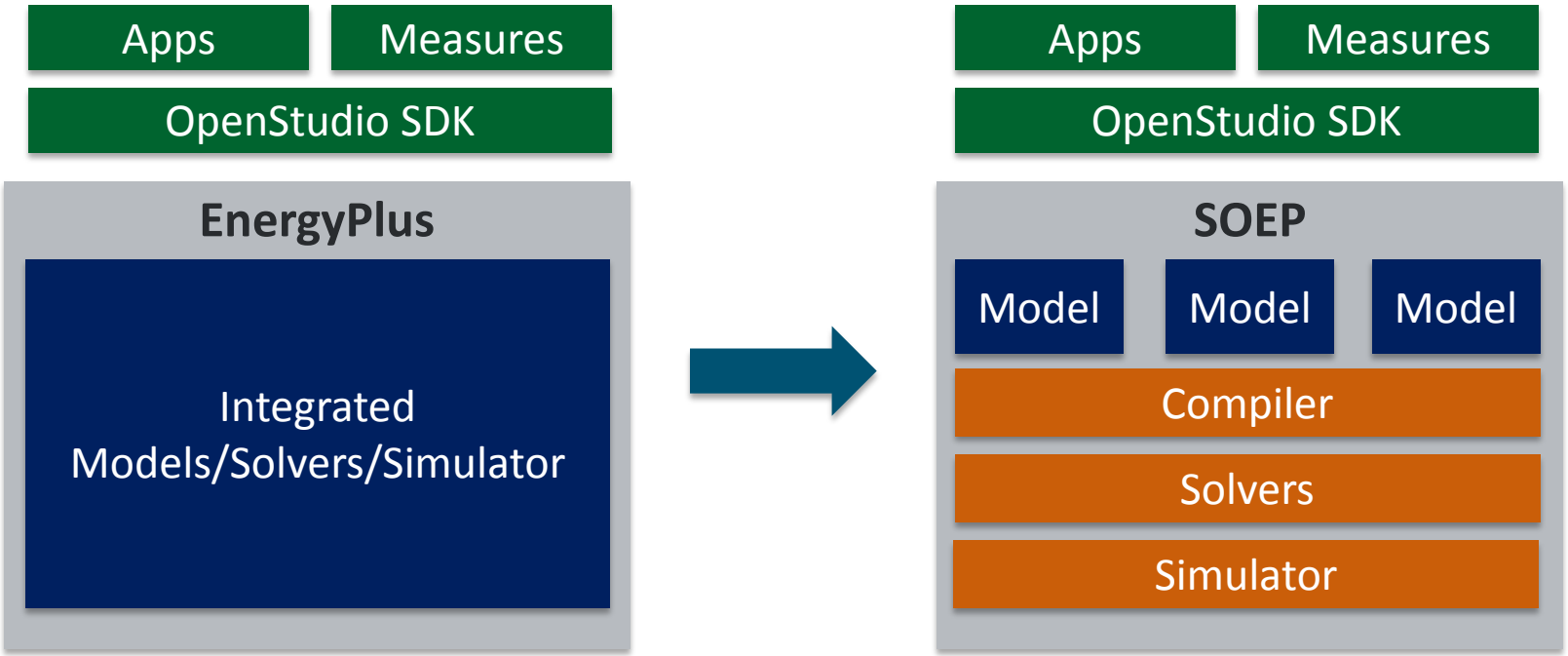
Approach



OpenStudio layer hides changes from 3rd-party developers and users

Separation of concerns – equation-based modeling language (Modelica)

- Building experts develop domain-specific models
- Numerical/software experts develop domain-neutral compiler/solver/simulator/optimizer

Modularity and inter-operability – use open standard simulation interface (FMI)

- Modular plug-and-play components

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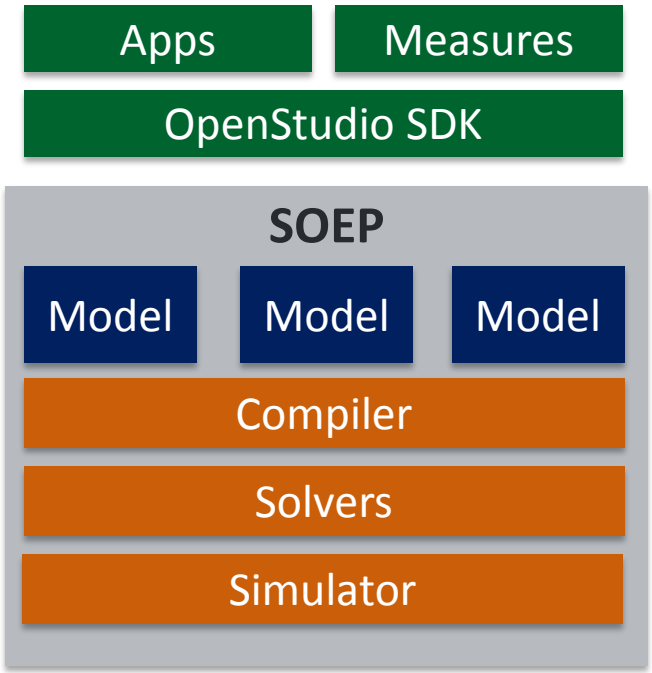
Expected Outcomes

Scalable, future-proof infrastructure

- Supported by >$100M in investment
- Benefits from advances in other engineering domains



Reduced maintenance effort

- EnergyPlus team responsible only for models
- Incorporates 3rd-party models
- Leverages open international model libraries

Reduced technology lag

- Manufacturers can share proprietary models
- Users can analyze non-conventional energy systems by quickly adding new models
- Manufacturers can prototype and test with hardware and software “in the loop”

Reusable control models that can plug into control workflows

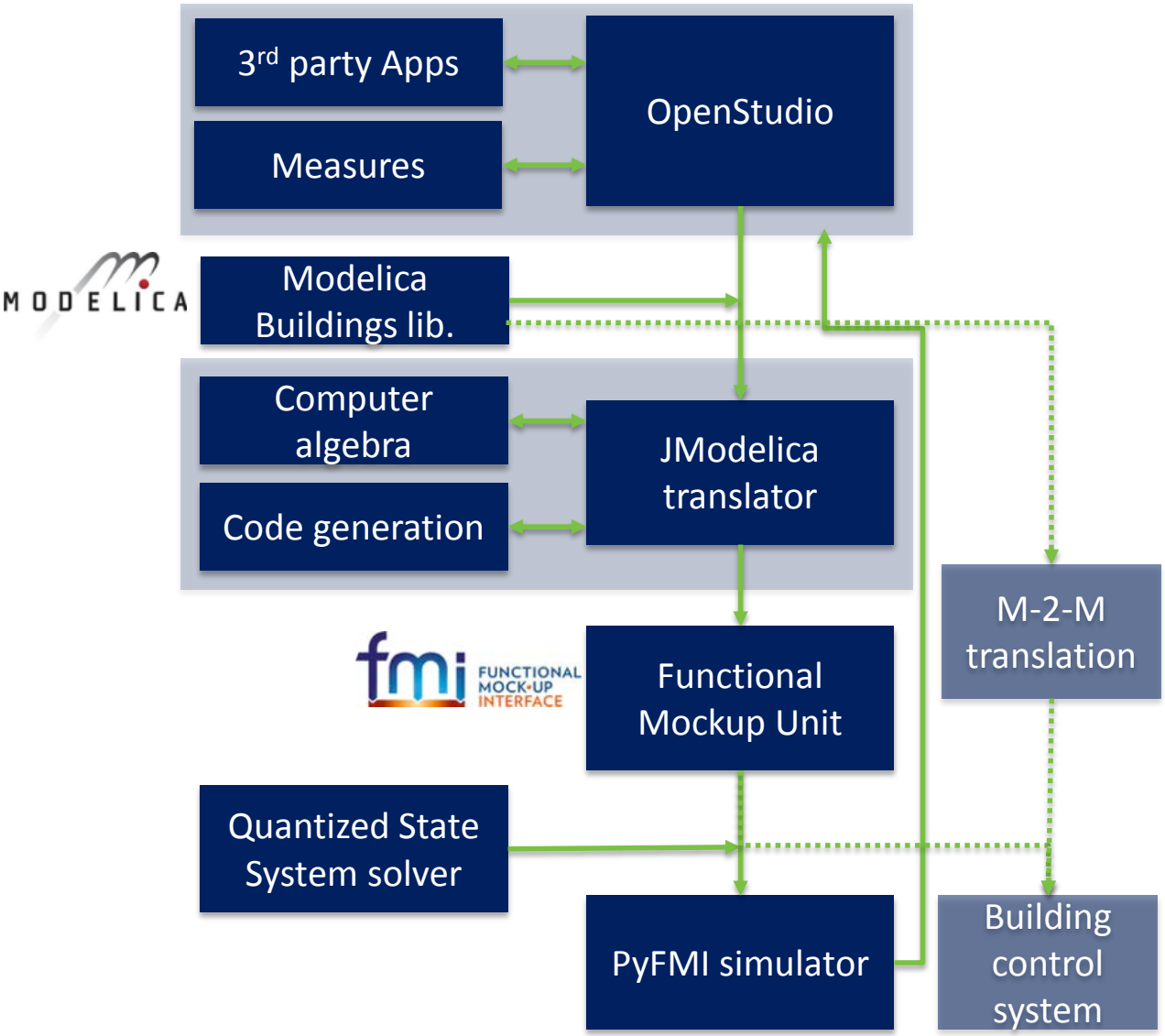
- Integrates EnergyPlus with control design, optimization, verification, and implementation

Better scalability and integration with other analyses

Expanded market and audience

- Architects/MEs, utilities, ESCOs + equipment/control manufacturers, building operators
- Potential to save 0.7 quad/year by 2030

Progress and Accomplishments – Architecture



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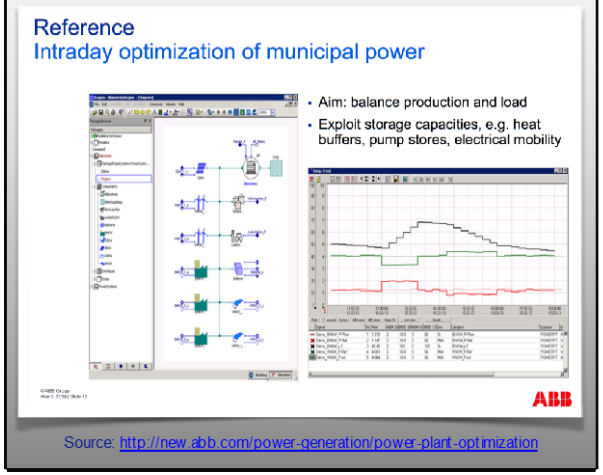
Foundational Standards – Modelica and FMI

https://modelica.org/

- Open, industry-driven standard for multi-physics modeling
- Developed since 1996
- Large ecosystem of free and commercial libraries and tools
- IEA EBC Annex 60: 42 institutes working on Modelica for building and district energy systems

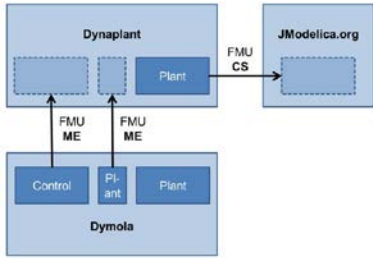
7% of German power production is optimized based on Modelica



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

https://www.fmi-standard.org/

- API standard to exchange simulators or models
- Developed since 2008
- Supported by >90 tools.

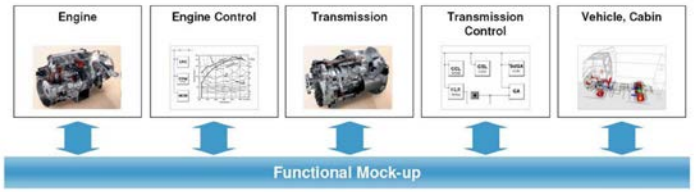


Powerplant simulation with Modelica (Dymola) coupled to in-house simulator (Dynaplant).

Source: Siemens, doi:10.3384/ecp1511817

Why standards?

- Leverages investments in related industries.
- Provides well-tested APIs for software integration.
- Provides to industry a stable basis for investment.
- Avoids vendor lock-in.

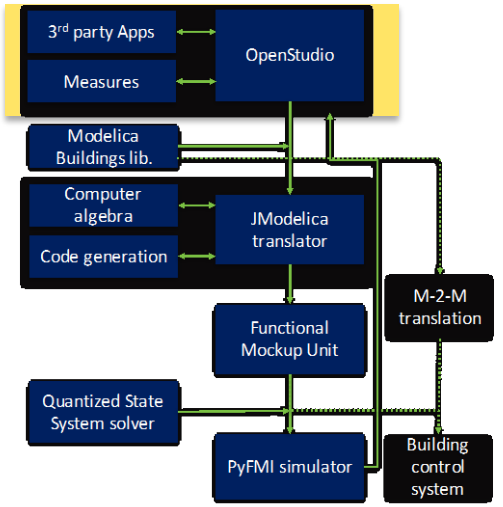


Cosimulation of the behavioral models and the embedded controller software

P and A – OpenStudio

OpenStudio SDK

- http://openstudio.net/
- Abstractions enhance BEM app development productivity



Past year

- Designed software stack to parse the Modelica Buildings Library, enabling new OpenStudio APIs and integrated documentation.
- Prototyped OpenStudio application program interfaces (APIs) for Modelica backend.
- Prototyped translator for subset of existing OpenStudio models to Modelica.
- Prototyped packaging techniques for SOEP distribution.

```
fan = OpenStudio::SOEP::Component.new("Fan");
fan.setAttribute("FanEfficiency", 0.75); OpenStudio::SOEP::connect(fan.port("AirOutlet"),
coil.port("AirInlet"));
```

Code snippet of OpenStudio script that instantiates Modelica.

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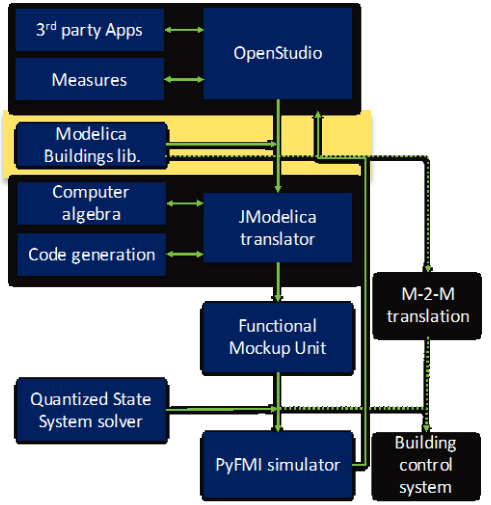
P and A – Modelica Buildings component library

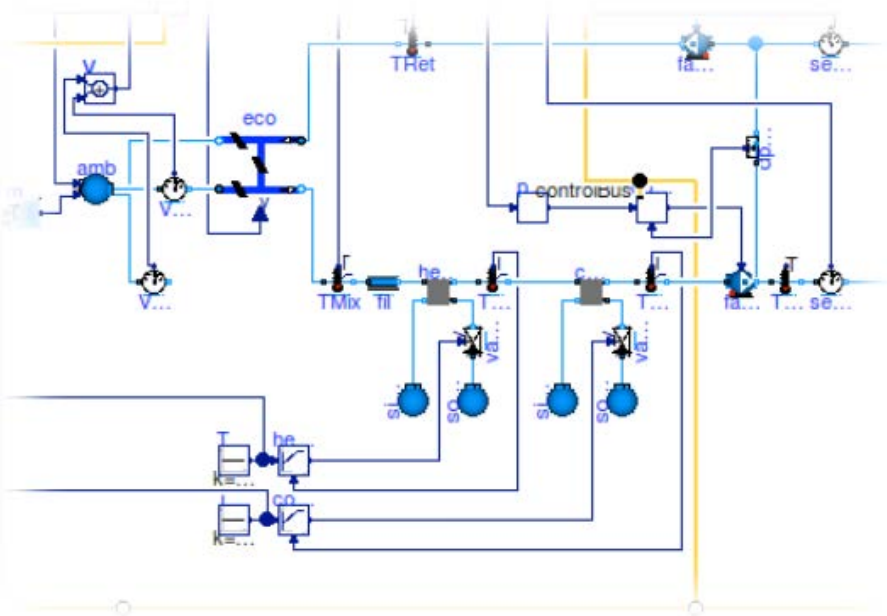
Modelica Buildings Component Library

- http://simulationresearch.lbl.gov/modelica/
- 500+ open-source component models
- Used for US-China project, DOE/BENEFIT projects, by major control vendors and equipment manufacturers
- Validated with BESTEST, EnergyPlus, TRNSYS, measured data



Past year accomplishments

- Reduced computing time up to 40% for large models
- Automated continuous integration & verification of results
- Added new models
  - Reduced order buildings [RWTH Aachen & KU Leuven]
  - Active beams [Aalborg University]
  - Heat pumps [Polytechnique Montreal]
  - Electrochromic windows [CEC funded]
  - District heating & cooling systems [LBNL LDRD]



Graphical rendering of HVAC secondary system in Modelica.

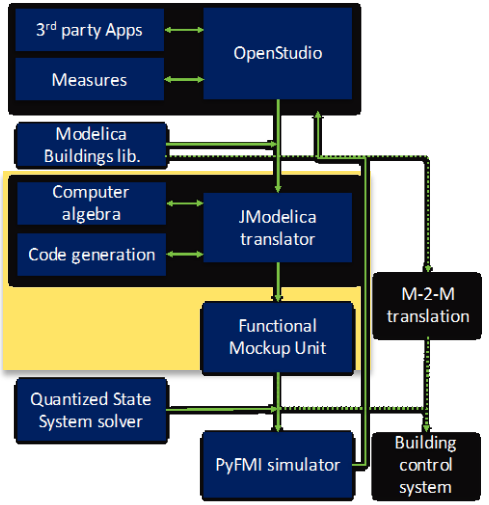
P and A – JModelica

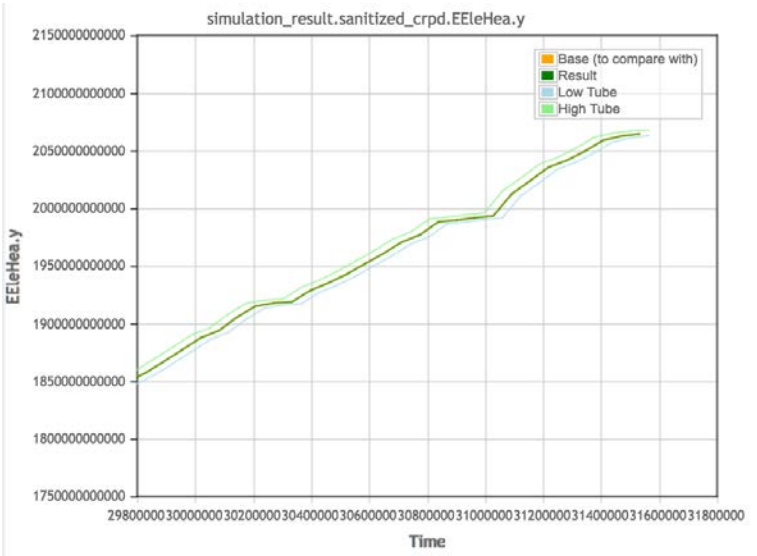
JModelica

- http://www.modelon.com/products/jmodelicaorg/
- Open-source Modelica environment

Past year

- Continuous integration & verification
  - 600 test cases
  - producing same results (10^{-3} tolerance) with Dymola (commercial)
  - verifies 3 million result points
- Improved code coverage and compliance with Modelica standard
- Improved solver for hybrid systems and stiff ordinary differential equations
- Designed API for QSS solvers



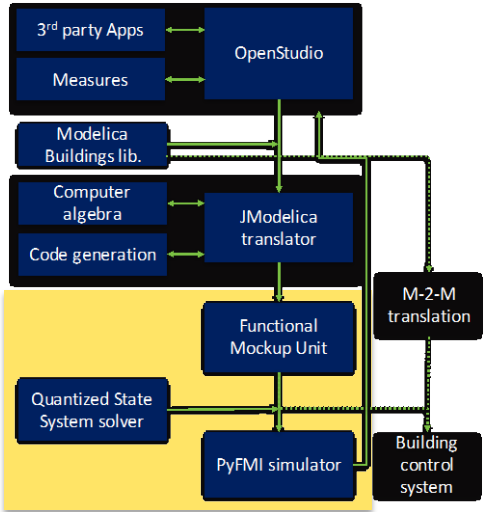


Verification test of JModelica-computed energy use versus Dymola-generated reference.

P and A – Quantized State System (QSS) solver

Quantized State System (QSS)

- Asynchronous integration based on component dynamics
- Needed for model scalability, in particular for models with feedback control

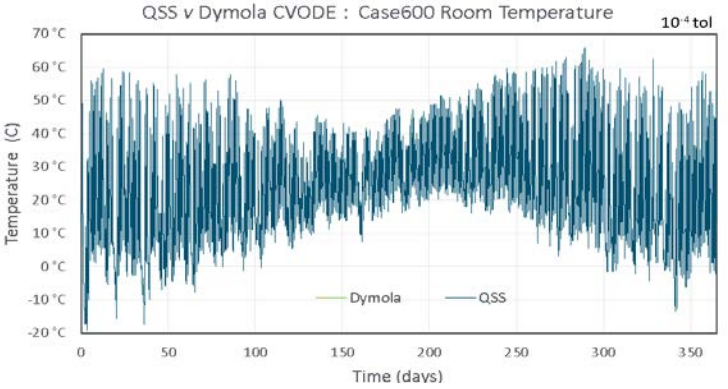


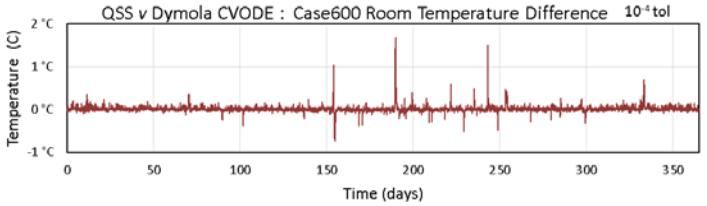
Past year

- Implemented a family of QSS solvers:
  - Explicit: QSS1, QSS2, QSS3
  - Implicit: LIQSS1, LIQSS2

Preliminary test with BESTEST model

- Case600FF:
  Modelica → Dymola → FMU → QSS1
  Modelica → Dymola → FMU → CVODE
- Results match well





Work in progress

- FMI API implementation for QSS
- Hybrid systems (mixed continuous/discrete dynamics)
- Algebraic equations
- Units support
- Performance/parallelization

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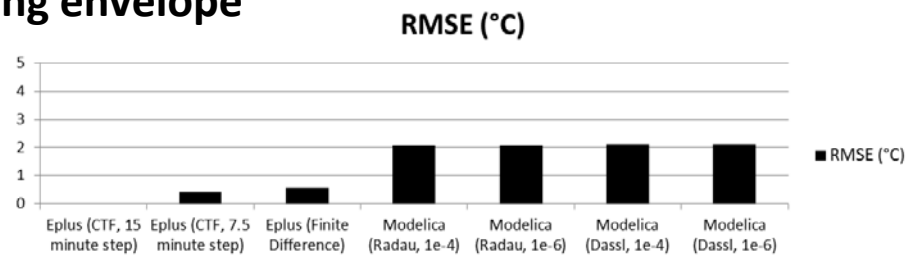
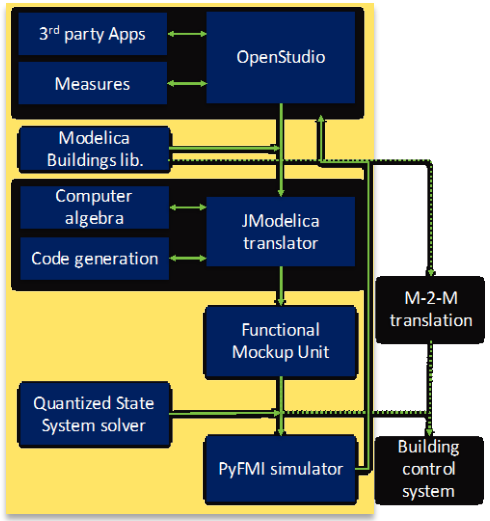
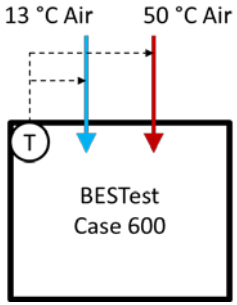
P and A – End-to-End Tool Chain Verification

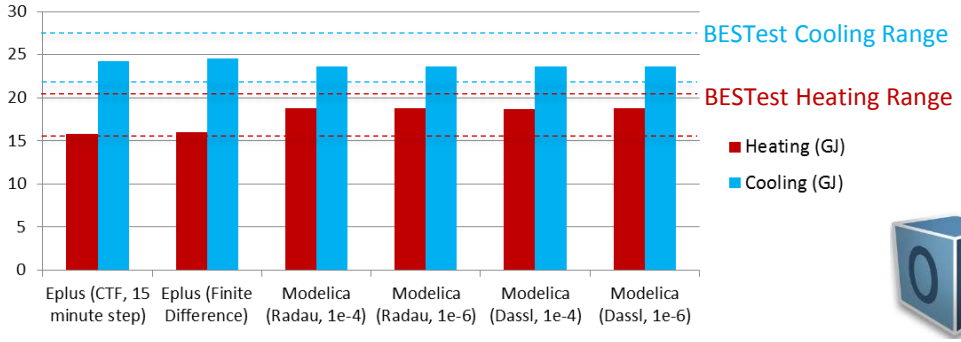
Free float building envelope



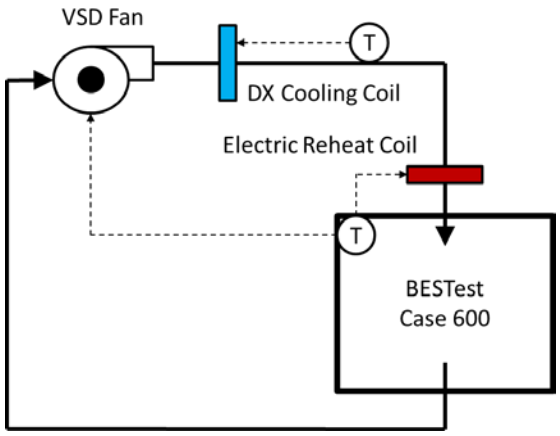


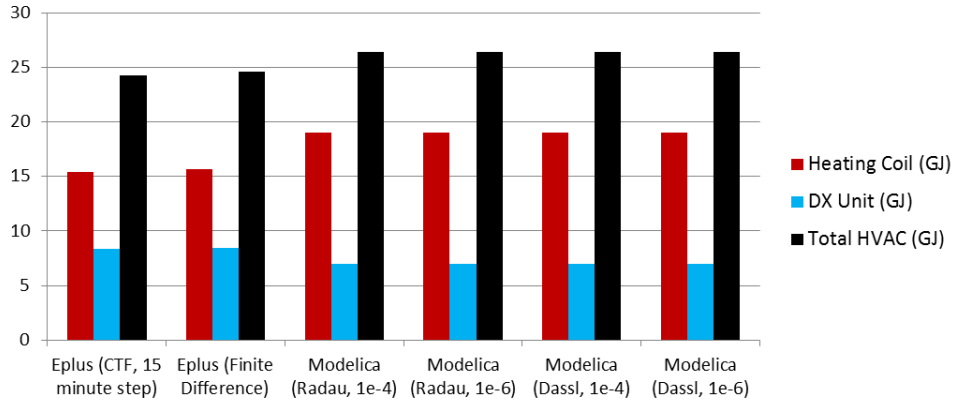
Ideal air HVAC system





Single Zone VAV System with full recirculation





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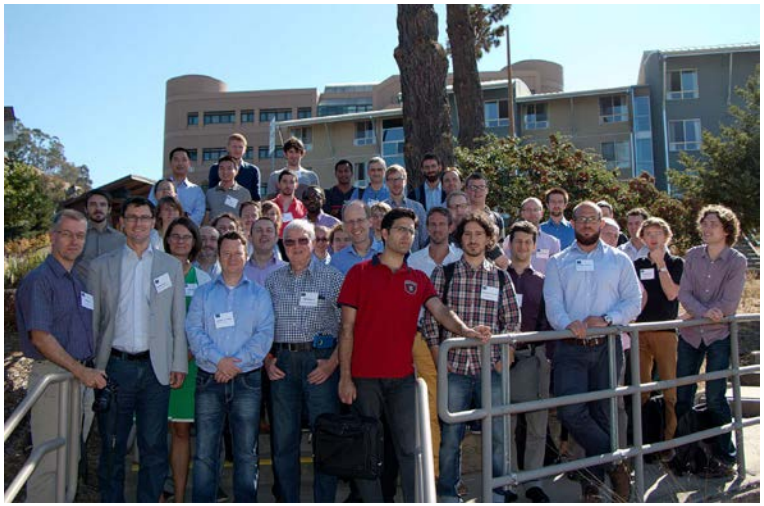
Project Integration and Collaboration

SOEP integrates directly with OpenStudio ecosystem, and also with BENEFIT projects OpenBuildingControl and Data Center Toolkit.

- Bi-weekly meetings.



IBPSA (International Building Performance Simulation Association) Project 1 2017-22

- https://ibpsa.github.io/project1
- BIM/GIS and Modelica Framework for building and community energy system design and operation
- Continues successful IEA EBC Annex 60 (42 institutes from 18 countries).
- 19 institutes so far, with > 60 FTE, 2017-22.

Training workshops

- LBNL 2016 (2 days),
- Corsica 2016 (5 days – IBPSA France sponsored),
- Modelica conference 2017 (Modelon sponsored)
- Building Simulation 2017 (NAMUG sponsored)

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Next Steps and Future Plans

By end of FY 17

- End-to-end MVP (Minimum Viable Product)

FY18-19:

- Scope roughly equivalent to EnergyPlus
- Performance meeting or exceeding EnergyPlus
- Availability as option to all OpenStudio applications

FY20-22:

- DOE ramps down EnergyPlus development, shifting resources to SOEP
- Large segment of developers and users using SOEP rather than EnergyPlus
- Active development and use of SOEP-based operational applications

Note: Technology could be applied to grid modernization and other DOE activities

- ABB optimizes in real-time 7% of all power produced in Germany using OpenModelica
- Modelon uses Modelica for waste heat optimization for power plants with district heating

REFERENCE SLIDES

Project Budget

Project Budget: 700k annual funding for SOEP, Modelica, and FMI, including support of legacy tools.
Variances: None.
Cost to Date: $210k spent by end of January
Additional Funding: Cost share shown as 0, although we leverage significant resources through

- Modelica and FMI (>$100M private and public investment),
- IEA EBC Annex 60 (42 partners)
- IBPSA Project 1 (18 partners), and
- working with Modelon which has private investments in their tools such as from ANSYS and Ricardo.

Budget History

FY 2016 (past)		FY 2017 (current)		FY 2018 – FY 2019 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
675k	0*	700k	0*	1400k	0*

Project Plan and Schedule

FY 17 focuses on setting up the tool chain for a minimum viable product.
FY 18-19 focuses on expanding model library, functionality and addressing performance bottlenecks.

Project Schedule													
Project Start: Oct. 1, 2015		Completed Work											
Projected End: Sep 30, 2019		Active Task (in progress work)											
		Milestone/Deliverable (Originally Planned) use for missed											
		Milestone/Deliverable (Actual) use when met on time											
	FY2016				FY2017				FY2018-19				
Task	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)					
Past Work													
Release Modelica Buildings library for use in E+													
Release early access of master algorithm through BCVTB													
Current/Future Work													
Release Modelica Buildings library for use in E+													
Prototyped OpenStudio to Modelica HVAC simulation													
Expand coverage of models													
Analysis and improve performance													