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
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)

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
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
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

- 3rd party Apps
- Measures
- Modelica Buildings lib.
- Computer algebra
- Code generation
- JModelica translator
- Functional Mockup Unit
- Quantized State System solver
- PyFMI simulator
- M-2-M translation
- Building control system
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

https://www.fmi-standard.org/
- API standard to exchange simulators or models
- Developed since 2008
- Supported by >90 tools.

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.
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.

```ruby
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.*
P and A – Modelica Buildings component library

Modelica Buildings Component Library

- 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.*
JModelica

• 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.
Quantized State System (QSS) (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
P and A – End-to-End Tool Chain Verification

**Free float building envelope**

- BESTest Case 600

**Ideal air HVAC system**

- 13 °C Air
- 50 °C Air

**Single Zone VAV System with full recirculation**
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](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)
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

<table>
<thead>
<tr>
<th>FY 2016 (past)</th>
<th>FY 2017 (current)</th>
<th>FY 2018 – FY 2019 (planned)</th>
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<tbody>
<tr>
<td>DOE</td>
<td>Cost-share</td>
<td>DOE</td>
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<tr>
<td>675k</td>
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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**

<table>
<thead>
<tr>
<th>Task</th>
<th>FY2016</th>
<th>FY2017</th>
<th>FY2018-19</th>
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<tr>
<td>Q1 (Oct-Dec)</td>
<td>Q2 (Jan-Mar)</td>
<td>Q3 (Apr-Jun)</td>
<td>Q4 (Jul-Sep)</td>
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<tr>
<td>Completed Work</td>
<td>Active Task (in progress work)</td>
<td>Milestone/Deliverable (Originally Planned)</td>
<td>Milestone/Deliverable (Actual)</td>
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**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