EnergyPlus
2014 Building Technologies Office Peer Review

Building Energy Modeling Engine

www.energyplus.gov

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Project Summary

Timeline:
Start date: 1997
• 1980s if counting predecessors, e.g., DOE2
Planned end date: N/A

Key Milestones:
1. V8.1 (FORTRAN)—Nov. 15, 2013
2. C++ transition—Mar. 31, 2014

Budget:
Total DOE $ to date: $65,000k+
• 2X if counting predecessors, e.g., DOE2
Total DOE $ future: $2,500k+/yr

Key Partners:
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<th>FSEC</th>
<th>GARD Analytics</th>
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<tr>
<td>Trane</td>
<td>Autodesk</td>
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Project Goal:
Maintain and advance EnergyPlus as BTO’s best-in-class product for whole-building energy performance modeling, by incrementally improving its capabilities and accuracy, and by supporting users and application developers.

Target Market/Audience:
Building energy modeling for building design, codes and standards development, controls, continuous commissioning, product design and master planning.
Purpose and Objectives

**Problem Statement:** “Develop, maintain, and support a software tool for fair and accurate assessment of different energy efficiency measures for all types of buildings projects.”

**Target Market and Audience:** Architects, mechanical engineers, energy consultants, standards bodies, standard-compliance officials, ratings organizations, energy-efficiency program managers, product developers, researchers, educators, software vendors.

**Impact:** via multiple use-cases
- Entrenched—development of standards & beyond standard design guides
- Elevating—integrative design
  - Can save 8-16 quads annually in 2050 [RMI “Reinventing Fire”]
  - 600 TBTU annually in commercial buildings by 2030 [BTO P-Tool]
  - Will track this via AIA+2030 Commitment Reporting
- Emerging—“integrative operations”
  - Continuous commissioning & fault-detection/diagnosis, control & demand response
Industry Context

EnergyPlus sets the pace for other energy simulation engines

- Others: DOE2.1E, DOE2.2, TRNSYS, IES Apache, Trane TRACE, Carrier HAP, ESP-r, TAS
- Only EnergyPlus combines state-of-the-art features & open-source licensing
- Allows EnergyPlus to serve as basis for codes & standards, e.g., ASHRAE 90.1 ...
- ... and for programs that build on them, e.g., IRS 179D, code-compliance, LEED, etc.
- Other engines gain legitimacy by comparison with EnergyPlus via ASHRAE 140 standard

EnergyPlus slowly displacing other energy simulation engines

- New tools & end-user applications primarily targeting EnergyPlus
  - OpenStudio helping here
- State & utility programs requiring EnergyPlus
- Commercial vendors dropping proprietary engines rather than investing in “catch-up”
  - Open-source makes partnering with EnergyPlus easy
- International support for and use of EnergyPlus is growing, e.g., Canada, Brazil

Energy simulation application universe is growing rapidly

- EnergyPlus & OpenStudio playing a big role
“Develop, maintain, and support a software tool for fair and accurate assessment of different energy efficiency measures for all types of buildings projects.” — simple to say, but a considerable undertaking

- Big building multi-physics & HVAC system integration engine, how big?
  - 700,000+ lines of code, 4,500+ pages of docs & 700+ of validation reports!
- Must keep up with an advancing technology landscape
  - Materials & assemblies, HVAC components & configurations, controls
- Also needs to be accurate, fast, transparent, supported, easy-to-use, etc.

Requires significant & sustained investment: currently $2,500k/yr

- DOE is the only viable source for this funding given transparency & neutrality needs
Approach, Issues & Characteristics

Approach:

- Large team (includes industry) with broad expertise & significant experience
- Draws heavily on ASHRAE-developed methods & research results
- Requirements process incorporates BTO, end-users & software vendors
- Rigorously tested according to ASHRAE 140

Key Issues:

- Characterization of accuracy ... and improvement where necessary
- Catching up to, then keeping up with HVAC&R & controls technology
- Execution speed
- Better integration with design tools ecosystem
- Support for operations use cases
- More readily-available training & support

Distinctive Characteristics:

- DOE-branded production software that supports standards & commercial tools
- Successful, multi-lab/contractor/university/industry collaboration
Approach—Team

Team: large & fairly stable with broad-base expertise & experience

- Labs, competitively solicited contractors & in-kind commercial partners
- Total ~7.0 FTE, Edwin Lee is only 1.0 FTE, others are 0.1-0.5 FTE
Approach—Project Management & Processes

**Requirements:** integrate BTO, vendors & end-users (helpdesk & surveys)

- Annual in-person team meeting for task planning & budgeting

**Development:** “agile” tools & processes for development, testing & release

- Bi-weekly all-team web-meetings & more frequent “scrum” in smaller teams
- Feature process: proposal $\rightarrow$ design $\rightarrow$ review $\rightarrow$ code $\rightarrow$ test $\rightarrow$ review $\rightarrow$ check-in
- GitHub code repository, PivotalTracker for bugs & features, nightly builds & tests
- Two annual releases with full documentation & validation reports

**Support:** handle ~100 request / mo via energyplus.helpserve.com

- Training at major conferences
- Goal is to bootstrap a self-sustaining training & support ecosystem
FY14 Activities—New Features

V8.1 release: Nov 15, 2013
• Improved cross- and natural- ventilation models
• Comprehensive models for unitary HVAC systems
• Many new HVAC templates including VRF, dual-duct, heat/cool VAV
• HVAC “optimal start” control
• Model for Daikin high-performance “Rebel” RTU
• Component model sizing diagnostics
• Some models for equipment & operation faults including airside economizer
• Full list available from energyplus.gov website

V9.0 release: planned for Nov 15, 2014
• Unified, updated routines for equipment sizing
• Unified model for room air and multi-zone air-flow network
• Better support for complex zone geometry & interior windows (via Radiance)
• Models for servers & some datacenter HVAC equipment
• Additional models for equipment & operation faults
• XML schema for input & output
• New command-line interface for easier scripted analysis
FY14 Activities—FORTRAN to C++ transition

Background & context

• EnergyPlus originally in FORTRAN due to origins in BLAST program
• FORTRAN has limited access to modern hardware, software libraries & programmers
• DOE considered internal C++ transition several times, but difficult to pull off
  – Can’t “stop the world” & little internal expertise

Autodesk stepped up to fund & lead translation

• To facilitate uptake of EnergyPlus into their products
• Objexx performed 2-step translation: i) V8.0, ii) V8.2 “catch-up”
  – “Stopped the world” for 3 months rather than 9
• Currently removing C++ performance overhead (30% remaining)
• Will add object-orientation incrementally, automated translation gave FORTRAN-ic code
Progress & Accomplishments

Downloads: ~20,000 downloads per version

Market Impact: new tools in past year (that we know of & can talk about)
- Interfaces: GreenSpaceLive gEnergy, ExpertApp N++, Sefaira Concept, ArchSim, Bentley AECOSim EnergySimulator V8i, DesignBuilder 3.4, LBNL/Digital Alchemy Simergy, OpenStudio application & Parametric tool*
- Others: Xcel EDAPT*, CEC CBECC-Com*, BTO Asset Score*, Concept3D Simuwatt*
- * based on OpenStudio SDK—most new development will use this path

Awards/Recognition: 2003 R&D 100 award
Project Integration & Collaboration

Top-down integration: goal is to support 50 vendors, not 50,000 end-users. EnergyPlus uses OpenStudio to accelerate vendor uptake. It’s working!

Bottom-up integration: team active on ASHRAE standards and technical committees and in IBPSA. Algorithms & data sets based on latest peer-reviewed & ASHRAE accepted results.
- Collaboration with ASHRAE MTG EAS on airflow modeling
- Collaboration with ASHRAE TC 9.9 on datacenter modeling

Research: combination of advanced capabilities & open-source licensing gives EnergyPlus a significant research presence. Most energy simulation research publications (ASHRAE, IBPSA) use EnergyPlus.

Communications: multiple channels
- energyplus.gov website (most hits in BTO, 3rd most in EERE)
- EERE progress alerts & GovDelivery on new releases
- EERE “success stories” & blog posts
- Seminars on new features & training sessions at major conferences (ASHRAE & IBPSA)
Future—Inaccuracy/Validation & Uncertainty/Calibration

**Target problem:** perceived & real “inaccuracy” of energy simulation

- Some is “inherent” to physical approximation, most is “propagated” from uncertain inputs
- Limits use cases to comparative (“A is X% better than B”), not predictive (“A EUI is X”)
  - Although you can actually do a lot this way
- Reduces confidence in all use cases, even comparative ones 😞

**Approach I:** inaccuracy & algorithm validation

- Characterize & attribute (in)accuracy
- Use small well-characterized setups to remove input uncertainty
  - FLEXLAB, Annex 58 participants, maybe MAXLAB FRP too
  - Currently working out initial set of experiments
- Formalize & publish test cases & results via ASHRAE standard 140
- Use 140 comparative testing to identify additional physical experiments

**Approach II:** uncertainty & input calibration

- Outside of EnergyPlus, but complements end-uses
- Implementing two mechanisms in OpenStudio
  - Bayesian: fast & easy, includes uncertainty
  - Evolutionary (Autotune): takes longer but gets you closer
Target problem: monolithic structure with built-in imperative solvers
- Inhibits parallelization and co-simulation
- Barrier to prototyping of models for new technologies
- Poorly suited to operations-based use cases

Long term vision: use Modelica for EnergyPlus HVAC&R/controls
- Modelica is a declarative modeling language
  - Decouples governing equations of the system from solver
  - Simplifies prototyping & sharing of models (no need to merge solvers)
  - Supports verification, optimization & direct implementation of control algorithms
- Developed & supported by international community (mostly EU)
- Born in automotive & aerospace world, but making headway in buildings

Approach: Spawn-of-EnergyPlus
- Develop Modelica library for components & systems (LBNL & IEA Annex 60)—started FY13
- Develop & pilot prototype simulation master (LBNL, ORNL)—FY14
- Couple C++ EnergyPlus to solver (use RFP)—FY15-16
  - Will look like conventional EnergyPlus interface to existing users
- Incrementally replace existing C++ components with Modelica components over time
REFERENCE SLIDES
Project Budget

**Project Budget**: funded since 1997 at $2,100—5,000k per year

**FY14 Spend to Date**: $925k

**Additional funding**: in-kind labor from Trane & Autodesk

**Additional funding**: supported by other BTO-funded projects
- ASHRAE 140 for testing
- FLEXLAB for validation
- Radiance for some geometry algorithms
- WINDOW for fenestration algorithms
- OpenStudio SDK and other CBI projects for deployment

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<td>1997 – FY2013</td>
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<td>(past)</td>
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<td>DOE</td>
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<td>~$65,000k</td>
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### Project Plan & Schedule

- Months 1-4: new features and planned enhancements
- Month 5: bug fixes, clean up, robustness testing
- Month 6: critical bug fixes, packaging, distribution testing
- Month 7: post release validation testing and reports

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#### Project Schedule

- **Project Start:** 1997
- **Projected End:** N/A

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