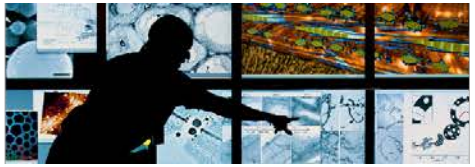
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Building Energy Modeling 0017-1505

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And a cast of dozens

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NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Mission Statements

Mission I: "Develop, maintain, and support a BEM engine for fair and accurate assessment of different energy efficiency measures for all types of buildings projects."

➔ **Project I: EnergyPlus**

Mission II: "Develop and maintain a framework for testing building energy simulation software tools that improves accuracy and consistency and increases user confidence"

➔ **Project II: ASHRAE Standard 140**

Mainstays of BTO's program …

- EnergyPlus since 1997 (DOE-2 prior to that)
- ASHRAE Standard 140 since 1989 (1st publication of Standard 140 in 2001)

… how to evolve them to meet new challenges & opportunities?

What Is EnergyPlus?

Advanced capabilities: critical for low-energy buildings

- Integrated zone conditions-system response solution can model under-conditioned spaces
- Heat-balance solution calculates surface temperatures for thermal comfort
- Combined heat & mass transfer that accounts for inter-zone airflow
- Illuminance & glare calculations for visual comfort & lighting control
- Sub-hourly time-steps for modeling systems with fast dynamics
- Component-based HVAC for new configurations + standard system templates
- Built-in lighting & HVAC control schemes + runtime language for custom controls

Only engine that combines these with open-source licensing

- Serves as basis for codes & beyond-code programs
- And for a large ecosystem of public & commercial software
- Lends legitimacy to proprietary engines by comparison via ASHRAE standard 140

Recent Accomplishments

Platform & process improvements

- Translation from FORTRAN to C++ (funded by Autodesk)
- Speed improvements beyond pre-translation levels
- Agile development process & tools, including continuous integration
- Commercial development partners: Trane, Autodesk, Carrier & Fraunhofer

Growing ecosystem of third-party software

- Plug-ins & utilities: jEPlus/JESS, MLE+, EnergyPlus Cloud, APIDAE, eppy, etc.
- User interfaces: DesignBuilder, AECOSim, OpenStudio, Simergy, N++, Sefaira*, etc.
- End-use specific applications: Simuwatt*, CBECC-Com*, Asset Score*, Qcoefficient, etc.
- Greatly helped by OpenStudio (* are OpenStudio-based applications)

Growing user community

- 20,000+ downloads of last four version updates
- Used in 16% of projects submitted to AIA 2030 Commitment in 2013 …
- … and in 20% of projects that met performance targets

Challenges & Needs

Maintenance of large, legacy code-base

- 750,000+ lines of code & 4,500+ pages of documentation

Execution speed

- Still more than 20X slower than DOE-2, how much of this is detailed physics?

Catching up to, then keeping up with HVAC, refrigeration & controls advances

- Help new technology be evaluated for use in building projects

Modeling existing buildings, including degraded conditions, faults & occupants

- Facilitate post-occupancy analysis & operational use cases

Support for residential modeling

- Allow DOE to unify its commercial & residential simulation platforms

Integration with control software development & testing workflows

- Ideally, same control description used for both simulation & physical implementation

Characterization of accuracy … and improvement where necessary

- ASHRAE Standard 140
- Also, a separate topic with its own proposal (1530)

How Do We "Know"?

Bugs & minor issues

- Reported by users via Helpdesk, Support List, UnmetHours, etc.

Execution speed

- Mentioned as primary drawback of switching to EnergyPlus from older, less capable engine
- Primary focus for development partner Autodesk

New features

- Requested by users (e.g., variable-speed heat-pumps), application developers (e.g., equipment sizing options), organizations (e.g., data centers) & BTO (e.g., advanced RTU)!
- Prioritized by occasional surveys (could be more frequent) & internal discussion
- Heavily scrutinized & planned before decision to proceed
- Open-source has enabled bug-fix & feature "donations"—have accepted a few
- Reduced emphasis as feature set has matured
- Focus on co-simulation & leveraging features in other engines rather than re-creating
- Exploring new methods of gathering data on feature use & importance

Accuracy

- Occasionally mentioned by users regarding specific features or configurations
- Frequently mentioned by BEM skeptics

Spawn-of-EnergyPlus

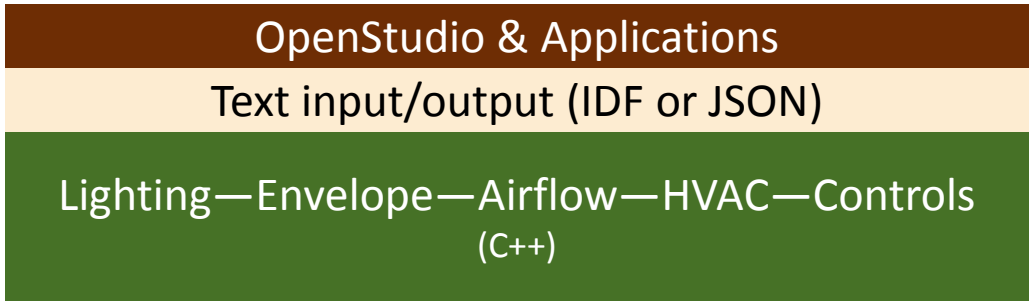
EnergyPlus

- Tightly integrated imperative “solvers” (i.e., time-steppers) for individual components
  - New component models require implicit, compatible solvers & cannot be reused
  - Unit testing is difficult
- Bespoke control language (EnergyPlus Runtime Language)
  - Meaningless outside of EnergyPlus

Spawn

- Internally generated initiative, intended to carry tool forward for another 20 years
- Well-defined component modules with input/output ports & open standard interfaces
  - \+ Facilitate unit testing & component reuse
- External (to components, not to EnergyPlus as a whole) “solver”/simulation master
  - \+ Facilitate rapid (even third-party) component development & reuse
  - \+ Exploit component-specific time-steps & parallelization for high performance
- Component models & control algorithms written in open-standard language, Modelica
  - \+ Unify simulation & control development workflows
- Same old EnergyPlus interface ➔ 99% of users & developers will not be disrupted

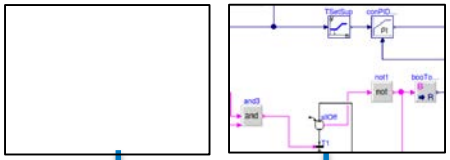
Spawn-of-EnergyPlus in Pictures

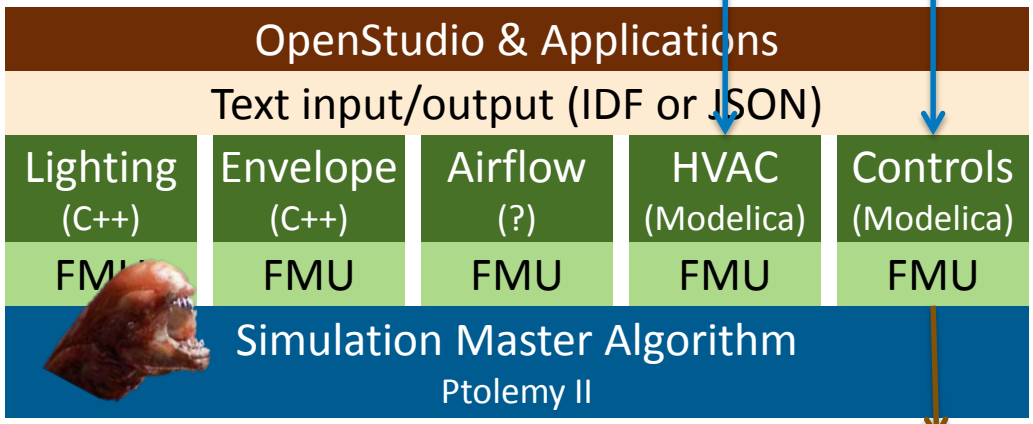


EnergyPlus

- Monolithic
- No channels for component reuse

HVAC & control models from open source or manufacturer (compiled) libraries

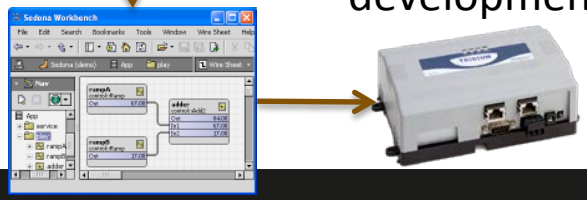




Spawn-of-EnergyPlus

- Modular
- Standard interfaces (FMUs)
- Exploit model libraries
- Inter-operability with control workflows and product development

Control models run directly on physical controllers (e.g., Tridium)



Spawn Master Algorithm

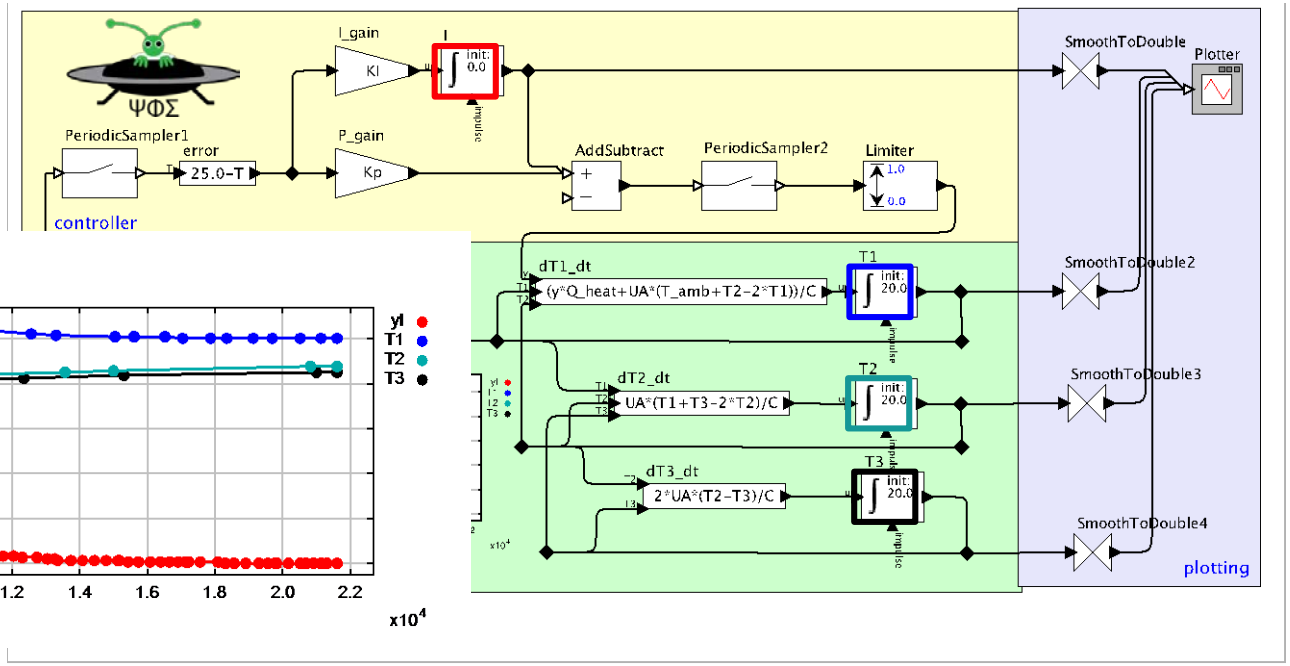
Ptolemy II actor-based platform

- Composes heterogeneous solvers: discrete time (envelope) & discrete event (HVAC)

QSS (quantized state system) master algorithm

- Evaluates fast changing components frequently, static ones infrequently ➔ saves time
- Illustration: Heat transfer problem with PI control

$$\begin{pmatrix} C & 0 & 0 \\ 0 & C & 0 \\ 0 & 0 & C \end{pmatrix} \frac{dT(t)}{dt} = \begin{pmatrix} -2 & 1 & 0 \\ 1 & -2 & 1 \\ 0 & -2 & -2 \end{pmatrix} UA\ T(t) + \begin{pmatrix} UA\ T_{amb} + \dot{Q}\ y(t) \\ 0 \\ 0 \end{pmatrix}$$

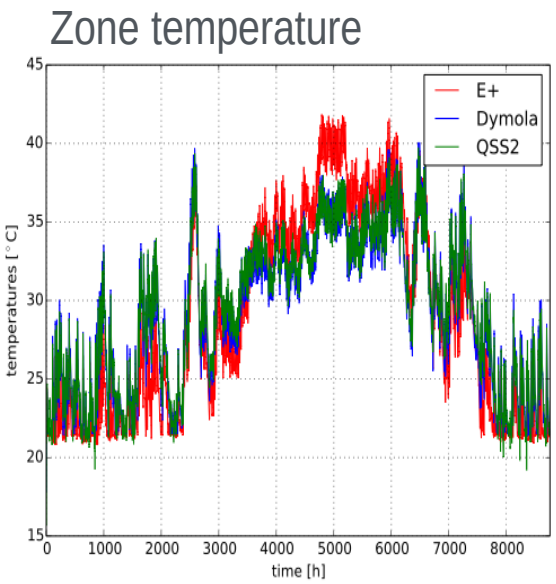


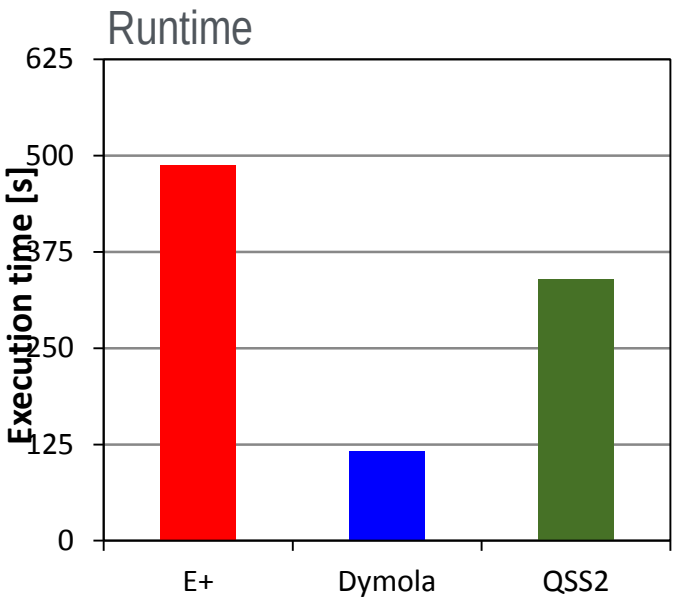
Spawn Master Pilot Results

How well does QSS work relative to EnergyPlus?

- 1-Zone model in 5 FMUs: 1. east wall/window, 2. other walls/air node, 3-5. radiant slab)
- 9-Zone model in 45 FMUs: 9 copies of 1-Zone stacked in 3x3 cube (results below)

- QSS tracks EnergyPlus results well (models are not 100% same) & 30% faster!
- Dymola (commercial tool solving entire system) is faster still—for this small example
- QSS has not been optimized or parallelized (which would be easy to do)
- Could approach Dymola performance





Multi-Year Vision

Important consideration: leverage considerable EnergyPlus momentum

- Cannot simply stop core EnergyPlus development until Spawn is ready
- Create a smooth, transparent-to-clients migration path with robust fallback options

Year 1 (FY16): process & structural improvement

- Tighten industry feedback loop to refine requirements & verify “satisfaction”
- Automate development “chores” to increase productivity
- Improve code to reduce maintenance burden & defects & to facilitate Spawn transition
- Investigate Spawn-specific development techniques
- Develop Spawn infrastructure & modules in parallel (e.g., “master algorithm”)
- Release early access to Spawn via BCVTB (Building Controls Virtual Testbed)

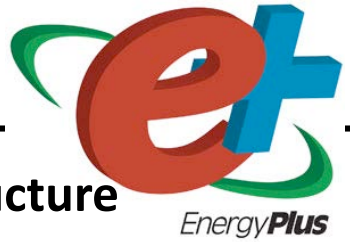
Year 2 (FY17): Spawn transition & alpha release

- Transition to Spawn development techniques
- Integrate Spawn elements into EnergyPlus & begin testing parity

Year 3 (FY18): Spawn beta release & continued development

- New features developed in Spawn

FY16 Work Plan



Exploit Fortran-to-C++ translation by moving to object-oriented structure

- Improves testability, lowers the threshold for external collaboration

Continue expanding test suite with unit & runtime tests

- Improve code robustness, reduce testing burden on developer

Continue improving runtime performance

- Focus on input/output performance & performance of inner loops via vectorization
- Shift simulation "logic" from component models to higher level "managers"

Selectively add new capabilities

- Fault models—new industry focus on evaluating energy-impacts of equipment faults
- Equipment sizing—important to industry partners, will help adoption
- Support for standards—ASHRAE 90.1 (minimum commercial building performance), 90.4 (data centers), 189.1 (green buildings), 55 (thermal comfort), 62.1 (ventilation & IAQ), 205 (equipment performance) & California T24 (whole building performance)
- Integrated attic model—for residential (collaboration with Fraunhofer CSE)
- Residential equipment models

Performers & Budget

Large team with broad expertise & significant experience

- Successful, multi-lab/contractor/university/industry collaboration

Core lab team with over a century of experience in building simulation

- NREL—Edwin Lee, Kyle Benne, Scott Horowitz (residential), etc.
- LBNL—Tianzhen Hong, Michael Wetter, Thierry Nouidui, etc.
- ORNL—Joshua New, Mark Adams, Bo Shen, etc.
- Labs collaborate on both EnergyPlus core (NREL lead) and Spawn

Competitively solicited 3-year development support sub-contract

- Funded separately from this proposal
- GARD Analytics, Florida Solar Energy Center, Oklahoma State U., Archmage Energy, etc.
- Can add needed expertise, e.g., Objexx performance, UC-Berkeley for Ptolemy II

Self-funded development by Autodesk, Trane, Carrier & Fraunhofer

Extensive collaboration within IEA EBC Annex 60 (38 institutes) & Modelica Assoc.

Mission Statements

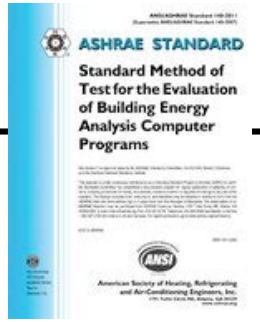
Mission I: "Develop, maintain, and support a BEM engine for fair and accurate assessment of different energy efficiency measures for all types of buildings projects."

➔ **Project I: EnergyPlus (and Spawn)**

Mission II: "Develop and maintain a framework for testing building energy simulation software tools that improves accuracy and consistency and increases user confidence; populate the framework with diagnostic test suites that cover the key models and algorithms in the tools."

➔ **Project II: ASHRAE Standard 140**

ASHRAE/ANSI Standard 140 Overview



What is it? Test cases & reference results for BEM software programs

- Statistical methods for establishing "acceptance" thresholds

EnergyPlus, EnerSim, EDSL Tas, DesignBuilder, AUTODESK GREEN BUILDING STUDIO, EnergyGauge Energy Analysis & Rating Software, eQUEST, TRNSYS 17, IC3 International Code Compliance Calculator, DOE-2, CoolTool AC & R technology, Carrier HAP, ekotrope, APOGEE INTERACTIVE, EnergyInsights™, 700, ies INTEGRATED ENVIRONMENTAL SOLUTIONS, REM/Design™, REM/Rate™

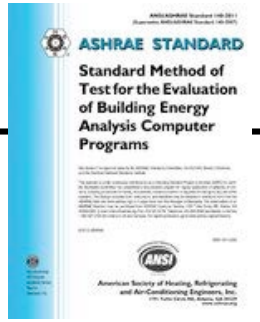
How is it used? IRS 179D tax credit qualified software procedure

- 13 commercial tools, 7 residential are qualified
- IRS list is referenced by many other programs: e.g., utility incentive programs

Standard 140 is also referenced by other standards

- ASHRAE 90.1 & 189.1 Minimum & Green Commercial Building Energy Efficiency Codes
- International Energy Conservation Code & International Green Construction Code
- European Union High Performance Building Directive
- Energy efficiency codes of many countries

Philosophy: Three Complementary Tests



Analytical (i.e., closed form) tests for simple cases

- Diagnostic, but not realistic & limited in coverage

"Comparative" tests for more complex cases

- Results defined by range of disagreement among engines that pass analytical cases
- Not selecting one engine as "the reference" allows state-of-the-art to advance
- Diagnostic & with arbitrary coverage, but lack "ground truth"

Empirical tests from well-characterized facilities

- Complex & costly, but necessary—see proposal #1530

Organized to maximize coverage & diagnostic capability

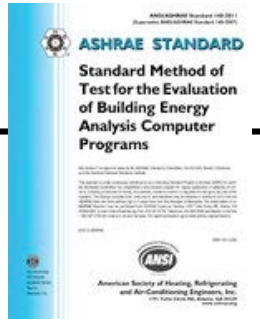
Developed using iterative field trials with leading engines

- Three rounds ensure specifications are unambiguous & engine neutral & simulation tool results are suitable for use as reference results

Existing test suites

- Thermal fabric, ground coupling, airflow, HVAC

FY15 Tasks & FY16-18 Workplan



Continuous Maintenance Version 140-2014 published

- Adds Slab-on Grade Ground Coupling test suite
- NREL/DOE has produced versions: 2001, 2004, 2007, 2011, and 2014.

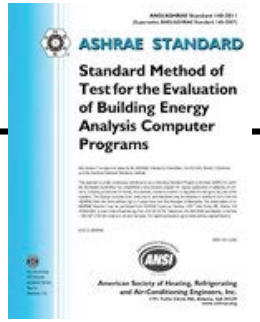
Airside HVAC Analytical Solution Test Suite

- Based on ASHRAE-RP #865—Fan-Coil, Packaged Single-Zone, CV+Reheat, VAV+Reheat
- Both heating & cooling cases, with parametric variation
- Seven engines participated from US, Japan, China, and UK (including EnergyPlus)
- All simulation trials, modeler reports & documentation have been completed

Update of Thermal Fabric Comparative Test Suite

- Existing suite is from 1995, pre-dates modern engines like EnergyPlus & IES-VE (& DOE-2.2)
- TMY3 weather, tall buildings, convection coefficients, pressure-driven infiltration, etc.
- One round of simulation trials completed, additional diagnostic test specs sent
- Seven engines participating (including EnergyPlus)

FY16-18 Workplan



FY16-18

- Complete these for Continuous Maintenance Version 140-2018
- Airside HVAC will be completed as addendum by 2017
- $300k/yr

Performers

- Ron Judkoff, NREL—former chair of ASHRAE SSPC 140 and IEA Annex 34/43 on validation
- Joel Neymark, JNA—current chair
- Engine developers donate time
- As do members of SSPC 140

Risks & Mitigation Strategies

EnergyPlus is an established project with a growing user & tool ecosystem

ASHRAE Standard 140 (and proposal #1530) mitigates accuracy risk

- For all BEM tools, not just EnergyPlus

Recent emphasis has been on reducing project risk

- Modern languages & tools reduce dependency on legacy & increase developer pool
- Object orientation & testing improve maintainability & robustness

Overarching risk mitigation: continuous contact with users & developers

- Existing channels: Helpdesk, Support Group, Unmet Hours, periodic surveys, relationships
- New channel: user & developer technical advisory group (TAG)
- Additional transparency in EnergyPlus planning & prioritization process

Risks & Mitigation Strategies

Spawn is a form of risk-mitigation & future proofing …

- Standard interfaces (FMI) & component/control description languages (Modelica)
- General-purpose solvers developed by numerical analysts & used in production systems
- Modular structure allows for swapping out components that don't perform as expected

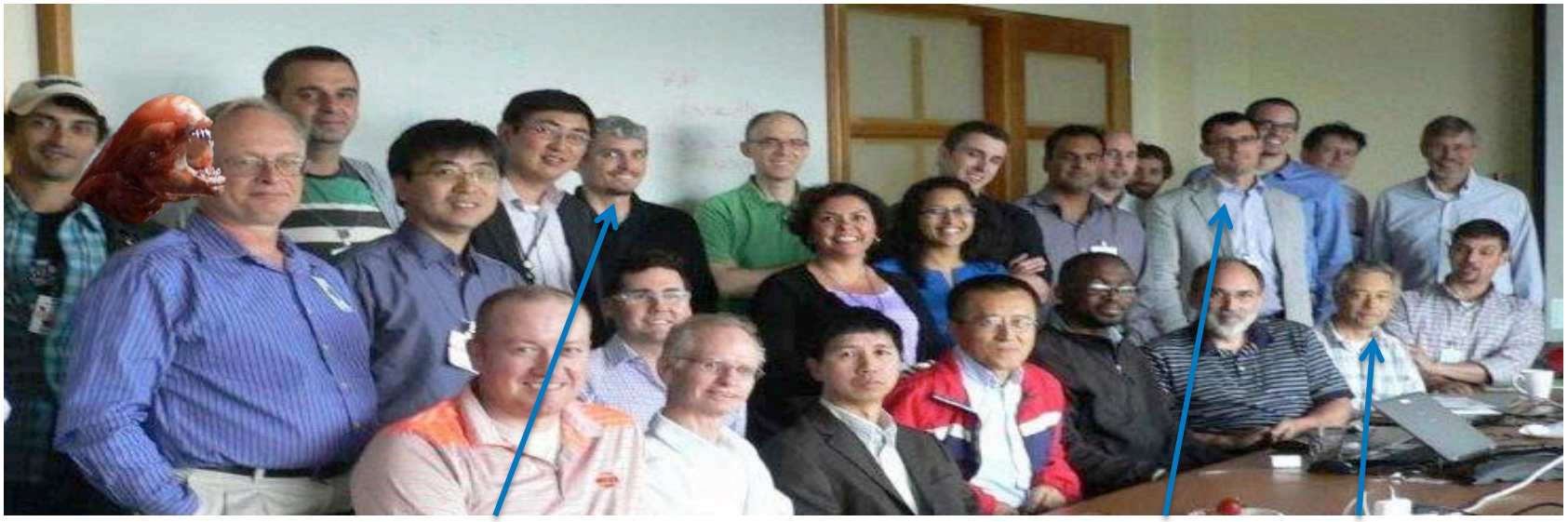
… but is itself somewhat risky

- Only a subset of the team is experienced in this methodology
- Will transition really be transparent for application vendors & users?
- How soon will Spawn match EnergyPlus in coverage and robustness?

These are mitigated by prototyping, parallel development & incremental migration

- Extensive prototyping to prove benefits & answer major questions
- Core functionality will be made available through related channels, e.g., BCVTB
- Not stopping EnergyPlus development—will always be available as a fallback
- EnergyPlus will benefit greatly even if Spawn doesn't fully work

Thank You



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Michael Wetter Luigi Polese

Questions?