2024 PROJECT PEER REVIEW

U.S. DEPARTMENT OF ENERGY
BUILDING TECHNOLOGIES OFFICE

EnergyPlus

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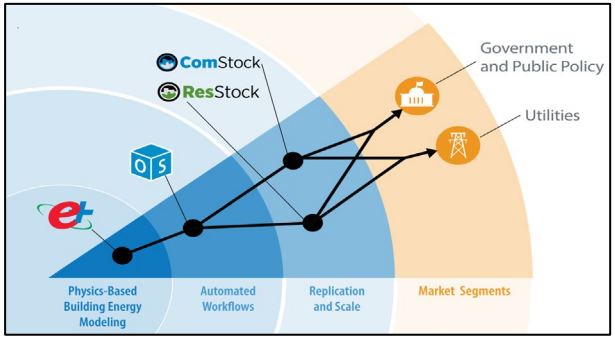
Project Summary

OBJECTIVE, OUTCOME, & IMPACT

EnergyPlus sits at the core of DOE projects, industry BEM software interfaces and research workflows, reaching tens of thousands of users. EnergyPlus enables analysis and simulation ranging from detailed digital twin to grid-scale building stock modeling. EnergyPlus provides the simulation needed to inform DOE R&D to reach DOE's nationwide energy goals.



One of <u>many</u> paths connecting EnergyPlus to Impact

TEAM & PARTNERS

- Lead Laboratory: NREL
- Partner Laboratories: LBNL, ORNL, PNNL
- Development team: UIUC, UCF/FSEC, GARD Analytics, Big Ladder Software, and Digital Alchemy
- Stakeholder Partners: Trane, Carrier, Ladybug Tools, DesignBuilder, SmithGroup, Autodesk and many more

STATS

Performance Period: FY23-25

DOE Budget: $2,037k in FY24

Milestone 1: Spring 2024 Release

Milestone 2: Progress Report: Refactoring, Features

Milestone 3: Fall 2024 Release

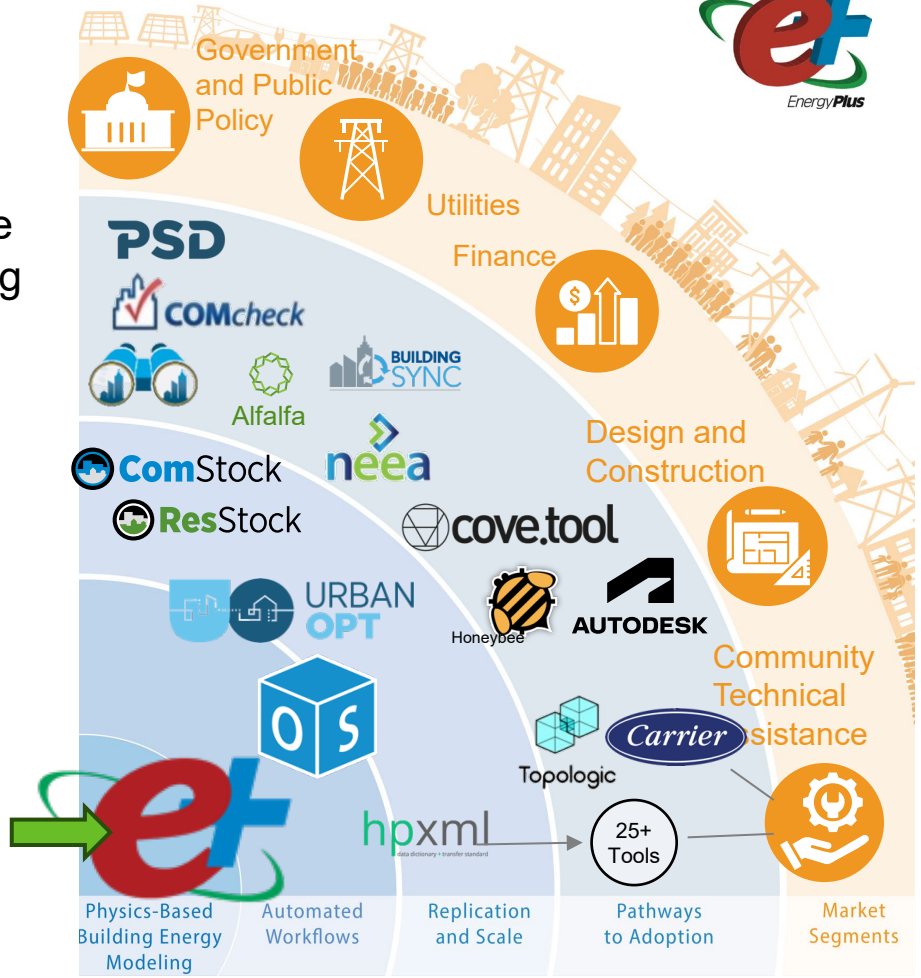
“Problem”

Many decisions related to building energy use rely physics-building Building energy modeling (BEM) for quantitative analysis.

At the individual building level, applications include design, code compliance, ratings, financial incentives, M&V, model predictive control, and digital twins.

Stock level uses include code and program development, pathway planning, technology road-mapping, and product development.

These use cases rely on a capable, robust, transparent, and documented physics engine



Alignment

Decarbonization Blueprint

"Provide tools to help stakeholders identify and implement measures to improve efficiency, increase demand flexibility, accelerate electrification, and deploy on-site generation and storage in buildings.“

"Issue determinations on the latest model building energy codes“

"Support decision science to explore key technology adoption channels"

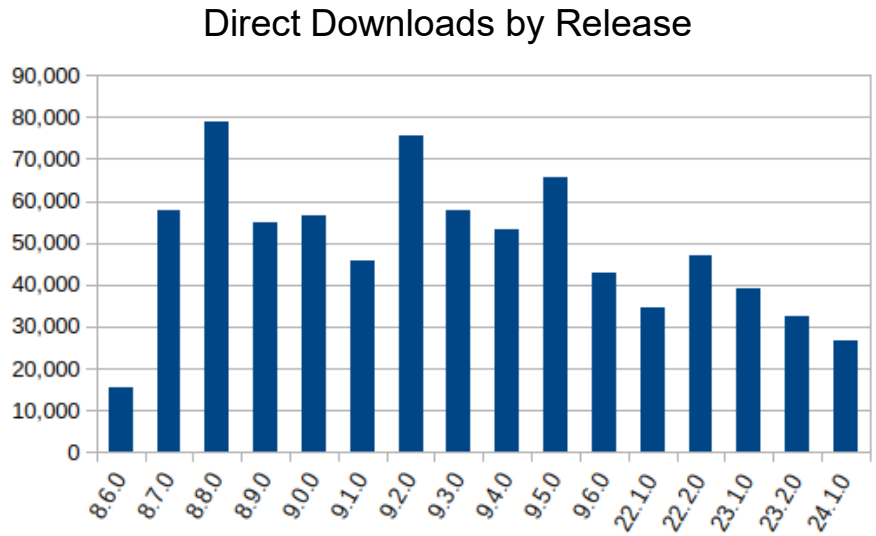
Cross-cutting goals and strategic priorities

- **Energy efficiency and onsite emissions reduction.** BEM/EnergyPlus support these goals in two ways: via use in design, compliance, and incentives for individual buildings and via the development of codes and programs that mandate or incentivize them.
- **Affordability and equity.** Large-scale BEM/EnergyPlus analysis is used to set performance and cost targets for new products, and to identify cost-effective measure packages in building projects.
- **Resilience.** BEM/EnergyPlus calculate not only energy use, but also indoor temperature, humidity, light, and contaminant conditions and can be used to create individual designs and broad guidance that promote safety and preserve basic function during outages and extreme weather events.

Market Adoption

Tools and Downloads

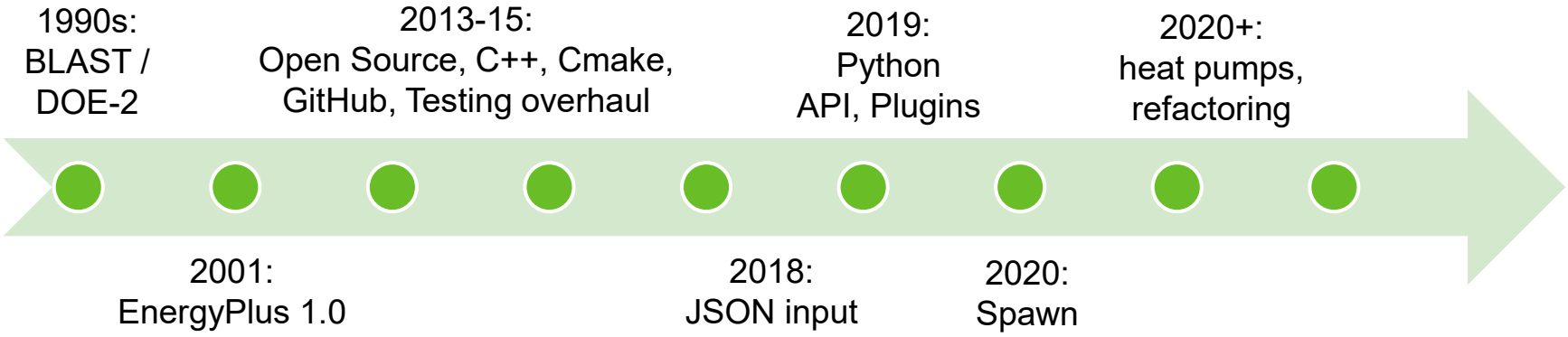
- 40k+ direct downloads per release
- Many tools build on EnergyPlus (e.g., DesignBuilder, Carrier HAP) are either downloaded separately or web services
- Major HVAC manufacturers, AEC/MEP and consulting firms have adopted



Project use (from AIA 2030) – 2023

- Cove.tool (EnergyPlus, also ASHRAE RTS method) – **1489 projects (189 high perf.)**
- Other EnergyPlus interfaces (DesignBuilder, TRACE, HAP) – **570 (258)**
- IES-VE – 633 (407). DOE-2.1 – 483 (196), DOE-2.2 eQuest – 404 (222)

Approach



- **EnergyPlus is a mature product**
  - Generally in “maintenance” mode, although major feature work is often needed
  - Budget history reflects maturity:
  - $4,000k/yr → $3,000k by 2010 → under $2,000k/yr in 2024.

Approach – Development Process

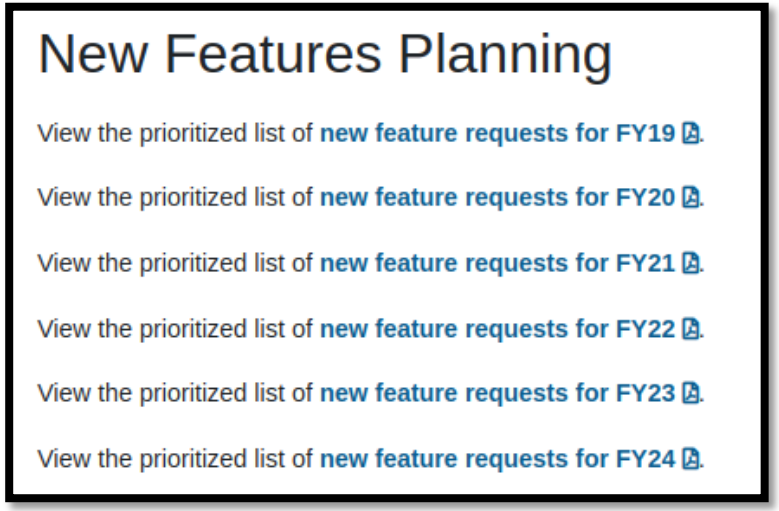
- **Codes use case necessitates transparency and best-known methods**
  - Models based on ASHRAE research and documented in handbook
  - Constantly tested and evaluated in the context of validation efforts
    - Google Scholar reports 81 "EnergyPlus" + "Validation" articles in just the last year
  - Complete engineering documentation along with example files
  - ASHRAE 140 testing
- **Products with 10k's of end-users require commercial-grade development**
  - Multiple platforms – Windows, Linux, MacOS
  - Up to date compilers and static code analysis tools
  - GitHub for source management, feature, defect, and issue tracking
  - CMake for multi-platform build management
  - Continuous integration with extensive unit, regression, and code-coverage testing

Negative impacts would result if the integrity of EnergyPlus is broken

Approach – Feature Prioritization

https://energyplus.net/documentation

- **Stakeholders guide feature prioritization**
  - ~100 stakeholders generate dozens of feature requests every year
  - Prioritized by impact, alignment, and … source (e.g., priority for DOE or major vendor)
  - Process and results (spreadsheet) are public on the EnergyPlus website
  - Requests regularly include updates for ASHRAE standards (90.1, 205, ...), modernized workflows, HVAC modeling flexibility, additional EMS actuators (see next slide for EMS)



Approach – Extensibility via Scripting

- **Unique EnergyPlus feature is EMS**
  - "Energy Management System" …
  - … but more than that
  - A simple programming language
    - ERL – akin to c 2000 BASIC
  - User functions called at runtime points (e.g., day time step, HVAC iteration)
  - Access internal "sensors", "actuators"
  - Can implement custom control logic, user-defined components, affect component sizing, and more

This example is as sophisticated as you can reasonably get

```
EnergyManagementSystem:Program,
 UpdateHeatingSetPoint,
 IF (DayOfWeek == 1),
 SET myHTGSETP_SCH = 15.6,
 ELSEIF (Holiday == 3) && (DayOfYear ==
21),
 SET myHTGSETP_SCH = 21.0,
 ELSEIF (Hour < 5),
 SET myHTGSETP_SCH = 15.6,
 ELSEIF (Hour < 6) && (DayOfWeek == 7),
 SET myHTGSETP_SCH = 15.6,
 ELSEIF (Hour >= 19),
 SET myHTGSETP_SCH = 15.6,
 ENDIF;
```

Example EMS program to update heating setpoint by sensing time variables

Approach – Python EMS and API

- **ERL → Python**
  - Most popular scripting language
  - Many users
  - Many useful open-source libraries
  - Code lives outside input file, this allows re-use and organization
- **Python API**
  - Can call EnergyPlus "as a library"
  - Enables new use cases
  - Use your own Python environment

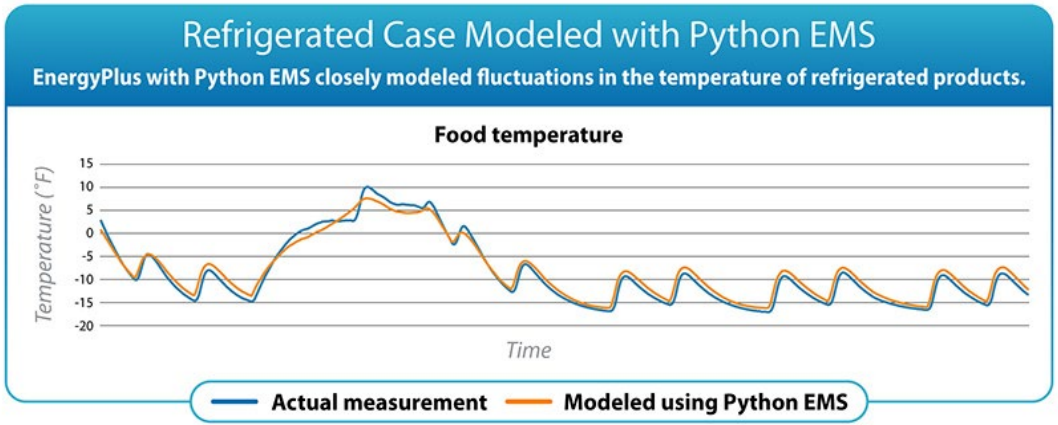
Much, much more sophistication possible

```
def on_begin_timestep_before_predictor(self, s):
    hour = self.api.exchange.hour(s)
    dow = self.api.exchange.day_of_week(s)
    doy = self.api.exchange.day_of_year(s)
    hol = self.api.exchange.holiday_index(s)
    if dow == 1:
        self.actuate(s, 15.6)
    elif hol == 3 and doy == 21:
        self.actuate(s, 21)
    elif hour < 5:
        self.actuate(s, 15.6)
    elif hour < 6 and dow == 7:
        self.actuate(s, 15.6)
    elif hour >= 19:
        self.actuate(s, 15.6)
    return 0
```

Example Python EMS program using the Exchange API to update heating setpoint after sensing time variables

Approach – Python EMS and API

- **Example use cases**
  - The Stor4Build Consortium's TESSBeD tool uses the new Python plugin system to enable impact assessment of building-integrated thermal storage
  - Supermarket Load Flexibility at Emerson Electric: NREL and Emerson Electric used Python EMS to prototype control strategies and extend the physics modeling to evaluate conditions and product temperatures inside refrigerated cases, predicting food safety.



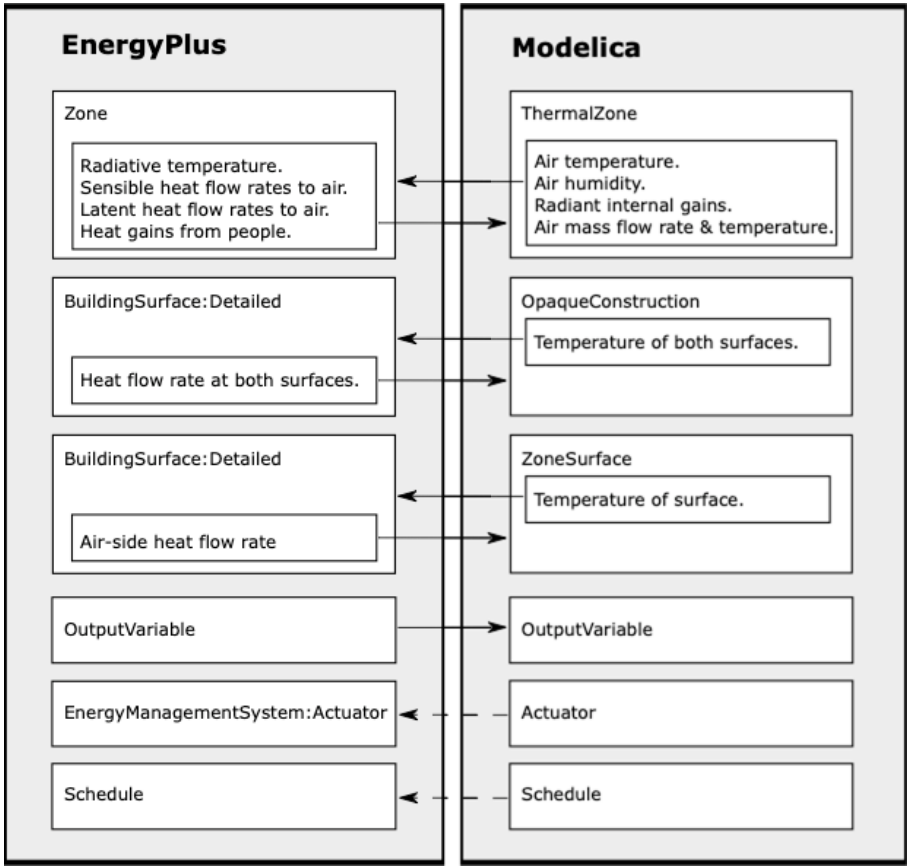
Validation results of Python EMS modeled food temperature inside refrigerated case. More details at https://www.nrel.gov/news/features/2022/python-opens-up-new-applications-for-energyplus-building-energy-simulation.html

Approach – Spawn Integration

Significant new capabilities

- Run with native HVAC/control disabled
- Start and stop simulation on demand
- Read and write values efficiently
- Run multiple EnergyPlus instances in the same process without interference
- Export an FMU

Implemented via Spawn project



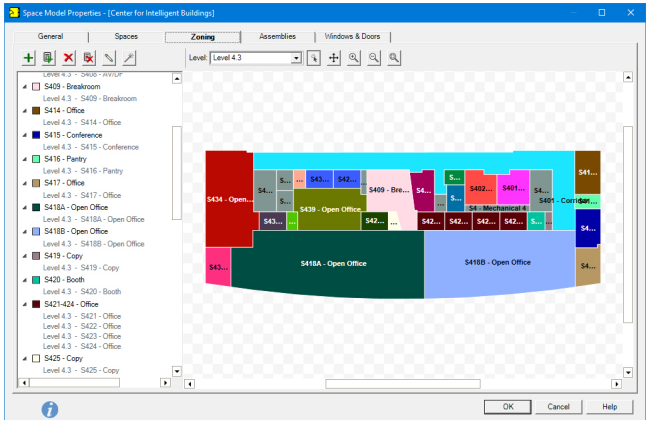
Other Features Since FY18 (Last Peer Review!)

- Kiva ground heat transfer model
- ASHRAE 205 performance maps for chillers
- Upgraded equipment auto-sizing
- Space-level lighting and loads→extending to indoor conditions
- Safety and resilience metrics
- Hooks for integrated urban- and micro-climate modeling
- JSON input, many output improvements
- Built-in G-function calculation for ground loop heat exchangers

FY24 Accomplishments

- 250 “pull requests” merged (https://github.com/NREL/EnergyPlus/pulls/)
- 20 related to new feature work
  - Output metrics for ASHRAE 90.1
  - ASHRAE 229P Ruleset Evaluation Schema (RES) export
  - Add heat recovery to air-water heat pump
  - Chiller economizer and free cooling enhancements
  - Improvements to VRF fan cycling and supplemental heater controls
  - TIER (Time-independent Energy Recovery) all-electric central plant model
- 97 related to defects/bugs
- The rest related to refactoring or other "behind the scenes" changes

Market Adoption



HAP v6 offers many technical upgrades to reduce what used to take a few days of labor to a couple hours of engineering time for building model creation. It integrates with the U.S. Department of Energy's EnergyPlus™ calculation engine to provide cutting edge system simulation capabilities. It utilizes the ASHRAE Heat Balance load calculation method to represent building physics more accurately.

https://www.carrier.com/commercial/en/us/news/news-article/carrier-releases-hap-v6--a-major-upgrade-to-hvac-system-design-software.html

Industry Quotes

- **Industry recognizes the impact of EnergyPlus, recurring themes …**
  - Importance of a public, transparent, reliable, and robust DOE supported simulation engine
  - EnergyPlus powers energy modeling across industry
  - EnergyPlus supports decarbonization projects
  - Stakeholder engagement

"The synergy between EnergyPlus and ASHRAE has played a pivotal role in advancing building performance analysis, as is the case with the history of our Building Performance Analysis Conference. **EnergyPlus is the engine that powers much of the industry's private sector energy modeling software** and is essential to the energy modeling software development and the professional energy modeling community."

2024-25 ASHRAE President M. Dennis Knight, P.E., BEMP, Fellow Life Member

"NRELs ongoing commitment to Autodesk by streamlining the build process, responding to bugs and providing guidance on latest developments is critically valuable to Autodesk as it works to provide our AECO customers with **the power of EnergyPlus and OpenStudio through Revit and next generation Insight**. These capabilities have never been more important to the industry, and we could not achieve the same level of speed and quality without NREL's expertise. Thank you, DOE and NREL for all of your hard work and partnership. We hope this can continue long into the future."

Ian Molloy, Senior Product Line Manager and Building Performance Analysis at Autodesk

More Quotes

"We have been using EnergyPlus/OpenStudio for different research projects. In ASHRAE RP-1771, we used EnergyPlus to develop prototype building energy models to support ASHRAE Building Energy Quotient Standard. In our National Science Foundation project, we are developing building energy models using EnergyPlus for building energy policy. In our DOE BSEC IFL project, **we are using EnergyPlus to understand how we can improve the energy efficiency and thermal resilience of Baltimore rowhouses for low-income communities.**"

Wangda Zuo, Ph.D., IBPSA Fellow
Professor of Architectural Engineering,
Pennsylvania State University

"The U.S. national blueprint of the building sector aims to reduce GHG emissions from U.S. buildings by 65% by 2035 and 90% by 2050, compared to 2005 levels. Daikin, as the world's largest and leading manufacturer of HVACR equipment, is committed to driving broader electrification, decarbonization, and energy efficiency of buildings with its highly efficient, inverter-driven heat pump technologies for HVACR and water heating. **EnergyPlus is an essential building simulation tool that supports the dynamic and accurate performance assessment of heat pump products, and informs our decarbonization-related state and local policies.** It also supports our market strategies and enables engineers to select and size appropriate heat pump systems for their applications. We expect EnergyPlus to continue its development and maintenance for supporting HVACR manufacturers, including Daikin, toward the decarbonization of the building sector."

Anuj Mistry
Manager of Technical Services at Daikin US Corporation

Random EnergyPlus Sighting in the Field

Ensembles of 20 OpenStudio/EnergyPlus models for every Washington, DC building subject to energy disclosure. Created by Introba to help implement Building Performance Standards. (Credit: Introba).

Future Work

FY25 features docket

- Heat-pump improvements – peak-demand effects and defrost cycle
- Improved air-to-water heat pump
- Support for sizing thermal storage components
- JSON output (for AI/ML applications!)

Other improvements

- Transition utilities from Fortran to Python
- Improve version compatibility and offer more frequent and easier updates
- Prioritizing the defect list to maximize impact
- Creating a new dashboard for runtime performance
- Moving more documentation to an online hub (ReadTheDocs, e.g.)
- Carve out APIs to lower the burden for interface developers
- Restructure and reduce the codebase to lower maintenance burden

Team – 200+ years of BEM experience

National Labs

Edwin Lee
Dareum Nam
Scott Horowitz

Tianzhen Hong
Yujie Xu

Pijlae Im
Jason DeGraw

Jian Zhang
Jeremy Lerond

Subcontractors

GARD Analytics
Building Energy Software, Modeling, and Standards

FSEC

bigladder SOFTWARE

University of Illinois Urbana-Champaign

EffiBEM

Digital Alchemy
THE BUILDING MODELING EXPERTS

Thank you

EnergyPlus Project WBS (3.5.5.13) Multi-Lab Project Principals		
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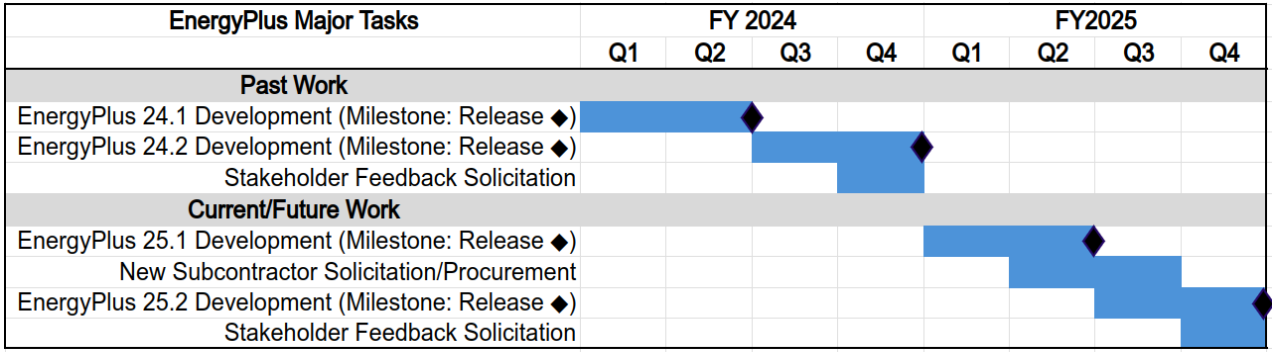
Lawrence Berkeley National Laboratory	Dr. Tianzhen Hong	Thong@lbl.gov
Oak Ridge National Laboratory	Dr. Jason W. DeGraw	degrawjw@ornl.gov
Pacific Northwest National Laboratory	Jeremy Lerond	jeremy.lerond@pnnl.gov

Reference Slides

Project Execution

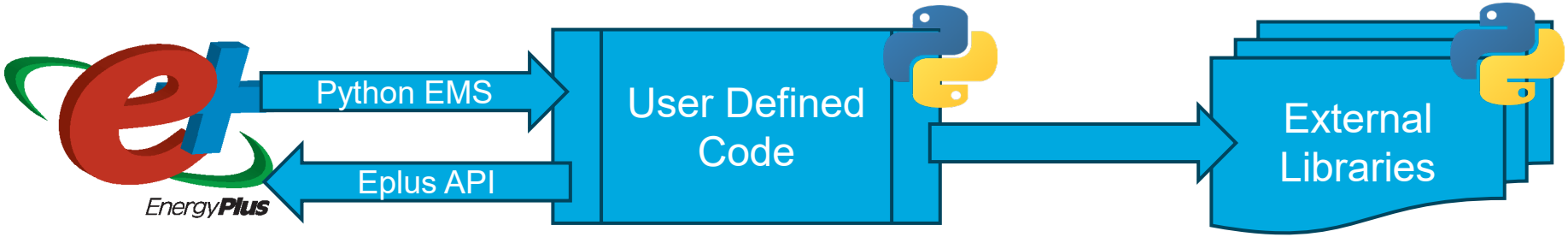


- The multi-lab EnergyPlus team has consistently met milestones on time for years.
- Major releases are the core deliverables, but development consists of:
  - Planning new features
  - Refactoring and adding new capabilities
  - Fixing defects
  - Organizing meetings
  - Stakeholder solicitations
  - Managing test frameworks and the software development stack
  - Creating and publishing official releases

Approach

How all the Python?

- Implementation: EnergyPlus can call Python code through plugins, or user Python code can call EnergyPlus as a library.



- Deployment: EnergyPlus can be deployed in a variety of ways for maximum
  - Desktop Users: Traditional installer
  - Servers and Applications: Built into a docker container
  - Automated Integration: Through GitHub Actions
  - Maximum Flexibility: "**pip install energyplus**" into user Python installations -- working on Linux, Windows and Mac soon