2024 PROJECT PEER REVIEW

U.S. DEPARTMENT OF ENERGY
BUILDING TECHNOLOGIES OFFICE

OpenStudio® Development, Maintenance, and Support

Performing Organization(s):
NREL, LBNL, ORNL, PNNL
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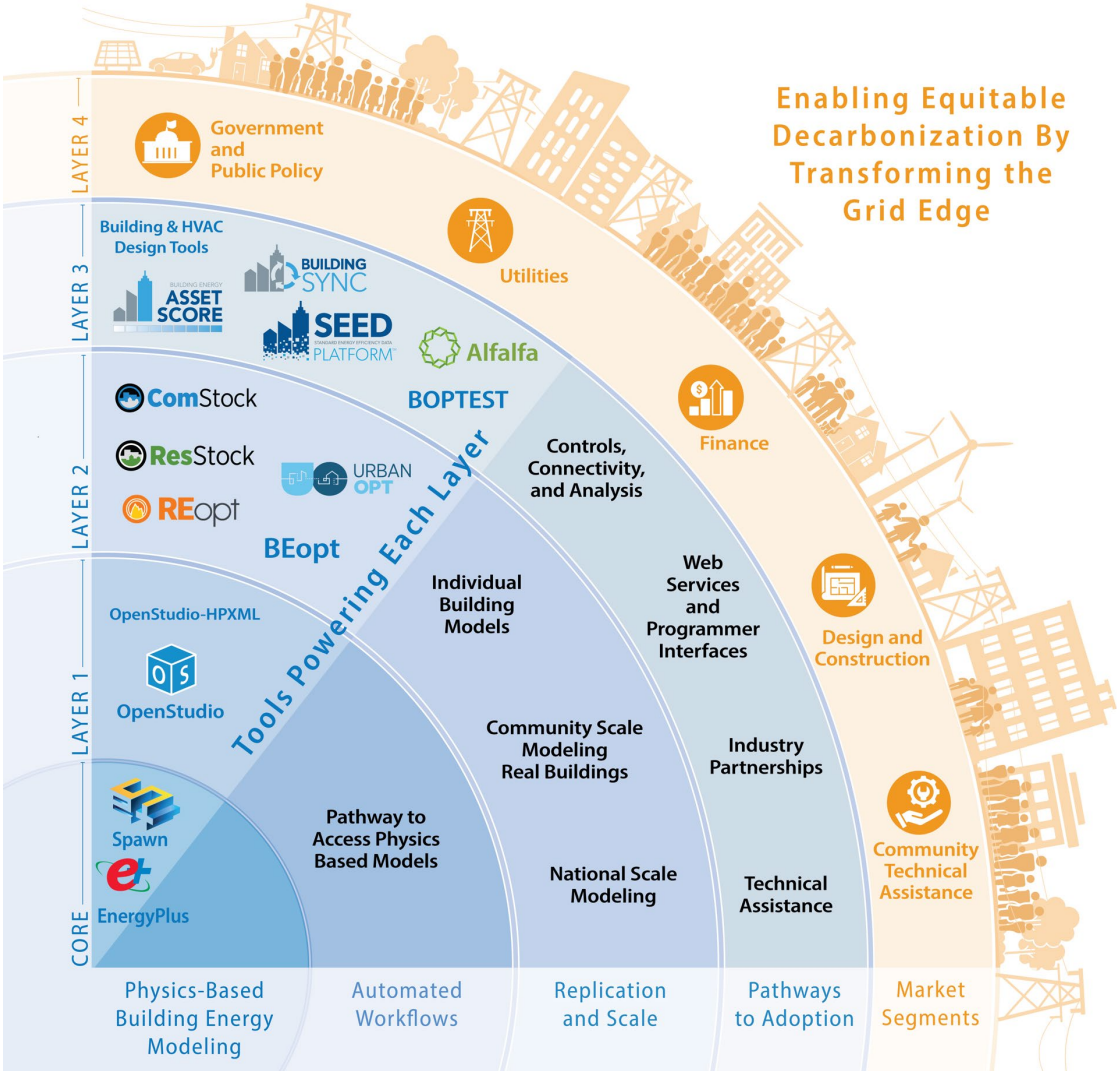
WBS#: 3.5.5.26 (NREL)
WBS#: 3.5.5.25 (LBNL)
WBS#: 3.5.5.23 (ORNL)
WBS#: 3.5.5.24 (PNNL)

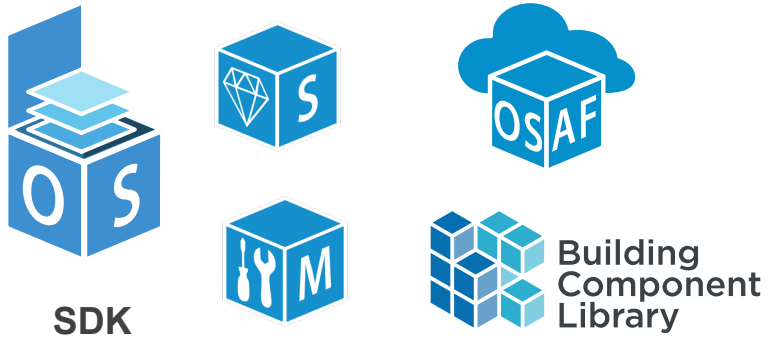


Project Summary

OBJECTIVE, OUTCOME, & IMPACT

OpenStudio enables building energy modeling (BEM) experts to encapsulate domain and process knowledge in such a way that makes it usable by a range of stakeholders.

This results in real world outcomes in the U.S. building stock to meet the Blueprints aggressive 90% reduction in building emissions by 2050.



TEAM & PARTNERS

NREL: Project Mgt. & Core Development

LBNL: GEB Measures

ORNL: Stakeholder Engagement and Refrigeration

PNNL: OpenStudio Standards Development

STATS (FY24)

Performance Period: 10/01/23 – 09/30/24

DOE Budget: $1,700k

Milestone: OpenStudio SDK 3.7.0 Major Public Release

Milestone: OpenStudio SDK 3.8.0 Major Public Release

Milestone: Building Standards Database 0.1.1 Major Public Release

Milestone (FY25): OpenStudio SDK 3.9.0 Major Public Release

Problem: How do we assure success of quickly and cost effectively meeting the DOE Blueprint's emissions, resilience, affordability and equity targets for the US building stock?

Most engineered products are modeled before they are built.

- Airplanes, cars, computer chips, televisions, toasters, table saws, electric razors, non-electric razors, etc.
- Individual building components too: windows, chillers, water heaters, dishwashers, etc.

Buildings are a different type of product with big impacts, including energy impacts.

- But modeling applies here too; BEM has many use cases.
  - Design, HVAC sizing, code compliance, incentive calculations, product development, policy analysis.

Buildings are not mass produced – there are similarities, but each one is unique.

- BEM must be cost effective on an individual building basis, and not just over millions of units.
- BEM cannot be the domain of a few experts, it must be accessible to diverse professionals.
  - Architects, mechanical engineers, control engineers, code officials, standards bodies, policymakers.
- But BEM is a deep discipline and requires expertise.

Our Solution: Reduce risk and optimize cost and performance with a BEM amplifier.

EnergyPlus probably needs very little introduction.

- Comprehensive features, vetted, designed for integration into other products.
- Input is extremely verbose – thousands of lines of text to describe a building.

OpenStudio is a software development kit (SDK) for BEM, specifically for EnergyPlus. It helps people write software to automate BEM/EnergyPlus workflows.

- Application Programming Interface (API) changes to EnergyPlus models **quickly** and **repeatedly**.
- Commercial-grade software development (continuous integration (CI) with unit, regression, and performance testing) – if you don't have this, you won't have commercial users either.
- Consistent model creation and EE measure application of across large collection of tools and workflows.

OpenStudio enables **BEM experts** to write code that can create and modify EnergyPlus models. Expert knowledge (not to mention manual labor) is encapsulated so that it can be used by a much larger group of professionals … over and over!

Alignment and Impact

Blueprint: We plan to enhance BEM capability to support the Blueprint's goals:

- Reduction of building emissions of 65% by 2035 and 90% by 2050 through analysis of energy efficiency and codes, load flexibility, and linking to external embodied carbon tools to support integrated analysis of operational and embodied emissions.
- Affordability and enhanced resilience.
- Accurate characterization of impacts in all communities, particularly low-income communities.

Current Approach:

- BEM capabilities lack enough customization and fidelity to answer the more challenging questions such as matching load profile shape to generation capacity and hourly emission factors.

Why Care: The OpenStudio ecosystem is designed for rapid scaling and impact. Top priority modeling enhancements we implement can positively impact 10 billion sqft. of new construction and retrofits annually.

Anticipated Accomplishments in FY25: We will enhance elements of building performance identified in the Blueprint that have the most impact and the most uncertainty. This is likely to include:

- Parametric schedule development to support load flexibility, model calibration.
- Passive survivability measure.
- Continue performance-based compliance development.
- External integration with embodied carbon tools to model operational carbon.
- User support for measure development.

Alignment and Impact

Cross-Cutting Goals

Equity: Increase fidelity and quality of inputs to accurately represent all buildings in the U.S.

Affordability: Support evaluation of new technologies and strategies.

Resilience: Enable easy to use analysis of passive survivability performance during power outages. This requires enhancements to modeling and simulation workflows.

Strategic Objectives

EE: Use analysis to assure that decisions are well informed and will meet expectations.

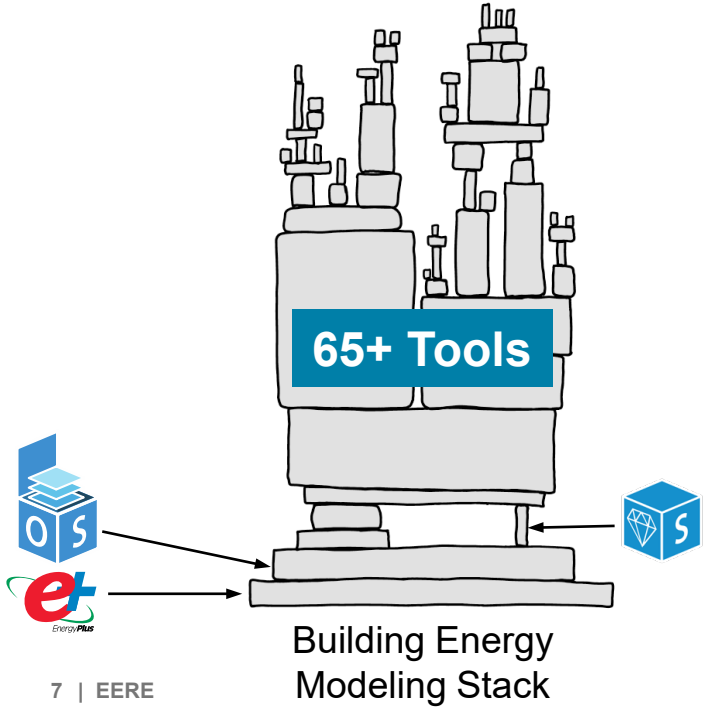
Onsite Emissions Reduction: Provide accurate and detailed results to inform how much onsite emissions are reduce and what the consequences might be to other metrics.

Transform the Grid Edge: Maximize buildings potential in load flexibility.

Minimizing Embodied Lifecycle Emissions: Support integrating analysis for operational and embodied emissions to inform material and system selection as well as when to retrofit and when to demolish and replace a building.

BEM supports these goals and objectives. OpenStudio supports BEM.

Alignment and Impact: Based on Blueprint projections more than $35 trillion will be invested between now and 2050 in U.S. buildings for new construction, retrofits, and utility costs.



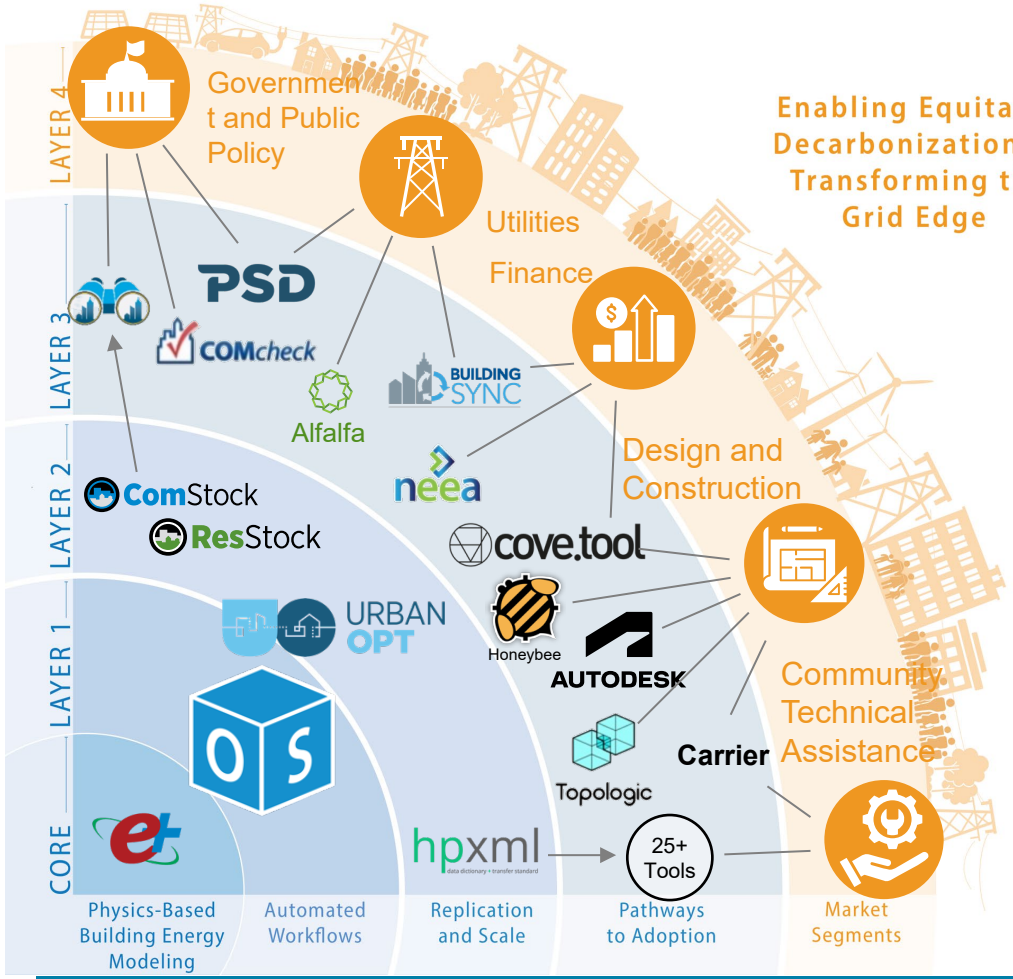
Building Energy Modeling Stack

Meeting the Blueprint's expected $107 billion in annual demand-side utility savings and $17 billion in annual avoided healthcare costs while making buildings more affordable and resilient won't just happen, it will require hard work. Each year we will prioritize high impact BEM work to support this effort.

- $125 billion annual savings / $10 million BEM budget* = 12,500x payback
- If 1% of savings due to BEM analysis, then it is still a 125x payback on each dollar
- This payback doesn't even include reduction on > $1 trillion annual construction cost that analysis would enable.

Not maintaining investment in BEM will cost money in the long run and increase risk of not achieving blueprint goals.

** OpenStudio budget is around $2 million, $10 million BEM assumption pulls in adjacent project that OS leverage and tools that leverage OpenStudio.*



Impact

Selection from 65+ tools and projects leveraging OpenStudio SDK accessible from more than 10 leading CAD/BIM interfaces.

Second tier indirect partners who use these tools expand impact even further.

OpenStudio makes EnergyPlus accessible to more researchers, vendors, and users.

This is what the community is saying!

Design Software and International Partners

"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 MEP and Building Performance,
Autodesk

"OpenStudio and EnergyPlus are the cornerstones of our efforts to determine cost-effective retrofits to existing buildings. This allows us to create and simulate many thousands of models of buildings, in different locations, with different retrofits, in hours. . . **We are also planning on generating tools which estimate both the embodied and operational carbon emissions represented by these retrofits models**. . .The work that the National Renewable Energy Laboratory and other U.S. Department of Energy national labs put into developing these tools, and working with them, greatly helps our own research in this area."

Phylroy Lopez
Senior Technical Advisor
National Resources Canada

This is what the community is saying!

Utility, Consulting, and Research Focused Partners

"The next step for these credentialed calculations and design tools is managing the grid edge impacts. **We need simulation-based tools built on OpenStudio and EnergyPlus to model reducing the design loads and sizing backup correctly. These investments will reduce the cost of energy for the entire grid by helping to avoid massive grid reinvestment.** PSD has obtained regulatory approval for peak load calculations for the Standardized Simulations. This is using OpenStudio and EnergyPlus to help bring value to grid edge investments."

Greg Thomas
CSTO,
Performance Systems Development

"Without OpenStudio, it's clear that the Ladybug Tools Grasshopper plugin never would have reached its current impact of being downloaded over 3/4 of a million times to be used in over 5,000 peer-reviewed research papers and applied on thousands of real building projects. In particular, the OpenStudio SDK transformed our software from an interesting experiment that helped architects simulate ideal loads into a full-fledged BEM platform capable of modelling real HVAC systems and forecasting utility bills with assumptions derived from codes and standards."

Chris Mackey
Co-Founder,
Ladybug Tools

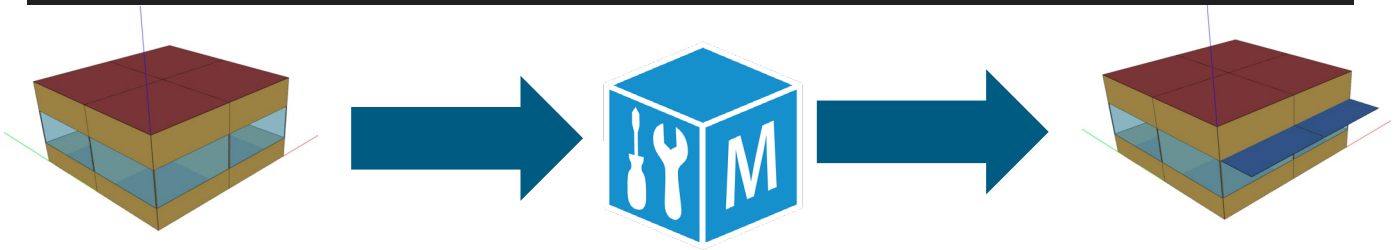
Approach: 50%: This special sauce is called OpenStudio Measures

API and measures is 50% of what you need to know about OpenStudio.

An OpenStudio Measure is a script that applies a specific transformation to a building model.

This one is simple, adding overhangs to south-facing windows. A more complicated measure creates a baseline building model using the ASHRAE 90.1 Appendix G procedure.

Measures encapsulate significant BEM knowledge and expertise (and code!), and are the technology behind OpenStudio's workflow automation, large-scale simulation, and extensibility (vendors and users can write their own). They provide significant added value to BEM.

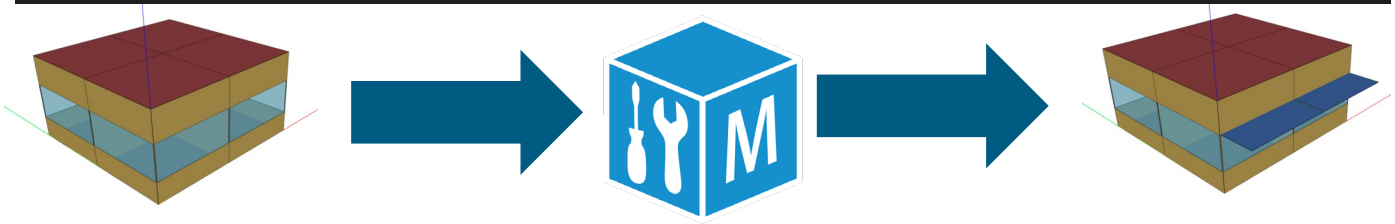


Approach: What does an OpenStudio Measure look like?

OpenStudio "understands" energy models.

And makes changes easy.

```ruby
# add overhang on south facing windows with a proj factor of 1
def run(model, runner, user_arguments)
  model.getSubSurfaces.each do |s|
    next if not s.outsideBoundaryCondition == "Outdoors"
    next if not s.subSurfaceType == "FixedWindow"
    orientation = OpenStudio::convert(s.azimuth,"rad","deg").get
    if orientation > 135 && orientation < 225
      s.addOverhangByProjectionFactor(1,0) #proj factor, offset
    end
  end
  return true
end
```



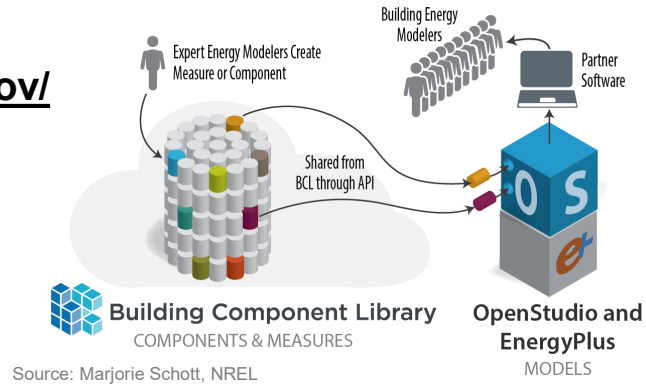
+ 30%: OpenStudio-Standards

- An expansion from “prototype” or “reference” models to **“typical” buildings** with diversity of geometry, HVAC systems, schedules, etc.
- Enables **large-scale analysis**, including program planning, deemed savings calculations, regional/national impact analysis, technology road-mapping, research, and education...e.g., ResStock, ComStock.
- Develop, share, and maintain **modeling data**, such as code requirements, modeling defaults, and typical designs and operations through software-agnostic database.
- Enable complex measures such as model transformation per ASHRAE Standard **90.1 Performance Rating Method (PRM)**.

Approach: + 10%: Building Component Library (BCL)

Building Component Library (BCL) https://bcl.nrel.gov/

- A versioned online repository of Measures and "Components."
- Experts can share with BEM community … BEM community can build and share on top of that.



Source: Marjorie Schott, NREL

Approach + 10%: OpenStudio Analysis Framework (OSAF)

- Humans are limited in time and ability to evaluate many building alternatives.
- OSAF has algorithms for exploring many options at scale, impossible for humans.
- Individual building/portfolios: design optimization, calibration.
- District scale analysis: measure impact analysis, program planning, code updates.
- Future work: Workflow for spawn, Advanced calibration workflows, Integrated ML / AI workflows.

Interactive OSAF tutorials and documentation on how to create these workflows without a GUI. https://github.com/NREL/docker-openstudio-jupyter

Approach and Timeline

SketchUp plug-in
- Edit EnergyPlus geometry
- Written in Ruby.

App SDK

Graphical Application
- Met lab modeling needs
- Demonstrated use of SDK for application integration.

OpenStudio Analysis Framework
- Demonstrates measures and scriptable large-scale analysis
- Cloud-enabled.

Command Line Interface (CLI)
- Easy integration of measure workflows.

2012: "Adopted" by BTO

2006

2020

SDK: C++ API with Ruby "Bindings"
- Faster
- Integration from multiple languages.

OSM

Component Library (BCL)
- Online repository for Measures and other "content" (e.g., weather files, component specs)

Building Component Library

"Standards"
- Content and Measures for prototype-building applications

Graphical Application "Cut Loose"
- Labs focus on DOE research needs and support for 3rd party integration.
- Now maintained by user-group driven OpenStudio Coalition.

Recent Progress: Measures, CLI, OSAF

- **Python Measure Functionality**
  - Support for Python on BCL.
  - Support for measure on BCL with Python Package or Ruby Gems (future).
  - Support for Python measures on OpenStudio analysis framework.
- **Ruby Upgrade (2.7.2 to 3.2.2)**
  - It took significant effort but was necessary to keep up with changing dependencies and with industry partners.
  - We upgraded from 1x to 2x Ruby in 2014. It was another 10 years before we changed to 3x.
- **Workflow logging**
  - Enhanced speed, reduced log size, easier debugging, defined log levels.
- **OpenStudio Analysis Framework**
  - Made much more robust for long runs to support 179d analysis.
  - Enabled spot instances.
  - 70% savings in cost for AWS.
  - Integrated URBANopt / REopt (for district scale modeling).
  - Better support for Amazon, Google, and Microsoft cloud.

Recent Progress: OpenStudio Standards create typical workflow and modules

Shift focus from prototype-driven workflow to typical model creation workflow with high level inputs and modularized data and methods.

Geometry:
- Custom geometry from external files
- Create bar based on space type ratios.

Hotel with retail and restaurant on the first floor.

Default hours of operation for hotel and retail, 12-11 p.m. for restaurant, parametric building schedules adjusted from hours of operation.

Electric heating (hydronic distribution) and **SWH**, gas for kitchen.

ASHRAE 90.1-2019 for envelope, loads, and system efficiencies.

FloorspaceJS

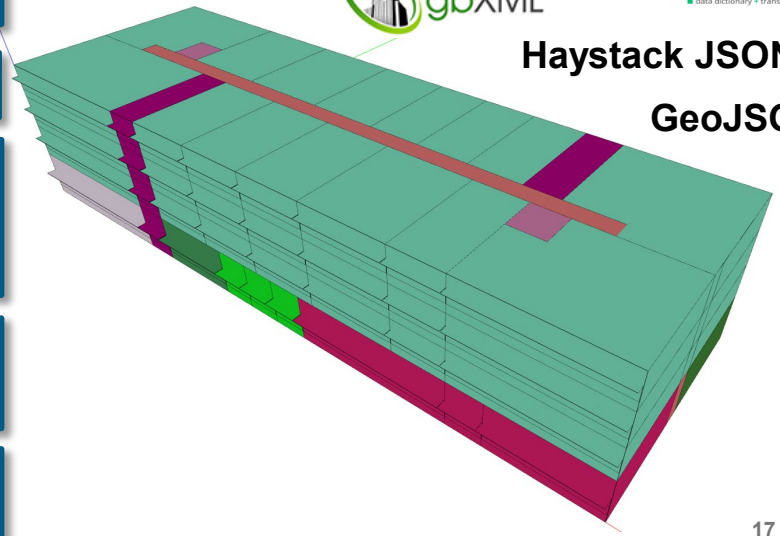
BUILDING SYNC

gbXML

hpxml

Haystack JSON

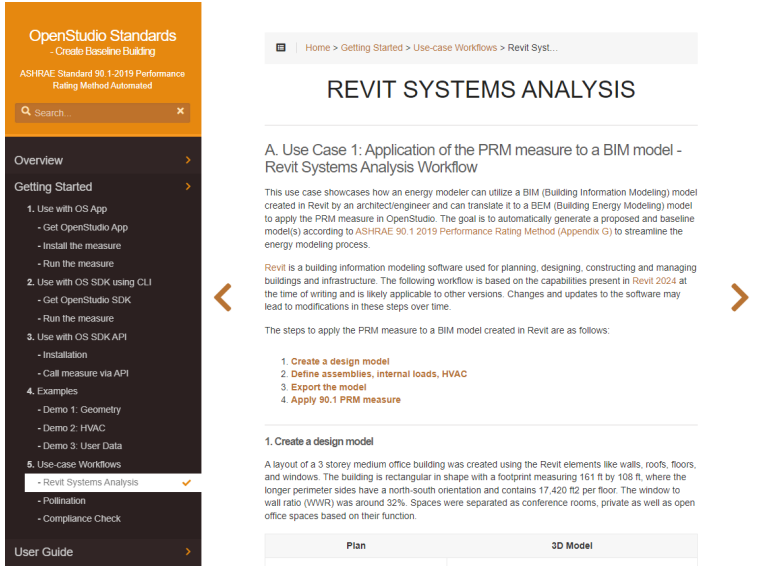
GeoJSON



Recent Progress: OpenStudio-Standards PRM Automation

- The “Create ASHRAE 90.1 2019 PRM Model” measure supports the automatic transformation of user models to Performance Rating Method (PRM) models per Standard 90.1. It accelerates the adoption of performance-based compliance, which is a pathway for net zero (Rosenberg et al. 2015 and 2020).

- Released the measure through BCL, Standards Gem, and its User’s Manual.
- Supports three workflows for different user types.
- Supports schema developed by ASHRAE Standard 229p.
- Identified gaps in the BIM-to-BEM workflow for PRM (SimBuild paper).
- Engaged with multiple stakeholders for their adoption.



Rosenberg et. al. 2015. Roadmap for the future of commercial energy codes, PNNL-24009, Pacific Northwest National Lab., Richland, WA.
Rosenberg et. al. 2020. Paving the Way for Net Zero Energy Codes through Performance Based Approaches. In ACEEE Summer Study on Energy Efficiency in Buildings, PNNL-SA-152343.

Recent Progress: OpenStudio Standards Software-Agnostic Database and Typical Designs

- The new Building Standards Database is a relational and software-agnostic database that hosts requirements and modeling defaults in Standards 90.1 and IECC.
- Designed for users and developers of any BEM engines for their accessibility, data integrity and scalability.
- Continue shifting from prototypes to typical buildings by adding to new features to support typical building

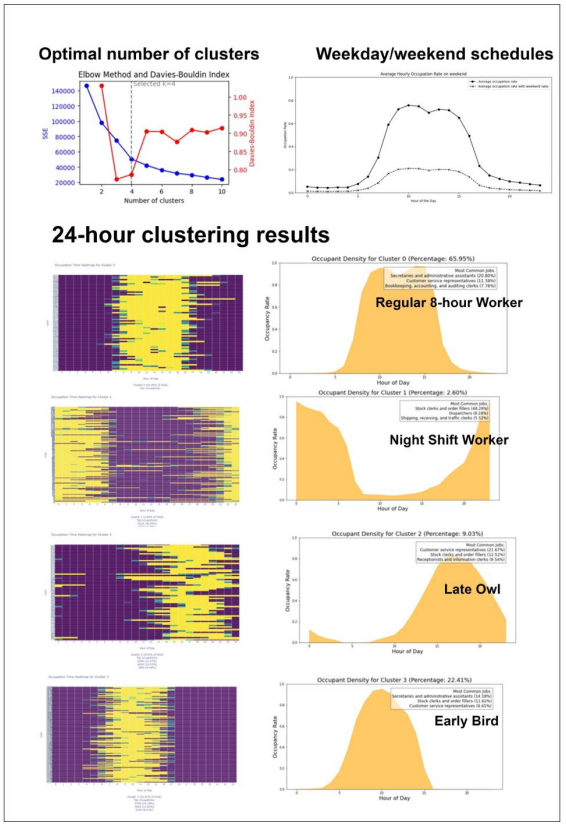
Sample search results from webservice API on lighting requirements for an office space in Std 90.1 2022


```
{
  "lighting_power_density": 0.56,
  "lighting_power_density_unit": "W/ft2",
  "method": "CS",
  "lighting_primary_space_type": "Office",
  "lighting_secondary_space_type": "Offices > 300 ft2",
  "rcr_threshold": 4,
  "automatic_daylight_responsive_controls_for_sidelighting": "REQ",
  "automatic_daylight_responsive_controls_for_toplighting": "REQ",
  "automatic_partial_off": "REQ",
  "automatic_full_off": "REQ",
  "scheduled_shutoff": null,
  "annotation": "From 90.1-2022 Table 9.5.2.1-1"
},
```


- Released the Building Standards Database webservice API https://besd.pnnl.gov and Python repository.
- Added or moved new space and building types to OpenStudio Standards, such as subtypes of warehouses and large offices, bar, refrigeration (ORNL), occupant types to allow mixed-use spaces and buildings (LBNL).
- Adding features to derive parameter-based schedules from operation and occupancy schedules.

Recent Progress:
OpenStudio Standards Database – Occupant Types

- Develop and implement office occupant types into OpenStudio Standards Database.
  - Design the occupant database structure.
  - Capture varying behavior patterns.
  - New literature/dataset support design occupant schedule/behavior/characteristics.
- Use cases
  - Predict EUI range assuming different occupant types.
  - Evaluate uncertainty of technology performance caused by different occupant types.
- Future Work
  - Develop occupant types for other building types.
  - Integrate into OpenStudio Standards workflow.

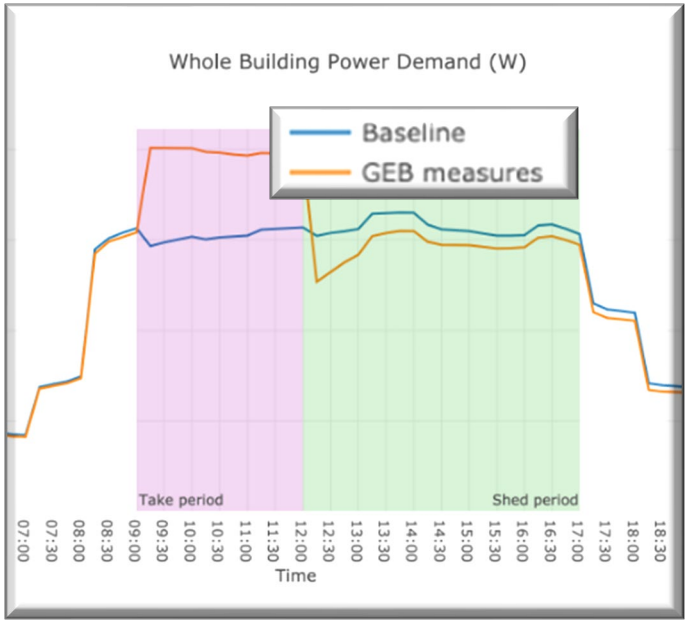


Recent Progress: GEB Measures

- **Adjust thermostat setpoints**
- **Pre-cooling**
- **Pre-heating**
- **Reduce MELs**
- **Reduce lighting loads**
- EV smart charging
- **Water tank with TES**
- DCV
- **Occupancy-driven lighting**
- Reporting metrics
- Change to HPWH
- Reduce DHW Usage
- Adjust DHW setpoint
- **Shading control**
- Electrochromic Windows
- Time averaged ventilation
- Rooftop PV System
- Reduce exterior lighting
- Ceiling fan
- TES for food storage
- Natural ventilation
- Night ventilation
- Dynamic coating for roofs/walls
- Radiative cooling.

https://github.com/LBNL-ETA/Openstudio-GEB-gem

Pre-cooing GEB measure



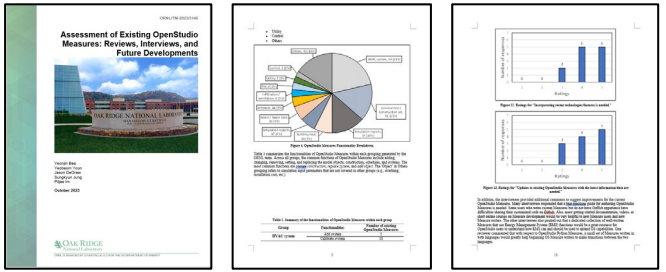
Pre-cooling sheds afternoon demand.

Several have been used in ComStock, URBANopt, and DECARB projects!

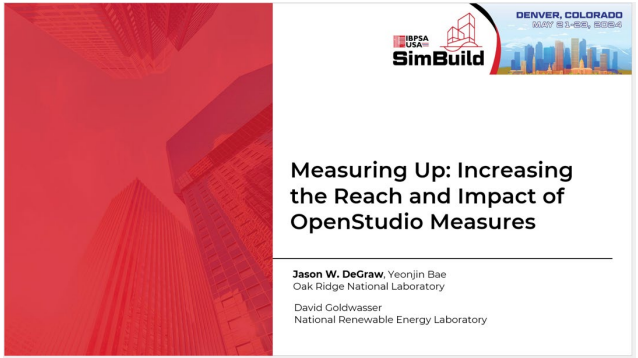
Progress: Stakeholder Engagement

OpenStudio Measure Development Roadmap

- Conducted user interviews
  - A total of 12 interviews from industry and academia
  - To gain insights into **how OpenStudio Measures are used** in building energy modeling community. (Bae et al., 2023).
- Hosted OpenStudio Measure development workshop
  - To enhance the reach and impact of OpenStudio measures, **brainstorming session** was held to explore **future measure development** and address **user needs** (DeGraw et al., 2024).



ORNL report: Assessment of Existing OpenStudio Measures: Reviews, Interviews, and Future Developments



SimBuild Workshop- Measuring Up: Increasing the Reach and Impact of OpenStudio Measures.

Bae et al. Assessment of Existing OpenStudio Measures: Reviews, Interviews, and Future Developments, ORNL/TM-2023/3146. October 2023.
DeGraw et al. Measuring Up: Increasing the Reach and Impact of OpenStudio Measures, IBPSA-USA SimBuild 2024.

Thank you

Performing Organization(s)
NREL: Project Mgt. & Core Development
LBNL: Load Flexibility Measures
ORNL: SDK Performance Improvements
PNNL: OpenStudio Standards Development

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Problem: Good BEM requires deep expertise, but to maximize impact BEM must be accessible to many different professionals working on many different use cases.

Solution: OpenStudio helps encapsulate BEM expertise so that it can be shared and built upon to make BEM more productive, consistent, and transparent.

Reference Slides

Project Execution: NREL

		FY24				FY25
Milestone	Description	Q1	Q2	Q3	Q4	Q1
1.a	OpenStudio SDK 3.7.0 Major Public Release					
1.b	Progress Update on Development Activities and Defects					
1.c	OpenStudio SDK 3.8.0 Major Public Release					
1.d	Progress Update on Development Activities and Defects					
Go/No Go	Identified Preferred Modelica Measure Design Approach					
2.a	(SMART) OpenStudio SDK 3.9.0 Major Public Release					

Project Execution: ORNL

	FY2024				FY2025			
Planned budget	$240,000							
Spent budget	$160,000							
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Past Work								
Q2 Milestone: Refactor Building Standard Data		◆						
Q4 Milestone: Develop OpenStudio Decarbonization Measures				◆				
Current/Future Work								
Q2 Milestone: Refactor the refrigeration system						◆		

Project Execution: PNNL

		FY24			
Milestone	**Description**	**Q1**	**Q2**	**Q3**	**Q4**
Stakeholder engagement	Complete stakeholder meetings, Release two identified use-case workflows on user documentation.				
Measure releases	Release PRM and create a typical building				
Release database repo	Release expanded database on PNNL GitHub				
Release refactored database	Release of the webservice/API up and running.				
Prepare PRM for RPD generation	Complete the update on PRM generated models for EnergyPlus RPD generation.				

Team

NREL

- Project Management
- Software Development for SDK, PAT, Server, Measures, FloorSpaceJS
- CI, Deployment (Releases)
- Third Party Development Support and Academic Outreach

BERKELEY LAB

- GEB and Occupancy Measures

OAK RIDGE National Laboratory

- Stakeholder Engagement and Refrigeration

Pacific Northwest NATIONAL LABORATORY

- OpenStudio Standards and Prototype Spacetypes

Team: NREL

David Goldwasser

Matt Dahlhausen

Joe Robertson

Brian Ball

Kyle Benne

Wenyi Kuang

Katherine Fleming

Team: LBNL

Tianzhen Hong

Senior Scientist

Kaiyu Sun

Research Scientist

Yilin Jiang

Technology Researcher II

Wanni Zhang

Technology Researcher II

Team: ORNL

Dr. Yeonjin Bae
R&D Staff

Jason DeGraw
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Yeobeom Yoon
R&D Associate Staff

Piljae Im
Senior R&D Staff and Group Leader

Team: PNNL

Jian Zhang

Weili Xu

Jeremy Lerond

Lingzhe Wang

Ammar Dehwah