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BUILDING TECHNOLOGIES OFFICE

Research & Development Roadmap for Building Energy Modeling—Draft—for Review Only

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Prepared by Navigant Consulting, Inc.

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Preface

The Department of Energy's (DOE) Building Technologies Office (BTO), a part of the Office of Energy Efficiency and Renewable Energy (EERE) engaged Navigant Consulting, Inc., (Navigant) to develop this roadmap for building energy modeling. The initiatives identified in this report are Navigant's recommendations to BTO for pursuing in an effort to achieve DOE's energy efficiency goals. Inclusion in this roadmap does not guarantee funding; building energy modeling initiatives must be evaluated in the context of all potential activities that BTO could undertake to achieve their goals.

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List of Acronyms

Acronyms	Description
AIA	American Institute of Architects
API	Application Program Interface
ASHRAE	American Society of Heating, Refrigeration, and Air-Conditioning Engineers
BCVTB	Building Controls Virtual Test Bed
BEDES	Building Energy Data Exchange Specification
BEM	Building Energy Modeling
BEMP	Building Energy Modeling Professional
beQ	Building Energy Quotient
BESA	Building Energy Simulation Analyst
BESTEST	Building Energy Simulation Test
BIM	Building Information Modeling
BLAST	Building Loads Analysis and System Thermodynamics
BMS	Building Management System
BTO	U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Building Technologies Office
CAD	Computer-Aided Design
CBECS	U.S. Energy Information Administration, Commercial Building Energy Consumption Survey
CVRMSE	Coefficient of Variation of the Root Mean Square Error
DeST	Designer's Simulation Toolkit
DOAS	Dedicated Outdoor Air System
DOE	U.S. Department of Energy
EDAPT	Energy Design Assistance Program Tracker
EIA	Energy Information Administration
EERE	U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy
EM&V	Evaluation, Measurement and Verification
EPRI	Electric Power Research Institute
ERDA	Energy Research and Development Administration
ESCO	Energy Service Company
EUI	Energy Use Intensity
GSF	Gross Square Feet
HAP	(Carrier Corporation's) Hourly Analysis Program
HERS	Home Energy Rating System
HVAC	Heating, Ventilation, and Air Conditioning
IBPSA	International Building Performance Simulation Association
IDF	Intermediate Data Format
IEA-EBC	International Energy Agency, Energy in Buildings and Communities
IECC	International Energy Conservation Code
IES	Integrated Environmental Solutions
IPMVP	International Performance Measurement and Verification Protocol
LEED	Leadership in Energy and Environmental Design

Acronyms	Description
LBNL	Lawrence Berkeley National Laboratory
MHEA	Mobile Home Energy Audit
MulTEA	Multifamily Tool for Energy Auditing
NAICS	North American Industry Classification System
NASA	National Aeronautics and Space Administration
NBI	New Buildings Institute
NC	New Construction
NEAT	National Energy Audit Tool
NIST	National Institute of Standards and Technology
NMBE	Normalized Mean Bias Error
NREL	National Renewable Energy Laboratory
ORNL	Oak Ridge National Laboratory
PNNL	Pacific Northwest National Laboratory
R&D	Research and Development
RECS	U.S. Energy Information Administration, Residential Energy Consumption Survey
SDK	Software Development Kit
SF	Square Feet
SEED	Standard Energy Efficiency Data Platform
TAS	Thermal Analysis Simulation
TBtu	Trillion British Thermal Units
TRACE	Trane Air-Conditioning Economics
USGBC	U.S. Green Buildings Council
VE	Virtual Environment
VRF	Variable Refrigerant Flow

Executive Summary

The U.S. Department of Energy (DOE), Building Technologies Office (BTO), Building Energy Modeling (BEM) Program seeks to increase the use of BEM tools for the design and operation of energy efficient buildings in the U.S. with the goal of reducing energy use in U.S. commercial and residential buildings, and enabling persistence of reduced energy use and demand resource costs over time. For decades, BTO has been advancing BEM in pursuit of this goal. It is currently the developer of the open-source BEM engine, EnergyPlus, and the open-source BEM software development kit (SDK), OpenStudio.

This roadmap outlines steps recommended to achieve this goal, based on technical analysis and stakeholder input collected throughout the roadmap development process. Outreach to obtain stakeholder feedback included telephone interviews and workshops with industry experts. This roadmap is informed by leading-edge information and thinking from some of the most knowledgeable BEM industry leaders and publications in the U.S., including software developers, architects, engineers, sustainability consultants, and HVAC equipment manufacturers.

Four interrelated, central themes emerged from this analysis:

1. ***There Is a Need to Establish and Promote a Clear Value Proposition for BEM:*** Most builders and building owners do not value BEM highly. They want designs completed quickly and inexpensively. Often, they do not trust BEM to provide significant value. Architects and engineers feel substantial pressure to minimize time spent on BEM. Developing and documenting compelling evidence that BEM leads to robust energy savings will help builders and owners value BEM appropriately.
2. ***There Are Opportunities to Increase the Value of BEM:*** Improving BEM tools will significantly enhance both their real and perceived values. Key opportunities are:
    a. Identifying the highest-value applications for BEM in building design, retrofit, and operation
    b. Accelerating the rate of BEM updates to include new technologies and control algorithms
    c. Improving the ability of BEM tools to accurately simulate measured building performance
3. ***There Are Opportunities to Lower the Cost Impacts of BEM:*** Current BEM tools are not interoperable with building design software, leading to duplication of time-intensive data entry. The data input process for many BEM tools can be simplified. Few (if any) BEM tools provide presentation-ready outputs, requiring time-intensive post-processing of outputs for presentation to clients and management. Ideally, software developers would provide a continuum of interoperable tools, or even unified individual tools, that serve modeling needs from conceptual design through building operation, including fulfilling the requirements (where applicable) for building energy codes, green building certification, and utility incentive programs.

4. ***There Are Opportunities to Grow and Expand the Applications of BEM:*** Stakeholder estimates suggest that BEM is used in only about 20% of new commercial building designs, and probably a smaller fraction of new residential building designs.[1] Use of BEM to support building operation is even more limited, despite the growing importance of demand response and other aspects of transactive energy.[2] Increasingly, building owners/operators will be financially motivated to not only operate their buildings efficiently, but to anticipate and actively manage their buildings' energy needs.

Table ES 1 summarizes the highest-priority initiatives recommended in this roadmap. None of these recommendations reflect fundamental changes in BTO's current program. Rather, they represent adjustments to approach and emphasis.

Table ES 1. Highest-Priority BEM Initiatives

Title	Recommended Action
Improve BEM's Accuracy through Better Training and Design/Operational Knowledge	Collaborate with industry stakeholders to identify improvement opportunities: » Promotion of Training/Certification Programs—approach training institutions such as ASHRAE (Building Energy Modeling Professional certification) and the Association of Energy Engineers (Building Energy Simulation Analyst™) » Commissioning—approach ASHRAE, Building Commissioning Association regarding how carry-through of design intent to the as-built building can be improved
Establish a Clear BEM Value Proposition	Develop and document compelling evidence that BEM leads to robust energy savings by publishing case studies for various building types and climates that: » Document the costs (labor hours) associated with BEM » Describe how BEM facilitates various energy-saving features and strategies » Show that projected energy savings are achieved during operation, and quantify the savings directly attributable to the BEM tool and BEM modeling process If used for building operation, show that BEM helps lower operational energy use persistently over the study period while maintaining a comfortable and healthy environment Quantify the energy savings that are directly attributable to BEM tools, independent of the influences of other factors such as design intent and prior experience Identify highest-value-added applications for BEM Demonstrate accuracy of simulated energy use relative to measured use Enable rapid inclusion of existing building information and control strategies, and new technologies, into BEM tools
Establish Ongoing Process for Assessing the Needs of Commercial Software Developers	Invite software developers and other stakeholders to submit written recommendations for future enhancements to EnergyPlus and OpenStudio Establish annual stakeholder meeting specifically to discuss EnergyPlus and OpenStudio development needs

[1] See Section 3.4

[2] The term "transactive energy" refers to techniques for managing the generation, consumption, or flow of electric power within an electric power system through the use of economic or market based constructs while considering grid reliability constraints. See: http://www.gridwiseac.org/about/transactive_energy.aspx

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1. Introduction

1.1 Overview of Building Energy Modeling Tools

Buildings use 41% of energy consumed in the United States.[3] Building performance analysis tools are widely used across the buildings industry to estimate the impact of energy use, energy costs, climate impacts, and water use, and to evaluate building design options to decrease energy use and costs, and improve building sustainability[4] over the lifetime of the building. Building Energy Modeling (BEM), defined below, is the most sophisticated of these building performance analysis tools, and enables building owners and their design teams to accurately estimate energy savings for existing or proposed buildings. BEM allows users to define whole building construction details, equipment specifications, occupancy/lighting/plug-load schedules, building operational schemes, and climate, and uses scientifically rigorous heat flow calculations and non-developer-specific equipment performance data to calculate electrical and fossil fuel energy use on an hourly basis.

1.1.1 Definition of Building Energy Modeling

For the purpose of this roadmap, BEM is defined as a physics-based simulation that, at a minimum, calculates:

» Thermal loads (based on climate, envelope characteristics, occupancy and other internal loads, and ventilation rates) at hourly (or finer) time steps

» Impacts of all common major building systems and equipment, *e.g.*, HVAC (equipment and distribution system), lighting, service water heating, refrigeration, cooking, plug loads, and controls

» Interactions among building systems (sometimes called secondary impacts)

» Energy use by fuel type

A BEM engine may also account for:

» Impacts of other equipment and systems, *e.g.*, on-site power generation, energy storage, and building-to-grid transactions

A BEM engine may also calculate secondary and derivative metrics such as:

» Visual and thermal comfort

» Indoor air quality

» Carbon emissions

» Water use

Capabilities or calculations that support BEM include:

- Calibration of model inputs using measured data

[3] U.S. Energy Information Administration (EIA). "In 2014, 41% of total U.S. energy consumption was consumed in residential and commercial buildings, or about 40 quadrillion British thermal units.", http://www.eia.gov/tools/faqs/faq.cfm?id=86&t=1

[4] Per ASTM E2114 – 08 Standard Terminology for Sustainability Relative to the Performance of Buildings, sustainability is defined as follows: **sustainability,** *n*—the maintenance of ecosystem components and functions for future generations. This terminology is under the jurisdiction of ASTM Committee E60 on Sustainability and is the direct responsibility of Subcommittee E60.01 on Buildings and Construction

- Prediction or stochastic description of occupancy and occupant behavior

In BTO's words, "BEM supports system-level 'integrative design' for new construction and retrofits that simultaneously optimizes the building's envelope, systems, and their controls to match its anticipated use profile and local conditions. [It also has the potential] to support 'integrative operations' in which a model incorporates real-time information from sensors, weather forecasts, and/or the building's energy management system to satisfy key energy and Indoor Environmental Quality objectives. Finally, at a larger scale, BEM also supports energy-efficiency codes, rating and labeling systems, incentive programs, product design, research, and education."[5]

1.1.2 Brief History

The roots of BEM go back to the 1970s; it was in 1971 when the U.S. Postal Service developed the first computer program (the "Post Office Program") to analyze energy use in post offices. In 1977, the Energy Research and Development Administration (ERDA), along with the California Energy Commission, developed the first modern whole building energy modeling tool called CAL-ERDA. It was based on NASA's Energy Cost Analysis Program. Shortly thereafter, ERDA became the modern DOE, and CAL-ERDA was renamed DOE-1. DOE continued developing DOE-1 and its successors DOE-2 and DOE-2.1 for the next decade and a half. The Department of Defense, Carrier Corporation, and Trane Corporation developed their own software in parallel, called Building Loads Analysis and System Thermodynamics (BLAST), Hourly Analysis Program (HAP), and Trane Air-Conditioning Economics (TRACE), respectively.

In the early 1990's, the Electric Power Research Institute (EPRI) and J. J. Hirsch and Associates began development of DOE-2.2 and secured the rights to distribute it. Rather than continuing with overlapping development of DOE-2.1, DOE rebooted its BEM efforts around the Department of Defense's BLAST program, looking to develop a modular engine based on physical first principles that would be easier to update and maintain and that included many new features. The rights to this new engine, named EnergyPlus, would be held jointly by the regents of the University of California, the operators of LBNL and the rights holders to DOE-2.1E, and by the Regents of the University of Illinois, holders of the rights to BLAST. BTO (the Building Technologies Program at the time) began EnergyPlus development in 1996 and released the first version in 2001. BTO has continued to develop EnergyPlus, releasing major version updates about every 18 months.[6] The most recent update (v8.4) was released in September 2015.

In January 2012, BTO made EnergyPlus (then v7.0) available under a permissive, commercially friendly, open-source license, which allows companies greater freedom to work with EnergyPlus, modify it, and incorporate it into their products. Enabled by this license, in 2013 Autodesk Corporation led work to translate EnergyPlus from its original implementation language FORTRAN to the more modern programming language C++. Autodesk donated the translated code back to BTO and LBNL. BTO released the first C++-based EnergyPlus version (v8.2) in September 2014, and is developing this code-base exclusively.[7]

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[5] From the contractor's work statement for this assignment.

[6] Early history based general knowledge of DOE programs (via discussions with BTO personnel), Lawrence Berkeley National Laboratory website information (available: http://eetd.lbl.gov/newsletter/cbs_nl/nl18/cbs-nl18-energyplus.html) and the Building Energy Modeling Body of Knowledge (BEMBook) website (available: http://www.bembook.ibpsa.us/index.php?title=History_of_Building_Energy_Modeling)

[7] Based on discussion with BTO personnel to track the history of the program

OpenStudio was originally developed by the National Renewable Energy Laboratory (NREL) as an EnergyPlus geometry plug-in for the SketchUp 3D drawing program. Beginning in 2009, NREL re-architected OpenStudio into an open-source middleware, or software development kit (SDK), aimed at reducing the effort and improving the value proposition of BEM application development. The SketchUp plug-in and a companion graphical application for entering non-geometry BEM information were client applications that demonstrated the power and productivity of the SDK. BTO began funding OpenStudio in 2011 and in 2012 reoriented and rearticulated its BEM deployment strategy around the OpenStudio platform. BTO began actively migrating existing projects onto the platform and recruiting third-party developers to develop new end-user applications.

Numerous other non-DOE tools have been developed for BEM, including:

» *IES Virtual Environment (IES-VE):* Integrated Environmental Solutions (IES) was founded in 1994 with funding from the UK government. Virtual Environment's engine, ApacheSim, has component-level HVAC and control simulation capabilities that are similar to those of EnergyPlus.
» *ESP-r:* An open-source building performance energy modeling software created by the University of Strathclyde. The tool integrates computer-aided design (CAD) software and the models created in this software can be exported to EnergyPlus.
» *Designer's Simulation Toolkit (DeST):* Tsinghua University developed a building simulation tool DeST in the early 1980s for building simulation in China. DeST was developed to couple the analysis of building loads with the analysis of HVAC systems, accounting for the dynamic performance of HVAC systems.[8] Developers claim that DeST improves the reliability of system design, ensures the quality of the system performance, and reduces energy consumption of buildings.
» *Thermal Analysis Simulation (TAS):* Environmental Design Solutions Limited was formed in 1989 to commercially develop TAS Software. TAS performs dynamic thermal simulations of buildings. Developers claim accurate prediction of building energy consumption, CO_2 emissions, operating costs, and occupant comfort.[9]

1.1.3 Role of BEM in Improving Energy Efficiency of Buildings

BEM provides insight about whole building energy performance that is not readily available by other means. Quantitative estimates of the relative efficiencies of different design alternatives, savings associated with particular energy efficiency measures, and calculation of annual and peak energy requirements provided by BEM are essential to decision makers and market actors such as architects, engineers, building owners, utilities, and manufacturers.

Table 1-1 lists examples of key activities where BEM is used, along with the typical actors who may use BEM. BEM is used for activities as diverse as sustainable building design and certification, estimation of utility program incentives, validation of utility program impacts and cost-effectiveness, utility program design, retro-commissioning and energy auditing, energy benchmarking, and optimization of building operations. As such, strategies to increase BEM use should consider as many uses and stakeholder groups as possible.

[8] See: https://www.researchgate.net/publication/237230496_AN_OVERVIEW_OF_AN_INTEGRATED_BUILDING_SIMULATION_TOOL_-_DESIGNER%27S_SIMULATION_TOOLKIT_DEST

[9] See: http://www.edsl.net/main/Software.aspx

Table 1-1. BEM Roles and Associated Stakeholders for Integrative Building Design and Market Activities

Activity	Architects	Engineers / Consultants	Building Owners	Utilities (Energy Efficiency Programs)	Policy Makers
New Construction Building Design	✓	✓	✓	✓ [a]	
Major Renovation Building Design	✓	✓	✓	✓ [a]	
Prioritizing Efficiency Upgrades in Existing Buildings		✓	✓	✓	
Code Compliance / Building Certification	✓	✓	✓		
Building Commissioning and Operation		✓	✓	✓	
R&D Investment Prioritization					✓

a) Utilities administer energy efficiency programs that require the submission of whole building BEM models as part of the application process. BEM comparison models are required to quantify the impacts of alternative energy efficient equipment selections. Such efficiency programs seek to directly influence design decisions by requiring BEM model comparisons (baseline versus efficient models) as the basis for providing financial incentives to building owners. Additionally, some efficiency programs provide an incentive to offset the cost of creating the whole-building energy model.

BEM is useful for code compliance because it can evaluate the performance of a building independently of its specific operations and occupancy by using standard assumptions—this is especially useful for evaluating a building before it has been built—and because it can evaluate the performance of the proposed building relative to the minimally compliant version of the same building. Many building energy efficiency codes include a BEM-based "performance" compliance path that provides more design-tradeoff flexibility than a checklist-based "prescriptive" path. The widely used ASHRAE Standard 90.1 has two performance paths: Energy Cost Budget for compliance and the Performance Rating Method, commonly known as Appendix G, for both compliance and beyond-code performance calculations.[10] Some jurisdictions such as California currently require BEM for code compliance. Table 1-2 shows a partial listing of codes supported by BEM.

Table 1-2. Example Standards Supported by BEM to Permit Performance-Based Compliance

Standard-Making Body	Standard Number	Standard Subject
ASHRAE	90.1	Minimum performance of commercial buildings
ASHRAE	90.2	Minimum performance of residential buildings
ASHRAE	90.4P	Minimum performance of data centers
ASHRAE	189.1	High performance commercial buildings
ASHRAE	55	Thermal comfort
ASHRAE	62.1	Ventilation & IAQ
ICC	IECC International Energy Conservation Code	Minimum performance of commercial and residential buildings
California Energy Commission	T24	Whole building performance

[10] The recently published ASHRAE 90.1 Addendum BM unifies the performance paths by allowing Appendix G to be used for code compliance.

Sources: Validation and Uncertainty Characterization for Energy Simulation (#1530), LBNL, BTO Merit Review - April 16/17, 2015; and above-referenced standards

Many building asset rating systems—which rate the building's physical assets while normalizing or controlling for occupancy and operations—also use BEM to evaluate buildings in an operation-neutral way. Rating systems often use code baselines and performance compliance paths to establish and apply the rating scale. For instance, USGBC's LEED-NC rating system uses ASHRAE-90.1 Appendix G as the basis for awarding Energy and Atmosphere credit points. Table 1-3 contains a partial listing of rating systems supported by BEM. Operational building ratings, less widely used than asset rating systems, have to date been statistically or empirically determined,[11] however, they are also a potential driver for increased BEM use (as described in Section 5.1).

Table 1-3. Example Building Rating Systems Supported by BEM

Rating Organization	Rating Systems
ASHRAE	Building Energy Quotient (bEQ)
RESNET: Residential Energy Services Network	Home Energy Rating System (HERS) Index
Department of Energy (DOE)	Home Energy Score Commercial Building Energy Asset Score
Green Globes	Green Globes for New Construction Green Globes for Existing Buildings
US Green Building Council (USGBC)	LEED –NC (Leadership in Energy Efficient Design-New Construction)

Source: Navigant internet research, partial listing

Finally, several energy efficiency industry guidelines also use BEM. Table 1-4 includes a partial listing of these.

Table 1-4. Example Guidelines Supported by BEM for Verification of Building Energy and Demand Savings

Publishing Organization	Guideline Description
International Performance Measurement and Verification Protocol (IPMVP)	IPMVP Concepts and Options for Determining Energy and Water Savings, Volume 1, January 2012 [a] The IPMVP provides an overview of current best practice techniques available for verifying results of energy efficiency, water efficiency, and renewable energy projects in commercial and industrial facilities.
American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE)	ASHRAE Guideline 14, Measurement of Energy and Demand Savings, June 2002[b] The purpose of this document is to provide guidelines for reliably measuring the energy, demand and water savings achieved in conservation projects.
National Renewable Energy Laboratory (NREL)	Uniform Methods Project [c] The project's aim is to publish protocols for evaluating, measuring, and verifying savings for energy efficiency measures.
ASHRAE	Advanced Energy Design Guides: [d] Guidelines outlining specific design options for building designers and contractors to target deep energy savings of 30% and 50% less energy use compared to buildings that meet the minimum requirements of Standard 90.1-2004.

a) http://www.evo-world.org/index.php?option=com_rsform&formId=113&lang=en

[11] Implementation Report June 2009 Draft, Building Energy Quotient, Promoting the Value of Energy

Efficiency in the Real Estate Market, ASHRAE Building Energy Labeling Program, Paris-ASHRAE_briefing.pdf

b) https://gaia.lbl.gov/people/ryin/public/Ashrae_guideline14-2002_Measurement%20of%20Energy%20and%20Demand%20Saving%20.pdf
c) http://www.nrel.gov/extranet/ump/draft_protocols.html
d) https://www.ashrae.org/standards-research--technology/advanced-energy-design-guides

1.2 Overview of Current BTO Building Energy Modeling Program

The Building Technologies Office (BTO) is part of DOE's Office of Energy Efficiency and Renewable Energy (EERE). BTO's BEM Program develops and maintains two major building energy simulation products, EnergyPlus and OpenStudio[12] —both tools are open-source, developer-neutral, and free. BTO also supports:

- Testing and validation of BEM engines
- BEM education and outreach via partnerships with professional organizations
- Competitively awarded initiatives that advance BEM and its applications.[13]

In addition to BTO's activities, EERE's Weatherization and Intergovernmental Programs Office[14] develops energy audit tools and technical guidelines to support multifamily residential energy design under the Weatherization Assistance Program.[15]

[12] http://energy.gov/eere/buildings/about-building-energy-modeling

[13] http://energy.gov/eere/buildings/building-energy-modeling-projects

[14] http://energy.gov/eere/wipo/weatherization-and-intergovernmental-programs-office

[15] http://energy.gov/eere/wipo/multifamily-retrofit-tools-and-workforce-resources

1.2.1 BTO BEM-Related Mission and Goals

BTO's BEM-related mission is driven by two factors:

- "DOE can build it:" BEM is software with no unit production cost
- "DOE should build it:" BEM is both a standards development tool and a product evaluation tool—transparency and impartiality are important.[16]

BTO's overall goal is widespread use of BEM (50% of gross square feet of new buildings and deep energy retrofits), achieving 20% reduction in design EUI over prescriptive design by 2020.[17] The BTO strategy to achieve this goal is to build a BEM engine and SDK (discussed in Section 3.1), and to support third-party software developers in their development of BEM tools for building-energy-efficiency professionals (including architects, engineers, and energy modelers), hereafter referred to as "BEM users". While some advanced BEM users may use BTO's engines and SDK directly, BTO anticipates that most BEM users will prefer to use third-party-supplied applications.

1.2.2 Current DOE BEM-Related Projects

Table 1-5 summarizes key current DOE-funded projects that support BEM, both within DOE/BTO and other DOE/EERE offices.

Table 1-5. DOE Building Energy Modeling Activities (Current and Recent Past)

Initiative	Project Name	Short Description	DOE Program	DOE Support
Engine	EnergyPlus	» Develop, maintain, and support free open-source whole building energy modeling engine » Has typically been used for commercial building applications	BTO Emerging Technologies	1997 to present
	Modelica Buildings Library/Spawn of EnergyPlus[a]	» Develop, maintain and support free, open-source library of models for zones, envelopes, HVAC components and systems, and control. Will eventually become HVAC and control subsystem of EnergyPlus » BTO anticipates making this an HVAC and control subsystem of EnergyPlus	BTO Emerging Technologies	2012 to present
	Radiance[b]	» Develop, maintain, and support free, open-source lighting engine	BTO Emerging Technologies	2005 to present
Testing and Validation	ASHRAE Standard 140	» Develop, maintain, and support standardized test procedures for testing, diagnosing, and improving BEM software	BTO Emerging Technologies	1990s to present
Interoperability	gbXML	» Improve robustness of gbXML export from design tools	BTO Commercial Buildings Integration	2011 to present
	BuildingSMART	» Support international Building Information Modeling (BIM) standard development	BTO Commercial Buildings Integration	1997 to 2014
	GST: Geometry simplification tool, SBT: Space boundary tool	» Develop, maintain, and support tools for transferring IFC 3D geometry for EnergyPlus	BTO Commercial Buildings Integration	2005 to 2014

Initiative	Project Name	Short Description	DOE Program	DOE Support
SDK /Middleware	OpenStudio	» Develop, maintain, and support a free, open-source software development kit for BEM applications using EnergyPlus and Radiance	BTO Commercial Buildings Integration	2010 to present
	Autotune	» Develop a methodology and implementation for model input calibration using evolutionary methods	BTO Commercial Buildings Integration	2012 to 2014
Applications	ASHRAE 90.1-2010 Ruleset	» Develop a CBECC-Com "ruleset" for ASHRAE-90.1-2010 Appendix G to automate compliance and LEED Eac1 certification	BTO Building Energy Codes	2013 to 2014
	Simergy	» As part of a public-private partnership, develop a free but not open-source graphical user interface for EnergyPlus	BTO Commercial Buildings Integration	2009 to 2013
	Home Energy Scoring Tool[c d e]	» Develop, maintain, and support a tool that rates the asset energy performance of a home » Currently using the DOE-2.1E engine but will transition to EnergyPlus in 2016 or 2017	BTO Residential Buildings Integration	2009 to present
	Commercial Building Energy Asset Scoring Tool [f g]	» Develop, maintain, and support that rates the asset energy performance of a commercial building and its major systems and identifies cost-effective asset upgrade opportunities	BTO Commercial Buildings Integration	2012 to present
	BeOpt	» Develop, maintain, and support a tool for home design optimization » Currently using both DOE-2.2 and EnergyPlus » Will be integrated into OpenStudio in 2016	BTO Residential Buildings Integration	2002 to 2016
	MulTEA	» Develop, maintain, and support an audit tool for multifamily buildings	DOE Weatherization Assistance Program	2011 to present
	COMFEN / RESFEN	» Develop, maintain, and support façade design tools using EnergyPlus and Radiance	BTO Emerging Technologies	1996 to present
	COMcheck [h]	» Develop, maintain, and support a tool to check code (IECC), ASHRAE Standard 90.1, and a number of state-specific energy codes for commercial and high-rise residential building projects	BTO Building Energy Codes	1996 to present

[16] Paraphrased from 2015 BTO Peer Review presentation for BEM: http://energy.gov/sites/prod/files/2015/05/f22/2015%20BTOpr%20Overview_Building%20Energy%20Modeling.pdf

[17] BTO 2015 Multi-Year Program Plan: http://energy.gov/eere/buildings/downloads/draft-multi-year-program-plan

Initiative	Project Name	Short Description	DOE Program	DOE Support
Resources	Conference sponsorships	» Provide travel grants to students and young professionals to IBPSA-USA SimBuild, IBPSA-World BuildingSim, and to ASHRAE Energy Modeling Conference	BTO Commercial Buildings Integration	2004 to present
	EnergyPlus commercial reference[i] and prototype buildings[j]	» Develop models of prototypical commercial buildings to support building stock analysis and typical savings calculations	BTO CBI and BTO Codes	2006 to present
	BuildingSync[k]	» Develop a standard building audit schema that can support simulation-driven analysis	BTO CBI	2014 to present
	BEM Library	» Develop an online repository of best practice BEM methods and processes	BTO Commercial Buildings Integration	2012 to present
	UnmetHours	» Develop and maintain a peer-to-peer question and answer site for the BEM community	BTO Commercial Buildings Integration	2014 to present
	Building Energy Software Tools Directory	» Develop and maintain a directory of building energy software tools	BTO Commercial Buildings Integration	2015 to present
	AIA2030 Design Data Exchange	» Develop a site for AIA 2030 Commitment reporting	BTO Commercial Buildings Integration	2014 to present

Source: Discussions with BTO; BTO and developer websites

- a) Modelica is a non-proprietary, object-oriented, equation-based language to model complex physical systems, developed by the Modelica Association: https://www.modelica.org/. Modelica simplifies sharing of models (reference: EnergyPlus 2014 Building Technologies Office Peer Review, Michael J. Witte, PhD). It will be used to develop a library of HVAC and Controls components and systems for use by EnergyPlus developers.
- b) Radiance is a free and open-source suite of programs for the analysis and visualization of lighting in design, developed by LBNL: http://radsite.lbl.gov/radiance/
- c) http://energy.gov/eere/buildings/home-energy-score
- d) http://homeenergyscore.lbl.gov/
- e) Based on LBNL DOE-2 engine. http://energy.gov/eere/buildings/home-energy-score-research-and-background
- f) Commercial Building Energy Asset Scoring Tool: http://energy.gov/eere/buildings/commercial-building-energy-asset-scoring-tool
- g) Commercial Building Energy Asset Scoring Overview: https://buildingdata.energy.gov/cbrd/resource/1105
- h) Supported by DOE-2.1 https://www.energycodes.gov/comcheck
- i) http://energy.gov/eere/buildings/commercial-reference-buildings
- j) https://www.energycodes.gov/commercial-prototype-building-models
- k) http://energy.gov/eere/buildings/buildingsync

Table 1-6 describes other software that is not BEM according to the definition in this roadmap, but however is used to support low energy design.

Table 1-6. Additional Software that Encourage Low Energy Design

Application	Software Name	Short Description	Developer
Audit tools for single family and mobile homes	National Energy Audit Tool (NEAT)/Mobile Home Energy Audit (MHEA)[a]	» A residential audit and retrofit recommendation tool developed by DOE's Weatherization Assistance Program	Oak Ridge National Laboratory
Models 2D and 3D heat transfer	THERM[b]	» a 2D/3D heat transfer engine used for detailed analysis of facades	Lawrence Berkeley National Laboratory

		» BTO is currently initiating a multi-year plan to open-source THERM, to add moisture modeling capabilities, and to connect THERM to whole building energy modeling	
Models moisture and heat transfer	WUFI[c]	» 2D/3D heat, mass, and moisture transfer engine developed by Fraunhofer IBP » BTO discontinued support for WUFI in 2015 with the idea of supporting a single unified open-source tool.	Fraunhofer IBP and Oak Ridge National Laboratory (ORNL)
Models attic and roofing technologies	AtticSim[d]	» 3D heat and moisture transfer, and duct model for simple attic configurations » AtticSim is combined with DOE-2.1E to create RoofSavingsCalculator, a Web-based energy savings estimation tool for residential and commercial roofs » BTO discontinued its support of AtticSim and RSC » BTO is working with Fraunhofer CSE to add detailed attic modeling functionality to EnergyPlus.	Oak Ridge National Laboratory

a) http://weatherization.ornl.gov/assistant_features.shtml
b) https://windows.lbl.gov/software/therm/therm.html
c) http://www.buildingenergysoftwaretools.com/software/wufi-ornlibp
d) http://energy.gov/eere/buildings/downloads/modeling-energy-efficiency-residential-attic-assemblies

Access to BEM-supporting resources developed and supported by BTO-funded partners is also essential in making BEM faster and easier for end users. Resources created by BTO and BTO-supported partners include:

» Standard Energy Efficiency Data Platform (SEED)[18]

» Building Performance Database[19]

[18] http://energy.gov/eere/buildings/standard-energy-efficiency-data-platform

[19] http://energy.gov/eere/buildings/building-performance-database

2. Roadmap Purpose, Scope, and Approach

2.1 Roadmap Purpose

BTO seeks to increase the use of whole BEM tools for the design and operation of energy efficient buildings in the United States with the goal of reducing energy use in U.S. commercial and residential buildings, and enabling persistence of reduced energy use and demand resource costs over time. This roadmap outlines the recommended steps to achieve this goal, based on technical analysis and stakeholder input collected throughout the roadmap development process. In addition to DOE, this roadmap can benefit BEM software developers, architects, building design engineers, sustainability consultants, equipment manufacturers, building owners and operators, building construction and related markets, utilities, and cities.

2.2 Roadmap Scope

This roadmap provides an actionable plan to increase the use of BEM tools, where BEM tools are as defined in Section 1.1 above. BTO considers BEM to be important to both the commercial and residential building sectors. Unless needed for clarity, further references to buildings include both commercial and residential buildings.

The information provided in this roadmap represents the essential historical and current information obtained from stakeholders and published sources, which directly informs the roadmap recommendations. As such, this roadmap is not intended to be a comprehensive sourcebook on the history and current status of BEM, rather it provides a targeted resource for understanding key BEM issues, and the recommended path forward to increase the use of BEM tools.

While we consider building codes in this roadmap, we limit discussion of codes to how state and local governments can leverage BEM to establish compliance requirements in their codes. BTO's role in developing and implementing codes is outside the scope of this roadmap.

Table 2-1 summarizes the roadmap scope.

Table 2-1. Roadmap Scope Overview

Subject	Description
Historical Overview and Current BEM Status	» An overview and history of BEM tools » Summary tables describing DOE-funded tools
Visioning	» Identification of stakeholders, and their current and future BEM needs and challenges
Path Forward	» Recommendations to support existing, future known, and future emerging BEM tools and their expanded use over the next 5 to 10 years » Does not include budgetary recommendations or recommended timelines

2.3 Roadmap Approach

Figure 2-1 outlines Navigant's approach to develop this roadmap to increase the impact of BEM tools:

Figure 2-1. Four Stages for Developing this Roadmap

Outreach to obtain stakeholder feedback included telephone interviews and workshops with industry experts. This roadmap is informed by leading-edge information and thinking from some of the most knowledgeable BEM industry leaders and publications in the U.S.

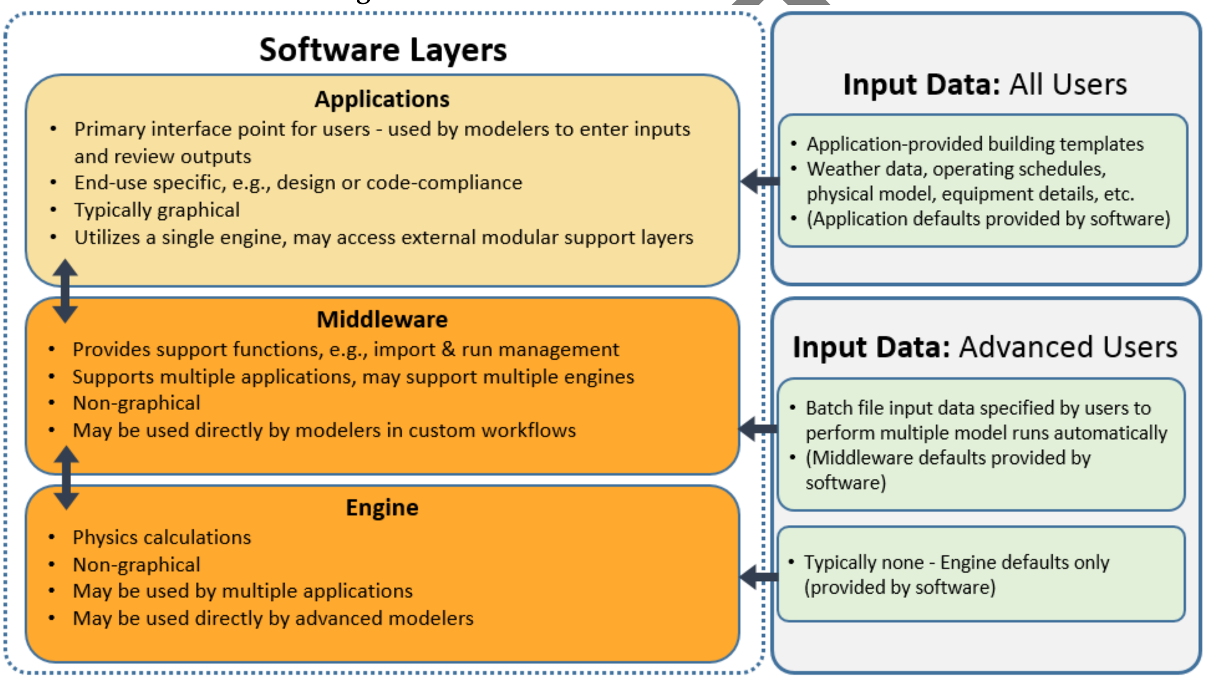
Summaries of the June 2015 workshops are presented in Appendix A and Appendix B. The workshop participants prioritized outcomes through multi-voting. While workshop outcomes informed our recommendations, those recommendations do not necessarily match workshop outputs.

3. Review of Building Energy Modeling Tools

3.1 Overview

In general, the BEM environment can be conceptualized as a three-tier software architecture comprising an engine, middleware, and BEM-user "turnkey" application, as well as the building professional who supplies inputs and guides the BEM process (see Figure 3-1).[20] Most BEM users interact only with the turnkey application, whereas advanced users may interact directly with the engine and middleware layers. Inputs include all information required to produce a complete energy model, and may include "intelligent" defaults in addition to user-specified inputs.

Figure 3-1. Overall BEM Software Architecture



Source: Navigant discussions with BTO and Navigant stakeholder interviews

BTO currently supports a range of BEM software applications by developing and maintaining the EnergyPlus engine and the OpenStudio SDK. Table 3-1 lists tools that currently use EnergyPlus and OpenStudio.

[20] BEM software tools are defined in Section 1.1.

Table 3-1. BEM Tools that use EnergyPlus and OpenStudio

	Developer	Tool	Comments
Uses EnergyPlus	**DesignBuilder**	DesignBuilder	Full-featured Windows interface, also supports lighting and CFD simulation http://designbuilderusa.com/
	AECOSim	AECOSim	Full-featured Windows interface, also supports code-compliance, http://www.bentley.com/en-US/Products/AECOsim/
	CADSoftSolutions	gEnergy	Web-based interface that provides cloud execution, http://www.cadsoftsolutions.co.uk/software/sketchup-pro/gtools/
	ExpertApp	N++	Windows interface, http://expertapp.com/npp.php
	EnSimS	jEPlus/JESS	Simulation and parametric/optimization services and service frameworks, http://www.jeplus.org/wiki/doku.php
	ArchSim	ArchSim	EnergyPlus plug-in for Rhino/Grasshopper 3D modeler, http://archsim.com/
	Digital Alchemy	Simergy	Full-featured Windows interface supports BIM/IFC import http://simergy.lbl.gov/
	BuildLAB	APIDAE	Simulation service that supports parametric analysis and optimization, https://apidaelabs.com/
	Autodesk	Insight 360	Revit and Formit addition for automated background energy analysis on the cloud, https://insight360.autodesk.com/
	Trane	TRACE 800 (beta)	EnergyPlus based version of Trane's TRACE 700 Windows interface, https://trane.com/beta/
		BCVTB	Building Controls Virtual Test Bed—Allows users to couple different simulation programs for co-simulation, and to couple simulation programs with actual hardware, https://simulationresearch.lbl.gov/bcvtb
Uses EnergyPlus and OpenStudio	**Xcel Energy/NREL**	EDAPT	Design assistance project and program tracker, https://www.eda-pt.org/
	CEC & NORESCO	CBECC-Com	Performance-path compliance for CA Title24 non-residential code, http://bees.archenergy.com/software.html
	Sefaira	Sefaira Systems	Web-based HVAC selection & sizing tool for early-stage design, http://sefaira.com/sefaira-systems/
	Sefaira	Sefaira Architecture	Revit and SketchUp plug-in for energy analysis, http://sefaira.com/sefaira-architecture/
	Concept3D	Simuwatt	Tablet-based tool for ASHRAE level 2 and 3 energy audits, http://www.simuwatt.com/

Table 3-2 lists example BEM tools that do not use EnergyPlus. Trane and Carrier, which developed TRACE 700 and HAP, respectively, are in the process of migrating away from their proprietary engines and toward EnergyPlus. Trane has launched a beta version of the EnergyPlus-based successor to TRACE 700, with the full version due in summer of 2016. [21] Carrier has started developing a successor to HAP based on EnergyPlus and OpenStudio in anticipation of revisions to ASHRAE Standard 90.1 that will encourage BEM-based performance paths in building codes.[22]

[21] http://trane.com/beta/

[22] *HVAC&R Efficiency Improvements*; presentation by Richard Lord, United Technologies/Carrier Corporation; presented at the U.S. Department of Energy, Better Buildings Summit; May 2015; Available at: http://betterbuildingssolutioncenter.energy.gov/sites/default/files/Wednesday%20-%20Maximizing%20Supermarket%20Refrigeration%20System%20Energy%20Efficiency.pdf

Table 3-2. BEM Tools that use Engines other than EnergyPlus

Developer	Tool
J. J. Hirsch, Energy Design Resources, CPUC	DOE-2.2/eQuest
EnergySoft	DOE-2.1/EnergyPro
Trane Inc.	TRACE 700[a]
Carrier Corporation	HAP[a]
Thermal Energy System Specialists, LLC	TRNSYS
Integrated Environmental Solutions (IES)	IES<VE>
Environmental Design Solutions Limited (EDSL)	TAS
University of Strathclyde, Scotland	ESP-r
Tsinghua University, China	DeST

a) At the time of roadmap publication, Trane and Carrier had begun migrating their products to EnergyPlus.

Table 3-3 compares the key characteristics of the most-used BEM software tools in the U.S. market.

Table 3-3. Comparison of Popular BEM Tools

	DOE-2.2/ eQuest	DOE-2.1E/ EnergyPro	TRACE 700	Virtual Environment	HAP	EnergyPlus /DesignBuilder /OpenStudio Sefaira[a]
Developer:	J. J. Hirsch & Associates	EnergySoft	Trane	IES	Carrier	BTO
Cost:	Free	Subscription	Subscription	Subscription	Subscription	Free
License:	Proprietary	Proprietary	Proprietary	Proprietary	Proprietary	Open-source
AIA2030 Use (2014):[b]	8%	12%[c]	2%	8%	2%[c]	57%
AIA2030 Use (2013):[d]	29%	12%	24%	7%	2%	16%
Support:	» Online community	» Email only	» Email & phone	» Email & phone license option » Online community & knowledge base	» Customer Service Technicians (phone & email)	» Email » Online community

a) This represents a family of tools using EnergyPlus and possibly OpenStudio, Parametric Analysis Tool and Building Component Library, including Sefaira, EnergyPlus Cloud, EDAPT, Radiance, CBECC, and Simuwatt.

b) 2014 Progress Report, AIA 2030 Commitment, Figure 10. Scale label in Figure 10 is mislabeled in the Progress Report. The horizontal axis should read "Percent of Projects". http://www.aia.org/aiaucmp/groups/aia/documents/pdf/aiab107447.pdf

c) We assume that HAP is included in the 'Other' category in the 2014 AIA Progress report. We report here the value from the 2013 Progress Report, AIA 2030 Commitment. Figure 6. Figure 6 is mislabeled. The horizontal axis should read "Percent of Projects": http://www.aia.org/aiaucmp/groups/aia/documents/pdf/aiab104793.pdf

d) Ibid; AIA 2030 (2013) values shown for comparison with 2014, showing shift of tool use for AIA projects.

3.2 Key Capabilities

This section highlights the key capabilities of BEM software tools. Of the most-used commercially available tools that do not use the EnergyPlus engine, only IES-VE (Virtual Environment) offers as many technology capabilities.[23] However, other factors are essential to the successful proliferation of a BEM tool.[24] These include accuracy of calculated building usage relative to utility bills, the ability to automate multiple design runs, fast execution speed, ease of use, and interoperability with other software programs in the building design workflow.

Error! Reference source not found. Table 3-4 summarizes the modeling capabilities for popular BEM tools.

[23] Navigant research of BEM software tool technology options.

[24] Stakeholder input, workshops

Table 3-4. BEM Tool Technology Modeling Capabilities

Area	Modeling Capability	Energy-Plus	DOE-2.2	DOE-2.1E	Trane TRACE 700	Carrier HAP	IES <VE>
Envelope	Complex fenestration	✓	---	---	---	---	✓
	Dynamic glazing	Partial	Partial	Partial	---	---	✓
	Thermal mass	✓	✓	✓	✓	✓	✓
	Thermal bridging	---	---	---	---	---	---
	Radiant barriers	✓	---	---	---	---	✓
	Phase-change materials (PCMs)	✓	---	---	---	---	---
	Thermal comfort	✓	---	---	---	---	✓
Airflow	Multi-zone airflow	✓	---	---	✓	✓	✓
	Natural Ventilation	✓	✓	Partial	Partial	Partial	✓
	Under-floor Air Distribution	✓ (2006)	Partial	---	✓	---	✓
	Displacement Ventilation	✓	Partial	---	✓	Partial	✓
HVAC	Dedicated Outdoor Air Systems (DOAS)	✓ (2009)	Partial	Partial	✓	✓	✓
	Variable Refrigerant Flow (VRF)	✓ (2011)	Partial	---	✓	✓	✓
	Variable Frequency Drive	✓ (2010)	✓	✓	✓	✓	✓
	Air-Source Heat Pump	✓ (2007)	✓	✓	✓	✓	✓
	Water-Source Heat Pump	✓	✓	✓	✓	✓	✓
	Ground-Source Heat Pump	✓	Partial	No	✓	✓	Partial
	Heat-Pump Water-Heater	✓	---	---	---	---	✓
	Radiant Heating	✓	Partial	---	---	Partial	✓
	Radiant Cooling	✓ (2009)	---	---	✓	✓	✓
	Heat Recovery	✓ (2007)	✓	Partial	✓	✓	✓
	Ice Storage	✓ (2003)	✓	✓	✓	✓	✓
	Commercial Refrigeration	✓	✓	---	Partial	---	---
	Evaporative Cooling	✓	✓	✓	✓	---	✓
	Absorption Chiller	✓	✓	✓	✓	---	✓
	Condensing Boiler	✓	✓	---	✓	✓	✓
	District Heating	✓	✓	Partial	✓	✓	✓
	District Cooling	✓	✓	Partial	✓	✓	✓
	Operational faults	✓	---	---	---	---	---
Control	Equipment cycling	✓	---	---	✓	✓	✓
	Optimal Start/Stop	✓	✓	✓	✓	✓	Partial
	Static Pressure Reset	✓	✓	---	Partial	---	✓
	User-defined control	✓	✓	Partial	---	---	✓
Lighting	Illuminance calculations	✓	✓	✓	---	---	✓
	Lighting controls	✓	✓	✓	✓	✓	✓
	Shade/blind control	✓	✓	✓	---	---	---
Renewables	PV	✓	✓	---	---	---	✓
	Building integrated PV	✓	---	---	---	---	---
	Solar Thermal	✓	---	---	---	---	✓
	Wind Turbines	✓	---	---	---	---	---
	Electrical Storage	✓	---	---	---	---	---
	Combined Heat and Power	✓	✓	✓	✓	✓	✓
Other	Complex tariffs	✓	Partial	---	---	---	Partial
	Life-cycle costs	✓	✓	---	✓	✓	✓
	Water use	✓	---	---	✓	✓	✓

Source: UnmetHours.com (https://unmethours.com/question/12738/engine-feature-comparison/)

Because of the level of physical detail EnergyPlus uses to model various phenomena, EnergyPlus has longer simulation times as compared to other engines.[25] Some EnergyPlus developers have overcome this through parallel-processing strategies,[26] and EnergyPlus gained significant execution speed after the translation of code from FORTRAN to C++.[27]

3.3 Development Status of EnergyPlus

Table 3-5 and Table 3-6 list current BTO activities to facilitate the growth of EnergyPlus and OpenStudio.

Table 3-5. Current BTO Activities to enhance Features in EnergyPlus

New EnergyPlus Features (Partial List)
Enhanced and expanded unit testing
Pervasive support for component, system, and control models represented as “model exchange” Functional Mockup Units allowing integration of externally developed models
Expanded support for fault modeling
Increased execution speed
Input/output based on the JavaScript Object Notation standard schema framework and format[a]

Source: Discussions with BTO

a) See: http://json.org/

Table 3-6. Current BTO Activities to enhance Features in OpenStudio

New OpenStudio Features (Partial List)
Enhanced and expanded unit testing including testing of measures
Comprehensive coverage of EnergyPlus HVAC components
Improved support for Radiance and CONTAM[a, b]
Streamlined builds and packaging for third-party developers, including command-line interface
Translator for Modelica components[c]
OpenStudio versions of Commercial Reference and Prototype Building Models
Geometry viewing and editing alternative to SketchUp[d]

Source: Discussions with BTO

a) Radiance is a free and open-source suite of programs for the analysis and visualization of lighting in design, developed by LBNL: http://radsite.lbl.gov/radiance/

b) CONTAM is a multi-zone indoor air quality and ventilation analysis computer program developed by NIST: http://www.nist.gov/el/building_environment/contam_software.cfm

c) Modelica is a non-proprietary, object-oriented, equation-based language to model complex physical systems, developed by the Modelica Association: https://www.modelica.org/

d) To replace SketchUp, which is no longer available.

[25] Based on stakeholder feedback

[26] Autodesk has the ability to run all months concurrently, effectively reducing model runtime.

[27] See the DOE EERE Building Energy Modeling (BEM) Program presentation, Appendix F

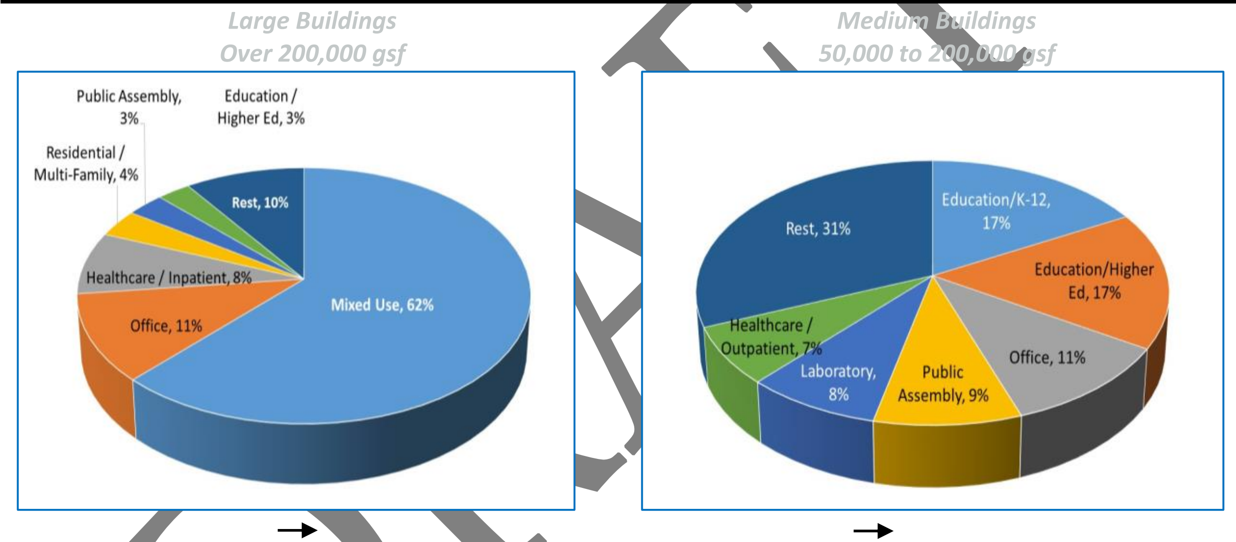
3.4 Current Use of BEM

Of the BEM uses outlined in Section 1.1.3 above, the increased use of BEM for building design is widely considered to be the area of greatest opportunity to increase BEM impact.[28]

Figure 3-2 shows the results of a BTO analysis of AIA micro-data on the self-reported modeled square footage for AIA 2030 Challenge[29] participant projects. The analysis shows that:

- 37% of large building square footage were modeled , a majority of which are Mixed Use buildings
- 51% of medium building square footage was modeled, approximately evenly distributed across the range of building uses.

Figure 3-2. AIA 2030 Characterization of Self-Reported Projects Utilizing BEM



Source: BTO analysis of micro data for AIA 2030 Commitment; provided to Navigant on 06/05/2015.

The AIA 2030 Commitment program is voluntary. Signatory firms commit to reporting the design performance of all of their projects. The data set is not necessarily representative of all new construction--participating firms are likely more performance-oriented than average and use of BEM is likely over-represented. It is not clear why there is relatively low uptake of BEM for large buildings; percentages of owner versus tenant occupancy could be a contributing factor, including whether the tenant or the owner pays for utilities. This is an example of a difference that is important to understand when targeting high impact BEM projects.

There are few data available on the frequency of BEM use in U.S. building design. Table 3-7 lists two available estimates, which range from 20 to 55 percent of U.S. commercial building designs.

[28] "…models solely as compliance and verification tools (~80% of their current use) to performance and design decision-making tools (~20% of their current use).", *Getting to Outcome-Based Building Performance*, Report from a Seattle Summit on Performance Outcomes, Event Report May 2015, New Buildings Institute, Page 1.

[29] "The 2030 Challenge has been adopted and is being implemented by 80% of the top 10 and 70% of the top 20 architecture/engineering/planning firms in the U.S." with the goal of slowing the growth rate of GHG emissions by adopting stringent energy performance goals for new and renovated buildings, http://architecture2030.org/2030_challenges/2030-challenge/. "Architecture 2030 is a non-profit organization established in response to the climate change crisis by architect Edward Mazria in 2002."

Table 3-7. Estimates of the Frequency of BEM Use in Commercial Building Design

Estimate	Description	Source/Comments
20%	Percent of U.S. commercial building designs that use BEM	Based on anecdotal evidence collected by one participant in the June 15, 2015 BEM Workshop (East Coast); no other workshop participants offered an alternative estimate when invited to do so.
55%	613 of 1112 commercial building designs submitted under the AIA 2030 Commitment that used BEM	BTO 2015 Draft Multi-Year Program Plan: http://energy.gov/eere/buildings/downloads/draft-multi-year-program-plan

The New Buildings Institute (NBI) posits that 80% of building projects that use BEM do so:

» To demonstrate code compliance or to obtain green building certification

» At the end of the design cycle—too late to inform and influence the designer's and owner's decision-making.[30]

In addition, stakeholder interviews and Navigant staff experience suggest that BEM is generally assigned to junior staff.

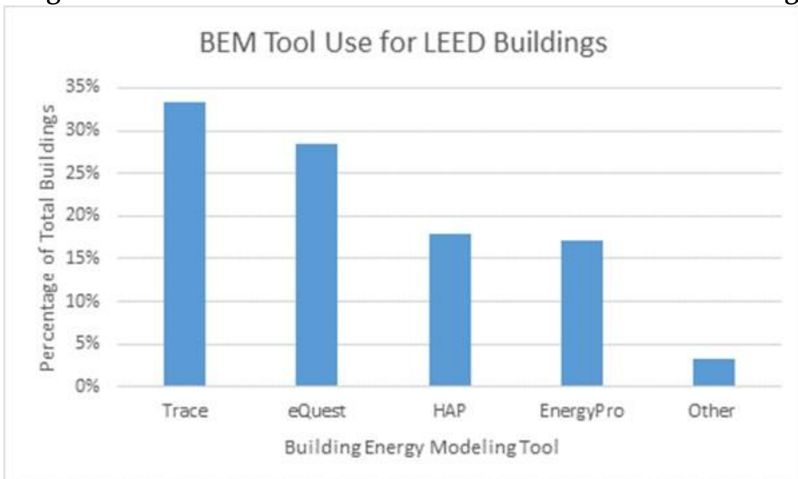
While BEM tools are more widely used for larger buildings in the commercial or multi-family market, there is significant opportunity for growth in single family residential applications. Currently available residential-specific design and compliance tools include CBECC-Res and BEopt.[31] The relatively small annual energy consumptions of most residences can make it difficult to justify the cost of BEM. On the other hand, large production builders often use the same or similar home designs many times in a single housing development, leveraging greatly the results of a single BEM analysis. As BEM tools become simpler, faster, and easier to use, one can anticipate greater use in residential applications.

[30] *Getting to Outcome-Based Building Performance*, Report from a Seattle Summit on Performance Outcomes, Event Report May 2015, New Buildings Institute, http://newbuildings.org/performance-outcomes-event-report

[31] REM/Rate, which is used to calculate Home Energy Rating Systems (HERS) indices, is not a true BEM tool based on the definition used for this roadmap. This tool uses monthly (not hourly) analyses.

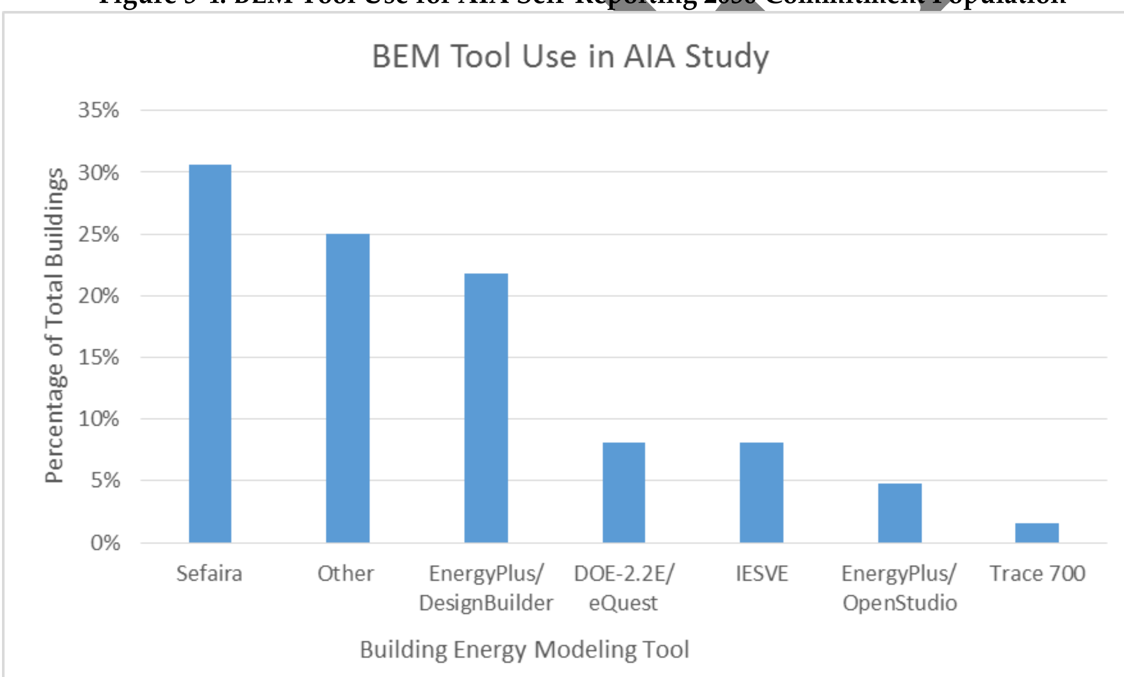
Figure 3-3 and Figure 3-4 show available data for BEM tools most commonly used for LEED certification. These data suggest that 50% to 60% of LEED projects are modeled using either Trane/TRACE or eQuest. Based on the discussion above, we can assume that most of these projects were modeled after the design was complete. Hence, designers may have selected BEM tools based largely on simplicity and convenience, rather than on ability to evaluate sophisticated low-energy strategies.

Figure 3-3. BEM Tool Use Distribution in LEED Office Buildings



Source: Cluster analysis of simulated energy use for LEED-certified U.S. office buildings; Mohammad Heidarinejad, Matthew Dahlhausen, Sean McMahon, Chris Pyke, Jelena Srebric, September 2014 *http://www.buildsci.us/uploads/publications/ENB%202014%20Heidarinejad.pdf*

Figure 3-4. BEM Tool Use for AIA Self-Reporting 2030 Commitment Population



Source: 2014 Progress Report, AIA 2030 Commitment, Figure 10. Note that scale label in Figure 10 is incorrect as shown in the Progress Report. *http://www.aia.org/aiaucmp/groups/aia/documents/pdf/aiab107447.pdf*

Although from Figure 3-3 and Figure 3-4 it seems that EnergyPlus/Open Studio is not yet widely used for building design, Sefaira is based on EnergyPlus/Open Studio, and DesignBuilder is based on Energy Plus. (see Table 3-1). In addition, many software developers to whom we spoke or heard from in workshops embrace the engine, and are investing substantial effort in EnergyPlus/OpenStudio-based tools. In a short time, an ecosystem of BEM software tools has sprung up based on EnergyPlus and OpenStudio, serving a range of applications from energy audits to compliance.[32]

Stakeholders with whom we spoke suggest that, compared to other tools that use other engines, BEM software tools that use EnergyPlus are generally more technically complete and accurate, but are also more difficult for developers to incorporate into turnkey BEM applications.

Developers and researchers are also building derivative tools that are based on BEM outputs that are free, simple to use, and publicly available. One example is the Database of Energy Efficiency Performance,[33] which provides preliminary energy- and cost-savings estimates. This database is free, Web-based, and requires no modeling knowledge. It is based on the results of EnergyPlus, EnergyIQ, and eQUEST. It is intended to give small- and medium-sized business owners quick access to potential cost and energy savings from energy efficiency retrofits.

[32] EnergyPlus website: http://energyplus.net/

[33] DEEP: A Database of Energy Efficiency Performance to Accelerate Energy Retrofitting of Commercial Buildings, Lee, Song Hoon; Hong, Tianzhen; Sawaya, Geof; Chen, Yixing; Piette, Mary Ann; Building Technology and Urban Systems Department, Environmental Energy Technologies Division in Lawrence Berkeley, http://cbes.lbl.gov/DEEP.pdf

National Laboratory, Berkeley, California. hyperlink: cbes.lbl.gov

4. Current Technical Gaps and Barriers to Use of Building Energy Modeling Tools

This section includes:

- » General technical barriers to BEM
- » Technical barriers specific to BTO's EnergyPlus and OpenStudio
- » Other technical gaps in BEM tools.

We differentiate "barriers" and "other gaps" as follows:

- » **Barriers** are gaps that significantly limit the increased use of BEM, or the energy savings achievable through the use of BEM
- » **Gaps** are opportunities for development and added value for existing BEM tools.

Unless otherwise noted, we identified and confirmed these barriers through stakeholder interviews, BEM workshops, and discussions with Navigant modeling experts.

4.1 General Technical Barriers

Table 4-1 presents key barriers to BEM use that are due to technical and logistical issues such as missing data, non-aligned data formats, missing capabilities such as new or advanced HVAC technologies, and mismatch between actual and modeled results. A discussion of each of these barriers follows.

Table 4-1. General Technical Barriers to Building Energy Modeling

Barrier	Description
Discrepancies between Predicted and Actual Energy Consumption	Actual building energy consumption can vary by ±30% or more compared to BEM predictions.[a] Simplified or inaccurate model inputs, as well as simplified and/or inaccurate algorithms in BEM tools, contribute to these discrepancies. See also discussion in Section 4.1.1.1.
Missing Input Data	BEM users may not have ready access to required input data
Time-Consuming Transfer of Input Data	Detailed building geometry data cannot be easily and automatically transferred from conceptual design tools and/or BIM to BEM—can require substantial time to manually re-enter data
Outputs not Formatted for Presentation	BEM outputs generally require post-processing before they are presentable to building owners or other decision makers
BEM Capabilities lag Technology Advances	BEM tools often cannot model an advanced building technology (most notably, advanced HVAC technologies) for several years after the market introduction of the advanced technology. In many cases, these advanced technologies are critical to achieving the energy performance that owners seek.

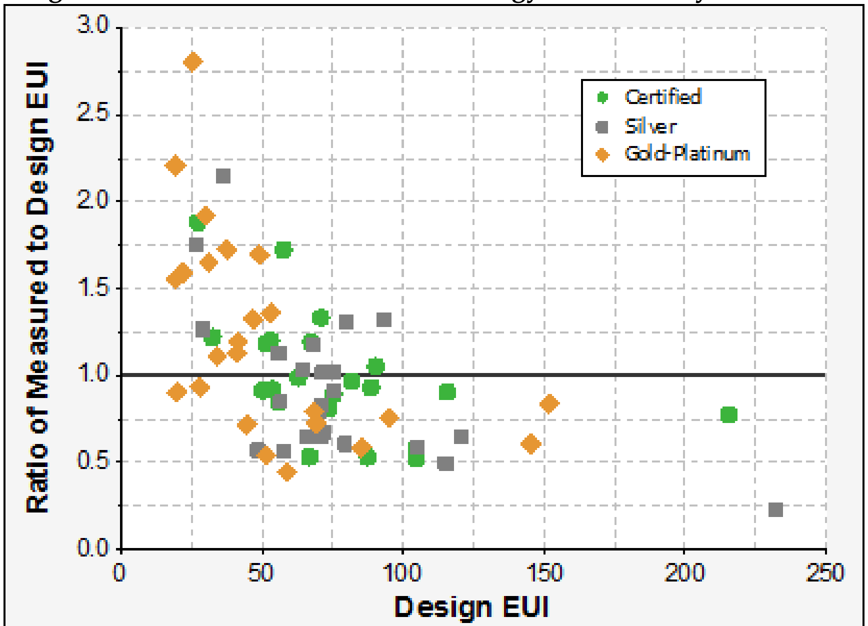
a) Based on discussions with stakeholders

4.1.1 Discrepancies between Simulated and Measured Energy Consumption

Figure 4-1 illustrates the range of variation between simulated and measured EUI for a sample of LEED-certified buildings. The figure shows that BEM tools:

- » Can over- or under-estimate measured performance 50% or more for this particular sample
- » Tend to under-estimate normalized annual energy use relative to actual for higher-performing (low design EUI) buildings. This does not necessarily indicate that the BEM tools are inaccurate. For example, when modeling buildings that have low design EUIs, BEM users may make design operating assumptions that are consistent with achieving low EUIs, but real-world operation may vary.

Figure 4-1. Design (Simulated) Versus Measured Energy Use Intensity (EUI) for LEED Buildings[a]



Source: Energy Performance of LEED® for New Construction Buildings, March 2008. Available: http://www.usgbc.org/Docs/Archive/General/Docs3930.pdf

a) Energy Use Intensities (EUI) is based on site energy in kBtu/sf http://www.usgbc.org/Docs/Archive/General/Docs3930.pdf

Some stakeholders suggested that models of LEED buildings do not represent typical BEM accuracy. These stakeholders cited two contributing factors:

» The LEED process does not simulate the actual building performance. Rather, LEED uses standard values for occupancies, plug loads, and operational settings that may differ from anticipated building use.

» Frequently, LEED building models are completed late in the design process only to comply with certification requirements, rather than early in the design process, as intended by LEED, when BEM could inform the design process. These stakeholders suggest that this factor contributes to the poor alignment between simulated and measured performance in this sample (implying that little care was taken when building many of these models).

Whether or not this particular sample represents the potential or even typical accuracy of BEM predictive capabilities, virtually all stakeholders agree that BEM simulated energy performance can vary from measured energy performance by ± 30% or more unless the model is specifically calibrated to actual building use and operation.

Because of the difficulty of obtaining or predicting key BEM inputs with certainty, many modeling use-cases compare the intended design to a baseline design. This approach isolates specific aspects of building performance while controlling (within limits) for the effects of uncertain inputs. LEED is such a comparative use case, comparing the proposed building to an ASHRAE 90.1-2010 Appendix G baseline.

Although comparative modeling reduces the importance of absolute predictive accuracy, it does not eliminate it. For one, better predictive accuracy often results in better comparative accuracy. More importantly, emerging uses such as design of zero energy buildings place greater emphasis on predictive accuracy—zero energy is an absolute goal, not a comparative goal.

Figure 4-2 illustrates BEM uncertainty when comparing BEM model results to actual building energy consumption for both calibrated and uncalibrated models. For models that are calibrated to actual building performance, ASHRAE Guideline 14 provides uncertainty metrics in terms of Normalized Mean Bias Error (NMBE) and Coefficient of Variation of the Root Mean Square Error (CVRMSE). No such standardized metrics exist for models that are not calibrated to building performance—we illustrate comparison of annual energy consumption because we have some data based on this metric (albeit poorly documented).

Figure 4-2. BEM Uncertainty when Comparing Simulated to Measured Energy Consumptions

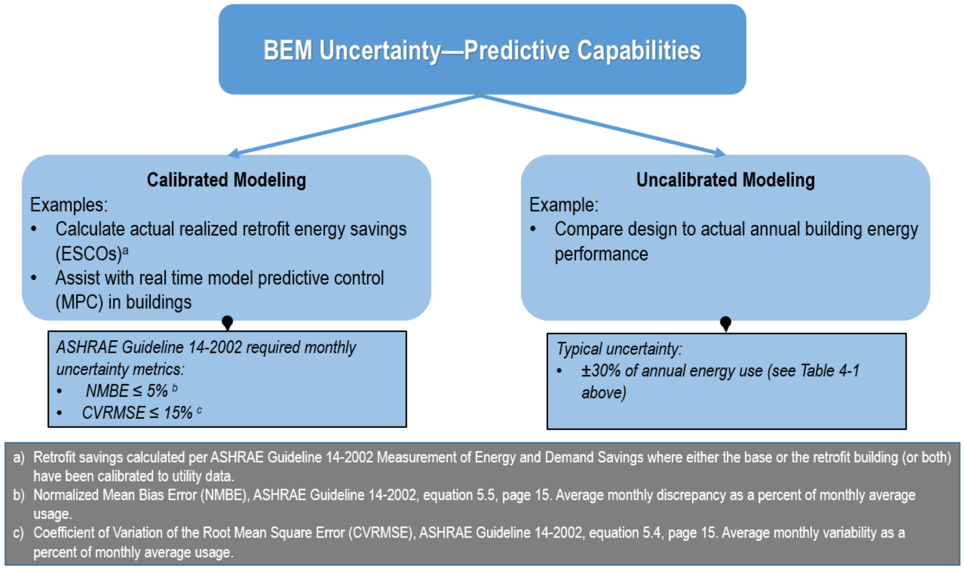
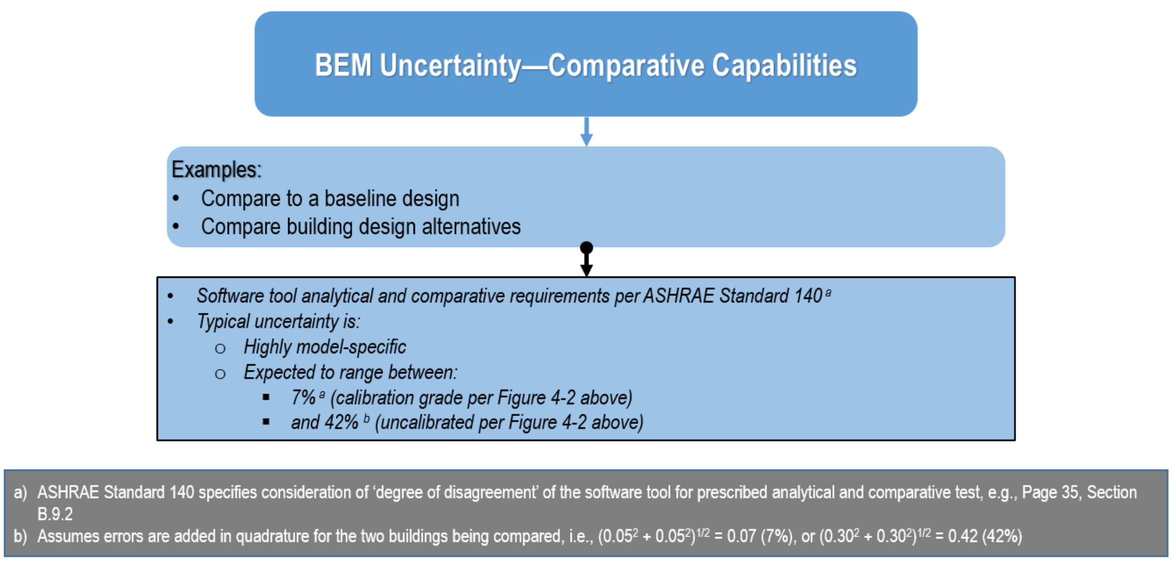


Figure 4-3 illustrates BEM uncertainty when comparing one BEM model result to another (perhaps to a baseline design, or to a design alternative).

Figure 4-3. BEM Uncertainty when Comparing Designs



4.1.1.1 Factors Impacting Absolute Accuracy of BEM

In general, the absolute accuracy of BEM tools depends on:[34]

» Accuracy of the algorithms in the BEM that are used for building physics, equipment, and controls simulation

» The experience of the BEM user

» How well the actual construction and operation, including as-installed equipment schedules, capacities and settings, match designer estimates and/or design specifications

» Weather

Three of the four factors above do not directly relate to the capability and accuracy of the BEM tool itself. Rather, they relate to how accurately the BEM user knows and reflects in the inputs the building design, construction, and operational details. By using an expected range for each BEM input, the BEM user can determine a range of energy use, and see how sensitive BEM is to each input variable. Additionally, the utility of the results depends on the output(s) of interest, which could be a specific end use such as cooling energy, or it could be whole building energy.

Engine/Algorithm Accuracy: Approximations used in BEM engines sometimes significantly over-simplify real-world building heat flow and equipment energy. A stakeholder offered the following example: Fan energy is calculated in a particular tool based on an assumed system static pressure drop curve rather than modeling fan energy based on airflows moving through the duct system. Using these simplified system curves for building fans may result in a large aggregate error in total annual simulated fan energy.

BEM User Experience: See further discussion in Section 5.2.4.

Carry-Through of Design Intent to Construction and Operation: BEM absolute accuracy depends on the extent to which commissioning and other best practices are followed to help ensure that the building is built and operated as designed. Even a well-designed commissioning process may not result in a perfect match between the designed and as-built buildings, particularly with respect to HVAC control sequences.

Occupancy and Occupant Behavior: While having good knowledge of intended building use can improve BEM absolute accuracy, occupancy and occupant behavior cannot always be predicted accurately. Absolute accuracy tends to be higher in buildings that are less likely to experience unexpected variations in occupancy and/or occupant behavior. One example is a building that uses a Building Automation System (BAS) to accommodate occupant control actions in a predictable manner.

4.1.1.2 BEM Verification and Validation

Software validation is confirmation that the software results agree with empirical tests, within experimental accuracy. Validation of BEM engines requires fine-tuned well-controlled experiments. For a building this means submetered energy consumption data, along with detailed design, construction, and operational knowledge. However, most buildings are too complex and have too many unknowns to support "validation-grade" experiments. Specially fitted and richly instrumented test facilities are better experimental platforms, but these are expensive to build and operate.

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[34] The first four factors are from email correspondence with an NREL researcher involved in supermarket refrigeration modeling research.

Because of these challenges, BEM engines have historically been only minimally and opportunistically validated, but more extensively verified and tested. Verification is confirmation that software results agree with analytical solutions, which exist for very small, simple, and often un-realistic configurations. A significant amount of verification and testing, under a wide variety of conditions, and of multiple BEM programs, provides some of the confidence and assurances associated with validation. This is the approach taken by the ASHRAE Standard 140 framework,[35] which combines analytical tests with comparative tests. BEM programs that pass the analytical tests are compared to one another using more complicated, more realistic tests that have no analytical solutions. Comparative tests are set up to add realism, one dimension at a time, to improve their diagnostic power.

The Standard 140 framework is also designed to accommodate validation, where BEM program results are compared to measured data from a real building, test cell, or laboratory experiment.

Table 4-2 shows the key standards for verification and validation of BEM.

Table 4-2. Table of Standards and Methods Governing BEM Verification and Validation

Standard	What is Being Verified	Purpose of Method
ASHRAE 140-2011[a]	Hourly Whole Building Energy Analysis Software	» Standard Method of Test is used for identifying and diagnosing differences in whole building energy simulation software
BESTEST-EX	Energy Audit Tools and Savings Calculator	» Method of Test that includes both building physics tests and tests of utility bill calibration algorithms

a) http://sspc140.ashraepcs.org/

4.1.2 Missing Input Data

BEM users may not have all the input information needed to develop an accurate model. This is often the case in the conceptual design stage, but can persist throughout the building design cycle. In some cases, the missing inputs don't exist. In other cases, they have not been given to the BEM user. Common examples of missing input data include: manufacturer-specific equipment performance data, equipment and system control schemes, and expected occupancy schedules and levels.

4.1.3 Time-Consuming Transfer of Input Data

This barrier refers to the lack of interoperability of BEM tools with other software commonly used in the building delivery workflow. A common example is that geometry entered into BIM software is not robustly exported and often needs to be debugged and fixed in the BEM tool or reconstructed from scratch. This not only increases modeling time and costs, but can lead to inaccuracies.

4.1.4 Outputs not formatted for Presentation

BEM model output files are frequently large and very detailed. Some BEM software tools provide formatted outputs for specific purposes such as LEED certification, however, client-friendly visuals are typically missing, requiring additional effort to reformat BEM outputs to make them presentable.

[35] International Energy Agency Building Energy Simulation Test and Diagnostic Method for Heating, Ventilating, and Air-Conditioning Equipment Models (HVAC BESTEST), Volume 1: Cases E100–E200, J. Neymark, J. Neymark & Associates, Golden, Colorado, R. Judkoff, National Renewable Energy Laboratory, Golden, Colorado, http://www.nrel.gov/docs/fy02osti/30152.pdf

ASHRAE Standard 209 is intended to help standardize output formats, which should help streamline BEM analysis workflows, allowing BEM users to focus on the model results rather than tool logistics and housekeeping.

4.1.5 BEM Capabilities Lag Technology Advances

In many cases the latest technologies and system types available in the market are not available in BEM tools until years later. Examples of this are Variable Refrigerant Flow (VRF; entered the market in the 1980s,[36] modeled in 2011 in EnergyPlus)[37] and Dedicated Outdoor Air Systems (DOAS; entered the market 2008, modeled in 2009), and Chilled Beams (entered the market 2007, modeled in 2009).

The absence of a model for a new technology may depress application and deployment of that technology. Designers and engineers may be wary of recommending or using a technology if they cannot evaluate it quantitatively.

As stopgaps, BEM users may employ workarounds yielding erroneous and/or inconsistent results, further eroding confidence in BEM, and potentially misrepresenting emerging technologies as well.

4.2 Additional Technical Barriers Specific to BTO's EnergyPlus and OpenStudio

Table 4-3 lists an additional technical barrier specifically related to EnergyPlus and OpenStudio. Below we briefly discuss this additional barrier.

[36] "VRF systems have been used in Japan since the 1980s", https://en.wikipedia.org/wiki/Variable_refrigerant_flow

[37] As reported in Nigusse, Bereket and Richard Raustad. *Verification of A VRF Heat Pump Computer Model in EnergyPlus*. Florida Solar Energy Center. 2013. Available at: http://www.osti.gov/scitech/servlets/purl/1093843

Table 4-3. Additional Technical Barriers Specific to EnergyPlus and OpenStudio

Barrier	Description
Lack of Developer Friendliness	Commercial software developers must invest significant time educating themselves before using EnergyPlus and/or OpenStudio.

4.2.1 Lack of Developer Friendliness

EnergyPlus is widely recognized as technically sophisticated and transparent, but many software developers report that it is difficult to incorporate into BEM applications, and that, once incorporated, it is difficult to migrate to the newer EnergyPlus versions. In particular, during the West Coast BEM workshop, software developers rated backward compatibility as being of high importance in improving developer friendliness for BTO BEM products (see Table A-1 of Appendix A). "Backward compatibility" means that client applications can upgrade to new versions of EnergyPlus and OpenStudio without breaking and without modification. Secondarily, it means that these new versions of EnergyPlus and OpenStudio can accept existing models developed using older versions. Software developers maintain that this is a significant constraint on their ability to leverage BTO's tools.

Another desirable feature that workshop participants emphasized is the ability to select greater or lesser levels of detail in EnergyPlus depending on design objectives and cost/time constraints (see Table A-1 of Appendix A).

4.3 Other Technical Gaps

4.3.1 Water Use

Water consumption is a growing concern, leading to increased interest in simulating the water consumption of buildings. Appendix C provides additional information about water stress, distribution of water uses, and methods for conserving water in buildings.

While one can analyze many building-related water uses without employing detailed modeling, not all water uses are simple to model. For example, several water uses are coupled to other building components and systems, including:

» HVAC-related systems (cooling towers, evaporatively cooled condensers, evaporative coolers (for space cooling), humidifiers, and steam boiler blowdown), which account for an estimated 5.5% of building water consumption on average,[38] but a much higher percentage for buildings that use this equipment

» Irrigation for green roofs (used to lower space-heating and cooling loads).

Many BEM tools do not currently model water consumption. One exception is EnergyPlus, which currently calculates water consumption for cooling towers and green roofs, and accounts for the impacts of the green roofs on building cooling loads.[39]

[38] California Sustainability Alliance. *Water-Energy Toolkit for Sustainable Development* (2013). http://sustainca.org/sites/default/files

[39] Betz, Fred and Willa Kuh. *Simulating Water: Supply and Demand in the Built Environment*. 2014 ASHRAE/IBPSA-USA Building Simulation Conference. September 10 – 12, 2014: https://www.researchgate.net/publication/264037890_Simulating_Water_Supply_and_Demand_in_the_Built_Environment

4.3.2 Urban-Scale Impacts

In the context of utility energy efficiency planning, BEM is currently used to inform building stock analyses.[40] Representative building sector models are calibrated to sector-level utility interval data, and the resulting disaggregated end uses facilitate energy efficiency and grid capacity planning.[41] Stakeholders report using BEM for district-level analyses and energy strategy development. Key applications for urban-scale analyses include:

- Integrated resource planning for utilities
- Planning for increased distributed generation
- Demand response planning
- Grid modernization (including improved resiliency).

The lack of BEM tools specifically designed to address these applications makes it more expensive and time-consuming to assess urban-scale impacts.

The use of BEM tools could aid in urban-scale analysis. Key urban-scale planning goals that could be aided by BEM tools include:[42]

- Data tracking over time
- Testing the efficacy of policy changes
- City-wide improvements in energy efficiency and carbon footprint reductions
- Energy retrofits translated into economic gains
- Actions increased as a result of informed, inspired and competing building owners
- Savings and reduced risks for building owners who can easily obtain reliable information without paying for exhaustive analysis.

4.3.3 Support for Building Operation

Enhanced, proactive building operation, including fault detection/diagnostics and other capabilities, is particularly important in light of the growing importance of demand response and other aspects of transactive energy.[43] Increasingly, building owners/operators will be financially motivated to not only operate their buildings efficiently, but to anticipate and actively manage their buildings' energy needs.

Most BEM tools were developed primarily to support static, off-line use cases like design, code-compliance, and green certification and require detailed building design data and varying load conditions such as weather and occupancy. Many stakeholders suggest that BEM tools could be enhanced

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[40] Based on methods such as those outlined in NREL's "The Uniform Methods Project: Methods for Determining Energy Efficiency Savings for Specific Measures", January 2012 — March 2013, NREL/SR-7A30-53827, Chapters 8, 10, and 11. http://www.nrel.gov/extranet/ump/draft_protocols.html, http://energy.gov/eere/about-us/about-ump

[41] http://www.eia.gov/consumption/residential/reports/smartmetering/pdf/assessment.pdf

[42] http://doee.dc.gov/sites/default/files/dc/sites/ddoe/publication/attachments/20141209_Smart%20Buildings%20Plan%20Project_Final%20Technical%20Report_FINAL.pdf

[43] According to the GridWise® Architecture Council, which was formed by DOE, "transactive energy" refers to 'techniques for managing the generation, consumption or flow of electric power within an electric power system through the use of economic or market based constructs while considering grid reliability constraints." See: http://www.gridwiseac.org/about/transactive_energy.aspx

to support on-line, dynamic use-cases such as ongoing commissioning , automated fault detection and diagnosis (AFDD), and model predictive control (MPC). Currently, however, most BEM tools lack the required features and capabilities, including:

- Interfaces to building management systems (BMS) to monitor actual building conditions and operations
- Ability to integrate "real-time" data about building conditions and operations (in lieu of pre-defined input schedules)
- Interfaces to existing AFDD systems to monitor equipment performance
- Ability to model faulty and degraded equipment.

The following capabilities are also needed:

- Calibration algorithms to improve the accuracy of simulated performance using actual building-condition and operating data
- Learning algorithms that can translate discrepancies between simulated and actual behavior into accurate diagnostics of building system faults.

4.3.4 Carbon Emissions

Buildings contribute to emissions of carbon and other global-warming gases in several ways. Key sources are:

- Carbon emissions from electric generation plants
- Leakage from the infrastructure that delivers natural gas to electric generation plants
- Leakage from the infrastructure that delivers natural gas to buildings
- Carbon emissions from the combustion of fossil fuels at buildings
- Refrigerant leakage from HVAC and refrigeration equipment.

While several BEM tools permit calculation of carbon emissions (or global-warming potentials), these tools often require the BEM user to input carbon emissions factors for the local electric generation, transmission, and distribution system. Finding regionally specific carbon emissions factors can, however, be difficult and time-consuming. Having BEM tools that automatically determine these emissions factors would be far more convenient.

Many BEM tools do not account for the direct-emissions impacts of refrigerant leakage from HVAC and refrigeration equipment.

Despite its climate impacts,[44] we are unaware of any BEM tools that account for leakage from the natural gas infrastructure.

[44] http://static.berkeleyearth.org/memos/climate-impacts-of-coal-and-natural-gas.pdf, https://www.nae.edu/Publications/Bridge/140630/140642.aspx

5. Market Drivers and Barriers for Building Energy Modeling Tools

5.1 Market Drivers

The promise of cost-effective energy savings that also enhance occupant comfort and health, and lower maintenance costs, is the fundamental market driver for BEM.

Table 5-1 shows the potential energy savings associated with BEM for the design and retrofit of U.S. commercial buildings. Based on the assumptions listed in the table, BEM could save 750 TBtu/year by 2030 in commercial buildings alone if used for all new construction and retrofits.

Table 5-1. Energy Savings Potential Associated with BEM for Building Design and Retrofit (U.S. Commercial Buildings Only)

Application	Affected Floor Space (Million Sq. Ft.)[a]		Technical Potential Savings (TBtu/yr.) in 2030[b, c]
	In 2020	In 2030	
Commercial Buildings—Post-2010 Construction	19,500	39,500	420
Retrofits of Commercial Buildings Constructed Pre-2010	69,600	58,700	330
Total Commercial Buildings	89,100	98,200	750

a) Commercial floor space constructed or potentially retrofitted between 2010 and the date noted. Calculated using BTO's Prioritization Tool, which is based on Energy Information Administration, Annual Energy Outlook 2014, projections of commercial floor space. See Prioritization Tool description at: http://energy.gov/eere/buildings/prioritization-tool

b) *Technical Potential* is the total annual savings (primary energy) that could feasibly be achieved given technology limitations. It assumes 100% of all buildings floor space could benefit from building energy modeling (new construction and deep-energy retrofits)

c) Assumes that BEM reduces HVAC energy consumption by 20% in post-2010 construction and 10% in retrofits of pre-2010 construction. Savings in other building systems are neglected. Uses Energy Information Administration projections for commercial building HVAC consumption. Projections are rounded.

Currently, however, most BEM is not used to inform design but rather for post-design green building certification (such as LEED) and performance-path code compliance.

As described in Section 3.4 above, as little as 20% of U.S. commercial building new construction benefits from BEM. While we have no quantified estimate, it's clear that there is much room for BEM growth in residential new construction as well. In addition to the growth potential for building design, there is ample growth potential in the use of BEM for building operation, urban-scale modeling, code compliance, and green building certification.

One development that could spur the use of BEM for design is the shift to outcome-based codes, *i.e.*, codes based on measured, rather than calculated, performance. Outcome-based rating systems, such as the EPA's ENERGY STAR Portfolio Manager, are commonly used. But ENERGY STAR is based on population statistics and it is voluntary. Outcome-based codes would be mandatory and based on technically derived EUI targets.

The intent of outcome-based codes is to close the gap between building design/construction and operations/maintenance/tenancy. Current codes and policies apply only the building's physical assets and ignore post-construction effects and the associated stakeholders.[45] Outcome-based codes based on

[45] Getting to Outcome-Based Building Performance, Report from a Seattle Summit on Performance Outcomes, Event Report May 2015, New Buildings Institute, Page 4.

measured usage would inherently include accountability of building owners, operators, and tenants in the overall building performance metric, and ensure a stable, predictable EUI over the life of the building.[46] Outcome-based code compliance would be based on a comparison between actual measured EUI from utility bill usage, and a range of expected EUIs for given building types, which may change with occupancy and primary use,[47] and would be enforced using a variety of methods, from disclosure statements to building contract requirements.

With existing "asset-based" codes, the use of BEM is focused on comparative performance with standard operating assumptions, often post-design if the code is not stringent. With outcome-based codes, BEM use would shift toward design and emphasize absolute, rather than comparative, modeling with intended occupancy and operational parameters. BEM could also be used during periodic compliance checks, to help attribute energy consumption to the building itself and its maintenance and central operation, *i.e.*, the owner, or to tenants. BEM could be needed even if tenant-level end use level sub-metering is available since sub-metering may not be able to directly account for the effects of the envelope. BEM would also be more heavily used during code development, to establish target EUI levels.

At the recent New Buildings Institute (NBI) Summit[48] in support of outcome-based building performance requirements—and specifically outcome-based building energy codes--industry experts outlined strategies to move toward a new building delivery process.[49] Their recommendations include:

- Supporting benchmarking and disclosure, measurement and metrics
- Shifting focus of codes toward outcome-based performance
- Supporting the evolution of BEM by:
  - Increasing information transfer between building owners and BEM users
  - Providing additional modeling protocols and guidelines. Examples include:
    - ASHRAE Standard 209P, *Energy Simulation Aided Design for Buildings Except Low-Rise Residential Buildings*[50]
    - The BEM Library[51]
    - COMNET, a compilation of default settings and assumptions (*e.g.*, for plug loads) and protocols (*e.g.*, for generation of a baseline model from a proposed

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http://newbuildings.org/performance-outcomes-event-report

http://newbuildings.org/sites/default/files/Performance_Outcomes_Summit_Report_5-15.pdf

46 Ibid, Page 1.

47 Ibid.

48 NBI Event: Outcome-Based Performance Summit, August 4-5, 2014 in Seattle, Washington. http://newbuildings.org/news/industry-experts-plan-future-focused-commercial-building-performance-outcomes

49 Getting to Outcome-Based Building Performance, Report from a Seattle Summit on Performance Outcomes, Event Report May 2015, New Buildings Institute, Page 14.

http://newbuildings.org/performance-outcomes-event-report

http://newbuildings.org/sites/default/files/Performance_Outcomes_Summit_Report_5-15.pdf

50 https://www.ashrae.org/standards-research--technology/standards--guidelines/titles-purposes-and-scopes#SPC209P

51 http://www.bemlibrary.com/

building model) that extends typical standard guidelines such as ASHRAE-90.1 Appendix G.[52]

The findings of the NBI Summit suggest that adapting BEM to operate buildings, and further advancements in BEM technical capabilities, will be required to support outcome-based approaches to providing energy-efficient buildings.[53] Gathering and organizing building performance data is equally important to a) establishing long-term meaningful, enforceable building performance targets, and b) understanding the gap between BEM-simulated and measured performance. [54]

5.2 General Market Barriers

Table 5-2 lists the key market barriers to increased BEM use that BTO can address (barriers specific to EnergyPlus and OpenStudio are covered in Section 5.3).

Table 5-2. Market Barriers to Increased Use of BEM

Barrier	Description
Concerns about Value/Cost-Effectiveness	Many building owners are concerned about the costs of BEM. Further, many are not confident that BEM will lead to substantial energy savings because: • Simulated energy consumption can vary substantially from measured • Lack of documented analyses proving attribution of substantial energy benefits to BEM (see Appendix D for an proposed method that could be used to attribute energy benefits directly to BEM tools and the BEM process) • Results can vary from user to user, and from BEM tool to BEM tool
Resistance to Code Changes	State or local governments must revise their building energy codes if they wish to encourage or require BEM for code compliance and design, but construction industry stakeholders (builders, owners, and real estate companies) often resist any changes to codes
Late Introduction into the Design Process [a]	BEM has the greatest opportunity to influence building design when it's introduced at the conceptual design stage. However, stakeholders report that BEM is often performed after the building design is largely complete, which leaves little opportunity to influence the building design. Counter to the intent of these programs, this can occur when BEM is performed to demonstrate compliance with the requirements of a building code, a certification program, or a utility incentive program.
Inadequate User Experience, Training, and Certification	• BEM is often delegated to inexperienced staff • No established requirements for BEM user credentials or certifications • Limited BEM curricula in academic institutions • Limited documentation of best practices • Can also contribute to the "Concerns about Value/Cost-Effectiveness" barrier outlined above

a) This "barrier" is arguably a symptom of the first barrier—concerns about value/cost-effectiveness. We list it separately because other factors may also contribute.

5.2.1 Concerns about Value and Cost-Effectiveness

Many owners question the value or cost-effectiveness of BEM. Stakeholders suggest that modeling costs can range from $5,000 to $20,000 or more for commercial buildings, depending on building complexity

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[52] http://comnet.org/

[53] Getting to Outcome-Based Building Performance, Report from a Seattle Summit on Performance Outcomes, Event Report May 2015, New Buildings Institute, Page 9.

http://newbuildings.org/performance-outcomes-event-report

http://newbuildings.org/sites/default/files/Performance_Outcomes_Summit_Report_5-15.pdf

[54] Ibid, Page 28.

and the detail with which it is modeled. As discussed in Section 4.1.1 above, BEM-simulated performance can vary from actual performance, which can lower designer/owner confidence in BEM predictions.

Among other benefits, BEM helps identify design approaches that achieve high energy efficiency, increase comfort, and minimize costs. It is, however, difficult to quantify the incremental benefits that BEM provides—who can say with confidence what design decisions would have been made absent BEM (the counterfactual dilemma)? Section 6.5.1 discusses some recommendations on how to address this question.

5.2.2 Resistance to Changes in Building Codes

Stakeholders report that construction industry stakeholders generally resist changes to codes that might result in higher building costs. In fact, the distinguishing feature of BEM is that it provides the basis for well-informed cost optimization, and could actually result in lower building costs for equivalent building energy performance. Because BEM provides the basis for trade-offs, it leads to more flexibility than strict prescriptive tracks. However, BEM adds time and expense to the building design process, leading some construction industry stakeholders to resist it.

5.2.3 Late Introduction into the Design Process

Stakeholders report that a building design team and/or owner may postpone BEM if the team thinks it can achieve the energy requirements of building codes and/or green building certifications without BEM, even when BEM will ultimately be required to demonstrate compliance. This practice significantly limits the opportunity for BEM to inform the building design.

5.2.4 Inadequate User Experience, Training, and Certification

Inadequate BEM user experience and training can lead to input errors, such as:

- Using input default values without verifying whether they are appropriate
- Misunderstanding software input processes or results
- Simple data entry errors[55]
- Using inaccurate guesses or assumptions when design information is lacking.

Specific examples include:

- Inputting inaccurate operational schedules and occupancy rates that either were not checked against the actual building and equipment schedules, or were incorrectly forecast.
- Using inaccurate assumptions or approximations when manufacturer-specific equipment has not yet been selected.
- Using manufacturer's equipment efficiencies without correcting for ancillary equipment modeled separately by the BEM software. For example, a BEM user could inadvertently double-count fan energy when entering the rated energy efficiency of a packaged rooftop air conditioner, if they do not realize that the engine already includes fan energy.

[55] Of course, highly experienced and well trained BEM users can make data-entry errors, but such users are more likely to identify these errors early in the modeling process.

Stakeholders suggest that cost and schedule pressures can lead design firms to assign BEM to junior staff with little or no experience in building design or energy modeling. Also, although there are at least two modeling certificate programs, ASHRAE's Building Energy Modeling Professional (BEMP)[56] and AEE's Building Energy Simulation Analyst (BESA)[57], these are not currently required for any BEM task nor is any specific training. Similarly, modeling best practices—or minimum practices—are not codified and required other than proprietary guidelines that might exist at specific firms. ASHRAE Standard 209P, "Energy Simulation Design for Buildings Except Low-Rise Residential Buildings," attempts to fill this gap.

These factors contribute to concerns about the value and cost-effectiveness of BEM (discussed above in Section 5.2.1).

5.3 Additional Market Barriers Specific to BTO's EnergyPlus and OpenStudio

Table 5-3 lists an additional market barrier to increased BEM use that is specific to EnergyPlus and OpenStudio.

Table 5-3. Additional Market Barrier Specific to EnergyPlus and OpenStudio

Barrier	Description
Market Inertia	OpenStudio and, to a lesser extent, EnergyPlus, are relatively new to the market. Commercial software developers would need to make significant investments to transition their products to use these tools, and they may not see the value in doing so. Further, BEM users may resist transitioning from the BEM tools with which they are already fluent.

5.3.1 Market Inertia

On the time scale of BEM tools, many of which have been in the market for decades, EnergyPlus and especially OpenStudio are relatively new. Software developers and their prospective customers must make a significant investment to switch their BEM products from current engines to EnergyPlus and OpenStudio. Further, software developers may not see the value of this change if their customers are not demanding it. In general, software developers have been reluctant to enter the turnkey BEM application market, because doing so implies competing with a free product (eQuest).

[56] https://www.ashrae.org/education--certification/certification/bemp-building-energy-modeling-professional-certification

[57] http://www.aeecenter.org/i4a/pages/index.cfm?pageid=347

6. Recommended BEM Initiatives

This section covers recommended initiatives that will increase the use of BEM tools in both building design and building operation. Where appropriate, we include preliminary recommendations for performance metrics to help measure progress toward addressing an initiative.

None of the recommendations made herein reflect fundamental changes in BTO's current program. Rather, they represent adjustments to approach and emphasis.

6.1 Roadmap Development Process Central Themes

Four interrelated, central themes emerged from the roadmap development process:

There is a Need to Establish and Promote a Clear Value Proposition for BEM: Most builders and building owners do not value BEM highly. They want designs completed quickly and inexpensively. Often, they don't trust BEM to provide significant value. Architects and engineers feel substantial pressure to minimize time spent on BEM. Developing and documenting compelling evidence that BEM leads to robust energy savings will help builders and owners value BEM appropriately.

There are Opportunities to Increase the Value of BEM: Improving BEM tools will significantly enhance both their real and perceived values. Key opportunities are

» Identifying the highest-value applications for BEM in building design, retrofit, and operation

» Accelerating the rate of BEM updates to include new technologies and control algorithms.

In addition, based on available data, simulated energy use does not consistently align with measured building performance, contributing to both a perceived and real limitation on their value/usefulness. A rigorous initiative to compare BEM predictions to actual building performance, followed by correcting/refining BEM tools as appropriate, will likely lead to improved tools and higher value.

There are Opportunities to Lower the Cost Impacts of BEM: Current BEM tools are not interoperable with building design software, leading to duplication of time-intensive data entry. The data input process for many BEM tools can be simplified. Few, if any, BEM tools provide presentation-ready outputs, requiring time-intensive post-processing of outputs for presentation to clients and management. Ideally, software developers would provide a continuum of interoperable tools, or even unified individual tools, that serve modeling needs from conceptual design through building operation, including fulfilling the requirements (where applicable) for building energy codes, green building certification, and utility incentive programs.

There are Opportunities to Grow and Expand the Applications of BEM: Stakeholder estimates suggest that BEM is used in only about 20% of new commercial building designs, and probably a smaller fraction of new residential building designs (see discussion in Section 3.4 above). Use of BEM to support building operation is even more limited, despite the growing importance of demand response and other aspects of transactive energy.[58] Increasingly, building owners/operators will be financially motivated to not only operate their buildings efficiently, but to anticipate and actively manage their buildings' energy needs. Further, BEM tools can be expanded to model:

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[58] The term "transactive energy" refers to techniques for managing the generation, consumption or flow of electric power within an electric power system through the use of economic or market-based constructs while considering grid reliability constraints. See: http://www.gridwiseac.org/about/transactive_energy.aspx

- Building water consumption, which is particularly important in water-sensitive regions of the U.S.
- Carbon and fugitive methane emissions, which depend on regional electric and natural gas supply infrastructures[59]
- Urban-scale impacts.

6.2 Priority Initiatives

Table 6-1 lists recommended initiatives based on the central themes outlined in Section 6.1 above, including priorities and references to the sub-sections that describe each initiative.

Table 6-1. Recommended Initiatives to Increase the Value of BEM

Initiative	Reference Sections[a]	Priority[b]
Improve BEM Absolute Accuracy through Better Training and Design/Operational Knowledge	6.5.3	Essential
Establish a Clear BEM Value Proposition	6.5.1	Essential
Establish Ongoing Process for Assessing the Needs of Commercial Software	6.4.1	Essential
Improve BEM Absolute Accuracy through BEM Software Enhancements	6.3.1	Important
Accelerate Integration of New Technology Models into BEM	6.3.2	Important
Increase Awareness of BEM	6.5.2	Important
Refine BEM to Increase User Productivity	6.3.3	Important
Add Capability to Evaluate Water Consumption	6.3.4	Supportive
Add Capabilities to Support Building Operation Capabilities	6.3.6	Supportive
Accommodate Urban-Scale Analyses	6.3.5	Supportive
Enhance BEM to Facilitate Estimating Regionally Specific Carbon Emissions	6.3.7	Supportive

a) Lists roadmap sections that provide more details of the initiative.
b) Essential: Critical if BEM use is to expand significantly
Important: Likely to contribute significantly to expanded BEM use
Supportive: Likely to contribute incrementally to expanded BEM use

6.3 General Technology Initiatives

This section covers technology initiatives, *i.e.*, initiatives directly related to software development and validation that apply generally to BEM tools. Section 6.4 addresses technology initiatives that are specific to BTO's EnergyPlus and OpenStudio.

[59] DesignBuilder (http://www.designbuilder.co.uk/helpv3/) and Hevacomp Simulator V8i (www.dtic.mil/get-tr-doc/pdf?AD=ADA552789) have regionally specific default emission factors for electricity that can be over-ridden by the user. Both Sefaira (confirmed by email to Sefaira) and EnergyPlus (http://apps1.eere.energy.gov/buildings/energyplus/pdfs/inputoutputreference.pdf) allow user inputs for emission factors for electricity. Determining regionally specific emissions factors can, however, be time-consuming and require specialized skills/knowledge.

6.3.1 [Important] Improve Absolute Accuracy of BEM through BEM Software Enhancements

Barrier Addressed: BEM-simulated energy consumption can vary significantly from measured consumption

Also see Section 6.5.3, which discusses non-software-related approaches to improving the absolute accuracy of BEM.

We consider two software-related approaches to improving the absolute accuracy of BEM:

- **Algorithm Corrections** – Correcting algorithms (including improving over-simplified algorithms) can improve modeling of both building components and whole systems, as measured using industry-accepted methods for BEM software validation.[60]
- **Automated input-error detection and warnings** – Improving automatic review of input data and warning the BEM user of potential errors or anomalies in advance of running the full model simulation helps avoid common input pitfalls that lead to erroneous results.

6.3.1.1 Correcting Algorithms [Small Impact Anticipated]

Researchers can identify potential algorithm deficiencies by validating BEM tools using actual measured building energy data.

Purpose-built laboratories[61] can be used to compare BEM tools to building performance for a limited set of building characteristics and climates. Validation using real-world buildings is also important because it is more convincing/compelling to skeptical stakeholders. Well documented, well understood, and well monitored buildings (such as ASHRAE Headquarters) should be considered as potential BEM test-bed buildings.

Based on stakeholder discussions, sophisticated BEM engines (such as EnergyPlus) include rigorous and well vetted modeling algorithms. Therefore, we anticipate that correcting algorithms will have only modest impacts on improving the absolute accuracy of BEM. However, BEM users must use the algorithms available, rather than using simplifications, to achieve BEM's full potential to accurately simulate building performance. While we anticipate modest impacts on improving absolute accuracy, characterizing and documenting the accuracy of BEM algorithms will help demonstrate the BEM value proposition (see further discussion in Section 6.5.1).

While this initiative will increase stakeholder confidence in BEM tools and the BEM enterprise as a whole, stakeholders suggest that the largest opportunities for improving absolute BEM accuracy are not directly related to BEM software (see Section 6.5.3).

6.3.1.2 Automated Input-Error Detection and Warnings [Medium Impact Anticipated]

Based on our discussions with energy BEM users, today's BEM tools provide surprisingly little assistance to help verify the integrity of inputs. Even simple error messages are often missing, such as providing a conspicuous warning when the specified HVAC system falls significantly short of meeting building heating or cooling loads. Variables such as unmet load hours that are available in standard model output reports, however, are not typically flagged automatically.

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[60] These methods include comparative testing and diagnostics, analytical validation, and empirical validation as outlined in standard ASHRAE 140.

[61] Laboratories that mimic representative buildings, or that actually are representative buildings. Their laboratory-grade control and monitoring capabilities distinguishes simulated-building laboratories from buildings under field test. Such labs may use simulated or actual occupants.

There are significant opportunities to improve BEM input screening functions to flag inputs that appear to be errors (such as the example above) or that appear inconsistent with common design practices for the building type and geographic location being modeled, including prevailing building codes.

Incorporating automated input-error detection in model inputs enables BEM users to avoid:

- » Costly and time-consuming BEM re-work to correct errors that are discovered later in the design process
- » Building designs where BEM is not effectively utilized to identify inefficiencies, as follows:
  - o BEM provides accurate metrics essential to the success of the design intent of the building, which would otherwise be estimated by the design team on a 'general rule' basis, or not at all, including:
    - Unmet load hours
    - Energy Use Intensity (EUI)
    - Average outdoor air fraction
    - Average CFM per ton
    - Chiller plant kW/ton

    These data are already available in the BEM tool, but either are not top-of-mind to the BEM user in early design phases, or are not easily accessible in the output reports.

Thus, this initiative represents an opportunity to highlight the inherent value proposition of BEM to the users and stakeholders, in addition to allowing users to capitalize on the full potential of BEM even during the early design process.

Stakeholders suggest that input errors are relatively common. Therefore, we anticipate that automated input-error detection and warnings will have a medium impact on the absolute accuracy of BEM.

6.3.1.3 Improving Description and Prediction of Occupant Behavior [Medium Impact Anticipated][62]

As discussed in Section 4.1.1.1 above, inaccuracies or oversimplifications in the description and prediction of occupant behavior can lead to inaccuracies in simulated energy use. One example of ongoing work in this area is the International Energy Agency, Energy in Buildings and Communities Programme (IEA-EBC Annex 66). IEA-EBC is working to:

- Set up a standard occupant behavior definition platform
- Establish a quantitative simulation methodology to model occupant behavior in buildings
- Understand the influence of occupant behavior on building energy use and the indoor environment.[63]

[62] We also address predicting occupant behavior in Section 6.5.3. Whether it's considered "software related" depends on whether the improved algorithms are incorporated directly into BEM (software related), or whether the improved algorithms are used to inform the inputs to BEM (non-software related).

[63] See http://annex66.org/?q=Introduction

Several BTO and DOE national laboratory staff contribute to these activities.[64]

6.3.1.4 Recommended Actions to Improve Absolute BEM Accuracy through Software Enhancements

Table 6-2 summarizes recommended BTO actions to improve absolute BEM accuracy through software enhancements.

Table 6-2. Recommended Actions to Improve Absolute BEM Accuracy through Software Enhancements

Recommended Action
Following the procedures in ASHRAE Standard 140, evaluate the absolute accuracy of a range of BEM tools using laboratory environments as well as the real-world building validation to identify model deficiencies that degrade a model's ability to accurately simulate building energy consumption. When simulated energy consumption varies significantly from measured: » For EnergyPlus and OpenStudio, define targeted software development needs » For non-DOE tools, communicate identified deficiencies to the software developers
Support improvement in automated input-error detection by providing real-world test buildings to help define ranges of expected model inputs. (See Section 6.4.1, which discusses establishing an ongoing dialogue between BTO and commercial software developers.)
For a range of building types and climates, conduct case studies of occupied buildings to further improve understanding of occupancy patterns, occupancy behavior, and impacts on building energy consumption (segmented by major subsystem).
Continue to contribute to, and monitor, IEA-EBC Annex 66 activities. As improved algorithms for describing and predicting occupant behavior become available: » For EnergyPlus and OpenStudio, accommodate new descriptions and algorithms » For non-DOE tools, recommend that software developers accommodate these new descriptions and algorithms

6.3.1.5 Performance Metrics for Improving Absolute BEM Accuracy

Table 6-3 lists preliminary example metrics and targets for measuring and tracking improvements in absolute BEM accuracy.

Table 6-3. Preliminary Example Metrics and Targets for Improving Absolute BEM Accuracy

Example Metrics[a]	Current Estimates ((without Calibration)	Example Targets (Without Calibration)[b]
Simulated annual EUIs vs. measured annual EUIs measured in purpose-built laboratories (for total building and for major subsystems), prior to calibration.[c] Simulated vs. measured annual EUIs for selected buildings (for total building and for major subsystems), prior to calibration. Use a set of representative buildings having carefully studied envelope characteristics, metered energy data, and occupancy patterns/occupant behaviors	» ± 30% for Whole Building [d]	» By 2020: ○ ±15% for whole building ○ ±10% for major subsystems » By 2025: ○ ±10% for whole building ○ ±7% for major subsystems

a) Metric: Tool or methodology by which to measure progress toward a goal. A metric may measure a proxy for (or indicator of) progress if progress toward a goal is difficult or impossible to measure directly.

b) Target: Desired value, preferably with a date, associated with a metric. Example targets are based on achieving significant improvements relative to current performance. During a 08-31-2015 telephone interview, Prof. Khee Poh Lam, Center for Building Performance and Diagnostics, Carnegie Mellon University, indicated that he and his research staff routinely achieve ±5% accuracy (based on EUI) prior to calibration to measured performance data for demonstration projects. He acknowledged that achieving this requires significant effort, which may be impractical in conventional practice due to resource constraints.

[64] See http://annex66.org/?q=node/26

c) ASHRAE 14-2002 Section 5.1.3 Whole Building Calibrated Simulation Approach. https://gaia.lbl.gov/people/ryin/public/Ashrae_guideline14-2002_Measurement%20of%20Energy%20and%20Demand%20Saving%20.pdf

d) As reported in Section 4.1.1, stakeholders estimate that BEM simulated performance currently deviates from measured performance within a range of ±30% or more.

6.3.2 [Important] Accelerate Integration of New Technology Models into BEM Tools

Barrier Addressed: BEM capabilities lag technology advances and code adoption

BEM tools cannot instantly model all the latest energy efficient technologies due to the time and resources required to develop and integrate models for each new technology class or family as it is commercialized. BEM users would benefit from accelerated integration of new technology models, which would expand energy savings options available for consideration.

BEM tools need a consistent and rapid update method that ensures prompt, accurate, and consistent incorporation of new technology models. Three plausible approaches to accelerate the development and integration of new technology models are:

- » Proactively solicit detailed performance data from manufacturers at the time of market introduction (requires manufacturer participation/support)
- » Conduct independent laboratory testing of new equipment upon market introduction and develop detailed performance correlations (independent of manufacturers)
- » Develop new technology models based on existing models for similar equipment, then adjust coefficients based on engineering ratios of published rating-point performance values.[65]

Detailed laboratory testing of new equipment is an effective way to develop performance correlations, but may be prohibitively expensive for BTO or other third parties to conduct on a large scale. However, it may be justified for specific products that show great promise for energy savings, for which BTO wants to accelerate market uptake.

Approximating detailed performance correlations by adjusting existing performance correlations based on rating-point performance is often a reasonable compromise between cost and accuracy.

Relying on a single approach is unlikely to be successful. BTO can use a combination of these approaches to help ensure that both BTO and commercial software developers have access to performance correlations for new, advanced technologies.

For the specific case of EnergyPlus, BTO is currently undertaking a re-engineering effort to create an EnergyPlus clone that uses a centralized, *i.e.*, “external” solver/integrator and simulates components and systems using a “model exchange” style.[66] In this approach, component behavior is described *explicitly* by writing down the governing equations, rather than *implicitly* by implementing a solver for those equations.

BTO anticipates that this EnergyPlus clone will be easier to maintain and significantly faster to run. From the standpoint of new technology models, the new architecture greatly simplifies the integration of externally developed component models and should allow manufacturers to develop their own models and incorporate them in to EnergyPlus. BTO anticipates that technology models developed this way will be distributed either as open-source or as an executable that includes embedded performance data. BTO anticipates that allowing technology models to be shared in a proprietary way will incent additional manufacturers to make models and performance data available. BTO expects that this capability will

[65] This approach is commonly used today.

[66] Based on discussions with BTO staff.

significantly shorten the time required to incorporate new technologies into EnergyPlus. Ideally, manufacturers would release new models as they release new technologies.

Table 6-4 summarizes recommended BTO actions to accelerate integration of new technology models. The first recommendation, evaluate the feasibility of a Web-based platform for publishing energy performance correlations, poses some challenges.

Table 6-4. Recommended Actions to Accelerate Integration of New Technology Models

Recommended Action
Evaluate the feasibility of a Web-based platform for publishing energy performance models for BEM tools. In addition, consider how to motivate manufacturers and other technology developers to publish detailed performance models that a) may be business-sensitive, and b) accurately reflect technology performance. If feasible, establish the platform, perhaps by enhancing BTO's Technology Performance Exchange (https://performance.nrel.gov/). Coordinate with ASHRAE 205P committee on standard representations of performance models.
Continue re-engineering effort to create an EnergyPlus clone using an external solver/integrator to facilitate rapid assimilation of models for new technologies into EnergyPlus.
Encourage commercial BEM developers that use EnergyPlus to upgrade their products promptly when BTO releases new versions of EnergyPlus to ensure that BEM users have access to the latest available technologies
Encourage commercial BEM developers that don't use EnergyPlus to develop approaches to incorporating new technology models that are best suited to their BEM tools.

6.3.2.1 Performance Metrics for Accelerating Integration of New Technology Models

Table 6-5 lists preliminary example metrics and targets for measuring and tracking the speed of integrating new technology models.

Table 6-5. Preliminary Example Metrics and Targets for Accelerating Integration of New Technology Models

Example Metrics [a]	Current Estimates	Example Targets [b]
Time lag between selected new technology launch and integration of new technology models into BEM tools (BTO determines which technologies warrant tracking; measured for each individual technology launch)	» 1 to 2 years [c]	» By 2020: 6 months after commercialization » By 2025: Simultaneous with commercialization

a) Metric: Tool or methodology by which to measure progress toward a goal. A metric may measure a proxy for (or indicator of) progress if progress toward a goal is difficult or impossible to measure directly.
b) Target: Desired value, preferably with a date, associated with a metric.
c) See examples in Section 4.1.5 above.

6.3.3 [Important] Refine BEM Tools to Increase User Productivity

Barriers Addressed: Time-consuming transfer of input data; outputs not formatted for presentation; concerns about value/cost-effectiveness; late introduction into the design process

Based on Navigant staff's experience building models with BEM software, we estimate that, depending on the final use for the model, user expectation of total modeling time, as determined by a breakdown of key modeling tasks, ranges from a couple of hours, to more than one week (see Table 6-6). This table reflects rough estimates of the time it takes for an experienced BEM user working on a medium to large sized office building with a simple, uniform geometry in eQUEST to perform each task.

The time expectation for each task varies depending on what the model will be used for—for example, an energy model used to litigate an energy savings dispute is more likely to require highly accurate model inputs, and calibration to utility data, which is time-consuming. While a metric such as "absolute accuracy per hour of BEM development" would depend strongly on building complexity and BEM user experience, it may provide an easy-to-understand basis for establishing the value proposition of BEM for the building owner.

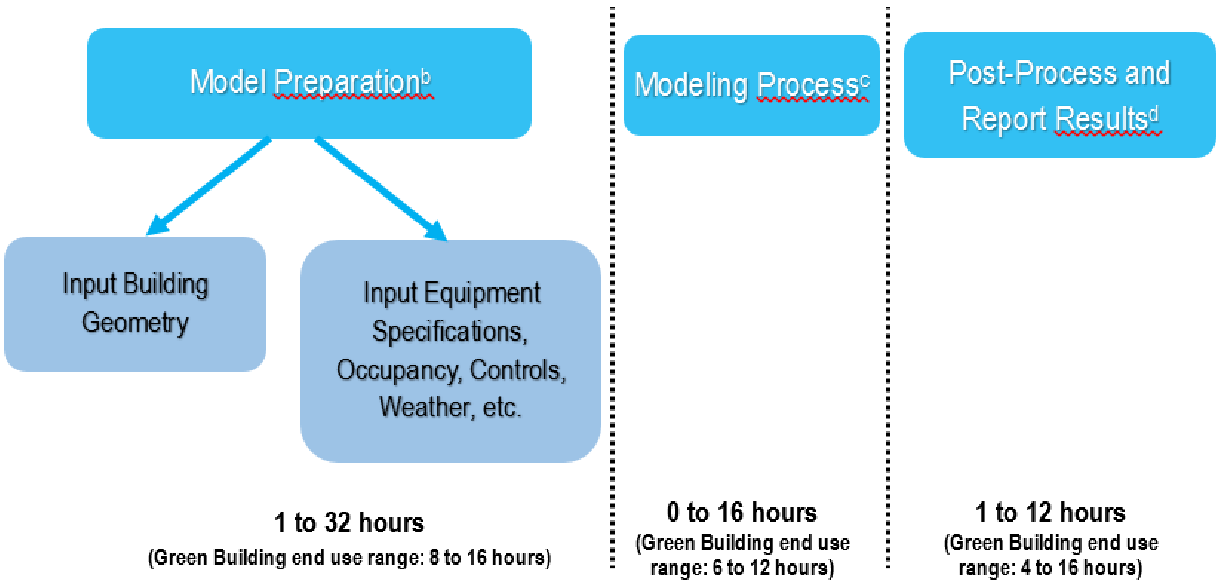
Table 6-6. User Expectations of Modeling Task Duration (Median Hours) [a, b]

Model Phase	BEM Task	Five Typical BEM End Uses: Design Concept	Energy Efficiency Program Application Submission [c]	(Green) Building Design Optimization [d]	Code Compliance	ESCO
Model Preparation [e]	Geometry Set Up Time	0.25	2	4	4	8
	Basic System Definition	0.5	2	4	2	8
	Detailed Schedules and System Operation	0.5	2	2	4	16
Modeling Process [f]	Initial Model Debug Runs	0	2	4	2	8
	Calibration / Iteration Runs	0	1	4	4	8
Post-Process and Report Results [g]	Final Runs and Results Review	0.25	2	4	2	1
	Reporting and Documentation	0.5	4	8	8	4
TOTAL		2	14	30	26	53

a) Based on a limited survey of Navigant building energy modelers, for five typical BEM uses ranging from initial design concept to detailed demonstration of Energy Service Company (ESCO) savings to fulfill contract requirements. Within each of the five BEM uses listed here, there is an expected range for each task depending on availability of information, building and equipment complexity, and BEM user skill and experience. See Figure 6-1 below for further information.
b) For a new mid- to large-sized commercial office building with simple, uniform geometry intended to exceed code minimum performance.
c) Refers to claimed savings estimates by a utility program implementer, not to energy efficiency program evaluation, which can take longer.
d) Ranges in values are due to factors such as the amount of information readily available to the BEM user. For example, how well the equipment is specified.
e) Where default or pre-built models are available and appropriate for the project, this phase may take very little effort.
f) For the purpose of this table and the related Figure 6-1 below, the model phase ''Modeling Process' includes time that the BEM user must spend editing the model inputs, and reviewing the model outputs, until the model is producing the desired outcome. Examples of desired outcomes of this phase include matching utility data within a specified level of uncertainty, or identifying and specifying efficient design options which produce the expected or desired energy and demand savings. Even for an experienced BEM user, the model may undergo substantial changes in this stage, which can be time consuming. For projects which may utilize two separate BEM comparison models such as Baseline versus Efficient case BEM models, this stage includes the time it takes to manage two separate versions of the model for the same building.
g) The level of effort required during the 'Post-Process and Report' phase depends on the intended audience for the results, and reporting requirements that may be imposed by code compliance officers, LEED, or utility-run energy efficiency program applications.

Figure 6-1 illustrates that the time required to develop and report results for a BEM model may range from a couple of hours to more than a week depending on the intended use of the model, and that a building optimization model (such as the 'Green Building Design Optimization' BEM end use in Table 6-6) may range from 18 to 44 hours for an experienced BEM user, assuming no major issues arise when gathering inputs or running the model.

Figure 6-1. Estimated Ranges for BEM Modeling Time by BEM Phase [a]



a) Based on the range of time estimates in Table 6-6 User Expectations of Modeling Task Duration, rounded to the nearest hour. Also shown in parentheses are example ranges for "Green Building Design Optimization" use. Ranges within a BEM model end use depend on availability of information, building and equipment complexity, and BEM user skill and experience.

b) Assumes experienced BEM user and no major issues arise when gathering geometry and specifications. Where default or pre-built models are available and appropriate for the project, this phase may take very little effort.

c) For the purpose of this figure and the related Table 6-6 above, the model phase 'Modeling Process' includes time that the BEM user must spend editing the model inputs, and reviewing the model outputs, until the model is producing the desired outcome. Examples of desired outcomes of this stage include matching utility data within a specified level of uncertainty, or the efficient design options producing the expected or desired energy and demand savings. Even for an experienced BEM user, the model may undergo substantial changes in this stage, which can be time consuming. For projects which may utilize two separate BEM comparison models such as Baseline versus Efficient case BEM models, this stage includes the time it takes to manage two separate versions of the model for the same building.

d) The level of effort required during the 'Post-Process and Report' phase depends on the intended audience for the results, and reporting requirements that may be imposed by code compliance officers, LEED, or utility-run energy efficiency program applications.

Approaches to reducing the time required to perform BEM analyses include:

» Simplify the data entry process – Software developers can simplify the data entry process by using wizards (*i.e.*, user-friendly on-screen dialogues) and application-appropriate input defaults.[67] At least one commonly used tool, eQUEST, uses a wizard to simplify data input, but many BEM tools do not.

» Enable automatic detection of obvious input errors associated with building geometry and materials, including errors/discrepancies imported or transcribed from computer-aided design/BIM tools used during the conceptual design stage.[68] Many of the BEM tools outlined in this Roadmap that have been publicly available for many years do not offer this functionality.[69]

[67] Defaults are values for input variables that are built into the model and that the BEM user can select if he/she does not know the appropriate value to select. Using defaults is generally more appropriate during the conceptual design stage when many design options must be evaluated quickly. However, as the design advances, few if any defaults should be used.

[68] Of course, it's best to detect geometry errors in the conceptual design stage, but best practices would suggest checking again during the detailed design stage. This approach also helps to improve absolute BEM accuracy, as outlined above.

[69] eQuest is one exception.

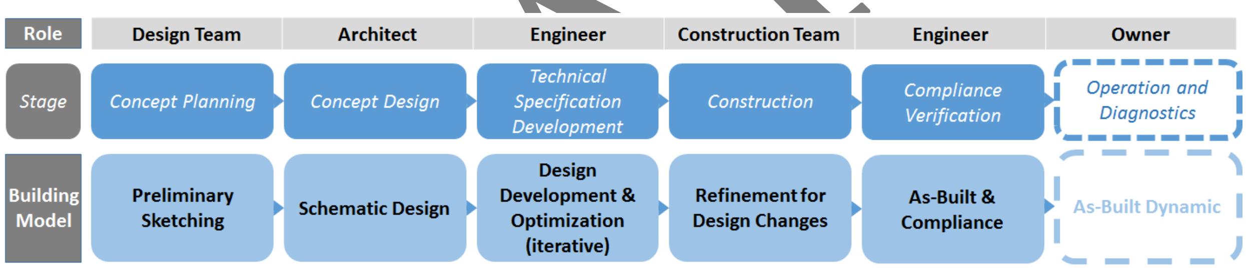
» Add presentation-ready output options – BEM users can spend significant time post-processing BEM outputs to put them in an appealing, easy-to-understand graphical format for presentation to their clients and/or their management. User-selectable options for graphical presentation of outputs could save significant time. A further improvement would be to have BEM graphical outputs in a standardized format, regardless of BEM tool.

» Eliminate the need to duplicate entry of building geometry data into architectural design tools and BEM tools. For example, for a large building where Building Information Modeling (BIM) software[70] is being used by the design team, building geometry and other details should be seamlessly transferrable between the BIM tool and the BEM tool. Updates to either building information software (BIM or BEM) should be readily accessible by all tools during all phases of the project. There are two approaches to eliminating the need to duplicate data entry:

  - Develop interoperable versions of design and BEM tools
  - Integrate design and energy analysis capabilities into a single tool.

We refer to these approaches collectively as providing a continuum of BEM tool use. Figure 6-2 shows a typical building-delivery workflow. Current BEM tools address various aspects of this workflow with different degrees of emphasis, however, few adequately address the entire workflow, resulting in inefficient use of time, and a dis-incentive to use BEM.

Figure 6-2. Example Design Build BEM Workflow



If it becomes more common to use BEM for building operation, either of the above approaches to BEM tool interoperability and integration into the building design process could be extended to include building operation. See also discussion in Section 6.3.6 regarding adding building operation capabilities to BEM.

Another approach to increasing BEM user productivity is to better align BEM tools with BEM-based building codes, certification programs, and utility incentive programs. Ideally, the same BEM tool would not only serve the design function, but also demonstrate compliance with the requirements of codes, certification programs, and utility programs. Current tools such as HAP and Trane/TRACE have built-in reporting functions that match LEED-required documentation, for example.

Under its current BEM development strategy, BTO does not develop turnkey use-specific applications (see discussion in Section 1.2.2 above). BTO can, however, encourage commercial software developers to use the approaches outlined above to refine their BEM tools to increase BEM user productivity. We recommend that BTO work with building owners to create market pull for these changes.

[70] For example, Autodesk BIM, http://www.autodesk.com/solutions/building-information-modeling/overview

BTO reports an important and recent development in the area of BEM user productivity—the introduction and rapid maturation of OpenStudio measures (*i.e.*, scripts that automate specific modeling tasks), such as:

» Applying an energy conservation measure to an OpenStudio model

» Querying a model to perform a quality assurance check

» Querying simulation results to create a custom report.[71]

BTO reports that OpenStudio measures are quickly improving productivity and workflow automation. BTO anticipates future developments to allow BEM users to create custom tools and workflows rather than rely on software developers to do it.

Table 6-7 summarizes recommended BTO actions to encourage BEM refinements that increase BEM user productivity.

Table 6-7. Recommended Actions to Encourage BEM Refinements that Increase User Productivity

Recommended Action
Create market pull to refine BEM for increased user productivity. While there are multiple ways to accomplish this, we recommend that BTO evaluate this approach: » Assemble a working group of stakeholders (building owners, architects, and design engineers) to outline targets (target time requirements, target elapsed time, etc.) » Translate targets into an abbreviated functional requirements document for BIM/BEM tools » Challenge commercial software developers to deliver tools that conform to this document.

6.3.3.1 Performance Metrics for Increasing User Productivity through BEM Tool Refinement

Table 6-8 lists preliminary example metrics (one qualitative and one quantitative) and targets for measuring and tracking BEM refinements that increase BEM user productivity.

Table 6-8. Preliminary Example Metrics and Targets for BEM Refinements that Increase User Productivity

Example Metrics [a]	Current Estimates	Example Targets [b]
End-user satisfaction surveys conducted by AIA, IBPSA, or other trade association	Not Available	Targets will depend on survey design
Hours to complete a specified building design simulation (using experienced BEM users)	44 hours [c]	22 hours [d]

a) Metric: Tool or methodology by which to measure progress toward a goal. A metric may measure a proxy for (or indicator of) progress if progress toward a goal is difficult or impossible to measure directly.
b) Target: Desired value, preferably with a date, associated with a metric.
c) Derived from Figure 6-2 above. For hours to complete a simulation project, the 'Current Estimate' column is based on an estimate of the time it currently takes a typical BEM user, using available BEM tools, to complete a complex Green Building Optimization project using BEM.
d) This example target is intended to reflect a relative target such as half the time it currently takes a typical BEM user to complete a complex Green Building Optimization project using BEM. The intent is that the BEM tool would be modified to enable the user to complete the entire project more quickly, in half the time it previously took.

[71] Discussions with DOE/BTO.

6.3.4 [Supportive] Add Capability to Evaluate Water Consumption

While the analysis of many building water end uses does not require detailed modeling, several water end uses are coupled to other building components and systems. BEM tools could be adapted to model water consumptions for these end uses. They include:

- HVAC-related systems (cooling towers, evaporatively cooled condensers, evaporative coolers (for space cooling), humidifiers, and steam boiler blowdown)
- Irrigation for green roofs (used to lower space-heating and cooling loads).

While they can be estimated without the benefit of BEM, it would be convenient if BEM tools also accounted for other common water uses in buildings, including:

- Irrigation for landscaping
- Rainwater catchment systems (which reduce water consumption).

As noted in Section 4.3.1 above, EnergyPlus currently calculates water consumption for cooling towers and green roofs, and accounts for the impacts of the green roof on building cooling load.

6.3.5 [Supportive] Accommodate Urban-Scale Analyses

Table 6-9 outlines BEM enhancements that would facilitate urban-scale analyses.

Table 6-9. Recommended BEM Enhancements to Facilitate Urban-Scale Analyses

Recommended BEM Enhancements to Facilitate Urban-Scale Analyses
Facilitated interface ("wizard") for calibration to utility data, including pooled utility data characterized by sector
Improved modeling of inter-building phenomena including shading, long-wave radiation, shared ground-field effects, heat island effects, and airflow and urban canyon effects
Improved modeling of multi-building systems including district heating/cooling (chilled water, hot water and steam), and microgrids (including combined heat and power)
Improved multi-resolution modeling so that not every building must be modeled in maximum detail all the time
Improved capabilities to couple building energy models to other models of interest, *e.g.*, grid models, traffic models, land-use models, *etc.*

6.3.6 [Supportive] Add Capabilities to Support Building Operation

Automation of building operation and control is currently most often accomplished using a Building Automation System (BAS). Most state-of-the-art BASs use simple, rule-based algorithms to operate building systems. Many stakeholders suggest that building operation could benefit from a predictive, optimization-based approach that incorporates both information about current building conditions as well as predictions for upcoming building use, weather, and grid conditions. Some stakeholders suggest that the predictive, and ultimately prescriptive function should be performed by a BEM engine, *i.e.*, BEM should be used to integrate these predictions and evaluate operation scenarios and responses. Other stakeholders maintain that full BEM is not necessary and that simpler, reduced-order models (sometimes called "black-box" or "data-driven" models) are sufficient for these applications. A third set believes that a hybrid approach that combines a detailed model of the systems under control with a reduced-order model of the building and its loads would work best. BEM-enhanced building operation is still in its early stages. Researchers and companies are evaluating these approaches, their relative strengths and weaknesses, and their target niches.

Table 6-10 summarizes recommended actions to improve BEM capabilities that support building operation.

Table 6-10. Recommended Actions to Evaluate and Enhance Operation Capabilities

Recommended Action
Investigate whether and how BEM tools could be enhanced to: » Model real-world control schemes and sequences, preferably represented in their "native" implementation languages like C, Python, or Modelica » Model faulty and degraded equipment » Integrate values from sensors and control-input status from Building Automation Systems (BAS) » Support evaluation of multiple control alternatives with a latency that is appropriate to the control time scale » Incorporate learning algorithms that calibrate the building model based on actual operating experience to more accurately simulate energy consumption, electric demand, and operational needs

6.3.7 [Supportive] Estimate Regionally Specific Carbon Emissions

Table 6-11 summarizes BEM enhancements that would facilitate estimating regionally specific carbon emissions.

Table 6-11. Recommended BEM Enhancements to Facilitate Carbon Emissions Estimates

Recommended Enhancements
Estimate carbon emissions from electricity consumption using regionally specific carbon emission factors for electric generation, transmission, and distribution
Estimate regionally specific, carbon-equivalent emissions impacts from leakage in the natural gas infrastructure, including the infrastructure supplying a) electric generation plants, and b) buildings
Estimate carbon emissions from building-site combustion of fossil fuels
Estimate equipment-specific, carbon-equivalent emissions from HVAC and refrigeration equipment

6.4 Technology Initiatives Specific to BTO's EnergyPlus and OpenStudio

This section covers technology initiatives that are specific to BTO's EnergyPlus and OpenStudio. Section 6.3 addresses technology initiatives that apply generally to BEM tools.

6.4.1 [Essential] Establish Ongoing Collaborative Process for Assessing Needs of Commercial Software Developers

Barrier Addressed: Lack of developer friendliness

BTO's strategy for BEM development is to support commercial software developers by providing and maintaining a free, open-source engine (EnergyPlus) and free, open-source SDK (OpenStudio). As Section 4 discusses, some commercial software developers indicate that BTO's EnergyPlus and OpenStudio are not as "developer friendly" as they could be. However, desired features may vary from developer to developer, and developer desires will not always align with BTO's mission, for example, some developers may wish to use EnergyPlus but not use OpenStudio, whereas BTO built OpenStudio to mitigate known developer challenges associated with using EnergyPlus directly. While there is no easy solution, both BTO and developers need to understand each other's perspectives for the partnership to work effectively. This is best accomplished through a structured, ongoing dialogue between developers and BTO.

BTO could hold annual stakeholder meetings specifically devoted to both EnergyPlus and OpenStudio development needs. BTO could also gather information in advance to accelerate information exchange and research key topics in advance as needed.

Table 6-12 summarizes recommended BTO actions to capitalize on existing DOE/industry partnerships and help ensure that new partnerships are fruitful. Table 6-13 lists initial stakeholder suggestions for improving the "developer friendliness" of EnergyPlus, which can inform the recommended actions outlined in Table 6-13.

Table 6-12. Recommended Actions to Promote Information Exchange between BTO and Software Developers

Recommended Actions
Invite software developers and other stakeholders to submit written recommendations for future enhancements to EnergyPlus and OpenStudio, perhaps through a Request for Information or BTO's UserVoice service[a]
Establish annual stakeholder meeting specifically to discuss EnergyPlus and OpenStudio development needs

a) See beta site for UserVoice at http://energyplus.uservoice.com/forums/258860-energyplus

Table 6-13. Stakeholder Suggestions for Improving EnergyPlus "Developer Friendliness"

Opportunities for Improving EnergyPlus "Developer Friendliness"
Adopt semantic versioning to simplify and clarify backward compatibility rules across version updates [a]
Transition to a key-value pair input schema and format (e.g., JavaScript Object Notation) to simplify the version update process [a]
Provide consistency in diagnostic messaging for easier handling of bulk errors by automated processes [a]
Develop an Application Program Interface (API) for easier integration [a]
Adopt a dynamic library architecture for reduced software footprints [a]
Enable developers and users to trade off speed for detail in a straightforward high-level way [a]
Provide support for "localization" [a]
Provide support for units conversion (OpenStudio has this, EnergyPlus does not) [a]
Develop a more intuitive method of accessing the many reports available from EnergyPlus [b]

a) Generated by one of the breakout groups at the West Coast BEM workshop
b) Recommended by a software developer working directly with the EnergyPlus engine.

6.5 Enabling Initiatives

This section covers enabling initiatives, *i.e.*, initiatives beyond software development that enable increased use of BEM.

6.5.1 [Essential] Establish Clear BEM Value Proposition

Barrier Addressed: Concerns about value/cost-effectiveness

Many building owners, building operators, architects, and engineers are not convinced that BEM consistently adds value commensurate with its costs when it's not required for code compliance, green building certification, or utility incentive program. Addressing this barrier requires (among other things) having a clear value proposition for BEM, which requires:

- Developing and documenting compelling evidence that BEM leads to robust energy savings
- Identifying the highest-value applications for BEM, and how to best leverage BEM for building design and operation
- The value of BEM would be further enhanced by demonstrating and validating the absolute accuracy of BEM (improving absolute accuracy is addressed in Section 6.3.1 above and Section 6.5.3 below)

While BEM can generally facilitate significant cost-effective energy savings in building design, retrofit, and operation, savings are not uniform across all applications. For example, complex, special-purpose designs such as laboratories and hospitals are difficult to design for energy efficiency without the benefit of BEM. At the other end of the spectrum, building designs that will be used multiple times in similar climate regions can achieve great leverage from a BEM analysis because one doesn't need to repeat the analysis for each building. Perhaps the most important consideration is the owner's or builder's willingness to invest to achieve significant energy savings relative to minimum code requirements. For most building types, BEM analysis is not currently necessary to achieve minimum code requirements. That could change as building codes become more stringent.

The question of attributing energy and demand savings to BEM has not been adequately studied. It is difficult to isolate the savings attributable to BEM because there is no building design or operation that is identical, except for the use of BEM, against which to compare results. That is, it's a counterfactual analysis. Metrics known as 'free ridership' and 'spillover' are measured by scoring formal survey batteries of multiple decision makers interviewed. A multiplier to be applied to the 'apparent' impact savings of the project is thereby developed. In the case of BEM, the 'apparent' savings is simply the difference between the less efficient, and the more efficient BEM models. Please see Appendix D for more details on attribution analysis in energy efficiency programs.

Table 6-14 summarizes recommended actions to address these needs. The recommendations include establishing the highest-value applications for BEM.

Table 6-14. Recommended Actions to Establish a Clear Value Proposition

Recommended Action
Develop and document compelling evidence that BEM leads to robust energy savings by publishing case studies for various building types and climates that: » Document the costs (labor hours and elapsed time) associated with BEM » Describe how BEM facilitated the various energy-saving features » Show that expected energy savings were achieved during operation, [a] and quantify the savings directly attributable to the BEM tool and BEM modeling process If used for building operation, show that BEM helps lower operational energy use persistently over the study period while maintaining a comfortable and healthy environment.
Quantify the energy savings that are directly attributable to BEM tools, independent of the influences of other factors such as design intent and prior experience [b]
Identify highest-value-added applications for BEM, including applications where: » The energy analysis of a single design can be leveraged across a multitude of buildings » Annual energy costs are relatively high » There is enough design flexibility to take advantage of key energy-saving design features
Demonstrate absolute accuracy by: » Identifying appropriate working 'Validation Buildings' to evaluate the absolute accuracy of BEM tools » Continuing supporting development of ASHRAE standards for BEM validation, including identification of variables that shall be accurately represented in building model calibrations
Enable rapid inclusion of existing building information and control strategies, and new technologies, into BEM tools

a) Some documentation already exists, but it is not sufficient. See, for example: Lovins, Amory, and Rocky Mountain Institute. *Reinventing Fire: Bold Business Solutions for the New Energy Era*. October 15, 2011. http://www.rmi.org/reinventingfire

b) Appendix D outlines a suggested attribution approach that DOE could use, based on methods used for utility energy efficiency program attribution for regulatory compliance.

6.5.2 [Important] Increase Awareness of BEM

Barrier Addressed: Concerns about value/cost-effectiveness

Once BTO establishes a clear value proposition (see Section 6.5.1 above), we recommend that BTO continue to raise awareness of BEM through the actions summarized in Table 6-15.

Table 6-15. Recommended Actions to Increase Awareness of BEM

Recommended Action
Raise awareness of, and promote, the value of BEM through: » Website publication of the value proposition and supporting reports/analyses » Articles in BEM-related trade journals, including ASHRAE » Presentations at BEM-related conferences, including ASHRAE » Other promotional activities conducted in partnership with the International Building Performance Simulation Association (IBPSA).

6.5.3 [Essential] Improve Absolute BEM Accuracy through Better Training and Design/Operational Knowledge

Barrier Addressed: BEM simulation of energy consumption can vary significantly from measured consumption

Section 6.3.1 above describes software-related approaches to improving the absolute accuracy of BEM. Non-software-related approaches include:

- » Improve training and/or certifying BEM users to reduce input errors [medium impact anticipated]
- » Enhance data-gathering and construction documentation practices [large impact anticipated]:
  - o Improve the quality of input data available to BEM users
  - o Ensure that energy features of design, including HVAC control sequences, are captured in the design and construction documents
  - o Reduce unintentional departures from building design during construction
  - o Ensure that the building systems operate as the designers intended

Stakeholders suggest that input errors are relatively common. Therefore, we anticipate that reducing input errors through improved training and certification will have a medium impact on absolute accuracy of BEM. Stakeholders also report substantial variations between design intent and as-built. Further, stakeholders report that building use and occupant behavior often deviate from the assumptions made during the design phase, and that these deviations typically have significant impacts on building energy consumption. Therefore, we anticipate large impacts on BEM predictive capabilities associated with both of these approaches.

Table 6-16 summarizes recommended BTO actions to address these opportunities.

Table 6-16. Recommended Actions to Improve Absolute BEM Accuracy (Non-Software-Related)

Recommended Action
Collaborate with industry stakeholders to identify improvement opportunities: » Promotion of Training/Certification Programs—approach training institutions such as ASHRAE (Building Energy Modeling Professional certification) and the Association of Energy Engineers (Building Energy Simulation Analyst™) » Commissioning—approach ASHRAE, Building Commissioning Association regarding how carry-through of design intent to the as-built building can be improved

6.6 Key Program Metrics and R&D Targets

In addition to assessing the effectiveness of supporting initiatives, BTO seeks effective methods to assess progress toward their goal of widespread use of BEM (50% of gross square feet of new buildings and deep energy retrofits), achieving 20% reduction in design EUI over prescriptive design by 2020.[72]

It is appropriate for BTO to base a goal on increased use of BEM because increased use of BEM is both measurable and within BTO's sphere of influence. The weakness of this goal is that it's not directly linked to energy savings because the energy savings from BEM can be highly variable. The most important example of this (discussed in Section 3.4 above) is that most BEM is currently performed after the building design is complete (simply to demonstrate code compliance or to obtain green building certification) —too late to inform the building design and influence its energy efficiency. We anticipate that the initiatives outlined above will help change this situation and dramatically increase the use of

[72] BTO 2015 Multi-Year Program Plan http://energy.gov/eere/buildings/downloads/draft-multi-year-program-plan

BEM to guide design decisions. Therefore, over time, measuring the increased use of BEM will correlate more directly to energy savings than it does today.

Through the stakeholder feedback process, Navigant solicited from stakeholders suggested metrics for measuring progress toward BTO goals (see Appendix E). Table 6-17 summarizes example metrics and targets inspired by these stakeholder inputs. We recommend that BTO develop and vet these further before adoption (see Table 6-18).

Table 6-17. Preliminary Examples of Metrics and Targets for Growth in use of BEM

Example Metrics [a]	Estimated Current Penetration	Example Targets [b]
Fraction of building floor space using BEM to guide operation	~0%	» By 2020: 3% » By 2025: 10%
Fraction of U.S. having BEM-based compliance alternatives in building energy codes [c]	~0%	» By 2020: 10% » By 2025: 20%
Fraction of commercial new construction floor space that is LEED-certified annually	~???%	» By 2020: 10% » By 2030: 20%
AIA 2030 commitment reporting—fraction of floor space modeled	~57% [d]	» By 2020: 70% » By 2025: 80%

a) Metric: Tool or methodology by which to measure progress toward a goal. A metric may measure a proxy for (or indicator of) progress if progress toward a goal is difficult or impossible to measure directly.
b) Target: Desired value, preferably with a date, associated with a metric.
c) Weighted based on population of the jurisdictions having such codes
d) http://www.aia.org/aiaucmp/groups/aia/documents/pdf/aiab100374.pdf

Table 6-18. Recommended Actions to Develop Program Metrics and Targets

Recommended Action	Key Issues/Questions
Develop definition for "modeled floor space"	» Outline how to count floor space modeled: ○ If a single BEM evaluation is applied to a multitude of buildings having nearly identical geometries that are constructed in the same climate zone, should BTO count the total floor space constructed? ○ If a building is modeled, but the results do not substantively inform the building design, should BTO count it?
Evaluate example metrics listed in Table 6-17	» How measurable is the metric? » How representative of growth is the metric?

6.7 Summary

We developed this BEM roadmap through soliciting stakeholder input, reviewing recent BEM literature, and technical analysis. Four interrelated central themes emerged that will enable BEM tools to support the design and operation of energy efficient buildings in the U.S. and reduce energy use in U.S. commercial and residential buildings:

1. ***There Is a Need to Establish and Promote a Clear Value Proposition for BEM***

2. *There Are Opportunities to Increase the Value of BEM*
3. *There Are Opportunities to Lower the Cost Impacts of BEM*
4. *There Are Opportunities to Grow and Expand the Applications of BEM*

The BEM roadmap process identified and prioritized eleven initiatives to increase the use of BEM (summarized in Table 6-19, Table 6-20, and Table 6-21 for essential, important, and supportive initiatives, respectively).

In addition to the eleven initiatives, the BEM roadmap process generated a set of four preliminary metrics and suggested targets that DOE could use to track growth in BEM use (see Table 6-17 above).

Table 6-19. Summary of BEM Essential Initiatives (3 Initiatives)

Initiative	Recommended Action	Reference Sections
Improve Absolute BEM Accuracy through Better Training and Design/Operational Knowledge	Collaborate with industry stakeholders to identify improvement opportunities: » Promotion of Training/Certification Programs » Commissioning	6.5.3
Establish a Clear BEM Value Proposition	Develop and document compelling evidence that BEM leads to robust energy savings For building operation, show that BEM helps lower operational energy use Quantify the energy savings that are directly attributable to BEM Identify highest-value-added applications for BEM Demonstrate absolute BEM accuracy Enable rapid inclusion of existing building information and new technologies into BEM tools	6.5.1
Establish Ongoing Process for Assessing the Needs of Commercial Software Developers	Invite software developers and other stakeholders to submit written recommendations for future enhancements to EnergyPlus and OpenStudio Establish annual stakeholder meeting specifically to discuss EnergyPlus and OpenStudio development needs	6.4.1

Table 6-20. Summary of BEM Important Initiatives (4 Initiatives)[a]

Initiative	Recommended Action	Example Metrics	Example Targets	Reference Sections
Improve Absolute BEM Accuracy Through BEM Software Enhancements	Following the procedures in ASHRAE Standard 140, evaluate the absolute accuracy of a range of BEM tools using laboratory environments as well as the real-world building validation Support improvement in automated input-error detection by providing real world test buildings to help define ranges of expected model inputs	» Simulated annual EUIs vs. measured annual EUIs measured in purpose-built laboratories » Simulated vs. measured annual EUIs for selected buildings	» By 2020: ±15% for whole building ±10% for major subsystems » By 2025: ±10% for whole building ±7% for major subsystems	6.3.1
Accelerate Integration of New Technology Models into BEM	Partner with manufacturers, BEM tool developers, and standards developers (ASHRAE 205P) to: » Publish detailed performance models for new technology » Standardize representations of technology performance models » Facilitate rapid assimilation of models for new technologies into EnergyPlus (and other BEM tools)	Time lag between selected new technology launch and integration of new technology models into BEM tools (BTO determines which technologies warrant tracking; measured for each individual technology launch)	» By 2020: 6 months after commercialization » By 2025: Simultaneous with commercialization	6.3.2
Refine BEM to Increase Modeler Productivity	Create market pull to refine BEM for increased modeler productivity by partnering with stakeholders to: » Identify BEM user expectations » Translate expectations into abbreviated functional requirements for use by commercial software developers in BIM/BEM tool development.	» End-user satisfaction surveys conducted by AIA, IBPSA, or other trade association » Hours to complete a specified building design simulation (using experienced BEM users)	» Targets will depend on survey design » 8 to 12 hours	6.3.3
Increase Awareness of BEM	Raise awareness of, and promote, the value of BEM through a variety of outreach mechanisms including online outreach, trade journal articles, and partnership with International Building Performance Simulation Association (IBPSA)			6.5.2

(a) Example metrics and targets are provided for selected initiatives.

Table 6-21. Summary of BEM Supportive Initiatives (4 Initiatives)

Initiative	Recommended Action	Reference Sections
Add Capability to Evaluate Water Consumption	Adapt BEM tools to model water consumption for HVAC, irrigation, and rainwater catchment end uses	6.3.4
Add Operational and Fault Detection/Diagnostic Capabilities	Evaluate BEM-based versus heuristic approaches to building operation and fault detection/diagnostics to determine when BEM-based approaches are attractive, and then enhance BEM tools to handle real-world faults, control schemes, and diagnostic signals	6.3.6
Accommodate Urban-Scale Analyses	Develop a facilitated interface ("wizard") for calibration to utility data for large datasets Improve modeling of inter-building phenomena and multi-building systems including district heating/cooling, and microgrids (including combined heat and power) Improve multi-resolution modeling so that not every building must be modeled in maximum detail Improve capabilities to couple building energy models to other models of interest, e.g., grid models, traffic models, land-use models, etc.	6.3.5
Enhance BEM to Facilitate Estimating Regionally Specific Carbon Emissions	Estimate carbon emissions from electricity consumption, and building-site combustion of fossil fuels, using regionally specific carbon emission factors for electric generation, transmission, and distribution Estimate carbon-equivalent emissions impacts from leakage in the natural gas infrastructure	6.3.7

Appendix A. West Coast Workshop Summary (6-9-2015)

U.S. Department of Energy's Research and Development Roadmap for Building Energy Modeling

Stakeholder Discussion Workshop Summary – Battelle, Pacific Northwest National Laboratory (PNNL), Seattle, WA

June 9, 2015 (Seattle, Washington)

A.1 Summary

On June 9, 2015, Navigant Consulting, Inc., on behalf of the U.S. Department of Energy's (DOE) Building Technologies Office (BTO), hosted a stakeholder discussion workshop to identify research and development (R&D) needs and critical knowledge gaps related to increasing the use of whole building energy modeling (BEM) tools. This workshop covered expanding the use of BEM tools and improving their functionality. Discussion focused on issues pertaining to BEM tools in general, as well as BTO's EnergyPlus and OpenStudio. BTO is the office through which DOE funds research to support emerging building technologies, with the aim of reducing total building-related energy consumption by 50% by the year 2030

BTO hosted the workshop at PNNL's Battelle facility in Seattle, Washington. Seventeen stakeholders participated, including university researchers, national laboratories, manufacturers, software developers, and representatives from industry organizations. A list of attendees and their affiliations is included at the end of this Appendix.

A.2 Objective

The objectives of this workshop were:

- Identify current challenges for developers and users.
- Find ways to significantly increase the impact of BEM in the design and operation of energy efficient buildings, and in support of related activities such as code compliance and utility energy efficiency programs.
- Establish and prioritize areas of research that will aid in the increased use of BEM.

A.3 Process and Results

Discussions at the workshop included a large group brainstorming session as well as smaller breakout group sessions. Each attendee participated in one of two breakout sessions. During the West Coast workshop, attendees could choose from the following topic areas:

- Codes and BEM: Relationship and Strategies
- Developer Friendliness[73]

[73] The terminology used in the workshop for this breakout group was 'vendor friendliness', however Navigant adopted the term 'developer friendliness' for the roadmap based on feedback from stakeholders.

The group brainstorming and breakout sessions together generated numerous R&D activities for BTO to consider (hereafter "initiatives"). At the conclusion of the workshops, Navigant posted all of the initiatives on the wall and asked the participants to prioritize the initiatives by voting on the ones that they felt were most valuable and promising for BTO to undertake. Each participant received 5 votes (stickers) to distribute among the different initiatives as they saw fit (regardless of topic area). Table A-1 shows the proposed initiatives.

Table A-1. High Priority R&D Initiatives

Session	Initiative	Votes
Codes/BEM Breakout Group	Establish an example software tool ruleset that a state or local government could adopt and modify to reflect the specific performance thresholds in its code	7
Codes/BEM Breakout Group	Establish a general framework for software tool rulesets that a state/local government could use to develop and encode its own ruleset	4
Codes/BEM Breakout Group	Develop a staged strategy that a state and local government could follow to gradually increase the use of performance-based compliance paths in its codes.	6
Developer friendliness	Facilitate adoption of new releases by simplifying the IDF converters that ship with new releases of EnergyPlus and improving backward compatibility of new versions of EnergyPlus "automatic updating"	4
Developer friendliness	Address developer needs by making available better coverage of HVAC systems, improve formatting of diagnostic messages, to handle in bulk by automated processes, the ability to compile EnergyPlus, and implement Units Conversion	10
Developer friendliness	Researcher needs; modularity, ability to dial in different levels of detail, better quality inputs, transparency of equipment performance curves	19
Developer friendliness	Execution time, features, complexity; reduce redundancies in code, improve usability, upfront diagnostics, create better integration of data on top of engine, for example from BMS	7
Developer friendliness	Limitations of intelligent defaults; outsource to ASHRAE, transparency vs. simplicity: defaults should run without crashing	3
Developer friendliness	Adequacy of EnergyPlus architecture; reduce footprint of software; improve API with pluggable architecture	9

Table A-2 shows the list of key challenges and barriers to increasing the effective use of BEMs in the design and operation of energy efficient buildings, and in support of activities and programs, as identified by stakeholders.

Table A-2. Challenges and Barriers for use of BEMs

Challenges and Barriers
Code-driven rulesets don't reflect actual performance
Designs can be inherently inefficient, yet BEM user is perceived to be in error
Prescriptive paths to compliance are becoming more stringent—prescriptive paths are no longer a viable option for many buildings
BEM needs to keep up with technologies
Tough to qualify for incentives if using a prescriptive design
TMY weather data set used can have big impact on results—can be issue for buildings on the border of climate regions
Everyone's intelligent defaults are different

The following tables in sections below document each proposed R&D initiative; these tables reflect the raw outputs of the workshop. The tables, therefore, do not perfectly reflect a single category of initiatives, but rather, documentation of the conversations that transpired during the session. The ideas from the workshop are divided by the breakout session where they arose.

A.4 Summary of Building Codes Breakout

State and local governments establish residential and commercial building energy codes, often adopting provisions in the International Energy Conservation Code (IECC), ASHRAE Standard 90.1, or other industry standards. While most building codes provide prescriptive paths for code compliance, a state or local government can also establish alternative performance-based paths that require Building Energy Modeling (BEM) to demonstrate compliance. Performance-based paths offer greater design flexibility to building owners and designers, allowing them to trade off the cost and performance characteristics for a multitude of building components and systems. This increased design flexibility can help overcome stakeholder resistance to adoption of stricter energy codes, accelerating the rate at which state and local governments can drive code-enabled energy savings. Codes that offer performance-based paths generally include, or require the development of, computer-processable forms of a code's energy-related requirements known as rulesets.

This breakout group outlined three options that BTO could pursue to facilitate expanded use of BEM to meet code requirements. These options either a) make it easier for state and local governments to adopt codes that incorporate performance-based alternatives, or b) make it easier to develop user-friendly BEM tools that can be used to demonstrate code compliance.

- ***Option 1:*** Establish an example software tool ruleset that a state or local government could adopt and modify to reflect the specific performance thresholds in its code
- ***Option 2:*** Establish a general framework for software tool rulesets that a state/local government could use to develop and encode its own ruleset
- ***Option 3:*** Develop a staged strategy that a state and local government could follow to gradually increase the use of performance-based compliance paths in its codes. A state and local government that elects to implement the strategy would introduce minimal BEM requirements in early years, then gradually increase requirements over time. This approach would ease the transition to performance-based compliance paths by allowing building designers and modelers to gradually develop the skills and processes needed.

Table A-1. R&D Codes and BEM: Relationship and Strategies

Initiative
Establish an example software tool ruleset that a state or local government could adopt and modify to reflect the specific performance thresholds in its code
Establish a general framework for software tool rulesets that a state/local government could use to develop and encode its own ruleset
For compliance, make BEM minimal to start, then increase over time toward 100% BEM-based compliance
Performance-based codes and LEED are driving BEM use—use the trend toward performance-based codes to increase BEM use » M&V required in Sweden » Seattle is considering M&V requirements » it is tough to qualify for utility program incentives using a prescriptive building design—use performance compliance paths to qualify for incentives

A.5 Summary of Developer Friendliness Breakout

Table A-2. R&D Developer Friendliness

Initiative
Facilitate adoption of new releases » simplify the IDF converters that ship with new releases of EnergyPlus » improve backward compatibility of new versions of EnergyPlus (so that developers tools that use prior versions will still operate with the new release of EnergyPlus) - "automatic updating"
Developer needs » make available better coverage of HVAC systems (*i.e.*, steam humidifiers) » improve formatting of diagnostic messages, particularly so they can better be handled in bulk by automated processes » some developers want the ability to compile EnergyPlus » implement Units Conversion--support for localization (OpenStudio has it; EnergyPlus does not have it)
Researcher needs » modularity » ability to dial in different levels of detail (tradeoff with uncertainty) » better quality inputs (this refers to more choice of defaults) » transparency of equipment performance curves
Execution time, features, complexity » reduce redundancies in code » improve usability, upfront diagnostics » create better integration of data on top of engine, for example from BMS
Limitations of intelligent defaults » outsource to ASHRAE » transparency vs. simplicity: defaults should run without crashing
EnergyPlus architecture adequate? » API/pluggable architecture is desirable » software is perceived to have a large footprint "inadequate"
Improve outreach to ensure no surprises about new releases of EnergyPlus » Should BTO own the engine?
Obtain bug fixes using "GitHub"
Develop Energy Management System improvements using » FMI » Modelica » Python
Establish share-ability across engines
Enable portfolio level analyses
Enable analysis of district energy systems
Enable richer set of outputs such as utility demand response
Establish Open Office question and answer sessions
Enable more information available during sizing runs
Enable the software to anticipate user intent
Enable data integration and expert models on top of engine » Pre-simulated runs, sanity checking » Multi-core parallelized analysis

A.6 Summary of Group Brainstorm Session

Table A-3. R&D Initiatives from the Group Brainstorm Session

Group Brainstorm – 7 Total Initiatives	
BEM support for commissioning and operation	2
Identify and understand impactful use of BEM	1
Characterize and drive down all sources of uncertainty	1
Improve communication of results to client	1
Link design and operation	1
Model existing buildings with operational faults	1
Model occupant behavior	1

A.7 Next Steps

Navigant, in consultation with BTO, will continue to refine and develop these R&D initiatives though additional research and follow-up interviews with individual stakeholders. Navigant will combine any duplicate or overlapping initiatives to ensure that all initiatives are unique. We will use a combination of qualitative criteria and stakeholder voting in developing final recommendations of the top R&D initiatives for BTO to consider. The opportunity assessment will serve as a guide for BTO and its partners on how best to increase the use and effective use of BEM.

A.8 Workshop Attendees

The stakeholder discussion workshop brought together 17 individuals representing a range of organizations across the industry. Table A-4 lists all the attendees and their affiliations.

Table A-4. Stakeholder Workshop Attendee List

Attendee Name	Organization
Jim McNeill	Affiliated Engineers
Peter Alspach	Arup
Krishnan Gowri	Autodesk
Brian Owens	CLEAResult
Richard See	Digital Alchemy
Amir Roth	BTO
Taylor Roberts	Group 14 Engineering
Tianzhen Hong	Lawrence Berkeley National Laboratory
Michael Wetter	Lawrence Berkeley National Laboratory
Philip Haves	Lawrence Berkeley National Laboratory
Mark Nieman	McKinstry Co.
Scott Horowitz	National Renewable Energy Laboratory
Emily Cross	Navigant Consulting, Inc.

Attendee Name	Organization
Robert Zogg	Navigant Consulting, Inc.
Dimitri Contoyannis	NORESCO
Michael Rosenberg	Pacific Northwest National Laboratory
Scott Criswell	Wrightsoft Corp.

Appendix B. East Coast Workshop Summary (6-15-2015)

U.S. Department of Energy's Research and Development Roadmap for Building Energy Modeling

Stakeholder Discussion Workshop Summary – Navigant Offices, Washington D.C.
June 15, 2015 (Washington D.C.)

B.1 Summary

On June 15, 2015, Navigant Consulting, Inc., on behalf of the U.S. Department of Energy's (DOE) Building Technologies Office (BTO), hosted a stakeholder discussion workshop to identify research and development (R&D) needs and critical knowledge gaps related to increasing the use of whole building energy modeling (BEM) tools. This workshop covered expanding the use of BEM tools and improving their functionality. Discussion focused on issues pertaining to BEM tools in general, as well as BTO's EnergyPlus and OpenStudio. BTO is the office through which DOE funds research to support emerging building technologies, with the aim of reducing total building-related energy consumption by 50% by the year 2030

BTO hosted the workshop at Navigant's offices in Washington, D.C. Twenty-eight stakeholders participated, including university researchers, national laboratories, manufacturers, software developers, and representatives from industry organizations. A list of attendees and their affiliations is included at the end of this Appendix.

B.2 Objective

The objectives of this workshop were:

» Identify current challenges for developers and users.

» Find ways to significantly increase the impact of BEM in the design and operation of energy efficient buildings, and in support of related activities such as code compliance and utility energy efficiency programs.

» Establish and prioritize areas of research that will aid in the increased use of BEM.

B.3 Process and Results

Discussions at the workshop included a large group brainstorming session as well as smaller breakout group sessions. Each attendee participated in one of two breakout sessions. During the East Coast discussion session, attendees could choose from the following topic areas:

» Role of BEM in Building Operation

» BEM to Support Utility Efficiency Programs

The group brainstorming and breakout sessions together generated numerous R&D activities for BTO to consider (hereafter "initiatives"). At the conclusion of the workshops, Navigant posted all of the initiatives on the wall and asked the participants to prioritize the initiatives by voting on the ones that they felt were most valuable and promising for BTO to undertake. Each participant received 5 votes (stickers) to distribute among the different initiatives as they saw fit (regardless of topic area). Table B-1 shows the proposed initiatives.

Table B-1. High Priority R&D Initiatives

Session		
Role of BEM in Building Operation	1. Existing Buildings: no existing model from the design phase—may need to develop from scratch, use reference buildings, use a simpler model than used for building design, use Google Earth and match building to reference building (relates to Initiative 6 below)	8
Role of BEM in Building Operation	2. For New Construction: Need streamlined modeling process from conceptual design through building operation, supporting data standards, contractual requirements to enforce (relates to Initiative 7 below)	19
Role of BEM in Building Operation	3. Demonstrate that it Works: show that it is cost-effective, show that it saves energy/energy costs (supported by Initiative 12 below)	11
Role of BEM in Building Operation	5. Standardize Process/Procedures for Energy Monitoring: define faults, define allowable bounds—measured vs. simulated	10
BEM to Support Utility Efficiency Programs	6. Streamline Evaluation, Measurement, and Verification (EM&V): Update reference buildings with real data: anonymize and share data (relates to Initiative 1 above)	8
BEM to Support Utility Efficiency Programs	7. Streamline Evaluation, Measurement, and Verification (EM&V): Create communication bridges, to increase interoperability from concept through to incentive (relates to Initiative 2 below)	7
BEM to Support Utility Efficiency Programs	9. BEM for Deep Energy Retrofit: Use calibration to utility data: make sure to specify what data shall be included in the calibration	7
BEM to Support Utility Efficiency Programs	12. BEM for Database Development: Data sharing is desirable to support cost-effective decision-making; make TPEx[a] available, make data sharing standard, provide large amounts of data (supports Initiative 3 above)	15

b) NREL's Technology Performance Exchange: https://performance.nrel.gov/

Table B-2 shows the list of key challenges and barriers to increasing the effective use of BEMs in the design and operation of energy efficient buildings, and in support of activities and programs, as identified by stakeholders.

Table B-2. Challenges and Barriers for use of BEMs

Challenges and Barriers
Tracking and sharing data difficulties pertaining to privacy, proprietary nature of data, data gathering and transfer, formatting and data cleaning
Identifying the essential data needed for BEM
Not all actors (architects, engineers, and sustainability consultants) understand their role in moving BEMs forward
Building owners either do not have interest or skill to use the BEM
Difficult to estimate unregulated plug loads for use in BEM
Difficult to measure energy use
Interoperability is difficult for current BEM tools
BEM can be time-consuming, however oversimplification (such as developing prescriptive databases) can lead to inaccurate results

The following tables document each proposed R&D initiative; these tables reflect the raw outputs of the workshop. The tables therefore do not perfectly reflect a single category of initiatives, but rather, documentation of the conversations that transpired during the session. The ideas from the workshop are divided by the breakout session where they arose.

Table B-3. R&D Roles of BEM in Building Operation

Initiative
Taxonomy of Building Operation (three components): » Implementation of control sequences » Health of building systems » Forecasts for both the building and the outside world
Initial ideas/questions generated: » Are models sufficiently accurate? How far out can we project? » Third-Party Services: ○ Building owner either doesn't care or doesn't have the skills ○ Provide load curtailment and other energy-related services ○ Do third parties need BEM to provide these services? ▪ Is BEM sufficiently accurate? ▪ Is BEM too expensive?
To what extent can reference buildings (aka, templates) be used? » What time step is needed?
How does one measure energy use? » Sensors fail » Build measuring capability into appliances/equipment?
More data will be available as more cities require building ratings
How does one predict occupancy/usage?
Need "multi-fidelity" models

Table B-4. R&D BEM to Support Utility Efficiency Programs

Initiative
1. BEM as a tool to streamline Evaluation, Measurement, and Verification (EM&V) a. Option D of the International Performance Measurement and Verification Protocol (IPMVP) requires utility data calibrated BEM modeling i. LEED used to require this, but instead will be moving toward 1. Advanced sub-metering and trending 2. Continuous commissioning requirements b. BEM can help streamline EM&V if we i. Update reference buildings with real data such that reference buildings can be used to reduce Program Administrator (Utility) costs associated with BEM 1. Related to this is the need to be able to anonymize and share data, to overcome barriers to the high costs associated with BEM—this is particularly important in the context of utility programs, which are required to show cost-effectiveness with indicators such as the Societal Cost Test and Program Administrator Cost Test. ii. Sort out how to estimate unregulated (hourly) plug loads, which are a wild card when using BEM to assess savings (baseline model minus efficient model), and plug loads (or 'non-measure-loads') may not be properly estimated, causing estimated savings from BEM to be incorrect when scrutinized through third-party evaluation. 1. An additional related risk to the utility is when the evaluator uses a different tool and approach than the utility used 2. Inputs are variable iii. Increase interoperability (concept → incentive) by creating communication bridges c. Align the intent of the model with the level of effort d. There is a large change in percent predicted savings when the baseline model is calibrated to utility data i. Large residential potential ii. Standardized buildings (BEM) would be helpful **e.** Automate the Quality Assurance steps of modeling

Initiative

2. BEM to promote deep energy retrofits *(i.e.*, >30% reduction over baseline)

a. What is the benefit of BEM
   - i. BEM + big data?
   - ii. BEM vs. big data?
   - iii. BEM:
     1. Looks at building as a whole
     2. Accounts for interrelationships between systems
     3. Allows for cost optimization
     4. Needs precise component data for accuracy and good decision-making
     5. How do defaults relate to:
        - a. Non-measured energy (*i*.e., plug loads)
        - b. Rooms affected (not all rooms are affected by specific measures, but all rooms have to appear in the model)
   - iv. Use calibration to utility data
     1. Make sure to specify what data shall be included in the calibration
        - a. Use the latest research to inform unknowns (for example, someone pointed out that much is known about occupant behavior, but no one includes it in models)
   - v. Use asset scoring as a first screening step to identify which buildings should receive more detailed full BEM attention
   - vi. Use BEM as an optimization tool (when deciding order of operations for measures, which retrofits to do first, or at all etc.).

3. BEM for Database Development for Prescriptive Measures (or other)

a. Risks of using databases are:
   - i. Actual inputs and assumptions may be very different that those used to generate the database outcomes
   - ii. New technologies and approaches may not be easily or quickly updated, in reality
   - iii. Additional Cons to using Databases:
     1. Assumed BEM buildings are too similar/uniform (*i.e.*, not representative of actual buildings)
     2. Interactivities may not be accurate
     3. Difficult to keep up with new technologies
     4. Occupant behavior is better understood with new research, however will not be accounted for in a prescriptive model
     5. What a project is allowed to claim savings for (in a utility program) is different from the predicted usage of the final building (two separate problems)

b. Data sharing is desirable to support cost-effective decision-making
   - i. Make TPEX available
   - **ii.** Make data sharing standard, provide large amounts of data

Table B-5. R&D Discussion from the Group Brainstorm Session - Metrics

Initiative

Brainstorm Ideas for Metrics:

- Survey IBPSA Members
  - Coordinate with IBPSA and ASHRAE to tap work in progress
- Measure growth in memberships and attendance at key conferences
  - Poll AIA Conference attendance
  - Poll ASHRAE Conference attendees
  - IBPSA SimBuild
- Poll ASHRAE members during membership renewal
- Add BEM question to building permit applications
- Work with key organizations to determine how many owners are using BEM
  - International Facility Management Association (IFMA)
  - Building Owners and Managers Association (BOMA)
  - Commercial Building Energy Alliance (CBEA)
- Random sample of buildings
  - EIA Commercial Building Energy Consumption Survey (CBECS)
  - EIA Residential Energy Consumption Survey (RECS)
- Determine energy savings from BEM
  - What portion of savings is attributable to BEM?
  - AIA is working on this for their self-reporting sample (2030 Commitment)
- City (or district) project—GSF modeled
- EPA ENERGY STAR Portfolio Manager
  - Record number of building owners/operators who say they operate their buildings using BEM

Table B-6. R&D Discussion from the Group Brainstorm Session - Gaps

Initiative

Gap: Accountability. This gap pertains to accountability of the larger BEM community, meaning those who perform BEM on behalf as clients and those who develop BEM software tools, to the end users they respectively serve (accountability of design professionals to their clients, and accountability of software developers to their end users). The issue being addressed was the issue of credibility of BEM: how to increase the perceived credibility of BEM, thereby increasing the value proposition, and increasing the uptake of BEM.

- Need measurement/benchmarks
  - Benchmarks based on measurement, and measurement itself, will serve two purposes: demonstrate to clients that the BEM community holds itself accountable, and simultaneously, consistently provide an outward measure of buildings held to a higher standard. The problem of attribution to BEM was not clarified here—a building with low energy use relative to its peers can achieve this without BEM. Therefore measurement and benchmarking would need to be particular to BEM.
  - Measurement could utilize utility meter data, submetered data from a customer-installed system, or a combination, as a basis for comparison of BEM outputs (hourly kWh, MCF, water use) with measured quantities.
  - Benchmarking could be relative to each building against itself, or could be against peers in its CBECS, NAICS, or other defined group, for example.

Initiative
» What else can we do? » LEED predicted vs. actual • This refers to measurement/benchmarking specific to high performing buildings • The benefit of focusing on this subset of all buildings is that LEED models are generally very thoroughly vetted, and therefore represent BEM models that have undergone a high degree of quality control. For a LEED verified model, the inexperience of the BEM user has largely been eliminated by the time the model is accepted for LEED credit. Therefore, discrepancies in predicted building vs. actual building using LEED models could be said to more closely represent factors associated with discrepancies in building inputs and software tool algorithms, rather than decision-making of the BEM user. » LEED Dynamic Plaque • This was a particular type of LEED certification that I believe is intended to recognize ongoing persistence of LEED measures • Share Data: by sharing data, there is the perception that there will be greater quality of outcomes of building models, such as low energy use and sustainability • Remove barriers to tracking and sharing data ○ This refers to the perception of the difficulties associated with tracking and sharing data, such as privacy, proprietary nature of data, data gathering and transfer, formatting and data cleaning which can be time-consuming. ○ Removing barriers to enable to free flow of data should also refer to identification of which data is most needed, and what questions it is trying to answer. • Quality Assurance/Quality Control for data: without proper labeling and protocols, low quality data is worse than no data at all because it can be misleading, wasting immense amounts of time (for example calibrating BEM to placeholder utility data) and resulting in poorly informed decisions resulting from BEM that do not represent the expected buildings ○ Protect consumers ▪ Poor data quality affects BEM software developers, design professionals who use BEM, and the owners and clients who are the ultimate beneficiaries (or victims) of decisions made using BEM
• Change building codes to make BEM the most desirable option » By creating prescriptive paths with fewer options, BEM-based compliance paths become desirable for building owners and design professionals due to more design options » BEM-based paths can more easily avail themselves of emerging technologies than prescriptive paths can, to the extent these are available or implementable in BEM • Credential BEM practitioners » Overall this action reduces costs associated with BEM. » Throwing less experienced staff into energy modeling does not necessarily save money in the long run, and reduces the credibility of both their firms and BEM itself when models fail to predict actual cost and energy use/demand outcomes. » Credentialing BEM practitioners is beneficial to all stakeholders, including the BEM practitioners themselves. » It is not clear whether it can be said to guarantee additional energy savings, however credentialing would almost certainly result in BEM cost and time savings, as well as increased credibility. » Additionally, this is a way the BEM community can take demonstrate accountability. • Separate conceptual vs. compliance model » This refers to the fact that there is no reason that an initial conceptual model for a project is expected to bear any resemblance to the eventual model used to determine compliance (with codes, where BEM is used as the methodology for compliance). » Within the idea of accountability, there needs to be recognition that there is not a one-size-fits-all model—there needs to be room for both conceptual and compliance models for the same building, without there being a perceived conflict if these are different. • Integrate BEM in educational systems » Teach BEM modeling in more schools » Which software? » Which types of schools? • Single accepted model vs. larger software market » What is more desirable? Is it easier to have accountability if there is a single well vetted engine/platform, or is a free market with several options the best path to accountability of BEM, in terms of actual accuracy, actual outcomes, and perceived value?

Initiative

Gap: Overall picture and individual firm contributions to the system

- » Common understanding is required.
- » In order to further BEM in the marketplace and increase BEM usage, we will go further faster if all stakeholder firms and organizations work together on the essential items as collectively and collaboratively agreed upon.
- » There is a general feeling that while we are moving in the right direction, particularly with organizations such as IBPSA, individual firms such as architects, engineers, and sustainability consultants, may not be clear how they fit in and what they can contribute to move BEM forward.

- Enterprise level platform for program administrators
    - » Align city and regulated utility efficiency project decisions
    - » "Open Efficiency" (uses OpenStudio)
        - » Commercialization award
        - » SEED
    - » Alignment
        - » OpenStudio export/standardization
        - » EDAPT/API
        - » Asset Score
        - » Portfolio Manager
        - » API

B.4 Next Steps

Navigant, in consultation with BTO, will continue to refine and develop these R&D initiatives though additional research and follow-up interviews with individual stakeholders. Navigant will combine any duplicate or overlapping initiatives to ensure that all initiatives are unique. We will use a combination of qualitative criteria and stakeholder voting in developing final recommendations of the top R&D initiatives for BTO to consider. The opportunity assessment will serve as a guide for BTO and its partners on how best to increase the use and effective use of BEM.

B.5 Workshop Attendees

The stakeholder discussion workshop brought together 28 individuals representing a range of organizations across the industry.
Table B-7 lists all the attendees and their affiliations.

Table B-7. Stakeholder Workshop Attendee List

Attendee Name	Organization
Ming Hu	American Institute of Architects
Melissa Wackerle	American Institute of Architects
David Bosworth	BUILDlab
Richard Lord	Carrier Corporation
Jared Langevin	BTO
Pat Phelan	BTO
Amir Roth	BTO
Jan Kosny	Fraunhofer Center for Sustainable Energy Solutions
Mike Witte	GARD Analytics

Attendee Name	Organization
Jason Glazer	GARD Analytics
Gail Hampshire	Green Business Certification
Ed Barbour	Navigant Consulting, Inc.
Emily Cross	Navigant Consulting, Inc.
Robert Zogg	Navigant Consulting, Inc.
Stuart Dols	NIST
Lisa Ng	NIST
Kyle Benne	NREL
Mark Davis	Office of Naval Research
Mark Spector	Office of Naval Research
Nora Wang	Pacific Northwest National Lab
Chris Balbach	Performance Systems Development
Greg Thomas	Performance Systems Development
Sandro Plamp	QCoefficient
Teresa Rainey	Skidmore, Owings & Merrill
Jelena Srebric	University of Maryland
Wangda Zuo	University of Miami
Dennis Knight	Whole Building Systems

Appendix C. Characterization of Water Uses and Conservation Approaches

For two of the four largest aquifers in the US, water is being depleted faster than it is being replenished.[74] The strain on water supplies has and will continue to increase US reliance on wastewater treatment and desalination technologies, driving up the energy required for water distribution. Of the total water withdrawn from freshwater resources in the United States, approximately 15% is distributed to residential and commercial buildings.[75] Therefore, understanding how this water is consumed and may be conserved in buildings is fundamental to sustainability.

An estimate for the state-by-state distribution of water stress attributed to residential and commercial buildings across the US is depicted graphically in Figure C-1. Water stress is defined by the annual amount of water withdrawn divided by the difference between annual precipitation and evaporation. As shown in the figure, stress from residential/commercial use is concentrated heavily in the western and southwestern US but also across parts of the Great Lakes and mid-Atlantic regions.

Figure C-1. Water Stress Attributed to Residential and Commercial Buildings

Source: US Global Change Research Program. National Climate Assessment (2014).
http://nca2014.globalchange.gov/highlights/report-findings/water-supply

In water-stressed southern California, a study of the ultimate end uses of the water distributed to commercial and residential buildings revealed toilets, faucets, and showers together represented nearly 73% of total indoor water consumption, which does not vary widely by state. Residential outdoor consumption, which can vary widely by state, represented 31% of the total water consumed (see Figure C-2).

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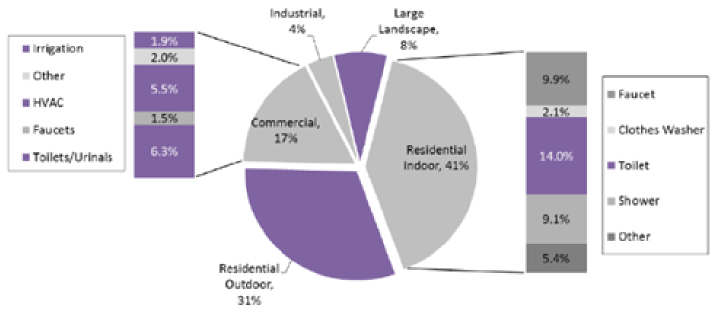
[74] NASA Jet Propulsion Laboratory. *Study: Third of Big Groundwater Basins in Distress (2015)*. http://www.jpl.nasa.gov/news/news.php?feature=4626

[75] The largest uses of water are for irrigation and electric power generation. Source: USGS. *Estimated Use of Water in the United States in 2010 (2015)*. http://pubs.usgs.gov/circ/1405/

Figure C-2. Distribution of Water Uses in U.S. Residential and Commercial Buildings



Source: California Sustainability Alliance. Water-Energy Toolkit for Sustainable Development (2013). *http://sustainca.org/sites/default/files*

Low-flow showerheads and faucet aerators, zero-water and low-flow urinals, as well as xeriscaping[76] efforts represent the most savings-intensive ways to reduce consumption across residential and commercial end uses. The cost and effectiveness of these and other select methods are presented in Table C-1.

Table C-1. Costs and Water Savings of Various Water Conservation Technologies and Measures

Measure	Additional Cost ($)	Water Savings (%)
Efficient sprinkler heads	$5-7/head	20%
Xeriscaping	$1-3/ft2	100%
Dual flush toilets	$50/toilet	33%
Low-flow urinals	$25-100/urinal	87%
Zero-water urinals	$90/urinal	100%
Low-flow showerheads	$5/showerhead	40%
Low-flow faucet aerator	$5/aerator	40%
Residential high efficiency dishwasher	$150-300/dishwasher	42%
Residential high efficiency clothes washer	$200-600/washer	35%

[76] Refers to landscaping in which additional irrigation is significantly reduced or eliminated

Appendix D. Attribution Studies for Regulatory Compliance

D.1 Attribution Studies for Energy Efficiency Program Evaluation for Regulatory Compliance

The concept of attribution studies used in energy efficiency (EE) program evaluation for regulatory compliance could be used to quantify attribution of energy efficiency savings to Building Energy Modeling (BEM) software tool use.

In attribution studies, a net-to-gross factor, NTG = 1 – FR + SO, is developed based on a sample of projects studied. In the case of BEM tools, FR and SO would be defined as:

» **Free ridership (FR):** A number between zero and one that measures whether the same design decisions would have occurred anyway, absent the BEM tool.

» **Spillover (SO):** A number between zero and one that credits a given project with building design decisions made for other projects, not modeled using BEM, based on the BEM building model for this given sampled project.

Using the same approach as EE program NTG analysis, the net savings attributable[77] to the BEM tool would be the apparent impact of BEM[78], times NTG, which is typically a number between zero and one (when there is no spillover). Thus, if FR is high, such as 1.00, the attribution study concludes that user would have made the same decision without BEM and the net savings attributable to BEM would be low (potentially zero).

FR and SO are generally developed using a battery of surveys of participants (users), and sometimes non-participants (non-users) of an EE program (or potentially a BEM software tool). The primary differences between an EE program NTG analysis and a BEM tool attribution NTG analysis would be the specific questions in the survey battery and the target populations for the surveys. The process of scoring the responses of various decision makers, where the questions are designed to determine what would have happened absent the BEM tool, would be similar.

The benefit of attributing energy savings to BEM tools using the same methodology as for EE program evaluation, in particular New Construction (NC) program evaluation, is that the methodology is established and rigorous.

Regarding the determination of apparent savings, in a review of utility New Construction (NC) projects incentivized using BEM recently evaluated for three utilities, Navigant found that, while the weighted-average evaluated electricity apparent savings for a sample of projects was within a few percentage points of the originally reported savings for the sample, about half the projects in the sample saved significantly less than the utilities originally estimated based on BEM inputs used at the time the energy

[77] Net Savings Attributable = Apparent Savings from BEM x NTG Factor

[78] The 'Apparent Savings from BEM' could potentially be derived from AIA study aggregate results, and the NTG attribution could then be applied to these apparent savings to calculate the net savings attributable to BEM. Alternatively, an approach similar to an EE program impact evaluation could be undertaken to determine the BEM apparent savings (baseline building energy use minus efficient building energy use) for a sample of buildings the population of interest, in this case the population of all buildings modeled using BEM during a specified time period (perhaps a period of several years).

efficiency measures were incentivized. The BEM inputs were later found to have changed for the 'actual' evaluated building compared to what was originally expected.

Thus, for a given individual owner of a single building, there can be both perceived and real risks regarding whether BEM results for his or her building are reliable enough to support decision making based on the BEM model. As suggested by the results of NC program evaluations mentioned above, for about half the projects, the projects save less than expected due to changes in basic BEM input values, such as quantity, capacity, and efficiency of equipment, building occupancy, and equipment schedules. From the point of view of a building owner, the level of effort they are willing to invest for their design BEM model may not match their own acceptable risk tolerance for lower than expected savings. As discussed above in this roadmap, a higher level of effort in the BEM building model reduces uncertainty in the BEM energy calculation.

Appendix E. Stakeholder Suggestions

E.1 Potential Metrics Suggestions from Stakeholders to Measure BEM Growth

» Number of LEED-certified buildings that require BEM

» AIA Commitment data

» Number of utility programs requiring BEM

» Number of software developers with high subscription rates

» Number of end users

» Number of State and local building codes requiring BEM

» Number of BEM listserve members

» Number of derivative products based on EnergyPlus/OpenStudio

» Number of IBPSA members

Appendix F. BTO BEM Workshop Presentation

DOE BEM Roadmap
Stakeholder Worksho

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