Pre-Read

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Thank you also to the following contributing sponsors who supported this Summit.

Contents

1 Purpose of this Pre-Read

This document is intended to be read and reviewed by all Building Energy Modeling (BEM) Innovation Summit ("Summit") attendees prior to the actual event. The purpose of this document is to provide all attendees with an understanding of the history and current state of the energy modeling industry within the United States.

Specifically, this Pre-Read document will:

- Begin to identify a vision for the future of energy modeling and identify gaps between that vision and the current state;
- Save time at the Summit by getting everyone on the same page in terms of background knowledge and serving as an information source during the breakout groups; and
- Identify gaps and barriers within the energy modeling sector to support the development of the agenda for the Summit.

While the focus of this pre-read is on energy modeling for large commercial buildings, many of the barriers, processes, and resources apply to modeling for smaller commercial buildings as well as the residential sector.

If you have a limited amount of time to review this document, please be sure to read Sections 2 and 3, as well as the section that corresponds to your breakout group (Methods & Processes, Simulation Engines & Platforms, Education, Training & Certification, Support & Resources, or Market Drivers & Customer Demand). If you do not know which breakout group you have been assigned, please contact Merritt Jenkins at mjenkins@rmi.org.

We look forward to our productive work together in March.

– The Rocky Mountain Institute Team

2 BEM Innovation Summit: Setting the Stage

This section outlines why the building energy modeling industry need the Summit, proposes what we could achieve if the Summit accomplished its goals, and provides more details on the actual event. Please refer to the Summit website for all logistical details.

2.1 Problem Statement

Reliable and consistent whole-building energy and financial analysis is necessary to achieve increasingly aggressive performance targets in the buildings sector, and to motivate building owners to invest in energy efficiency. Software developers have been working on whole-building energy modeling software since the 1960s (see Figure 1). Its early applications supported research and high-level sector studies to identify energy savings potential.

To meet today's market needs, the number of energy modeling practitioners has increased dramatically in a short period of time. These practitioners must follow complex modeling and reporting procedures, and very few have received formal training. Additional pressure is placed on the process since the modeling timeline is usually abbreviated, to coincide with the building design schedule.

During the rapid growth of this industry, professional organizations, national labs, and even private consulting firms, have all made great contributions to the field of energy modeling. Despite these intentional (and often self-funded) efforts, there has been little collaboration amongst these various stakeholders, and many opportunities still exist to increase the effectiveness of modeling to support low energy building design and operations. In order to realize these opportunities, we need to address several issues within the industry, including:

1. Lack of **Credibility:** Customers (of energy modeling services) and other stakeholders do not have confidence in energy modeling results, for the following reasons:
    a. Lack of Quality: Energy modeling results may not reflect realistic building energy consumption and costs.
    b. Lack of Reproducibility: Different practitioners do not produce the same energy modeling results, even when using the same tools and building characterization data.
    c. Misguided Expectations: Customers do not have a clear understanding of what modeling can and should provide.
    d. Difficulty in Assessing Skills: It is difficult for customers to assess the skill level of a practitioner.
2. Limited Time for **Critical Thinking**: Currently, practitioners do not spend the majority of their time on critical thinking and informing design.

3. Need for More **Experienced and Skilled** Practitioners: A limited number of energy modelers possess sufficient skills and experience.
4. Low **Market Demand:** The demand for and value of energy modeling services could be much higher.

2.2 Opportunities and Potential Impacts

Why is it important that we overcome the issues stated above and improve the effectiveness of building energy modeling? What opportunities exist and what are the potential impacts to the global environment (i.e. fossil fuel reductions from low energy buildings)?

As more and more building owners and decision makers recognize the importance of energy modeling within an integrated design process, we face a unique opportunity to convene the currently fragmented stakeholders to improve energy modeling services. Since the start of LEED, design teams have performed energy modeling on over 17,000[1] potentially LEED certified buildings, and used the results to inform an increasing number of retrofits and residential buildings as well. By addressing some of the issues facing this sector, we have opportunities to:

- increase the number of skilled practitioners through education and training,
- develop greater credibility for modeling results and performance comparisons,
- improve the toolset and data available to all practitioners to better meet their needs,
- increase the proportion of time and fees spent by practitioners on critical thinking and informing design,
- influence the design and decision making process through quality and consistent energy modeling results, and
- expand the market for building energy modeling.

Realizing these opportunities could improve confidence in energy modeling results. Decision makers would increasingly demand and use analysis to inform design choices, ultimately driving energy reductions in new and existing buildings.

2.3 Challenges to Realizing Opportunities

What are the significant challenges to addressing these problems facing this industry? While there are many, this section characterizes the important conditions of the industry that present challenges to effecting change and realizing a new vision for the future.

First, the **current tools are fragmented**. Within the U.S., there are about 7-10 whole-building energy modeling tools that are widely used, each having their own strengths and weaknesses. Typically, practitioners must use one tool to inform another in the process of analyzing a single building. Sharing algorithms and data between these fragmented tools is not practical since the tools do not use standardized application program interfaces. Each

[1] Green Building Certification Institute. (2011). *Total number of registered and certified LEED NC, CS and Schools projects (assumes 90% had energy models)*. Retrieved from http://www.gbci.org/main-nav/building-certification/registered-project-list.aspx

tool also uses different techniques of solving a problem and there are fundamental differences in the assumptions and simplifying techniques they use. Thus, when a tool adds and validates a model of a new technology, it is hard to apply this advance in other tools to progress the state of the art.

Next, **practitioners are isolated**. The thousands of energy modelers in the U.S. work all across the country for various firms and have limited interaction with each other. Practitioners are often self-taught, as university programs (see Section 5.7.1) have only recently begun to offer formal instruction on this topic. In many cases, a single energy modeler resides within a firm, with no in-house support or guidance. Additionally, firms have created their own "patches" or "work arounds" to address analysis needs, but they are rarely shared, standardized, or vetted by the industry.

Third, **the market for energy modeling is not well defined or educated**. Not all current and potential customers of energy modeling services are aware of appropriate applications and their associated value. The consumer may not know when energy modeling is appropriate, what type of services to ask for, and may struggle to compare proposals from different service providers. The more commonly understood applications (e.g. LEED energy credit calculations) typically have less value in terms of actual energy reductions compared to other applications such as conceptual design studies or comprehensive life cycle cost analysis.

Finally, **software developers face significant challenges** on the tool development side. The developers of free tools face significant time and money constraints, and improvements are often driven by the source of their funding (see Section 5.4). The developers of tools available for purchase are competing with free alternatives and facing the challenge that most business owners do not place a high enough value on this type of analysis to purchase additional software. Furthermore, there is not always a clear dialogue between the practitioners, software developers, and funding parties and the developers must balance many competing needs and demands.

2.4 Why a Summit? Why Now?

The need to identify best practices and deliver quality tools for performing in-depth performance analysis has never been greater. Many of the challenges outlined above could benefit greatly from simply convening stakeholders within the energy modeling sector and starting a collaborative dialogue. Industry organizations such as ASHRAE, IBPSA, USGBC, and IMT are playing a large role in influencing the energy modeling industry, and recognize the importance of collaborating with other efforts taking place. The growth and success of energy modeling services can be largely attributed to the voluntary efforts of various stakeholders over the years. By coordinating and building upon these efforts, we can truly capitalize on the opportunities that exist for continued growth and success.

2.5 The BEM Innovation Summit

2.5.1 Objective

The objective of this event is to collaborate and capitalize on the biggest opportunities for building energy modeling to support widespread solutions for low-energy buildings with reduced electric demand.

2.5.2 Attendees

In addition to RMI personnel, approximately 55 invited guests will attend from the following stakeholder groups:

- Software developers of building energy use simulation tools and Building Information Modeling (BIM) tools
- Expert building energy modeling practitioners and educators
- Key representatives from the Department of Energy (DOE) and national labs
- Decision makers from professional and industry standards organizations

Please refer to the current RSVP list for specific attendees.

2.5.3 Industry Partners

The Summit is a Rocky Mountain Institute event, developed in partnership with the following organizations:

- ASHRAE: American Society of Heating, Refrigeration, and Air-Conditioning Engineers
- IBPSA-USA: The United States Regional Affiliate of the International Building Performance Simulation Association
- IMT: Institute for Market Transformation
- USGBC: The U.S. Green Building Council

Along with RMI, these organizations have committed to working together in a spirit of collaboration and partnership to mutually promote an effective, coordinated, improvement of the building energy modeling industry through the upcoming Building Energy Modeling Innovation Summit.

In Appendix A, we provide a detailed description of each organization and statements about why the growth and improvement of energy modeling is important to each organization's mission and plan for future work.

2.5.4 Charting a Roadmap

A key activity of the Summit will be to frame and develop the roadmap. This roadmap will describe a longer-term vision (5+ years) for the industry, and also highlight key short-term (2-5 years) needs and action items. The topics we will cover include, but not be limited to:

- how to provide the resources that diverse practitioner groups need to perform high quality energy modeling;

- what is the best way to develop and verify new algorithms;
- how we can impact key market drivers to encourage and incent this future vision;
- how we can expand BEM's market demand and improve the value proposition;
- how each stakeholder can best contribute and also benefit; and
- how we can achieve seamless information transfer between tools.

2.5.5 Summit Outcomes

In addition to covering a long term vision, or roadmap, for the future of energy modeling, the Summit will identify critical needs that are immediately actionable, prioritize efforts, and facilitate solutions within the following broad categories related to energy modeling:

Methods and Processes	**Software Tools (includes engines and platforms)**	**Education, Training, and Certification**	**Market Drivers and Customer Demand**	**Support and Resources**

A post-Summit report will summarize the roadmap components targeting long-term needs, as well as the immediately actionable solutions we identify at the Summit. During the Summit, we will likely create collaborative working groups around each of the categories listed above. These could potentially become subcommittees under an appropriate ASHRAE Technical Committee (TC), such as TC 4.7 – Energy Calculations. The figure below provides some tangible examples of short-term (implementable within 2-5 years) outcomes that could result from these working groups. The outcomes will be driven by the long-term vision for the future, and classified according to short-term and long-term actions.

Table 1: Example Short Term Outcomes

Focus of Collaborative Working Group	Sample Outcome (actionable within 2-5 years)
Methods and Processes	Develop practical application guide and supporting tools for calibration informed by methods in ASHRAE research project 1051.
Simulation Tools	Identify critical gaps and immediate term needs for tools to streamline the modeling process. Coordination on future modeling tool needs with tool developers.
Education, Training, and Certification	Coordinate future development and maintenance plan for the IBPSA BEMBook WIKI to serve as a centralized, vetted body of knowledge for energy modelers.
Market Drivers and Customer Demand	Facilitate industry vetting of COMNET[2]. Ensure market applications adhere to standardized and consistent processes for developing model input values and reporting submittals.
Support and Resources	Create a partnership with the Energy Information Administration (EIA) and work to add benchmark data for additional building types, such as museums and car dealerships.

[2] Commercial Buildings Energy Modeling Guidelines and Procedures: http://www.comnet.org/

2.5.6 Ground Rules

In order to remain collaborative in spirit and purpose, the Summit will be free from commercialism and product marketing will not be allowed.

The Summit will convene many stakeholders who may work for competing companies or develop competing tools. We ask that all attendees refrain from promoting or discrediting a particular software tool or organization, unless it is constructive to the overall objectives. This is so that we can make the most of this unique opportunity to allow for open exchange and a creative collaboration for improving the industry.

> ***In some areas, incremental change is appropriate. In others, there is the opportunity to re-think the way things work and will work for the next 5-10 years and beyond. Together, in a room of our peers and competitors, we have an opportunity to address common issues in which we all have a stake. Ideally, short-term solutions will be part of a long-term future vision.***

Also, as we have a very limited amount of time to convene and a great deal of information to cover, we request that you keep Summit discussions focused on the topics set forth in the agenda, and use the socializing time (such as the Thursday evening dinner) to discuss other issues. So that we can make full use of your time, knowledge, and experience, please leave your laptops and smart phones in your hotel rooms, and provide your full attention during the event. Thank you!

3 Summit Approach

3.1 Assess the Current State of the Industry

The first step towards reaching the objectives of the BEM Innovation Summit is to take an honest and comprehensive look at the energy modeling industry as it exists today. The bulk of this Pre-Read document (Section 5) is dedicated to this evaluation of the current state of energy modeling. It is provided to give all Summit attendees a common basis of understanding on the topics and to be used as a reference during the event itself.

3.2 Develop a Vision for the Future

A key component to creating lasting solutions is to look forward and create a long-term roadmap and future vision for the BEM industry. This should be a collaborative effort, but there will likely be more than one future vision, or variations that not everyone will agree with. This collaborative effort to develop the future vision should not be overly constrained by what is working or not working today.

Of course, these long term visions are likely to be the most contentious and draw the most passion from our attendees. Can we be nimble while charting a better course?

To stimulate thinking on this topic in advance of the Summit, RMI solicited vision statements from all attendees (see Appendix B for those that we received).[3] Additionally, in Table 2 we have attempted to characterize some of the broader issues related to the future vision in terms of those aspects around which most would agree (Common) vs. those that would generate a significant amount of debate (Different).

We will address these broad visions in various ways during the Summit. For the Common issues, we will address select barriers in order to move the industry in the right direction. The outcomes could be 2-5 year objectives, which we may address by forming collaborative working groups to focus on these specific issues. For the Different items, we will have structured agenda activities that stimulate group discussion to help determine the various paths that could be taken in the long-term roadmap.

[3] If you have not yet provided your vision statement, please send to Merritt Jenkins (mjenkins@rmi.org).

Table 2: Broad Visions for the Future of Energy Modeling

Common Vision (Most people would agree)	Different (People will likely have different answers to these questions)
The majority of energy modeling practitioners are trained and highly skilled.	What role should open- source tools play in the BEM world?
There is a centralized, vetted body of knowledge[4] for practitioners to reference.	Should there be one tool that does it all, or specialized tools to take care of different aspects (CFD, daylighting, load calcs)?
BEM is used to inform design, improve building energy performance, and to audit actual performance. A model is carried from design to operation and assists measurement, verification, control, fault detection and diagnostics etc.	How do we balance standardization vs. innovation? What value does standardization bring to the market? How do we help the 80% of practitioners that are using typical tools without suppressing innovation?
BEM is effectively used to make a compelling business case for low energy buildings.	What role should each stakeholder group play?
Practitioners spend the majority of their time and fees analyzing efficiency and design strategies and interpreting and presenting results to inform building design and operation.	When should practitioners use the more standard tools (and be limited by the constraints of a given interface and simulation engine) vs. a more flexible tool chain that supports modular specification?
For a person skilled in building physics, the application of BEM is intuitive and transparent, and innovation is not constrained by limitations of the software tools.	Should there be a mandatory certification/testing program for energy modelers? Should there be mandatory third-party quality assurance?
Well-crafted regulations incentivize innovation and quality within BEM.	When should energy modeling be used and for what purposes?
There are common metrics that are used to track and evaluate the state of the industry and to prioritize work efforts.	Should tools be free, low-cost, or have a reasonable fee? Should a fee pay for support fees, a license for installation/development, etc.? Should tools be paid for by public funds?
The industry has confidence (and associated value) in the quality and credibility of energy analyses and the results are trusted to inform decision-making.	Should BEM be easily accessible to a non-technical user or are experts (with knowledge of building sciences) required?
	Should BEM tools implement performance standards in terms of software "rule sets"?

[4] i.e. building science behind energy modeling, solutions for common pitfalls, best practices for quality control and sensitivity analyses

3.3 Identify Barriers to Future Vision

After defining a future vision, or visions, for the industry, we have highlighted the gaps between the current state and future vision. This activity will support discussions on prioritization of efforts moving forward.

As a starting point, we have identified some specific causes of, and barriers to, solving the problems listed in Section 2.1. These barriers can be organized into the following categories:

- **Methods & Processes**: Barriers for streamlining tasks exist due to the lack of standardized, industry-accepted methods for performing key tasks within the energy modeling process, such as quality control, calibration, sensitivity studies and uncertainty analysis.
- **Software Tools (includes Engines & Platforms)**: Barriers to effective energy modeling exist as a result of the limitations and constraints within the actual software tools available.
- **Education, Training, & Certification:** The quality, consistency, and replicability of energy modeling results could be improved by providing appropriate education and training and a professional certification program that addresses industry needs.
- **Support & Resources**: The quality, consistency, and reproducibility of energy modeling results could be improved by providing a vetted body of supporting resources. Additionally, there are many important data sources[5] required for quality, comprehensive energy modeling. Gaps in available data create a barrier to the development of accurate energy models.

- **Market Drivers & Customer Demand:** There are certain mechanisms that drive the development, direction and use of energy modeling; we refer to these as "market drivers".[6] In many cases, certain aspects of these market drivers contribute to the issues described above, by making processes time consuming and redundant, which detracts from the effectiveness of the modeling application. Further, potential customers do not thoroughly understand the value proposition for energy modeling services in all markets.

Table 3 summarizes specific barriers to solving the problems described above, and characterizes them according to barrier type, as well as the issues they relate to.

[5] For example, benchmark data, metered data, metrics on predicted vs. actual performance, and a variety of required input data for models.

[6] Examples include performance baselines for energy codes, green building standards, utility programs and regulations, tax incentives, government regulations, and funding sources.

Table 3: List and Categorization of Barriers to Effective/Quality Energy Modeling

Specific Barrier	Barrier Category	Overarching Problem (see key above)
There is a perception that engineering expertise and knowledge of building physics is not a critical requirement for an energy modeler.	Market Drivers & Customer Demand	credibility, market demand
Potential customers perceive the cost of energy modeling services to be prohibitive.	Market Drivers & Customer Demand	market demand
The value proposition for energy modeling services is not clear to potential consumers, who often misjudge the best uses of energy modeling and have unrealistic expectations. A better business model must be developed to educate potential clients, expand the market, define different types of services, etc.	Market Drivers & Customer Demand	credibility
There is a lack of perceived risk among BEM practitioners and software developers vs. other modeling industries, i.e. the aerospace or automotive industry. Market drivers do not adequately incentivize quality analysis work.	Market Drivers & Customer Demand; Simulation Tools	credibility
The market for various modeling services is not well defined. There is not a standard menu of services available to customers, and those services that are most commonly understood, such compliance calculations, have less impact on building performance than other services such as conceptual design studies.	Market Drivers & Customer Demand; Education, Training, & Certification	market demand, credibility
Recent studies and publications have presented misleading results that have hurt the credibility and value of energy modeling	Market Drivers & Customer Demand	credibility, market demand
Energy models do not accurately predict absolute building usage, and do not always correlate well to real world results. New market drivers are highlighting this shortcoming.	Methods & Processes; Market Drivers & Customer Demand; Support & Resources	credibility, market demand
Many practitioners lack knowledge about inverse modeling for the analysis of existing buildings. When can it be effectively applied?	Methods & Processes; Education, Training, and Certification	experienced & skilled
Not all practitioners consistently implement quality control (QC) procedures within the energy modeling process, due to: • A lack of consistent and standardized methods • Unfamiliarity with the QC process (both energy modelers and their managers) • Limited QC features within existing software tools	Methods & Processes; Education, Training, & Certification; Simulation Tools	credibility, critical thinking, experienced & skilled

Specific Barrier	Barrier Category	Overarching Problem (see key above)
Modelers seldom practice Sensitivity/Uncertainty Analyses due to: • A lack of standardized methods and training for these processes • The time required to perform these analyses within existing software tools • The lack of data with uncertainty distributions needed to quantify the expected variability in predicted energy use	Methods & Processes; Education, Training, & Certification; Simulation Tools; Support & Resources	credibility, critical thinking, experienced & skilled
Modelers often do not conduct Measurement & Verification (which could improve modeling credibility and close the feedback loop) because: • The process is perceived to be costly and onerous • There is a lack of understanding of the value of M&V • The results from M&V are rarely made available to software developers to improve performance assumptions or model algorithms.	Methods & Processes; Market Drivers & Customer Demand; Education, Training, & Certification	credibility, market demand
Modelers rarely complete accurate, quality calibration of energy models for existing buildings due to: • The lack of understanding and consistent use of standardized methods. • Building energy modeling being an over-specified problem • The expense and time needed to obtain the required hourly sub-metered data • The lack of integrated tools and automated methods that could assist calibration	Methods & Processes; Simulation Tools; Education, Training, & Certification	credibility, critical thinking
There are multiple certification programs available for energy modelers, but none have gained real traction, nor are they able to distinguish between skill levels.	Education, Training, & Certification	credibility
There is often no clear career path progression for practitioners and "burn out" contributes to high turnover rates.	Education, Training, & Certification; Methods & Processes	critical thinking, experienced & skilled
There are limited comprehensive and formalized training opportunities for industry professionals.	Education, Training, & Certification	experienced & skilled, credibility
Few Universities offer a strong curriculum in building physics, energy systems, and computer aided engineering that would raise the skill-set of energy modelers and provide new talent for developing tools. The type of education that is provided is not consistent across programs.	Education, Training, & Certification	experienced & skilled, credibility
Not all energy modelers have a solid understanding of building science/system design nor know how to correctly translate building info into simulation inputs.	Education, Training, & Certification	experienced & skilled, credibility

Specific Barrier	Barrier Category	Overarching Problem (see key above)
Some practitioners do not have the skills or experience to know when a whole building model is appropriate vs. another type of analysis, nor have the experience to identify the proper tool for a given application.	Education, Training, & Certification; Methods & Processes	experienced & skilled, credibility
Energy modelers struggle with correctly interpreting the existing vast array of energy codes, performance baselines, and green building standards relevant to the industry. There is a lack of consistency between different applications and the definition and use of a performance baseline.	Education, Training, & Certification; Market Drivers & Customer Demand; Methods & Processes	critical thinking, experienced & skilled
There is a gap in expertise between the architect and design team and the building science/energy model experts. There is not enough support and guidance for how the architectural community should interact with energy modeling.	Education, Training, & Certification; Simulation Tools; Market Drivers & Customer Demand	critical thinking, market demand, experienced & skilled
Tool development efforts are driven by, and prioritized according to the short-term demands of many diverse stakeholders and market drivers. This results in: • A lack of industry knowledge about tradeoffs in accuracy and versatility • The need for better communication within practitioners/researchers and developers • Most development efforts being focused on typical practitioner needs. The advanced users find many of the existing tools to be insufficient for their needs. • Incremental improvement of the tools without addressing broader, more structural problems of the tools and their development process.	Simulation Tools; Market Drivers & Customer Demands	critical thinking
A significant amount of translating and pre-processing is required to bridge the gap between design/project specifications and energy model inputs.	Simulation Tools; Methods & Processes	credibility, critical thinking
There are various issues associated with algorithm development: • The method for developing new algorithms varies across tools, and there is no consistent 3rd party validation that empirically addresses algorithm verification • Time lag between algorithm development and standard of verification • There is no standard to exchange and share the investment in models across different tools.	Simulation Tools	credibility
There is a tradeoff amongst current software tool options between computation time and user interface and technical accuracy.	Simulation Tools	critical thinking

Specific Barrier	Barrier Category	Overarching Problem (see key above)
Commonly used energy modeling tools are not capable of analyzing the energy and cost implications of many energy saving technologies: • Time lag between the market release of new technologies and their incorporation into energy modeling tools • Most tools only allow new features to be added by the developer • No standard to exchange/share the investment in models across different tools. • Most tools have limited capabilities for modeling control/operation sequences. • Most tools do not adequately support changes to building form and thermal zoning that evolve during the design process.[7]	Simulation Tools; Market Drivers & Customer Demand	credibility, critical thinking, market demand
There is a shortage of people who are qualified to develop these simulation tools: requires knowledge of cutting-edge (i.e. fast) numerical solution techniques, building physics, fundamentals of energy transfer, and programming languages.	Simulation Tools; Education, Training, & Certification	experienced & skilled, credibility
Multiple tools and models are often required for a single building, with no easy way to convert and share data between tools. The current processes for converting and importing 3D building model data[8] into energy modeling programs are cumbersome and error-prone.	Simulation Tools	critical thinking
Energy modeling tools are difficult to use for design (to answer *how* to design a system, not just how much energy it uses), for sizing (in particular if active/passive energy storage is used), and hardly ever used during operation.	Simulation Tools	critical thinking, credibility
The technology (software architecture, solvers, data formats) in energy modeling tools are often designed ad-hoc; there is little collaboration with experts or adoption of technologies from other disciplines.	Simulation Tools	credibility
It is difficult to obtain the necessary data from equipment manufacturers to accurately model performance (for both the practitioners and developers). • Lack of sharing between manufacturers and tool developers • No standard data format (Extra work to generate necessary data)	Support & Resources	critical thinking, credibility

[7] This leads to a failure to update models to match later design changes, or waiting to start models until after major design decisions are finalized.
[8] Include HVAC equipment and control specifications and schematic diagrams

Specific Barrier	Barrier Category	Overarching Problem (see key above)
There is limited data available for some aspects of building energy use, such as reliable weather data, plug loads and operational schedules. • Difficult to measure for existing buildings • No existing database to pull assumptions from for new buildings • Necessary, reliable weather data is not readily available in the format required for all analyses, for all locations.	Support & Resources Simulation Tools	credibility, critical thinking
Quality benchmark data for energy consumption is not available for all building types (i.e. museums).	Support & Resources	credibility, critical thinking
There is a lack of studies/data showing how people interact with and operate buildings - as a result, practitioners must use individual judgment and assumptions.	Support & Resources	credibility, critical thinking
When an energy modeler has a question, there is no centralized, vetted body of knowledge to which to refer.	Support & Resources	credibility, critical thinking
There is a lack of real calibrated feedback to validate and support future modeling confidence, in particular as it applies to passive solutions.	Support and Resources	credibility
Modelers rarely conduct and use comprehensive life cycle cost analysis (LCCA) to make design decisions. It is very difficult and time consuming to obtain the necessary capital and operating and maintenance costs required.	Support & Resources; Methods & Processes	critical thinking, market demand, experienced & skilled

As we have limited time to convene at the Summit, it would not be possible to individually address each barrier described above. While we will devote part of the agenda to developing a broad, overarching long-term vision, we will also spend time delving into key barriers under each breakout group category (Methods & Processes, Simulation Tools; Education, Training, & Certification; Market Drivers & Customer Demand; and Support & Resources) that we must address in the 2-5 year near term. These breakout group activities will:

1) Define the current business as usual (strengths, barriers, current players, redundant efforts). Answer the question: What is the current trend, assuming no intervention?
2) Define potential long-term visions and highlight key aspects of common desired outcomes.
3) Describe actions required to address key barriers.
4) Identify the immediate needs regardless of the larger more contentious issues.
5) Create an implementation plan.
    a) Who/what organization becomes the steward of these initiatives?
    b) With which partnerships/existing efforts/organizations does this align with?
    c) How are these efforts funded?
    d) What is the 2-5 year timeline for these efforts?
    e) What metrics do we use to track progress and success?
6) Identify questions for the larger group and support required from other breakout groups.

4 Background

4.1 History of Building Energy Modeling

This section briefly covers the history of Building Energy Modeling, focusing on U.S.-based programs. It is important to address the origins of these programs and past relationships with academia, professional organizations, and the U.S. government in order to understand present states and existing barriers.

Pre-1960s: Foundational Algorithms
The origins of building energy modeling can be traced back as early as 1925, when Nessi and Nisolle used Response Factor Methods (RFM's) to calculate transient heat flow. However, it wasn't until the early 1960s that Mitalas and Stephenson published several papers examining heat transfer through walls using RFM's.[9] All of these papers appeared in the *ASHRAE Transactions*, and ASHRAE has remained an important nexus for the development and dissemination of building energy modeling techniques.

[9] Haberl, J., & Cho, S. (2004). *Literature review of uncertainty of analysis methods*. Manuscript submitted for publication, Texas Engineering Experiment Station, Texas A&M University, College Station, Texas. Retrieved from http://repository.tamu.edu/handle/1969.1/2072

In 1959, the merger of American Society of Heating and Air-Conditioning Engineers (ASHAE) and the American Society of Refrigerating Engineers (ASRE) formed the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE).

1960s: The Beginnings of Computer Use

By the early 1960s, HVAC companies were using manual procedures for calculating dynamic heat flow in buildings to determine peak cooling loads. Carrier published its *System Design Manual* in 1960, to educate the industry on HVAC system design. However, it was the American military that recognized the potential for computers in this field.

In the late 1960s, the National Bureau of Standards (NBS) boasted some of the most advanced computers in the country. Bradley Peavy, an NBS scientist under sponsorship of the Office of Civil Defense, took advantage of the computing power at NBS and developed techniques to map heat conduction in underground fallout shelters.[10] His 1968 paper titled "Analytical Studies of Probe Conduction Errors in Ground Temperature Measurement" details his research.

Building upon Peavy's work, Tamami Kusuda, sponsored by the Department of Housing and Urban Development, developed a computer program to predict thermal performance.[11] The program was named the National Bureau of Standards Load Determination (NBSLD).[12] Kusuda's program, which relied on the Response Factor Method (RFM), was very basic and could only model a single room. However, this was a major first step towards whole building energy modeling. According to the National Institute of Standards and Technology (NIST):

> *"It combined algorithms for transient conduction in the building structure, solar heat gains and radiant transfer, and convection between building surfaces and the room air to allow the prediction of temperatures and heating and cooling loads under dynamic conditions."*[13]

Frank Powell and Douglas Burch validated the accuracy of Kusuda's model by measurements performed on a log cabin, a mobile home, masonry wall buildings, attic ventilation homes, different types of passive solar houses, houses with a whole-house fan, daylight utilization systems, thermostat setback operations, and large office buildings.[14] The NBSLD program laid the groundwork for future BEM programs.

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[10] Wright, R. N. (2003). *Nbs/nist 1975-2000* [NIST BSS 179, Environmental Systems, pp.13-15]. Retrieved from http://www2.bfrl.nist.gov/info/bfrl_history/

[11] ibid.

[12] National Institute of Standards and Technology, (n.d.).*Computer program for heating and cooling loads in buildings*. Retrieved from nvl.nist.gov/pub/nistpubs/sp958-lide/266-269.pdf

[13] ibid.

[14] ibid.

In 1967, around the same time as NBSLD was being developed, Automated Procedures for Engineering Consultants, Inc (APEC) developed a program called the APEC Heating and Cooling Peak Load Calculation (HCC). HVAC designers used this program for calculating hourly peak and annual heating-cooling HVAC systems loads.[15] This group of APEC members later formed the ASHRAE Task Group on Energy Requirements (TGER), which used much of the NBSLD work on energy calculation algorithms.[16]

1970s: The Oil Embargo and the Rise of Building Energy Standards

In 1970, Kusuda presented his first paper regarding the use of computers in BEM, titled "Use of Computers for Environmental Engineering Related to Buildings" at the first international building performance simulation conference in Maryland. The symposium was sponsored by the National Bureau of Standards (NBS), ASHRAE, and the Automated Procedures for Engineering Consultants, Inc. (APEC)[17] and hosted presentations of 62 papers by authors from 11 different countries.[18]

In 1971, the U.S. Post Office commissioned the General American Transportation Corporation (GATC) to develop a computer program to analyze energy use in post office buildings. This became the first public domain BEM program and is known as the 'Post Office Program'.[19]

While the BEM community was already making significant headway, the Arab oil embargo of 1973 fueled incentives, funding, and regulation of building energy efficiency. As a result of the embargo, the National Conference of States on Building Codes and Standards (NCSBCS) asked the National Bureau of Standards (NBS) to develop state guidelines for building energy consumption.[20] NBS released NBSIR 74-452 in 1974 and it became the first document to address building standards beyond human safety. The following year,

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[15] Haberl, J., & Cho, S. (2004). *Literature review of uncertainty of analysis methods*. Manuscript submitted for publication, Texas Engineering Experiment Station, Texas A&M University, College Station, Texas. Retrieved from http://repository.tamu.edu/handle/1969.1/2072

[16] Wright, R. N. (2003). *NBS/NIST 1975-2000* [NIST BSS 179, Environmental Systems, pp.13-15]. Retrieved from http://www2.bfrl.nist.gov/info/bfrl_history/

[17] Kusuda, T. (Nov. 30-Dec. 2, 1970). Use of computers for environmental engineering related to buildings. *Proceedings of the Procedures of a Symposium sponsored by the National Bureau of Standards, the American Society of Heating, Refrigerating and Air-conditioning Engineers, Inc. and the Automated Procedures for Engineering Consultants, Inc.*, held at NBS, Gaithersburg, Maryland

[18] Hensen, J. (n.d.). *Past, present, and future plans of the international building performance simulation association (IBPSA)*. Unpublished manuscript, Universiteit Eindhove, Eindhoven, Netherlands. Retrieved from http://www.ibpsa-nvl.org/cms/fileadmin/user_upload/symposia/2000_conferentie/getpageb093.pdf?phpMyAdmin=K64unCUwBR5yeM2mHyzw3rViTr7

[19] Haberl, J., & Cho, S. (2004). *Literature review of uncertainty of analysis methods*. Manuscript submitted for publication, Texas Engineering Experiment Station, Texas A&M University, College Station, Texas. Retrieved from http://repository.tamu.edu/handle/1969.1/2072

[20] Hunn, B., & Conover, D. (2010). 35 Years of Standard 90.1. *Encyclopedia britannica*. Retrieved January 20, 2011, from http://media.web.britannica.com/ebsco/pdf/324/48850324.pdf

ASHRAE adopted this standard as ASHRAE Standard 90-75, the first standard to address building energy conservation.[21]

ASHRAE also published the TGER procedures in a report titled: *Procedure for Determining Heating and Cooling Loads for Computerizing Energy Calculations; Algorithms for Building Heat Transfer Subroutines*. Haberl and Cho explain that the TGER publication included algorithms for simulating HVAC system components, procedures for simulating the dynamic heat transfer through building envelopes, and methods for calculating psychometric properties.[22]

The same year, in 1974, the National Aeronautics and Space Administration NASA developed the NASA Energy Cost Analysis Program (NECAP), based off of the 'Post Office Program'.[23] At around the same time, the U.S. Department of Defense (DOD) gained interest in building energy modeling as well, primarily to improve designs of nuclear fallout shelters. The U.S. Army Construction Engineering Research Laboratory (CERL) created the Building Loads Analysis and System Thermodynamics (BLAST) program. It was initially able to model some basic building systems and later multiple zones.[24]

By 1977, the Energy Research and Development Administration (ERDA) and the California Energy Commission (CEC) upgraded NECAP and renamed it CAL-ERDA.[25] In 1978, the CEC adopted CAL-ERDA as California's official BEM program, ERDA became DOE, and CAL-ERDA became DOE-1.[26] The following year, DOE modified DOE-1 to become DOE-2.

Independent of the development of these other programs, in the early 1970s the University of Wisconsin-Madison Solar Energy Lab and the Colorado State University Solar Energy Applications Lab began a joint project to study emerging solar energy technologies.[27] The solar branch of ERDA (now DOE)[28], funded this project, which involved the construction of a model house in Colorado. As his graduate thesis, Sandy Klein of the University of Wisconsin-Madison developed a Fortran program to predict the energy use of the model building. This program became known as The Transient Energy System Simulation Tool

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[21] Hunn, B., & Conover, D. (2010). 35 Years of Standard 90.1. *Encyclopedia britannica*. Retrieved January 20, 2011, from http://media.web.britannica.com/ebsco/pdf/324/48850324.pdf

[22] Haberl, J., & Cho, S. (2004). *Literature review of uncertainty of analysis methods*. Manuscript submitted for publication, Texas Engineering Experiment Station, Texas A&M University, College Station, Texas. Retrieved from http://repository.tamu.edu/handle/1969.1/2072

[23] Ayres, J., & Stamper, E. (1995). *Historical Development of Building Energy Calculations.* Retrieved from http://www.jmayres.com/computersoftwarehistory.pdf

[24] National Institute of Standards and Technology, (n.d.).*Computer program for heating and cooling loads in buildings* Retrieved from nvl.nist.gov/pub/nistpubs/sp958-lide/266-269.pdf

[25] Haberl, J., & Cho, S. (2004). *Literature review of uncertainty of analysis methods*. Manuscript submitted for publication, Texas Engineering Experiment Station, Texas A&M University, College Station, Texas. Retrieved from http://repository.tamu.edu/handle/1969.1/2072

[26] ibid.

[27] *TRNSYS - The Transient Energy System Simulation Tool*. (n.d.). Retrieved from http://www.trnsys.com/

[28] J. Haberl, personal communication, Jan. 28 2011

(TRNSYS). 1975 marked the release of the first public version of TRNSYS, version 6. Sandy Klein completed his PhD thesis in 1976.

1980s: Revision, Refinement, and Title 24

The 1980s was generally an era of updates to existing BEM programs. The US DOE updated DOE-2 to DOE-2.1a in 1981, and consistently supported further development of the program until the mid-1990s. The DOD upgraded BLAST to BLAST 1.2 and later BLAST 2.0.

An increasingly important use of BEM programs is to support the development of building energy standards. Throughout the 1980s, DOE-2 was used in support of energy standards in the US (ASHRAE 90.1 and 90.2), as well as a half-dozen other countries. The introduction of the Title 24 energy code in 1980 was another major driver, as it relied almost entirely on BEM for both its development as well as enforcement. The California Energy Commission saw a need to develop a BEM tool that evaluated compliance with a performance based energy code via "rule sets" that are embedded within the tools themselves. This led to the development and release of COMPLY 24 in 1985, a graphical front-end of the DOE-2.1 engines customized for Title-24 compliance. The introduction of compliance codes is important, as the market demand for BEM today is driven almost entirely by the need for compliance calculations or related analysis.

The 1980s witnessed the introduction of one major program. Carrier Corporation released a PC-based program in 1981 called Commercial Load Estimating v1.0. This was followed by HAP v1.0 a unified tool for peak load estimating, system design and hour-by-hour energy analysis released in 1987.

In 1987, the incorporation of the International Building Performance Simulation Association (IBPSA) provided a medium for promoting and advancing the practice of building energy modeling around the world.

Microsoft released its Mac-compatible version of Excel in 1985, and quickly followed with a Windows-compatible version in 1987. Microsoft Excel is still used today as a modeling tool for custom situations.

1990s: The Rise of the PC

The early 1990s was a time of reevaluation and redirection. In the early 1990s, DOE-2's lead software developers at James J. Hirsch & Associates (JJH), entered into a joint development effort with DOE/LBNL and the Electric Power Research Institute (EPRI) for the development of a new version of DOE-2, to be known as DOE-2.2. One main driver for the development of DOE-2.2 was to provide support for a fully interactive operation rather than just batch mode operation from a "DOS prompt." JJH, with several development partners, under funding from the electric utility industry via EPRI, created the PowerDOE program in parallel with the DOE-2.2 development effort. PowerDOE was a visual interface version of DOE-2.2 and not simply a stand-alone interface to the program. During the development of

PowerDOE a dispute arose between JJH and the DOE/LBNL regarding who had the rights to distribute DOE-2.2 and under what licensing terms DOE-2 would be distributed to end users. The settlement of that dispute resulted in JJH pursuing the commercialization and future development of the DOE-2 program utilizing mostly non-Government funding sources. DOE/LBNL then turned their attention to creating a new simulation program rather than pursuing DOE-2 any further.[29]

PowerDOE v1.0 was released on November 16, 1996. EPRI provided JJH with licensing to distribute PowerDOE to end users under a fee-based license, whereas JJH was distributing DOE-2.2 as freeware. The difficulty in maintaining the long term single-source funding required to improve and support PowerDOE led to its development ceasing in 2001. eQUEST v1.0, an interface for the DOE-2.2 platform developed by James J. Hirsch & Associates, was released June 3, 1999. An updated version, eQUEST v1.2, was released Jan 27, 2000.[30] Development of eQUEST has continued to this date.

At this time, the Department of Energy focused its development efforts on its new program called EnergyPlus. The EnergyPlus software has its roots taken from the iBLAST program as well as features drawn from DOE-2.1E, with substantial changes to the solution methods and many modeling additions. The Department of Defense cut its funding to BLAST in 1995, and EnergyPlus became a program designed to combine the advantages of BLAST and DOE-2.1E. Dru Crawley of Bentley notes that another driving force behind the development of EnergyPlus was the advantage of a modular program. Aside from the licensing issues noted above, DOE perceived that it had become too difficult, costly, and time-consuming to add new features to DOE-2.[31] In 1996, the development of EnergyPlus began, funded almost exclusively by the Department of Energy.[32]

Despite redirection among the Department of Energy, Department of Defense, and other vested parties, several modeling programs stayed on their original course. In 1993, TRaNsient SYstem Simulation Program (TRNSYS) released its first Windows compatible version 14.2. In 1998, Trane TRACE (TRACE) released 'TRACE 700', its first Windows version.

The 1990s also marked innovation in building energy modeling. In 1991 Abacus Simulations Limited developed a suite of building simulation tools called BIDS (Building Integrated Design System), which were limited to Unix-based Silicon Graphics workstations. BIDS used a derivative of the ESP system called ESP+ as its thermal simulation tool. IES Ltd. expanded this concept for Windows applications and replaced ESP+ with the Apache Thermal analysis system, and released the first commercial version of the IES Virtual Environment (Version 3.0) in 1998. The IES VE was the first commercially

[29] J. Hirsch, personal communication, February 25, 2011
[30] S. Criswell, personal communication, January 5, 2011
[31] D. Crawley, personal communication, January 6, 2011
[32] S. Criswell, personal communication, January 5, 2011

available suite of integrated building analysis tools that used a common data model for all of its broad range of analysis applications.[33]

Approaching building design issues from a different direction, Bentley released its Windows compatible Microstation 95 in 1995, and its first building information modeling (BIM) program to run on Microstation in 1997.[34] Noting the lack of integration and communication between the new BIM models and established BEM models, Green Building Studio, Inc. began development of Green Building XML. With funding provided by the California Energy Commission PIER Program and Pacific Gas and Electric, Green Building Studio designed Green Building XML as an open schema to facilitate the transfer of building properties from BIM programs to building energy analysis tools. The first version of the Green Building XML schema appeared in June of 2000.[35]

2000 – Present: ASHRAE 90.1, LEED, and BIM

The past decade has seen remarkable growth in the BEM industry, primarily driven by more stringent building standards and a growth in voluntary certification programs. In 1998, the USGBC released the pilot version of LEED, known as LEED 1.0. LEED 2.0, released in March of 2000 to the marketplace, quickly followed. However, it wasn't until later in the decade that LEED would drive demand for energy modeling.

The introduction of ASHRAE Standard 90.1 Appendix G – Performance Rating Method, provided more regulation-driven demand for building energy modeling. Appendix G, first introduced in 2004 as informative language, and introduced in 2007 as normative language, provided a building performance rating method for non-residential structures exceeding ASHRAE Standard 90.1 code and required the use of simulation software.

In 2007, LEED introduced a two-point minimum requirement for the Energy and Atmosphere Credit 1 (EAc1). This required a building to meet certain energy reduction criteria in order to receive LEED certification, and about 90% of EAc1 submittals relied on energy models to demonstrate this.[36] In 2009, the USGBC introduced LEED v3, its most recent version, which weights each LEED credit according to its overall importance. EAc1, which relies on energy modeling to quantify the predicted energy savings over a baseline, is one of the most heavily weighted credits. This has translated into the use of BEM for nearly every LEED certification.

Echoing the importance of more stringent building energy standards in the BEM industry, software developers have recognized the necessity of program certification for specific modeling tasks. In April of 2007, the CEC approved the first version of eQUEST (v3.6)

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[33] D. McLean, personal communication, January 28, 2011

[34] *BIM history*. (2009). Retrieved from http://www.bimechanics.com/bim-history.htm

[35] *History - green building xml*. (2010). Retrieved from http://www.gbxml.org/history.php

[36] M. Opitz, personal communication, Jan. 20 2011

certified for Title-24 analysis,[37] and in September 2009 the DOE added eQUEST v3.63b to the list of Qualified Software for calculating Commercial Building Tax Deductions (EPACT 2005). In August of 2010, eQUEST v3.64 introduced a compliance analysis feature designed to automate the generation of LEED baseline building models.[38]

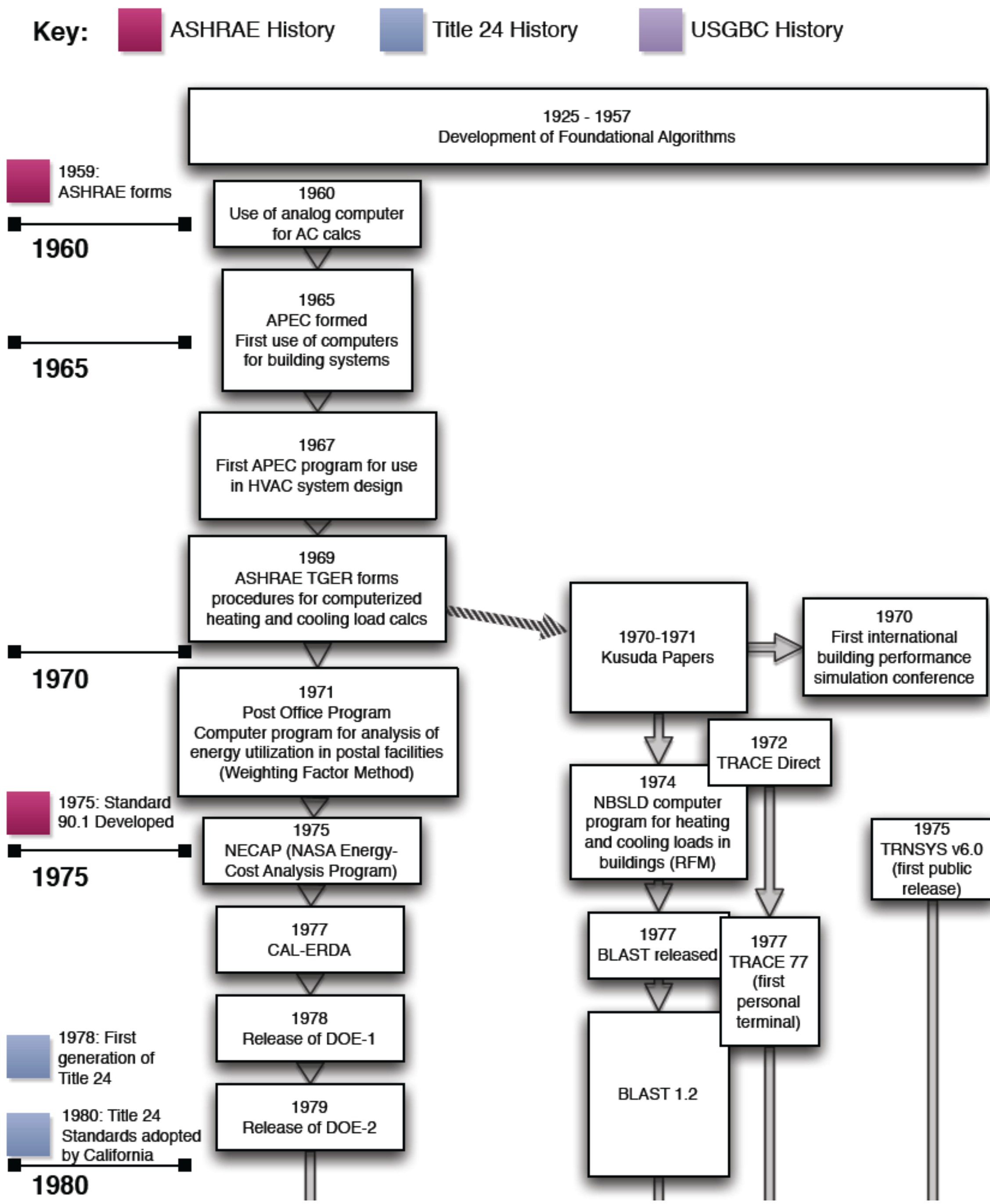
Perhaps foreshadowing a major change in which data for building energy modeling is processed and analyzed, in the past decade both Autodesk and Bentley acquired companies with energy modeling capabilities. Autodesk acquired Revit Technologies in 2002, injecting its company into the building information modeling industry, and acquired Green Building Studio in 2008. Green Building Studio is Autodesk's web-based energy modeling tool that uses a gbXML format and runs a DOE-2.2 engine. Autodesk now offers Revit Architecture 2010, Revit Conceptual Energy Analysis, and Autodesk Project Vasari. Conceptual Energy Analysis and Project Vasari are the first BIM tools to directly export to DOE-2 and EnergyPlus[39]. Bentley acquired Hevacomp in 2008, initially allowing it to incorporate mechanical system sizing into its BIM package[40]. Hevacomp also provided building energy modeling, running EnergyPlus. Bentley currently offers Hevacomp Simulator V8i.

gbXML incorporated as a California public non-profit in 2009, assuming the name Open Green Building XML Schema, Inc, and is now the most widely used format for data transfer between BIM and BEM programs.[41] A number of programs offer plug-in analysis tools for BIM software.

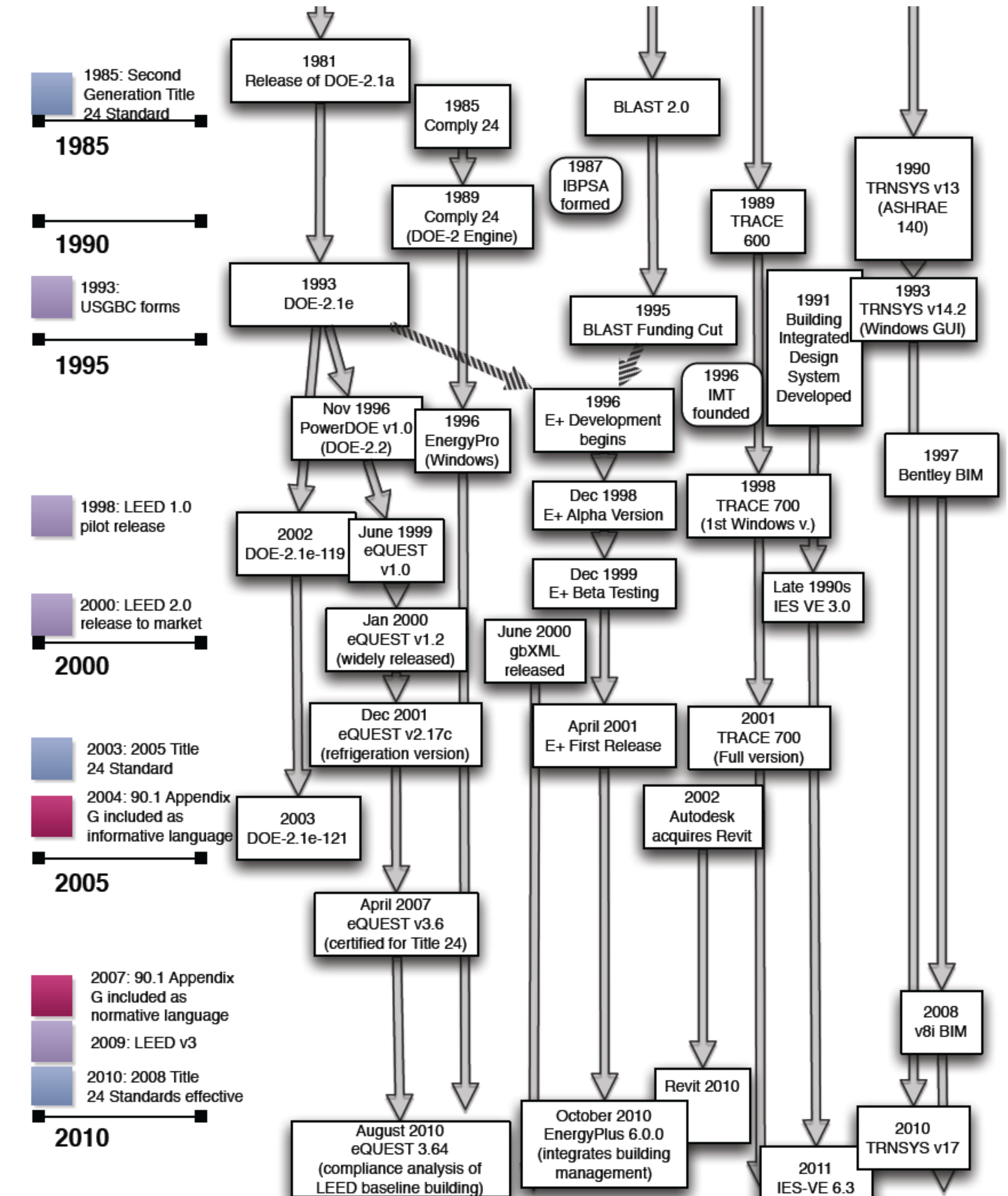
Figure 1 graphically displays the evolution of building energy modeling[42]. The flow chart highlights the development and release of many BEM software programs, and also marks key market drivers along the timeline, such the release of ASHRAE 90.1 Appendix G.

[37] S. Criswell, personal communication, Jan. 5 2011
[38] ibid.
[39] J. Kennedy, personal communication, Jan. 28 2011
[40] Malin, N. (2008, April 3). Bim companies acquiring energy modeling capabilities. GreenSource, Retrieved from http://greensource.construction.com/news/080403BIMModeling.asp
[41] ibid.
[42] A portion of this flow chart was adapted from: Haberl, J. & Cho, S. (2004). Literature review of uncertainty of analysis methods. Texas Engineering Experiment Station, Texas A&M University, College Station, Texas.

Figure 1: Timeline of Energy Simulation (cont. on next page)[43]



[43] A portion of this flow chart was adapted from: Haberl, J. & Cho, S. (2004). Literature review of uncertainty of analysis methods. Texas Engineering Experiment Station, Texas A&M University, College Station, Texas.



*A portion of this flow chart was adapted from: Haberl, J. & Cho, S. (2004). *Literature review of uncertainty of analysis methods*. Texas Engineering Experiment Station, Texas A&M University, College Station, Texas.

4.2 Major Stakeholders

This is a summary of the major players, or stakeholders, in the energy modeling sector and comments on:

- Why is energy modeling important to them?
  and
- If the Summit accomplishes its goals, what will they gain (ideal outcomes)?

Table 4 represents the major stakeholders vested in the future of energy modeling.

Table 4: Characterization of Stakeholder Groups

Stakeholder Group	Sample Representatives	Energy Modeling Priority	Ideal Outcomes
Practitioners (users of simulation tools)	- Consultants - Researchers - Students	- Modeling tools - Resources - Streamlined methods	Improved methods, quality control, accuracy & credibility
A&E Service Providers[44]	- Architects - MEP engineers - Contractors - Cost Estimators	- Performance goals - Contract requirements - Design feedback	- Improved design - Better reputation - Higher reward fees - Quality analysis
Building Operations Service Providers	- Facility managers - Cx agents - ESCOs	- Energy Management - Verification of savings and performance	- Better performance - Lower energy costs - Methods to meet contract (ESCOs)
Owners	- Single building/ portfolio owners - Property managers	- Certification - Marketability - Achieved performance - Energy savings	- Greater lease-ability - Less vacancy - More income (lower operating costs)
Educators	-University Professors - Professional Trainers	- Teaching aids - Methods - Tools - Resources/Case studies	- More qualified building energy analysts
Software Developers	- National labs - Private sector	- Modeling methods - Application needs - Codes & Standards - Algorithm verification	- Improved product - Greater sales - Access to more open source tools
Codes and Standards Developers	- DOE - ASHRAE - CEC - GBCI	- Energy/cost savings - Energy use forecasts	- Better compliance and enforcement - Meet energy policy objectives
Utility Demand Side Management (DSM) Programs	- Pacific Gas & Electric - Duke Energy	- Energy/cost savings - Energy use forecasts	- Meet DSM goals - low cost/ savings & real, verifiable results

[44] AE service providers can also be "practitioners", but this grouping represents the architects and engineers that rely on energy modeling to inform their design work.

Stakeholder Group	Sample Representatives	Energy Modeling Priority	Ideal Outcomes
Federal Research Labs	- DOE - EIA - National Labs	- Energy/cost savings - Energy use forecasts	- Improved compliance methods – Meet energy policy objectives
Professional Organizations	- IBPSA - ASHRAE - IMT	- Analysis tools/methods - Resources/Case studies - Teaching materials	- Improved methods and services
Energy organizations	- USGBC - RMI	- Business case for energy efficiency	- Support mission
Industrial Companies	Researchers from manufacturing companies	- Support R&D of new technologies - System-level analysis - Energy/Cost Savings	- Reduction of time to market for new inventions
Product Manufacturers	HVAC and lighting equipment manufacturers	- Support R&D of new technologies - Energy/Cost Savings for their technologies	- Verified performance savings for products - Increased sales
Society	Every living being	-Significant and real building energy use reductions	-A more sustainable world with high quality of life

4.3 What Can We Learn from the International Community?

A wide range of building energy modeling approaches and applications exist throughout the world. In the U.S., the field is dominated by a few relatively monolithic, procedural software applications maintained by small groups. It is often difficult for many practitioners to model cutting-edge design ideas with these tools because the software updates cannot keep pace with the emergence of new technologies.

In the international design community, countries such as the United Kingdom, Ireland, and Australia have been intensive users of commercially available BEM tools to provide energy-efficient design since the mid to late 90s. In the international modeling community, there tends to be more interest in, and application of, modular frameworks (such as TRNSYS) and more flexible modeling languages (such as Modelica). These types of tools adapt better to distributed development strategies, allowing for faster modification and extension of tools. Perhaps this type of innovation in software architecture and development strategies can help modeling in the U.S. keep up with new building technologies.

Different cultural attitudes and values have contributed to varied approaches to energy modeling. For example, in North America there has been a bias toward informal pragmatism (make it run, we'll worry about the details later). While this approach has provided the ability to get useful results right now, it may be limiting the ability to get optimal results in the future. In contrast, European academic traditions tend to favor more formal approaches, involving gathering experimental data and reconciling results. Although this approach is typically slower and more time intensive, it is more rigorous and leads to greater validation of the results, as well as researchers with deep expertise in what they are modeling. Further, this more rigorous process may actually save time and resources in the long term, as the solutions can be easier to maintain and lead to tools that are easier to use.

Additionally, international clients often have a greater willingness to consider more design alternatives and recognize value in the high level of analysis that is used to evaluate them. This is likely due, in part, to the rigorous processes that yield results that track closely with actual operating energy costs. Additional motivation likely comes from aggressive local and regional energy mandates and carbon emissions reductions targets, such as the European Union's (EU) Energy Performance Buildings Directive (EPBD) which sets minimum energy standards for new buildings and requires a Building Energy Rating (BER) at the point of sale or rent for new and existing buildings. Prescriptive regulations can drive energy use reductions to a certain degree, but energy modeling is required to demonstrate predicted emissions reductions.

On the other hand, in some European regions there is regulatory enthusiasm that restrictively specifies tools or assumptions. While standardizing analysis procedures is helpful for bringing building modeling into the mainstream, it is crucial to create regulations that allow evolution with the field.

There are also differences in the focus of energy modeling programs internationally. In the U.S., the emphasis of simulation programs has been on large HVAC systems. Alternatively, in Europe the focus is on simulating passive design and building envelope options. In addition to higher energy costs, European regulations tend to be more stringent, such as those that do not allow mechanical cooling for certain building types and climates, or that require work places to have daylight access. The U.S. could learn from the stronger understanding of building physics used in European countries to analyze passive systems that include thermal mass, shading technologies, daylight, and natural ventilation, optimize their design, and calculate the energy savings from these strategies.

4.4 Simulation in Other Engineering Communities

This section describes trends in other (non-building) fields that also use modeling and simulation to support the design and operation of engineered dynamic systems, and compares these trends to the building energy modeling community. In various engineering communities, such as the aerospace, automotive, chemical, and controls communities, there is a trend towards the use of general purpose modeling environments that are customized with domain-specific libraries and modules. Frequently, these tools have mechanisms to package models to make them accessible to non-experts. Examples of such general purpose modeling environments include Modelica, MATLAB/Simulink, gPROMS and COMSOL. Various factors motivated the change from writing domain-specific simulation programs towards the use of these general purpose modeling environments:

- The trend toward increased system integration (e.g., hybrid engines of cars) posed challenges on the flexibility of the tools to integrate and analyze models from different domains (combustion, thermodynamics, electrical generators and motors, translational dynamics of drive train, batteries, controls) that evolve differently in time (fast and slow continuous time dynamics for physics, discrete time dynamics for control).
- The control of such integrated systems became increasingly complex. This required tools that allow the development and testing of control sequences in simulation, and the automatic deployment of these control sequences to hardware to avoid errors during implementation.
- The pressure for shorter product development cycles and more complex system architecture led to tools that allow a designer to draw the system architecture and use this schematic diagram to test and improve its performance in simulation.

The tools that are used in these industries evolved:

1. from the use of *procedural code* (e.g., Fortran)
2. to *object-oriented code* (e.g., C++)
3. to *block-diagrams* with graphical blocks that process input signals to compute output signals (e.g., Simulink or TRNSYS) and finally
4. to *acausal schematic diagrams* that contain objects with ports that define boundary conditions without imposing the causality of input and output variables as the causality can change depending on the model use (e.g., Modelica, IDA/NMF, SPARK, Simscape, gPROMS).

The majority of the programs that are used for building energy modeling (DOE-2, EnergyPlus, TRNSYS) are still based on procedural code, with some (TRNSYS) allowing the composition of system models using block-diagrams.

Declarative languages (Modelica, NMF, Simscape etc.) allow expressing physical laws and control logic, i.e., the *mathematical model*, without describing how to compute a time trajectory for these equations. In contrast, imperative languages (C, C++, FORTRAN etc.) describe how to compute a time trajectory, i.e., they implement a *simulation program*. A notable trend in the system simulation community is the evolution from the use of imperative languages to the use of declarative languages. The benefits of expressing the physics and control logic in a mathematical model instead of a simulation program include increased code reuse and more flexible support for new use cases, as well as the ability to use the same model for different applications.

For example, using the same model, different code can be generated for time-domain simulation on parallel computers or on embedded systems with real-time constraints and limited memory, or for optimization of the system-performance. Furthermore, the use of advanced mathematical methods allows the simulation and analysis required when combining continuous and discrete time controls with the dynamics of building systems.

These advanced mathematical models can also be used to optimize the operation of large scale systems as is done routinely in chemical plants.

4.4.1 Contrast with Building Energy Simulation Programs

In contrast, building energy simulation programs, with the exception of IDA/ICE, are not built on general purpose modeling environments that separate the mathematical model from its implementation in executable code. While the general purpose modeling environments allow a modeler to declare the system architecture in a graphical schematic editor, most building simulation programs still require the practitioner to parameterize models of pre-defined systems in order to simulate a system, or to write code within a rigid framework of the simulation program. Consequences of these rigid simulation frameworks include:

- Many innovative building energy systems and control sequences cannot be simulated if they were not implemented by a program developer (or expert user), in particular if they contain non-standard ways of heat recovery, piping and duct networks, and equipment sequencing.
- There exists no robust way for generating a simulation based on a Building Information Model (BIM), as BIMs (such as IFC) allow the specification of HVAC schematics that are outside the scope of many building simulation programs. Furthermore, if next-generation BIMs also include the specification of control sequences, then mathematical methods (i.e., solvers for stiff differential equations that are coupled to discrete-time and event-driven systems) will be needed that are beyond the possibilities of today's major building simulation programs.
- Many dynamic phenomena cannot be analyzed (such as dynamics introduced by closing control loops that can lead to equipment that cycles or dampers that are hunting each other).
- Adding new code is time-consuming and difficult for both, developers as well as end-users. Frequently, adding new models takes too long to be viable within the building delivery schedule.
- Use of these tools in conjunction with efficient optimization methods is difficult if not impossible.

Analysis tools with a set of pre-defined black box models are unsuitable for most research (except perhaps architecture studies). The reason is that commercial tools only include models that are known widely enough to be marketed and have been around long enough to have implementations incorporated into these special purpose tools. On the other hand, research focuses on new and innovative things that are by their very nature not widely understood and have not been around long enough to be incorporated into off-the-shelf tools. For this reason, general purpose tools have dominated most research activities outside of the building energy realm (for example, in the automotive industry in the development of the Ford Hybrid Escape).[45]

5 Current State of Building Energy Modeling

This section covers the current status of building energy modeling in terms of tools, processes, training and educations, supporting resources, etc. This is meant to document the current state of the industry, as a comparative basis for the future vision.

After summarizing how energy modeling is currently used, we summarize practitioner and customer demographics and explore how the industry is currently funded. In sections 5.5 through 5.9 we characterize the current state of the energy modeling industry in the areas of:

- Standardization of Methods and Procedures
- Simulation Engines and Platforms
- Education, Training, and Certification
- Support and Resources for Practitioners
- Market Drivers and Customer Demand

This information will be used to guide the structure and content development for the breakout groups during the Summit.

5.1 How and When Energy Modeling is Used

A variety of practitioners and other professionals in the building energy field use energy modeling. The most common applications of energy modeling the "typical practitioner" performs are:

- to inform early design decisions
- to refine design decisions and control strategies throughout the design process
- to predict the actual energy consumption and costs of building
- to provide inputs for a life cycle cost analysis
- to inform retrofits of existing buildings (requires a model calibrated to actual usage)
- to verify the performance of a building post-occupancy (requires a model calibrated to actual usage)
- to determine performance compared to a given baseline (i.e. ASHRAE's Performance Rating Method, or a specific target for Energy Use Intensity)
    - to meet performance goals set by the owner or design team
    - to determine compliance with an energy code, tax credit, regulation, or piece of legislation, or
    - to determine compliance with, or points for, a green building rating system

Beyond the "typical practitioner," there are many other types of users, each with unique needs. Energy modeling practitioners can be categorized into different groups based on

[45] M. Tiller, personal communication, Jan. 19 2011

their anticipated needs and modeling capabilities. Different types of practitioners use BEM software in unique ways and, therefore, have different priorities about how BEM should develop.

Table 5: Characterization of Practitioners

User	Modeling Capabilities and Demands
Typical Practitioner	▪ Uses wizards and interfaces for simulation engines ▪ Models standard systems for code compliance, tax credits, LEED, etc. ▪ Uses modeling to evaluate options and inform new design and major renovations ▪ Tools commonly used: eQUEST, HAP, Trane TRACE, EnergyPro ▪ Tools sometimes used: EnergyPlus, TRNSYS
Advanced Practitioner (includes researchers)	▪ Simulates unconventional systems beyond the limits of packaged software, often requiring outside workarounds ▪ Building specific tools (based on procedural code): EnergyPlus, TRNSYS ▪ General purpose modeling environments used: Modelica, MATLAB/Simulink, IES-VE, and COMSOL
Building Operators	▪ Very few currently use energy modeling ▪ Could use modeling to cross check actual building performance against design intent ▪ Would likely use packaged tools with wizards and interfaces ▪ Requires more training, education, and exposure to energy modeling
Energy Service Companies (ESCOs)	▪ Some use modeling to predict and verify savings for performance contracts, while the majority still rely on spreadsheet calculations ▪ Uses packaged tools with wizards and interfaces ▪ Requires more training, education, and exposure to energy modeling
Building Commissioning Agents	▪ Very few currently use building energy modeling ▪ Could use BEM to cross check actual building performance against design intent ▪ Building specific packaged tools are likely used (i.e. eQUEST, EnergyPlus, HAP, IES-VE, Trane TRACE etc) ▪ Requires more training, education, and exposure to energy modeling
Systems and Controls Manufacturers	▪ Industrial R&D for new products and systems (i.e. mechanical system controls, or the automotive industry) ▪ Detailed simulation required to show how their tools interface with their business offerings ▪ Need small time steps to match with control algorithms ▪ Typically use TRNSYS or one of the general purpose modeling environments where they can specify differential equations and numerical methods to simulate controls reliability
Policy Analysts	▪ Performs models across a very large numbers of buildings and locations ▪ Evaluates the impact of new rules in energy codes and standards, appliance standards, tax policies ▪ Typically uses EnergyPlus or the DOE-2 simulation engine based tools

5.1.1 Customer Demographics

For the purposes of this Summit, we are defining 'customer' as the individual or institution who is commissioning the results of the building energy model(s). The objective of learning about customer demographics is to shed light on the following line of inquiry: *Who is currently demanding energy modeling and why? Are any sizable demand categories currently driving the development of energy modeling?* The answers to these questions can inform: *What kind of shift in market demand is required for energy modeling to be employed for its "best and highest uses" in the future?*

To our knowledge, little to no statistical data on comprehensive BEM customer demographics currently exists. Based on our research, we have assembled the following table that identifies the prominent customers in today's BEM's market, and the reasons those customers are demanding energy models.

In Table* 6, *<u>underlined</u> reasons are perceived to be the biggest drivers of energy modeling development today. Those marked with an asterisk (*) are ones we propose could best achieve the Summit Objective (support widespread solutions for low-energy building).

Table 6: Characterization of Customers

Customer	Reason(s) for Demanding Energy Models
Building owners/ developers/ design team	▪ <u>To comply with mandatory requirements (e.g. federal regulations and legislation, energy codes)</u> ▪ <u>To comply with program requirements for desired outcomes (e.g. LEED certification, qualification for tax incentives, qualification for utility incentives)</u> ▪ <u>To inform design choices for new construction and major renovations</u>* ▪ To verify and improve post occupancy operation* ▪ To help commission the building* ▪ To gauge achievement of key performance project goals* ▪ As part of a corporate sustainability or reporting plan The majority of models performed for this customer type are for individual commercial buildings > 10,000 SF (including high-rise residential buildings).
Municipalities, State and Federal Governments	▪ To perform whole building energy benchmarking and evaluate the impact of new rules in energy codes and standards, appliance standards, tax policies, etc. Policy analysts model prototypes and extrapolate results across building and climate types or geographic jurisdictions.
Researchers	▪ To inform various research initiatives, verify new technologies, and to inform the development of design guidelines, codes and standards (typically in national labs) ▪ ASHRAE uses modeling to inform development of Design Guidelines and Standards

Customer	Reason(s) for Demanding Energy Models
Systems/Controls Manufacturers	▪ To inform the development of and test new product offerings *
Utilities (with DSM programs)	▪ To inform development of Demand Side Management (DSM) programs and compliance formats for those programs

For information on customer demand trends and potential untapped markets for BEM to support widespread low-energy building, please see Section 6.

5.1.2 Opportunities for Improvement and Better Application

Can that energy model report be done tomorrow? How many LEED points will this building earn? These are the frequent demands of clients, architects, and project managers that can detract from the value of strategic energy modeling. In today's energy modeling world, practitioners spend a significant amount of time building, debugging, and reporting results, and are left with relatively little time to question results, explore alternatives, communicate opportunities to the design team, and push the implementation of key design recommendations. Design teams often introduce energy modeling too late in the game to really affect key design decision and instead use it as an accounting or code compliance tool to establish that minimum requirements are met. Used in this way, design teams overlook significant opportunities to inform and improve building design.

Equally important, design teams need to evaluate whether or not a whole-building energy model is the right application for a given problem. In some instances, a simpler, more "back of the envelope" type of approach may be more appropriate and sufficient for the level of accuracy required. This decision is typically based on reporting requirements and industry norms for when energy modeling is used. Instead, at the start of a project, the team should make a key evaluation and judgment to ensure that energy modeling is the best tool for a given situation.

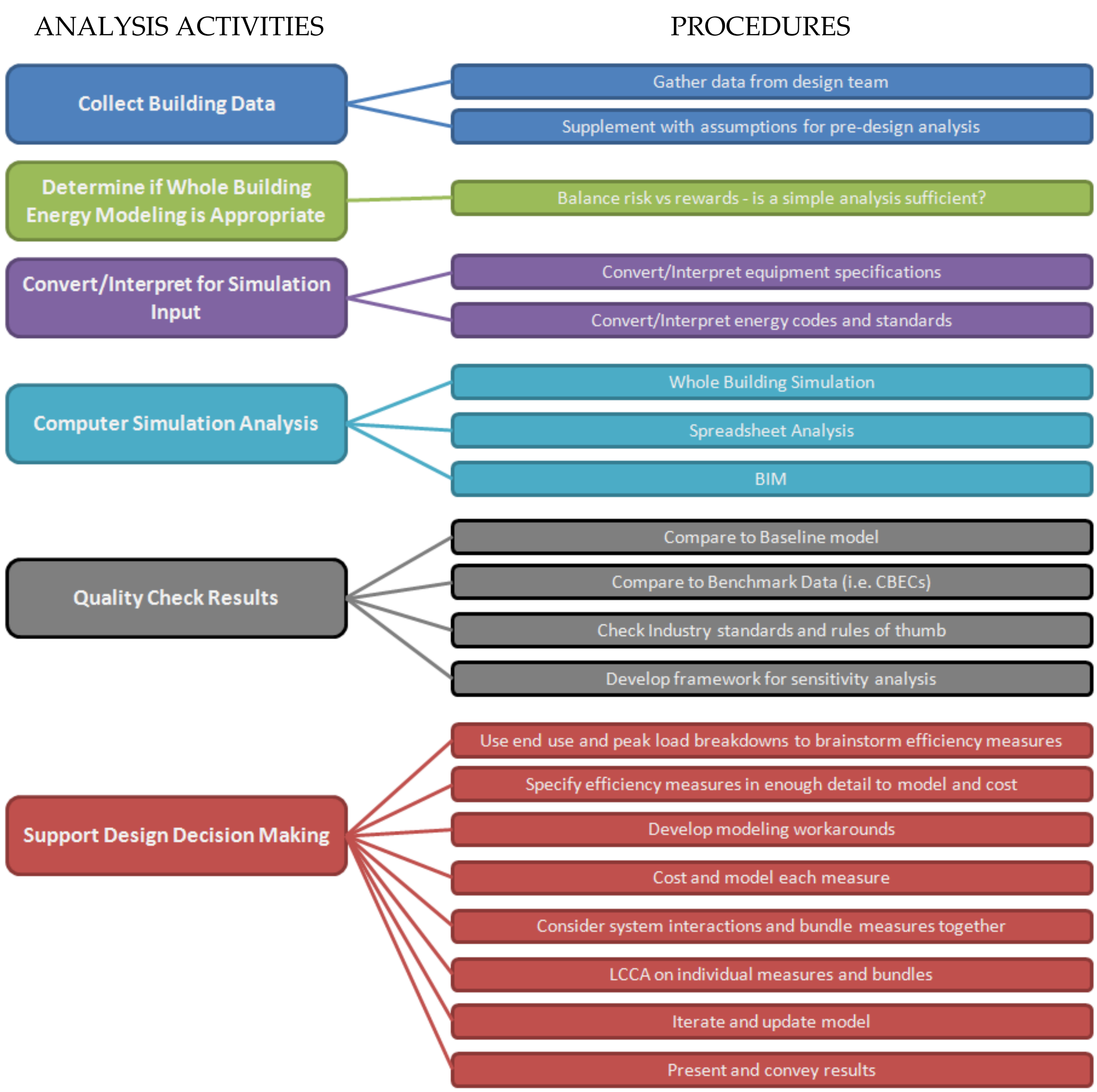
Finally, more work is required to educate and involve architects in the energy modeling process. A knowledge gap currently exists for the majority of licensed architects between today's standard design and construction practices and what will be required when high performance building codes, like the IgCC, begin to be adopted by municipalities in 2012. One of the largest areas of education and training needed for architects is how energy modeling can be used as an iterative, early design tool, by architects and engineers, through-out all stages of design. Architects also need to learn how to better present to a client what the results of an energy model mean (and why today's energy modeling software can't always predict the actual energy use of building).

Please refer to Section 6 on Market Opportunities for a discussion on future trends and uses that could shape modeling demand.

5.2 Modeling Tasks to Inform Design

This section outlines how energy modeling can be used to inform the design process. This is most applicable to new construction, although most steps apply to major renovations as well. As mentioned above, design teams often use energy modeling as an accounting or code compliance tool and fail to capitalize on all opportunities to inform and improve a building design. Properly used, energy modeling can provide outputs that optimize a building's energy consumption, reduce life cycle costs, and even reduce first cost. Figure 2 shows these steps and the procedures that modelers take throughout an effective analysis process.

Figure 2: Analysis Activities and Procedures for Modeling in the Typical Design Process



Of the procedures and tasks shown in the flowchart above, the following often prove to be the most difficult and/or time-consuming for practitioners:

- Determine if whole building energy modeling is appropriate
- Convert and interpret equipment specifications and performance baseline guidelines into energy modeling input
- The interaction of energy modeling and building information modeling
- The need to develop modeling workarounds to address limitations of software tools
- Performing and understanding sensitivity analysis
- Costing and modeling a variety of energy efficiency measures
- Present the results to make a compelling business case for low energy buildings

Because so many of these tasks are difficult and time consuming, energy modeling practitioners rely on a number of different supporting resources throughout this process. Please refer to Section 0 for a discussion and list of these resources.

5.3 Modeling Tasks to Inform Post Occupancy

New construction and major renovation projects can utilize energy modeling soon after construction and occupancy to reconcile actual performance with predicted performance and to calculate verified savings. Existing buildings can also benefit from modeling to explore the value of operational changes, equipment replacements or major renovation projects. In either application, the modeling process includes calibration to actual consumption, which includes reviewing utility billing data, collecting on-site survey data, and aggregating building performance data to support the model development and refinement. The depth to which calibration takes place (whole-building, end-use, system, or equipment) is dependent on the needs of the project, and the availability and level of performance data collected. In general, more data translates to more analysis time and greater cost. The cost should be justified based on the value (i.e. how much energy cost savings can be achieved for a project) of the study being conducted.

As part of the calibration process, actual performance data are compared to predicted performance data. Differences can indicate that modeling assumptions need to be further refined or that the building is not performing optimally. Completing this reconciliation process can reveal performance improvement opportunities not uncovered through the commissioning or audit process.

Practitioners can conduct measurement and verification (M&V) activities once the building is operating as intended and its operation has stabilized. Calculating verified savings allows an owner/investor to determine and report the value of their investment. There are four M&V Options (A, B, C, and D) that have been established as the industry standard through the International Performance Measurement & Verification Protocol (IPMVP). Two of the options involve modeling. Option B applies to system-level modeling and Option D applies to whole-building modeling. For either option, savings are determined by comparing as-built performance with baseline performance. The baseline may be defined based on the original existing building condition before renovation, or on a new construction standard (e.g. ASHRAE Standard 90.1 Appendix G). In either case, it is critical that the baseline model be adjusted for actual conditions not related to performance (e.g. weather, setpoints, number of occupants, operating hours, etc.). Energy modeling activities appear in Figure 3 within the context of a typical energy management process.

Figure 3: Analysis Activities and Procedures for Modeling for Post Occupancy

Of the procedures and tasks in the flowchart above, the following often prove to be the most challenging and/or time-consuming for practitioners to perform:

- Determine the right timing for a major renovation
- Gather all data (sub-metered end uses) required to build calibrated model
- Create custom weather files

- Identify and classify unknown parameters
- Estimate feasible ranges for Unknown Parameters
- Iterate to calibrate the model to address individual loads and QC results
- Develop modeling workarounds to address limitations of software tools
- Perform and understand sensitivity analysis
- Cost and model a variety of energy efficiency measures
- Present results to make a compelling business case for low-energy buildings

Because so many of these tasks are difficult and time-consuming, energy modeling practitioners rely on a number of different supporting resources throughout this process. Though many resources currently exist, there are gaps to be filled. Please refer to Section 0 for a discussion and list of these resources. Table 7 summarizes key resources for this application of energy modeling and highlights the gaps that exist.

Table 7: Supporting Resources for Post Occupancy Modeling

	Existing	Not Existing
Methods	▪ ASHRAE Guideline 14-2002 (soon to be updated) ▪ ASHRAE Research Project 1051 - Procedures for Reconciling Computer-Calculated Results With Measured Energy Data ▪ ASHRAE Research Project 1404: Measuring, Modeling, Analysis, and Reporting Protocols for Short-Term M&V of Whole Building Energy ▪ IPMVP Volumes ▪ FEMP M&V Guidelines ▪ ASHRAE Guideline 14	▪ Practical calibration application guide ▪ Practical M&V application guide(s)
Tools	• ASHRAE Research Project 1050: Inverse Modeling Toolkit (IMT) • Energy Explorer (Kissock, Univ. of Dayton) • U.S. Army M&V Costing Toolkit (Haberl, TAMU) • Visualize-It (KEMA formerly RLW Analytics) • PG&E Universal Translator • CCC Energy Charting and Metrics (ECAM) macro for Excel spreadsheet analysis • ASHRAE Research Project 1093 – Compilation of Diversity Factors and Schedules for Energy and Cooling Load Calculations • Plus 100s of tools related to energy modeling listed in the EERE Energy Modeling Tools directory	▪ Tools to streamline the calibration process ▪ Tools to support the data conditioning process ▪ Tools for developing modeling input from metered data ▪ Tools to support actual weather data file creation
Data Sources	• CBECs • Design rules of thumb • Performance metrics • ASHRAE 90.1 Standard energy end use schedules • Title-24 energy end use schedules • Publications providing end use loads and load shape data • Historical weather data	• Ranges of values for loads and load shapes of actual buildings • Database of plug and process loads

5.4 Funding

This section seeks to identify the most meaningful (not comprehensive) contextual aspects of funding for software tools, educational and training resources, professional organizations, and national labs, and to explain the resulting impacts to tool, research, and training development as they relate to the scope of the Summit. Many tools and organizations are not included, largely due to a lack of available data. In some cases, we highlight funding-related opportunities some Summit attendees (who are cited) advocated as we draft a roadmap for the future.

5.4.1 Department of Energy (DOE)

DOE budget is year-to-year and sensitive to the political cycle, the priorities of the current administration, the general state of the economy, and competing interests and programs. It is also line itemed at the program level (e.g., Building Technologies, Solar Energy Technologies, Vehicle Technologies, Wind and Water Power). This means that money can be reallocated within programs much more easily than it can be across programs. Once a budget passes, program allocations are law.[46]

Program budget requests (and the resulting appropriations) are based on priorities set by the president and secretary, and by pitches made by top-level program management, hopefully supported by commercial data and powerful voices from science, technology, and industry. Preference is given to programs that have a good chance of delivering "results" (e.g., energy savings, savings to consumers, new jobs) and to programs that have delivered results in the past. A similar process occurs within individual programs as smaller subdivisions (e.g., Standards, Codes, Commercial, Residential, Emerging Technologies and Tools within the Building Technologies Program) are rolled together for budget requests; funds are then parceled out for implementation after appropriations. This illustrates at a very high level how funds are appropriated from the DOE level down to the Buildings Technologies Program level, to BEM and then to individual BEM projects.[47]

The Building Technologies Program concentrates its efforts in *creating demand* for building energy efficiency. Building codes and appliance standards, for instance, are classic demand side tactics that the government is best positioned to wield. The Program also -- to a lesser degree -- tries to address supply services and products that the market, left to its own devices, could not create on its own either efficiently or quickly enough. Addressing supply is seen as a smaller role for the Buildings program because:

- the private sector is typically more efficient than the government at making things, and

[46] A. Roth, personal communication, February 25, 2011.
[47] Ibid.

- government products, which are funded by public money, are free-of-charge and therefore risk distorting the market or counter-productively discouraging private supply.

Government can more defensibly play a role on the supply side when:

- the government can fill a gap not addressed by private investment,
- expensive basic research is required, or
- aspects other than efficiency are important, like transparency, impartiality, availability, and auditability.

BEM tools are a supply side lever. Therefore, when the Buildings Technologies Program participates in BEM tools, it also needs to make the case that the government is not replicating, or interfering with, commercial actors. Government participation would have improved traction if there were more visible success stories on which to build.[48]

Funding allocation among individual BEM projects (research, development, training, education) is a balancing act because resources are limited. Amir Roth, Program Manager for Building Performance Simulation Tools, has taken the approach of trying to partner with other organizations and companies in addition to working through the DOE's national labs and historical contractors. External partnership allows the Program to get external feedback and validation that it is investing resources into projects the private industry is likely to steward after the explicit collaboration ends.[49]

5.4.2 California Energy Commission (CEC)

The CEC has two principal sources of funding for building energy modeling tool advancement and use in energy policy program deployment.

First, the Public Interest Energy Research (PIER) Program funds Research Development & Demonstration (RD&D) in the area of building energy efficiency. BEM tool advancement projects compete with all other building energy efficiency RD&D project proposals submitted into various types of competitive solicitations. PIER has successfully funded numerous BEM data and tool advancement projects over the last 15 years to support both residential and commercial building energy efficiency improvements. Public and private scientists and engineers working in national labs, universities, large consulting firms and small entrepreneurial companies have received PIER funding to complete these projects. The CEC's PIER Program rarely identifies specific BEM projects to fund but instead evaluates both solicited and unsolicited proposals and selects projects to fund based on PIER staff understanding of market needs and project suitability for receipt of public RD&D funding. This type of project selection process could be improved in the future to better advance BEM

[48] A. Roth, personal communication, February 25, 2011.
[49] Ibid.

data and tools. For example, the BEM community (such as that gathered for this Summit) could develop criteria for BEM data and tool RD&D project selection and/or suggest specific project areas that deserve priority consideration within a public goods RD&D program.[50]

Second, the CEC's High Performance Buildings and Standards Development Office has an annual contract budget of approximately $2.5M. These funds are largely used to fund technical support service contracts, which provide professional consulting services to CEC staff in the development and implementation of state energy efficiency policy programs such as the Building Energy Efficiency Standards (Title 24, Part 6), existing building energy performance rating programs, and existing building energy efficiency improvement programs. A relevant example is the CEC's current solicitations for teams of consultants to specify, develop, and demonstrate software that will implement the performance standard requirements for the 2013 update of Title 24, Part 6. These solicitations seek involvement by the BEM community in three ways:

1. building science processionals with BEM expertise are encouraged to participate on the consultant teams responding to the solicitations,
2. each contract resulting from the solicitations will use a Program Advisory Committee made up of building science professionals and policy makers to guide the BEM tool development activities undertaken by the CEC, and
3. one task in each contract includes demonstrating the use of performance standard compliance plug-ins in third party BEM tools.[51]

One significant additional source of BEM tool funding in California is through the public goods charge (PGC) energy efficiency programs administered by the Investor Owned Utilities. For example, this is the source of funding principally responsible for the initial release of eQUEST (please see below). Funding decisions are not coordinated or discussed between the funding parties listed above in any explicitly organized way. This has resulted in BEM tools designed for very specific purposes, with different ownership/licensing/availability, with little to no opportunity to leverage each other's work, or develop derivative tools and share common software platforms. According to Martha Brook of CEC’s High Performance Buildings &Standards Development Office, the CEC is very interested in planning collaborative, open source BEM tool development using all possible sources of public funds in the future.[52]

5.4.3 Software Tools

The primary determining factor for how a tool is developed and funded depends on whether a tool is proprietary. Here, we delve into more detail on two freely available,

[50] M. Brook, personal correspondence, February 24, 2011
[51] Ibid.
[52] Ibid.

publically funded tools and one proprietary tool. Please refer to Appendix C for a description of many additional widely used simulation tools, and indications of which are publically funded. Those not listed as publically funded are proprietary programs.

eQUEST:
The ongoing development of eQUEST is funded in the majority (close to 90%) by money from the California ratepayer Public Goods Charge (PGC) energy efficiency programs. eQUEST is made available to the public for free through this funding source, but because utilities are the primary conduit for how that money is spent, it follows that the large majority of proposed changes and improvements that are ratified are those that support the implementation of specific utility efficiency programs. Typical proposals from utilities include requests to enable modeling of a specific technology, or generation of specific outputs as required for utility program reporting. The key decision makers for what is ultimately funded are utility project managers, who can choose to fund between one- to two-thirds of proposed changes based on the money available and the current priorities of efficiency programs.[53]

There have been instances when user suggestions have been funded based on public good and universal demand arguments, but those are the exception rather than the rule. For example, the added functionality in 2010 to allow for LEED baselining was a repeated user suggestion that ultimately passed because of an overwhelming demand for documenting and supporting increased LEED certification. [54]

EnergyPlus:
The DOE developed EnergyPlus, and provides close to 95% of the funding that supports the ongoing national lab development of that software tool. The other 5% includes contributions from various entities (i.e. universities, manufacturers) with a particular interest in developing the program to model specific technologies.[55]

The DOE's development of EnergyPlus was in support of the analysis of energy standards, using a modular program that would be relatively easy to update (in comparison to DOE-2). Initially, DOE researchers added new features based on the DOE's observation of user market demand. The DOE also prioritized supporting California Energy Commission (CEC) analysis needs. Over the last 5 to 6 years, a long list of proposed enhancements (several hundred) have accumulated; these are reviewed every year or so to determine priority and feasibility. Proposed enhancements vary greatly in scope and budget requirements. Priorities include:

- Responding to user feedback;
- Supporting California Energy Commission analyses;
- Supporting other DOE building research; and

[53] S. Criswell, personal communication, January 4, 2011.
[54] Ibid.
[55] D. Crawley, personal communication, January 6, 2011.

- Responding to software developers who interface to EnergyPlus.[56]

The DOE allocates a rough three-quarters of available funds to the support of new features and enhancements to the program. The remainder is spent in part to fund support services like user-support, training and education. EnergyPlus organizes 2-3 workshops annually, and has trained a total of close to 1200 individuals since inception. Attendees range widely between commercial simulation practitioners and university students. [57]

Transient Systems Simulation (TRNSYS):

Until the end of the 1990s, the DOE funded TRNSYS development (along with the development of other energy modeling software tools such as DOE2, Blast, HVACSim+, and some others). DOE funding for TRNSYS ceased in the late 1990s with the decision for the DOE to concentrate its efforts on the development of EnergyPlus. Since then, TRNSYS has been largely self supported. Revenue from sales is reinvested into development. Developments that take place during consulting projects also (when possible) inform the software package.

5.4.4 Professional Organizations

American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE):

ASHRAE is a largely membership driven entity. In terms of establishing overarching direction and strategy, a volunteer-based Board of Directors and Councils are tasked with setting broad priorities for the Society. Technical Committees and various other working groups then carry out actual implementation. While Technical Committees most often adhere to the strategic plans established by the Board and Councils, they also operate with a fair amount of autonomy. When it comes to addressing new or urgent needs, ASHRAE has a lot of flexibility to establish a committee or other type of working group, even when designated funding is not explicitly yet in place.[58]

ASHRAE funds a fair amount of research, sometimes as co-funders and largely as primary funders. Research proposals and projects are managed through a process (primarily carried out by the Technical Committees) that identifies research needs, identifies research institutions to execute the studies, and then oversees the execution of the research.[59]

U.S. Green Building Council (USGBC):

The USGBC is a non-profit funded in large part by the following diverse revenue sources: membership dues, fees for educational services, fees from LEED building

[56] D. Crawley, personal communication, January 6, 2011.
[57] Ibid.
[58] C. Wilkins, personal communication, 01/14/2011.
[59] Ibid.

registration and certification, and fees from hosted conferences and meetings. To a much smaller degree, additional funds are provided through grants, sponsorships and investments.[60]

The USGBC Board of Directors is primarily responsible for articulating and upholding the vision, values, and mission of USGBC. Board composition is intended to represent a diverse range of perspectives related to the green building industry; directors are elected by USGBC membership or appointed by the Board to represent specific perspectives.

The Strategic Planning committee, established by the Board of Directors, set the strategic goals and objectives for the organization's current five-year strategic plan (2009-2013). In that process, the committee identified and assessed relevant trends and issues to the green building industry through engagement and interviews with board members and diverse member and non-member organizations, including local and regional member chapters. The Executive Management Team is then responsible for establishing metrics, criteria, and identifying specific tactics and action items to carry out the plan.[61]

International Building Performance Simulation Association (IBPSA):
IBPSA is a non-profit international society of building performance simulation researchers, developers and practitioners. The Association is run by volunteer efforts; priorities are member-driven, and membership is free. The majority of Association revenue is generated from IBPSA-hosted conferences and invested back into Association operations and efforts.

IBPSA has 20 regional affiliates, of which IBPSA-USA is one regional affiliate. IBPSA-USA itself has various regional chapters. IBPSA and its regional affiliates are typically not funding R&D in BEM, but rather use their resources to exchange knowledge among its membership through conferences, meetings and publications. However, starting last year, IBPSA-USA has been investing some of its resources in the development of education material in the form of energy modeling workshops and wikis. The funds are primarily used to augment gaps that are not already addressed by larger funding entities, that are of broad use to its membership, and that are aligned with its mission.

The funding priorities are determined by the Board in consultancy with its membership. The primary activities of IBPSA and its regional affiliates are to organize a world-wide annual conference every two years, with local conferences in the years

[60] U.S. Green Building Council. (revision date not available on USGBC site) Retrieved 02/21/2011 from http://communicate.usgbc.org/2008/
[61] U.S. Green Building Council, 2008. "U.S. Green Building Council Strategic Plan, 2009-2013," p.19.

between. A major activity within IBPSA and its regional affiliates is also the dissemination of research results through its conferences, through the Journal of Building Performance Simulation, the IBPSA Newsletter, and various local meetings.

Institute for Market Transformation (IMT):

The IMT is a non-profit organization promoting energy efficiency, green building and environmental protection in the United States and abroad; programs at the IMT include technical and market research, educational outreach, and the crafting of building codes and other policy and program initiatives. The majority of IMT funding is provided through foundation grants including the Energy Foundation, Kresge Foundation and the Climate Works Foundation, which has selected IMT to house the US hub of its Global Building Performance Network. Limited contracts with federal, state, and municipal agencies and jurisdictions address specific research targets.[62]

IMT funders are unusually tolerant of risk. This has allowed IMT to pursue high-risk, high-reward projects like COMNET. IMT engages with Capitol Hill, the DOE and EPA, BOMA, USGBC, and other NGOs to ensure the Institute is aware of current developments, emerging needs, and future opportunities. Funders typically empower IMT to select policy programs for its portfolio, and IMT bears the responsibility to funders for the efficacy of these programs. In effect, IMT shares the risk and credit with its funders but reserves strategic planning for itself. As a small organization, the executive director seeks census among the staff for priorities, strategic directions, and changes.[63]

5.4.5 National Laboratories

National laboratory work and research is funded mostly by the DOE and must respond to overarching DOE strategic plans; however, different types of research are funded by different entities within the DOE, along different time frames and with different motivations. The Office of Energy Efficiency and Renewable Energy (EERE) typically funds all building-related national labs work, and is focused on proposals with 1- to 2-year or 3-year development and deployment horizons. The Office of Science funds fundamental research in the areas of mathematics, super-computing, and physics, focusing on 5+ year investments with longer development and deployment horizons.[64]

This gap in investment horizons (very few projects in the 3-5 year investment window) has potentially important ramifications for how energy simulation research projects are shaped and executed by the national laboratories. For example, under the current protocol, a proposal to change code for energy modeling is most likely to happen within the 1 to 2-year project horizon, and approached from a standpoint of

[62] R. Nelson, personal correspondence, February 26, 2011.
[63] Ibid.
[64] M.Wetter, personal correspondence, February 24, 2011

incremental improvements. Fundamental changes to energy modeling code, however, are potentially more appropriately addressed in the 3- to 5- year time horizon. There are potentially many other tools and investigations that fit into the 3- to 5-year time horizon, which require significant investment upfront before they are can be matured, distributed, or compete with established methods or software. The amount of money spent on research and development in energy and building energy modeling is a fraction of what is allocated for research and development in other large industries. This is a potential window where government can develop a productive role in the next years to come.[65]

5.5 Methods & Processes

Standardization of energy modeling methods and processes improves reproducibility, increases accuracy, builds confidence in results, supports streamlining, and promotes adaptability to future changes in the modeling process (e.g. code updates). Specific areas of energy modeling that could benefit from standardization include:

1. Baseline definition
2. Calibration of existing building models
3. Quality assurance (QA) and quality control (QC)
4. Sensitivity analysis
5. Uncertainty analysis

Some initial steps have supported the standardization of energy modeling methods, including:

- The ASHRAE 90.1 Performance Rating Method (PRM): Outlines procedures for defining a baseline and proposed design building for making relative performance comparisons.
- ASHRAE Guideline 14 – 2002/2010 draft: Establishes a minimum acceptable level of performance in the measurement of energy and demand savings from energy management projects Provides instructions for model calibration. Outlines uncertainty analysis methods.
- IPMVP Volume I and III – Provides industry-accepted procedures for verifying energy savings from energy efficiency projects. Option B and Option D utilize component and whole-building models, respectively. Includes uncertainty analysis.
- The Title-24 Alternative Calculation Manual: Specifies methods for translating code compliance data into model input and calculations for describing the baseline and proposed design buildings.
- The Commercial Energy Services Network (COMNET): Defines a framework for organizing multiple sets of compliance data and uses rules to translate it into model input. System also seeks to standardize output reporting and develop professional accountability standards.

[65] M.Wetter, personal correspondence, February 24, 2011

- Rethinking Percent Savings (AEC and SCE): Proposes a new more stable scale to replace present savings with a score of 100 representing average energy consumption at the turn of the millennium with net-zero as 0.
- Professional training workshops focused on methods: For example, the IBPSA BEM Workshop presents information on fundamentals, ASHRAE PRM, modeling during the building life cycle and best practices.
- Building Energy Modeling Body of Knowledge (BEM Book) Wiki: Outlines a comprehensive body of knowledge to support building energy modeling
- ASHRAE Research Project 1051 – Procedures for Reconciling Computer-Calculated Results with Measured Energy Data
- Various technical and conference publications

Within the industry, a "surplus" of baselines are compared against proposed-design models for determining relative performance. Baseline definitions include: CBECs/Energy Star Benchmark data, ASHRAE 90.1, Title-24, local code, existing building conditions, etc. Some of the different modeling applications and their baselines are summarized below:

Federal Tax Deductions	• ASHRAE 90.1-2001 with ASHRAE 90.1-2004 Appendix G with Title-24 building operating schedules
LEED Building Design + Construction Rating System	• ASHRAE 90.1-2007 PRM
Local Energy Code Compliance	• Baseline varies by location
Absolute ratings like the Zero Energy Performance Index	• Proposed 2003 CBECS by building type and climate zone
Incentives offered through utility demand-side-management programs	• Various baselines

Having multiple baseline definitions introduces added complexity for interpreting model inputs. In addition, modeling time requirements increase if modelers must use more than one baseline to satisfy different project application requirements (e.g. LEED, Federal tax credits, code compliance, etc.). Also, as the "Rethinking Percent Savings" report points out, performance comparisons based on percent savings past a code minimum become unstable as policy and codes approach net zero.

The COMmercial energy services NETwork is a new system for assessing and rating the energy efficiency of commercial and multifamily buildings. The COMNET Building Energy Modeling Guidelines and Procedures (MGP) support the standardization of energy modeling in several ways, including: accurately specifying the baseline building and restricting operating assumptions. It currently includes calculation procedures for federal tax deductions, LEED 2009, and Title 24. In the future it will incorporate other standards, such as the zero energy performance index (zEPI). COMNET is in the initial stages of development and the industry has not fully vetted its methods. Current concerns about its procedures stem from its roots supporting the DOE-2 simulation program, which is one of the oldest energy modeling codes. This may force newer programs to adhere to old methods – possibly diverting evolution and innovative efforts.

Modeling professionals with degrees in architectural engineering, mechanical engineering, or other related degrees have a strong foundation from which to build modeling skills. But given the current lack of standardization, even modelers possessing fundamental concept knowledge must develop their own ad-hoc approach to modeling methods, including:

- Converting manufacturer's data to model input data (design, part load, etc.)
- Translating ASRHAE 90.1 PRM directives to modeling input
- Characterizing the performance of energy conservation measures to develop model input data
- Developing workarounds outside of the simulations tools to model technologies that are not adequately addressed with the tools
- Reviewing single run input data for error checking
- Comparing multiple run input data for consistency
- Extracting key output data and reviewing for reasonableness
- Comparing output data to benchmark data, metrics, and other runs
- Extracting results and completing rating system submittal forms

The need for modelers to develop in-house procedures for many modeling steps contributes to a lack of consistency and reproducibility across service providers. In addition, it causes practitioners to rely upon a piece-meal analysis approach, which contributes to increased errors, labor inefficiencies and high service costs.

IBPSA's efforts to develop trainings and information resources (described in detail in Section 5.7.3) should prove valuable for supporting the industry. Their initial work could be leveraged through coordination with different industry stakeholders to share development of a common knowledge base.

As outlined above, lack of standardized, vetted methods for energy modeling has vast implications. However, the area of greatest concern may be the effect upon modeling credibility (refer to Section 5.8.10 for more detail). Many building owners and design teams are questioning the ability of energy models to predict actual energy savings for efficiency projects. This perception detracts from the benefits that modeling offers the industry. It is also important to keep in mind that while standardization may be beneficial for the majority of today's users, standardization could also inhibit true innovation. Any attempts at standardization should address this and take steps to avoid investing into the wrong approach.

The following sections describe in more detail two modeling areas that would greatly benefit from standardization – quality assurance (QA) and calibration. Incorporating quality assurance procedures into one's modeling practice is important for all modelers, but critical for less-experienced modelers who are also the most likely to exclude them. Thus, standardizing quality assurance procedures will support the modelers that need it the most. Calibration can benefit from standardization because it is a multi-step, time-consuming process that relies on significant professional judgment. Standardizing the approach will help streamline the process and allow practitioners to focus on its more critical elements.

5.5.1 Quality Assurance Procedures

The design of a simulation program can support or detract from performing building energy modeling QA. Typically, most programs only allow acceptable ranges of input values and provide reasonable default values. Some simulation programs provide quality assurance reports, which check results relative to the Commercial Building Energy Consumption Survey (CBECs) data and/or expected equipment operation. In general though, the bulk of quality assurance responsibilities fall to the modeler.

A survey of a few local energy modeling consulting firms revealed a range of QA efforts that includes:

- no formal procedures,
- check list review by senior staff, and
- pre- and post-processing in-house tools for running parametrics and comparing output of key performance parameters.

Ideally, modelers should incorporate and complete QA as part of the modeling methods that they regularly employ. Nominally this would include: checking input values for errors and checking output values for reasonableness through parametric analysis and by making comparisons with performance metrics. Since there is little direction provided by the industry regarding QA, it is difficult to speculate the level at which formal procedures are typically employed.

A major obstacle to effective QA is the vast amount of input and output data that a modeler needs to manage. While published values of building performance metrics are available, it is not a simple process to compare them to run results since modeling programs can produce 1000s of pages of output data. To make these comparisons requires extracting data manually or developing post-processing tools. It can also be challenging to manage and examine the results from a series of different modeling runs (e.g. representing incremental changes made to the model). Thus to save time, modelers combine packages of design options into a single run. This practice makes it more difficult to detect errors by examining changes in performance.

Below, we provide an outline of helpful procedures that modelers can incorporate into their methods to support quality assurance. We expect more rapid adoption, however, if they become standardized as part of simulation program design.

- Use parametric analysis and work from a single base input file to complete all runs
- Check base input file and run results against benchmarks and metrics defined at the building, plant, system, and equipment level
- Perform runs incrementally by changing one parameter value at a time
- Make side-by-side comparisons of parametric run input values
- Make side-by-side comparison of parametric run output values
- Follow a QA self-check list that lists common modeling issues to check
- Incorporate a QA process throughout the modeling process that includes checking in with more experienced modelers.

5.5.2 Calibration Procedures

Calibration is the process for refining assumptions modelers made during design and updating the as-designed model to represent as-built conditions. Unless calibration occurs, the model created as part of the design process cannot be expected to reflect actual performance. Calibration relies on a multi-step process that requires the modeler to coordinate with other building professionals (facilities managers, commissioning agents, auditors, etc.), collect metered data, survey data, and audit data. Some of the steps associated with model calibration, include:

- During design or auditing, identify metering needs based on owner's needs, at-risk savings, and verification of modeling assumptions. Coordinate with commissioning agents or building operators to ensure that meters are in place.
- Collect building information including utility billing data and climate data.
- Collect on-site data, including: occupant surveys, facility manager interviews, and information characterizing the building systems and operations.
- Collect metered data through energy management systems or stand-alone meters.
- Transfer the collected data to a spreadsheet or data base. Review the data for gaps and errors. Condition the data so that it has the same time stamp and time step as the modeled data.
- Create a weather file for the project location and appropriate timeframe. This often requires gathering hourly data from various sites, scaling and converting the data, and converting the file into the appropriate format for a given simulation tool.
- Update the energy model to reflect as-built and/or actual operating conditions. Perform preliminary calibration by comparing results against utility billing data.
- Compare selected metered data against predicted performance data. Evaluate for additional savings opportunities or modeling assumption refinement.
- Perform sensitivity studies to bound the calibration problem. Identify strong parameters and possible range of values.
- Evaluate how well the modeled performance and actual performance compare by calculating calibration criteria. Refine model until criteria values are within the recommended range.

It is apparent from the calibration task list that the process can be quite time consuming and subjective. An ASHRAE sponsored research project, *ASHRAE RP 1051 - Procedures for Reconciling Computer-Calculated Results with Measured Energy Data*, investigated a statistical approach for automating the calibration process. While the report is a valuable reference for calibration, the method is not practical for today's practitioners to employ since it requires ~ 3,000 simulation runs to bound and solve the problem. Finally, the report concludes that "… a detailed simulation program involving numerous input parameters is a highly under-determined problem (i.e., the presence of too many parameters is likely to result in any solution being non-unique)." While it is inevitable that calibration requires the modeler to exercise professional judgment, standardization efforts could help to streamline the process and promote reproducibility.

The principles of RP-1051, in particular the use of goodness-of-fit that accounts for both bias and hourly variance errors, has been implement by Clean Urban Energy (CUE). CUE initiated a demonstration project in 2008 in Chicago that currently has fifty-six buildings enrolled, thirty-one audited, and nine modeled. Their web-based technology utilizes models for real-time predictive control planning of cost-saving HVAC strategies. The strategies account for weather effects, real-time price incentives and demand response signals to accurately predict hourly usage. In 2010, CUE plans to demonstrate its on-line, automated version of their technology in fifty large buildings in Chicago.[66]

Other recent efforts to standardize the calibration process are described below.

ASHRAE Research Project 1404 – Measurement, Modeling, Analysis, and Reporting Protocols for Short Term M&V of Whole Building Energy Performance (Due 1/2012): Identifies analysis methodologies using field monitored data for less than one year that meet preset accuracy levels of determining verified annual performance savings. Employs a multi-parameter heating and cooling change-point model approach.

BESTEST-EX: An NREL research project to test software predictions of retrofit energy savings in existing homes. The method ensures calibration procedures perform up to a minimum standard and quantifies impacts of data uncertainties.

Residential Automated Calibration Tool for Code Compliance – A TAMU research project utilizing code-compliant simulation and ASHRAE Inverse Modeling Toolkit. Includes a calibration method to automatically calibrate the code-compliant simulation from weather and utility bill data.

[66] Personal communication with Gregor Henze, February 15, 2011

5.6 Simulation Engines & Platforms

5.6.1 List and Summary of Whole Building Simulation Tools

This section summarizes the major building energy modeling tools. It is a small sampling representing the tools most widely used today's U.S. markets. All summaries except for IES Virtual Environment are directly from the U.S. Department of Energy office of Energy Efficiency and Renewable Energy's Building Energy Software Tools Directory available at:

<http://apps1.eere.energy.gov/buildings/tools_directory/subjects.cfm/pagename=subjects/pagename_menu=whole_building_analysis/pagename=subjects#T>

The tools are categorized into 'Simulation Engines', 'Graphical Front-Ends', and those that exhibit both capabilities. The programs that are publically funded and/or free are labeled accordingly. For-profit companies develop all of the other programs listed. As discussed in section 5.9, we recognize funding sources as a major driver behind the direction of tool development, and thus important to address.

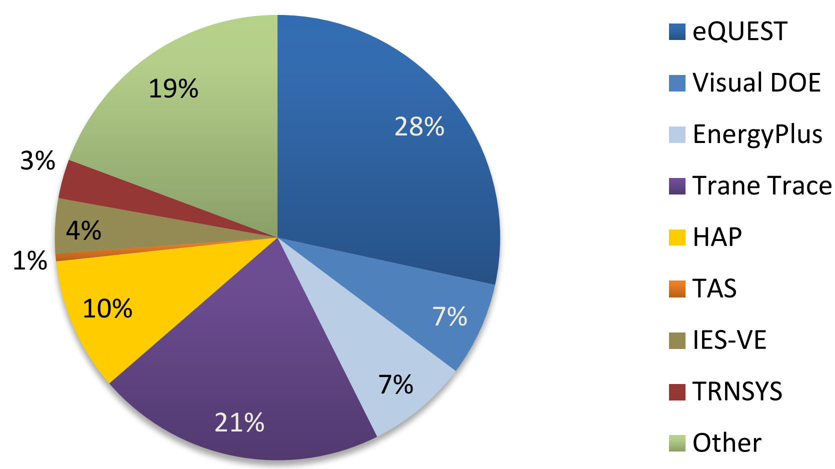
Table 8: Categorization of Major Simulation Tools

Engine	Interface	Publically Funded	Free
DOE-2.1e	EnergyPro		
	VisualDOE	✓	✓
DOE-2.2	Autodesk GBS		
	eQUEST	✓	✓
Energy-10		✓	
EnergyPlus	Bentley Hevacomp		
	DesignBuilder		
	OpenStudio	✓	✓
HAP	HAP		
IES-VE	IES-VE		
TRACE	TRACE		
TRNSYS	TRNSYS	✓	

See Appendix C for detailed descriptions of each tool.

It is also informative to examine tools that are most commonly used amongst active practitioners. To determine this, we gathered data from a total of 94 individuals at three recent training sessions hosted by RMI and sponsored by IBPSA-USA and ASHRAE. The RMI training sessions are considered to be tool-neutral because they focus on building physics behind energy modeling, ASHRAE's Performance Rating Method, best practices and quality control, and how to use energy modeling effectively as part of an integrated design process. Although every tool has its own training courses specific to that tool, this course intentionally focuses on topics that apply regardless of the tool chosen.

Figure 4: What Tools are Being Used for Energy Modeling?



The DOE-2 related programs appear to be the most popular in the current market, with Trane TRACE also commonly used. The 'other' category includes EE4, EnergyPro, Elite, ESP-r, and BLAST.

We also examined the total number of unique downloads of several programs in order to understand the magnitude of the industry. Appendix D outlines the total number of downloads from specific programs.

5.6.2 Other Energy Analysis Tools

It is important to note that energy analysts do not limit themselves to using the whole-building, hourly simulation tools described above. Practitioners also make use of agile front-end tools such as Ecotect, Project Vasari, Hevacomp, Climate Consultant, Energy Scheming, Google Sketch-Up and others to help shape the direction and focus of early design. There is a need for modelers to get into the design process early and nimbly and high-level analysis, using very simplified tools, can inform the direction of design without performing detailed energy analysis.

The use of Microsoft Excel also plays a major role within energy analysis, including, but not limited to:

- early design evaluation of strategies based on hourly weather data;
- manipulation of hourly weather data for hourly simulation programs;
- pre-processing of required inputs to hourly energy models; and,

- post-processing of hourly energy modeling results to account for strategies that cannot be directly simulated within the tools.

5.6.3 Building Information Modeling (BIM) Tools

Building information modeling (BIM) is a process that involves the use of computer programs to represent a building as a system of parametrically defined 2-d or 3-d objects. The BIM modeler defines components of the building in relation to each other, allowing component and spatial relationships to be quickly changed and modified. BIM facilitates not only automatic checking of spatial conflicts, but also informs the design team throughout the design process. BIM is an important tool for examining design trade-offs because of its capabilities in lighting, acoustic, and energy analysis, as well as examining material costs.[67] The BIM world has recognize the need for improving interfacing capabilities with other programs, such as building energy simulation, and this is a key development area.

Autodesk and Bentley are the two major players in the building information modeling software industry. Both are working to integrate building energy modeling with building information modeling, and have used acquisitions to jumpstart this process. Autodesk currently offers several products that integrate energy modeling with BIM. Green Building Studio is a web-based energy modeling tool, and it allows individuals to input their architectural model developed in a program such as Revit. This program converts the BIM file into a readable gbXML format, and provides the user with a DOE-2.2 or an EnergyPlus file. Autodesk also offers Conceptual Energy Analysis in Revit and Project Vasari. Both of these tools are intended for use during the conceptual design phase and allow the user to download DOE-2.2 or EnergyPlus file from directly within Revit.

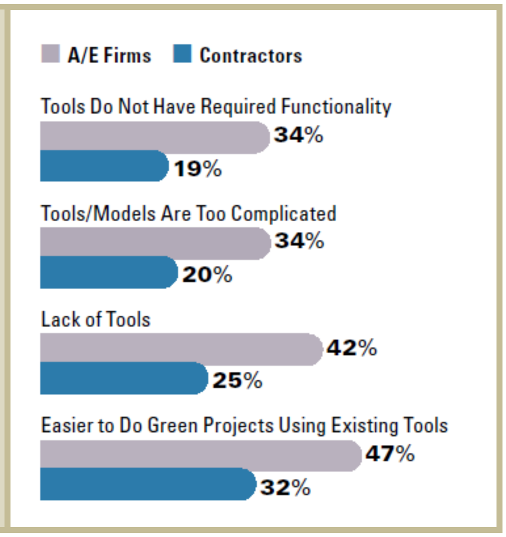
Bentley currently offers Hevacomp v8i and Tas Simulator V8i BIM programs. Hevacomp V8i runs on an EnergyPlus platform, whereas the Tas Simulator V8i runs on a custom-designed simulation engine. Hevacomp and Tas Simulator V8i have the ability to import gbXML from other Bentley programs. Both Bentley energy simulation programs are used for energy simulation and compliance analysis.

There are a few key obstacles to achieving more widespread adoption of BIM. One obstacle is that practitioners perceive the tools to be difficult to use and therefore do not demand it. The other is the actual limitation of current tools. The McGraw-Hill Company outlines both of these obstacles in their 2010 GreenBIM SmartMarket report. The perceived difficulty of tool use is a more general obstacle to overall BIM adoption (see graphs below).

[67] Eastman, C. (2009, August). *Building information modeling*. Retrieved from http://bim.arch.gatech.edu/?id=402

Figure 5: Factors Behind Not Using BIM for Green Projects[68]

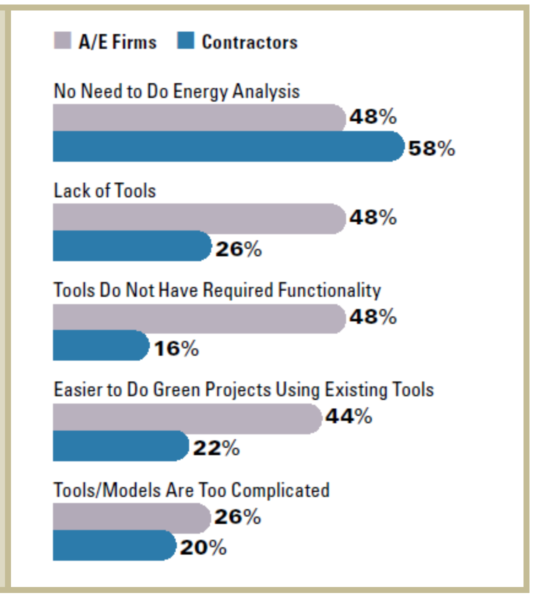
47% of A/E firm respondents to the McGraw-Hill Study cite that it is easier to do green projects with existing (non-BIM) tools.



Further, these obstacles are preventing the widespread use BIM for energy performance simulations (see Figure 6). A major limitation is the software integration between BIM tools and energy simulation software and facility management software. In both cases, the software cannot utilize the depth of data available in BIM models, often requiring models to be rebuilt in the other software programs because the information cannot be transferred between programs.

Figure 6: Factors Behind Non Use of BIM for Energy Performance Simulations[69]

A general lack of demand for energy modeling is another barrier, as 58% of contractor respondents to the McGraw-Hill study cited no need to do energy analysis.[70]



[68] Bernstein, H. McGraw-Hill Construction, SmartMarket Report. (2010). Green BIM: How building information modeling is contributing to green design and construction.
[69] Ibid.
[70] Ibid.

The limitations of current tools are a barrier to further adoption as well as a hindrance to future development plans for BIM. Individuals cite improved interoperability between BIM and building energy modeling software, as well as between different aspects of the BIM process, as a critical area for improvement. Interoperability is not just important for building energy modeling, but for greater capability of BIM programs in general.

Quality of translation is another issue. John Kennedy and Kyle Bernhardt of Autodesk note that WYSIWIG (what you see is what you get) is a major goal for the future of BIM and energy modeling integration. While gbXML has the capability to import any data necessary for an energy model, the exporting process requires additional conversion, which does not necessarily result in a 1-to-1 ratio.

While building information modeling is the place of record for construction documentation, it is not currently the place of record for energy modeling data. When BIM becomes the place of record for analytical data, materials properties, and schedules of operations, it will have greater capability to predict building performance and perform lifecycle cost analysis.[71] Building information modeling has the potential to provide integration of many aspects of building performance in one software package, making building energy modeling more accessible to the construction and A/E industry.

5.6.4 Common Barriers and Demands

The ground rules for the Summit prohibit the discussion of pros and cons of specific tools. Instead, we feel it will be more productive and collaborative to focus on common demands placed on, and barriers faced by, all software tool developers. Table 9 summarizes these demands and barriers related to the development of building energy simulation engines and platform interfaces.

[71] J. Kennedy and K. Bernhardt, personal communication, January 28, 2011

Table 9: Summary of Common Issues Faced by BEM Software Developers

Barriers/Limitations	Demands on Software Developers
Need for Better Communication: - of practitioners' needs to developers - between the researchers and developers	Tools are expected to bridge the gap from performance modeling methods and equipment specifications to model inputs
Development efforts are expected to satisfy many different stakeholders and user groups with conflicting needs (see Table 5). There is a lack of industry knowledge about tradeoffs in modeling accuracy and versatility.	Conflicting features: - simple and complex at the same time - improved accuracy without increased computation time
Issues with new algorithm development: - Methods for developing new algorithms vary across tools, and there is no consistent 3rd party validation that empirically addresses algorithm verification - Time lag between algorithm development and standard of verification	A shorter time lag is desired between the market release of new technologies and their incorporation into modeling tools.
There is a shortage of people who are qualified to develop these tools: requires knowledgeable of cutting-edge (i.e. fast) numerical solution techniques, building physics, fundamentals of energy transfer, and programming language.	The end user community is demanding higher quality and reproducibility from energy modeling results.
Funding/Market Barriers: - The market doesn't understand the value of improving the building physics capabilities of simulation tools - Gaps in 3-5 year EERE investments for tool development - Free, publicly-funded tools compete with the market for privately-funded tools	Improved quality control and automatic features within existing software tools are desired
Lack of perceived risk among BEM software developers vs. other modeling industries.[72]	More integrated tools with better application of numerical methods
There is lack of data with uncertainty distributions to quantify the expected variability in predicted energy use	Users demand better modeling capabilities to perform optimization and sensitivity and uncertainty analysis
There is no standard to exchange and share the investment in models across different tools.	User want better capabilities for modeling building operation and control sequences
Successful integration with BIM requires: - more robust data attribution in BIM, such as thermodynamic properties of materials - the ability to communicate the right data between programs, such as HVAC sizing - Improved data availability	Users want an easy way to convert and share data between tools and a more streamlined process for converting and importing 3D building model data and into energy modeling programs.

[72] The risk of poor execution is increased energy demand, which is rarely visible to the user. This is in contrast to other industries (i.e. aerospace or automotive) in which poor execution can result in fatalities or product recalls.

Algorithm Development Process

While the word "algorithm" is often used for numerical solvers, in this pre-read, we use it to refer to the defining equations and conditions used to represent the physics of various aspects of building systems.

There currently exists no vetted process for algorithm development. While a lack of such a process may be more conducive to innovation, it also poses concern, as the absence of a review process could allow bias to be incorporated into simulation engines.

BEM programs rely on user feedback, software interface developer feedback (in the case of EnergyPlus), and feedback from vested funding parties (in the case of eQUEST and EnergyPlus) to annually prioritize general and algorithm-based changes. When applicable, this prioritization is often heavily influenced by the funding sources.

eQUEST, publicly funded by California ratepayer public goods charges, must strongly consider needs and desires from California utilities.[73] Although the DOE primarily funds EnergyPlus, it must also balance addressing both user needs and feedback from the CEC and DOE buildings research areas. Matt Biesterveld of Trane Commercial Systems sees the tie to user demands and that associated level of detail as often lost in a research environment.[74] He notes that development priorities may lean toward research specific needs rather than popular systems such as variable air volume.[75]

The method of TRNSYS code development operates quite differently from that of other programs. Once users must purchase a license to access the source code, they are free to add component models into the package. "Official" development of the package is still completed by the software's producers. Some of the development is prioritized based on user requests. But, since the producers are also some of the most prominent users, it is mainly prioritized based on what enhancements they need to improve their own work flow. The open source is more of a method whereby users can look at how the code works to verify performance.[76]

As a private company, TRACE can focus on user feedback, and relies on data from ASHRAE, national labs, and internal lab work to develop its algorithms.[77] However, Scott Criswell of SAC Software notes that corporations also have vested interests in the modeling of a particular technology, and there exists no process to ensure an accurate BEM representation of that technology.[78]

[73] S. Criswell, personal communication, January 5, 2011
[74] M. Biesterveld, personal communication, January 18, 2011
[75] ibid.
[76] D. Bradley and T. McDowell, personal communication, January 24, 2011
[77] ibid.
[78] S. Criswell, personal communication, January 5, 2011

Currently, ASHRAE Standard 140 is used to check new algorithms. However, the standard does not include many new technologies, and thus algorithm developers can only use ASHRAE Standard 140 to ensure the algorithms have not affected old algorithms previously verified by the standard.

In general, funding available to software developers is not sufficient for the creation of elaborate new engineering models. Rather, software developers only have the resources to implement models that are already formulated or are straightforward to derive. Often it is the case that new technologies and systems need fundamental engineering testing, research, and model development (where models explicitly target the BEM context) before new algorithms can be added to BEM tools.[79]

Algorithm Verification Process

Unlike other systems' simulations, complete empirical validation of BEM models is impractical, if not impossible. This is due to the innumerous variables that effect building energy models. The BESTEST (Building Energy Simulation TEST) procedure, developed by the National Renewable Energy Lab (NREL), field-tested in collaboration with the International Energy Agency (IEA), and adopted in ASHRAE Standard 140, represents the most thorough verification process to date.

Nine BESTEST procedures are available:

- The IEA BESTEST evaluates hourly time-step simulation programs;
- HVAC BESTEST Volume 1 evaluates analytical verification tests of space cooling equipment;
- HVAC BESTEST Volume 2 evaluates comparative tests of space cooling equipment;
- Furnace BESTEST evaluates space heating equipment;
- HERS (Home Energy Rating System) BESTEST evaluates programs that model private homes;
- Florida HERS BESTEST evaluates programs that model buildings in hot and humid climates;[80]
- BESTEST-EX evaluates programs that model retrofits for existing homes, including the ability to calibrate base-case model predictions to utility bills for the purpose of developing more accurate retrofit savings predictions;
- BESTEST Ground-Coupled heat transfer model tests evaluate slab-on-grade heat transfer models; and
- BESTEST Multi-Zone Non-Airflow tests evaluate multi-zone conduction, multi-zone shading and internal windows.

[79] B. Griffith, personal communication, January 26, 2011
[80] *Energy analysis and tools*. (2010, October 4). Retrieved from http://www.nrel.gov/buildings/energy_analysis.html#bestest

The IEA BESTEST procedures serve as the foundation for ASHRAE Standard 140.[81] The first four BESTEST procedures are the basis for 140-2007; the HERS BESTEST will be added for 140-2011; and the Ground Coupling and Multi-Zone tests will follow as addenda to 140-2011.[82]

The verification process of ASHRAE Standard 140 is a combination of analysis of a program's accuracy in modeling simple systems, and precision across modeling programs. As Judkoff and Neymark (2006) note, there are three ways in which a building energy simulation program can be verified:

1. **Empirical Validation**: calculated results from a program, subroutine, algorithm, or software object are compared to monitored data from a real building, test cell, or laboratory experiment.
2. **Analytical Verification**: outputs from a program, subroutine, algorithm, or software object are compared to results from a known analytical solution or a generally accepted numerical method for isolated heat transfer under very simple, highly constrained boundary conditions.
3. **Comparative Testing**: a program is compared to itself or to other programs.[83]

ASHRAE Standard 140 requires the simulation of different systems of theoretical buildings. These tests range from 'basic' thermal envelope modeling such as direct solar gain and internally generated heat, to varied sensible internal gains and outdoor dry-bulb temperature, to more complicated models that must be verified comparatively rather than analytically. ASHRAE Standard 140 (2007) outlines these tests as useful for:

(a) Comparing the predictions from other building energy programs to the example results provided in the informational Annex B8 and/or to other results that were generated using this [standard method of test],
(b) Checking a program against a previous version of itself after internal code modifications to ensure that only the intended changes actually resulted,
(c) Checking a program against itself after a single algorithmic change to understand the sensitivity between algorithms, and
(d) Diagnosing the algorithmic sources of prediction differences; diagnostic logic flow diagrams are included in the informational Annex B9. (p. 2)

These tests are designed to identify differences in predictions caused by software errors and "to generate a range of results from several programs that are generally accepted as representing the state-of-the-art in whole building energy simulation

[81] Judkoff, R. et al. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., (2007). *ANSI/ASHRAE Standard 140-2007: standard method of test for the evaluation of building energy analysis computer programs* Atlanta, GA: Retrieved from http://www.techstreet.com
[82] J. Neymark, personal communication, February 4, 2011
[83] Judkoff, R., & Neymark, J. (2006). Model validation and testing: the methodological foundation of ASHRAE Standard 140. p. 2. *Proceedings of the ASHRAE 2006 Annual Meeting*, http://www.nrel.gov/docs/fy06osti/40360.pdf

programs". [84] However, Standard 140 often does not have the capability to test new, state of the art algorithms. [85] Furthermore, although an analytical solution is a "mathematical truth standard," according to Judkoff and Neymark (2006), it "only tests the solution process for a model, not the appropriateness of the model" (p. 2). The extent of empirical testing in ASHRAE Standard 140 is limited to manufacturer data on space-cooling and space-heating equipment.

While Standard 140 is on continuous maintenance and new test cases are being added, the time it takes to adequately vet and field test new tests cannot keep up with advances in the industry. The volunteer approach for ASHRAE committee work is especially problematic for the rate of progress on SSPC140 because the process of normalizing new test cases requires significant modeling and reporting effort by many volunteers who have technical expertise in various BEM tools.

Highlighting the difference between empirical validation and analytical verification/precision analysis is the fact that section 5.2.1.5 of Standard 140 requires modeling thick floor insulation in order to thermally decouple the floor from the ground. Verification of a mathematical truth standard does not necessarily emphasize correlation to overall empirical performance, but is useful for isolating the behavior of specific algorithms, and diagnosing disagreements, if they occur. ASHRAE Standard 140 is not an analysis of a simulation program's accuracy, but rather an important tool in debugging, analytical solution verification, and precision analysis.

Amir Roth of the Department of Energy office of Energy Efficiency and Renewable Energy (EERE) notes that a building energy simulation has many components, both algorithmic and in terms of input, and that end-to-end validation of a simulation requires validating all of them. If these components were easy to decouple, then a straightforward approach to validation would be to break down the problem into manageable pieces and to validate each piece separately. The problem is that many of the components interact with each other in non-linear ways that make decoupling difficult if not impossible. This coupling defeats the binary search procedure that allows you to quickly hone in on problem spots and dramatically slows down the end-to-end validation process. This discourages both researchers as well as funding agencies.[86]

Despite these hurdles, end-to-end validation is a priority for EERE going forward. While there are small projects planned for the next year, the full scale of "end-to-end validation" work is not scoped or funded as of now. Facilities such as the new Oak Ridge National Laboratory (ORNL) test facility, the recently funded PSU (Penn State

[84] Judkoff, R. et al. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., (2007). p. 97. *ANSI/ASHRAE Standard 140-2007: standard method of test for the evaluation of building energy analysis computer programs* Atlanta, GA: Retrieved from http://www.techstreet.com
[85] N. Long, personal communication, January 12, 2011
[86] A. Roth, personal communication, February 1, 2011

University) Buildings Hub, and the Lawrence Berkeley National Laboratory (LBNL) test facility coming on line in 2012 should provide valuable empirical data for this effort.

The TRNSYS verification process functions more similarly to open-source code, allowing users to make or suggest modifications to an overseeing body. Modifications to the fundamental kernel require comparison to pre-modification simulations, whereas component model development is based on manufacturer data. New fundamental components are based on the source of the algorithms.[87]

Standard 140 is a critical component of the BEM algorithm verification process. It provides a benchmark to which other BEM programs can be compared, and a useful way to ensure programs are free of bugs. However, variation in BESTEST results between modeling programs highlights the need for more empirical verification. "End-to-end validation" would lend more consistency and credibility to simulation.

5.6.5 Open Source Tools in the BEM World

The term "open source" occasionally arises in discussions about BEM software tools. However, experience has shown that open source is not well understood by the BEM industry. Open source is more than just access to the source code of a program. Open source is both a software licensing scheme and a software development method. The opposite of open source is "closed source" or proprietary software.

Examples of some open-source products include the Mozilla Firefox web browser, the OpenOffice suite of office productivity programs, the Linux computer operating system, and the Android mobile phone operating system. These well-known products have risen into the public consciousness within the last ten years. But software developers have widely used open-source tools, libraries, and languages for more than 25 years. Open source also powers many ubiquitous internet and web-based technologies including Wikipedia, WordPress, Joomla, Drupal, PHP, Ruby on Rails, MySQL, Sendmail, and the Apache HTTP Server.

Despite the growing prevalence of open-source software for consumer products, developer tools, and internet technologies, open source is still relatively rare in the BEM industry. We believe the following is a comprehensive list of all programs[88] related to building energy modeling and distributed under an open-source license:

[87] D. Bradley, personal communication, January 24, 2011
[88] Showing recent activity as of 2009 or later.

Table 10: List of Open Source BEM Tools

Program	License
ESP-r	GPL v2
GenOpt	modified BSD License
JEPlus	GPL v3
Learn HVAC	Open Source License 3.0
OpenStudio (legacy)	GPL v3
OpenStudio	LGPL v3

Because there are so few open-source BEM programs, many people in the industry may struggle with how to define "open source." The Open Source Initiative (OSI) is a nonprofit organization that acts as a de facto standards body for approving open-source licenses. The OSI maintains an official definition of open source along with a list of approved licenses on its website[89]. The full definition from the OSI is lengthy and we will not reproduce it here. Instead we distill the definition down to the three criteria that form the bedrock of all open source licenses:

1. "The license shall not restrict any party from selling or giving away the software…" Users are allowed to freely redistribute the software. This criteria usually eliminates all commercial software that is licensed for a fee.
2. "The program must include source code…" This is the obvious requirement for open source. If the source code is not included directly, the distributor is not allowed to charge more than a nominal reproduction cost to provide it.
3. "The license must allow modifications and derived works, and must allow them to be distributed under the same terms as the license of the original software." Developers are allowed to create derivative works and distribute them.

[89] The Open Source Initiative, http://www.opensource.org

The Free Software Foundation (FSF) provides an alternate definition of open source. In a now-classic distinction, the FSF definition emphasizes the difference between the users' "freedom" and software that is simply "free" of cost[90].

The implication of "free" software is clearly more ideological than the OSI definition. The FSF advocates a more extreme viewpoint, mainly originating from the open-source legend, Richard Stallman. The primary license recommended by the FSF is the GNU General Public License (described below).

Types of Licenses
Broadly speaking, there are two types of open-source licenses that are in common use. They can be characterized by the GNU General Public License on the one hand and the MIT License on the other.

The GNU General Public License (GPL) and other similar licenses are called "copyleft" licenses. The GPL requires that any derivative works *also be distributed under the GPL license*. The effect of this requirement is that the license has a viral characteristic. In other words, a developer cannot combine a GPL program with her own application without requiring that the resulting software also be licensed under the GPL. This ensures that any derivative works will be propagated as open source. Conversely, derivative works are blocked from becoming integrated into a commercial product. The GPL was designed by the FSF to foster the proliferation of open-source software. Today it is the most widely-used, open-source license.

The MIT License is representative of several of the more permissive open-source licenses. This group also includes the BSD Licenses and the GNU Lesser General Public License (LGPL). Under these licenses, the main requirement is that the original copyright notice be reproduced in any derivative works. Otherwise developers are largely allowed to do whatever they want with the software, including distributing a modified version **without source code**. This allows a developer to potentially integrate the open-source software into a closed-source commercial product and distribute it under a proprietary license. The LGPL is slightly different. It

"Free software" is a matter of liberty, not price. To understand the concept, you should think of "free" as in "free speech," not as in "free beer."

Free software is a matter of the users' freedom to run, copy, distribute, study, change and improve the software. More precisely, it means that the program's users have the four essential freedoms:

1. The freedom to run the program, for any purpose.
2. The freedom to study how the program works, and change it to make it do what you wish. Access to the source code is a precondition for this.
3. The freedom to redistribute copies so you can help your neighbor
4. The freedom to distribute copies of your modified versions to others. By doing this you can give the whole community a chance to benefit from your changes. Access to the source code is a precondition for this.

[90] http://www.gnu.org/philosophy/free-sw.html

was designed specifically to allow open-source libraries to be integrated with closed-source software while maintaining the library itself as open source. Under the LGPL no one is allowed to distribute the library as closed source under any scenario.

There are no hard-and-fast rules for choosing a software license. The developer must decide between closed source versus open source, and if the latter, GPL versus a more permissive license. A developer's decision can depend on numerous factors including her business model, her competitors, her target market, and her values. There are legitimate uses for every license. However, experts recommend that developers should choose one of the existing, widely-used licenses rather than creating a brand new license[91].

Development Method

Open source is more than a licensing scheme. Perhaps most importantly, open source is a software development method. At its best, open source parallels the spirit of the scientific method, "to document, archive and share all data and methodology so they are available for careful scrutiny by other scientists, giving them the opportunity to verify results by attempting to reproduce them." Other scientists can then improve on the experiment and publish new results, thereby advancing the scientific body of knowledge.

> *"If I have seen further it is only by standing on the shoulders of giants."*
> *–Sir Isaac Newton*

Substitute "software developers" for "scientists" to make the comparison literal. The OSI expresses the open-source development method as follows:

> **Open source is a development method for software that harnesses the power of distributed peer review and transparency of process. The promise of open source is better quality, higher reliability, more flexibility, lower cost, and an end to predatory vendor lock-in.**

[91] http://www.dwheeler.com/essays/gpl-compatible.html

The commonly-ascribed benefits of open source for users are:

1) **Lower cost**: There is no upfront cost to use the software; the software is free.
2) **Better quality and reliability**: Continuous peer review and the practice of "release early, release often" uncover and resolve bugs quickly[92].
3) **No black boxes**: Independent developers inspect the source code to examine assumptions and algorithms on behalf of users.
4) **User empowerment**: Users are empowered to drive the development process. Users, or their organizations, are enabled to program (or hire someone to program) the features and bug fixes that they need.

The commonly-ascribed benefits of open source for developers are:

1) **Lower development costs**: Collaboration between developers across different organizations helps to spread out the cost. Developers accomplish more together than any one individual developer could accomplish in isolation.
2) **Integration with other open-source software**: Depending on license compatibility, developers may be able to integrate other open-source software (for increased productivity and lower costs) that would otherwise be incompatible with a closed-source project.
3) **Volunteer contributions**: Developers harness free contributions from a community of volunteers, both developers and users. Users actively contribute bug reports and feature requests.

Proponents of open source would suggest that the development method is a critical ingredient for producing successful open-source software and reaping the benefits for both users and developers.

5.7 Education, Training & Certification

As is evident by the range of tasks comprising modeling services, an energy modeler must possess a depth and breadth of domain knowledge – and couple it with professional judgment— to competently deliver services. Modelers can gain knowledge and experience through many avenues, including: degreed programs, on-the-job mentoring, and professional training. In the last year, new opportunities have arisen for modelers to demonstrate their capabilities and distinguish themselves by earning professional modeling certifications. These avenues for developing and demonstrating modeling competency are described below.

5.7.1 College Curriculums

Across the country, there are over a dozen degreed programs that offer courses specifically focused on building energy modeling methods and tools. See the table below for a list of schools offering these higher-education modeling classes.

[92] Raymond, Eric S. "The Cathedral and the Bazaar", http://www.catb.org/~esr/writings/cathedral-bazaar/cathedral-bazaar/ar01s04.html

Table 11: List of Universities Offering Energy Modeling Curricula

University	Affiliated Department or Research Center
Arizona State University	School of Architecture
Catholic University of America	Sustainable Design Program
Carnegie Mellon University	Center for Building Performance and Diagnostics
Colorado State University	Architecture and Engineering
Drexel University	Architectural Engineering
New York University School of Continuing and Professional Studies	Architecture, Engineering, and Construction
Oklahoma State University	Building and Environmental Thermal Systems Research Group
Oregon Institute of Technology	Renewable Energy Engineering
Pennsylvania State University	College of Engineering
Stanford University	Precourt Energy Efficiency Center
Syracuse University	Building Energy and Environmental Systems Lab
Texas A&M University	Energy Systems Laboratory
University of Arizona	Architecture Graduate Masters of Science
University of California, Berkeley	Center for the Built Environment
University of Central Florida	Florida Solar Energy Center
University of Colorado, Boulder	Building Systems Engineering
University of Illinois	Illinois Sustainable Tech. Center
University of Kansas	School of Engineering
University of Massachusetts	Building Energy Research Laboratory
University of Nebraska, Lincoln	Architectural Engineering
University of Texas, Austin	Energy Simulation in Building Design
University of Wisconsin, Milwaukee	Energy Systems Research School of Architecture and Urban Planning
University of Wisconsin, Madison	Solar Energy Laboratory

Not surprisingly, most of the universities that do offer building energy modeling coursework are affiliated with a lab or research centers that study building systems. Despite the opportunity to combine research of physical processes with modeling training, Drury Crawley (Bentley) argues that BEM training is too heavily weighted toward tool use. He notes that although tool-focused training may teach basic simulation skills, modelers with engineering judgment skills are what we really need. There are too many tools for different applications that require different skill sets to focus on specific tools in an academic setting. Similarly, Michael Wetter (LBNL) notes the imperative for more emphasis on building science and building physics for architects in higher education. Crawley's and Wetter's vision for BEM education in universities requires foundational skill sets that enable an individual to understand a simulation program's underlying concepts. Of course, some people disagree. Architects and not engineers could model buildings given highly automated software programs. Others suggest that tool interfaces should reveal the building science concepts employed as a reminder to the user. Thus, the level of building science education required for modelers could be dependent on the level of automation and the type of interface incorporated into modeling tools.

Building energy modeling coursework is growing in popularity among university students. Moncef Krarti (University of Colorado at Boulder) notes that his building energy modeling class has consistently grown over the past three years. What used to be an enrollment of ten students has ballooned to 50-60 students from the building systems engineering and architectural engineering schools. While Krarti's class focuses on simulation tools, specifically eQUEST and EnergyPlus, he stresses the need for an understanding of the physics behind these modeling programs. While understanding the fundamental concepts behind the programs may not be necessary for architects making preliminary models, it is critical for distinguishing between energy-efficient options and for using analysis to inform design choices.

5.7.2 Mentorship and Professional Development

Many modelers learn modeling-specific methods and tools through informal on-the-job training. With high demand and high growth for modeling services, meeting training and professional development needs can present a challenge to businesses.

Ellen Franconi experienced these challenges first hand while working at Architectural Energy Corporation and leading their energy analysis group. The group grew from six to twelve analysts within two years. To help evaluate new modeler skills and outline professional development plans for others, she defined a continuum of capabilities based on increasing levels of domain knowledge and professional judgment. While at RMI, she more fully developed the concept and termed it "black belt energy modeling." An abridged version of the Black Belt Energy Modeling Matrix appears below.[93]

The matrix shows modeling belts ranging from "trainee" to "master" and the incremental capabilities associated with each. The framework and content of the matrix are based on providing integrated design assistance as typically delivered to the private sector. Thus the outline may not align well to other applications. It does not reflect the benefits of a streamlined BIM process or software that automatically generates a minimally code-compliant building model. The concept and framework might be further developed and applied to modeling education and training.

[93] An expanded version can be found at http://www.rmi.org/rmi/ModelingTools.

Table 12: Black Belt Energy Modeling Matrix

Belt		Capabilities
Trainee	White	• Collect modeling input data
	Yellow	• Perform input data calculations
	Orange	• Develop building geometry and zoning
Technician	Green	• Create building input file using software wizard
	Blue	• Build minimally-code compliant building model
Core Analyst	Purple	• Review results for reasonableness • Complete calibrations
	Brown	• Perform complex modeling • Complete detailed QC • Complete system level calibration
Master	Red	• Understand the algorithms • Use supplemental analysis
	Black	• Balance modeling level of detail against accuracy of results needed to support decision making

5.7.3 Professional Training

As the demand for energy modeling services increases, professionals from related fields are refocusing their responsibilities to carry out modeling tasks. Professional energy modeling training opportunities supports retraining needs. It also introduces industry-accepted procedures to a work force that has historically been self-taught.

The introduction of ASHRAE Standard 90.1 Performance Rating Method and LEED 2009 are clearly drivers behind the increase in popularity of energy modeling. However, Valerie Oviatt of the Association of Energy Engineers cites an increased demand for certification as another driver of training course popularity. She argues that certification may differentiate an individual in a competitive market, and this drives demand.

Bill Worthen of AIA cites a knowledge gap that exists for the majority of licensed architects between today's standard design and construction practices and what will be required when high performance building codes, like the IgCC, are adopted in 2012. He further notes that most licensed architects and small to mid-sized architectural firms have never had the opportunity to work on the design and construction of a green building.[94]

[94] B. Worthen, personal communication, January 21, 2011

Further, Energy Center University, the education arm of Energy Center of Wisconsin (ECW) notes a growing demand for BEM classes, but even more so, a rise in demand for online classes.

Overall, most professional development classes focus on particular tools. Publically funded classes generally focus on eQUEST or EnergyPlus, whereas workshops and online training provided by software vendors and other commercial entities tend to focus on specific commercial software tools, such as IES Virtual Environment, TRACE, and TRNSYS.

See the table below for a list of the most popular professional development programs available. While the vast majority of individuals currently being trained in BEM are engineers, the increased demand for tool-based and online classes may be reason for concern in the future. The underlying physics of BEM programs is generally not taught in professional development classes.

Table 13: Professional Development Training Course for BEM

Sponsoring Organization	Training Location	Focus
AEE	Various	eQUEST and Processes
ASHRAE Learning Institute	Georgia	eQUEST and Processes
Autodesk	Various	Autodesk software
Bentley	Various	Bentley software
Building Simulation User's Group	Oregon	Various tools and processes
GARD Analytics	Various	EnergyPlus
IBPSA/RMI/ASHRAE	Various	Processes
IES-VE	Live e-Training	IES-VE
Northwest Energy Efficiency Alliance	Northwest	eQUEST and Processes
PG&E Pacific Energy Center	California	Many tools
Trane	On site throughout U.S., Headquarters (La Crosse, WI)	Trane TRACE 700
TRNSYS	On site or at TESS in Madison, WI	TRNSYS
Energy Center of Wisconsin (Energy Center University)	Wisconsin	eQUEST and Processes

Perhaps the most formalized professional development program in this field, the Energy Center University offers 75 live event and online continuing education programs every year on topics related to energy efficiency and high performance buildings including a two-day beginner and intermediate course on eQUEST. In addition to the Energy Center, the University of Wisconsin, Madison, offers continuing education courses through its Department of Engineering Professional Development (EPD). EPD offers 114 courses related to buildings, and a modeling course titled: Energy Modeling High Performance Buildings. The course covers such topics as energy modeling versus load calculations, eQUEST use and features of other software, and modeling for code compliance.

Over the last year, IBPSA-USA, RMI and ASHRAE have developed training materials for a full-day BEM Workshop. Since completed in August 2010, the organizations have delivered the training five times, with three more events planned through summer 2011.

In January 2011, IBPSA introduced the *Building Energy Modeling Book Of Knowledge* (BEMBook) - a wiki containing modeling knowledge and resources (http://www.bembook.ibpsa.us). The wiki is being "seeded" with the BEM workshop materials. Once the base knowledge is in place, the wiki will be open to contributors to build on and add to the posted modeling subject matter. The BEM Workshop slide presentation files, including speaker notes, are also posted on the wiki. The files are available for download through a non-commercial creative commons licensing agreement.

5.7.4 Certification for Practitioners

Owners and design teams increasingly recognize energy modeling as an effective way to achieve energy efficiency and high-performance buildings. As the service industry has grown, so has the concern about analysis quality and the ability to distinguish capable modelers. In response to this, two modeling certification programs emerged in the last year – the ASHRAE Building Energy Modeling Professional (BEMP) and the AEE Building Energy Simulation Analyst (BESA). In addition, COMNET plans to build on the BEMP credential to distinguish professionals that are proficient with the COMNET body of knowledge. All of these certification programs are pass/fail and do not distinguish between varying skill levels. However, both certifications require modeling experience, ranging from two years of modeling experience with a professional engineer or architect certification, to six to seven years of experience in BEM or a related field and a two-year professional degree. A description of each of these programs appears below.

ASHRAE BEMP Certification (www.ashrae.org/BEMP)
To ensure that professionals modeling a building's energy use have the skills necessary to produce an accurate model, ASHRAE has launched the Building Energy Modeling Professional certification. ASHRAE administered the first exam for the new certification program on Jan. 27, 2010, at the Winter Conference in Orlando, Fla. Modelers can now take the exam at professional examination centers located across the country.

ASHRAE has developed the certification program with the aim of increasing the accuracy of building energy models, which will help address some of the growing concerns within the building community that building designs do not necessarily translate to actual energy use once a building is constructed. Additionally, energy modeling will play a vital role in ASHRAE's soon-to-be launched Building Energy Quotient (EQ) program, which will feature both an "As Designed" and "In Operation" component. Careful and consistent energy modeling will allow modeling results to be compared with the results of models from other buildings.

Professionals who pass the certification exam will have demonstrated their ability to evaluate, choose, use, calibrate and interpret the results of energy modeling software, as well as confirm their competence to model new and existing buildings and systems with their full range of physics. The certification will also highlight a consultant's ability to act as a leader for projects that focus on energy efficiency, especially projects that deal with green buildings and building labeling programs, such as Building EQ.

The BEMP program will help the individuals who earn it to distinguish themselves by providing confirmation of their skills and specialties by an internationally recognized engineering society. Professionals with such certifications have better chances of being hired, promoted and/or tapped for working on certain types of design projects. Presently, there are 110 practitioners listed as BEMP-certified on the ASHRAE website.

BEMP Eligibility Requirements

Any individual who meets one of the following combinations of academic and work experience requirements will be eligible to take the examination for the Building Energy Modeling Professional certification.

- Government-issued or government-recognized license as a professional engineer or architect and a minimum of two (2) years' building energy modeling experience
- Minimum of Bachelor's degree in engineering or a related field (e.g., building science, architecture, physics, or mathematics) from an accredited institution of higher learning and a minimum of five (5) years' energy-related HVAC, architecture, lighting, or renewable energy experience, including a minimum of two (2) years' building energy modeling experience; up to two years of graduate studies at an accredited institution of higher learning can be counted toward the five (5) years' experience in this category
- Associate's degree or Technical degree or certificate in design, construction, or a related field from an accredited institution of higher learning and a minimum of seven (7) years' energy-related HVAC, architecture, lighting, or renewable energy experience, including a minimum of two (2) years' building energy modeling experience
- High School diploma or equivalent and a minimum of ten (10) years' energy-related HVAC, architecture, lighting, or renewable energy experience, including a minimum of two (2) years' building energy modeling experience

AEE BESA (www.aeecenter.org)
New for 2010, the Association for Energy Engineer's (AEE) Building Energy Simulation Analyst (BESA) professional certification is designed to recognize individuals with special expertise and experience in the area of utilizing building energy simulation software to assess a facility's energy performance. The objectives of the certification include:

- To raise the professional standards of those engaged in energy simulation.
- To improve the practice of energy simulators by encouraging energy simulation in a continuing education program of professional development.
- To identify persons with acceptable knowledge of the principles and practices of energy simulation through completing an examination and fulfilling prescribed standards of performance and conduct.
- To award special recognition to those energy simulation professionals who have demonstrated a high level of competence and ethical fitness in energy simulation.

  BESA Eligibility Requirements
  Candidates are required to meet one of the following criteria:

  - A four-year degree from an accredited university or college in engineering or architecture, or be a registered Professional Engineer (P.E.) or Registered Architect (R.A.). In addition, the applicant must have at least three years of experience in building modeling, commercial energy auditing, energy management, or related.
  - A four-year non-engineering degree with at least five years experience in building modeling, commercial energy auditing, energy management, or related.
  - A two-year technical degree with at least six years experience in building modeling, commercial energy auditing, energy management, or related.
  - Ten years of experience in building modeling, commercial energy auditing, energy management, or related.
  - The current status of Certified Energy Manager (CEM®).

COMNET Credentialing (www.comnet.org)
The Institute for Market Transformation (IMT) conducted a review of current professional credentialing programs in the commercial building industry that revealed three significant drivers for the implementation of a new professional building energy modeler credential:

- Significant variations among the prerequisites, examination procedures and training requirements that jeopardize consistent evaluations

- Requirements for a professional license such as Professional Engineer (PE) or Registered Architect (RA) for accountability that increase costs
- No built-in standards for monitoring building assessments for quality and compliance with standards that compromise quality assurance

Working with a coalition of building professionals representing practitioners, field engineers, and program administrators for regulating agencies, IMT convened a Credentialing Committee to establish credentialing requirements and processes to ensure quality assessments for COMNET building energy modelers, building energy verifiers, and building energy auditors. To maintain alignment with evolving practice in industry, the committee intends to periodically reevaluate and amend its credentialing requirements and processes.

Launched in August 2010, the Committee's efforts seek to:

- Define the roles and responsibilities for the building energy modeler, building energy verifier, and building energy auditor
- Establish education and experience prerequisites
- Define bodies of knowledge
- Develop the application process for COMNET credentials
- Determine what testing is required and develop appropriate examinations
- Establish a third party quality assurance verification process
- Design processes for professional accountability and complaints resolution
- Develop process for renewal of credential
- Define the standard of ethics

The committee’s initial priority is to develop the COMNET building energy modeler credential. Analysis of the COMNET Modeling Guidelines and Procedures, ASHRAE 90.1, and current practice revealed that the incremental body of knowledge for the COMNET modeler did not significantly reach beyond the knowledge required for a generic building energy modeler, e.g. knowledge for the BEMP program from ASHRAE, or equivalent credential. Thus the Committee recommended that COMNET modelers hold the BEMP Credential or equivalent, and pass a written open-book examination covering the COMNET-specific methodologies. As yet, the exam and other administrative processes identified in the list above have not been addressed.

5.8 Support & Resources for Practitioners

Because so many of these tasks involved with energy modeling are difficult and time-consuming, practitioners rely on a number of different supporting resources throughout this process (see Figure 7). **While most of the items listed have already been dealt with in other sections, more detail is provided in this section for those shown in the darker color**.

Figure 7: Supporting Resources for Energy Modeling

Supporting Resources:

Energy model practitioners reference and rely on many types of supporting resources to perform their analysis. Software and user group support is key, along with technical publications and standards for reference. Education and training is required to provide them with an understanding of building science, modeling skills, and engineering judgment.

Codes, guidelines and regulations can help define performance baselines and metrics for modeling, while quality and reliable data sources are crucial to provide model inputs. Finally, methods (standardized or developed ad-hoc) are employed for various activities associated with energy modeling.

5.8.1 User Support Groups and WIKIs

Most software tools offer some sort of direct support services, either for a fee, or as part of the general license fee. In addition, there are many list serves or user groups that provide a forum for asking questions and receiving feedback. The most comprehensive are the One Building List Serves, maintained by Gard Analytics. One Building includes list serves to support the following:

- TRNSYS
- eQUEST
- HAP
- TRACE
- IES-VE
- BLDG-SIM: a mailing list for users of any building energy simulation programs
- BLDG-RATE: a mailing list for people using building performance rating systems.

Notably absent from One Building's list serves is EnergyPlus. Although there remains user-to-user support activity via the EnergyPlus Yahoo Group, the vast majority of developer-to-user support is conducted privately via a software system designed for user support (http://energyplus.helpserve.com/).

There are also smaller blogs and forums that have been launched by individual practitioners. Brandon Nichols maintains a blog, ELCCA Exchange, devoted to documenting useful knowledge and tricks of the trade related to eQUEST. Another relatively new forum for eQUEST (http://www.esimforums.com/equest/index.php) does not have a lot of traffic yet, but is well-organized and has potential to be a resource.

In terms of tool neutral resources and user support, IBPSA has recently launched the Building Energy Modeling Body of Knowledge (BEM Book) wiki, which will eventually house a comprehensive body of knowledge to support building energy modeling. The Building Simulation User's Group (BSUG) is a practitioner support group in the Pacific Northwest that has grown to over 500 analysts. The group holds presentations on various modeling topics and tools.

5.8.2 Code, Standards and Guidelines

This is a summary of important energy codes, standards, and guidelines that deal with direct or indirect energy modeling practices (see Section 5.9.1 for more info).

- ASHRAE Guideline 14: Measurement of Energy and Demand Savings
- ASHRAE Research Project 1051 - Procedures for Reconciling Computer-Calculated Results With Measured Energy Data
- ASHRAE Standard 55: Thermal Environmental Conditions for Human Occupancy
- ASHRAE Standard 62.1: Ventilation for Acceptable Indoor Air Quality
- ASHRAE Standard 90.1: Energy Standard for Buildings Except Low-Rise Residential Buildings
- ASHRAE Standard 90.2: Energy Efficient Design of Low-Rise Residential Buildings
- ASHRAE Standard 100: Energy Conservation in Existing Buildings
- ASHRAE Standard 105: Standard Methods of Measuring, Expressing and Comparing Building Energy Performance
- ASHRAE Standard 140: Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs
- ASHRAE Standard 189.1 - Standard for the Design of High-Performance Green Buildings Except Low-Rise Residential Buildings
- Federal Energy Management Program (FEMP) M&V Guidelines
- International Energy Conservation Code (IECC)
- International Green Construction Code (IgCC)
- International Performance Measurement and Verification Protocol (IPMVP) Volumes
- Title 24, Part 6, of the California Building Code (Building Energy Efficiency Standards)

Additional Resources on Codes and Standards:

- U.S. DOE Building Energy Codes Program: http://www.energycodes.gov/

- Building Codes Assistance Project: http://bcap-ocean.org/
- International Code Council: http://www.iccsafe.org/Pages/default.aspx
- Green Building Initiative: http://www.thegbi.org/index.shtml

5.8.3 Green Building Rating Systems

This is summary of important rating systems that deal with direct or indirect energy modeling practices (see Section 5.9.3 for more info).

- Leadership in Energy & Environmental Design (LEED®)
- Green Globes®
- ENERGY STAR
- ASHRAE Building Energy Quotient Program (Building EQ)

Many of the rating systems rely on comparison with a performance baseline. There are now application guides that were developed to assist with the development of these performance baselines.

Application Guides for Performance Baselines

- Title 24 ACM (Alternative Calculation Method) Manual
- Commercial Energy Services Network (COMNET): Application Guide for ASHRAE 90.1 Performance Rating Method
- Advanced Energy Modeling for LEED, Technical Manual v1.0 (available for purchase from the USGBC)

5.8.4 Other Resources (recommended for BEMP Certification)

Other resources that are commonly referenced, and are recommended as preparation for ASHRAE's BEMP Certification include:

- CIBSE (Chartered Institution of Building Services Engineers) Applications Manual AM11
- IESNA (Illuminating Engineering Society of North America) Lighting Handbook
- ASHRAE Handbooks
- Solar Radiation and Daylight Models by T. Muneer
- Heat and Mass Transfer in Building Services Design by Keith J. Moss
- Mechanical and Electrical Equipment for Buildings by Walter T. Grondzik, Alison G. Kwok, John S. Reynolds, Benjamin Stein

Beyond those references recommended for the BEMP exam, a few text books are available that address fundamental and advanced topics of building energy modeling:

- Jan L.M. Hensen and Roberto Lamberts, Building Performance Simulation for Design and Operation, 2011.
- Chris Underwood, Modeling Methods for Energy in Buildings, 2004.
- Ali Malkawi and Godfried Augenbroe, Advanced Building Simulation, 2003.
- Joe Clarke, Energy Simulation in Building Design, 2nd Ed., 2001.

5.8.5 Supplementary Tools and Templates

Despite the array of whole building energy simulation tools available, practitioners are still responsible for a large amount of pre and post processing. To aid with this process, there are a number of supplementary tools and templates that have been developed. These supplementary tools provide a wide variety of services, including but not limited to:

- Thermal comfort calculations
- Computational fluid dynamic (CFD) simulations
- Indoor air quality calculations
- Daylight simulations
- Weather file conversions and manipulations
- Translation of performance baseline requirements into energy model inputs
- Translation of equipment specifications into energy model inputs
- Templates for collecting on site energy audit data
- Templates for filling out compliance reports

5.8.6 Supporting Organizations

There are a number of non-profit, professional, or governmental organizations that provide support for energy modeling.

Table 14: Organizations that Provide Support for the Energy Modeling Industry

	About the Organization	Relevant Aspect of BEM
ASHRAE: American Society of Heating, Refrigeration, and Air-Conditioning Engineers	International organization dedicated to advancing technology to serve humanity and promote a sustainable world	Research, standards writing, and education
IBPSA: International Building Performance Simulation Association	Non-profit international society of building performance simulation researchers, developers and practitioners, dedicated to improving the built environment	Education; Research and development for simulation technologies, methods, and data
USGBC: The U.S. Green Building Council	Non-profit working to transform buildings and communities to enable an environmentally and socially responsible, healthy, and prosperous environment	LEED Green Building Certification program, Education
IMT: Institute for Market Transformation	Non-profit promoting energy efficiency, green building and environmental protection	Building codes & other policies, COMNET
EVO: Efficiency Valuation Organization	Non-profit working to develop and promote the use of standardized protocols, methods and tools associated with energy and water	Measurement & Verification
AIA: American Institute of Architects	Professional association for licensed architects. The AIA is building key partnerships to ensure the needs of architects are well represented in energy modeling tools and green code language.	Training, Resources, Tool development and code/rating system recommendations
NEEA: Northwest Energy Efficiency Alliance	Non-profit using the market power of the northwest to accelerate the innovation and adoption of energy-efficient products, services and practices	Trainings, user group support, guidelines for designers/owners, tool enhancement (limited)
CEC: California Energy Commission	California's primary energy policy and planning agency	Research, Building Energy Efficiency Standards, Performance Rating Programs
NIBS: National Institute of Building Sciences	Non-profit focused on the problems that hamper the construction of safe, affordable structures for housing, commerce and industry throughout the U.S. NIBS's buildingSMART alliance™ supports open interoperability and full lifecycle implementation of building information models.	Produces the National BIM Standard (NBIMS)
IFMA: International Facility Management Association	The world's largest and most widely recognized international association for professional facility managers	Conducts BIM market research

ASHRAE has a number of Technical Committees (TCs) and other groups whose focus and research involves building energy modeling.

- TC 4.1 Load Calculation Data and Procedures
- TC 4.7 Energy Calculations
- TC 7.1 Integrated Building Design
- TC 7.6 Building Energy Performance
- TRG4 Sustainable Building Guidance & Metrics
- SPC 100 Energy Efficiency in Existing Buildings
- SSPC 90.1 Energy Efficient Design of New Bldg.
- SSPC 90.2 Energy Efficient Design of New Low Rise Residential Bldg.
- SSPC 140 Standard MOT for Evaluation of Bldg. Energy Analysis Computer Program
- GPC 14 Measurement of Energy Demand Savings

Description of Abbreviations

GPC: Guideline Project Committee
SPC: Standard Project Committee
SSPC: Standing Standard Project Committee
TC: Technical Committee
TG: Task Group
TRG: Technical Resource Group

5.8.7 Quality Input Data for Energy Models

When building an energy model, an enormous number of data inputs are required. For new construction, this data should come from design drawings, controls sequence, equipment specifications, etc. For existing buildings, this data should come from data gathered during the audit, and any from any as built drawings.

But what about when energy models are being performed in the very early design phases, and little information is know about the buildings? Or when drawings and equipment nameplates are missing and data is difficult, if not impossible, to sub-meter during existing building audits?

In these cases, assumptions are made and model input data must be pull from other sources. Some data, such as residential appliance energy consumption or lighting power density by space type, is very easy to find. EnergyStar databases and prescriptive energy code requirements provide a solid starting point for these data assumptions. However, it is very difficult to find quality data for some important model inputs. The tables below summarize and description the current data gaps.

Table 15: Gaps in Existing Data Sources for Energy Models

Existing Data Sources	Not Existing (but required) Data Sources
• CBECs • Design rules of thumb • Performance metrics • ASHRAE 90.1 Standard energy end use schedules • Title-24 energy end use schedules • Prescriptive energy code requirements • EnergyStar database • Published reports and papers providing end use loads and load shape data • Historical weather data for some locations	• Ranges of values for loads and load shapes of actual buildings • Database of plug and process loads • Data on user behavior • Part load performance curves • Actual, comprehensive hourly weather data for a given timeframe for all locations

Table 16: Discussion of Gaps in Available Data

Type of Data	Discussion of Gaps
Part Load Performance Curves	The ability to simulate the part load performance impacts of mechanical equipment is one of the things about energy modeling tools that far exceed what is capable via hand calculations. However, gathering the right data in order to create accurate part load curves is a daunting task, especially when the performance is dependent upon multiple variables. Published documentation could be improved and updated to cover this topic, with sample data sets and curves generated for various programs. However, even when the energy modeler knows what data is needed, they rarely have access to the equipment selection software required to generate it, This requires requesting detailed and lengthy amount of data from equipment representatives. Template spreadsheets could be generated to help practitioners request the appropriate data from the equipment manufacturers.
Plug Load Power Density	There is a large gap between published data on measured peak plug load power densities and what is required by building owners for system sizing. The application guides for energy performance baselines (COMNET and the Title 24 ACM Manual) provided operation schedules and estimates for peak plug load power draws for common space types. Still, there are gaps in, and much disagreement amongst, these data sources. Both ASHRAE and USGBC are sponsoring research efforts to gather more reliable data on this topic, and these efforts would likely benefit from collaboration.
User Behavior	There is little published or documented on the topic of how users interact with, and operate, different building types. Do office employees power down or put their computers to sleep? Are the lights shut off during off hours? In naturally ventilated or mixed mode buildings that rely on heavy user interaction, what are typical behavior patterns?

Type of Data	Discussion of Gaps
Process Loads	Anyone that has ever modeled a building with significant process loads understands the huge data gap that exists on this topic. Because process loads covers so many varied types of energy consuming devices, it would be best to focus on those process loads most commonly encountered in whole building energy modeling such as: data center servers, commercial refrigeration, commercial kitchen equipment, atrium fountains, swimming pools, common manufacturing equipment, etc.

There are some research studies already underway to address the lack of available data for plug loads.

ASHRAE Research Projects

A 2010 ASHRAE Research Project (RP) RP-1482 (Hosni and Beck, 2010) updated data for the ASHRAE handbooks to include notebook computers.[95] ASHRAE TC 7.6 currently has a research topic submitted for accepted entitled, "Standard Plug Load & Lighting Load Profiles." The co-sponsoring committee is TC 4.7 and the lead author is Michael Deru.

New Buildings Institute (NBI) Research Project

NBI is managing the three-year "Evidence-Based Design & Operations Research Program" as a part of the Public Interest Energy Research (PIER) Program funded by the California Energy Commission. The effort is a linked series of projects that examine the variation in energy use of commercial buildings through an evidence-based assessment of high performance buildings. One aspect of this project includes an in-depth assessment in two buildings of the extent to which plug load energy use (computers, printers, monitors, cell phone chargers, etc) can be reduced through relatively simple, cost-effective measures. Findings will inform the project's development of key feedback performance indicators, and will also form the basis for plug load energy reduction policies and programs that utilities and policy-making entities could undertake.

Electric Power Research Institute (EPRI) Project 170.021

EPRI is conducting a research project on Electronics, Plug Loads and Lighting Efficiency. This project undertakes to perform baseline measurements, develop measurement procedures, develop efficiency specifications, and inform policy makers with valid technical data. Each year is a continuation that includes additional categories of electronic equipment and their power supplies.

5.8.8 Benchmark Data for Energy Consumption

Benchmark data is useful to quality check the results of energy models, for total building consumption as well as end use breakdowns. Benchmark data can come in

[95] C. Wilkins, personal communication, March 1, 2011.

many different metrics (energy use intensity, average energy cost per square foot, etc.). While there are multiple sources that offer some portion of this data, the U.S. Energy Information Administration (EIA) maintains the most comprehensive and trusted database for building energy consumption.

The EIA conducts two national building energy end-use consumption surveys. These provide the only source of nation-wide estimates of annual energy end uses and energy-related building characteristics in commercial buildings and homes.[96] As such, they have come to be used widely as benchmarks against which to judge individual building energy performance. It should be noted that building energy end-use estimates for both commercial and residential buildings are not generated from metered data collected on-site. Instead, the EIA applies regression and engineering models to estimate end-use breakdown based on more general data collected in the surveys (e.g., average age of equipment, type of equipment used, building square footage, total building energy consumption). The following link explains this process: http://www.eia.gov/emeu/cbecs/tech_end_use.html

The two surveys are, briefly, as follows:

- The **Residential Energy Consumption Survey (RECS)** of the occupied housing portion of the residential housing sector, conducted 13 times (including the 2009 RECS update to be released in 2011 or early 2012) since 1978. "The 2005 survey collected data from 4,382 households in housing units statistically selected to represent the 111.1 million housing units in the United States." [97] Household building energy use estimates are provided at the following geographical granularities: national, Census regional (4 Census regions in the U.S), Census divisional (9 Census divisions in the U.S), and state-level for the four most populous states – California, Florida, New York, and Texas. The 2009 RECS update collected sample data from close to 25,000 housing units, and is anticipated to provide up to 15 state-level estimates for household energy consumption.[98]
- The **Commercial Buildings Energy Consumption Survey (CBECS)** of the commercial buildings sector, conducted 9 times (including the 2007 CBECS update, release TBD) every three or four years since 1979. The 2003 CBECS update surveyed 5,215 commercial buildings that were statistically selected and weighted to represent the estimated **4,859,000** buildings in the U.S. commercial building

[96] California's Commercial End Use Survey (CEUS) (http://www.energy.ca.gov/ceus/) is a resource for commercial building energy usage, but specific only to California.
[97] U.S.Energy Information Administration. (revision date not available on EIA site) Retrieved 01/19/2011 from http://www.eia.doe.gov/emeu/recs/contents.html
[98] National Opinion Research Center at the University of Chicago. (revision date not available on NORC site) Retrieved 01/20/2011 from http://www.norc.uchicago.edu/projects/Residential+Energy+Consumption+Survey.htm

stock. Commercial building energy use estimates are provided at the national, Census regional, and Census division level.[99]

This section of the pre-read will focus on the CBECS, as the Summit will be primarily focused around commercial building energy modeling; however, many of the same issues and concerns that apply to commercial building benchmark data also apply to the residential sector. [100]

CBECS Process

The CBECS is a resource-intensive process administered in two stages:

(1) In stage one, a voluntary Building Characteristics Survey is conducted for each selected building via a 30-45 minute interview with selected building owners, managers, or tenants to collect data about building size, building use, types of energy-consuming equipment and conservation measures in place, types of energy sources used, and amount and cost of energy used in the building.

(2) For those cases where data is unsatisfactory or incomplete, a mandatory Suppliers Survey is sent to the appropriate energy suppliers to ascertain actual building energy consumption and expenditures.[101]

The building types surveyed fall into the following big-heading categories, as defined by the EIA:

Education, Food Sales, Food service, Health Care, Lodging, Mercantile, Office, Public Assembly, Public Order and Safety, Religious Worship, Service, Warehouse and Storage, Vacant, and Other.

Limitations to CBECS Data Quality and Scope

Energy modelers have a large stake in the quality and scope of available CBECS data because they can benefit greatly from a consistent, free, national database of current, building energy consumption data. Ideally, practitioners would be able to accurately benchmark individual building performance targets and actual performance against similar building types (in terms of construction, age, program, location, climate). Perhaps more importantly, this benchmark data provide a crucial point of reference for quality control – an energy modeling can sanity check the energy use intensity of their model, as well as the end use breakdowns. From an energy modeling perspective, the current top limitations to CBECS data are as follows:

[99] U.S.Energy Information Administration. (revision date not available on EIA site) Retrieved 01/19/2011 from http://www.eia.doe.gov/oiaf/servicerpt/energydata/chapter3.html

[100] It should be noted that there is a large gap in both the RECS/CBECS scope in addressing mid- to high-rise multifamily housing. D&R International, Ltd's 2007 report entitled "Benchmarking Utility Usage in Public Housing" says: "For multifamily buildings, RECS data is compiled from less than 200 residential units—units located inside multifamily buildings, not the buildings themselves. That is a small data set, and by using data on residential units, the effects of common and shared spaces are left out of the utility use profile, decreasing the potential accuracy." The EPA's "EnergyStar Multifamily High Rise Program – Simulation Guidelines" is a recent attempt to address appropriate relevant modeling processes.

[101] U.S.Energy Information Administration. (revision date not available on EIA site) Retrieved 01/19/2011 from http://www.eia.doe.gov/emeu/cbecs/2003howconducted.html

- The CBECS method for estimating energy end use breakdowns does not correspond with the end uses breakdowns in building energy simulation programs;
- The surveyed and analyzed building types in the CBECS are limited; energy modelers have a need for increased building types to be benchmarked to serve the range of building types they are modeling (i.e. museums, theaters);
- Because the majority of data is acquired from interviews (and not metered), the data is not as accurate as desired.

Other stakeholders (who have a vested interest in energy modeling) also have other motivations for enhancing CBECS data. These entities include:

- Other government entities like the EPA who use CBECS to produce energy performance benchmarks for different building types
- Professional organizations and national labs like ASRHAE and NREL, who have a need for accurate data to evaluate the impact of efficiency labeling programs (like ENERGY STAR) and new efficiency technologies and designs per climate zone.
- Municipalities and cities that have an interest in using CBECS data to evaluate the adoption rate and efficacy of specific local efficiency programs and incentives. [102]

These varied stakeholders all have an interest in improving CBECS data in the following ways that could also improve functionality for energy modeling:

- Increased frequency of surveys to better monitor trends in building energy end uses and consumption;
- Decreased time lag between period of data collection and public data release to provide more timely information to inform contemporary policies and technology development;
- Increased number of buildings surveyed to provide additional data points;
- Additional survey questions to ascertain data about building operation and maintenance, level of compliance with energy codes, etc. to better enable multivariate statistical analyses;
- Data estimates at increased geographic granularities (i.e. at the state and city level) to increase data precision for geographic areas; and
- Increased building types to enable benchmarking for a wider range of building uses and to enable more specific benchmarking per building type (especially for big energy users like data centers, labs, convention centers, etc).

[102] U.S.Energy Information Administration. (revision date not available on EIA site) Retrieved 01/19/2011 from http://www.eia.doe.gov/oiaf/servicerpt/energydata/chapter3.html

The EIA recognizes stakeholder needs[103] to a great extent but has a limited ability to respond because of:

- *Limited human resources and funds*. Evolving CBECS in ways described above is a serious undertaking that involves a lot of time, training, and money. The EIA estimates the cost of one such proposal at an additional $6,800,000 per four-year cycle above and beyond established projected costs for the 2011 CBECS update.
- *Need to comply with data confidentiality laws*. The EIA is required by law to protect the identity of individual survey respondents; in practice, this means aggregating data into larger pools to protect respondent identity, and/or refraining from publishing certain statistics at state-level or lower.[104]

Noteworthy collections of useful benchmark data have been gathered by other entities (i.e. utilities, building certification programs, portfolio property managers and managers, design professionals, professional organizations like LABS21[105]). However, public access to that data can be limited; when accessible, data collection points and methods differ from that of CBECS and prevent simple comparison.

Target Finder and Portfolio Manager

The EPA has developed two free, interactive energy management tools that pull from CBECS data to provide users simple online interfaces to benchmark individual building performance.

- For goal setting, users can enter individual building design data into **Target Finder** to set energy targets by benchmarking against CBECS estimates for similar buildings.[106]
- For performance evaluation, users can enter actual individual building energy data (from utility bills) into **Portfolio Manager** to compare against statistical CBECS estimates for similar buildings. While the tool does not allow users to compare individual data to other users' data, it does allow users to share actual data with the public.[107]

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[103] Stakeholder needs continue to grow quickly as more aggressive and varied energy efficiency initiatives are developed. Communication about how CBECS data within the government is used is not often seamless; as Joelle Michaels (CBECS Survey manager of the EIA) presented in a 4/15/2008 presentation to the Interagency Sustainability Working Group (ISWG), "The inclusion of CBECS in EISA was news to us." Retrieved 01/19/2011 from *www1.eere.energy.gov/femp/pdfs/michaels_pres0408.pdf*

[104] U.S.Energy Information Administration. (revision date not available on EIA site) Retrieved 01/19/2011 from http://www.eia.doe.gov/oiaf/servicerpt/energydata/chapter3.html

[105] For more information on LABS21®: http://www.labs21century.gov/

[106] For more information about Target Finder: http://www.energystar.gov/index.cfm?c=new_bldg_design.bus_target_finder

[107] For more information about Portfolio Manager: http://www.energystar.gov/index.cfm?c=evaluate_performance.bus_portfoliomanager

Both tools generate an EnergyStar rating on a scale of 1-100, as per the EPA's energy performance rating system (see Section 5.7.3).

5.8.9 Metered Data for Existing Buildings

Metered data for existing buildings are data that indicate performance over time. Thus, the data provide information regarding maximum connected load and load variation over a period of time. Sources of existing building data are helpful references for developing realistic peak loads and load shapes in new building and existing building models. A list of available sources for these data is provided below.

- Default schedules available in hourly simulation programs
- The ASRHAE 90.1 Standard includes recommended operating schedules for select end uses by building type. The User's Guide also provides typical values for plug loads by building type and schedules.
- Title-24 includes default schedules for evaluating baseline building performance. These are automatically added to the baseline building and proposed design building when using Title-24 hourly simulation compliance software (eQUEST and EnergyPro).
- Research reports and articles involving the development of load shape data from metered data, for example:
  - Akbari, H. and S.J. Konopacki, 1998. "Application of an end-use disaggregation algorithm for obtaining building energy-use data", *ASME Journal of Solar Energy Eng*., 12, pp. 205-210, August.
  - Bou-Saada, T., Haberl, J. 1995a. "A Weather-Daytyping Procedure for Disaggregating Hourly End-use Loads in an Electrically Heated and Cooled Building from Whole-building Hourly Data", Proceedings of the 30th Intersociety Energy Conversion Engineering Conference, July 31- August 4, 1995, Orlando, Florida.
- Research reports and articles describing individual building performance data
- Research reports and articles outlining calibration methods using metered data, for example:
  - Lunneberg, T.A., 1999. "Improving simulation accuracy through the use of short-term electrical end-use monitoring", IBPSA Conference, Kyoto, Japan, Sept. 13-15.
  - Manke, J., and D. Hittle, 1996. "Calibrating Building Energy Analysis Models Using Short Term Test Data", Proceedings of the 1996 ASME International Solar Engineering Conference, ASME Solar Energy Division, pp. 369-378.

As noted above, default and code-compliant assumptions for schedules for electrical end-uses are available in hourly simulation software. There is some published data about actual measured performance in buildings but there is no single exhaustive resource. And the data that are available are not in a form that can be readily incorporated into model input. Developing sources of existing building data will allow modelers to better understand the possible variation in loads and load shapes for buildings of the same type. Understanding the range will improve initial model development and support calibration efforts.

5.8.10 Predicted Vs. Actual Performance

On October 8, 2010, a class action lawsuit was filed against the U.S. Green Building Council asserting amongst other things that "the LEED system does not live up to predicted and advertised energy savings."[108] Regardless of the validity of the claims for this specific example, the question of how energy model predictions match up with actual performance (and how they should) is becoming more and more important in the quest for designing and investing in high performance buildings.

Though controversial, the 2008 New Buildings Institute study[109] still serves as one of the most comprehensive looks at predicted performance versus actual performance. In comparing the ratio between measured and design (predicted) EUI for all LEED certification levels, the study found the average ratio of the analyzed sample (that excludes high energy use buildings) is 92%, indicating a good level of accuracy. In some respects this is a surprising finding, given that for new construction projects, there should be little expectation that the design energy model matches actual performance. Calibration factors such as operating schedules, temperature setpoints, occupancy, actual airflow rates, and weather data can cause distinct differences between the design model and measured performance. These factors must be adjusted and refined through calibration processes prior to making comparisons.

For existing buildings, even with the most thorough audit processes, uncertainty still remains when identifying and modeling building parameters. This uncertainty propagates throughout the final calibrated model and can affect the quality of the energy saving estimates. This is especially important in instances such as performance contracting, where the accuracy of the model is paramount, and every single input and assumption requires scrutiny (and as a result, models may be more accurate).

Overall, the importance of predicted results versus actual performance is determined by the intent of the model. For ratings or labels that only compare the difference between models, less accuracy is required between the model and measured performance. For instances like performance contracting, accuracy is more critical.

5.9 Direct Drivers of Energy Modeling

Why would you build an energy model? There are many industry trends (rising fuel costs, potential carbon regulation, and increased awareness of energy use for example) that

[108] Sacks, S. (2010, October 10). USGBC sued for fraud and more! [Web log message]. Retrieved from http://californiagreenbuildingblog.com/category/usgbc-leed/

[109] Turner, C., & Frankel, M. (2008). Energy performance of LEED for new construction buildings.

influence energy efficiency and ultimately, the demand for energy modeling. But, there are also specific drivers—showing compliance with a code or earning a building label—that require or necessitate the use of energy modeling. This section focuses on these specific reasons why energy models are created.

Recognizing the driver for an energy model is critical. For example, a building energy modeler seeking to document achievement of points for LEED credit EAc1 will need to adhere to different modeling protocols and inputs than a modeler using building simulation to compare the design energy savings of one HVAC system to another for an interested client. Understanding the intent behind the energy model directly informs the appropriate modeling approach and outputs.

Unfortunately, software and guidance to address most of the drivers discussed here has only occurred after the fact (e.g. LEED was created prior to training and educating energy modelers or legislation has been passed before software needed for compliance was developed). Additionally, action to address these drivers through tailored changes to software programs has been slow to develop. This section provides basic background information on the following 8 key drivers of building energy modeling:

1. Compliance with state and local **energy codes and standards**,
2. Compliance with **federal legislation and regulations**,
3. Achievement of **green building ratings and labels**,
4. Participation in **utility programs**,
5. Participation in, and receipt of, **government funding and tax incentives**,
6. Client-driven **design assistance**,
7. Creating and validating **performance guarantees,** and
8. Government and academic **research**.

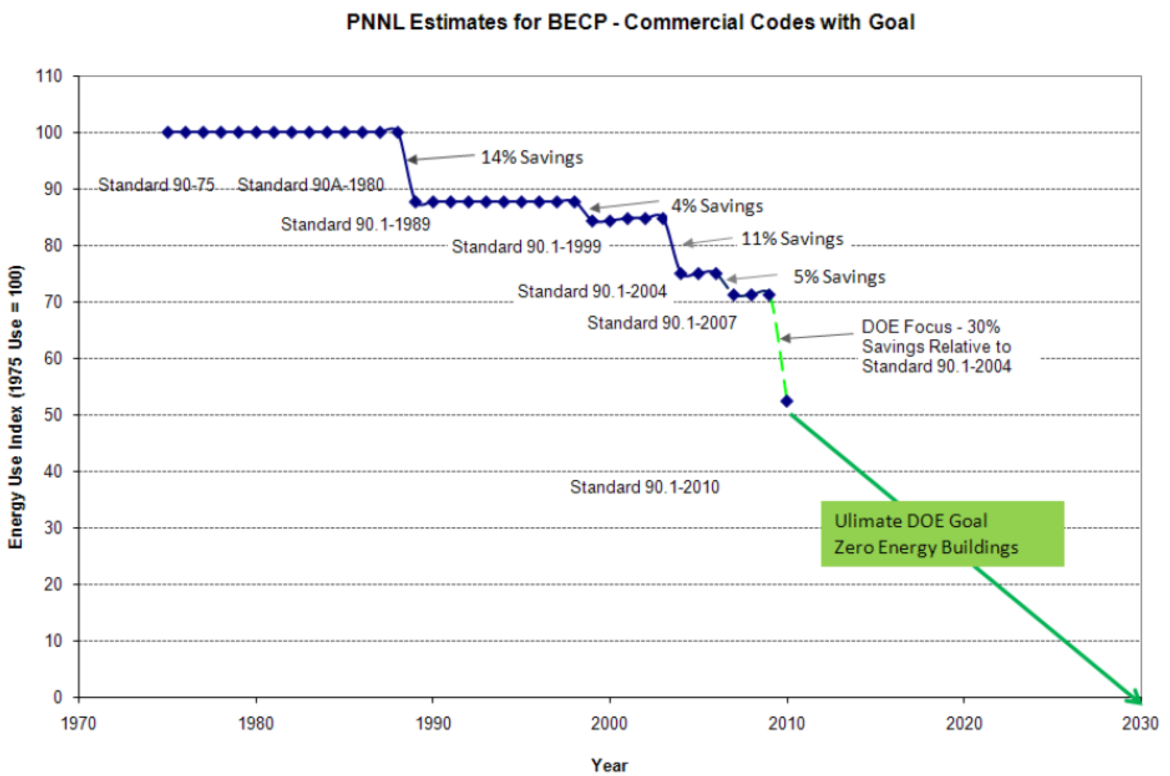
These 8 drivers serve as direct reasons for why an analyst would build an energy model (e.g. you need to demonstrate compliance with a code or you need to conduct research on various HVAC control sequences). Beyond these direct reasons, there are indirect drivers of energy efficiency (and thus potentially energy modeling) that should also be noted. These include elevated energy prices, potential carbon regulation, reduced operations and maintenance costs resulting from energy efficiency projects, and the growing recognition of many of the softer (though often most important) benefits of energy efficiency such as attraction and retention of high credit tenants, rental and sales premiums, and increased employee productivity.

5.9.1 Energy Codes & Standards

Energy codes and standards are one of the biggest drivers of energy modeling as they typically offer modeling compliance paths. Codes and standards set minimum requirements for new and existing building energy-efficient design and construction.

Energy codes "specify how buildings *must* be constructed or perform and are written in mandatory, enforceable language" while energy standards "describe how buildings *should* be constructed to save energy cost-effectively."[110] State and local jurisdictions adopt model energy codes (such as the International Energy Conservation Code) or develop their own energy codes that leverage common standards (such as ASHRAE Standard 90.1-2010). Over time, codes are getting more and more stringent (Figure 8). By 2030, the Department of Energy (DOE) is targeting net zero energy buildings. To reach these targets, energy modeling will play an ever-increasing role.

Figure 8: Historical and Future ASHRAE 90.1 Code Progression[111]



Most common energy codes and standards (such as those listed in Table 17) have a performance-based compliance option (in addition to prescriptive and/or trade-off options) that relies upon simulation tools to compare the performance of a proposed building design to a reference case defined by the code or standard. Demonstrating code compliance via performance-based simulation options is becoming more and

[110] Bartlett, R. (2007, January). *Codes 101 training: overview*. Retrieved from http://www.energycodes.gov/moodle/course/view.php?id=7

[111] Liu, B. Pacific Northwest National Laboratory. (2010, May). *Using the Reference Building Models for the Standard 90.1-2010 Development*. Retrieved from: http://apps1.eere.energy.gov/buildings/publications/pdfs/corporate/ns/webinar_commercial_reference_05_2010.pdf (slide 3)

more popular, though requires more engineering judgment (and often time) than pursuing the prescriptive approach. Also, differences between codes and standards can make the transfer of knowledge from an energy model for one client or project to another overwhelming and time-intensive. For more detail on codes and standards, see Appendix E.1 and E.2.

Table 17: Common Energy Codes & Standards Used in Energy Modeling

Code or Standard	Use of Energy Modeling
IECC 2009	Residential code offers a "Simulated Performance Alternative" while the commercial code offers a "Total Building Performance" building simulation based compliance option.
ANSI/ASHRAE/IES NA Standard 90.1-2010	Standard 90.1 offers a building energy simulation compliance path via the "Energy Cost Budget Method."
Title 24 (CA)	Title 24 allows the use of computer programs to demonstrate that a proposed building design meets a defined building energy budget (Section 141). The T24 building energy budget is one of the most stringent of all baseline buildings defined by various codes or standards.
IgCC	The current draft version of the International Green Construction Code does include a performance-based energy simulation option that uses a new metric, the Zero Energy Performance Index (zEPI), to determine compliance.
ANSI/ASHRAE/USGBC/IES Standard 189.1-2009	Standard 189.1 defines a "Performance Option" in section 7.5 of the standard that requires the building project has an annual energy cost less than or equal to the comparison building defined by normative Appendix D ("Performance Option for Energy Efficiency")

5.9.2 Federal Legislation & Regulations

As federal requirements for energy efficiency become more and more stringent, we are seeing increased demand to demonstrate compliance through energy modeling. While federal buildings are under the most pressure to demonstrate compliance, some municipal and private building projects that are using federal regulations and legislation to benchmark their own energy consumption goals are also following suit.

While building energy simulation is not explicitly called out as a requirement in major contemporary federal regulations, the regulations nevertheless encourage energy modeling because:

- They often specify a reduction in design energy cost, use, or fossil fuel consumption as compared to a baseline (commonly defined by ASHRAE, CBECS, or previously documented energy use when applicable for existing buildings).

Energy modeling is considered the most definitive way to forecast whole-building energy consumption for use as comparison against established baselines.

- They often require design teams to demonstrate that energy efficiency measures are cost-effective, and in some cases explicitly require design teams to produce financial and/or life cycle cost analyses (LCCA). While energy cost savings from simple efficiency measures could be evaluated individually using simple spreadsheet calculations, only whole building energy models can estimate total cost savings from integrated packages of measures. Whole building energy simulation is required to determine savings from part load efficiencies and system interactions that would result from real-life interactions between components.
- They are directing projects to use integrated design principles that emphasize synergies between design strategies. Again, synergies for energy use from a whole-building's perspective is best captured using energy modeling.

Major federal regulations that are helping to drive the use of building energy simulation are summarized below in Table 18.

Table 18: Federal Regulations and Legislation as a Driver of Energy Modeling

Federal Legislation & Regulations	Role of Energy Modeling
EPAct 2005	Requires new federal facilities to reduce energy operating costs by 30% compared to the current ASHRAE 90.1 or IECC baseline. For congressional buildings, requires design team to submit description of LCCA used to determine cost-effectiveness of proposed project.
EISA 2007	Requires new construction and major renovations to reduce fossil-fuel consumption by 100% by 2030 (up from 55% by 2010) from 2003 CBECS baseline. Requires LCCA to demonstrate cost-effectiveness of proposed design.
EO 13423	Directs federal agency new construction and major renovations to comply with energy operating costs reductions requirements provided in the Guiding Principles for Federal Leadership in High Performance and Sustainable Buildings.
EO 13514	Requires all new Federal buildings entering design phase in 2020 or later to pursue cost-effective strategies to achieve zero net energy by 2030. Directs all new construction, major renovations, repairs or alterations to comply with energy operating costs reductions requirements provided in the Guiding Principles for Federal Leadership in High Performance and Sustainable Buildings (above).
Guiding Principles for Federal	These principles require new construction to reduce energy operating costs by 30% compared to the current ASHRAE 90.1 baseline. For new construction and major renovations, they require an energy use

Federal Legislation & Regulations	Role of Energy Modeling
Leadership in High Performance and Sustainable Buildings	intensity (EUI) reduction of 20% below pre-renovations 2003 baseline. For existing buildings, they give the option to reduce EUI by 20% from 2003 or 2004 documented energy use, reduce energy operating costs by 20% from current ASHRAE 90.1 baseline if design information is available, OR to achieve an EnergyStar rating of 75 of higher.
GSA's Minimum Performance Criteria for Recovery Projects	Requires all GSA projects funded by the Recovery Act to comply with the energy operating costs reductions requirements provided in the Guiding Principles for Federal Leadership in High Performance and Sustainable Buildings (above).
GSA Facility Standards	The 2010 version of P-100: *Facilities Standards for the Public Buildings Service* requires that the A/E firm use energy modeling and life cycle cost analysis to inform design.
Better Buildings Initiative	The President's recently announced Better Buildings Initiative plan on February 3, 2011, calls for the cost-effective upgrade of commercial buildings to be 20 percent more energy efficient by 2020. Details are pending as to how implementation will unfold or be enforced. The use (if any) of energy modeling to support the initiative is unclear.

For more detail on federal legislation and regulations, see Appendix E.3.

5.9.3 Green Building Rating Systems & Labels

Achievement of green building rating systems and labels is perhaps the largest driver of energy modeling in the U.S. today. A variety of ratings and labels either require or offer energy modeling as a compliance path. The certifications considered in this pre-read are primarily U.S. based, though international rating systems also rely on energy modeling (e.g. the UK's BREEAM or Australia's Green Star).

It is important to note how green building ratings and labels influence an energy modeler's time and eventually actual building design and performance. Oftentimes, achievement of certifications results in time spent filling out forms, interpreting cryptic rules or "guidance," and calculating baseline requirements (e.g. fan power). This time would be better spent analyzing more design options or doing more quality control. Also, "gaming" of ratings and labels can lead to poor design decisions (e.g. bringing in additional outside air because Appendix G doesn't penalize you for this in terms of energy – but in actual building operation, it uses more energy). Though there are clear upsides to having and using ratings and labels, there is clearly room for improvement in using energy modeling as an effective (and more informative) compliance path.

Table 19: Green Building Rating Systems & Labels as a Driver of Energy Modeling

Rating or Label	Use of Energy Modeling
LEED®	Energy & Atmosphere Credit 1: Optimize Energy Performance (EAc1) offers three compliance paths for New Construction & Major Renovations, one of which relies on whole building energy simulation and the use of the "Performance Rating Method" in Appendix G of ASHRAE Standard 90.1. Appendix G helps to define the energy efficiency rating of buildings that exceed the minimum requirements of Standard 90.1.
Green Globes®:	Green Globes® relies upon energy modeling in order to compare projected performance to the Environmental Performance Agency's Target Finder.
Designed to Earn the ENERGY STAR	New building projects can receive the "Designed to Earn the ENERGY STAR" designation if they demonstrate that the energy performance target (identified at the 95% construction document stage through energy analysis) exceeds the ENERGY STAR rating of 75.
ASHRAE Building Energy Quotient (EQ) Program	The "as designed" rating component of Building EQ will require an energy simulation performed by a certified building modeler.

For more detail on green building ratings or labels, see Appendix E.4.

5.9.4 Utility Programs

When utilities are incentivized to save energy, they have often relied on building energy simulation as a method for apportioning efficiency incentives to building owners and occupants. In the nineties, utilities in the Northeast and California would offer energy modeling services at low-cost or no-cost to architects and engineers designing new buildings. Today, utilities have outsourced this service, using ratepayer funds to incentivize designers and building owners to use energy models (see Appendix E.5 for examples).

Beyond encouraging customers to reduce energy use, building energy models are also used by utilities to estimate the bottom-up energy efficiency potential in a range of building types in their territories. One example is the SWEEP's publication "The New Mother Lode: The Potential for More Efficient Electricity Use in the Southwest", which was intended to help utilities in the Southwest understand the amount of cost-effective energy efficiency available in their region.

Finally, though metered data is preferred, utilities sometimes use building energy models to assess the impact of utility programs. Though third-party measurement & verification entities such as ICF International and Enernoc acknowledge energy models are not a perfect proxy, energy models are far better than other alternatives such as savings calculation equations or regression expressions for providing data on how much energy a package of measures can save and over what time periods.

Because utilities often rely on energy modeling in the capacities described above, they are also often a huge driver of energy modeling software development and training. Many upgrades to eQUEST have been funded through California ratepayer "public goods charges." Though any upgrades are clearly helpful, those to eQUEST in particular are not often aligned with the needs of 90% of its users.

5.9.5 Government Funding & Tax Incentives

To obtain tax deductions in recently enacted policies, energy models have been required as a mechanism to demonstrate savings. Without building energy model software, policies with tax deductions for building energy efficiency may not be feasible because the Internal Revenue Service (IRS) and other governing bodies would not have the means to certify that the buildings are designed to perform at or beyond the levels of efficiency the building owners may be claiming. Though a useful compliance approach, proving achievement of savings through an energy model can be time-consuming and often does not impact design (as models to earn incentives are often intentionally produced late in the process). As a result, in some cases the time and resources needed to create the model may not even justify the tax benefit.

The commercial building tax deductions (first enacted under the Energy Policy Act of 2005 26 USC § 179D and then later extended until 2013 by the Emergency Economic Stabilization Act of 2008) provide a tax deduction of $1.80 per square foot to building owners of new or existing buildings who reduce regulated building energy cost by 50% or more compared to a building meeting the minimum requirements of ASHRAE Standard 90.1 -2001. To qualify for the full deduction, energy savings must be calculated using energy model software that meets the requirements that the IRS has established in conjunction with the DOE. This tax deduction program is a rapidly growing driver for energy modeling. IRS notices 2006-52 and 2008-40 provide additional guidance on qualifying for and calculating the 179D tax deduction. Note that buildings that don't meet the 50% energy reduction option can also qualify for partial lighting, HVAC, or water heating tax deductions up to $0.60 per square foot.

Commercial building tax deductions may change in the near future however, pending further details on President Obama's recent announcement of a "Better Buildings" initiative aimed at making commercial buildings 20% more efficient by 2020. Amongst other strategies, the initiative will likely transform current commercial building tax deductions into more generous tax credits.

For residential buildings, there is a tax credit for homebuilders (also part of EPACT 2005 26 USC § 45L and extended through the Tax Relief, Unemployment, and Job Creation Act of 2010 HR 4853) of $1,000 if energy consumption is reduced by more than 30% relative to the International Energy Conservation Code Standard and $2,000 if energy consumption is reduced by more than 50%. Like the commercial building tax deductions, the IRS requires that homebuilders calculate the home's energy consumption with approved energy modeling software.[112]

5.9.6 Design Assistance

Even when other drivers are not in play, building owners, architects, and engineers often desire energy modeling to simply inform investment decisions. Is it more cost-effective to invest in better glazing or better frames? Should direct expansion (DX) units be installed or is a chilled water system a better long-term choice? While some of these questions can be answered based on experience or spreadsheets models, oftentimes a whole building energy simulation is the only way to easily compare options and packages of options. In these cases, outputs from a whole building energy simulation should feed into a life cycle cost analysis (LCCA) to provide a building owner with several investment options to consider.

Using energy modeling to simply inform design is perhaps the best use of a modeler's time. In these circumstances, however the modeler is often trying to push the envelope, thus they more often run into challenges simulating more complex systems. Because there is no government or utility entity with huge demand for simulating more complex systems, upgrades to existing software are slow to develop. Similarly, there is little training on more advanced simulation methods as most of the focus is on meeting the needs of those dealing with code compliance or ratings and labels.

5.9.7 Performance Guarantees

As energy providers and energy service companies become more sophisticated in the packages of energy efficiency measures offered to clients, the use of proprietary spreadsheets becomes more and more difficult (as clients demand greater transparency and third party review of analysis). As such, the use of energy models is becoming more attractive. This was the case for the Empire State Building project where Johnson Controls (the contracted Energy Service Company) opted to use eQUEST to estimate energy efficiency savings in lieu of spreadsheet models. The energy savings estimates from the eQUEST model were then used in the performance guarantee, the key contractual document between the building owner and Johnson Controls. The building owner requested multiple reviews of the energy model and savings estimates—which were easily provided given that the analysis was conducted using industry available software. The eQUEST model was also heavily relied upon to provide inputs to the life cycle cost analysis.

Groups using energy modeling tools to guarantee savings have unique needs such as the ability to simulate advanced controls, with shorter timesteps and the ability to precisely calibrate models to actual utility bills. Overall greater accuracy is required as

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[112] For more information on qualifying software, visit http://www1.eere.energy.gov/buildings/qualified_software.html for commercial buildings and http://www.irs.gov/businesses/small/industries/article/0,,id=155445,00.html for residential buildings.

large sums of money can be on the line. This translates into more time required to collect inputs (in lieu of using standard occupancy or operational assumptions) and more sleuthing into the characteristics of currently installed equipment.

5.9.8 Research

A final driver of building energy modeling is academic, industry, and government research. Most building simulation programs were originally developed for research purposes, not for use by industry (hence some of the user-friendly challenges that exist today). Today, groups such as the Building Technologies Simulation Research Group at LBNL,[113] the Center for the Built Environment at UC Berkeley,[114] or the National Renewable Energy Lab are either researching ways to improve building energy simulation tools or are using the tools to conduct research on specific technologies or building design processes. Researchers also conduct policy-scale analyses that have unique demands related to modeling large numbers of different buildings in different locations. With research, the key energy modeling needs are flexibility and comprehensiveness.

6 Market Opportunities

As we described in Section 5.9, there are 8 key drivers for today's energy modeling industry:

1. Compliance with state and local **energy codes and standards**,
2. Compliance with **federal legislation and regulations**,
3. Achievement of **green building ratings and labels**,
4. Participation in **utility programs**,
5. Participation in, and receipt of, **government funding and tax incentives**,
6. Client-driven **design assistance**,
7. Creating and validating **performance guarantees,** and
8. Government and academic **research**.

When considering future market demand for this industry, we will consider:

Are the current drivers incentivizing the best applications of energy modeling services? How can BEM best be leveraged to support wider adoption of low-energy building? What kind of shift in market demand and customer education is required for energy modeling to be employed for these uses?

[113] The Simulation Research Group. (2010). *Building technologies simulation research group*. Retrieved from http://simulationresearch.lbl.gov/

[114] Center for the Built Environment. (2007). *Energy performance modeling of underfloor air distribution systems*. Retrieved from http://www.cbe.berkeley.edu/research/briefs-ufadmodel.htm

This section provides fodder for that discussion by examining:

- What are relevant current trends in U.S. new buildings and retrofits?
- What are growing trends within energy efficiency and BEM that appear to be shaping the future trajectory for use of BEM?
- What untapped or underserved markets could benefit from BEM in the future?

6.1 General Trends in U.S. Building Stock

In 2008, the EIA estimated the U.S. building stock to consist of approximately 81 billion square feet. Further, they estimated that between 2010 and 2025, the building stock would increase to 97.5 billion square feet. More importantly, the EIA projected the total market for renovations and new construction between now and 2025 to be 41 billion square feet. While this data does not account for the recent hiccup in the construction market, it highlights long-term projected industry growth. Pike Research expects much of the retrofit market to be in the private/commercial space sector.[115]

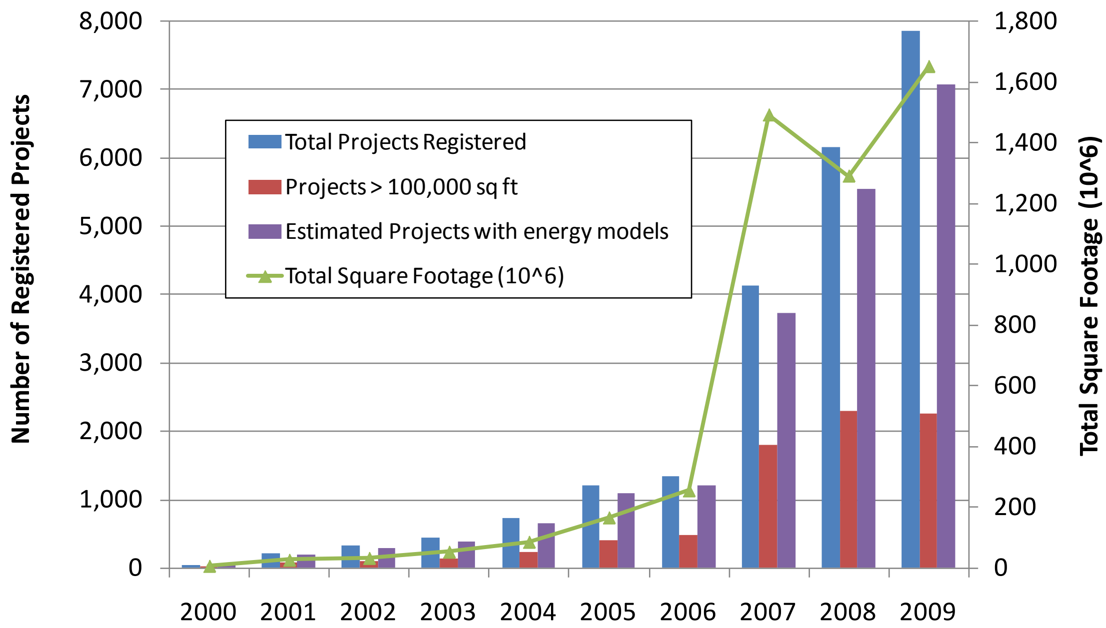
In 2005, green building had just started to emerge in the market, comprising 2% of new construction. By 2008, that share had grown dramatically to 12% of commercial construction and 8% of residential construction.[116]

6.2 Trends in LEED Certification Program

It is useful to consider the growth in demand for LEED certification over the years, as this has been a key driver of the growth in demand for energy modeling services. Figure 7 shows the dramatic growth in the number of registered LEED projects for the categories that utilize energy modeling (New Construction, Core and Shell, Schools, and Retail).

[115] Pike Research, Research Report. (2009). Energy efficiency retrofits for commercial and public buildings
[116] Bernstein, H. McGraw-Hill Construction, SmartMarket Report. (2010). Green BIM: How building information modeling is contributing to green design and construction.

Figure 9: Registered LEED Projects by Year (include NC, CS, Schools and Retail)



According to Mike Opitz of the USGBC, approximately 90% of current School, NC, CS, and Retail LEED projects utilize an energy model. Reflecting the building size commonly modeled in a BEM program, the average size of LEED certified buildings in 2010 was 164,707 square feet.[117]

The graph above does not include 2010 data. The 2010 total certified floor area nearly equaled the previous ten years' certified floor area combined. However, much of this growth was driven by certification in India, the UAE, and China. The GreenBiz Group's year-end forecast of LEED registrations is down almost 70 percent. This indicates that LEED registrations are subject to fluctuations in the construction market.

6.2.1 Potential for Growth Based on BIM Trends

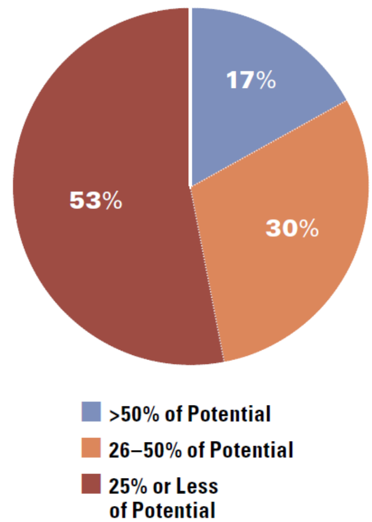
McGraw- Hill Construction conducted the 2010 Green BIM Study to assess the level and scope of use of BIM tools on green building projects and with energy simulation.[118] Although this report was focused on BIM, the results can be extrapolated and applied to the potential for growth in building energy modeling. The research in this report was conducted through an internet survey of industry professionals with 494 geographically dispersed respondents (architects, engineers, contractors, owners, product manufacturers, etc). Throughout this section, when McGraw-Hill is referenced, it refers to the information in the 2010 Green BIM Study.

[117] Watson, R. (2010). Green building market and impact report. *GreenBiz Group*, Retrieved from http://www.greenbiz.com/sites/all/themes/greenbiz/doc/GBMIR_2010.pdf
[118] Bernstein, H. McGraw-Hill Construction, SmartMarket Report. (2010). Green BIM: How building information modeling is contributing to green design and construction.

While the industry perceives great value in using BIM on green projects, market penetration has thus far been slow. If barriers, such as poor tool integration, can be addressed, than the use of BIM with whole building energy simulations could experience significant growth.

Figure 10: Realization of BIM's Potential to Achieve Green Objectives[119]

The McGraw Hill study found that BIM is poised for significant growth. 78% of BIM users who do not currently use it for green projects expect to do so within 3 years. Only 17% of Green BIM practitioners[120] currently realize more than 50% of BIM's potential to help achieve green objectives.



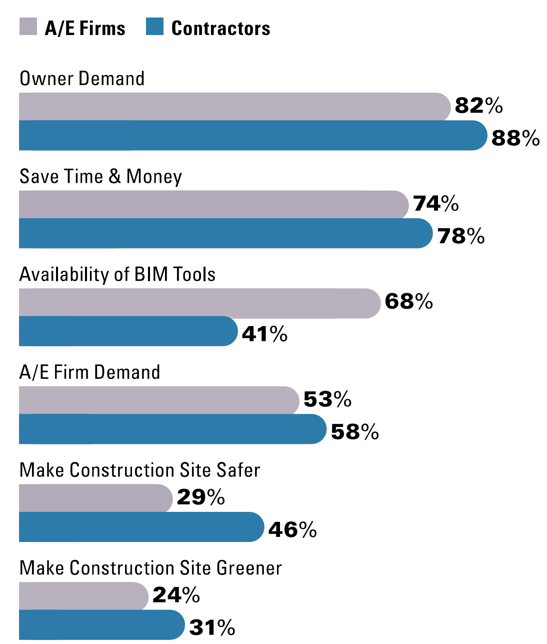
The McGraw Hill study also reports that 95% of firms using Green BIM will do energy performance simulations within 2 years, compared to 73% now. Even more dramatic, 79% of non-Green BIM firms will conduct such simulations, compared to only 21% now. However, of the Green BIM practitioners that are performing energy simulations, they are doing so on only one quarter (or less) of their projects.

When thinking about how to increase the market penetration of energy modeling services, the McGraw Hill BIM study provides some useful data. Thus far, architects have played the largest role in driving the adoption of BIM. Moving forward, the McGraw Hill study showed that creating more owner demand would be the most effective way of penetrating the market.

[119] Bernstein, H. McGraw-Hill Construction, SmartMarket Report. (2010). Green BIM: How building information modeling is contributing to green design and construction.
[120] Firms in which more than 75% of their total projects are green

Figure 11: Factors Triggering Market Penetration of BIM Practice in Green Design[121]

In order to create more customer demand, potential customers (such as building owners) must be educated about the value of BIM and energy modeling.



The data above indicates that potential customers need to better understand the best applications for BIM/energy modeling and the overall value propositions. Potential customers should understand the following:

- What value do I get from commissioning energy modeling services? What will it help me do, decide etc? What is the business value associated with this?
- When is a whole-building energy model the right application for a given problem? In some instances, a simpler, more "back of the envelope" type of approach may be more appropriate and sufficient for the level of accuracy required.
- At point during the design/retrofit process is energy modeling most effective?
- What can I expect from the results of the energy model? Will this energy model predict actual building usage or just determine comparative performance?

6.2.2 Other Trends and Potential Future Uses for BEM

Beyond the current drivers for BEM, we can begin to outline a preliminary list of potential trends in energy efficiency and energy modeling that could shape future BEM use. We can also identify possible future uses for BEM that currently represent untapped or underserved markets (marked with an asterisk); these should be considered for feasibility and impact.

[121] Bernstein, H. McGraw-Hill Construction, SmartMarket Report. (2010). Green BIM: How building information modeling is contributing to green design and construction.

Consider:

Which of these potential trends and future uses will be the strongest drivers of low-energy building in the future? Should BEM play a supporting role in helping to set goals and/or to provide guidance in meeting them? How?

Table 20: Potential Trends for Future Uses of BEM (* indicates untapped markets)

Trends	Provocations
To meet increasingly stringent Federal regulations and legislation	Recent legislation/regulation appears to be enforcing a shift from prescriptive standards to outcome-based goals. Energy efficiency trends in Europe are often perceived to be "ahead" of those in the U.S.[122] ➢ *What are the most impactful ways for BEM to support federal initiatives? Would those methods change if we adopt regulation/legislation like those in Europe or other parts of the world?*
To meet increasingly stringent municipal and local regulations	Local/municipal regulations are typically more stringent than federal regulations. ➢ *Can or should BEM be leveraged in different ways at the local scale to enforce municipal goals?*
To meet increasingly stringent guidelines, standards, and codes	➢ *What are the best ways to leverage BEM in design guidelines and standards? Can we coordinate the conflicting requirements for BEM at the federal, municipal, and building code level?*
To leverage results from a few models to inform a large number of buildings	➢ *When is it more appropriate to use prototypical models to inform building design and efficiency strategy selection? What are the implications of using prototypical models versus individual building models?*
To inform real estate asset ratings*	➢ *Is BEM a good way to inform asset ratings for real estate? What must happen to make this a trusted method?*
To assess perceived risk for financial investors*	➢ *Is BEM a good way to inform asset ratings for real estate? What must happen to make this a trusted method?*
To inform design for currently underserved building types*	➢ *BEM services are not currently used for some building types, notably residential and small commercial. Should BEM be leveraged to inform these underserved markets, and how?*

THANK YOU FOR MAKING IT TO PAGE 102! We look forward to our productive work together in March.

- The Rocky Mountain Institute Team

[122] Note the EU Energy Performance of Buildings Directive (recast in 2010) mandates meeting nearly net zero building energy for all public buildings by 2018, and for all other new buildings by 2020.

APPENDICES

A. Appendix A: Statements from Summit Organizer and Industry Partners
B. Appendix B: Vision Statements
C. Appendix C: Descriptions of Simulation Tools
D. Appendix D: Statistics on Tool Downloads
E. Appendix E: Direct Drivers Additional Information

A. Appendix A: Statements from Summit Organizer and Industry Partners

The BEM Innovation Summit is a Rocky Mountain Institute event, developed in partnership with ASHRAE, IBPSA-USA, IMT, and USGBC. These organizations are committed to this effort because the growth and improvement of energy modeling is important to each organization's mission and plan for future work.

Rocky Mountain Institute (RMI) - Summit Organizer
RMI's vision is a world thriving, verdant, and secure, for all, for ever. Since 1982, RMI has worked to drive the efficient and restorative use of resources. RMI's strategic focus, executed through specific initiatives designed to take our work rapidly to scale, is to map and drive the transition from coal and oil to efficiency and renewables.

RMI impacts hundreds of buildings per year, and employs energy simulation life cycle cost analysis (LCCA) on at least 90% of projects. RMI has identified competent energy and financial analysis as a key factor in making the business case for low energy buildings. To address this, RMI created a work stream called the Energy Modeling Toolkit, which addresses barriers related to energy modeling with a 3-pronged approach: improving education and training, addressing gaps within software tool capabilities, and providing industry master plan guidance. The Summit is the first major step in creating a collaborative master plan for the future of energy modeling.

As a non-profit organization with 28 years of experience advocating for the benefits integrated energy and costs analysis, RMI is uniquely positioned to convene key stakeholder groups that are sometimes fragmented or in direct competition with one another. We have held dozens of these types of events and enjoyed great success with this model. A few examples include (follow links to download full reports):

- PV Balance of System Design Charrette: Focused on balance of system cost-reduction opportunities for commercial and small utility photovoltaic (PV) systems, this charrette convened over 50 industry experts. Industry competitors collaborated to provide hundreds of ideas for cost reduction, formulate design principles, develop specific designs, and consider concrete implementation recommendations.
- Smart Garage: RMI united experts for 3-day a summit meeting to identify breakthroughs needed to electrify the U.S. auto fleet. In the broadest assortment of stakeholders yet assembled on this topic, the gathering instigated several key initiatives to realize the "Smart Garage" -- a new energy paradigm that allows cars to plug in to homes and buildings, uniting our transport, building and grid energy systems.

American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) - Summit Partner
ASHRAE, founded in 1894, is an international organization of some 50,000 persons with the following mission: to advance the arts and sciences of heating, ventilating, air conditioning and refrigerating to serve humanity and promote a sustainable world. ASHRAE fulfills its mission through research, standards writing, publishing and continuing education. With these efforts, ASHRAE and its members are leaders in sustainable design and support the energy modeling field by providing technical guidance including a high performance green building standard, Advanced Energy Design Guides (AEDGs), a certification program for building energy modeling professionals (BEMPs), and the development of the Building Energy Quotient (EQ) energy labeling program.

ASHRAE's most recent research strategic plan includes proposals to:

- develop more accurate methods to relate building energy simulation models to actual building energy use;
- to continue to develop BIM to automate the creation or energy models from BIM data files;
- to update existing energy analysis calculation engines to model building components and systems that will be needed to meet current and future requirements; and
- to develop models and design procedures for natural and hybrid ventilation systems.

ASHRAE supports building energy modelers in creating an accurate model that is useful throughout the entire life of the building in order to provide a preview into a building's likely energy use and allow decisions affecting energy use to be made before a shovel even hits the ground. Doing so allows modelers to evaluate, choose, use, calibrate and interpret the results of energy modeling software used to design more energy efficient buildings.

International Building Performance Simulation Association, United States regional affiliate (IBPSA-USA) - Summit Partner
IBPSA-USA is organized for educational and scientific purposes to foster development and effective application of building simulation techniques. IBPSA-USA supports improvement of the performance of buildings in the United States by pursuing the following objectives:

- To hold national conferences to collate, preserve, and publish current developments in the field of building simulation and to transfer information about building simulation to practitioners.
- To facilitate exchange of information among members and others with interest in building simulation through meetings, newsletters, electronic publication, and other means.

- To provide financial and career-development support to students in building simulation fields.
- To engage in educational initiatives concerned with the teaching of building simulation in educational institutions and to building industry practitioners.
- To sponsor research and develop technical programs aimed at improving the technology of building simulation.
- To support harmonization activities to regularize the application of building simulation through activities such as the definition of standard methods for performance assessment, the provision of supporting data, promulgation of common data formats, and participation in development of building codes and rating systems.
- To form strategic alliances with professional organizations such as engineering and architectural societies to promote mutual understanding of the requirements of other professions and the effective use of building simulation technology.
- To foster regional activities that promote local support for IBPSA-USA objectives.
- To participate in international activities as an affiliate of the central IBPSA organization.

Institute for Market Transformation (IMT) - Summit Partner
The mission of the IMT is to "promote energy efficiency, green building and environmental protection in the United States and abroad." The organization's activities include technical and market research, educational outreach, and the crafting of building codes, legislation and other policy and program initiatives. In its efforts to strengthen linkages among property value, green building and energy performance, IMT partnered with the Architectural Energy Corporation (AEC), the New Buildings Institute (NBI), RESNET and others to establish COMNET, the Commercial Energy Services Network. COMNET seeks to standardize the assumptions and procedures for commercial asset ratings using building energy modeling tools.

As a building energy modeling methodology, the initial release of the COMNET Modeling Guidelines and Procedures (MGP) facilitates green ratings, tax deductions, and asset ratings. Starting with a single model for the proposed building, COMNET compliant software will be able to appropriately simulate building energy performance for each of the rule sets associated with these three applications or baselines. Reference buildings will be automatically generated as required. The model parameters for all simulation inputs and the output results can then be submitted to the appropriate rating authorities using standardized XML schema through automated portals. Future releases of the MGP may support additional baselines.

U.S. Green Building Council (USGBC) - Summit Partner
The mission of the USGBC is to transform the way buildings and communities are designed, built and operated, enabling an environmentally and socially responsible, healthy, and prosperous environment that improves the quality of life.

For the last 15 years the LEED program has been accelerating the adoption of best practices in the high performance buildings industry. LEED has always placed a heavy emphasis on energy efficiency: for new buildings, design compliance with ASHRAE 90.1 has been a requirement since the beginning, with LEED v2009 now requiring energy performance at least 10% better than 90.1. Optional points in LEED also stress energy efficiency, accounting for almost 20% of the total available points. Over 7,000 projects have certified in LEED to date, and experience has shown that the vast majority of them used energy models to demonstrate energy compliance. Thus, LEED has been a significant force in moving energy modeling from a niche specialty toward mainstream practice. Going forward, USGBC wishes to collaborate with other industry stakeholders to further accelerate this budding market transformation.

B. Appendix B: Vision Statements

Each attendee was asked to submit a one to two sentence statement expressing what the future of energy modeling would look like in terms of their organization's stake in the industry. The table below summarizes the vision statements received thus far. If you have not yet submitted a vision statement, please send yours to Merritt Jenkins at mjenkins@rmi.org.

Attendee and Affiliation	Vision Statement
Godfried Augenbroe (Georgia Tech)	"Building energy modeling is inherently flawed as it idealizes the behavior of an object whose use, state and behavior is messy and to a large extent unpredictable. Rigorous uncertainty analysis therefore needs to transform current practice."
Chip Barnaby (Wrightsoft)	"BIM that works -- each building has a unified shared model that is assembled and maintained by all participants throughout project life (design, construction, operation, refitting, and destruction). BEM studies can be efficiently done at any point in the life cycle using automatic 'thermal views' and analysis tools that perhaps do not yet exist."
John Bacus (Google)	"Energy modeling should be so easy, accurate and trustworthy that you do it both early and often during the design process."
Vladimir Bazjanac (LBL)	"Semi-automated simulation would eliminate the dependence on availability and competence of simulation modelers, the need for modeling labor with its inherent errors and omissions, would deliver reproducible results and do so within a fraction of time it takes to generate simulation results today, and would dramatically reduce the cost of modeling and simulation so it would be affordable to every project that develops an openBIM in its conduct."
Lynn G. Bellenger (ASHRAE)	"Building design teams use energy modeling in the earliest stages of concept design to make informed decisions on the building shape, envelope, and passive design features to minimize building loads and throughout the design process in selecting systems to optimize building performance. This integrated design process is widely accepted throughout the industry and embraced by owners, developers, architects, engineers, contractors, occupants, and operating personnel."
Matt Biesterveld (Trane Commercial Systems)	"Practical, comprehensive and accurate building energy modeling software that include complete equipment performance data, robust systems modeling capability and seamless BIM integration to a wide variety of tools for a holistic approach to building design and analysis."

Attendee and Affiliation	Vision Statement
Robert Bolin (Syska)	"Building energy modeling tools will be sufficiently sophisticated to model a more comprehensive array of building HVAC system alternatives such as radiant systems and natural ventilation, and provide more effective interoperability with other simulation tools for daylighting, fluid dynamics (CFD) and thermal comfort."
Michael Brandemuehl (ASHRAE and CU Boulder)	"When the energy model and measured data disagree, the data are viewed with suspicion."
Martha Brook (CEC)	"BEM software used for energy code compliance encourages and credits high performance, low energy buildings. Energy code compliance processes are integrated into the BEM tools used for architectural and engineering design."
Lane Burt (USGBC)	"Building energy models and modelers that are capable of answering the most common and basic questions. Is the model a prediction of future performance, a comparison of only the design to a code baseline, or somewhere in between? If the models and modelers are already capable of sufficiently answering the questions as asked, then are they being asked the right questions?"
Aaron Buys (RMI)	"Design teams integrate energy modeling into all phases of design and construction. Energy codes require energy modeling done by a professionally certified modeler for compliance in medium and large commercial buildings."
Coreina Chan (RMI)	"Energy efficiency is perceived to be a low-risk investment, as 'safe' or 'safer' than government bonds, with attractive yields. Energy modeling is viewed as part of a trusted approach for vetting different investment proposals."
Dru Crawley (Bentley)	"Automate the mundane -- liberate the creativity."
Scott Criswell (SAC Software Solutions)	"Building energy modeling software users will have access to a variety of free or inexpensive tools that are able to share data and communicate with each other, resulting in more accurate and less time consuming BEM analysis."

Attendee and Affiliation	Vision Statement
Ery Djunaedy (NEEA / University of Idaho)	"A vibrant, robust community of energy modelers develops simulation capabilities that keep pace with emerging building energy performance strategies. Equivalent to other open-source software platforms, simulation algorithms are readily available for review, testing and verification and quickly become part of modelers' tool kits. Widely referenced, peer-reviewed, online journals increase access to a broad array of performance modeling resources. Modelers become integral members of design teams."
Peter Ellis (Big Ladder Software)	"Software tools are a highly-leveraged, unhampered extension of the energy modeler's brain--the software equivalent of a super-powered, mechanized exoskeleton."
Caroline Fluhrer (RMI)	"Energy modeling is a user-friendly, cost-effective, and trusted approach to minimizing energy use in any type of new or existing energy-consuming facility."
Ellen Franconi (RMI)	"The practitioner no longer has to waste their time with drudgery work. Critical methods are standardized. Software does the piece work. Modeling becomes the creative process that it should be."
Philip Haves (LBL)	"Simulation is used to support and link each stage of the building life-cycle. In particular, it provides a means of enforcing accountability for building performance between design, construction and operation."
Roger Hedrick (AEC)	"Energy modeling is fully integrated into the design process, and is streamlined to allow its use early and often. Common data frameworks allow seamless data transfer between design tools, energy models, and code and rating authorities."
Joe Huang (White Box Technologies)	"Foster open-source development of software, and reduce the distinction between code developers and users."
Merritt Jenkins (RMI)	"Building energy modeling programs are validated through empirically verifiable data."
John Kennedy (Autodesk)	"WYSIWYG - What You See Is What You Get."
Erik Kolderup (Kolderup Consulting)	"Modeling tools efficiently support the evolution of a building model from conceptual design to occupancy (and beyond). These tools support – and perhaps even encourage – evolving geometry, thermal zoning, HVAC system assignments, operating schedules, and other currently time-consuming modeling tasks."

Attendee and Affiliation	Vision Statement
Steve Kromer (EVO/IPMVP)	"Building modeling tools that are standardized and modular such that practitioners can share data and algorithms between platforms. Users could 'plug in' to the models with any amount of specific data, and call on standard resources for generalized data. A hierarchy of typical building retrofits would be available. Each ECM would have standard parameters that can be communicated through xml or other data standard. Users would be able to easily run parametric analysis for their specific building/climate/use to determine manageable or reducible uncertainties."
Cliff Majersik (IMT)	"Service providers in the energy modeling sector have the resources and credibility they need to quickly and profitably make the business case for aggressive energy efficiency. Mutual adoption of a single set of verified modeling procedure guidelines and quality assurance standards by rating authorities, code officials, program administrators, financial markets and the IRS harmonizes modeling requirements, streamlines modeling processes and enhances the credibility of energy models."
Timothy McDowell (TESS)	"Moving Building Energy Modeling out of the 1970's and into the 21st century."
Don Mclean (IES Virtual Environment)	"Education about building physics is not only essential in being able to implement energy efficient strategies but also to understanding the limits of the tools that are being used. A competitive market promotes innovation, which is necessary to produce dynamic building simulation technology critical to climate change mitigation strategies."
John Melchert (The Weidt Group)	"Energy modeling should provide design teams and owners continuous feedback throughout the design and life of the building."
Linda Morrison (Ambient Energy)	"The industry gets concrete energy consulting feedback that guides excellent building performance design decisions and is reflected in actual performance during occupancy at a price that is appropriate for project complexity and standard for even the simplest projects."
Dan Nall (Flack + Kurtz)	"Building energy simulation programs will utilize BIM models for input with clever graphical tools easily to simplify data into energy modeling input format. Standard formats for performance data for various specific pieces of equipment will be recognized and manufacturers will make information available in that format much as they make BIM blocks available. System portions of building energy modeling programs will be object oriented and will feature graphical network creation and drag and drop for equipment 'objects'."

Attendee and Affiliation	Vision Statement
Satish Narayanan (United Technologies Research Center)	“Critical decision makers in building delivery chain, from concept to detailed design and commissioning, are equipped with necessary analysis tools to rapidly optimize whole building energy performance and ensure robust building operation”
Ron Nelson (IMT)	"Design and operation teams confidently model building energy performance starting with the schematic design phase and continuing through the operation and maintenance phase. The simulations are so reliable that control algorithms employ BEM and weather forecasts to optimize energy efficient operations and to issue alarms when forecast energy consumption is not realized."
Mike Opitz (USGBC)	"Energy models are used robustly and broadly as tools to assess design trade-offs, but in the design context are NEVER treated as predictions of actual energy use after the building is operational. In fact, energy modelers as a group must quit using the term "predicted energy use" when they only mean "as designed" or "as simulated". This will avoid implying that design-phase models are intended to predict actual operational energy use, a common misconception that has needlessly hindered the broader acceptance of energy modeling as an essential assessment tool for 20 years."
Aleka Pappas (Group 14)	"As energy modeling services expand and the tools improve, the market will pursue greater innovation resulting in significant energy savings."
David Reddy (360 Analytics)	"Develop tools and techniques that integrate energy modeling into all phases of the building life cycle, starting with design phase, through post-occupancy verification, and beyond to ongoing evaluation of building performance."
Michael Rosenberg (PNL)	"Energy efficiency design guidance, first and life-cycle cost information, and energy code compliance feedback are seamlessly combined in a software tool that can provide feedback at all stages of a building’s life. The software tool has an intuitive user interface, supports multiple data exchange capabilities with other software tools, and provides robust and accurate cost, energy, and code compliance reports."
Amir Roth (DOE)	"BEM is a key component in an integrated bid-design-construction-commissioning-operation chain that produces the next generation of high-performance, low-energy buildings and deep building retrofits. BEM also supports meaningful, performance-driving standards and financial incentives. Standardized interfaces and protocols facilitate information flow and back-flow throughout building lifetime, enable automated compliance checking and financial credit administration, and feed public databases which support building rating and policy analysis."

Attendee and Affiliation	Vision Statement
Cherlyn Seruto (RMI)	"When stating "I model" in response to the question "what do you do for a living?", your audience associates your profession with one robust in influencing positive energy efficiency decisions in the building industry, as opposed to strutting on the runway in front of flashing cameras."
Kevin Settlemyre	"(BIM + BEM) provides validated workflows, within and across tools, facilitating an integrative design process enabling a large number of users/teams to develop timely cycles of energy analysis, test innovative system designs (w/o workarounds), and leverage the results to inform design decisions (with confidence) starting from the earliest stages of a new or retrofit project process through to proactive use of calibrated energy models to inform building O&M, so that the bar on building performance can be raised..."
Muthusami Swami (Florida Solar Energy Center)	"While it is good that standards are being written in code-enforceable language, they also need to consider writing it in unambiguous software-implementable language so that there is consistent application of codes and standards. Submission is a critical element of the code and rating processes. Developers and approving authorities should consider automation in the submission and approval process to ensure quick feedback and turnaround."
Kendra Tupper (RMI)	"The quality and credibility of modeling have improved due to existence and application of standardized methods that have been vetted by the industry, as well as a mandatory certification program that determines the skill level of an energy modeler. The toolsets support innovation and creativity and can seamlessly transfer data amongst various tools."
Michael Wetter (LBL)	"Energy analysis tools are based on modern technologies, sound science and open standards that makes them flexible, transparent, intuitive and extendable by users to meet today's needs and to innovate future applications. Modeling and simulation are used across the building life-cycle to accelerate the invention and adoption of new products and systems, to improve the design of buildings, and to improve the operation of buildings."
Tom White (Green Building Services)	"It will become common knowledge that powerful simulation software tools cannot be expected to produce predictions of building energy use with spot on accuracy – there are just too many variables. Architects and engineers, however, will come to appreciate the potential of these software tools to highlight unexpected energy savings opportunities in both design and operations, because their insights will be founded on an understanding of how buildings behave as complex, adaptive systems."

Attendee and Affiliation	Vision Statement
Chris Wilkins (Hallam-ICS)	"Improve the efficacy of tools and practitioners' skill in applying these tools while at the same time increase the awareness of other stakeholders as to the both the benefits and limitations of the energy modeling process. It is far too common for actual building performance to lag predicted performance and for the expectation of stakeholders to far exceed the ability of the energy modeling process to deliver."
Bill Worthen (AIA)	"Architects and engineers understand how energy modeling can be used as an iterative, early design tool, throughout all stages of design, to help meet green building codes, like the IgCC."
Peggy Yee (GSA)	"Owners will have the tools to make informed decisions throughout the building lifecycle to achieve organizational sustainability goals, by simulating selecting, and measuring building performance."

C. Appendix C: Descriptions of Simulation Tools

C.1Energy Simulation Engines:

DOE-2 FREE, Publically Funded
Hourly, whole-building energy analysis program calculating energy performance and life-cycle cost of operation. Can be used to analyze energy efficiency of given designs or efficiency of new technologies. Other uses include utility demand-side management and rebate programs, development and implementation of energy efficiency standards and compliance certification, and training new corps of energy-efficiency conscious building professionals in architecture and engineering schools. Both eQUEST and VisualDOE are front-end interfaces for the DOE-2 simulation engine.

EnergyPlus FREE, Publically Funded
EnergyPlus includes innovative simulation capabilities including time steps of less than an hour, modular systems simulation modules that are integrated with a heat balance-based zone simulation and input and output data structures tailored to facilitate third party interface development. Recent additions include multizone airflow, electric power simulation including fuel cells and other distributed energy systems, and water manager that controls and report water use throughout the building systems, rainfall, groundwater, and zone water use.

C.2Graphical Front-Ends:

Autodesk Green Building Studio (Autodesk GBS)
Seamlessly links architectural building information models (BIM) and certain 3-D CAD building designs with energy, water, and carbon analysis. Autodesk GBS enables architects to quickly calculate the operational and energy implications of early design decisions. The Autodesk GBS web service automatically generates geometrically accurate, detailed input files for major energy simulation programs. GBS uses the DOE-2.2 simulation engine to calculate energy performance and also creates geometrically accurate input files for EnergyPlus. Key to the integrated interoperability exhibited is the gbXML schema, an open XML schema of the International Alliance of Interoperability's aecXML Group. By using gbXML-enabled applications, GBS web service users are able to eliminate redundant data entry and dramatically reduce the time and expense traditionally associated with whole-building energy simulation analyses.

Bentley Hevacomp Design Simulation (Bentley)
For more than 28 years Bentley Hevacomp has provided designers, building engineers, and consultants with the tools they need to meet the challenges of creating energy-efficient buildings that are tuned to their environment, perform for their occupants, and provide ROI for their owners.

Bentley Hevacomp offers software for building performance design, simulation, and energy certification based on the EnergyPlus analysis engine. Supporting ISO, IEE, CIBSE, and ASHRAE standards, these industry-leading tools are used around the world to help predict a building's real-world performance as well as quickly analyze design options to see if they pass or fail certification and provide the appropriate documentation, such as those mandated by U.K. Part L, Australia Section J, and the U.S. Green Building Council's LEED program.

DesignBuilder
User-friendly modeling environment where you can work (and play) with building models. It provides a range of environmental performance data such as: energy consumption, internal comfort data and HVAC component sizes. Output is based on detailed sub-hourly simulation time steps using the EnergyPlus simulation engine. DesignBuilder can be used for simulations of many common HVAC types, naturally ventilated buildings, buildings with daylighting control, double facades, advanced solar shading strategies etc.

Energy-10 FREE, Publically Funded
Conceptual design tool focused on making whole-building tradeoffs during early design phases for buildings that are less than 10,000 ft^2 floor area, or buildings which can be treated as one or two-zone increments. Performs whole-building energy analysis for 8760 hours/year, including dynamic thermal and daylighting calculations. Specifically designed to facilitate the evaluation of energy-efficient building features in the very early stages of the design process.

EnergyPro
Comprehensive energy analysis program that can be used to perform several different calculations:

- California Title 24 hourly energy analysis of low-rise residential buildings with an approved residential simulation (ResSim)
- Residential design heating and cooling load calculations (Res Loads)
- California Title 24 energy analysis of nonresidential buildings, hotels/motels and high-rise residential buildings with either a prescriptive method approach which individually calculates compliance for the envelope, lighting, and mechanical building components (NR Prescriptive), or a performance simulation method using an approved version of DOE-2.1E (Win/DOE)
- Nonresidential design heating and cooling load calculations (NR Loads)
- DOE-2 energy analysis to determine actual energy use, with or without EnergyPro as a pre-processor.

eQUEST **FREE, Publically Funded**
eQUEST® is a widely used, time-proven whole building energy performance design tool. Its wizards, dynamic defaults, interactive graphics, parametric analysis, and rapid execution make eQUEST uniquely able to conduct whole-building performance simulation analysis throughout the entire design process, from the earliest conceptual stages to the final stages of design. eQUEST's simulation engine, DOE 2.2, is also time-proven, well known, and widely used.

OpenStudio **FREE, Publically Funded**
OpenStudio Plug-in allows you to use the standard SketchUp tools to create and edit EnergyPlus zones and surfaces. You can explore your EnergyPlus input files by using all of the native SketchUp 3D capabilities to view the geometry from any vantage point, apply different rendering styles, and perform shadowing studies. The plug-in allows you to mix EnergyPlus simulation content with decorative content such as background images, landscaping, people, and architectural finish details—all within the same SketchUp model.

The plug-in adds the building energy simulation capabilities of EnergyPlus to the SketchUp environment. You can launch an EnergyPlus simulation of the model you are working on and view the results without leaving SketchUp.

VisualDOE **FREE, Publically Funded**
A Windows interface to the DOE-2.1E energy simulation program. Through the graphical interface, users construct a model of the building's geometry using standard block shapes, using a built-in drawing tool, or importing DXF files. Building systems are defined through a point-and-click interface. A library of constructions, fenestrations, systems and operating schedules is included, and the user can add custom elements as well.

C.3Energy Simulation Engine and Graphical Front-End:

Hourly Analysis Program (HAP)
A versatile system design tool and an energy simulation tool in one package, Carrier's Hourly Analysis Program (HAP) provides the ease of use of a Windows-based graphical user interface and the computing power of modern 32-bit software.

HAP's design module uses a system-based approach to HVAC load estimating. This approach tailors sizing procedures and results to the specific type of system being considered. Central AHUs, packaged rooftop units, split systems, fan coils, water source heat pumps and PTACs can easily be sized, as can CAV, VAV and multiple-zone systems. Calculation rigor and integrity are provided by the ASHRAE Transfer Function Method for calculating building heat flow.

IES Virtual Environment (VE)[123]
IES Virtual Environment (VE) is an integrated suite of tools designed to allow building performance analysis to be easily integrated into commercial workflows across the entire design lifecycle. There are 4 tiers: VE-Ware (free), VE-Toolkits (early indicative), VE-Gaia (guided architectural) and VE-Pro (detailed advanced).

The IES APACHE Thermal Analysis system is the core thermal design and energy simulation component in all four tiers of the VE. In design mode, APACHE covers the calculation of heating, cooling and latent room loads, the sizing of room units, internal comfort analysis and codes/standards checks. In simulation mode, APACHE can operate at time-steps as small as one minute and performs a dynamic thermal simulation using hourly weather data. Integrated components of APACHE permit simultaneous simulation of HVAC plant, solar gains and shading, natural ventilation and dimming strategies.

Trane TRACE 700 (TRACE)
Trane's TRACE 700 software - the latest version of Trane Air Conditioning Economics - brings the algorithms recommended by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) to the familiar Windows operating environment. Use it to assess the energy and economic impacts of building-related selections such as architectural features, comfort-system design, HVAC equipment selections, operating schedules, and financial options.

TRaNsient SYstem Simulation Program (TRNSYS) Publically Funded
An energy simulation program whose modular system approach makes it one of the most flexible tools available. TRNSYS includes a graphical interface, a simulation engine, and a library of components that range from various building models to standard HVAC equipment to renewable energy and emerging technologies. TRNSYS also includes a method for creating new components that do not exist in the standard package. This simulation package has been used for more than 30 years for HVAC analysis and sizing, multizone airflow analyses, electric power simulation, solar design, building thermal performance, analysis of control schemes, etc.

IDA Indoor Climate and Energy
Although not widely used in the industry tool, this tool is an example of a building energy simulation program that is structured around mathematical models. This is a tool for simulation of thermal comfort, indoor air quality and energy consumption in buildings. The mathematical models in IDA ICE are described in terms of equations in a formal language, NMF. This makes it easy to customize the models for the needs of a particular project. Advanced users can do this themselves by using the IDA Simulation Environment (IDA SE).

[123] D. Mclean, personal communication, Jan. 28

D. Appendix D: Statistics on Tool Downloads

Many BEM and BIM programs are licensed through institutions. Thus, it is difficult to determine the number of individual users for each tool. Table 21 is a short list of some commonly used (within the U.S.) tools, based on who provided us with data. Download data is proprietary to certain companies, thus this list is incomplete. Furthermore, it is unknown whether downloads of free programs accurately reflect the total number of users. However, this compilation of unique download helps to estimate the magnitude of the industry.

Table 21: Number of Energy Modeling Practitioners by Tool

Program	Number of Unique Downloads	Version	Institutional vs. Individual	Notes
EnergyPlus[124]	14,000	6.0	Both	Only EnergyPlus website
	11,200	5.0	Both	
	15,000	4.0	Both	
EnergyPro[125]	6,000		Both	
eQUEST[126]	6,388	3.64	Both	Does not include other sources, such as the EDR website
	23,193	3.63b	Both	
	4,260	3.63	Both	
OpenStudio	5,300	1.0.6		
	4,500	1.0.5		
TRNSYS[127]	750	TRNSYS 16	Institutional	
	550	TRNSYS 17	Institutional	
Trane TRACE[128]	"Several thousand" active licenses		Both	42 countries

Please note that for the number of TRACE downloads, it is impossible to differentiate which users are performing energy modeling vs. load calculations. To see a more comprehensive list of all building energy modeling tools, please visit the Building Energy Software Tools Directory: http://apps1.eere.energy.gov/buildings/tools_directory/alpha_list.cfm

[124] N. Long, personal communication, January 18, 2011
[125] M. Dodd, personal communication, January 19, 2011
[126] S. Criswell, personal communication, January 5, 2011
[127] D. Bradley, personal communication, January 13, 2011
[128] M. Biesterveld, personal communication, January 6, 2011

E. Appendix F: Direct Drivers Additional Information

E.1 Energy Codes

Additional information[129] on energy codes that offer simulation-based compliance include:

- ***International Energy Conservation Code 2009 (IECC 2009)***: The 2009 IECC is a model building code developed by the International Code Council that applies to both residential and commercial buildings and contains both prescriptive and performance based compliance paths. The residential "Simulated Performance Alternative" is described in section 405 while the commercial "Total Building Performance" option is described in Section 506 of the model code. Both simulated-based compliance options have requirements regarding simulation documentation and capabilities. The next IECC version is planned for release in 2013.
- ***ANSI/ASHRAE/IESNA 90.1-2010:*** Standard 90.1, the first iteration of which was released in 1975,[130] provides minimum standards for the energy-efficient design of buildings, excepting low-rise residential. Energy simulation is referenced within the standard as part of the Energy Cost Budget Method (Section 11) compliance path.
- ***Title 24, Part 6, of the California Building Code (2008 Building Energy Efficiency Standards):*** The Energy Efficiency Standards for Residential and Nonresidential Buildings, established in 1978, allow the use of computer programs to demonstrate that a proposed building design meets a defined building energy budget. The California Energy Commission must approve building simulation programs used under the performance approach.[131]

E.2 Green Building Codes

Newer green building codes that offer simulation-based compliance include:

- ***International Green Construction Code (IGCC):*** The IGCC is an under-development green building code planned for release in 2012. "What sets it apart in the world of green building is that it was created with the intent to be administered by code officials and adopted by governmental units at any level on a *mandatory* basis"[132] as opposed to a voluntary basis as is the case with most green building rating systems. Regarding energy simulation, the current draft version does include a performance-based energy simulation option that uses a new metric, the Zero Energy Performance Index (ZEPI), to determine compliance.

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[129] For general information on codes and standards visit the Building Codes Assistance Project (http://bcap-ocean.org/) or the U.S. DOE Building Energy Codes Program: http://www.energycodes.gov/

[130] Kirkwood, R.R. (2010). The genesis of standard 90, ASHRAE takes on energy standard. *ASHRAE Journal*, (June), 34-40.

[131] Only 2 simulation programs are approved for use with commercial buildings. Visit http://www.energy.ca.gov/title24/2008standards/2008_computer_prog_list.html for more information.

[132] International Code Council, (2010). International green construction code synopsis.

- ***ANSI/ASHRAE/USGBC/IES Standard 189.1-2009 (189.1):*** This new standard, released in 2009, is intended to help bridge the gap between green rating systems (that are voluntary) and current less-stringent codes (that don't address green building and energy efficiency with much rigor). ASHRAE 189.1 is designed for adoption by users such as municipalities, green building rating system developers, and universities. Standard 189.1 is very similar to popular green building rating systems (described later in this section) including LEED® and Green Globes®, though unlike these voluntary systems, it is enforceable by its adopters. The energy efficiency performance option in Standard 189 is nearly equivalent to that outlined in Standard 90.1. DOE and NREL has estimated that Standard 189.1-2009 provides site energy savings of 29.7% compared to Standard 90.1-2007.[133]

E.3 Federal Legislations and Regulations

Additional information on federal legislations and regulations that encourage/necessitate building energy simulation includes:

- ***Energy Policy Act of 2005 (EPAct 2005)***: Put into effect in August 8, 2005, this legislative Act called for the reduction of federal agency building energy consumption by 2% annually (per GSF per agency) from a 2003 CBECS baseline (Section 102), and directed the increase of renewable energy consumption as a percentage of total agency building energy consumption to 7% by 2013 (Section 203). In support of these goals, the Act required new federal buildings (commercial or residential) to be designed – "if life-cycle cost effective"-- to an energy operating costs reduction of 30% from ASRHAE 90.1-2004 or 2004 IECC baseline (Section 109). [134]

- ***Guiding Principles for Federal Leadership in High Performance and Sustainable Building***: 16 federal agencies signed this to commit to design, construct and operate their facilities in an energy-efficient and sustainable manner. The initial Federal Leadership in High Performance and Sustainable Buildings Memorandum of Understanding was signed in 2006 by 16 federal agencies, in commitment to sustainable design, building, and operation principles for federal facilities. The guiding principles have since been updated on December 1, 2008 to reflect updated efficiency requirements.[135]

- ***Executive Order 13423 (EO 13423)***: Signed by President Bush on Jan 24, 2007 to strengthen and clarify the energy goals set by EPAct 2005, this Executive Order increases the required annual energy use reduction from 2003 CBECS baseline for each federal agency to 3%. The intended result is to achieve a total 30% energy reduction by the end of fiscal year 2015 across the board at the agency-level. At the

[133] Crawley, D., Torcellini, P., Long, N., Bonnema, E., & Field, K. (2010). Modeling energy savings. *ASHRAE Journal's Guide to Standard 189.1*, S30-S32.
[134] For more information on EPAct 2005: http://www1.eere.energy.gov/femp/regulations/epact2005.html
[135] For more information on the MOU: http://www.epa.gov/oaintrnt/projects/buildings_mou.htm.
For link to download full text of the Guiding Principles, refer to http://www.gsa.gov/portal/content/104252

individual building level for new construction, major renovations and existing buildings, projects are directed to comply with the energy operating cost savings required in the Guiding Principles.[136]

- ***Energy Independence & Security Act of 2007 (EISA 2007)***: Signed into law on December 19, 2007, this legislative Act reiterates the 3% annual energy reduction specified in EO 13423 (Section 423). It also requires a stepped fossil fuel energy consumption reduction from 2003 CBECS baseline for individual new construction and major renovation projects aimed at reaching zero net energy by 2030.[137]
- ***Executive Order 13514 (EO 13514)***: Signed into law on October 5, 2009, this Executive Order requires all new federal buildings entering the design phase in 2020 or later to be designed to achieve zero net energy by 2030 (in support of EISA 2007). It also requires that all new construction and major renovations comply with the Guiding Principles.[138]
- ***General Services Administration's (GSA) Minimum Performance Criteria for Recovery and New Construction and Major Renovations:*** On March 16, 2010, the GSA revised the minimum performance criteria required of GSA projects funded by the Recovery Act. The minimum criteria require all Act-funded GSA projects to comply with the Guiding Principles.[139]
- ***General Services Administration's (GSA) P100—Facility Standards for the Public Buildings Service:*** This standard establishes design standards for major and minor upgrades for the Public Buildings Service (PBS) of the General Services Administration (GSA). Related to energy modeling, the standard requires that trade-offs between building enclosure systems and mechanical systems be considered. The performance of the design must be evaluated and verified using Appendix A of the standard.[140]
- ***Better Buildings Initiative (BBI):*** President Obama proposed this initiative on February 03, 2011 to reduce commercial building energy consumption by 20% by 2020. Key elements of the plan include: transforming the current tax deductions for commercial building upgrades into tax credits, larger loan sizes for small businesses and competitive grans for state and municipal government to streamline relevant local standards and processes.[141]

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[136] For more information on EO 13423: http://www1.eere.energy.gov/femp/regulations/eo13423.html
[137] For more information on EISA 2007: http://www1.eere.energy.gov/femp/regulations/eisa.html
[138] For more information on EO 13514: http://www1.eere.energy.gov/femp/regulations/eo13514.html
[139] For more information on the GSA's Minimum Performance Criteria: http://www.gsa.gov/portal/content/104252
[140] For more information on the GSA's P100 standard, see: http://www.gsa.gov/portal/category/27243
[141] For more information on the BBI: http://www.whitehouse.gov/the-press-office/2011/02/03/president-obama-s-plan-win-future-making-american-businesses-more-energy

E.4 Green Building Labels and Rating Systems

Additional information on green building labels and rating systems:

- ***Leadership in Energy & Environmental Design (LEED®):*** LEED®, perhaps the most common green building rating system in the United States, is an industry-recognized, voluntary standard that rates high performance buildings. Energy & Atmosphere Credit 1: Optimize Energy Performance (EAc1) offers three compliance paths for New Construction & Major Renovations, one of which relies on whole building energy simulation. This credit has been largely responsible for much of the increased demand for (and confusion regarding) energy modeling over the past 10 years. The credit relies heavily upon ASHRAE Standard 90.1 Informative Appendix G Performance Rating Method to help rate the energy efficiency of building designs that exceed the minimum requirements of the Standard. The under development version of the unofficially named "LEED® 2012" rating system will place even greater emphasis on energy modeling possibly requiring project teams to use energy modeling to influence design, not just to document compliance. Requirements regarding the modeling process (e.g. the process for considering various energy efficiency measures) may also be instituted.[142] The use of energy modeling for measurement & verification is also driven by LEED®.
- ***Green Globes®***: Green Globes®, whose U.S. license is owned by the Green Building Initiative, is similar to LEED®, offering a third-party certification (of one to four Green Globes) based on performance achievement of points in seven assessment areas. It differs from LEED® in the specific requirements for achievement, the quantity of documentation required, and the certification process. Green Globes® relies upon energy modeling in order to compare projected performance to the EPA's Target Finder. The Green Building Initiative is currently piloting the new ANSI/GBI standard—*ANSI/GBI 01-2010:* **Green Building Assessment Protocol for Commercial Buildings.**
- ***Designed to Earn the ENERGY STAR***: New building projects can receive the "Designed to Earn the ENERGY STAR" designation if they demonstrate that the energy performance target (identified at the 95% construction document stage) exceeds the ENERGY STAR rating of 75. This rating is generated by from the U.S. EPA's Energy Performance Rating tool Target Finder.[143] The energy use estimate for the building is generated by an energy analysis. The EPA suggests that "Energy modeling is among the most robust" approaches for generating an accurate estimate of building energy use, though also emphasizes that different approaches to generating the energy use estimate should be considered.

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[142] Roberts, T. (2010). Your guide to the new draft of LEED. *Environmental Building News*, Retrieved from http://www.buildinggreen.com/auth/article.cfm/2010/11/8/Your-Guide-to-the-New-Draft-of-LEED-2012-public-comment-USGBC

[143] U.S. Environmental Protection Agency, (n.d.). *Design to earn the energy star* Retrieved from http://www.energystar.gov/index.cfm?c=cbd_guidebook.cbd_guidebook

- ***ASHRAE Building Energy Quotient Program (Building EQ)***: The Building EQ program differs from most energy rating credits or certifications in that it provides two key rating metrics—the "As Designed" or asset rating of the building that defines the buildings' potential energy performance based on installed equipment and the "In Operation" rating of the building that indicates how well the building actually performs. While the operational component will require an analysis of energy bills and an on-site audit, the as designed rating will require an energy simulation performed by a certified building modeler. Using both energy simulation and actual energy bills to create an overall energy rating for the building will help to "close the gaps between intention and operation."[144]

E.5 Utility Programs

Examples of utilities offering incentives that require the use of whole-building energy simulation include:

- ***California Utilities (Savings by Design)***: This program awards owner and design team incentives (up to $500,000 and $50,000 respectively) for buildings that exceed Title 24 by at least 10%. For the whole building option, the submission of a summary report with the simulation files is required to demonstrate that savings thresholds can be met.[145]
- ***Xcel Energy (Energy Design Assistance).*** Xcel Energy provides energy analysis support and whole building financial incentives for businesses and design consultants under this program. The target market is new non-residential buildings greater than 50,000 square feet. The Energy Design Assistance Program (EDA) has two levels of incentives, "Basic" and "Enhanced". The "Basic" program track pays for energy modeling services when businesses commit to achieving at least 15% energy savings (relative to the Performance rating Method (PRM) in Appendix G of ASHRAE 90.1-2004) and also reimburses program-related design fees up to $12,000. The "Enhanced" program track is for projects in the pre-design or early schematic design phase committed to achieving 30% energy demand savings and includes the "Basic" services as well as support for additional services such as daylight analysis and calculation for LEED Energy and Atmosphere Credit I.[146] The EDA program (and others like it) uses the energy analysis provided by a handful of pre-qualified firms, in order to facilitate program administration, keeps the program cost effective, and ensure quality and consistency. In some cases, this leads to the creation of multiple energy models for the same building when design teams who are not affiliated with the EDA firms create their own energy models to inform the design, calculate LEED points, or to go beyond the scope required by the EDA program.

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[144] ASHRAE Building Energy Quotient Program. (2010). *What's your building eq*. Retrieved from http://buildingeq.com/

[145] Pacific Gas & Electric, (2010). *2010-2012 savings by design participant handbook*

[146] Xcel Energy (2009). *Energy Design Assistance Information Sheet*.

- ***National Grid (Design 2000plus/ Large Businesses Program).*** This program provides financial incentives and technical assistance to developers and design professionals to encourage the use of design features and electrical equipment that optimize energy efficiency in large commercial, government, and industrial facilities. National Grid has a pre-approved list of third-party technical assistance vendors (engineers), and the costs of these vendor services are split 50/50 between the utility and the project sponsor.[147]

[147] Best Practices Benchmarking for Energy Efficiency Programs (2003). National Grid Design2000plus.