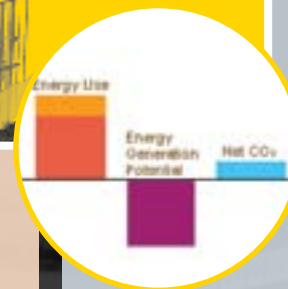
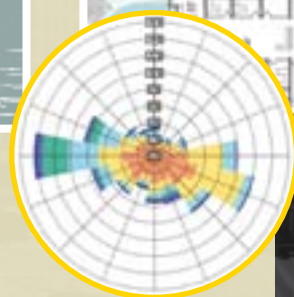
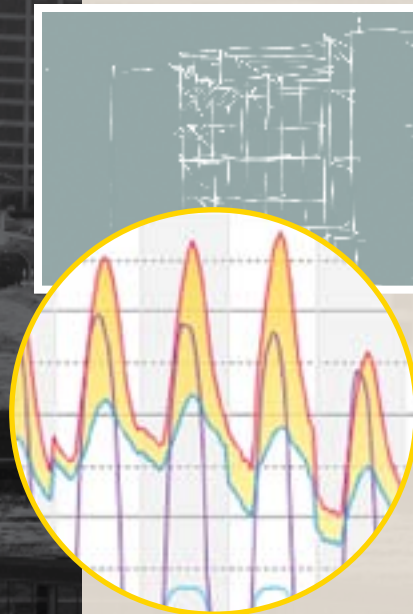
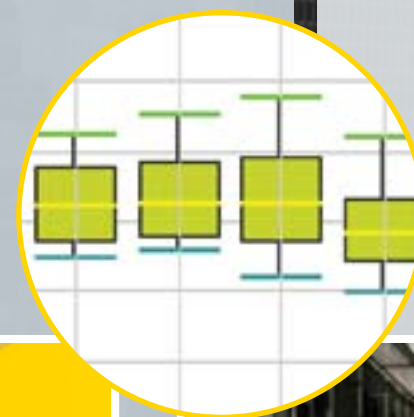
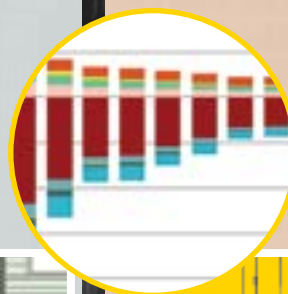


An Architect's Guide to INTEGRATING **ENERGY MODELING** IN THE DESIGN PROCESS



EARLY

COMPARATIVE

QUANTITATIVE

PREDICTED

COMPLIANCE

ACTUAL



THE AMERICAN INSTITUTE
OF ARCHITECTS

Acknowledgements_

The AIA would like to thank all the volunteer members of the AIA's Energy Modeling Working Group, the cohort of industry experts who have added value and in-depth subject knowledge, and the staff who have supported the Energy Modeling Practice Guide's development. This group's intelligence, tenacity, love of design, and passion for the continuing improvement of our profession serve as an inspiration to current and future generations of architects. As well, the AIA thanks the dozens of technical peer reviewers, whose constructive criticism led to a far more robust and useful document.

With special thanks to



Foreword_

Practice inevitably moves forward, as the ways we measure building performance become more sophisticated. AIA members have always stood for exemplary standards of practice. The AIA's *Energy Modeling Practice Guide* builds on this commitment and seeks to position architects as collaborative leaders at higher thresholds of building performance. This is not only desired by every member of the building team, but expected across the marketplace.

As the practitioner grows more fluent with the principles and implementation of energy modeling, the relationship with the client will become more positively interactive. Indeed, the client's (*and* user's) role in facility management is absolutely crucial to the success of the energy performance aspirations. Quite simply put, high performance buildings and places demand high performance users. We believe comprehensive understanding of energy modeling and measurement techniques provides the architect with the means to project and deliver, as well as to enjoy a much richer relationship with our clients.

If we are to be stewards of the environment, these skills must be among the first deployed in shaping better places and communities. After all, aren't more livable and sustainable communities the ultimate challenge to which we are all called? This *Guide* is the latest resource the AIA has developed to equip all of us to rise to that worthy challenge. You will find the contents both enlightening and transformative.

Jeff Potter, FAIA
2012 AIA president

Introduction_

Building energy modeling is an evolving area of expertise and this document contains only a summary of the most prevalent tools for performance and energy modeling currently used in the industry, along with key terminology, processes, and practices that have been shown to help architects include high performance and energy reduction as integral aspects of the design process. We hope the knowledge contained here will encourage you to engage—whether on your own or with your consultants—in thoughtful, informed energy efficient design, using both design performance and building energy modeling early and often throughout the design process.

AS OUR PROFESSION FACES NEW CHALLENGES, the American Institute of Architects is committed to providing its members with the resources to be successful in practice and leaders in their communities. With the increasing awareness and focus on sustainability, the twenty-first century architect must become fluent with vocabulary and technologies that predict, test, and quantify energy performance in buildings. This fluency is essential to respond to the requirements of new green building codes and savvy clients who demand to know how actual performance matches predictions of energy consumption by their design team. The energy model and focus on energy performance is not meant to supplant the importance of design. Rather, a building energy model is a tool that can be utilized throughout the design process to test various design options and optimize the performance of all building typologies.

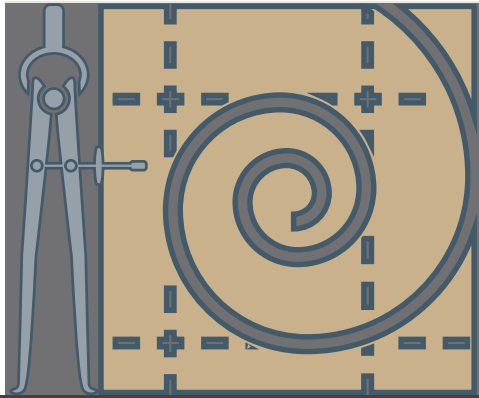
The twentieth century tradition of professional practice taking place in “silos,” in which architects design buildings as formal constructs, and engineers then make them work at the building systems level, does not support the more integrated design thinking now being driven by the need for highly energy-efficient, high performance buildings. Architects, engineers, and energy modelers can learn how to work better together and more collaboratively than they do under today's business-as-usual practices. A key step in doing so is to better understand each other's language—or, even better, to forge a new, common, language that comprehends all of the interests of design, including building systems, client needs, and code requirements. Such an evolution of design communication can better prepare architects for future outcome-based design codes and the more collaborative design thinking they will require. It can also lead to better, ongoing working relationships with the project's clients, facility managers, property managers, and appraisers and the greater real estate community—opening up avenues of business opportunities. Building energy modeling provides such an avenue.

The architect needn't become a technical expert on energy modeling or the myriad software tools currently available. A working understanding of the energy modeling process, its parameters and benefits, however, is needed to empower us to fold this necessary and valuable capability into our fundamentally integrative work. Along the way, we gain a keener understanding of the interrelated nature of elements and systems that energy use analysis reveals. Accompanying this enhanced comprehension of the building itself is also a greater appreciation of the interrelationships among all of the contributors to the building endeavor.

We hope the information in this guide will entice you to develop enhanced communication with your colleagues on every project team and better engage engineers and energy modelers in their knowledge of energy and performance issues early and throughout the design and operation processes. We further hope that it will tempt a number of you to become more actively involved in the continued development of energy modeling tools that better respond to how architects work, and that you will encourage your colleagues to use these tools in their practice.

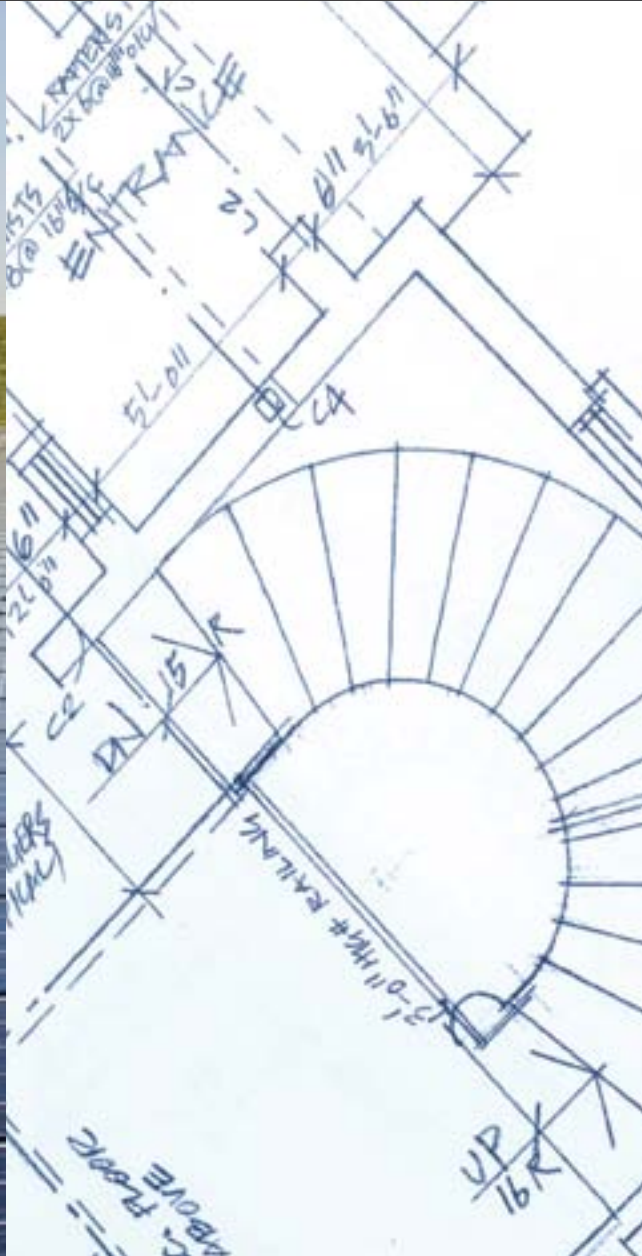
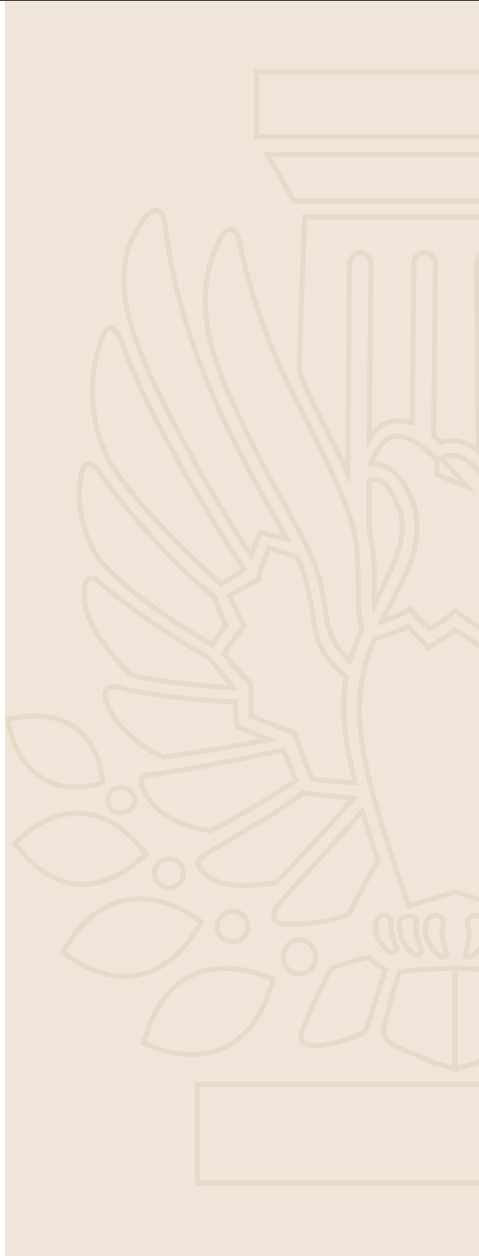
Take advantage of the rich opportunities offered by the rapid advance of Building Energy Modeling and Design Performance Modeling. Apply your creative imagination, build a common understanding, and demonstrate the lasting benefits of energy integration—to our clients and to society at large.

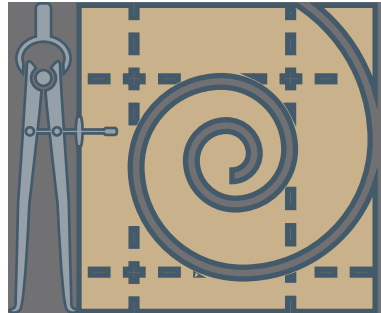
—The AIA Energy Modeling Working Group. August, 2012



1

SECTION 1_ ENERGY IS A DESIGN PROBLEM





“Energy is a *design* topic, not a technology topic, but there are few of us who have always believed this.”

—Donald Watson, FAIA

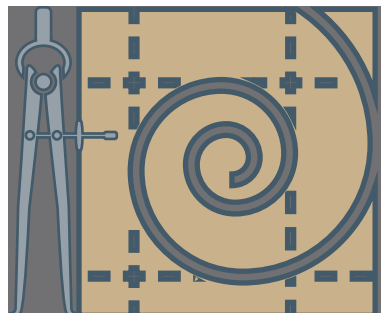
Section 1_ ENERGY IS A DESIGN PROBLEM

Designing spaces and places in the built environment with energy in mind takes much more than a technical understanding of science, tools and technology. The physics of materials and enclosure, no matter what the architectural form, define the need for supplemental building systems, including mechanical or passive heating, cooling, air circulation, lighting, and human conveyance. For much of the last century and in large part since architecture and engineering became separate professions, energy has typically been addressed at the building systems level, taking a back seat to many other drivers of the design and construction process.

Today, engineers typically size buildings systems to meet the demands created by program, use, and aesthetic desire. Architects and our clients have become addicted to what engineers can do for us. No matter what we design, we assume our engineering counterparts and other consultants will be able to make our ideas work at the building systems level. High performance building codes like CALGreen and the International Green Construction Code (IgCC), as well as many local building codes and ordinances, voluntary green building programs, the AIA 2030 Commitment, and the 2030 Challenge, are beginning to show us that this long-accepted way of working is not yielding optimal results. A more holistic, collaborative approach to design will be vital as energy and operations costs rise and as energy targets are codified.

High-performance design, including energy efficiency, is becoming as fundamental a design service as meeting basic programmatic, budgetary, and life-safety needs. A deliberately multidisciplinary approach to building performance—including energy performance—coordinated and managed by the architect, should be embedded into every project team's workflow. This approach should begin at project inception and utilize simple, easily manipulated performance modeling throughout project design and construction. It should engage energy modeling directly with design generation, thus informing major design decisions and providing continuous feedback. Continuous and iterative modeling throughout all stages of the design process optimizes energy efficiency and, ultimately, the comfort, health and welfare of the occupants.

Design, performance, and energy modeling are iterative processes. Initial models address fundamental design parameters, including the building envelope, orientation and massing, typically without including mechanical or electrical systems in a manner that provides crucial, and sometimes surprising, design guidance. As models develop, they provide feedback to the design team on how the form, orientation, programmatic strategies, and other variables will likely affect the project's performance in terms of energy, daylighting, comfort, and other design characteristics. As new performance/energy modeling software tools become available and architects and modelers become more sophisticated and more informed, the process will become easier, the results more accurate.



What is an Energy Model?

In its simplest form, an energy model is a calculation engine that accepts inputs such as building geometry, system characteristics, and operations schedules and produces outputs such as performance comparisons and compliance reports.

+ ENERGY MODELS AND MEASUREMENTS: KEY DEFINITIONS

The language surrounding energy and resource modeling can be confusing at times and can mean slightly different things to different people. Similarly, several terms and concepts are confusing because their definitions are evolving as energy modeling becomes more robust and widespread and high performance building codes expand. The definitions that follow provide some clarity for practitioners.

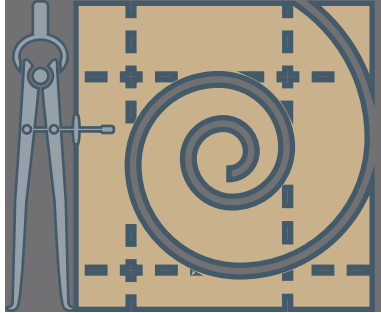
Of the four most common types of energy/performance modeling—Design Performance Modeling, Building Energy Modeling, Building Operations Modeling, and Project Resource Modeling—this guide focuses primarily on the first two. It is nevertheless helpful to understand the others, the differences between them, and where they most appropriately fit into a sustainable, energy-efficient design process. It is also crucial to note that Building *Energy* Modeling (BEM) and Building *Information* Modeling (BIM) are quite different, and that incorporating BIM tools into the design process is *not* covered in this document.

There are, as well, a variety of acronyms associated with energy use and energy modeling currently in use. A number of these terms, while employing significantly different parameters, unfortunately have very similar nomenclature. Recognizing that this is not ideal, it is critically important to understand these terms in order to navigate the energy efficiency expectations of clients, technical professionals and regulatory officials.

Design Performance Modeling (DPM) informs design decisions by predicting a building's performance with respect to energy efficiency, daylight penetration, glare control, thermal comfort, natural ventilation, and similar factors. It is typically prepared during the early stages of design, before engineering systems are incorporated. Its analysis of energy use is accordingly less complex and time consuming than

that of Building Energy Modeling, to allow for more rapid exploration of a greater number of parameters, which may include architectural form impacts, window-to-wall ratio implications, glazing and shading options, R-values of opaque walls, and the like. DPM allows cost, aesthetics, and performance (including energy performance) to be given value and discussed among the project team and with the client in real or almost real time.

Building Energy Modeling (BEM) predicts a building's anticipated energy use and corresponding energy savings, as compared to a standard baseline. In so doing, it demonstrates project compliance with local, regional or national energy codes. BEM predicts energy performance based on Typical Meteorological Year (TMY) data, as well as assumptions about building operation and maintenance.



Accordingly, *the prediction is only as accurate as the assumptions*, which should be documented and understood by the project team, as well as the client, the building operator, and the end users. Changes made during the design and construction process should be used to update the BEM, to increase its utility and predictive accuracy.

Building Operation Modeling (BOM) introduces actual utility bills, use patterns, hours of operation, functioning of systems, and real weather conditions for a completed building into a model structured similarly to the Building Energy Model. It thereby allows the comparison of actual energy use with the predicted use. This comparison can be used to determine causes of discrepancies between predicted energy use and actual energy use, which in turn facilitates tuning of systems to better meet—or even exceed—the design goals. The process of comparison of the BEM and the BOM is known as “calibrated simulation” or Measurement & Verification (M&V). [Presently, there is little industry agreement on a method that accurately compares BEMs to BOMs, accounting for all the potential variations of building use and operations. ASHRAE Guideline 14 and the USDOE’s International Performance Measurement & Verification Protocol (IPMVP) provide the currently agreed methods for this type of work.] The Building Operation Model is also used to satisfy emerging building code requirements for post-occupancy monitoring.

Project Resource Modeling (PRM) is the most extensive and broad of the four most common forms of modeling. It assesses multiple resource issues that affect and are affected by the development of a project, including energy, water, material selection, and solid waste. It may also include transportation, primary growth issues, manufacturing, social and agricultural elements, embodied energy, carbon emissions, health, and other factors. This type of extensive study typically addresses the interrelationships among resources, their consumption, efficiencies, and conservation. PRM can assess existing site resources, as well as components that may be brought to the site. It is important to note, in the context of this guide, that energy is only *one* of the resources considered in this broader resource modeling process.

Energy Use Intensity (EUI) is a measurement that describes a building’s annual energy consumption relative to the building’s gross square footage. To date, this term is most often used as an expression of an existing building’s actual, metered energy consumption, or as a comparative average, which is derived from a data set of metered information for a particular building use type in a specific location. Both of these uses of EUI are based on real, measured building energy use data.

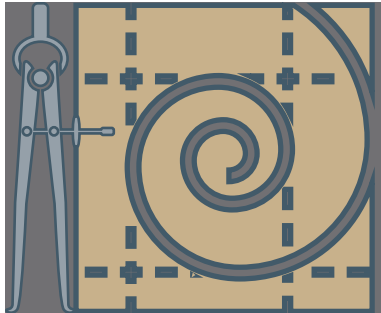
EUI can be relative to either site or source energy.



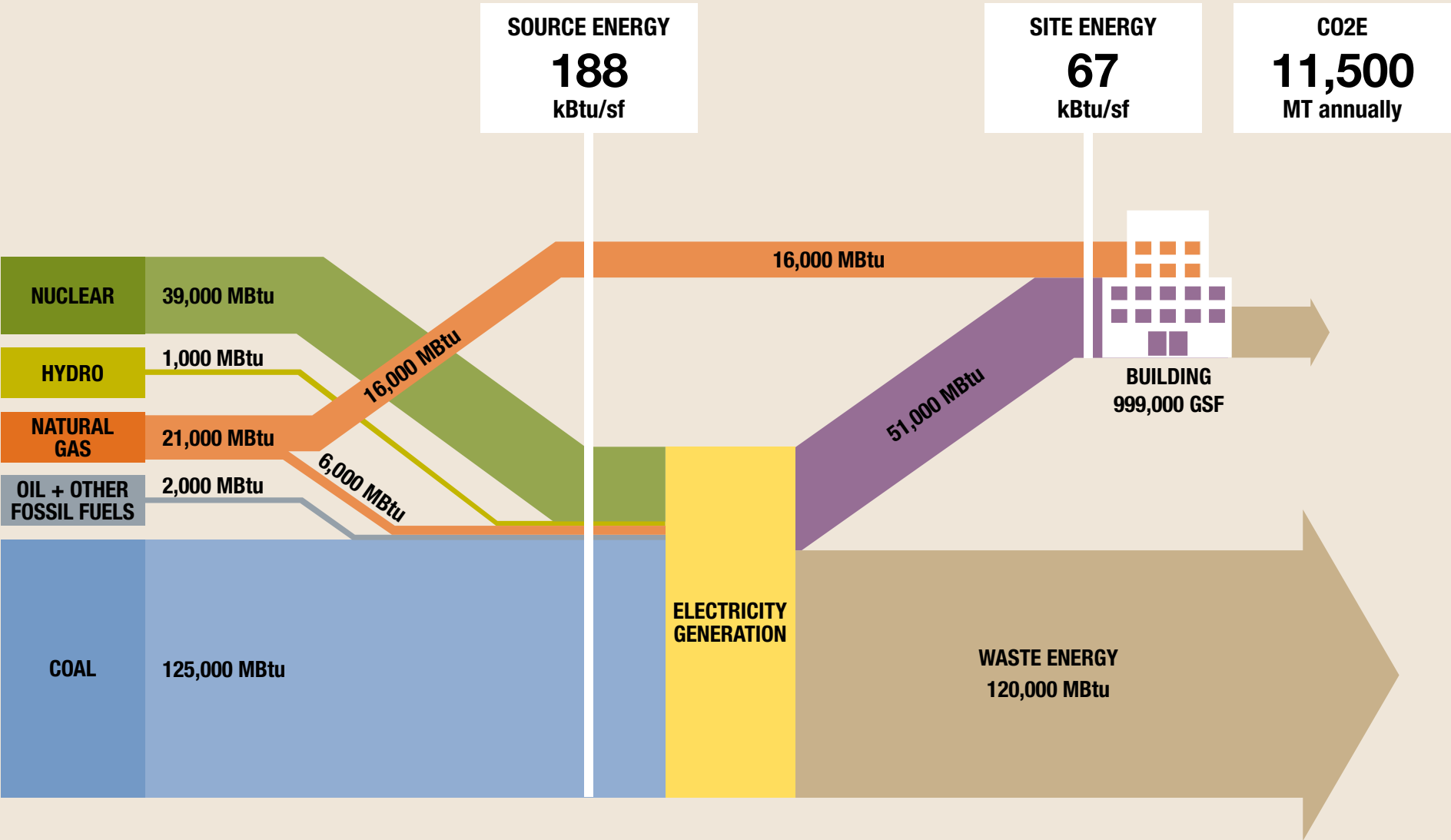
Site energy is the measure generally familiar to the design profession. It is the amount of energy consumed by a building and is reflected in utility bills paid by the building owner.



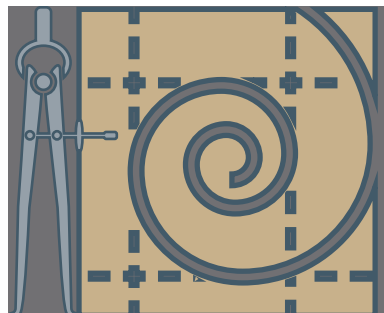
Source energy is a more accurate measure of a building’s energy footprint, because it includes energy that is lost during production, transmission, and delivery to the building. Electricity is the prime example; what is consumed at the building is only a proportion of the fuel energy fed into the power plant.



Source Energy / Site Energy / Carbon Equivalent Example for High Rise Out-Patient Care Facility



This diagram is specific to a high-rise out-patient care facility in Chicago. Fuel use ratio determinations stem from the eGrid multiplier. Based on the multiplier for this region, it takes 3.340 kBtu of energy to produce and deliver each 1.000 kBtu used at a building site. Note the amount of waste energy relative to the energy used on the site.



eGrid is a multiplier that describes the mix of electrical generation types (e.g., coal, natural gas, nuclear, solar, hydro, etc.) that make up national and regional power grids. eGrid accounts for differences in regional electricity generation source capacities, which has implications on the amount of resulting carbon dioxide emissions. It thus provides data that enable architects to understand the real environmental impact of our building design's energy consumption. Importantly, eGrid relates the energy lost due to inefficiencies inherent in generation and distribution systems to the on-site electrical consumption of a building, which accounts for only a portion of the electrical power generated to serve the building. Understanding the full impact of our building designs means understanding how the electricity is generated that serves the building as well as the associated emissions. eGrid is currently accepted as the way to convert *site* energy to *source* energy.

How is EUI calculated?

A building's EUI is the ratio of the energy consumed in one year (measured in kBtu) to the gross floor area of the building.

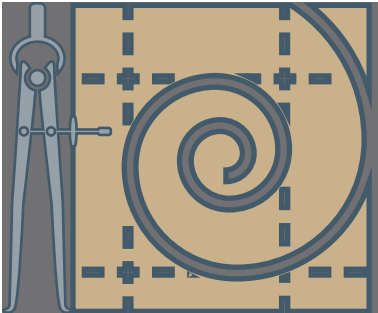
[EUI = kBtu/sf-yr]

For example, if a 50,000-square-foot school consumed 7,500,000 kBtu of energy last year, its EUI would be 150. A school of equal size that consumed 9,000,000 kBtu of energy would have a higher EUI (180), reflective of its higher energy use. Generally, for a particular building use in the same climate zone, the lower the EUI, the better the energy performance.

[kBtu = one thousand (1,000) British thermal units. A British thermal unit is approximately the amount of energy needed to heat one pound of water one degree F.]

Why do some buildings have much higher EUIs than others?

Certain building types will always use more energy than others. For example, an elementary school uses relatively little energy compared to a hospital, which has different operating parameters, higher process loads, ventilation rates, and conditioning requirements. A small office building that supports eighty workers will use considerably less energy, overall, than a skyscraper that supports thousands; yet, if the load densities are similar, the skyscraper with high-performance systems may have a lower EUI than the small office, since EUI is calculated per square foot of building area. Accordingly, it is not appropriate to compare the EUIs of different building types to each other; rather, buildings should be understood in terms of EUI for the building use type. A more focused EUI comparison will also account for a building's geographic location. This will allow the EUI expression to account for the factors of both climate and fuel source.



To help understand a building's place on the energy use continuum, the table below provides a sampling of typical EUI values (in kBtu/ft²), as determined by the 2003 Commercial Building Energy Consumption Survey (CBECS) (<http://www.eia.gov/consumption/commercial/index.cfm>):

Sample U.S. National Average Site EUI

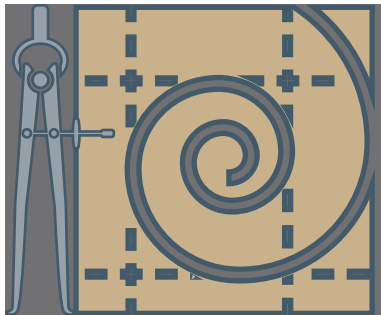
BUILDING TYPE	U.S. NATIONAL AVERAGE SITE EUI
Residential - Single-Family Detached	44
Religious Worship	46
Office - 10,000 sf	74
Education - K-12 School	75
Bank/Financial Institution	77
Health Care - Clinic	84
Office - 10,001 to 100,000 sf	90
Lodging - Hotel/Motel	94
Public Assembly - Entertainment/Culture	95
Office - 100,001 sf or greater	104
Public Assembly - Library	104
Health Care - Hospital Inpatient	227
Food Service - Fast Food	534

Per the AIA 2030 Commitment

Predicted Energy Use Intensity (pEUI) describes the energy use for a project based on *modeled site* energy. pEUI is a modeled number and, because of the distinctions described earlier between Building Energy Modeling and Building Operation Modeling, very likely will not match actual building operations. pEUI equals the *site* kBtu per year divided by the project's square footage.

[pEUI = site kBtu/sf-yr]

This is the data currently reported in the AIA's 2030 Commitment Program (<http://www.aia.org/2030commitment>).

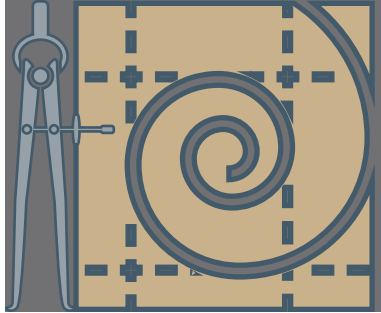


Energy Use Intensity Proposed (EUIp) describes the energy use for a project based on *modeled source* energy. Being source-based, rather than site-based, it includes energy generation and transmission losses and is therefore a better prediction of the total energy footprint of your project than pEUI. EUIp equals the *source* kBtu per year divided by the project's square footage.

[EUIp = source kBtu/sf-yr]

This is the reference data currently required by the International Green Construction Code.

It is absolutely crucial to note that EUI, the IgCC's EUI definition, pEUI, and EUIp, are not necessarily equal values, and serve different purposes. The terms are obviously alike enough to create confusion—a reality that the industry recognizes and is seeking to resolve.



Zero Energy Performance Index (zEPI) is a value that represents the ratio of energy performance of a proposed building design compared to the average energy performance of buildings with similar occupancy and climate types, benchmarked to the year 2000. It is the ratio of a proposed building's EU_p to the EU of a baseline or reference building model, multiplied by 100 to give a scalar value, which can range from zero (for a zero energy building) to 100 (for a building that uses the same amount of energy as the baseline model). The lower the value, the better the energy performance. The 2012 International Energy Conservation Code (IECC) requires a zEPI of 57; the 2012 International Green Construction Code (IgCC) requires a zEPI of 51, which represents a 10% increase in efficiency over the 2012 IECC.

Understanding the zEPI and its implications are necessary for establishing appropriate energy consumption goals for buildings designed and constructed under the new IgCC. Additionally, understanding the implications of design choices on zEPI for a project will help the design team to design to an energy budget and to succinctly communicate design ramifications to interested parties, such as the client, financiers, and donors.



2

SECTION 2_ Why Should Architects Care About Energy Modeling?





“Anyone can throw up roadblocks and barriers against any action toward change, but now is the time for you and your firm to make a difference.”

—Norman Strong, FAIA

Section 2_
WHY SHOULD
ARCHITECTS
CARE ABOUT
ENERGY
MODELING?

A recent study by the Association of Collegiate Schools of Architecture showed that most architects don't understand energy use, even though they acknowledge its importance. We are building leadership, looking for ways to advance our understanding and capabilities in this area, and creating new opportunities that come from greater expertise. Architects in all types and sizes of practice can and should be leaders in energy modeling for the building industry, taking responsibility as designers for assuring that buildings perform to high standards. To do so, we must learn new terms, strategies, and methods of calculation, as well as how to integrate this knowledge into the early decision making of a project. Where do we begin? By clarifying some common misunderstandings, by articulating the benefits to all project stakeholders, by recognizing the opportunities for our practices, and by meaningful leadership in this arena of crucial professional, national, and global importance.





+ COMMON MISUNDERSTANDINGS



Energy modeling isn't for me. Isn't it a big firm, big project need?

No. Every project you touch can benefit from this heightened level of design and innovation. If we, as a profession, are going to be leaders

in energy resource conservation and the response to climate change, we must act now, on every project, whether new construction or not, for every client.



Energy modeling is too detailed. Can't we get what we need to know without it?

To a certain degree, yes. But there are many levels of energy modeling that we, as designers, can undertake early in the design process to better understand the effects of our strategies. Full-on Building Energy Modeling is highly detailed and requires a more complete design to get

results we can use for construction documents and post-occupancy commissioning. Design Performance Modeling, on the other hand,

“stays to the left of the decimal point” and provides a good indication of how design options will affect energy use before they are fully developed.

We don't have energy modeling staff. How can we do it, on top of all the other pressures we face?

True, many firms don't have staff dedicated to modeling, and that is one reason for this document. With a better understanding of what energy modeling is and isn't, architects will be better prepared to engage in energy discussions early in design, with the aid of either outside consultants or internal staff experts. Are you ahead of the curve?



Will energy modeling detract from my other design goals?

No. In fact, energy modeling empowers design. It adds value to owners and brings deeper meaning to architectural services. Architects can design beautiful, energy efficient buildings that create desire and inspire, beyond the savings in cost and environmental impact.

Photo credits: © Brooks+Scarpa, John Linden





Why is energy modeling important for my firm, my clients, and my community?

Energy modeling is here to stay, and it will lead to improved building performance. Designing for energy efficiency is key for architects to be better leaders in this new world of energy sensitive design and construction. What can be wrong with conceptualizing a more valuable design that saves our clients money by reducing operating costs? That is the ques-

tion we should ask ourselves. Architects hold the key to ensuring the success of energy efficient design.

Energy modeling takes time and resources. Can our firm afford to do it?

Can we afford not to? A wealth of experience has shown that including information that facilitates robust design decisions early in the design process, spending time up front, before major systems and siting and basic building massing decisions are made, can ultimately prove to be far less expensive than spending the time later modifying design decisions to meet requirements. The later this elemental information is considered, the more potential it has to require additional time to unravel and re-design. A seemingly minor design change to one system may have many ramifications. For example, a change in

the configuration of external shading may necessitate the complete redesign of HVAC systems, lighting systems, and controls.

Also, the depth and time commitment of energy modeling varies. Design Performance Modeling that provides useful guidance can be quick and comparative. Building Energy Modeling and Building Operation Modeling are more detailed and do require relatively more time. Project needs vary, but the need to attend to energy in design and to model in some manner is universal.



I'm worried that energy considerations and integrated design teams will limit design decisions.

No; they refine the palette and focus the image. There is a perception that including energy discussions early in design will put "too many cooks in the kitchen" and will impose pressure to commit early, thereby limiting a designer's ability to make well-considered design

decisions later in the project. Yet, including technically knowledgeable individuals and detailed performance information that guides design decisions must happen at some point in the process. It's just a question of when. Since many design decisions that influence integrated system performance, including energy efficiency performance, happen early in the design process, having the information available early makes a lot of sense. Even early in the design process, time can still be taken to make thoughtful design decisions.

Photo credits: © Brooks+Scarpa, John Linden



+ FROM CODE COMPLIANCE TO DESIGN DEPTH

Energy Modeling for Code Compliance

The new editions of both the International Energy Conservation Code (IECC) and International Green Construction Code (IgCC) will require a greater understanding of the effects of a building's energy consumption, in which code-compliant energy criteria have significant architectural implications, such as new daylighting requirements. For example, the integration of windows into the building envelope is key to determining whether a building can be designed to meet prescriptive energy conservation requirements or will need to use performance requirements. Prescriptive requirements allow up to a certain ratio of glass to opaque wall area, above which the building will need an energy model to demonstrate code compliance. Architects will need to know what these thresholds are, so that we can understand the implications for scope development during proposals and contract negotiations. If we are not aware of these thresholds, we are at risk of having to negotiate for additional fees should the design evolve to require an energy model. The architect, energy modeler, and engineer can work together to consider the most effective ways to improve the understanding of energy in the early stages of design. Traditionally, a Building Energy Model (BEM) is used to demonstrate code compliance or to certify to the code official that minimum predicted energy-use performance requirements will be met. Whenever a BEM must be created for compliance, the architect should leverage the use of that model for design improvements.

Energy in Green Codes Standards and Ratings

CODES/STD/RATG	OTHER	ENERGY MODELING	OTHER	OTHER	OTHER
IgCC	X	X	X	X	X
CALGreen		X			
189.1		X			X
90.1	X	X	X		
LEED-BDC		X			
LEED-EB		X*	X		X
GGLO BES		X			

* Energy modeling may or may not be required for LEED-EB.



The AIA Guide to the IgCC is available [here](#).



Energy Modeling as a Design Tool

Projects designed for energy efficiency or to meet zEPI targets necessitate designing above and beyond many current code-minimum energy compliance requirements. Many architects and engineers have realized that to do this cost-effectively requires systems integration. For example, using low-energy mechanical systems like radiant panels or under-floor AC may require tuning building envelope glazing areas and performance with external shading and wall insulation to control solar loads. Similarly, energy sensitive design could necessitate an understanding of how far daylight can be anticipated to penetrate into a space, so that dimming controls can be cost-effectively employed to reduce electricity usage. Performance/energy modeling is crucial to understanding the interplay among building systems and components, to reduce demands and to “right-size” low-energy systems, and ultimately to improve the building’s overall energy performance and save clients long-term energy expenditures.

Energy efficient design is revealing a long-known but oft-forgotten truth: design is an iterative process, yet many building systems, including many aspects of the building envelope, are conceptually “fixed” during the very early design stages. Therefore, design teams should consider the early use of performance modeling to inform design decisions that are refined throughout the design process. With enough forethought, a building energy model can easily serve as the basis for a compliance energy model and subsequently a building operation model, saving the design team and the client time, money, and aggravation.



Photo credit: ©BNIM

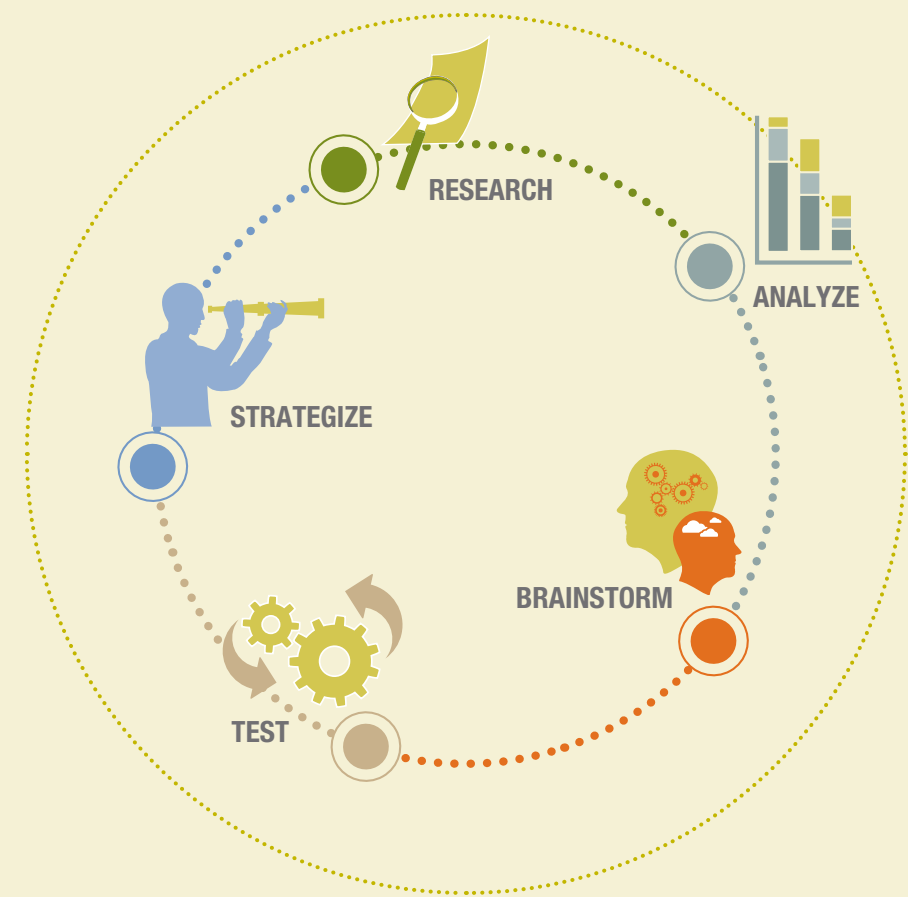




+ BENEFITS OF ENERGY MODELING

Using energy modeling early and often during design offers meaningful value to a range of stakeholders.

Energy Modeling Enables a Cycle of Benefits Throughout the Design Process



For Architects and the Design Team

Enabling Design: Energy modeling enables design teams to focus their time effectively and to articulate energy as a component of efficiency highly valued by clients. It can assist significantly in the development of building envelope schemes with respect to air tightness, flashings, insulation types and installation, membranes, solar heat gain coefficients, and other thermal properties of the envelope. And, by enabling performance-based, rather than prescriptive compliance, with code requirements, it enhances design flexibility and team integration.

New Expertise: The additional technical expertise associated with energy modeling makes the involvement of the architect more valuable throughout the project.

Increased Referrals: The ability to use energy and performance modeling effectively throughout the design and construction process can foster more collaborative relationships among team members, which can result in higher client and project team satisfaction—and future referrals.



For Building Owners

The major benefit of design-performance modeling is that it can provide the information necessary for the design team and client to make strategic, best-value decisions about cost versus performance tradeoffs early and throughout the design process. Some energy efficient buildings may have greater up-front costs, compared to projects and jurisdictions where energy modeling and energy performance are not considerations. But these costs are often recovered in several ways:

Reduced First Cost through Right-Sizing: Energy modeling allows reduction of the safety factors traditionally applied in sizing costly building systems, resulting in a corresponding reduction in initial costs.

Reduced Change Orders: Early scrutiny of, and agreement on, design parameters reduces changes during construction.

Reduced Operating Costs: Energy modeling facilitates design choices that reduce energy use and, accordingly, utility costs.

Reduced Maintenance Costs: More durable materials and more effective systems lower long-term maintenance costs.

Greater Predictability of Operating and Maintenance Costs: The dependability of performance of a well-modeled building enables more cost-effective business and financial decision-making.

Guidance for the Structuring of Real Estate Agreements: Being familiar with the metrics and monitoring of energy systems gives the owner valuable information for structuring leases, maintenance agreements, and the like.

Incentives: Many utilities offer financial incentives for highly energy efficient buildings. Energy modeling can quantify the financial impact of these incentives, as well as provide the evidence of anticipated energy performance the utilities require to receive these incentives.

Increased Asset Value: Many property developers agree that appraised values of energy- and resource-efficient projects have been steadily increasing with raised awareness of and desire for the financial and planetary benefits of sustainable design. Common Area Maintenance Fees can often be reduced. Properties with high EnergyStar ratings show an increase of 16 percent in selling price and of six percent in rental rates over similar, non-rated buildings (Eichholtz, Kok, & Quigley, 2009). And studies show that buildings that reduce resource consumption with improved indoor air quality, daylighting, and strategic siting are more attractive to prospective employees (Libby, 2011).

Further, with the growing number of energy disclosure ordinances in cities around the country, an owner's ability to position the design activity within the real-estate market is becoming increasingly important to the asset value.

For Occupants

Enhanced Comfort for Occupants: Post occupancy surveys demonstrate a correlation between energy efficient design and occupant comfort, due to better control of envelope radiant losses and gains and reduced infiltration. Energy modeling enables the design team, client, and occupants to understand the impact of component and material choices on comfort.

Higher Occupant Satisfaction: Use of additional performance modeling tools, which assess thermal comfort, daylight penetration, glare-control, etc., alongside energy performance can lead to a space that is more productive, vibrant, and satisfying to the occupant. Maximizing daylighting has been shown to improve health, stress levels, and productivity. Daylighting and views to the outdoors increase alertness and decrease absenteeism (Edwards & Torcellini, 2002). Ventilation and thermal comfort also affect worker productivity and health (Heerwagen, 2000).



For Builders

Fewer Call-Backs: A more collaborative design and construction process that shares energy modeling assumptions and anticipated performance facilitates the punch-list, operation startup, initial operation calibration, and trouble-shooting. It can result in fewer call-backs from owners, saving time, money and reputation. Facility managers can confidently focus their time on aligning actual building energy performance with modeled, predicted building performance.

For Communities and the Environment

Improved Environmental Performance: Energy modeling helps the design team quantify potential reduction in energy use and generation and associated greenhouse gas emissions, ultimately reducing infrastructure and utility demands and the depletion of the resources of our one and only planet. A 2010 survey of commercial building energy managers found that 84% reported energy efficiency to be a high priority for both new construction and retrofits. Reducing building energy use was the top goal of 38% of the responders (Johnson Controls, n.d.).

Potential Energy Savings, Performance and Comfort Add Value

ENERGY EFFICIENCY DESIGN	ENERGY EFFICIENT BUILDING	OCCUPANT COMFORT AND USE
Setting energy performance goals and benchmarks	Minimizing changes during construction	Elevating employee recruitment and retention
Controlling first costs	Integrating building systems	Reducing building/occupant liability
Optimizing renewable energy and passive systems	Increasing financial incentives	Enhancing employee/user productivity
Evaluating building envelope schemes	Elevating property values	Providing tenant placement incentives
Integrating architectural features	Estimating and reducing total cost of ownership; including ongoing operation and maintenance costs	Enhancing health and well-being (both physical and psychological)



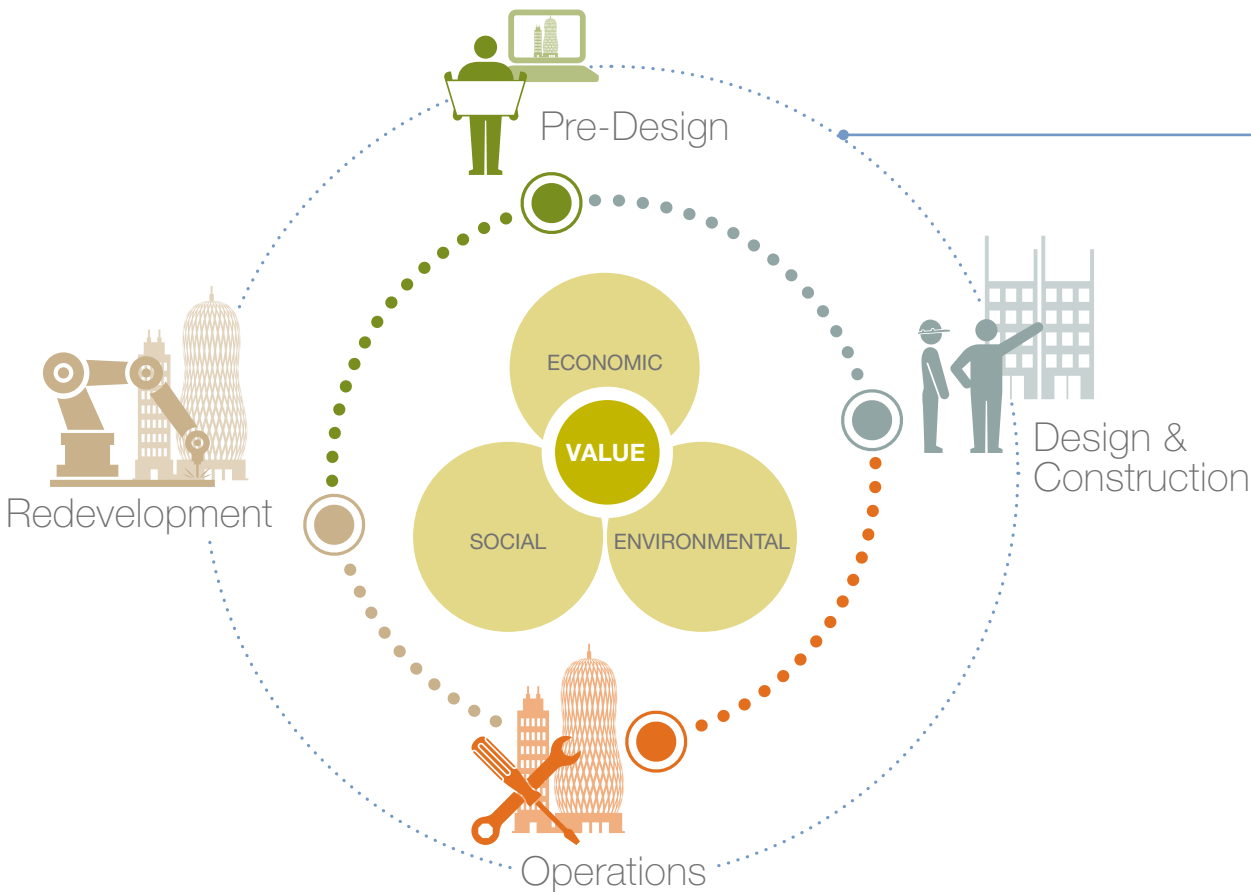


+ POTENTIAL FOR NEW AND ONGOING SERVICES

“Energy modeling should provide design teams and owners continuous feedback throughout the design and life of the building.”

—John Melchert, *Vision Statement* from the 2011 Rocky Mountain Institute Building Energy Modeling Innovation Summit

Energy Modeling: Ongoing + New Opportunities



A building’s complete lifecycle, from pre-design through long term operations – and beyond, affords numerous opportunities for energy modeling to enhance performance. Energy efficiency, optimized through energy modeling at all building design and construction stages, and periodically during post-occupancy, can achieve the triple bottom line goals of sustainability.



Energy modeling helps establish the expectations for a building's performance over its entire lifetime. Doing so is an enormous opportunity for the architect. It is an opportunity for industry leadership, for serving our clients better, and for developing expanded, ongoing services and lasting relationships with the people who live, work, and play in the buildings we design. Such opportunities exist not only in new design and construction, but also in building operations and the renovation of our extensive stock of existing buildings. Imagine a practice that provides design services with a long-term perspective on building operations and asset value.

Energy modeling creates new possibilities for specialization within architectural practice. We are already seeing the emergence of energy modeling consulting services. Many others are possible:

Pre-occupancy Envelope Commissioning reviews the installation of assemblies during construction to assure they meet the requirements developed by the energy model.

Post Occupancy Services are opportunities to continue our relationship with the owner, commissioning agent, and contractor after construction is substantially complete.

Building Operations Consulting can assist facility managers or building superintendents understand, track, and resolve operational problems; facilitate effective supervision and education of building staff; and communicate with residents to achieve optimal building operations.

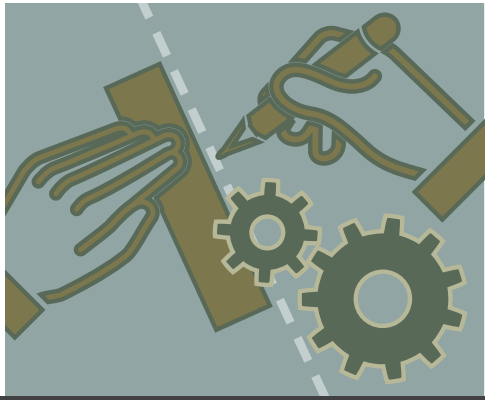
Facility Benchmarking and Assessment can help property owners and asset managers establish concrete baselines for comparative data analysis to identify performance gaps and establish meaningful strategies for both immediate and long-term improvement.

Energy Auditing and Utility Analysis provides two ways of saving money on energy: using less and paying less. Utility billing audits and web-based utility tracking services offer the benefits of long- and short-term trend management, monitoring and reporting of monthly energy usage, comparison of available utility rates, and identification of billing errors and simple operational changes that will save money.

Energy Master Planning establishes long-term energy goals that holistically incorporate energy efficiency, resiliency, and overall system sustainability throughout and beyond the design process. It explores the tools and infrastructure necessary for the best use of facility energy resources and mitigates energy supply disruptions.

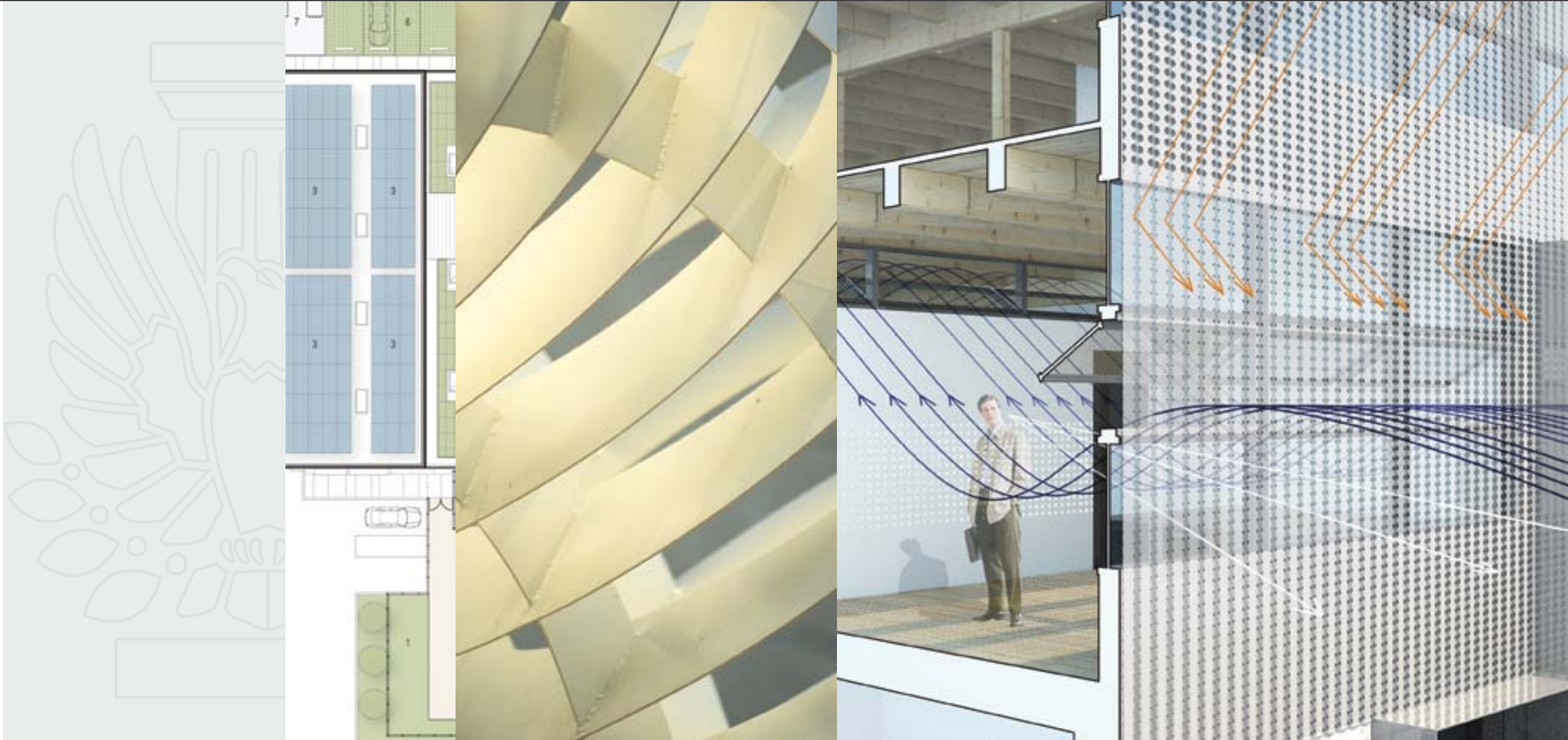
Renewable Energy Deployment ensures we meet our targets for renewable energy by working closely with delivery partners and project stakeholders to accelerate deployment. It requires work across sectors and technologies. Key inter-dependencies exist with other policy areas, including financial support, understanding feed-in tariffs, unblocking barriers to delivery, and bringing technologies forward that are still at early stages of development but could become important contributors to net zero energy.

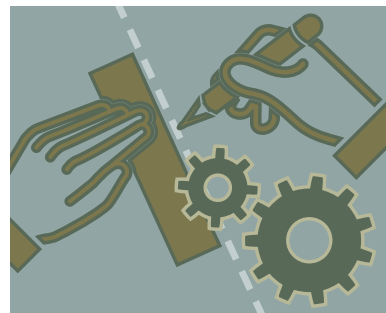
Operational Standards Development establishes policies and procedures to maintain safe, clean, functional, and pleasant operational environments and to better assist with the management, maintenance, and emergency services needs of building systems around the clock.



3

SECTION 3_ PERFORMANCE DESIGN PROCESS





“To exploit the full capability of these modeling tools, we must transform our design approach from a sequential process to a collaborative process, where all of the disciplines involved in the building design and construction work as a team from the beginning.”

—Lynn G. Bellenger, P.E., Fellow ASHRAE President 2010-2011, “Modeling a Sustainable World”

Section 3_

PERFORMANCE DESIGN PROCESS

+ BASIC METHODOLOGY

Regardless of the size of firm in which architects practice, we must take ownership of the energy modeling process. Because we hold unique expertise in the integration of programmatic goals, spatial organization, and building systems, we are the most appropriate team members to assume a leadership role in the process. The following methodology can be fruitfully employed using any of the many energy modeling software packages currently available.

For smaller or less complex projects, decide whether energy modeling is appropriate

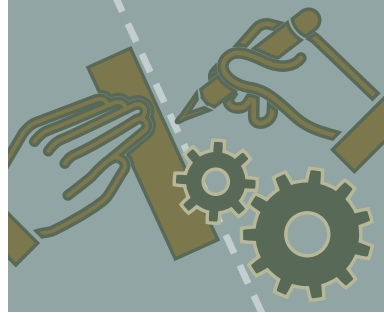
In smaller or less complex projects, it is entirely possible that a prescriptive path could be selected to comply with code-identified energy performance. This path will specify glazing properties, floor, wall and roof R-values, and even the allowable percentage of glazing necessary for compliance. Such cases will not require energy modeling. And, if the project is small enough, there may be enough flexibility within the prescriptive elements to creatively achieve the project objectives without modeling.

However, a unique site, unique views, ambitious project energy goals, a dedicated design professional, and forward-thinking owners may seek creative solutions that surpass the limitations of a prescriptive

compliance path, even for small projects. At this point, a discussion with the owner is appropriate to understand the role that Building Energy Modeling or Design Performance Modeling of targeted aspects of the design can play in the design process. Are you working to achieve a specific daylighting concept? Are you attempting to capture specific views on the north side of the building that will require compensation on other building elevations, with a higher-performance building envelope? Are you being challenged to generate a significant portion of the annual building energy budget from on-site renewables? What information are you seeking from an energy model that will inform the important decisions you need to make during the building design process?

Integrate energy modeling early in the process

The energy dialogue should be deliberate and start early in a project. It is vital that architects understand the effects of our design decisions on energy use early in our design process, perhaps even as early as in the marketing or proposal phases of the project. The information we acquire early should provide comparative data that will inform the development of the design direction. The answers we need at this early stage are not overly specific, generally providing ranges of performance options. Without them, however, we miss important design opportunities.



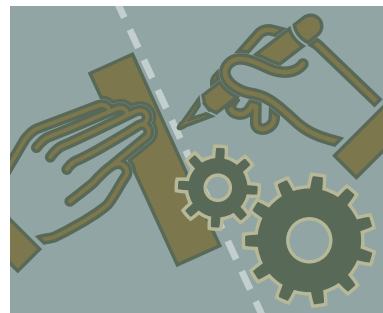
Early in the project, we must look for opportunities for collaborative problem solving with our consultants and other team members to identify the key questions and concepts that will affect project assumptions. Developing an early understanding of project energy use implications and their potential financial implications is important in steering the project appropriately toward a successful conclusion. We need to ask a lot of questions early and often; when we are not sure what questions to ask, we should ask that question as well.

The adjacent images display:

- + In the upper image, today's standard practice or business-as-usual project timeline along the top and the modified timeline associated with Integrated Project Delivery, displayed along the bottom.
- + In the lower image, today's business-as-usual incorporation of energy-modeling within the design process timeline along the top and the agreed need for incorporation of energy-modeling 'early and often' throughout the design timeline required to deliver a larger number of high-performance, highly energy-efficient projects.

In the upper image it's worth noting that the overall time line does not have to change; rather, more time is spent in the early phases of design, working to establish and define energy and performance design goals, using an interactive team approach to work through the synergies of building envelope, energy, siting, and building systems, up front, saving time spent revisiting design decision implications later in the design process. This inclusive process encourages early contribution, input and buy-in from all project stakeholders.

Conversely, the lower image illustrates the current 'business as usual' use of energy-modeling primarily to document performance for code compliance during the later construction documents and construction phases of work. Whereas, to achieve a prevalence of higher energy-efficient projects, *energy-modeling tools really need to be used early and often throughout the design process*. And increasingly in the future, will be needed to corroborate VE system/component changes during construction and to calibrate/validate the final project's actual performance with that predicted during later design. Thus one can see that becoming intimately familiar, particularly with using early DPM tools (as well as increasing one's ability to converse effectively with energy-modeling consultants about the whole-BEM process for performance code compliance) is critical for the well-rounded architectural professional.



Where to Include Energy Modeling in the Work Plan:

- Integration Plan
- Owner's Project Requirement (OPR)
- Basis of Design (BOD)

Develop a smart work plan

In today's market, we are being asked to deliver enhanced quality professional services and incorporate new skill sets for the same or reduced fees. Needless to say, it is a challenge that we must address creatively within the fee structure and work plan. Do not expect energy modeling to be truly successful without appropriate allocation of time and resources. While it may seem obvious, up-front design attention and planning brings benefits later in the process, not least of which are savings in design time. Part of a successful, collaborative focus on building energy use is setting appropriate goals and mapping out the strategies to accomplish them.

Set performance goals and benchmarks

Energy goals and benchmarks should be established in dialogue with the owner and building operator in order to understand operating standards, resource consumption criteria, and performance expectations for the completed project. They may be set in terms of energy use per unit of area, percent better than code, or other measures of energy efficiency (see "Energy Models And Measurements: Key Definitions").

Identify constraints

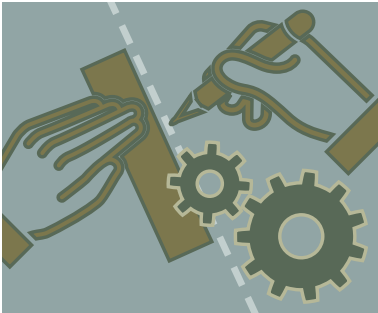
At the early stages of design, it is important to recognize that there are any number of code, planning, sociological, programming, and other constraints to consider alongside the optimization of site, orientation, massing, and envelope energy efficiency. There are times when one or another of these design issues will be considered sacred, unable to be modified to suit a particular optimal energy or performance efficiency choice. An example of this is a dense, city center site, where land values may dictate an orientation and massing that are not ideal for energy efficient envelope design. Even so, energy modeling during early design stages, used conscientiously, can identify a range of options within the design constraints and can compare the relative performance of those options.

Balance performance indicators

When modeling, analyzing, and discussing efficiency, consider more than just energy efficiency. Seek, instead, to balance efficiency among the performance indicators specific to the particular system in question; e.g., for the building envelope, energy efficiency must be balanced with thermal comfort, visual comfort, daylight penetration, and view.

Explore synergies

Each individual architectural and engineering system could be considered independently for energy efficiency, but this approach is a poor way of achieving overall integrated building energy efficiency. Designed independently, each system will typically have to be more robust than if the synergies of interrelated systems are fully tapped. Accordingly, the performance simulation should illustrate impacts on adjacent systems wherever possible. Orientation, window shading, and HVAC systems are, for example, interrelated; if solar loads can be controlled, low-energy-use systems, such as radiant cooling or natural ventilation, might be used. While this is exactly the type of information that facilitates informed decision-making, it invariably means exploring a matrix of options and thus developing lots of simulations and organizing a lot of data.



Explore passive systems first

Explore renewable energy and passive systems before considering mechanical solutions.

Eliminate unnecessary systems

Combined component efficiencies can even eliminate the need for a supplemental system altogether, thus saving not only energy and energy cost, but providing a huge savings on the first cost of an entire system.

Compare alternatives

Particularly during the initial design phases, decisions are made by weighing different options against one another. Thus, comparative illustration of the efficiency of alternatives that includes all relevant performance indicators is exceedingly helpful. This, again, means a great deal of options, simulations, and data to organize and present for discussion.

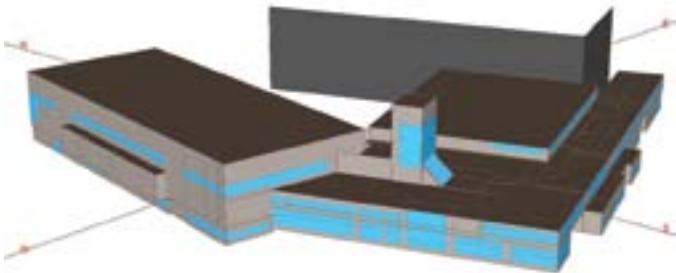
An eQuest model output that demonstrates where major consumption occurs in a building. Baseline and design cases will vary, depending on project parameters.

Illustrate your analysis

Performance analysis results typically need to be represented to high-level decision-makers, many of whom may never have seen energy performance numbers before. To spark effective and efficient discussion, consider portraying results graphically, in a manner that can be quickly and easily understood, rather than just through numerical reporting. Note that comparative analysis results are well suited to these types of graphics. However, the results from the modeling tools often require interpretation and reformatting to be readily understood.

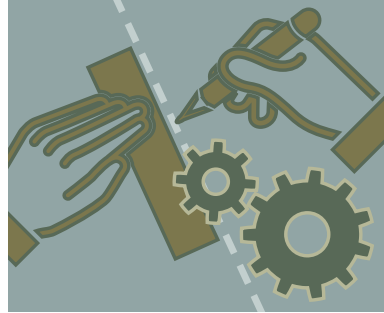
An Example of Energy Model Output and Results

SIMULATION RUN	ELECTRICITY USE (kWh x 10 ⁶)	NATURAL GAS USE (MBtu x 10 ³)	ENERGY USE INTENSITY (KBtu x 10 ³)	ENERGY SAVINGS (%)
Baseline Building	34	39	114	–
ECM#1-LPD=0.8	22	45	90	21
ECM#2-Add Wall Insul.	34	39	114	0
ECM#3-Add Roof Insul.	34	39	114	0.2
ECM#4-Improved Glazing	33	30	106	7.5



Simplify the model

Consider simplifying the simulation model as much as possible. At the early stages of design, there are as yet no “building” or detailed system components, so a simple, one-room model can often suffice. This simple model can be used to experiment with orientation, façade treatments, HVAC options, and lighting control alternatives. This simplification saves an enormous amount of model-development time. As the project continues, the energy model will develop higher fidelity.

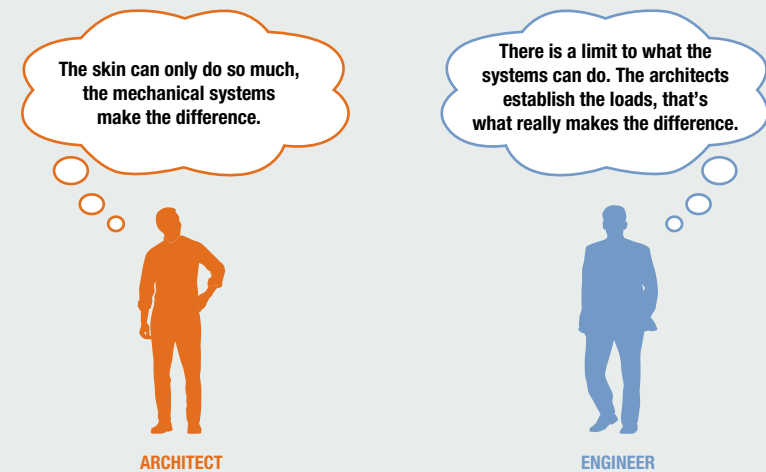


+ THE ARCHITECT'S EVOLVING ROLE: REFRAME THE DISCUSSION

Our role as architects is to challenge conventional thought and, through critical inquiry and our ability to analyze complex problems, to ask tough, insight-yielding questions. At the same time, our work requires well-organized, dependable practice structures and methods, which inevitably resist change. Design performance modeling will shake up our standard practices. To take advantage of the opportunities it offers, as well as to cope with its challenges, we should:

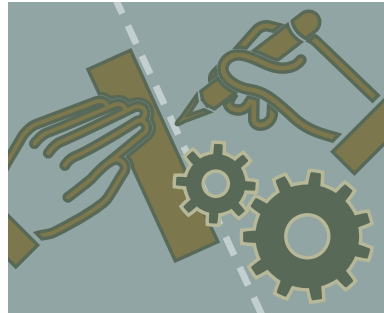
- + encourage broad staff participation and understanding, rather than relegating modeling to isolated subject experts
- + foster collaborative attitudes and nurture collaborative skills, through active engagement
- + convene face-to-face sessions when possible; they tend to be more effective than web-based approaches
- + follow up with more detailed information, and utilize feedback;
- + remember that, ultimately, this is about architectural practice and delivering better projects, not a new service line.

Standard Practice



Active Engagement





Small Firms

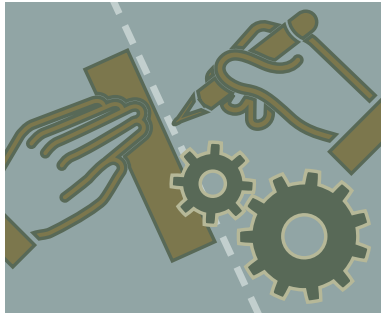
Small firms have particular challenges in equipping themselves to engage in a productive dialogue on energy modeling. The big issue for the small firm practitioner is time. How much time will it take to gain a reasonable working understanding of the issues we need to grasp to be effective in these discussions? How much time do I have and can allocate to this study? Fortunately, because of the traditional training and understanding of building systems and energy systems, there is a good knowledge base already.

Large Firms

Large firms often have experts and resources that can be called upon to lead the adoption of energy modeling. The challenge in such firms is how to engage and enlist a vast, diverse, and often highly specialized staff. Within such firms, predicted, modeled energy information on all design projects can be collected and shared in a variety of ways that build both understanding and enthusiasm. Data can be shared based on building use type, office geography, project leadership, size, or market attributes. Each of these categories will represent particular stakeholder groups within the firm. The simple act of transparent information sharing can have a huge effect on the engagement in energy reductions.

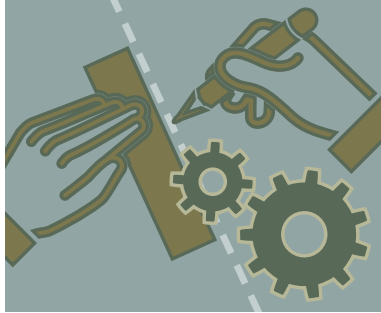
Use Energy Modeling to Demonstrate the Value of Design

Energy modeling more fully informs the design process, leading to a higher quality and more efficient building. It also affords the opportunity to demonstrate to clients and users tangible, measured benefits of well-integrated design. Energy modeling and other performance simulation tools do not replace expertise and experience, but offer support, providing concrete feedback that enables architects to sharpen their intuitive judgments both within the project and from project to project. It underscores the value of synthesis—the integration of the many disparate systems and elements that make up a building. This is the architect's unique contribution to an endeavor in which every other participant is a specialist, tasked with optimizing a particular system or element. Only the architect is responsible for the collective optimization of all the components of building. Energy modeling measures one crucial benefit of this collective optimization; other performance modeling tools measure others. We can demonstrate the value of design by showcasing the relationships between our expert intuition and measured performance.



Broad Energy Modeling Goals and Benefits

	CONCEPT DESIGN	SCHEMATIC DESIGN	DESIGN DEVELOPMENT	CONSTRUCTION DOCUMENTS	CONSTRUCTION/ POST-OCCUPANCY
TEAM GOALS	<p>Use early Design Performance Modeling to help define the goals of the project</p> <p>(NOTE: Design Performance modeling could be with either component modeling tools or a basic building energy model, but should at this stage address other performance parameters in addition to energy.)</p> <p>Define the project requirements, as informed by modeling results</p>	<p>Review financial and performance energy information from model to guide design decisions</p>	<p>Review design alternatives based on initial goals, as informed by modeling results</p> <p>Create baseline and alternatives to choose from</p>	<p>Create documentation needed to accompany energy model results for code compliance</p> <p>Create documentation needed to accompany energy model results for commissioning and metering/ monitoring validation</p>	<p>Use results of the as-built model for commissioning</p> <p>Compare results of the as-built model against metered data to look for operating problems</p>
ENERGY MODELING GOALS	<p>Experiment with building siting and orientation</p> <p>Determine effective envelope constructions</p> <p>Assess the effects of daylighting and other passive strategies</p> <p>Explore ways to reduce loads</p>	<p>Create a rough baseline energy model</p> <p>Test energy efficiency measures to determine the lowest possible energy use</p> <p>Set up thermal zones and HVAC options</p>	<p>Create proposed models with system alternatives to choose from</p> <p>Refine, add detail, and modify the models, as needed</p> <p>Provide annual energy use charts and other performance metrics for baseline vs proposed</p> <p>Evaluate specific products for project</p> <p>Test control strategies</p> <p>Do quality control check on the models</p>	<p>Complete the final design model</p> <p>Do quality control check on the models</p> <p>Create final results documentation needed to submit for code compliance</p>	<p>Complete the as-built model with installed component cut-sheet performance values</p> <p>Collect metered operating data to create a calibrated model to share with outcome-based database</p>
BENEFITS TO CLIENT	<p>Get entire design team united around project goals</p> <p>Use modeling results to make design decisions informed by integrated system performance</p>	<p>Test different options before implementing them</p> <p>Determine the most efficient and cost effective solutions</p>	<p>Determine the most efficient and cost effective solutions</p> <p>Size mechanical equipment correctly</p>	<p>Use energy model as part of LEED or other sustainable design certification application</p> <p>Provide ability to better predict energy use in the building</p>	<p>Provide ability to refine operations to meet reduced energy use goals in the built project</p>



+ WHAT ENERGY MODELING MEANS FOR OTHER STAKEHOLDERS

“Thermal qualities—warm, cool, humid, airy, radiant, cozy—are an important part of our experience of a space; they not only influence what we choose to do there but also how we feel about the space.”

—Lisa Heschong, *Thermal Delight in Architecture*

In the new paradigm of sophisticated technology and analysis tools, energy modeling, advanced building controls, monitoring, and building operation energy dashboard systems, design is no longer an independent activity isolated from the other phases of a building's life-cycle. The interdependence of all parties in the building development process is a necessity for delivering a building that performs as designed.

As with much in the practice of architecture, once we educate ourselves, we must then educate others who are integral to constructing a building: the client, the contractor, and the code official. The questions for all of us are essentially the same, but nuanced to the mindset and priorities of each party. It is important for us to understand their perspective, to communicate with them about their concerns, to manage their expectations, both of the project and of us. The questions can all be grouped into five general categories:

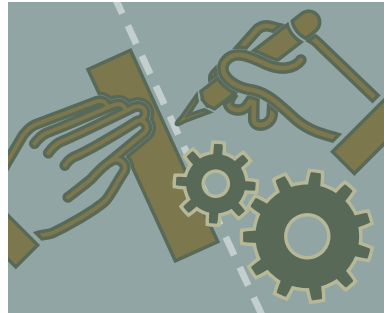
- + **Why** do we have to do Building Energy Modeling?
- + **Who** is going to do it? Who else is involved? Who has to participate?
- + **What** are the products of an energy model?
- + **When** are these products produced? When is the model complete?
- + **How** much will energy modeling cost and over what period of time?

Some of the answers depend on who is asking the question and understanding what their issues and priorities are. For example, it might be broadly generalized that owners are concerned about total cost out of pocket, but contractors care if the cost is in overhead or is direct with mark-up. Code officials don't care about who pays or how much it costs, just that the regulations are met.

Prediction and Outcome

There seems to be a prevalent misconception, within both the design community and the general population, that buildings are used and managed in precisely the way the architects and engineers designed them. Consequently, many owners, facility managers, and occupants often don't understand why the building and systems don't meet performance predictions of the BEM. In some cases, they may get irritated to the point of legal action when the building performance does not meet predictions or expectations.

Yet, in fact, prediction and reality often diverge significantly. One recent study looked at 120 LEED® certified buildings that had presented energy modeling results as part of their certification requirements. The predicted energy use results of the modeling compared to those actually reported or metered are all over the map, with some buildings reporting energy use that would not even comply



with the code baseline and others saving much more than predicted (Frankel & Turner, 2008). Some of these discrepancies may be due to uncertain modeling skills, but most are likely due to the large number of variables that affect building energy use and that models cannot necessarily capture or predict.

As we head down the path of performance and outcome-based code compliance, it is essential that all participants in the building enterprise, including clients, facility managers, and occupants, understand the limitations of energy modeling. They must also understand their responsibilities in both informing the model and in operating the building effectively.

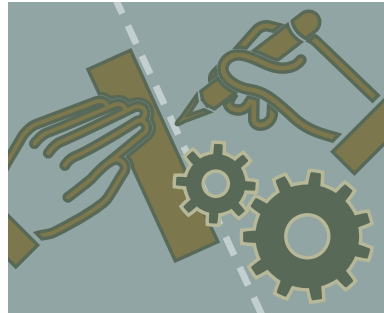
Clients

While energy modeling for code compliance often occurs at the end of the design process, getting the client's early buy-in is crucial to engender the most informed design decisions. Section 2, "The Benefits of Energy Modeling," describes the usefulness of modeling to clients and building owners. For its successful implementation, it is essential that the client understand the following points:

- + **Energy modeling can serve two goals: the design of an energy efficient building or simply code compliance.** If a highly efficient building is a goal, the team will need to use energy modeling as an early design tool; it is the only way for the design team to evaluate cost effective solutions and the trade-offs between first costs and operational energy costs. For code compliance, energy modeling may only be required for a performance-based compliance option.
- + **A Building Energy Model may be provided by the architect or by a consultant.** Such a consultant could be part of the mechanical engineering team or could be independent and specifically tasked with energy consulting.
- + **Allowances must be made for energy modeling in the overall scope and fee for the project.** Energy modeling requires

effort: the expenditure of time and resources. The client must agree to appropriate compensation for this effort.

- + **Building Energy Models are based on assumptions.** The more accurate the assumptions the client can provide, the better the predicted outcomes will be. Note that if specific values are not known—for example, when a developer-client is not sure yet who the tenants may be—target end-user alternatives could be explored, with possible outcome scenarios and the implications on design and cost addressed. If the actual use, occupancy, or operation doesn't match the assumptions, actual energy use and cost will very likely not match predictions. Refining assumptions for greater correspondence with actual outcomes becomes critical as the industry moves more and more towards outcome-based design.
- + **The client is responsible for some of the assumptions used in the model.** The client is likely to have the best knowledge of some of the parameters needed for energy modeling assumptions, such as how and when the building is going to be used. For energy modeling to be most effective, the client needs to agree on many of the assumptions that will underlie the model—plug load estimates, for instance.
- + **A Building Energy Model is not a guarantee of building performance.** Because a Building Energy Model is based on assumptions, it will not exactly replicate actual building operations and energy use. Construction, operations and maintenance, seasonal weather variations, and occupant use patterns will affect the actual building performance in ways that will inevitably depart from the modeled conditions. Today's modeling tools are not intended to provide any higher degree of predictive certainty for actual energy use than the miles-per-gallon ratings displayed on the window sticker of your new car predict real-life mileage. The Owner-Architect Agreement should recognize this reality and clearly distinguish between Building Energy Modeling and building performance.



- + **Front-loading the design process with better intelligence and modeling brings greater value and reduced risk.** As even small projects become increasingly complex, the most cost effective building performance decisions are the earliest ones, enabled by modeling. And energy modeling is the only way to account for the performance impact of interdependent systems, such as the envelope impact on cooling, heating, and lighting.
- + **Value engineering can be counter-productive.** Major system or component substitution requests should require additional runs of the energy model to validate that the proposed changes have no adverse effects on other associated materials, components, system performance, or cost. Who does this evaluation and how this is to be accomplished so that it is a valid comparison should be addressed in the Client-Contractor agreement.

Contractors

It is important that the general contractor understands that, when proposing substitutions or alternative systems, usually done to help reduce first costs, the energy model may need to be additional run as a part of that substitution request. If it hasn't been agreed upon as part of the original contract with the general contractor, negotiations would then need to occur as to how and by whom the modified energy model is to be run. Any re-run should be done with all previous assumptions held constant, to ensure an apples-to-apples comparison. When the energy model is required by code, re-running the model will likely be mandatory.

Code Officials

Code officials are primarily focused on the use of BEM to satisfy building code requirements. Owners and design teams may need to engage code officials to determine if BEM is necessary and, if so, what level of data and documentation will be required. Code officials may not care who provides the BEM data, unless such is stipulated in the code or regulation. Depending on the regulatory requirements,

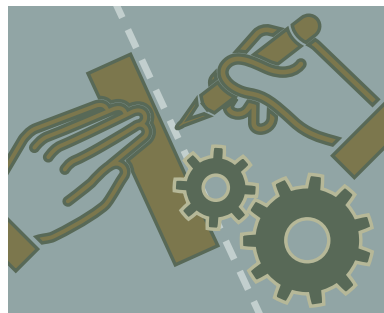
the code official will be looking for BEM documentation as part of the permit submission; it may also be required as part of commissioning or during post-occupancy for final certificates of occupancy. If development incentives are tied to meeting energy reduction goals, BEM documentation may be required as part of analysis of actual energy consumption.

Facility Managers

The building's facility manager may be unfamiliar with the appropriate operation techniques, schedules, and maintenance needed for optimal operation assumed in the BEM for newer HVAC, lighting, and envelope strategies, or for systems and controls used in highly energy efficient buildings. Without education and training, the facility manager may operate the building in a manner reflective of previous practice, which may not be appropriate for these new systems. Facility manager training in operation and ongoing maintenance of newer building systems may be a potential additional scope of work opportunity for architects and engineers.

Occupants

Particularly with highly energy efficient buildings that employ occupant-controlled systems as part of energy reduction measures, educating the users on how to operate the new technology is critical to achieving the optimal system performance assumed in the BEM. Experience has shown that occupant education and training not only improve operation towards meeting the desired energy-use reduction and building performance goals but also significantly reduce frustration and complaints that "the building isn't working."



+ ENERGY MODELING, STANDARD OF CARE AND CONTRACTS

Building Energy Modeling is becoming an increasingly integrated part of standard architectural services, driven by new regulatory requirements; client requests for a sustainability certification such as LEED™, Green Globes™, The Living Building Challenge™, or Energy Star; and an ongoing evolution of the professional standard of care. As jurisdictions adopt or develop building codes that require increasingly rigorous energy practices, the agreement between the Owner and the Architect must be crafted to manage expectations, clearly outline roles and responsibilities, and recognize the time and cost of this work. Prescriptive compliance with the code may be an option for some projects, but an increasingly large proportion of projects will require a performance-based energy modeling process.

AIA Document D503™-2011, *Guide for Sustainable Projects, including Agreement Amendments and Supplementary Conditions*, was developed to assist users of AIA Contract Documents in understanding contractual considerations unique to sustainable design and construction projects. It is available free at <http://info.aia.org/aia/sustainabilityguide.cfm>. It describes the relationship between energy modeling and the Architect's Standard of Care in the following terms:

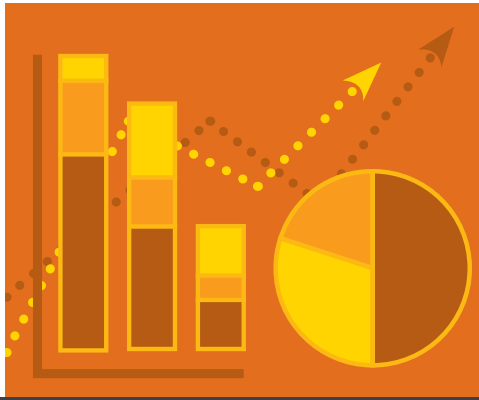
The Architect's Standard of Care is an evolving concept. As more jurisdictions require sustainable, energy efficient building design, more clients require this level of service, and more architects incorporate this into the scope of Basic Services, the Architect's Standard of Care may eventually be construed to include energy modeling as an accepted baseline standard of performance for the Architect. Whether or not energy modeling is part of the Architect's Basic Services or an Additional Service, it is important to address this in the Owner / Architect Agreement in order to manage expectations and establish an appropriate process. Owner's building energy goals

should be a clearly outlined Objective. The design elements, construction means or methods, and aspects of the project's delivery are Measures that will be developed as the design evolves. An implementation Plan describing the Measures focused on achieving the Objective through the use of Building Energy Modeling, should describe the roles and responsibilities of the Architect and the Architect's consultants, the Owner, and the Contractor, appropriate design reviews and other means to be used. The Plan should become a part of the Contract Documents and connect the Objective and Measures to the Contract for Construction. Because Building Energy Modeling is a whole-building performance-based approach to meeting an energy design Objective, describing specific Measures at the time of contract negotiation is difficult. This is the purpose of incorporating into the contract the deliberate steps of establishing the Objective, articulating the Measures and developing the Plan. The Plan may or may not, describe additional Architectural design scope. If the Plan requires the Architect to provide services beyond those contemplated at the time of execution of the Agreement, those services should be provided in accordance with the appropriate section of the B101™ – 2007 that addresses additional services. In addition, the Agreement between the Architect and the Owner should acknowledge that energy modeling early in the design process is considerably less accurate than later in the design due to lower level of detail inherent early in the design process.



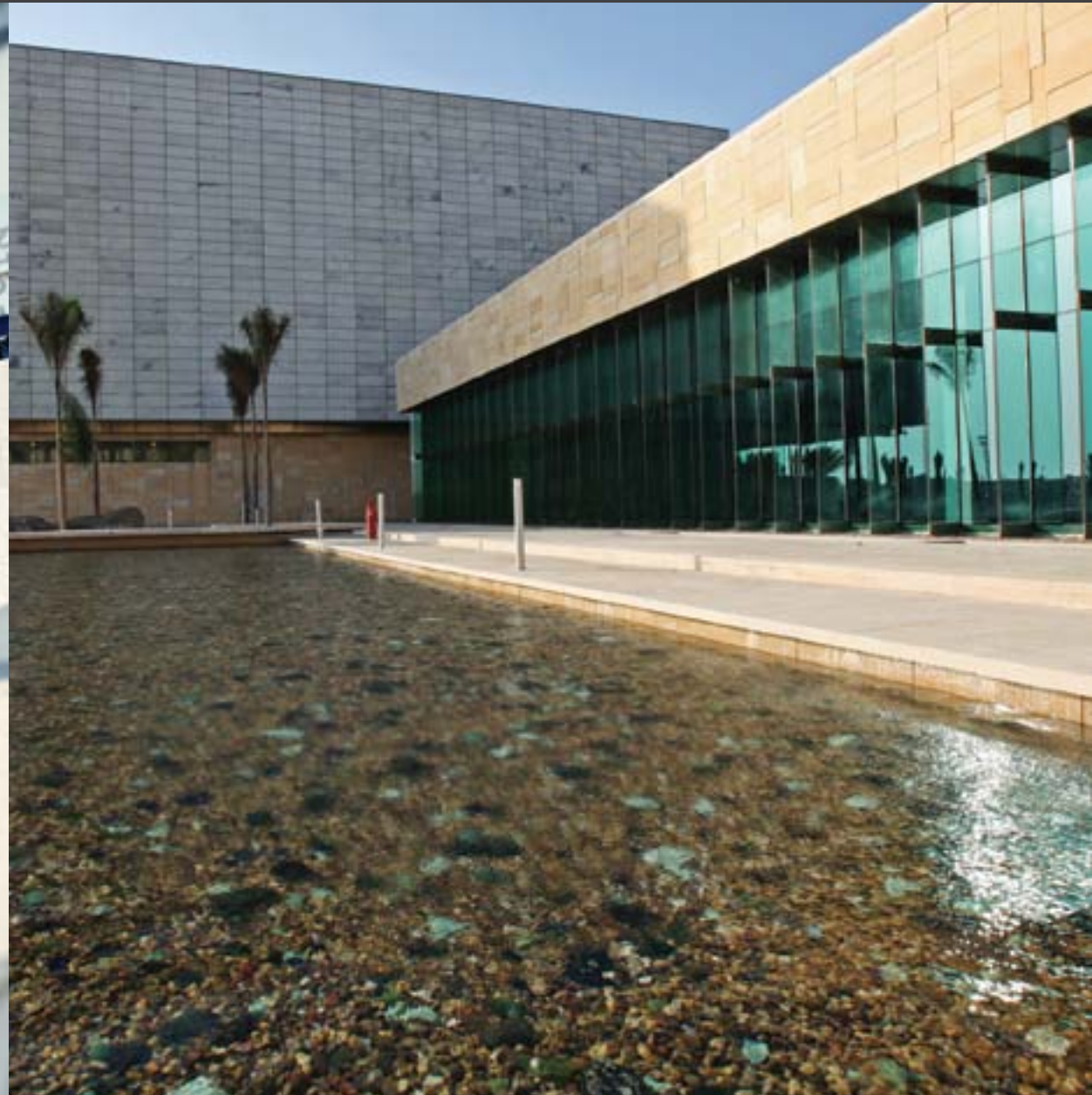
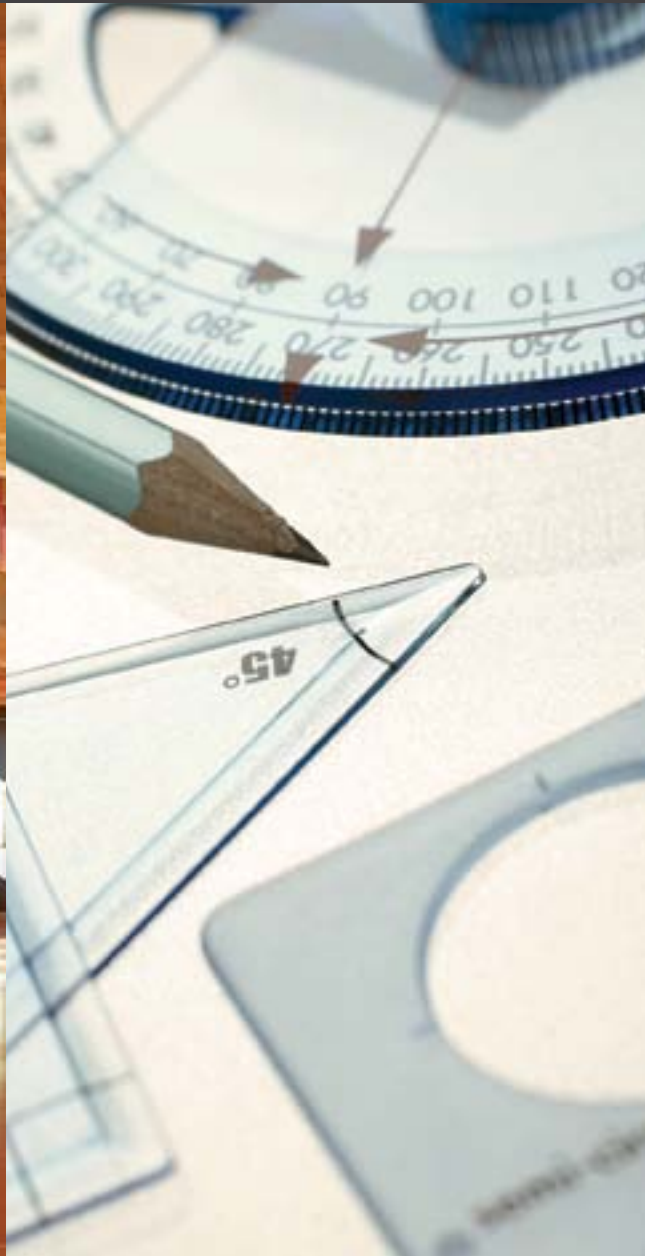
If energy modeling is provided by a consultant, AIA Document C401™ – 2007 is the standard form of agreement between the Architect and the Consultant; it utilizes a flow-down provision that requires the Consultant to assume toward the Architect all obligations and responsibilities that the

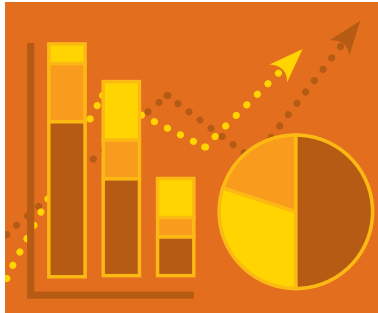
Architect assumes toward the Owner in the Prime Agreement, as applicable to the Consultant's Portion of the Project.



4

SECTION 4_ PERFORMANCE ANALYSIS AND MODELING





“Energy modeling should be so easy, accurate and trustworthy that you do it both early and often during the design process.”
—John Bacus, Vision Statement from the 2011 Rocky Mountain Institute Building Energy Modeling Innovation Summit

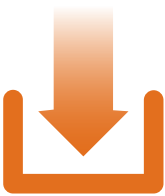
Section 4_
PERFORMANCE ANALYSIS AND MODELING

+ WHAT IS AN ENERGY MODEL?

As noted previously, in its simplest form, an energy model is a calculation engine that accepts inputs such as building geometry, system characteristics, and operations schedules and produces outputs such as performance comparisons and compliance reports. As is true of any family of software, not all energy-modeling tools are equal; they vary in terms of the inputs they accept, the level of sophistication of their engines, and the character of their interfaces, among other things. A familiarity with the range of capabilities found in current energy-modeling tools and the range of uses to which they may be put can help you match the right tool to the job at hand.

Energy models are most useful when they are used for Design Performance Modeling, affording an understanding of the interrelated factors that determine building energy use, in turn facilitating informed discussions between the design team and client about optimal design alternatives for the project. Used this way, modeling enables designers a better understanding of how energy use is distributed throughout a project, what combination of options use more energy, and what alternatives, both physical and behavioral, will be most effective at reducing project energy use. Because of their interdependence, design decisions such as skin configuration, shading devices, glass choices, conditioning approaches, equipment selection, or

In its simplest form, an energy model is...



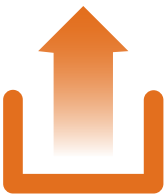
a set of inputs and default variables

(Building geometry/ massing/form, system type, operation schedules, etc.)



a calculation engine

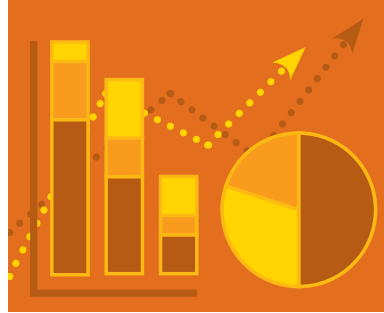
(DOE-2, EnergyPlus, Apache, etc.)



the results or output the program delivers

(Performance comparison graphs, compliance reports, etc.)





control options can be quite complex; modeling allows entire sets of energy efficiency measures to be evaluated as single entities and compared to other options. In addition, Design Performance Modeling allows other issues to be considered, such as occupant comfort, performance, cost, and schedule. As long as the modeling is sound enough to accurately predict patterns of energy use, the comparative predictions between different energy efficiency measures can be used to prioritize design decisions. It is impossible to model every variable with the highest degree of accuracy, but experienced modelers will have detailed knowledge of which variables require high accuracy and which have less impact on the final outcome for a specific situation or set of energy efficiency measures. This familiarity with what is worth spending time modeling in detail (and what is not) is the greatest advantage of a “more expensive” modeling consultant over a “cheaper,” inexperienced consultant or intern.

The most accurate energy models are ones that try to recreate past energy use performance of existing buildings using measured data. These are referred to as “calibrated models.” Ideally, in this kind of modeling, all end uses are monitored with sufficient resolution that the data can be used to tune a highly accurate computer model. Theoretically, a model like this can then be used to predict future building energy use. However, even here one often cannot predict occupancy patterns, plug loads, weather, or unexpected situations, such as the remodeling of parts of the building.

Building Energy Modeling tools are best understood as being composed of front-end interfaces, with which the user interacts to enter data and assumptions; and engines, which perform the calculations behind the scenes, and in some cases (we wish there were more) ‘back-end’ interfaces, with which the user interacts to define the graphic display of the results. In some cases, more than one interface is available for an engine; they may have been developed by the developer of the engine or by another party. In other cases, engine and interface come as an integrated suite.

Levels Of Modeling

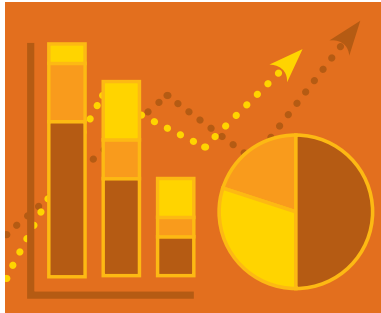
There are a number of factors needed to describe the features of a building being evaluated through energy-modeling simulation that impact energy use.

Through several steps, these elements are entered into, ideally, a single building simulation program, with ever-increasing detail added as the project design progresses through the design stages.

In addition, utility rate information can also be input if the energy model is to incorporate economic analysis such as life-cycle assessment or payback on operational energy savings.

Renewable energy and systems that contribute to the reduction in building load and do not necessarily consume energy can also be integrated into the model.

Note that it is important to discuss assumptions for the internal loads schedules alongside the more traditional design parameters addressed during design. Operating schedules can often be left out of modeling discussions and then assigned whatever might have been used on a previous project, likely with no relevance to the project at hand, and having major impacts on anticipated energy use of the project. (A detailed list of potential assumptions is included in the Additional Resources Section.)



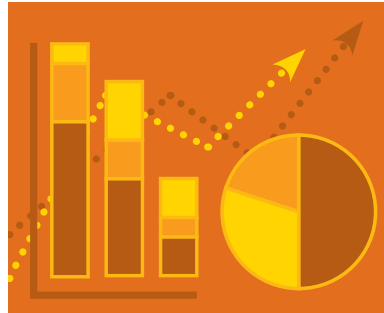
When using the same energy-modeling simulation tool throughout the design process:

- + The input/assumptions (+ an estimate of window to wall ratio for each elevation and default construction-makeup for a particular ASHRAE climate zone) can often suffice for a simple, quick very early design model to assess massing and orientation alternatives impact on potential building energy use.
- + Modeling the parameters possibly even on a single zone of each building orientation is often used to evaluate different envelope, glazing and shading alternatives (typically assessed in the earlier stages of design, before system choices, layouts and sizes are defined.)
- + A model constructed with both aforementioned parameters typically includes the level of detail one would expect to see towards the end of the Schematic Design phase and could then be used to conceptually assess different HVAC system strategies and add detailed system information as it evolves.

Levels of Modeling Elements and Inputs

MODEL ELEMENT	INPUT INFORMATION
Architectural massing + form	Building shape + orientation, Principal building function, Total floor area, Number of floors + thermal zoning of floors, Floor-to-floor height + Floor-to-ceiling height
Envelope	Window dimensions (for different locations), Window sill and head height (above floor), Window to wall ratio, Window+skylight characteristics (SHGC, U-value, VLT, frame-type), External shading geometry, Wall, roof + foundation construction makeup, Interior-partitions, Internal-mass and Infiltration assumptions
Internal loads	Anticipated building occupancy, lighting power density, plug-load density + exterior lighting peak power, Daylighting and/or occupancy sensors to be used?, Elevator?
Internal load schedules	Anticipated occupancy, lighting, plug-load + exterior-lighting schedules (summer/winter; weekday, weekend, holiday hours of use)
HVAC equipment + schedules	Type of system, Size (efficiency, capacity, etc.) Schedule of operation and controls



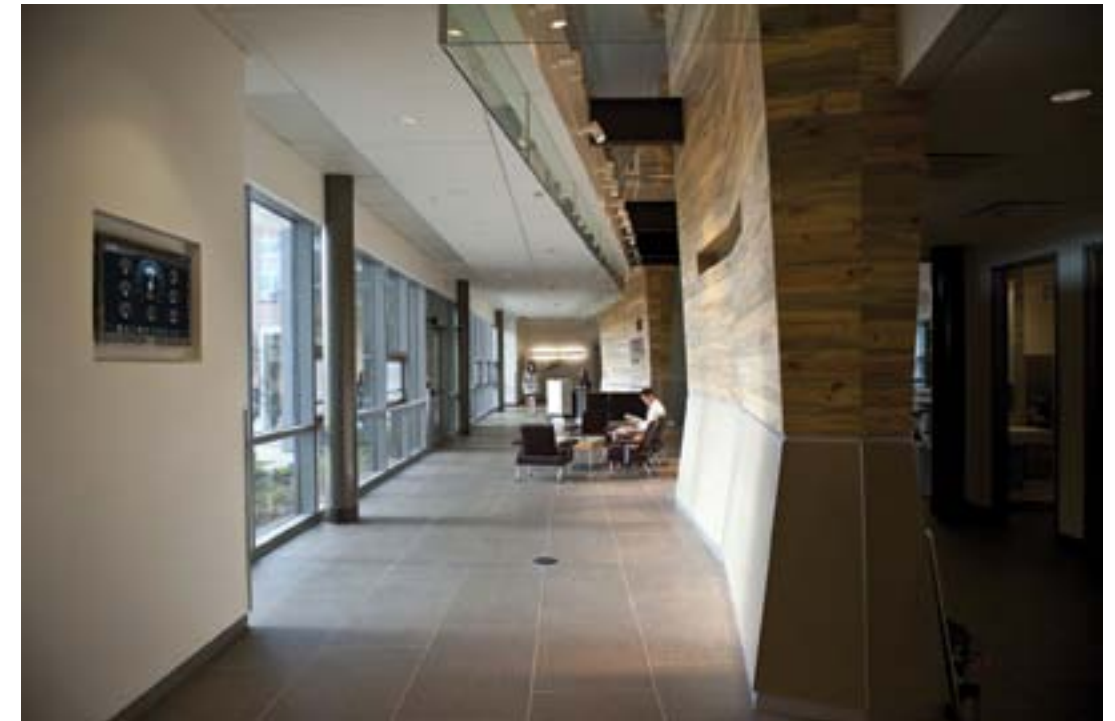


+ MEASUREMENT & VERIFICATION, MONITORING, REPORTING, AND CALIBRATION

Measurement and Verification

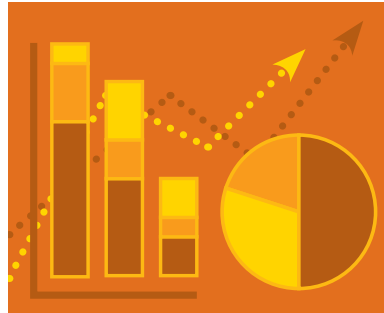
Measurement and Verification (M&V) is the comparison of measured energy use before and after implementation of a project or, for new construction, the validation that the building's measured energy use aligns with that of an accepted benchmark. M&V has historically been done for retrofit projects with financial incentives tied to energy efficiency upgrades. With the advent of green building programs and new codes, such as the IgCC, M&V will be integrated into many new construction projects. Because of this requirement, there is another opportunity for the design team to use the M&V process to enhance the performance of the project. The International Performance Measurement and Verification Protocol (MVP) provides an overview of current best practice techniques; it lays out four main options for evaluating performance, based on the type of project and the level of rigor required.

Measurement can involve as little as tracking monthly utility bills and as much as sub-metering all building end uses. Determining what questions about building performance need answering will determine what needs to be measured. For example, if the main question is how much energy a building uses compared to similar buildings, utility bills can suffice. But without sub-metering, the question of why a building is performing the way it is cannot be answered. When innovative features are designed into the building, a higher level of rigor is often



needed to evaluate these systems and determine if they are operating effectively. Further example questions include: Do the lighting systems utilize daylighting controls effectively, and how much energy does this save? How do the mechanical systems respond to night flushing, and how many hours can the building sustain itself before the spaces must be conditioned?

Photo credit: ©Dennis Schroeder/NREL



Monitoring

Once the M&V strategy is identified and the measuring systems are in place, verification that these systems are working properly and collecting the right information is critical. Ideally, a monthly report is developed, so that the entity evaluating the performance can check the data in regular cycles to ensure correlation between the monitored performance and the predicted performance.

Depending on the M&V method used, the process of evaluating performance and identifying next steps can vary. Some options require calibration of the Building Energy Model to the measured data, while others require engineering analysis of the data to assess the performance.

Calibration

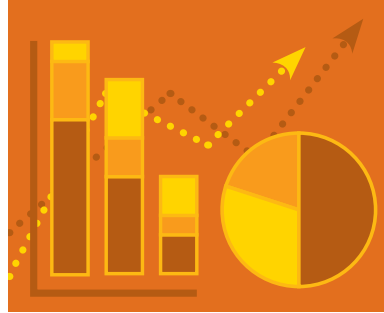
Building Energy Model calibration plays two roles: it adjusts the model using actual occupancy and operations patterns, and it identifies areas for operational improvement.

When calibration of the energy model is required, at least a year's worth of operations data, representing a full climatic cycle, is collected to provide a baseline data set. The team gathers as much information as possible about the operations of the building, as well as weather data representative of the site for the period. Ideally, team members will do a walk-through of the building and interview the building engineer and commissioning agent, to gain a better understanding of actual operations and how they have diverged from the design assumptions. The team will also look at as-built drawings, occupancy patterns, and plug loads.

A second approach to M&V does not use calibrated energy modeling, but instead uses a higher level of metering information to benchmark the building in order to evaluate performance. Benchmarking can be done against several different baselines. The US Environmental Protection Agency's Energy Star Portfolio Manager is a commonly used on-line benchmarking program, in which "statistically representative models are used to compare [the] building against similar buildings from a national survey conducted by the Department of Energy's Energy Information Administration. This national survey, known as the Commercial Building Energy Consumption Survey (CBECS), is conducted every four years, and gathers data on building characteristics and energy use from thousands of buildings across the United States (U.S. Environmental Protection Agency & U.S. Department of Energy, n.d.)." Despite the Congressionally mandated, four-year survey schedule, the most recently available CBECS, as of this writing, is based on 2003 data.

Portfolio Manager uses energy values based on the building's operational characteristics, including location, size, occupancy, and computing intensity. A building can receive an unofficial rating by inputting the data into the Portfolio Manager system; to receive an official score, it must undergo an audit from a professional engineer.

Photo credit: ©Alex Swindler/NREL



Buildings can also be benchmarked for other metrics, including water consumption, occupant comfort, maintenance and operations, waste generation, and recycling. Benchmarking can also be used to make comparisons during the design process—for example, to evaluate EUI metrics of the project at several points along the way, either at the whole building level or by space type. The Department of Energy has developed guidance on these performance measurement protocols to encourage a more consistent approach (Fowler, Wang, Romero, & Deru, 2010).

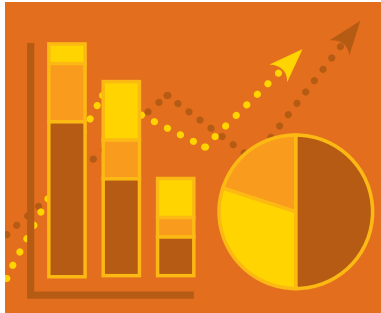
Reporting

Typically, the contractual requirements for execution of the M&V plan call for a detailed report on the model calibration, identifying how systems are operating in relation to the design estimates, along with suggestions for adjustments to the systems. It is here, in the ongoing enhancement of building performance, that the monetary benefits of M&V are realized.

In addition to reporting the results from the model calibration, the information gathered by the metering systems can be displayed in real time on a dashboard to engage the occupants and building operations team to optimize operations and energy savings. (The building automation systems that facility managers use focus on on/off and timed cycles, rather than energy consumption optimization.)

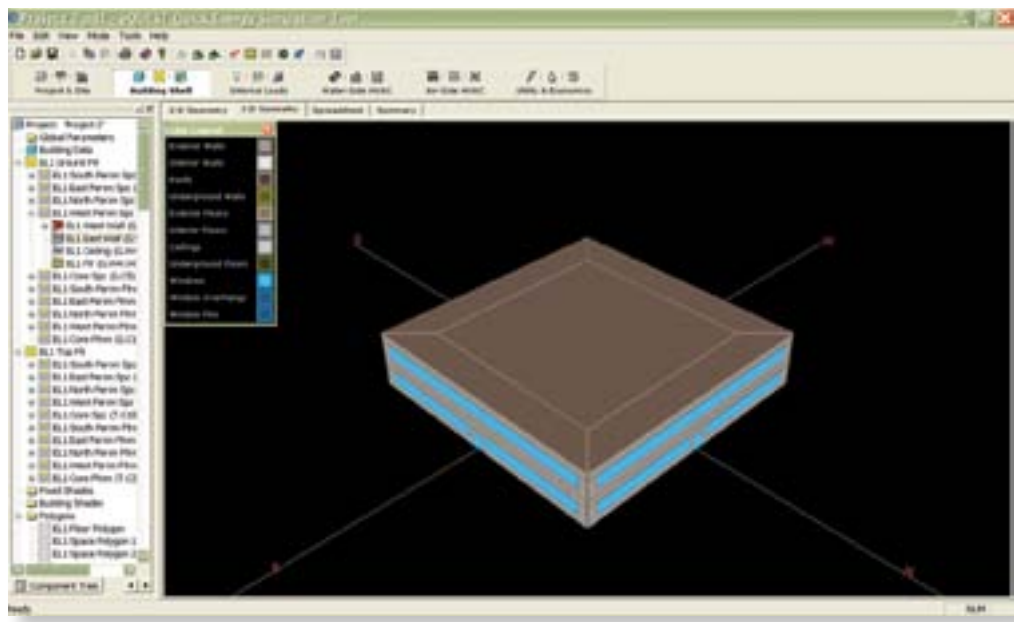


Photo credit: ©Morley Von Sternberg



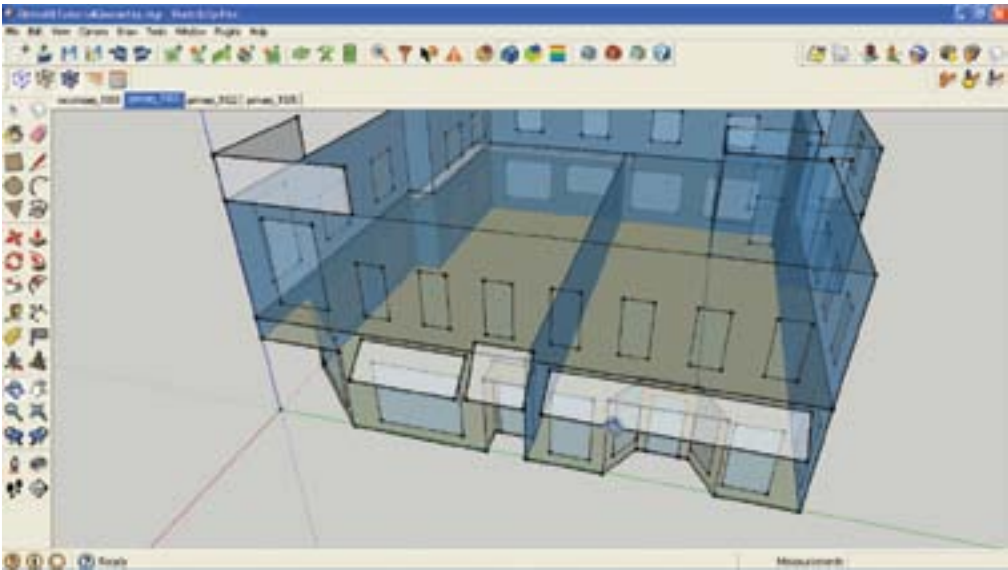
+ DESIRABLE CHARACTERISTICS OF ENERGY MODELING TOOLS

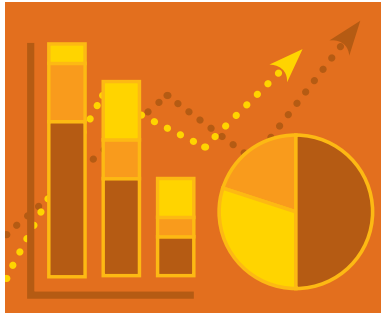
Ideally, a Building Energy Model should be simple to use and include a 3-D import and default system selection, to encourage the architect to use it to inform design decisions early in the design process. Further, it should be robust enough to support sequentially added complexity and granularity and to be used by the energy-modeling consultant for verification that the final building project meets energy performance targets and goals, and then to provide code compliance paperwork as part of its output. The current reality is only part way there. Design Performance Modeling tools are currently separate from the more complicated and time-consuming Building Energy Modeling programs or code compliance software, which add yet another set of software tools.



Data Transfer

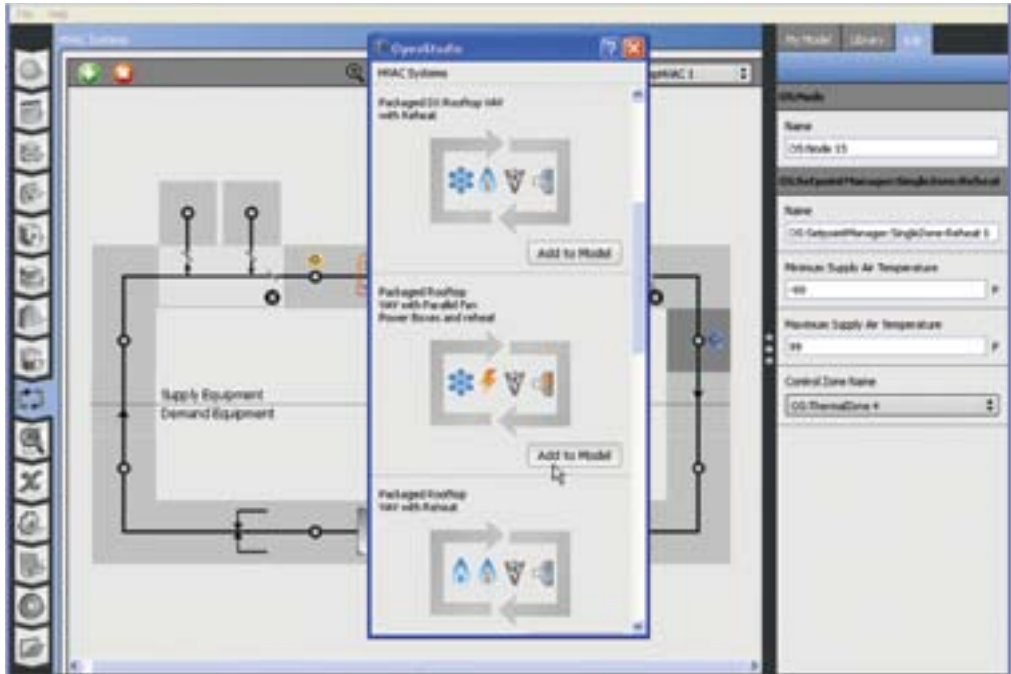
Tools with the most usefulness to the majority of architects should be able to accept (and return) the building configuration from other frequently used 3-D software (such as AutoCAD, Revit, SketchUp, etc.). Such a capacity is effectively non-existent in most modeling tools at this time; it is, however, under development by a number of vendors. The ability to input data once and use it for multiple purposes is critical to encouraging early and frequent use of energy modeling throughout the design process.





Building System Defaults

Many tools have system selection and schedule defaults to simplify the choice of these components for early design phases, when these systems have not yet been fully developed. These defaults should facilitate the use of the product in early design stage decision-making, in addition to the final documentation of a project’s compliance to energy code requirements.

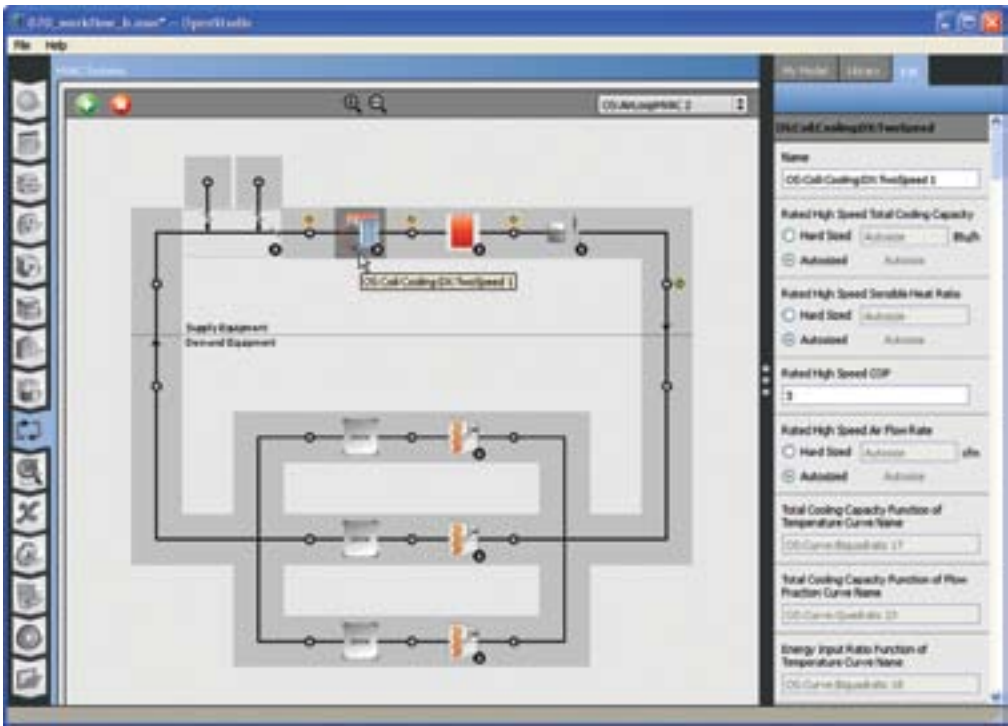


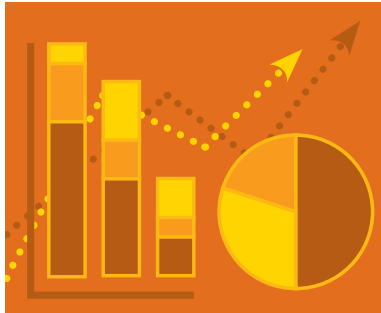
Robust Engine

The simulation program’s calculation engine should be robust enough to provide building performance, energy use, and cost results for most traditional systems and components, as well as for low-energy systems and components, such as radiant ceilings, under floor air, thermal mass, and passive cooling, without complicated and questionable “work-arounds.”

Comprehensive Resource Analysis

Ideally, an energy modeling tool would link to tools that model other resource flows, including water, materials, daylight, waste, and comfort. Such comprehensive resource modeling tools are currently non-existent; tools are, however, available to model some of the various resource flows typically associated with building design and operation.





Clear Graphic Output

The modeling tool should represent performance results in an easily understandable graphic format. It should include the ability to illustrate a comparison between *modeled* pEUI and *targeted* pEUI—the concept of “designing to an energy budget” being a highly effective means both to implement an energy efficient design and to communicate the value of this process to the client.

Real-World Accuracy

The tool should represent real-world building performance and energy use data, if system performance and operation schedule assumptions align with the actual operation of the constructed building project. Current tools do not achieve such accuracy, but if we are to move to “outcome-based design,” which is the direction of the industry, future tools will have to become far more accurate.

The modeling tool should also be capable of drafting a simple code compliance report of the final project, easy for the design-team and code official to understand, check and sign-off on.

Sample output from COMCHECK; the current industry standard code compliance report for *prescriptive* energy compliance, currently used on most projects.





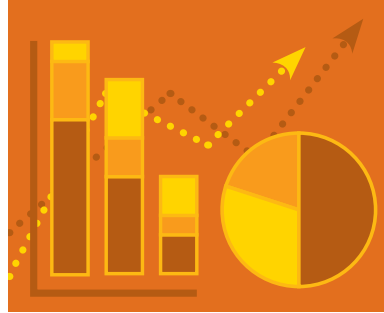
+ THE COMPLIANCE PROCESS

Currently, the most prevalent uses of Building Energy Modeling (BEM) are for code compliance or sustainable-design rating system compliance (e.g., LEED). The process typically entails a minimum of three passes through a pair of models developed and refined in parallel. These are 1) a simulation of the proposed building, with all systems and materials being considered for final construction, and 2) a baseline simulation, which is a model of the same geometry/massing/form as the proposed building, but with minimally code compliant building envelope, lighting, power, and HVAC systems for the particular building type and location/orientation. The comparison of these two models demonstrates that the proposed building should meet or exceed the minimum requirements embedded in the baseline model.

In current practice, the two models are developed toward the end of the Design Development (DD) phase or the beginning of the Construction Documents (CD) phase. These initial building models are first created, then de-bugged, by comparing the model input assumptions and results. Once de-bugged, the two models are run and analyzed, to compare the results against one another and generate the energy-use improvement output needed for compliance or rating certification. Results from this step are sometimes used to validate design decisions made during DD, particularly system choices.

Toward the very end of the CD phase, the proposed and baseline models are updated with any design modifications and additional details, including materials make-up and system components and their controls and schedule information. For example, the model's early assumptions of lighting power density (LPD) based on a

Sample Energy Pro output document demonstrates energy modeling for code compliance. [See Additional Resources for excerpt.](#)



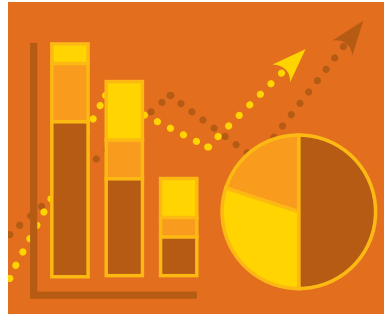
percentage reduction in watts/ft² can be replaced with more refined LPD data determined by doing a space-by-space calculation based on actual lighting layout. The models are then run again and the results compared to one another to generate the final design phase energy-use improvement results. Throughout the construction phase, the general contractor needs to assist with updating both the proposed and baseline models with the actual material construction and system component performance data supplied by the manufacturers. The models are then run again to generate the final energy-use improvement results and subsequently any code compliance or rating certification documents.



Front-end Design Performance Modeling (DPM)

Design teams should always evaluate whether and when a time-consuming, detailed Building Energy Model is the right application. In some instances—a small or less-complex project, for example—a simpler, rule-of-thumb or back-of-the-envelope approach may be more appropriate, more cost effective, and completely sufficient. It should be noted, however, that modeling “bundles” of energy efficiency strategies has proven old rules of thumb to be ineffective at accounting for many inherent synergies. Practitioners, especially designers, would be better served by utilizing simple Design Performance Models in the early stages of design, to analyze building siting, massing, orientation, and fenestration, for example. It may make more sense to explore early design details in partial models—such as a classroom module that repeats, rather than the whole building—to understand the impact by extrapolation, or to use agile, front-end, Design Performance Modeling to help shape early design decisions. See Section 5 for descriptions of many of the currently available DPM tools.

Photo credit: ©The Kubala Washatko Architects Inc./Zane Williams



+ QUESTIONS THE ARCHITECT SHOULD ASK ABOUT THE MODELING TOOL

Ease of use

- + Does this tool work well throughout the different phases of design (adding sequential levels of detail as the design proceeds)?
- + What systems or components will require “work-arounds” to use this tool?
- + Are low-energy systems, such as radiant ceilings, underfloor air, thermal mass, and passive cooling supported directly in this tool?

Time and cost

- + What is the estimate of time expended and cost to use this tool at the various phases?
- + Will it be more cost-effective to use this tool only for final compliance and to use other tools during the design process?
- + What is the estimate of time expended and cost to use a multiple-tool process?

Interoperability

- + Can the program easily import a 3-D architectural model?
- + If so, what programs does it support easily (e.g., SketchUp, Autocad, Revit)?
- + When importing from a 3-D architectural model, how much cleanup time is needed for the calculation engine to work appropriately? In terms of time and cost, how does this process compare to building the model from scratch?
- + Is the BEM tool both forward and backward interoperable with 3-D or BIM—i.e., if the 3D model is modified in the BEM program, can it be imported back into the 3D architectural modeling program with the changes?

- + Are there opportunities to use the model and results in other lifecycle or carbon analysis modeling for the project? Does it link seamlessly with lifecycle and carbon analysis tools?

Input

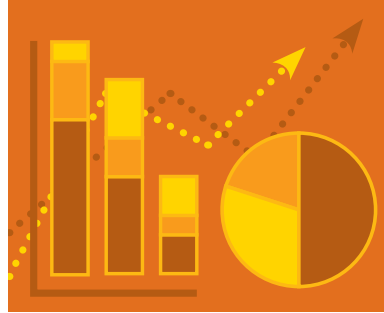
- + Are there default values for systems, system components, and assumptions that can be used during the early design stages, before we know all the system details? Are these appropriate defaults for these systems?
- + Are there “work-arounds” for this energy model’s defaults?
- + What are the assumptions this tool needs defined to generate a Building Energy Model?

Output

- + What type of output does this tool generate (graphs, charts, comparative analysis, just numbers)?
- + Will this tool generate the requisite code compliance paperwork, or is yet another program needed for this?
- + Will this tool generate easy-to-understand charts and graphs of different performance information, or do you need to include additional time to generate this information from subsequent spreadsheet manipulation?
- + What type of performance information does this tool generate, besides overall energy use—e.g., daylight/glare performance or thermal comfort performance, etc.?

Accuracy

- + How accurate are the results?



+ IMPORTANT AREAS TO INVESTIGATE DURING THE ENERGY MODELING PROCESS

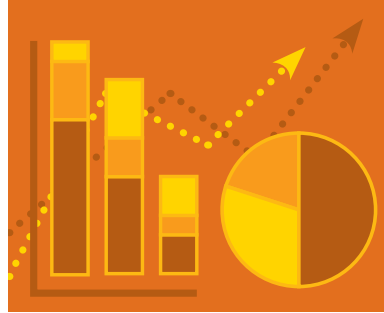
DURING DESIGN & CONSTRUCTION

Project Brief

- + Who will be performing the energy modeling for this project (architect, consultant, mechanical engineer, etc.)?
- + What is the scope of the modeling (only for code compliance, include early design modeling comparisons, include a post-occupancy calibrated model, etc.)?
- + Has the individual modeled comparable projects in terms of building complexity and system types?
- + Is the modeler familiar with the required code compliance or rating system requirements for this project?
- + What is a reasonable Energy Use Intensity (EUI) value for this project type?
- + What should the EUI reduction goal be for this project?
- + What percent reduction is the EUI goal from the project's relevant energy code or standard (ASHRAE 90.1, California Title 24, IECC, IgCC, etc.)?
- + What percent reduction is the EUI goal from the AIA 2030 Commitment regional benchmark EUI?
- + What are the opportunities for daylighting and natural ventilation?

Pre-design / Concept

- + What are the major building energy end uses, such as heating, cooling, lighting, fans and pumps, and plug loads?
- + For each of the energy end uses, what design strategies could be employed toward energy reductions that meet the EUI goal?
- + What is the relative effect of orientation and massing options on these end uses?
- + How can the envelope design contribute to meeting the project's EUI goal?
- + What is the optimal floor plan aspect ratio for the project to meet the EUI goal?
- + What is a reasonable expectation of occupant use patterns?
- + Are there any program adjacencies or arrangements that could contribute to energy reductions or increases?



Schematic Design

- + What is the breakdown of energy consumption by fuel type?
- + What is the source of each fuel type and how does it affect the greenhouse gas footprint for the project?
- + For the major energy end uses, how do the building components, such as envelope, roof and wall, conduction, window solar heat gain and/or loss, lighting, occupants, plug loads, ventilation, or infiltration contribute to the energy consumption?
- + What design strategies could be employed to optimize these building components?
- + From a lifecycle energy consumption perspective, how might the construction budget be employed for greatest impact?
- + Could the model be used as a framework for building commissioning, operations, and measurement and verification?

Design Development

- + Given the project location, climate, occupancy, and building type, what are the most effective environmental control strategies that maintain occupant comfort for this project?
- + If a building component were fully optimized, what is the impact as compared to the baseline and how does it relate to zEPI goals?
- + Do modeling inputs, such as location, set-points, envelope U-values, percent glazing, infiltration, lighting power density, plug loads, occupant loads, lighting schedules, plug load schedules, occupancy schedules, or systems types accurately reflect the design?
- + How will energy be managed and accounted for during building operations (including peak-load times), and does the building metering strategy support this?

Contract Documents

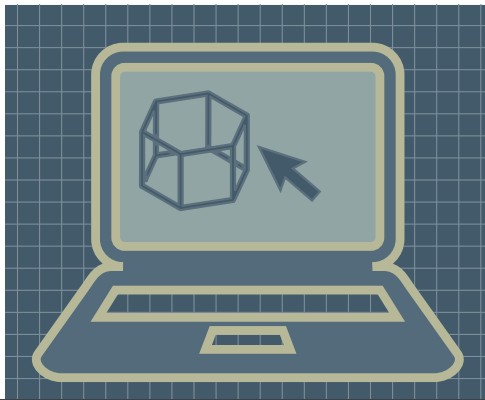
- + How does the detailed energy model compare to the EUI goal established at the start of the project?
- + Are the assembly and system performance requirements from the energy modeling inputs reflected in the project specifications?
- + Is there a means for builder substitutions to be evaluated based on performance impact?

Construction

- + Have any construction substitutions or changes been made that affect the energy performance of the building?

Post Occupancy

- + How does the annual energy consumption compare to the model results?



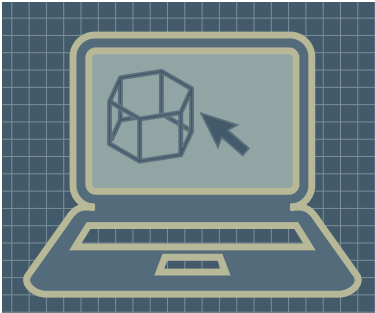
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SECTION 5_ CURRENT TOOLS



Photo credit: ©Johnsen Schmaling Architects





“It’s not rocket science. It’s building science.”
—Bill Worthen, AIA, Vision Statement from the 2011 Rocky Mountain Institute Building Energy Modeling Innovation Summit

Section 5_
CURRENT TOOLS

+ THE BUILDING ENERGY MODELING INDUSTRY

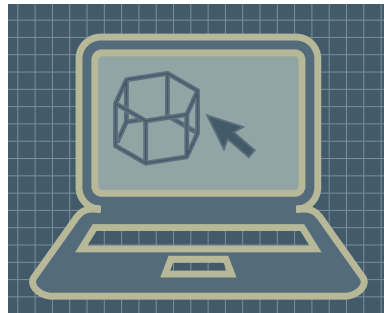
The past decade has seen remarkable growth in the Building Energy Modeling industry, primarily driven by more stringent building energy efficiency standards and a growth in voluntary building energy certification programs such as LEED. Following are descriptions of the most widely used Building Energy Modeling (BEM) tools in the United States, both calculation engines and interfaces, at the time of writing of this guide. While extensive, this list makes no claim to being comprehensive.

Please note that these tools are currently and typically used later in the design process, once engineering system selection has occurred, and for code or third party rating/certification compliance. The energy modeling simulation and program development industry is gaining widespread adoption at an increasingly rapid rate; thus, new whole building modeling tools, as well as associated Design Performance Modeling, tools are being developed and released regularly.

It may be worth noting that the holy grail of energy modeling software has yet to be found. Architects and software developers are still on this quest, and all tools have pros and cons. What is important is to pick one that seems appropriate for your practice and that you are comfortable with and to simply start using it.

Who Develops Simulation Tools

ENGINE	INTERFACE	PUBLICLY FUNDED?	FREE?
DOE-2	eQUEST	yes	yes
	Visual DOE	yes	yes
	EnergyPro		
	Autodesk GBS		
EnergyPlus	Bentley Hevacomp		
	Design Builder		
	OpenStudio	yes	yes
	Simergy	yes	yes
Energy 10		yes	yes
TRNSYS	TRNSYS	yes	yes
HAP	HAP		
IES-VE	IES-VE		
TRACE 700	TRACE 700		



+ BUILDING ENERGY SOFTWARE TOOLS DIRECTORY

Many of the brief summaries of building energy software on the following pages are based on information currently posted on the product's website and/or from content currently posted on the EERE tools directory: http://apps1.eere.energy.gov/buildings/tools_directory/. When available, screenshots of sample input and output screens are provided for each tool.

The tools and products listed in this directory have been included for informational purposes only. The suitability of a given tool or product will vary depending on your specific needs and circumstances. The listing of any company or product in this directory should not be construed as an endorsement by the AIA, and the AIA is not responsible for, and expressly disclaims all liability for, damages of any kind arising out of the use, reference to, reliance on, or performance of such listing or products. The AIA does not approve, sponsor, or endorse any product or material of construction or any method or manner of handling, using, distributing, or dealing in any material or product.

HIGHLIGHTS OF SOME CURRENT BUILDING ENERGY MODELING TOOLS

DOE-2 (engine)

DOE-2 is a Building Energy Modeling program developed by Lawrence Berkeley National Laboratory, funded by the Department of Energy. It calculates energy performance and life-cycle costs of operation of whole-building projects. Two versions exist: DOE-2.1E and DOE-2.2.

ASSOC. INTERFACES: VisualDOE and EnergyPro for DOE-2.1E; eQUEST for DOE-2.2.

TARGET USERS: Engineers and energy modelers.

PROS: Capable of providing detailed, hourly, whole-building energy analysis of multiple zones in buildings of complex design; widely recognized as the industry standard.

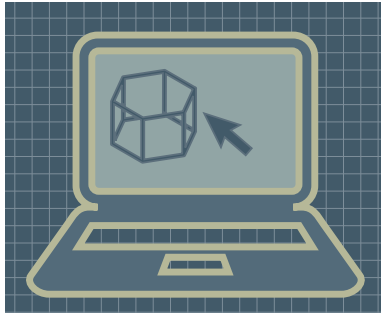
Well-validated simulation of buildings with HVAC systems that are fully mixed, such as variable air volume systems.

Associated with EnergyPro and eQUEST, some of the most popular and widely used front-end interfaces for whole-building and code-compliance simulation.

CONS: While a robust calculation engine at the time and still adequate for traditional projects, the DOE-2 engine is now updated only in a very limited fashion. DOE development financing has been shifted to support development of the EnergyPlus (E+) engine, which many users feel can deliver more detailed simulation results and model some of the newer system technologies better.

Requires a high level of user knowledge.

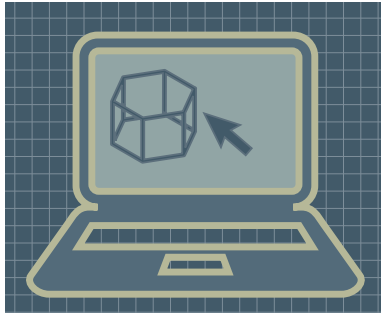
WEBSITE: <http://doe2.com/DOE2/index.html>



Currently Available Building Energy Modeling Software Tools

MODELING TOOL	CALCULATION ENGINE	GRAPHIC INTERFACE FOR FRONT-END INPUT	GRAPHIC RESULTS PROVIDED	APPROPRIATE FOR EARLY DESIGN PHASE	APPROVED FOR CODE COMPLIANCE MODELING	FREWARE
COMFEN (RESFEN – residential)	EnergyPlus	Yes	Yes	Yes	No	Yes
DesignBuilder	EnergyPlus	Yes	Limited	Yes	Yes	No
Ecotect	CIBSE Admittance Method	Yes	Yes	Yes	No	No
EMIT1.2	None (spread-sheet)	No	Not specifically, (but s/s capability)	Yes	No	Yes
EnergyPro	DOE-2.1E	No	No(auto-generates compliance report)	No	Yes (easiest to use)	No
eQUEST®	DOE-2.2	Yes	No	Must be far enough along to input HVAC	Yes (most popular)	Yes
Green Building Studio / Vasari	DOE-2.2	Yes	Yes	Yes	No	No
Hourly Analysis Program (HAP)	Transfer Function Method	Limited	No	No	Yes	No
IES Virtual Environment	Apache	Yes	Yes	Gaia + Toolkit Yes Pro requires input of HVAC	Yes	No
OpenStudio	EnergyPlus	Yes (similar to SketchUp)	Yes	Must be far enough along to input HVAC	Yes	Yes
Sefaira Concept	Sefaira	Yes	Yes	Yes	No	No
Simergy	EnergyPlus	Yes	Limited	Not yet	Yes	Yes
TAS	TAS	Yes	Yes	Yes	Yes	No
TRACE® 700	TRACE	No	Limited	Must be far enough along to input HVAC	Yes	No
TRNSYS	TRNSYS	Yes	No	No	No	No





EnergyPro

EnergyPro is an interface for the DOE-2.1E engine that can be used to perform several different whole-building energy modeling calculations, most widely used for California code compliance: California Title 24 hourly energy analysis of low-rise residential buildings with an approved residential simulation (ResSim*); or California Title 24 energy analysis of nonresidential buildings, hotels/motels and high-rise residential buildings with either a prescriptive method approach (NR Prescriptive*), or a performance simulation method (Win/DOE*).

Note: (title) indicates the name of the specific package that should be used for the associated project type or compliance path.*

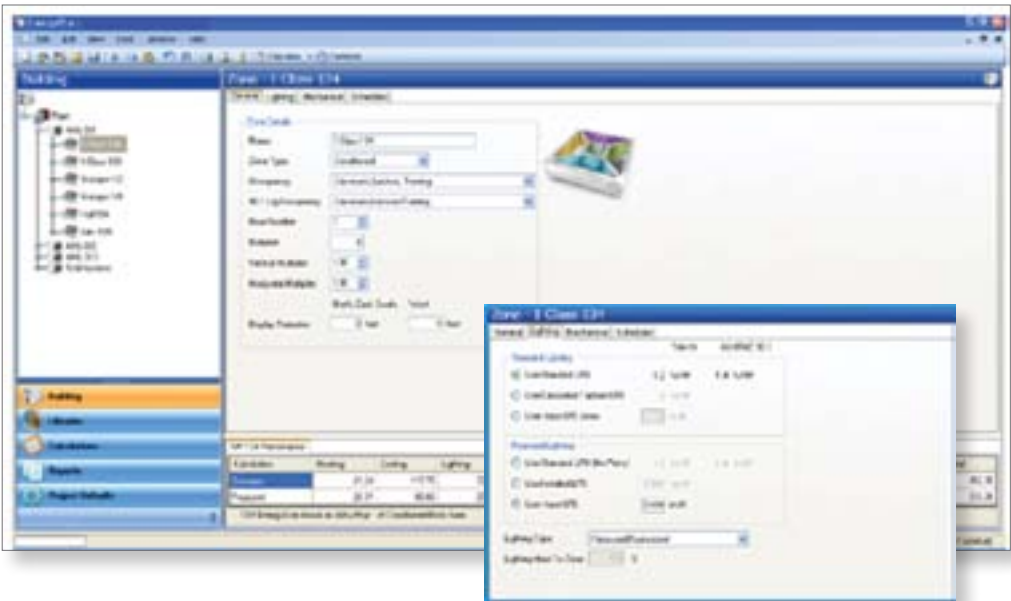
TARGET USERS: Primarily engineers and energy modelers.

PROS: Input and output forms are relatively straightforward.
Walks the user through generating easy-to-understand reports and forms for the code officials.

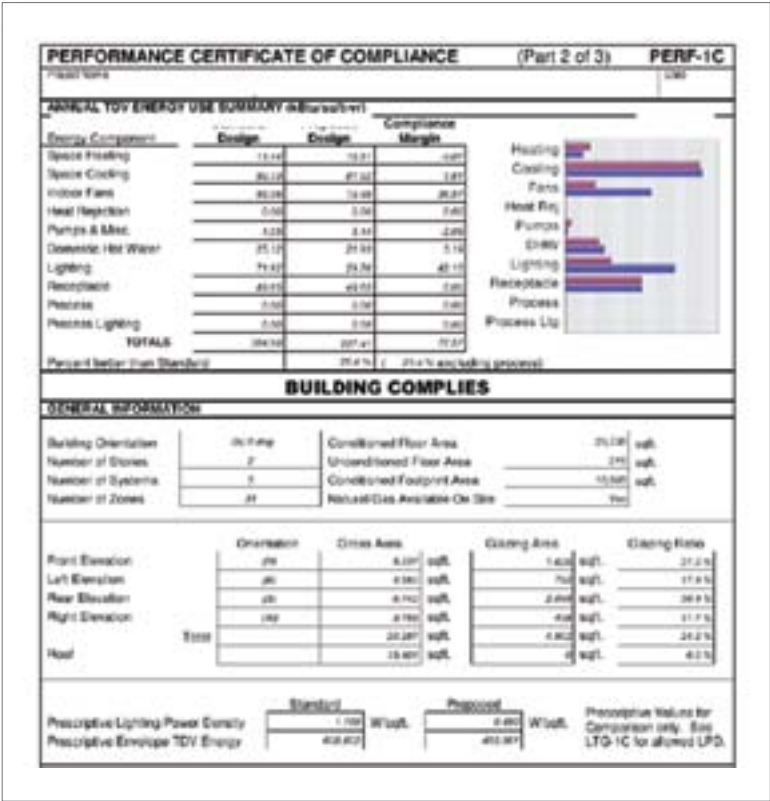
CONS: Not free.
Does not provide a 3D building model for frame of reference understanding of the final code compliance reports.

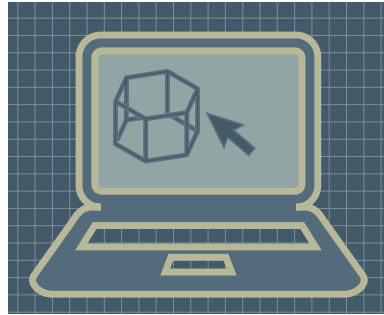
WEBSITE: http://www.energysoft.com/main/page_energypro_ep_information.html

EnergyPro sample input screen



EnergyPro sample output screen





VisualDOE™

VisualDOE is a Windows interface for the DOE-2.1E energy simulation engine, through which users can construct a model of the building's geometry using standard block shapes, a built-in drawing tool, or by importing DXF files. It is arguably friendlier and easier to use than eQUEST. Building systems are defined through a point-and-click interface. A library of constructions, fenestrations, systems, and operating schedules is included, from which the user can choose, although the user can add customized elements as well.

TARGET USERS: Engineers and energy modelers.

PROS: Easy to use.

As the first graphic interface for the DOE-2 engine (DOE-2.1E) [for DOE-2? -TC], VisualDOE still has a number of users, so it is still maintained and supported.

CONS: Not free.

Lacks an enhanced graphic input capability as compared to the newer generation of similar tools.

90% of DOE-2 users have now transitioned to eQUEST and its later DOE2.2 engine and associated greater system modeling capability.

WEBSITE: [file://localhost/Website/http://www.archenergy.com/products/visualdoe/](http://localhost/Website/http://www.archenergy.com/products/visualdoe/)

Green Building Studio (GBS)

GBS links Autodesk architectural building information models (BIM) and certain 3D CAD building designs with energy, water, and carbon analysis, enabling architects to quickly receive feedback about 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 (see below).

TARGET USERS: Architects.

PROS AND CONS: Same same as those of Project Vasari (below).

WEBSITE: <http://usa.autodesk.com/green-building-studio/>

Project Vasari

Project Vasari is the newest generation of Autodesk's GBS (above), which combines with Ecotect to provide Building Energy Modeling specifically geared to early design.

TARGET USERS: Architects.

PROS: The Cloud-based service provides simple, automatically generated models and large-capacity computing power to manipulate a variety of parameters and get results quickly.

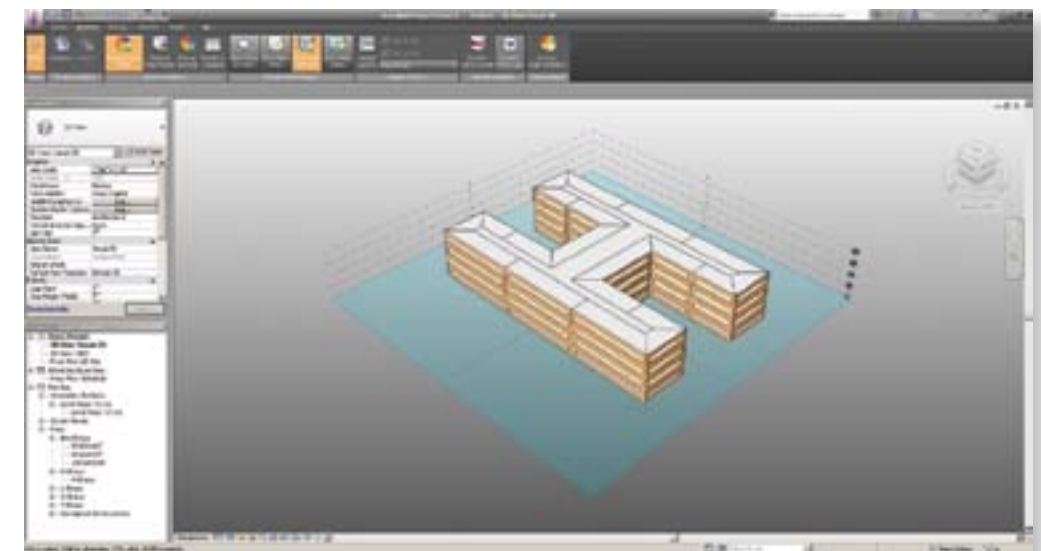
CONS: Not free.

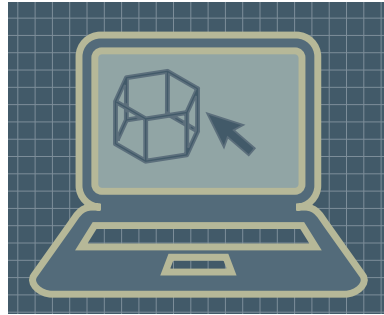
The "web-service automatically generated detail" reportedly doesn't always fully satisfy the architect's or energy modeler's desire for detailed manipulation of building components past the schematic design phase.

As a Cloud-based service, it is a bit of a black box, making it challenging to track where energy-saving results are coming from and what building or system components are influencing those savings.

WEBSITE: <http://labs.autodesk.com/utilities/vasari/>

Vasari sample input screen





eQUEST®

eQUEST is probably the most widely used graphic interface for the DOE-2.2 calculation engine. Its wizards, dynamic defaults, interactive graphics, parametric analysis, and rapid execution make eQUEST able to conduct whole-building performance simulation analysis throughout the entire design process, from the earliest conceptual stages to the final stages of design.

TARGET USERS: Engineers and energy modelers.

PROS: Freeware.

Affords three levels of modeling complexity to address different/developing user experience and expertise: a schematic design wizard with really simple inputs; a design development wizard, which allows significant detail but can still be set up in a few hours; and the fully detailed input mode, which accesses nearly all keywords in the DOE-2.2 software.

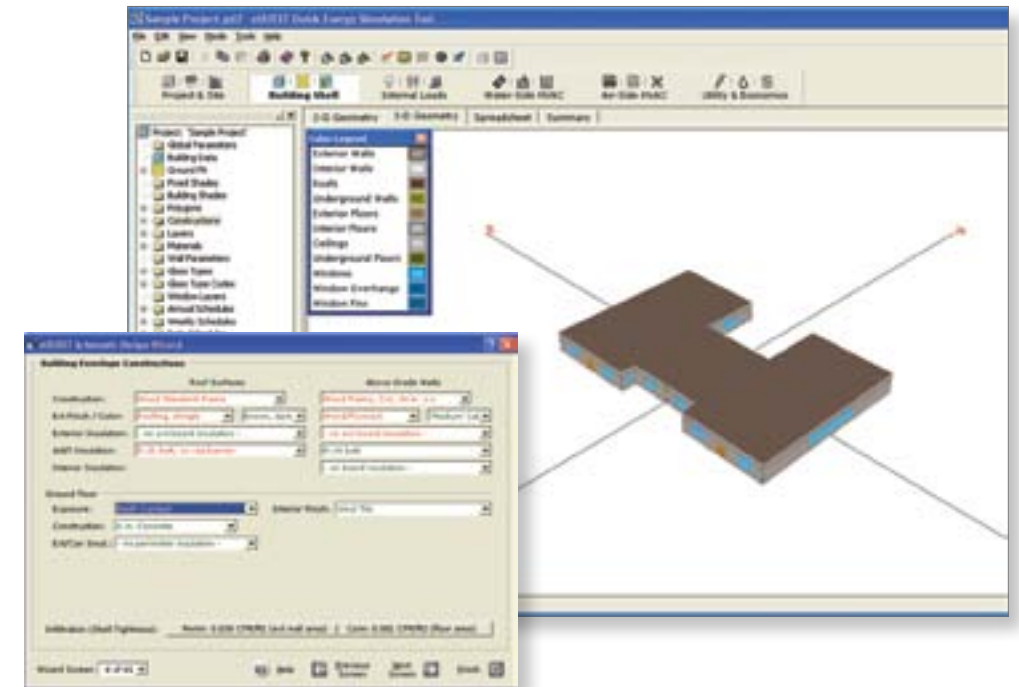
While building geometry can be imported from BIM architectural model, this process typically requires an experienced user to clean up the result before calculation; thus, it is often easier and quicker to re-build the building geometry within the eQUEST interface.

CONS: While simple to use, the geometry creation interface uses simple extruded plans with “windows” that are merely representative of window to wall ratio, rather than including the level of detail an architect would most likely desire.

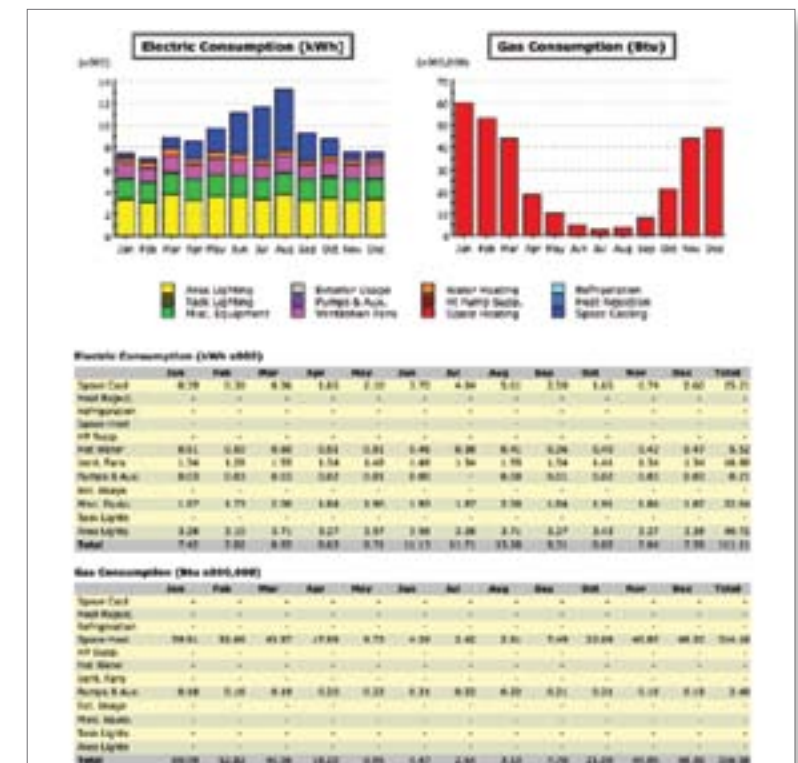
As eQUEST is now freeware, it is no longer as well supported as previously; it is currently so widely used, however, that most of the software related questions can typically be resolved through online public forums.

WEBSITE: <http://doe2.com/equest/index.html>

eQUEST sample input screen



eQUEST sample output screen





EnergyPlus (engine)

EnergyPlus is DOE's flagship Building Energy Modeling tool. Replacing the DOE-2 engine, EnergyPlus provides more accuracy, fewer workarounds, and enables the analysis of more innovative and complex mechanical system and building designs. DOE has been funding on-going improvements to the analysis capabilities of this powerful engine to increase its application for existing buildings and low-energy designs, as well as new-construction, conventional buildings. While, to date, EnergyPlus has been used primarily by researchers, an increasing number of programs are linking and developing interfaces to the EnergyPlus engine to provide users with the capability to analyze natural ventilation, ground source heat pumps, and radiant systems within their overall building designs.

ASSOCIATED INTERFACES: Simergy; OpenStudio, DesignBuilder.

TARGET USERS: Engineers and energy modelers.

PROS: Freeware.

Currently well-funded by the US Department of Energy, with the intent that it deliver the latest thinking in energy modeling, including more detailed simulation results and the ability to better model some of the newer system technologies, such as radiant and displacement mechanical cooling systems.

CONS: EnergyPlus is significantly slower than other engines; this is the price of increased physical modeling detail and is a barrier to iterative and interactive modeling. Making EnergyPlus faster is one of DOE's priorities.

WEBSITE: <http://apps1.eere.energy.gov/buildings/energyplus/>

Hourly Analysis Program (HAP)

Carrier's Hourly Analysis Program (HAP) is a versatile system design tool and an energy simulation tool in one package, with a Windows-based graphical user interface. 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. Calculation rigor and integrity are provided by the ASHRAE Transfer Function Method for calculating building heat flow.

TARGET USERS: Engineers.

PROS: Very good for engineering system sizing.

CONS: Not free.

Architectural users report HAP as being less nimble for the type of performance and early-design energy modeling architects want most.

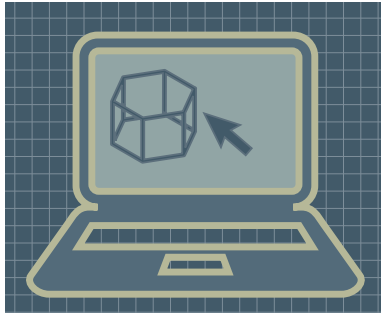
WEBSITE: http://www.commercial.carrier.com/commercial/hvac/general/0,,CLI1_DIV12_ETI496_MID4355,00.html

TRaNsient SYstem Simulation Program (TRNSYS)

TRNSYS is a commercially-available, i.e., not free, Building Energy Modeling 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 HVAC analysis and sizing, multizone airflow analyses, electric power simulation, solar design, building thermal performance, analysis of control schemes, etc.

TARGET USERS: Transys is essentially a programming language and is used primarily in university and research work but also in a few specialty engineering consulting firms.

WEBSITE: <http://www.trnsys.com/>



DesignBuilder™

DesignBuilder provides a user-friendly modeling environment, accommodating 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.

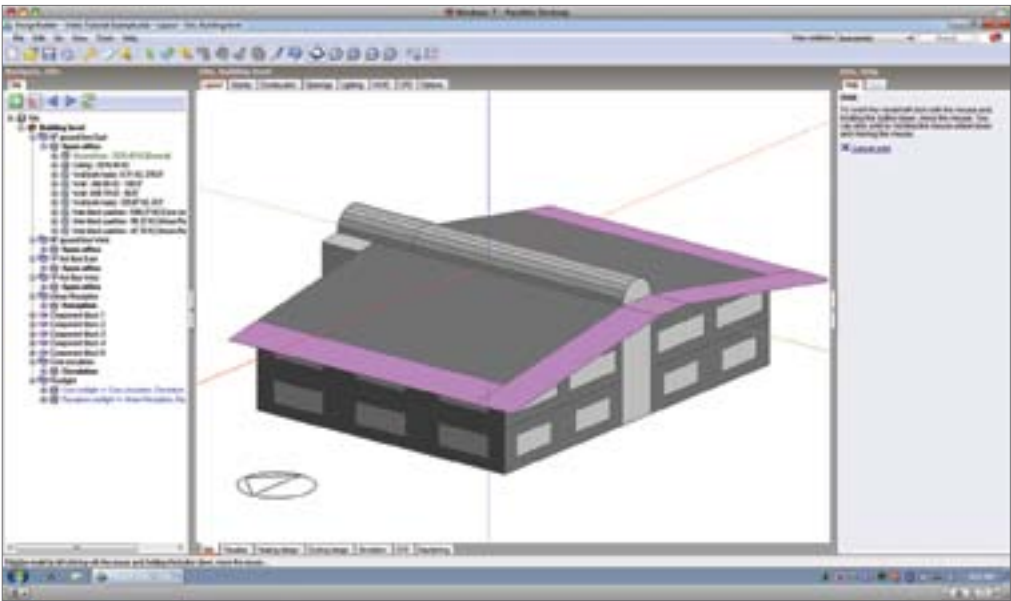
TARGET USERS: Engineers and energy-modelers but intuitive enough for architects, as well.

PROS: A simple interface, at the moment the most intuitive interface out there for EnergyPlus.

CONS: Not free.
There is no import function, so models must be built within the DesignBuilder interface, which requires the user to build models the way engineers build models, as extruded floor plans.
While it provides good intuitive access to some of the more traditional HVAC systems, it has limited ability to model complex systems.

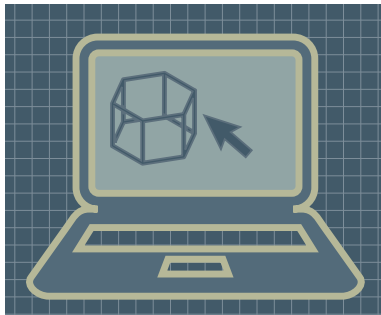
WEBSITE: <http://www.designbuilderusa.com/>

DesignBuilder sample input screen



DesignBuilder sample output screen





OpenStudio

Developed by the National Renewable Energy Laboratory, OpenStudio is an interface that provides users easy access to a number of building analysis engines. OpenStudio's reputation is in providing easier access to the energy analysis engine EnergyPlus, and increasingly, interfaces with other performance analyses engines such as Radiance for lighting, and CONTAM for airflow and air quality simulation. OpenStudio includes a SketchUp-type modeling capability that allows users to 'build'/specify geometry, space types, and thermal and lighting zones in a 3D modeling construct, similar to architectural 3D modeling programs (rather than the extruded floor-plan constructs of most energy modeling graphic interfaces.) It gives users access to editing building schedules, constructions, internal loads, and mechanical systems, with an intuitive, drag-and-drop interface and also includes basic visualization modules for viewing simulation results in more intuitive formats.

TARGET USERS: Architects as well as engineers and energy-modelers.

PROS: Freeware and open-source

Includes easy-to-apply templates that contain construction and building activity data for a number of building types, vintages, and climate zones

Has a rapidly evolving set of capabilities including support for LEED reporting (coming soon), and support for performance-path code compliance (coming a little later)

Is fully entrenched in DOE's development and deployment roadmap for energy modeling, and has a growing number of partners and users.

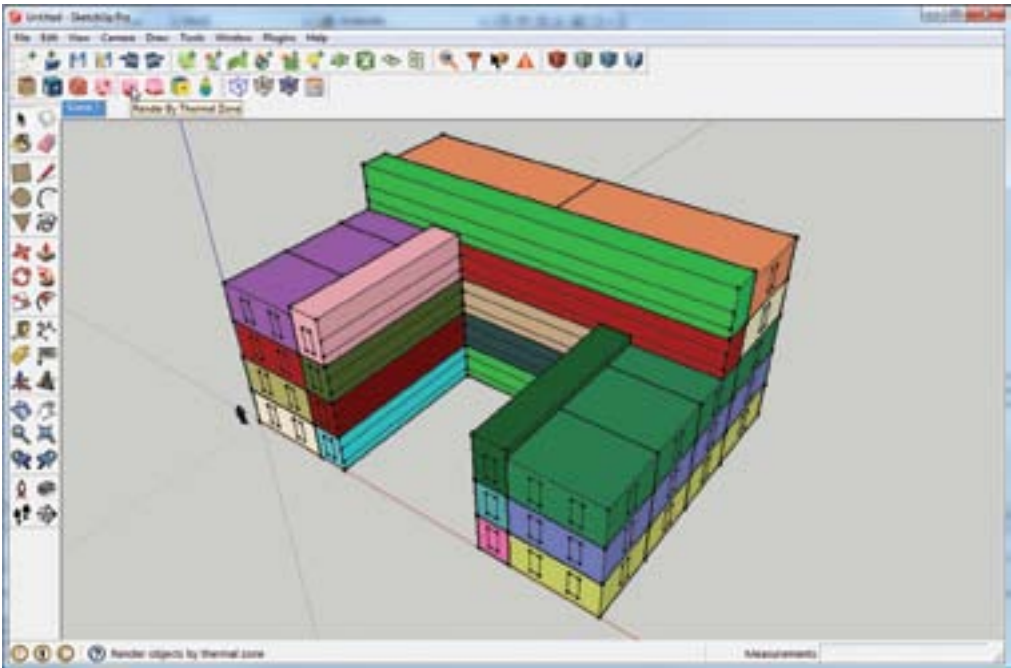
CONS: Is not a commercial product and so can be "rough around the edges" in places and support provided on a best effort basis

Currently provides graphic access to only the most common EnergyPlus features (more advanced features must be accessed via the EnergyPlus input file format)

Uses the 'SketchUp plug-in' to provide access to OpenStudio geometry, but cannot read and convert native SketchUp files nor export back into SketchUp

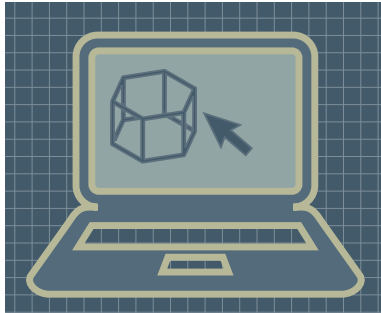
WEBSITE: <http://openstudio.nrel.gov/>

OpenStudio sample input screen



OpenStudio sample output screen





Simergy

Simergy is the newly developed graphic interface for EnergyPlus, affording more user-types the ability to analyze design performance at different stages in the design process. In addition to analyzing alternatives related to building form, glazing percentage/type, exterior shading, and aspects of daylighting at early stages of design, Simergy also allows high performance HVAC systems to be effectively included. A comprehensive set of templates and libraries for ASHRAE 90.1, LEED, California Title 24, and low energy HVAC systems allow the user to incorporate innovative HVAC systems, such as chilled beams with displacement ventilation, into the building energy model without questionable work-arounds.

TARGET USERS: Engineers and energy modelers.

PROS: Freeware.

The advanced user can also utilize the Results Visualization capabilities to view any of the 4,000+ EnergyPlus output variables in isolation or in combination.

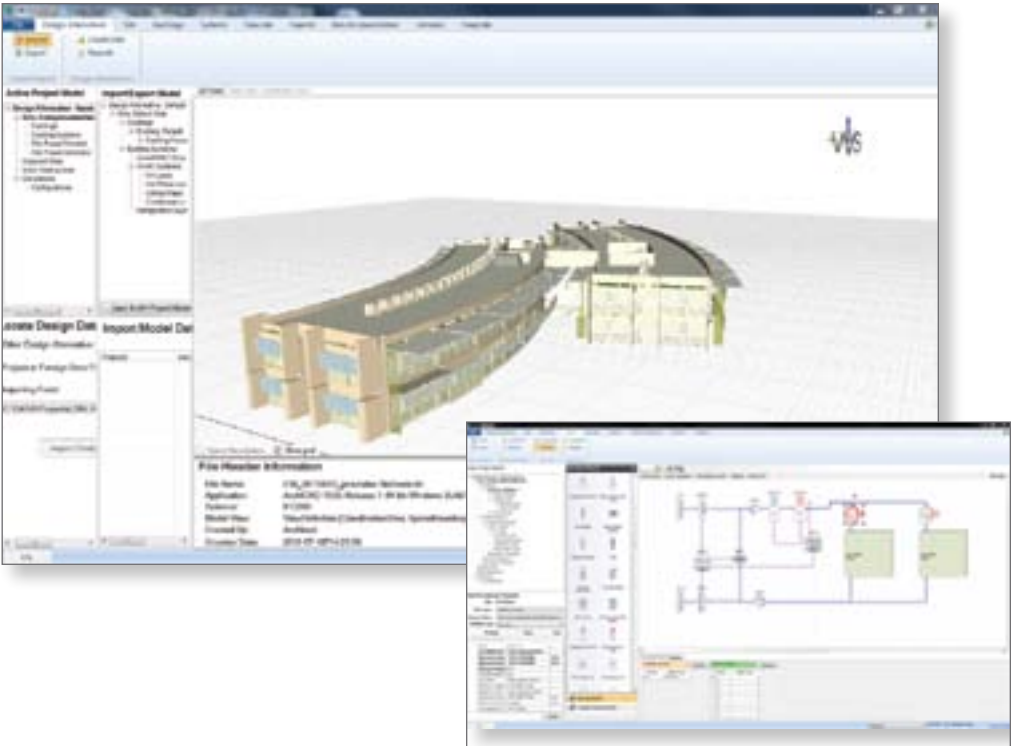
Simergy provides effective and useable translation for architects to import 3D models using Industry Foundation Classes (IFC) or gbXML. Architects can also import 2D CAD drawings (.dxf or .dwg) or create a BEM from scratch using Simergy's simple geometry tools.

CONS: Currently lacks the simplicity, ease, and agility needed for early design performance energy modeling.

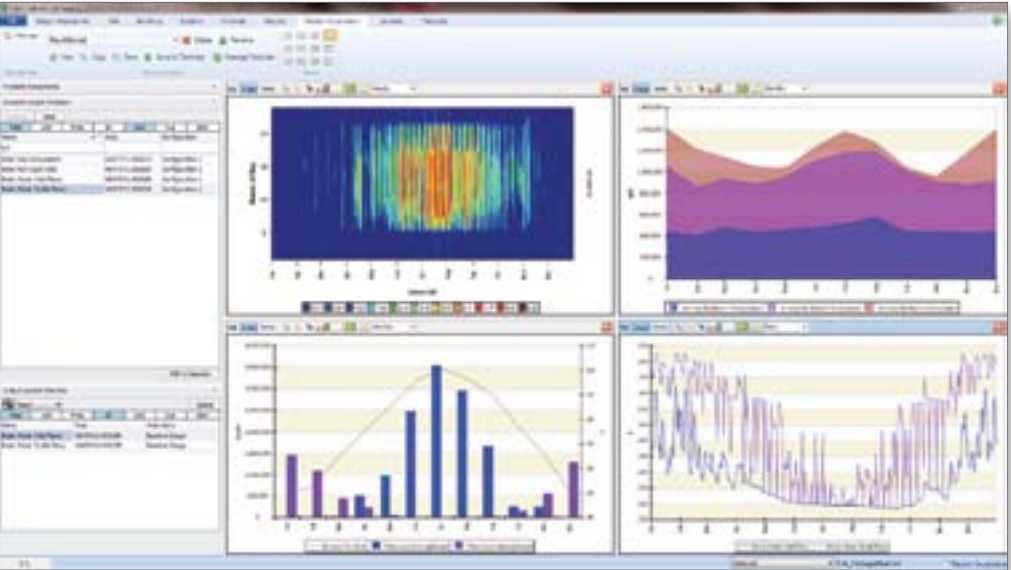
Does not yet support a modeling process aligned with the architect's design process.

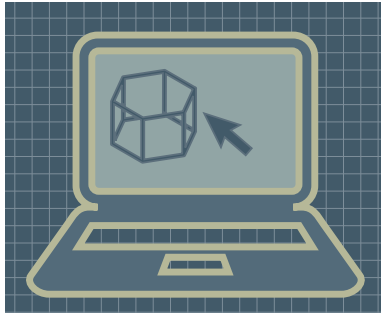
WEBSITE: <http://simulationresearch.lbl.gov/projects/gui>

Simergy sample input screen



Simergy sample output screen





IES® Virtual Environment

IES Virtual Environment is an integrated suite of tools designed to allow building performance analysis to be easily integrated into commercial workflows across the entire design lifecycle. The APACHE engine is the core energy simulation component in all four of the Virtual Environment tiers (backed up by other engines for related performance analysis, such as Radiance for daylighting). 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.

TARGET USERS: While initially created with engineers in mind, IES-VE is working to develop different tiers of toolkits ranging from the ability to plug in a Revit or Sketchup model to a series of internal wizards/navigators to guide a user through the steps of defining a building model internally within IES-VE, to the full-blown, high-detail capacity tier, which no doubt will make it more appealing to a broader range of users.

PROS: The accuracy of the simulation and user support is among the best in the industry. In contrast to OpenStudio, IES-VE's Revit/Sketchup plugins truly allow the user to import 3D models and stay in a Revit/Sketchup environment to set thermal characteristics and run the energy analysis; thus, any model modifications made to improve energy performance are also in the 3D model.

CONS: Not free. IES requires license and maintenance fee and is on the high end of the price comparison for energy modeling software.

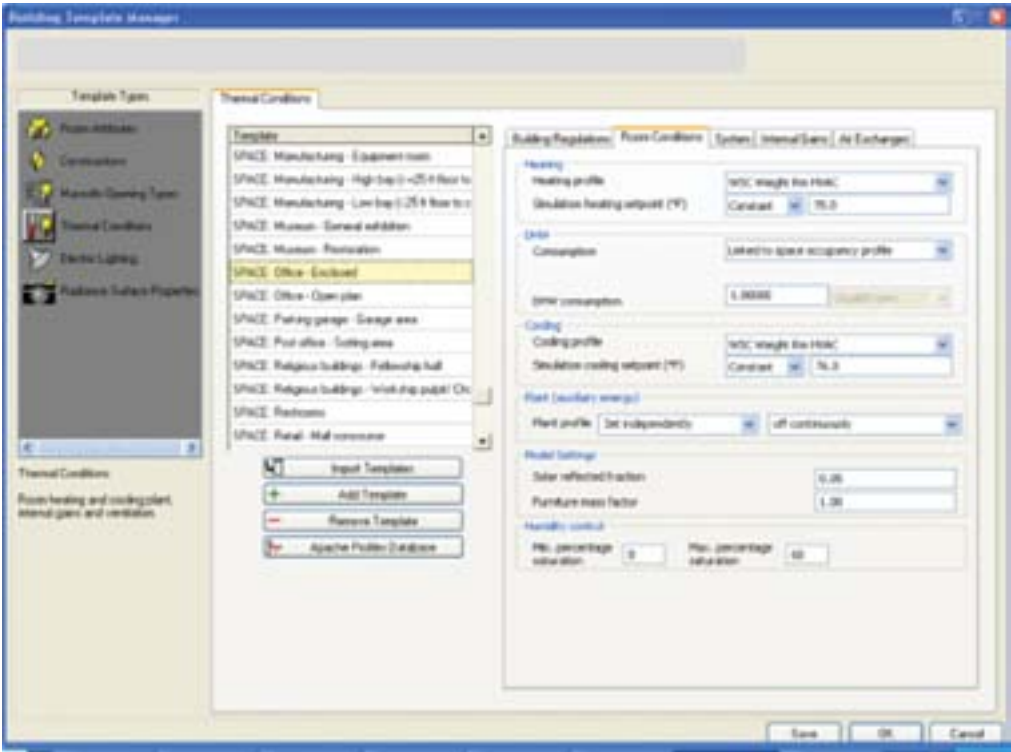
While including some graphic results capability, it does not currently report what is needed most by architects to assist in informed decision-making at the early design stage.

For most users, IES is a bit of a “black box”; one has to be a “power user” to refine details later in the process.

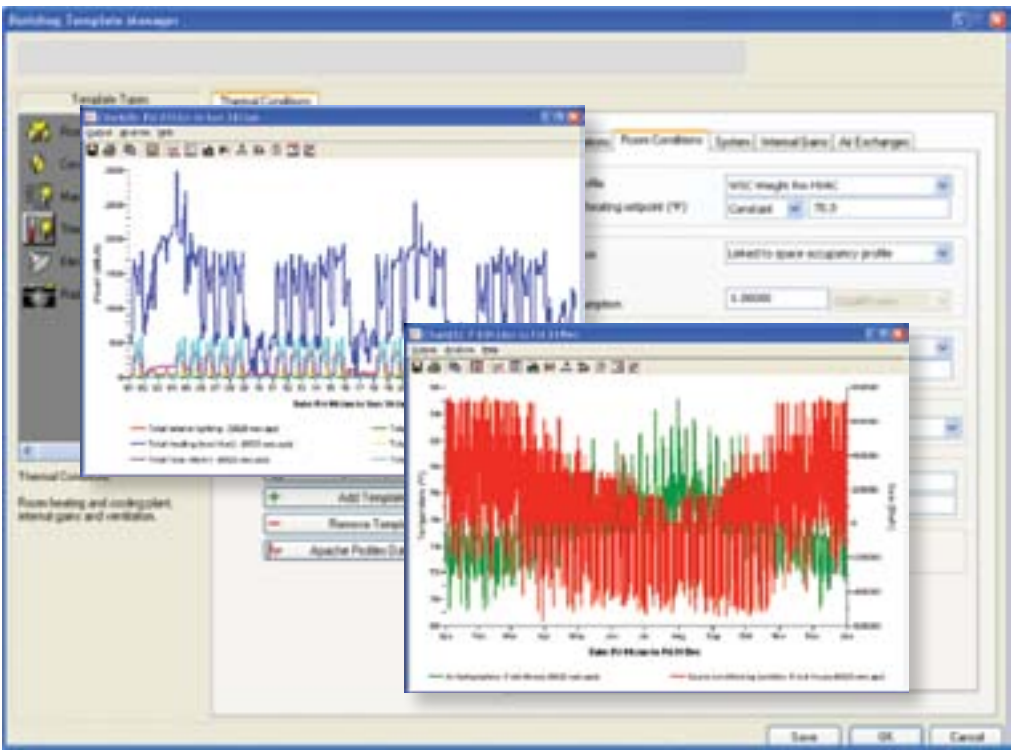
Many of the help manuals and calculation methodologies still reflect IES's initial development for European standards and design practices.

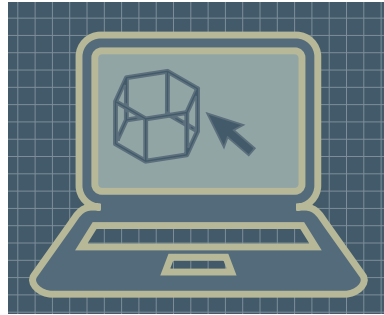
WEBSITE: <http://www.iesve.com/>

IES sample input screen



IES sample output screen





TRACE® 700

Trane Air Conditioning Economics, or TRACE, is a design and analysis tool developed to help professionals optimize the design of a building's heating, ventilating, and air-conditioning system based on energy utilization and life-cycle cost. It is a complete load, system, energy, and economic analysis program that compares the energy and economic impact of building alternatives, such as architectural features, HVAC systems, building utilization, or scheduling and economic options. Users can choose from a large variety of systems, economizers, and plant configurations, including water-source and central or distributed ground-source systems, underfloor air distribution systems, dedicated outdoor-air systems, and optimized control strategies. TRACE 700 includes ASHRAE Standard 90.1 equipment and envelope libraries, gbXML imports, weather files, templates, Building Information Modeling, and more. TRACE 700 complies with Appendix G for Performance Rating Method of ASHRAE Standard 90.1-2007 for LEED analysis, and was the first simulation software approved by the IRS for energy-savings certification.

TARGET USERS: Engineers.

PROS: The industry accepted standard for mechanical system sizing.

Smaller firms in particular may value TRACE 700's flexibility, as it can be used for both system sizing and total building energy use/energy savings calculations for code compliance, rather than using two different programs.

CONS: Not free.

While typically used primarily to calculate peak loads for mechanical system sizing, TRACE 700 also has an overall building energy-modeling capability. However, the user needs to be careful to employ the correct methodology for the intended purpose, as extrapolating from peak values may overestimate annual building energy use for energy-modeling compliance.

Relies primarily on numeric input and does not have a graphic interface.

Less nimble for the type of early-design energy and performance modeling architects want most.

WEBSITE: <http://www.trane.com/COMMERCIAL/DNA/View.aspx?i=1136>

Energy-10 (engine)

Energy-10 is a Design Performance Modeling tool focused on making tradeoffs during early design phases for buildings that are less than 10,000 sf floor area, or buildings that 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 design.

TARGET USERS: Seems to have been developed with architects in mind.

PROS: One of the simplest Building Energy Modeling tools, Energy-10 uses a “two zone box model,” which works great as a quick analysis and comparison tool. Originally designed for buildings less than 10,000 sf, comparisons of simple building shapes much larger than this size has yielded similar results to eQUEST.

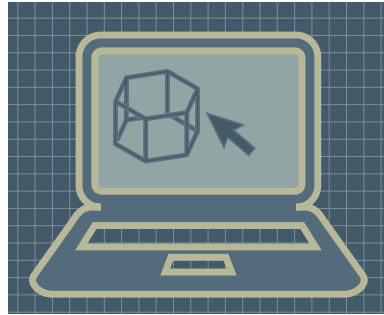
Particularly suited to early-phase design of small projects.

The wall R-value calculator is a great tool in itself, as is the WeatherMaker program, which is useful for showing graphic images of Typical Meteorological Year weather data.

CONS: Not free.

Mechanical systems choices have been designed around small buildings, thus providing only a limited number of options.

WEBSITE: http://www.nrel.gov/analysis/analysis_tools_tech_basic.html



+ DESIGN PERFORMANCE MODELING (DPM) SIMULATION TOOLS

Many of the Building Energy Modeling (BEM) tools outlined above can be used to assess performance and energy efficiency during the early design decision-making process. This approach can facilitate the efficient use of the same software throughout the design process by adding sequential levels of detail commensurate with added design detail. The challenge, however, is in providing the added level of system complexity that whole-building modeling requires, but which is often unavailable at early design stages; most whole-building analysis programs typically require detailed information about mechanical and electrical systems to attain accurate results. Such tools also require significant training. In most instances, it will be best to work with an engineer or modeler who is familiar with the program and the engineering system detail.

There are, however, also a number of Design Performance Modeling (DPM) tools designed expressly for early design decision-making, and development continues as demand increases. While many of these tools are fairly easy to use, they are typically capable of only basic analysis, appropriate to inform early design decisions, but not intended to provide whole-building analysis for code compliance. Additionally, to make them quick and easy to learn and use, most of these software programs have been developed as stand-alone programs that do not integrate seamlessly with existing CAD software packages and platforms.

For all DPM packages below:

Targeted users: Architects and modeling consultants who want to understand early-design performance implications in a simple, quick, but less detailed study.

Pros: Provides simple, quick analysis to help understand particularly early-design performance implications thus assisting in making performance-based design decisions.

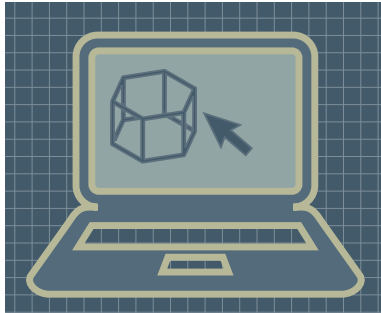
Cons: Software is typically component oriented (rather than ‘whole-building’) thus able to capture only part of potential performance improvements.

The following are among the currently most commonly used Design Performance Modeling tools:

Ecotect

Ecotect is a for-purchase software from Autodesk that readily accepts input from REVIT or Autocad. Its results are reported in intuitively understandable graphic displays. Unfortunately, Ecotect uses a “black-box” analysis engine that is not currently well supported, and imported models are not back-compatible with Revit or Autocad if manipulations have been made in Ecotect.

Website: <http://usa.autodesk.com/ecotect-analysis/>



OpenStudio

Developed by the National Renewable Energy Laboratory, OpenStudio provides a plug-in for SketchUp, along with a supporting interface to the EnergyPlus whole building energy modeling engine. OpenStudio includes the ability to define and apply space types, thermal zones, HVAC systems, and daylighting concepts, with an underlying analysis platform for evaluating design tradeoffs. The software includes basic results visualization capabilities to convert results into a more user-digestible format, and files may be exported from OpenStudio as EnergyPlus models or Radiance models for more detailed analysis.

Website: <http://openstudio.nrel.gov/>

Sefaira® Concept

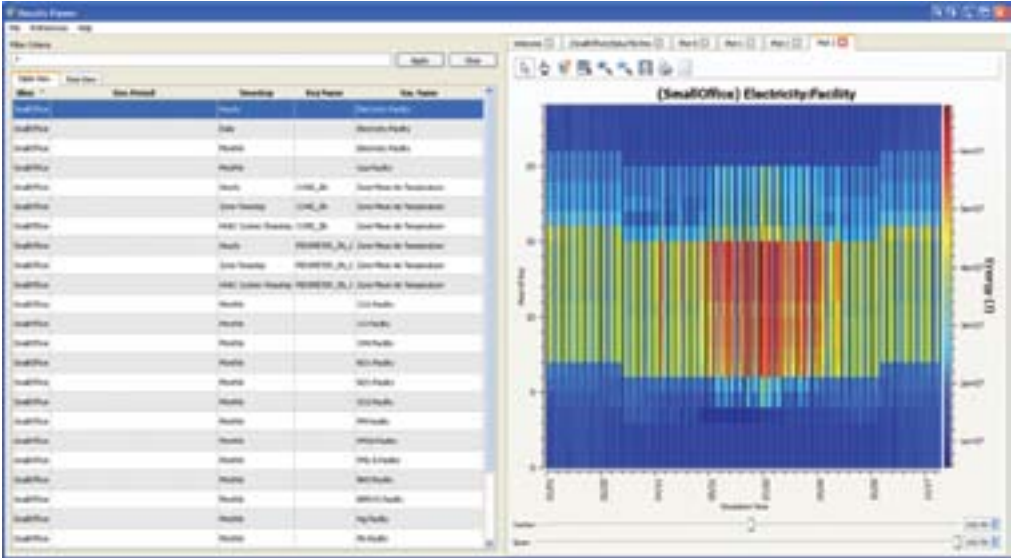
Sefaira Concept provides a comprehensive framework for real-time sustainability analysis that integrates existing building data with physics-based modeling. The software delivers deep decision support to help designers, planners, and consultants choose the optimal strategies to achieve best value energy use and to reduce carbon emissions. Sefaira Concept is purpose-built for early stage design, and it provides designers with many benefits, such as Cloud power for rapid and dynamic thermal analysis of buildings and integrated modeling of energy, water, carbon and renewables. It allows users to compare multiple massing alternatives in real-time. It accepts direct import from SketchUp. Its interface provides elegant ways to save time and cut down on the volume of spreadsheets. It is Web-based for easy collaboration. Sefaira Concept is exclusively deployed to a number of leading global design firms through an Early Adopter Program (EAP).

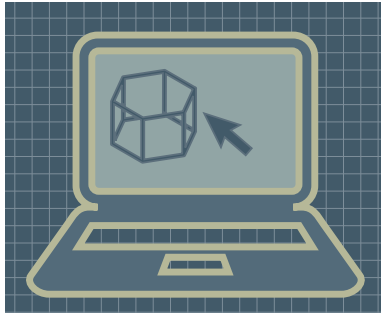
Website: <http://www.sefaira.com/products/sefaira-concept/> and <http://www.sefaira.com/info/early-adopter-program>

High level results after running a simulation



Flood plot created in ResultsViewer, part of the OpenStudio suite of tools





COMFEN and RESFEN

Free downloads developed by Lawrence Berkley National Laboratory, these programs provide comprehensive, detailed analysis of a single zone model for energy, daylighting, and comfort, with the EnergyPlus engine under the hood. They enable quick, comparative analysis of different scenarios, to explore early design ideas related to the façade within the context of the overall energy picture for the space. In addition, models can easily be set up for multiple orientations and sizes that can inform design decisions at the overall building level and influence later BEM inputs. The COMFEN software in particular provides graphic output by processing results into a more user-friendly format that compares options to one another, as well as providing numeric output that can be imported into Excel to be graphed in any way the user wishes.

COMFEN Website: <http://windows.lbl.gov/software/comfen/comfen.html>

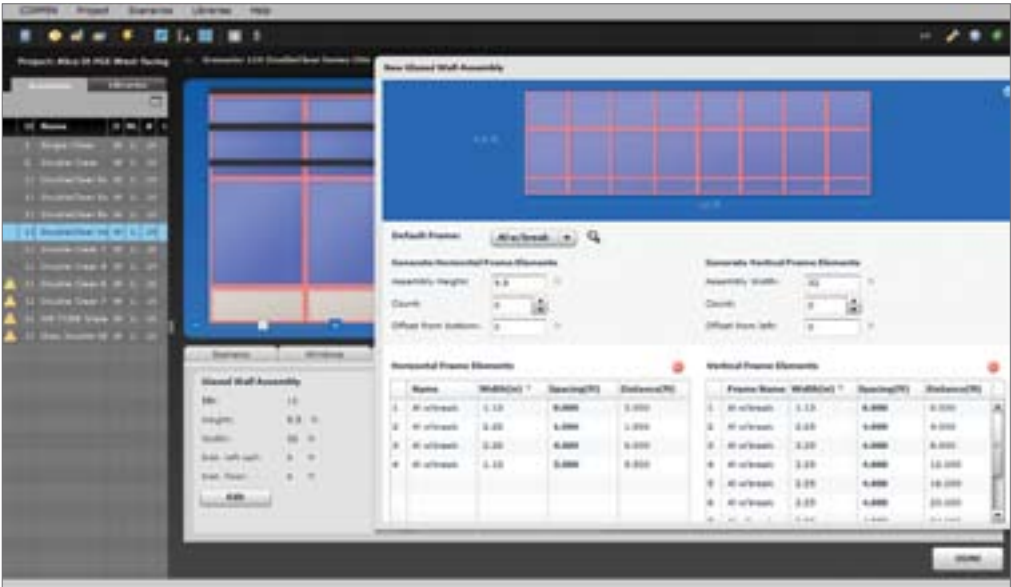
RESFEN Website: <http://windows.lbl.gov/software/resfen/resfen.html>

EMIT1.2™

The Rocky Mountain Institute's EMIT1.2.xls (Energy Model Input Translator) is a compilation of spreadsheet-based calculators developed in response to the need for tools that help building professionals translate design data and code requirements (ASHRAE 90.1-2007) into typical energy model inputs. It also includes a feature that will generate hourly schedules from spreadsheet data for use in eQUEST and EnergyPlus. This tool is only a pre-processor for some energy modeling inputs. Additional whole building modeling is required to predict overall building performance and code compliance.

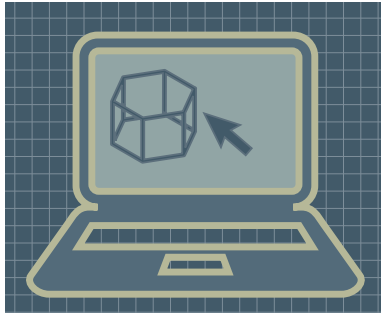
Website: <http://www.rmi.org/ModelingTools>

COMFEN sample input screen



COMFEN sample output screen

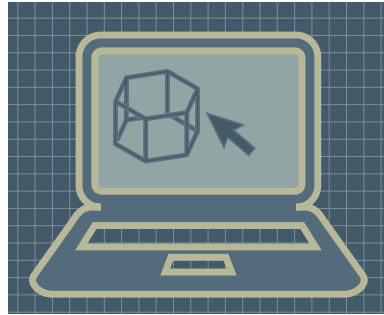




Early Design Performance Modeling Tools

EARLY DESIGN PERFORMANCE MODELING TOOL	ADVANTAGES	CHALLENGES
Ecotect	Somewhat Revit / Autocad compatible Graphic intuitively understandable results Easy to learn / use	For-purchase software Not well supported Models not back-compatible
OpenStudio	SketchUp-style input models Freeware EnergyPlus analysis engine Easy to use if familiar with SketchUp	Only provides numeric output (currently no graphic results) SketchUp not yet compatible with Autocad / Revit / Archicad, etc Some training on defining components that E+ understands required
COMFEN (Commercial Projects) RESFEN (Residential Projects)	Very easy to use Freeware Well supported (LBNL - help-desk) EnergyPlus analysis engine Graphic intuitively understandable results Provides the broadest range of performance implications (including energy)	Provides only envelope alternatives analysis (doesn’t address mechanical or electrical system alternatives specifically) Only assesses performance of a single-zone (does not address a whole building) Not yet compatible with Autocad / Revit / Archicad, etc
Spreadsheets (RMI-EMIT 1.2)	Easy to use if familiar with spreadsheets Freeware	Only assesses specific components (does not address a whole building) Provides numeric output with only basic graphic results
Sefaira	User-friendly, with SketchUp-type input environment Is a whole-building model (can specify different conceptual mechanical systems) Graphic intuitively understandable results Allows comparisons of multiple options side-by-side Uses its own engine (faster, multiple models)	For-purchase software Not yet compatible with Autocad / Revit / Archicad etc. Uses its own engine (black box / unvalidated by ASHRAE?) Doesn’t provide code compliance information
Whole-Building EM-Tools (Equest, Simergy, etc.)	Some are somewhat Revit / Autocad / Archicad / SketchUp compatible Early component assessment can easily transition into a whole-building energy analysis	Some are for-purchase software, some are freeware Not easy to learn / use without training Typically only provides numeric output





+ ENERGY MODELS AND DAYLIGHTING SIMULATION TOOLS

Daylighting design is arguably one of the most important energy efficiency measures, one that both reduces energy use and usually increases user acceptance. Accurate modeling is important in any high performance design project, for both daylighting performance and the resulting energy performance of the building itself, due to the reduced need for electric lighting. Most energy modeling software packages include daylight-energy predictive algorithms that can be used to help predict the energy savings that daylight can afford.

The important thing to remember is that an energy modeling tool is not a daylighting simulation tool. An energy model can help predict the effects of daylighting design, but it will not provide the designer with the information necessary to design a well daylit space. The daylighting algorithms used in energy simulation software are fairly simplistic; they interpolate energy use through a prediction of a limited number of sample points, sometimes as few as two, and then modulate the amount of electric lighting to make up the difference. They typically assume that the electric lighting system can be throttled up or down in the same manner as daylight, and effects of direct sun or sky glare on human behavior are not part of the calculation. Obviously, these are significant limitations.

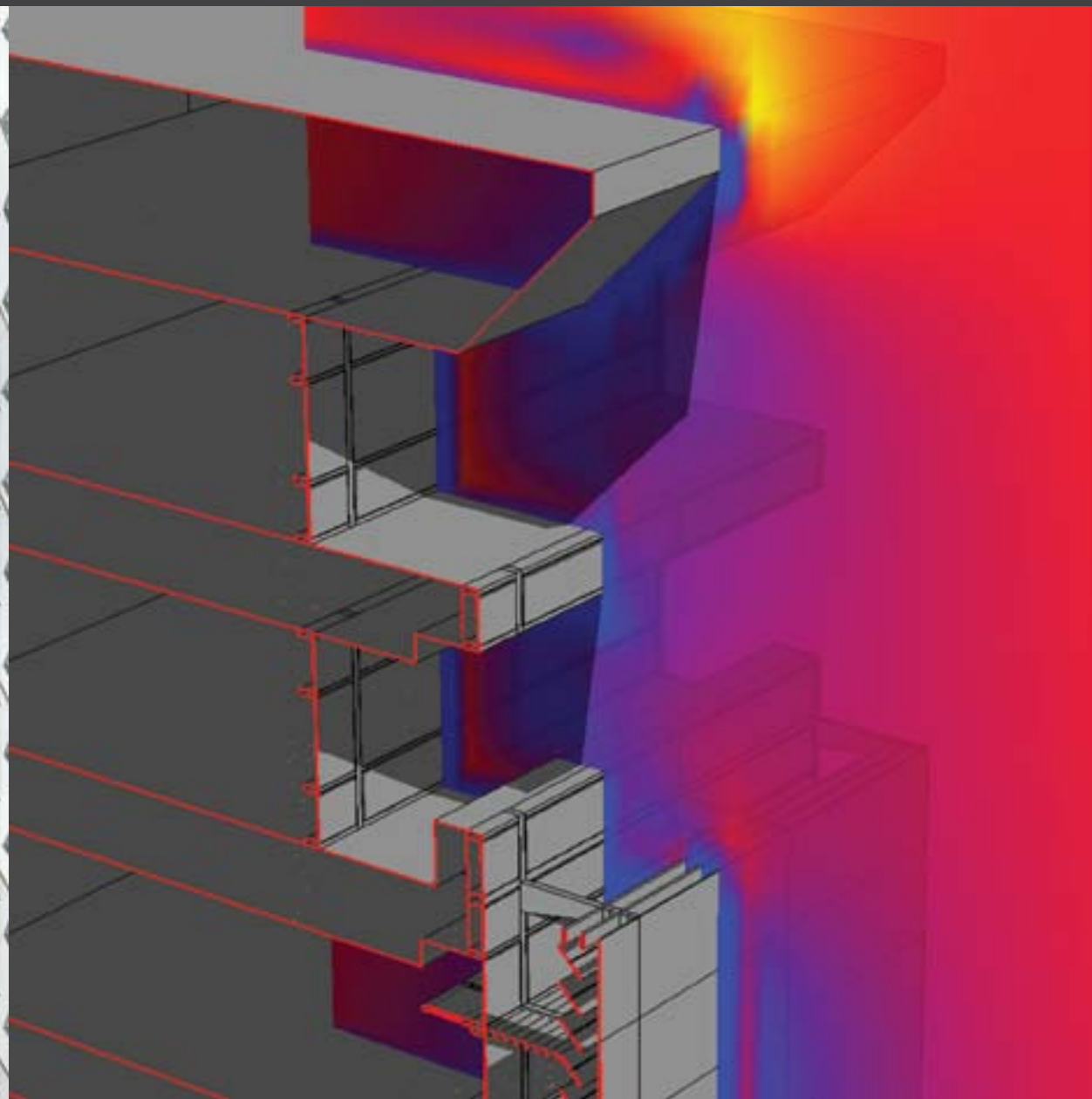
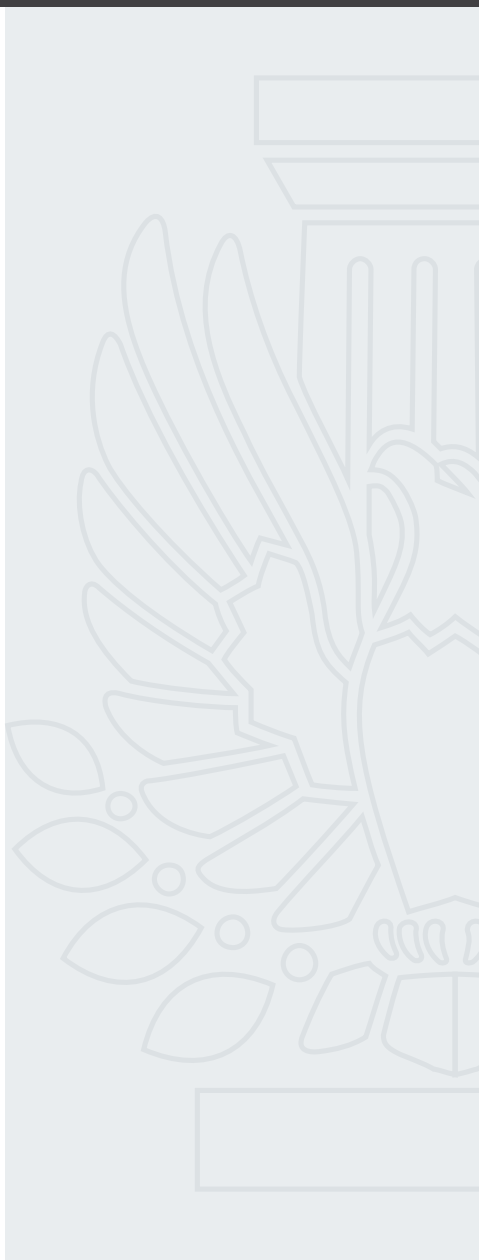
Specialized software, such as Radiance or Daysim (www.daysim.com), will help the designer understand the daylight performance of the space much better than any daylighting prediction outputs of energy modeling software. Such software can predict luminance, illuminance, glare, electric lighting contribution patterns, and their perception by the occupant.

Currently, daylight prediction is a time intensive process. High-end software packages will normally perform a point-in-time calculation as opposed to annual performance. Some software, like Daysim, will do annual calculations, but including these in an energy simulation package is not yet streamlined. Ecotect COMFEN and others also perform preliminary day-lighting analysis, which can be used for comparative purposes in initially choosing systems and components. Before long, daylight prediction software will be able to provide outputs that can be directly imported into energy simulation software.



6

SECTION 6_ OUR FUTURE BEGINS TODAY





“The energy code and modeling world is in a state of rapid change and the workflows of engineers and architects are changing to try to meet the growing demand of clients need for building performance metrics.”

—John Kennedy, AutoDesk

Section 6_

OUR FUTURE BEGINS TODAY

+ FURTHER TOOL DEVELOPMENT

Initially, BEM tools were developed to respond to new policy requirements. Architects now need to help drive the development and utility of energy modeling tools to make them useful earlier in the evolving design process. The tools available today are somewhat cumbersome, difficult for the typical architect to utilize in the fast-paced, fluid setting that is the design process. Plus, software developers are continually working towards better integration with design modeling tools and can benefit from architects' input on how we actually work with their products, particularly for small and mid-sized firms.

As client-driven and regulatory criteria for building performance steadily increase, software tools need to allow architects to understand the energy implications of fundamental design decisions in real time, within their main workflow. This will call for tools that provide enough accuracy to make informed decisions, without requiring detailed inputs that are out of sequence with early stage design process. To achieve this, tools require a tiered approach to accuracy, allowing architects and engineers to methodically increase input details by replacing assumptions or default values with actual design inputs as project knowledge increases. The “level of accuracy” that corresponds to increasing levels of known detail should be included in the corresponding results.

We know that the most cost effective ways to increase performance lie in early design decisions, especially concerning such things as solar orientation, massing, and site design. Quantifying each and every advantage from concept design forward with simple tools that the designer can control will add real, tangible value to our services, showing our clients a return on their investment with a holistic cost and performance approach, with each strategy tested at an appropriate level as design progresses. Our clients should expect no less, and we should work to develop tools that can meet this expectation.

The process workflow architects will need to follow to take advantage of energy modeling tools will change as our industry places more value on measured performance. As architects begin to see energy data even at the concept design level, we can begin to leverage that data across the lifespan of the project, as durable design and operations information.

The vision going forward is software interoperability that begins with performance data generated in an architect's early performance, energy, and resource modeling and ends with that data as part of a deliverable operations dataset, in a format compatible with a range of platforms, from “smart home” systems to large scale commercial building management system (BMS) software. This is the path which other resource intensive industries, such as automotive and aviation, are on, bringing *designed performance* and *operational performance* closer to each other.



Building Energy Modeling tools designed for architects need to:

- + have architect-friendly (graphic) interfaces;
- + be open-source and easily exchange information with other professional software;
- + correspond in their sophistication to the complexities of building design;
- + allow for increasing levels of information to be added;
- + match the level of detail at each stage of design;
- + keep pace with the design process;
- + generate outcome predictions quickly;
- + be able to better quantify passive design elements, including thermal lag/storage, natural ventilation, orientation, and water usage;
- + quantify embodied energy, carbon, and life-cycle-cost/payback;
- + enable HVAC system type options to be part of early stage analysis; and
- + provide client-friendly (graphic) output.



Photo credit: ©Assassi



+ DIRECTION OF THE INDUSTRY

A wide variety of industry leaders and experts representative of the most current thinking in the energy modeling community, meeting at the *RMI Building Energy Modeling Summit* in March of 2011, identified the following key themes for advancement:

The energy modeling community needs to increase its efforts around marketing and consumer education; we must improve the credibility of the industry, and potential energy modeling tool consumers need to better understand the value proposition.

Most energy modeling service providers need more education and training, especially around building physics—the science of how buildings work, the technology and systems of a building.

In the future, we should be able to effectively utilize energy modeling in building lifecycle analyses. We are currently missing opportunities to inform and improve building operations throughout its lifecycle.

We need to determine what can (or should) be standardized and/or automated.

We could improve the quality of analysis by providing practitioners with access to better knowledge and data resources.

Modeling many standard and innovative building technologies requires work-arounds that often call into question whether the scope of current tools captures the relevant phenomena.

Current software validation tests do not address many low energy technologies or interactions between HVAC and control systems.

Increased coordination and information exchange are essential.

The Role of the Department of Energy

To increase the use of energy modeling in the design process while preserving the productivity and sanity of architects, the Department of Energy is helping to develop design and analysis software tools that all work within one energy modeling ecosystem. In this new energy modeling software vision for the future, building model information will flow seamlessly from design tools to analysis tools, while results flow seamlessly back. Architects create and maintain a single design model, while software extracts model subsets and translates them for use by analysis software tirelessly and with perfect fidelity, allowing for integrative design processes that include energy analysis.

DOE is working with a variety of energy modeling vendors and partners to ensure that design tool exports are robust and uniform. At the same time, DOE is supporting the creation of free tools for standardizing the derivation of analysis geometry from IFC. DOE is also working to develop a single, accepted framework for mechanical system specification, which will be instrumental in all energy modeling software, providing replicable and consistent building energy use predictions.



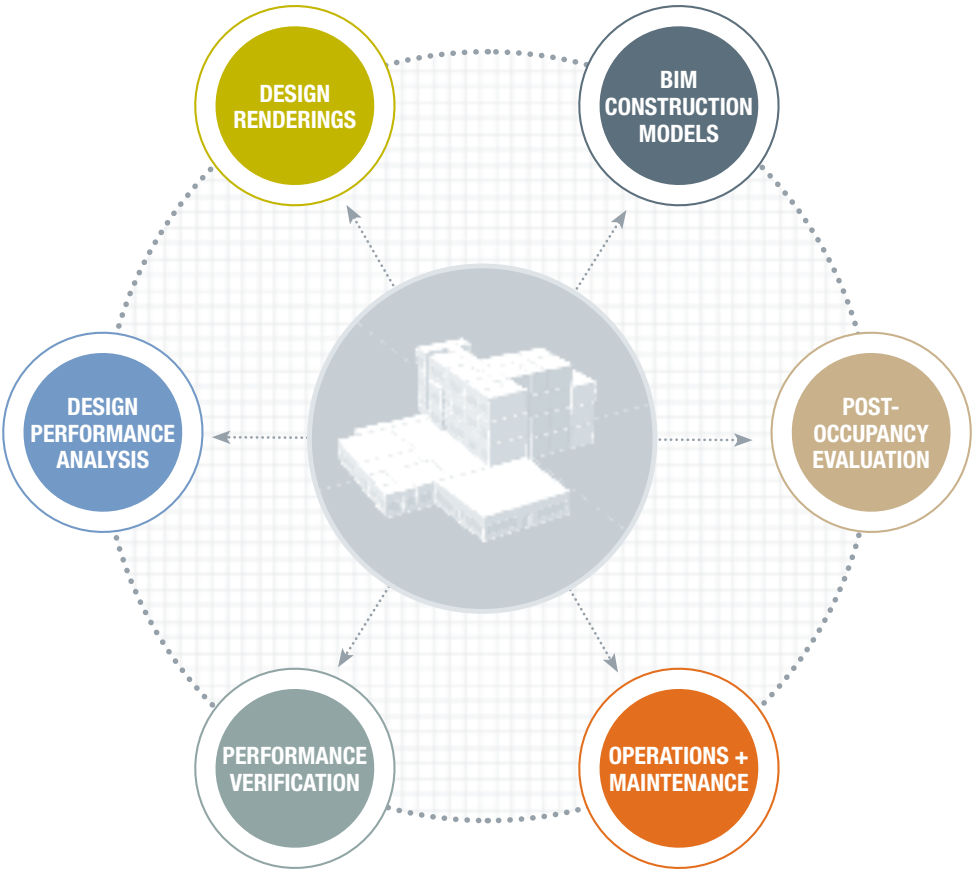
+ INTEROPERABILITY

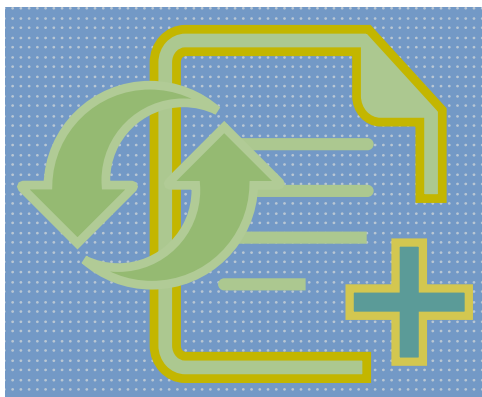
It is essential that the transfer of models from the front-end design tools to analysis engines become more uniform, seamless and accessible in exporting 3D data with integrated energy data, without altering the underlying architectural model.

Architects want and need the ability to create a single model that can be used on multiple software platforms in order to do performance analysis on multiple levels, for the duration of the project. The model should be easily transferrable to our consultants and contracting team. Not only would it save the architect's time and effort in the office, it would also be a wise and efficient use of client resources.

A single model should be able to be used for performance analysis in design, design renderings, BIM construction models, post-occupancy evaluation, operations and maintenance, and performance verification.

If building energy modeling is to make a truly meaningful impact on architectural practice, software and model developers must accomplish this holy grail of interoperability as soon as possible.

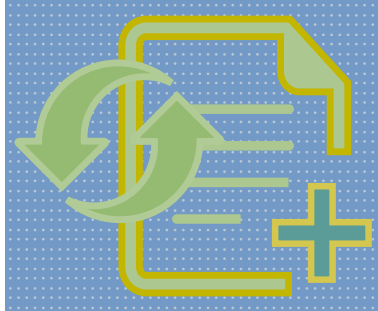




7

SECTION 7_ **ADDITIONAL RESOURCES AND CREDITS**





“You can never learn less, you can only learn more.”

—R. Buckminster Fuller

Section 7_

ADDITIONAL RESOURCES AND CREDITS

+ Additional Resources and Credits

For Further Reading

Advanced Energy Modeling for LEED – Technical Manual v2.0

September 2011 Edition. US Green Building Council.

Best practices for data collection?

Forum thread seeking advice on data collection in energy modeling for a LEED project.

Building Energy Modeling Innovation Summit - Vision Statements

Short statements by attendees of the Rocky Mountain Institute's Building Energy Modeling Innovation Summit on the future of energy modeling.

Energy and Daylight Modeling-Report from the Trenches – Meeting Minutes

Panel discussion notes on energy and daylight modeling from a Boston Society of Architects' Sustainability Education Committee meeting.

Energy Modeling

From Wikipedia, an online sustainability resource. Brief description of energy modeling and its benefits.

Energy Modeling

From Green Garage, a Detroit-based sustainability promoter. Description of energy modeling, its importance, and examples of how to use it.

Energy Modeling, ASHRAE 90.1 and LEED

Article on using energy modeling to help achieve LEED certification.

Energy Modeling Checklist

Checklist of some of the information needed to begin energy modeling.

Energy Modeling and the Design Process

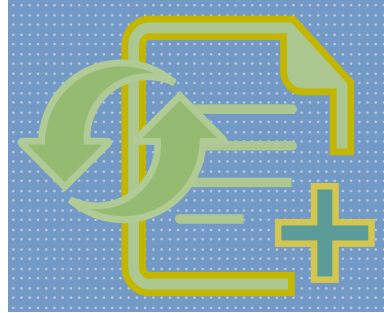
General statement on the connection between energy modeling and design.

Energy Modeling Further Demystified

Blog post recommending additional resources for learning more about energy modeling.

Energy Modeling—For Energy Efficiency

Robert M. Carver, Senior Project Manager. New York State Energy Research and Development Authority, Albany, NY. *Livable New York Resource Manual*.



Energy Modeling Practice Guide Peer Review Notice and Invitation

A copy of the AIA's invitation to participate in the peer review of the Energy Modeling Practice Guide.

Sustainable Performance Institute's Course Catalog

Description of course offered by the Sustainable Performance Institute on combining sustainability goals and company operations and management.

T-24 energy and LEED energy modeling credits: Understanding the similarities and differences

Kevin P. Gilleran. Gilleran Energy Management. May 5, 2010

Understanding Energy Modeling

Erik Kolderup, PE, BEMP, LEED AP. *USGBC-NCC Sacramento Branch. May 12, 2011. SMUD*

Understanding the Energy Modeling Process – Simulation Literacy 101

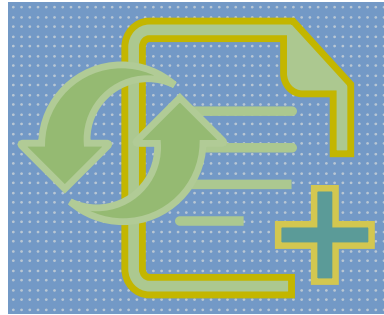
Marc Rosenbaum, PE. *Pittsburgh Papers, From the 2003 Conference, held in Pittsburgh, PA*

Understanding What an Energy Model Can and Can't Do Is Critical to Its Success

Article on the specific advantages energy modeling provides in helping to reduce building energy consumption.



Photo credit: ©Kuwabara Payne McKenna Blumberg Architects



Detailed Energy Modeling Assumptions Checklist

General Geometry/Massing+Form

Building shape and orientation
 Program – principal building function (e.g., small office, large office, hospital/medical, hotel, etc.)
 Total floor area
 Number of floors
 Thermal zoning of floors (perimeters and core)
 Floor to Floor height
 Floor to Ceiling height

Envelope

Window dimensions (each orientation if different, lower vs upper floors if different)
 Glazing sill and head height (above floor, each window type)
 Window to wall ratio (each orientation if different, lower vs upper floors if different)
 Shading Geometry (for each orientation if different)
 Windows + Skylights (SHGC, U-value + visible light transmission [vlt], frame-type)
 Wall, Roof + Foundation construction / makeup
 Interior Partitions, Internal Mass (furniture), Infiltration assumptions
Infiltration schedule (weekday, weekend, holiday)

Internal Loads + Schedules

Anticipated Occupancy (average no. of people)
 Lighting power density (average W/sqft)
 Daylighting sensors? Occupancy sensors?
 Plug load power density (average W/sqft)

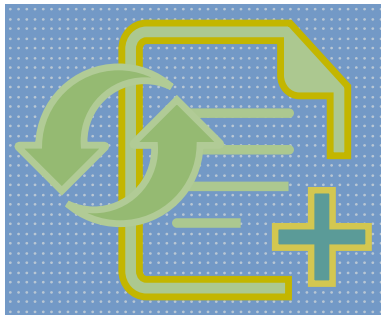
Exterior lighting peak power

Elevator? (type, peak motor power, schedule of use)
Occupancy schedule (summer/winter; weekday, weekend, holiday hours of use)
Lighting schedule (summer/winter; weekday, weekend, holiday hours of use)
Plug-load use schedule (summer/winter; weekday, weekend, holiday hours of use)
Exterior lighting schedule (summer/winter; weekday, weekend, holiday hours of use)

HVAC Systems + Schedules

System-type (heating + cooling)
 Sizes (capacity + efficiency) or 'autosize to design day'?
 Distribution type (e.g., VAV terminal boxes with electric reheat, under-floor plenum, etc.)
 Thermostat set-point and set-back (heating + cooling)
 Ventilation / Outdoor-air requirements
 Economizers? Energy recovery?
HVAC fan operation schedule (summer/winter; weekday, weekend, holiday hours of use)
Heating schedule of operation (summer- weekday, weekend, holiday hours of use)
Cooling schedule of operation (winter- weekday, weekend, holiday hours of use)
Minimum Outdoor-air schedule (weekday, weekend, holiday hours of use)

In more detailed analysis, modeler will also need: Fan efficiency, Pump type/efficiency, Cooling-tower type/efficiency, Service water type/efficiency/volume/T-setpoint and service hot-water schedule of use)



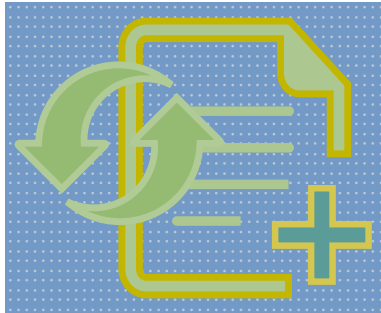
EnergyPro Compliance Document Excerpts

The following are excerpts from an Energy Pro compliance document—in this particular case, for Title 24 (California) compliance. However, the information illustrated below is the same information required for other similar energy code compliance.

Certificate output—general project information just possibly developed in other programs (eQuest, IES, etc. although could also be Energy Pro) and reported in a slightly different format that meets local jurisdiction requirements and specific code official expectations.

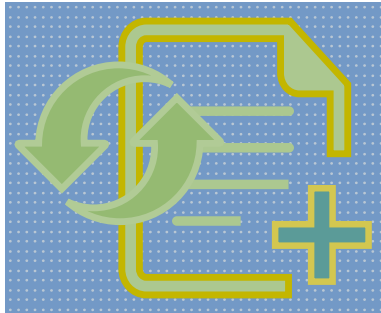
Certificate output—summary output (note compliance margin) and general configuration (floor-plate and envelope) information





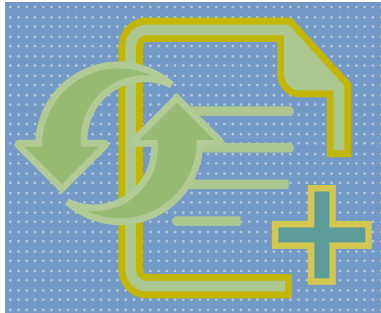
Certificate output—summary list of project zones (area, occupancy type, and lighting power density)

Sample envelope construction checklist—including both opaque-wall details and fenestration details (there will be as many pages as there are envelope construction-types in the project)



Sample roof construction checklist (including ‘cool roof’ exemptions)

Sample lighting systems checklist (there will be as many of these sheets as there are lighting systems in the project)

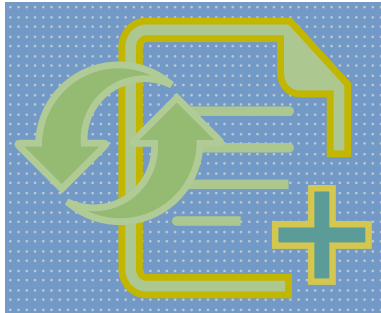


Primarily for the mechanical engineer:

Sample HVAC systems checklist + HVAC component detail checklist (there will be as many of these sheets as there are HVAC systems in the project)

HVAC systems summary (there will be as many of these sheets as there are systems in the project)

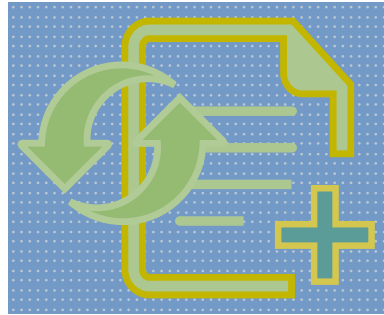




Most reports will also include a list of envelope, lighting and mechanical systems mandatory measures, such as:

- + manufacture and installation certifications and requirements for the building envelope systems,
- + manufacture rating and control requirements for lighting systems and
- + ventilation, control and efficiency requirements for HVAC systems.





Works Cited and Credits

American Society of Heating, Refrigerating and Air-Conditioning Engineers, U.S. Green Building Council, and Chartered Institution of Building Services Engineers. (2010). *Performance measurement protocols for commercial buildings*. Available from <http://www.ashrae.org/standards-research--technology/special--project-activities>

Edwards, L., & Torcellini, P. (2002, July). *A literature review of the effects of natural light on building occupants*. (Report No. NREL/TP-550-30769). Golden, CO: National Renewable Energy Laboratory. Retrieved from <http://www.nrel.gov/docs/fy02osti/30769.pdf>

Efficiency Valuation Organization. (2006). *International Performance Measurement & Verification Protocol: Concepts and practices for determining energy savings in new construction volume III part 1*. Retrieved from <http://www.evo-world.org>

Eichholtz, P., Kok, N., & Quigley, J. M. (2009). *Doing well by doing good? Green office buildings*. Berkeley, CA: University of California Energy Institute. Retrieved from <http://escholarship.org/uc/item/4bf4j0gw>

Fowler, K. M., Wang, N., Romero, R.L., & Deru, M. P. (2010). *Performance metrics for commercial buildings* (Report No. PNNL-19830). Pacific Northwest National Laboratory, & National Renewable Energy Laboratory. Retrieved from <http://sustainablecolorado.org/documents/performance-metrics-for-commercial-buildings>

Frankel, M., & Turner, C. (2008). *How accurate is energy modeling in the market?* New Buildings Institute. Retrieved from http://newbuildings.org/sites/default/files/ModelingAccuracy_FrankelACEEE2008_0.pdf

Heerwagen, J. (2000). Green buildings, organizational success, and occupant productivity. *Building Research & Information*, 28, 353-367. doi:10.1080/096132100418500

Heschong, L. (1979). *Thermal delight in architecture*. Cambridge, MA: MIT Press. Johnson Controls. (n.d.). 2010 Energy efficiency indicator results for North America. Retrieved from <http://www.institutebe.com/Energy-Efficiency-Indicator/north-america-energy-efficiency-indicator.aspx>

Libby, B. (2011, Nov-Dec). The original platinum office. *Eco-Structure*, 9 (6). Retrieved from <http://www.eco-structure.com/commercial-projects/the-original-platinum-office.aspx>

U.S. Energy Information Administration. (2012). Commercial buildings energy consumption survey (CBECS). Retrieved from <http://www.eia.gov/consumption/commercial/index.cfm>

U.S. Environmental Protection Agency, and U.S. Department of Energy. (n.d.). Portfolio manager overview. Retrieved from http://www.energystar.gov/index.cfm?c=evaluate_performance.bus_portfoliomanager

Graphics

EUI by Building Type

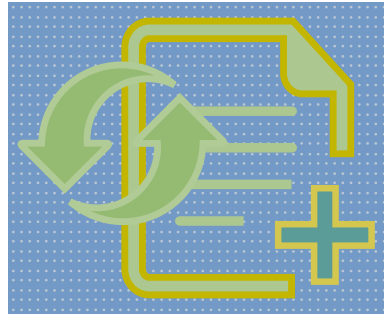
U.S. Energy Information Administration. (2012). Commercial Buildings Energy Consumption Survey (CBECS). 2003 Data Retrieved from <http://www.eia.gov/consumption/commercial/index.cfm>

U.S. Energy Information Administration. (2012). Residential Energy Consumption Survey (RECS). 2009 Data Retrieved from <http://www.eia.gov/consumption/residential/index.cfm>

U.S. Environmental Protection Agency, and U.S. Department of Energy. (n.d.) ENERGY STAR. Retrieved from <http://www.energystar.gov/index.cfm?fuseaction=buildingcontest.eui>

Understanding Lower Is Better

New Buildings Institute. Eley, C. (2009). Rethinking percent savings. Project developed by Architectural Energy Corporation with Southern California Edison. Graphic adapted from http://newbuildings.org/sites/default/files/Rethinking_Percent_Savings.pdf



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Credits



AIA Energy Modeling Working Group

Dennis A. Andrejko, FAIA

Andrejko + Associates

Rochester Institute of Technology

Martha Brook

California Energy Commission

Rand K. Ekman, AIA, LEED AP BD+C
Cannon Design

Christopher J. Green, AIA, LEED AP
Ago Studios, Inc.

George A. Loisos
Loisos & Ubbelohde Associates

Maurya McClintock, Assoc. AIA, LEED AP
McClintock Facade Consulting

Sandra Ford Mendler, AIA
Mithun, Inc.

Christopher S. Morrison, AIA, LEED AP
Cunningham | Quill Architects

Linda Morrison, PE, BEMP, CEM, LEED-AP BD+C
Ambient Energy

Emily Rauch
Pacific Northwest National Laboratory

Marjorie Schott
National Renewable Energy Laboratory

Norman Strong, FAIA
The Miller Hull Partnership, LLP

Jeffrey L. Till, AIA
Woods Bagot Architects PC

Steven R. Winkel, FAIA, PE, CASp
The Preview Group

William J. Worthen, AIA LEED AP
Urban Fabrick

AIA Staff

Brett K. Rosenberg
Director, Sustainable Practice

Joanna Goldfarb
Project Assistant