Architect's Guide to Building Performance

Integrating performance simulation in the design process

Contents

1. Introduction

Welcome to the *Architect's Guide to Building Performance: Integrating Simulation into the Design Process*. This guide's primary goal is to help architects use building performance simulation to inform decisions throughout the architectural design process. Use it as a roadmap to harness architectural experience and apply analysis and metrics to design better high-performance buildings for the twenty-first century and beyond.

This guide is built from a foundational premise that building performance is essential to quality twenty-first century architecture and is central to the ongoing relevance of the profession of architecture—within our own firms, in the eyes of our clients, and within local and global communities. Building performance is critical even to our shared life on earth.

The importance of building performance is clearly articulated in the AIA 2018 Code of Ethics and Professional Conduct through Canon II: Obligations to the Public; and Canon VI: Obligations to the Environment. Of particular importance to this guide is Ethical Standard 6.1, which states "Energy Conservation: Members should set ambitious performance goals for greenhouse gas emission reduction with their clients for each project."

Building performance simulation is no longer just a good idea for some architectural practices; it is an essential part of building design and delivery. Yet an AIA survey of members indicates that only 41 percent use building performance simulation to improve energy performance. This guide seeks to change that number by providing an orientation to, information about, and—most importantly—the necessary knowledge for building performance simulation for every project.

During a relatively brief period of design, architects make many decisions that affect the lifetime energy use of a building. These include a building's relationship to site and microclimate, its orientation, massing, envelope and glazing materials, lighting and daylighting, and programming. The median lifespan of a commercial building is 70 to 75 years, and the expected lifespan of many building components ranges from 15 to 35 years. Over that period, human population will continue to grow, and, along with it, energy demand and the potential for greater climate change impacts. These factors combine to place even more requirements on building design. Designing buildings for today isn't enough. Buildings must be designed for a future in which energy performance is an even greater concern than it is today. If the built environment is to reduce its environmental impact, design decisions must be verified through building performance simulation rather than relying on rules of thumb.

The architectural community is thinking beyond single projects. Members of the community are coming together to share information and learn, continuously raising the bar on performance and striving to meet or exceed the 2030 Challenge to make all new buildings, developments, and major renovations carbon neutral by 2030. The AIA 2030 Commitment supports the architectural community by providing a mechanism to share design energy performance and actual performance for a firm's portfolio of projects. 2030 Commitment data provides a true indicator of how far the community has come and how far it still has to go by requiring all projects be reported based on size, and not just a reporting of high-performing projects. The 2017 reporting cycle (for 2016 projects) saw nearly 17,000 projects, which accounted for more than 3 billion square feet reported, but there is still significant room for improvement. Increased sharing can provide a more informed picture of where things stand while improving benchmarking and quantifying the role of building performance simulation.

As the key leaders in creating the built environment, architects play a pivotal role in determining lifetime building energy performance. Asking the right questions and testing options through building performance simulation early and often throughout the design process add to a recipe for success that delivers value to firms, clients, building occupants, and society. No matter the size of your practice, this guide can help you.

Progress made and progress still needed

AIA published the first edition of this guide in 2012. Since then, there has been notable progress related to building performance simulation, even as continued progress remains essential.

Market penetration. More than 3 billion square feet of project work was reported in the most recent AIA 2030 Commitment annual reporting. That's more than a sevenfold increase since the 2030 Commitment launched in 2010. The GSF of 2030 Commitment design projects is comparable to more than one-third of the construction start market in the United States. 2030 Commitment signatories represent 59 percent of the *Engineering News- Record* 2018 Top 100 Green Buildings Design Firms.

Marketing and consumer education. The AIA 2030 Commitment, LEED and other programs highlight firms that integrate building performance simulation in their projects to communicate the value proposition of designing to optimize energy performance to potential users of simulation tools and consumers of simulation services.

State and municipal energy benchmarking ordinance. The Institute for Market Transformation Building Rating database shows more than 25 state and municipal energy benchmarking ordinances across North America. This is a new regulatory condition that underpins the need for architecture design to deliver asset value through lower energy design.

Education and training. AIA, ASHRAE, IBPSA, USGBC, and other organizations continue to stress the critical role building science and building performance simulation play in achieving high-performance goals and net zero energy targets. Education underlies several professional accreditation programs, and the industry continually challenges itself to do better.

Automation and standardization. Performance documentation for code compliance, financial incentives, and certificates (e.g., LEED) involves comparison of final building design to a variant of the design that is modified to meet minimum prescriptive energy-efficiency requirements. In the past, using building performance simulation to provide this comparison required significant labor resources. Recently, many widely available building performance simulation packages have automated the process of creating a modified "baseline" model from the model of the final design. This frees up resources to support using simulation earlier in the design process. Many packages also automate parametric analysis.

Quality of analysis. It is always the case that quality of analysis will be improved by providing practitioners with access to better knowledge and data resources. A resource such as the AIA's 2030 Design Data Exchange (DDx) shows definite progress. The DDx allows firms to report whether projects have used building performance simulation to simulate energy performance, the tool(s) used, and other optional fields such as the cost of simulation and energy cost savings.

Scope of current tools. Building performance simulation to optimize energy performance often plays catchup as building technologies advance. However, many simulation tools can now directly model high-performance components and systems including radiant cooling, variable-refrigerant flow (VRF) heat pumps, and dedicated outdoor air systems (DOAS). Although workarounds may still be needed for some systems and strategies in some tools, the number is shrinking quickly.

ASHRAE Standard 209. In 2018, ASHRAE published its Standard 209-2018–*Energy Simulation Aided Design for Buildings Except Low-Rise Residential Buildings.* Building performance simulation has traditionally been used as a compliance tool late in design, but Standard 209 provides a methodology to apply building performance simulation early in an integrative design process to improve building energy performance. The standard's "modeling cycles" also include provisions to help ensure energy performance goals remain intact through design, construction, and operations. Standard 209 is discussed in Part 5.1.

Client demand and firm practice. According to AIA client survey data from 2016, 89 percent of building owners surveyed were planning to include energy efficiency systems attributes in their projects over the next three years. Contrast that with another survey conducted by the AIA indicating that 41 percent of firms do not use energy modeling. This disconnect makes it clear that architects must begin to incorporate building performance simulation to optimize energy performance in their projects now to adequately meet client demand.

2. The case for building performance simulation

Building performance simulation is a critical tool to improve both the quality and performance of architectural design. Simply stated, it is an essential mechanism to achieve the holistic design architects are expected to deliver. Buildings must reflect many qualities: They must provide places of beauty, joy, and interest; places with purpose, function, and clarity; places of generosity, endurance, and sustainability; and places that contribute to the built fabric as well as the betterment of the human condition.

In addition to these qualities, buildings must provide high performance. High-performance buildings use less energy to operate, have reduced energy costs and carbon emissions, and contribute less to climate change. They can also be cheaper to build than conventional buildings. High-performance buildings improve occupant experience, health, and productivity by providing greater visual and thermal comfort along with improved indoor air quality. These buildings also improve the local community by avoiding contributions to heat islands and stormwater runoff, while supporting resiliency by maintaining core operations and services during emergencies. They also offer additional societal benefits by supporting green economies and sustainable communities.

Architecture must be designed for long-term impact with deliberation toward quality and performance. But you can't know whether you've successfully delivered quality and performance without first having defined and tracked what successfully doing so actually means. Building performance simulation provides the design rigor, analysis, and feedback to get there.

The architect makes many decisions early in the design process. Passive design decisions made early in the design process are usually the sole responsibility of the architect. These decisions affect mechanical system size, cost, and energy-usage decisions made in later stages of design.

The benefits of high-quality and high-performance design can be achieved by first focusing on passive design. Passive design requires establishing clear goals and designing passive measures that reduce energy demand in the early stages of design. After passive design is optimized, then high-performance mechanical systems are designed. And after all efforts have been made to optimize passive design and mechanical systems, then deploy renewable energy technologies either onsite or through renewable energy purchasing.

It is impossible to optimize passive strategies for cost and performance without using building performance simulation. When led correctly by the architect, building performance simulation determines the relative performance of many strategies. The architect and client can then choose only those strategies that are the most effective to meet goals based on site, typology, and other project realities. For some projects, building performance simulation can eliminate costly rule-of-thumb strategies that don't actually provide the performance benefits the design team initially considered.

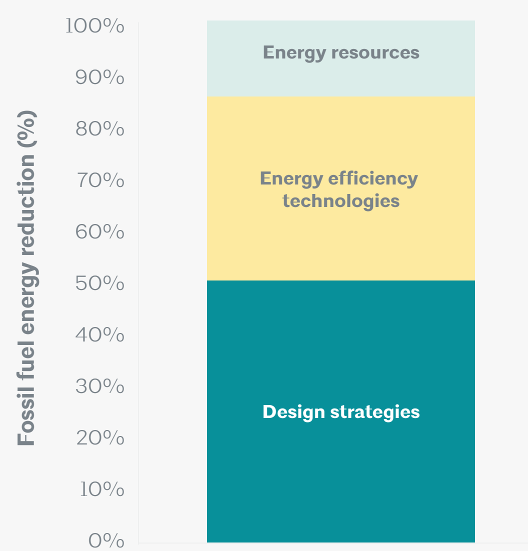


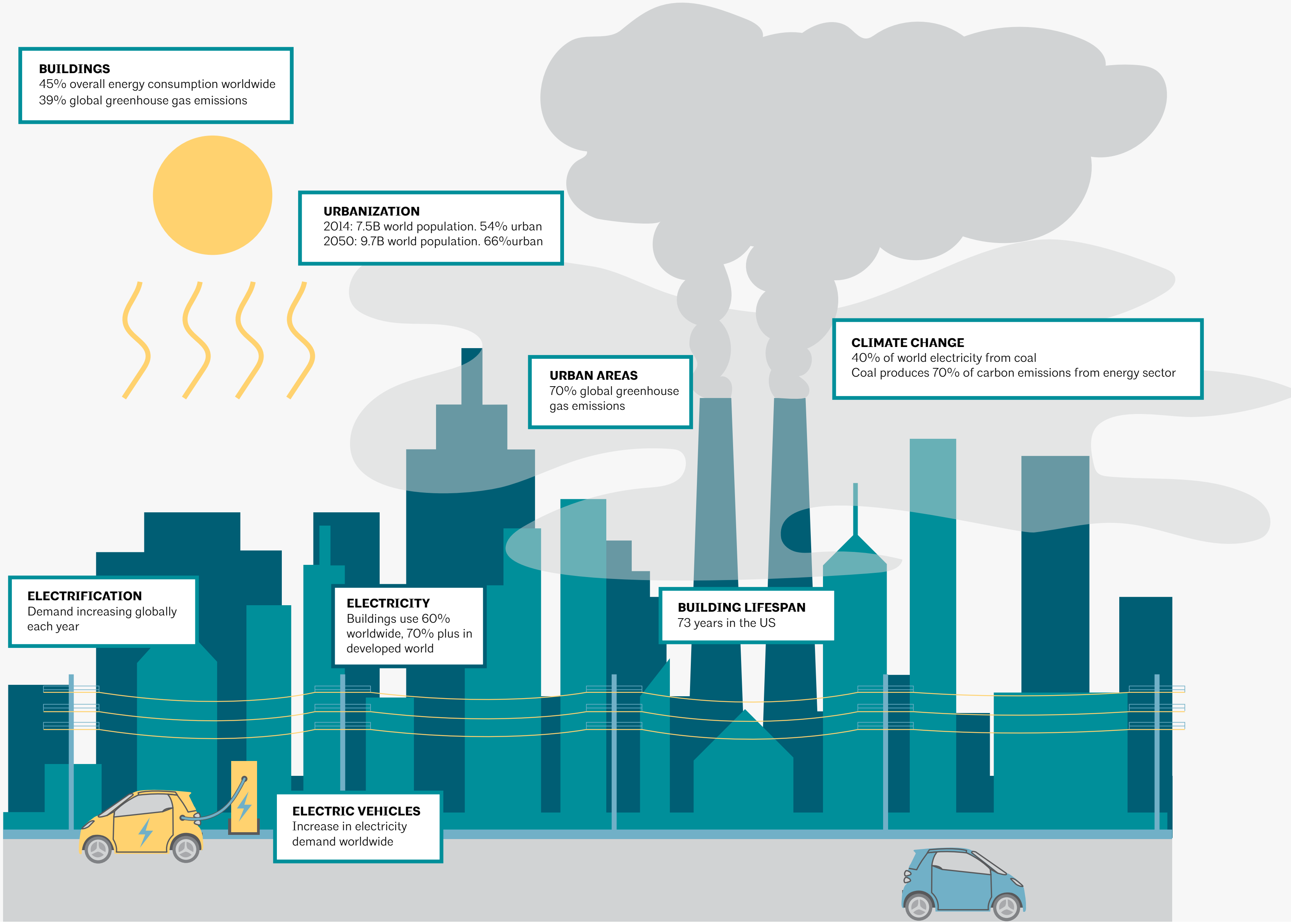
Figure 2.1

Design strategies have the greatest impact on building energy use, and architects have the greatest impact on design strategies early in the design process.

Original graphic by Architecture 2030 for the AIA+2030 Online Series

Figure 2.2: Cities, buildings, energy and climate change

Architects design with consideration of nature and the environment. Building energy use has a huge impact on the environment, which is under historically unprecedented stress from human activity.

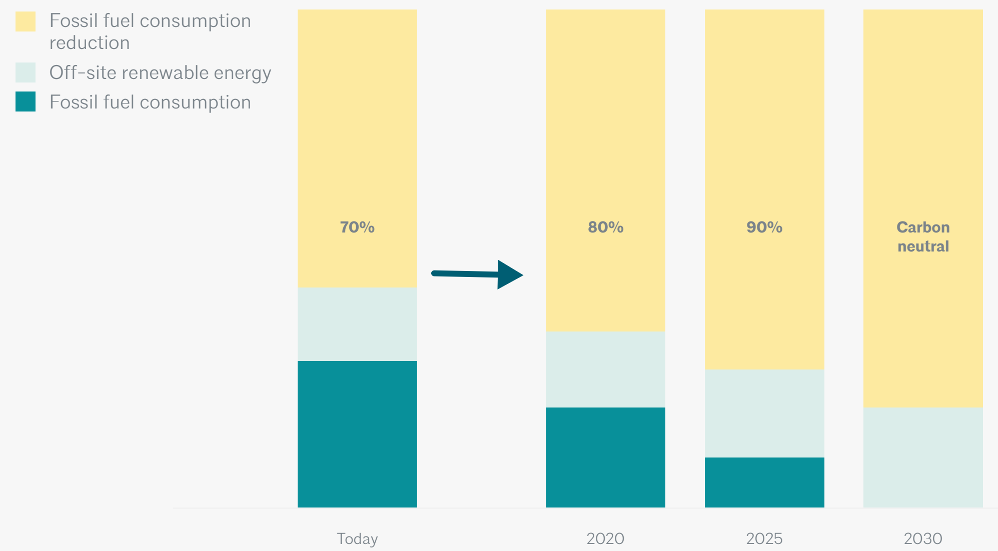


2.1. The larger context: challenges, opportunities, and how building performance simulation can help

Buildings make up cities and house the world's growing population. Architects design those buildings for a specific client at a specific moment in time, and the lifetime of those buildings continues long beyond that moment. To respond to perhaps the most defining issue of our day—climate change—architects must create high-quality, high-performance buildings that use design to optimize passive strategies and rely less on mechanical systems to provide comfort. These buildings must also feature renewable energy options as much as possible, resulting in spaces that use less fossil-fuel energy and emit fewer greenhouse gases while providing a functional, comfortable, enjoyable, and resilient built environment. Using building performance simulation in the design process is essential to reaching this potential.

Figure 2.3: The AIA 2030 Commitment

The AIA 2030 Commitment empowers architects on the pathway to carbon-neutral buildings by the year 2030.



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The 2030 Challenge and 2030 Commitment

The 2030 Challenge responds to climate change with targets to reduce greenhouse gas emissions. It states that operations in all new buildings, developments, and major renovations will be carbon neutral by the year 2030. The challenge was issued in 2006 by Architecture 2030, and AIA officially adopted it that same year. The 2030 Challenge maps a path for the design community to reduce the climate change impacts of new construction and major renovation projects (Figure 2.3). The challenge can be met through design strategies, energy efficient technologies, on-site renewable energy systems, and off-site renewable energy (up to 20 percent of the reduction).

AIA's 2030 Commitment, a response to the 2030 Challenge, provides reporting and analysis tools to help designers measure their progress toward the 2030 Challenge targets. The AIA 2030 Design Data Exchange (DDx) provides a platform for firms to record, analyze, and compare predicted project energy performance across their portfolios. It also helps firms understand which performance targets to set at the early stages of design. It's an invaluable tool for design firms to quantify impact and communicate progress.

For the reporting metric, AIA is currently using *site* predicted energy use intensity (pEUI) (see definitions in Part 3.1) as compared to a measured *site* EUI for the same building type. This important metric is reflective of what clients are most likely to understand and be concerned with because it most closely aligns with their energy costs. However, to reach carbon neutrality, *source* EUI and *source* pEUI must be considered. This metric takes into account all raw fuel required to operate a building, including grid transmission, delivery, and production loses. Although the 2030 Challenge and 2030 Commitment deal with relative targets (percent improved above a baseline), carbon neutrality hinges upon an absolute target of 0 kBTU/ft^2/year for source EUI.

Opportunities beyond energy

High-quality, high-performance buildings lead the way to new notions of beauty and sustainability. These buildings are in the forefront of innovation in design. Performance analysis can provide opportunities for informed creativity and innovative design solutions. Although this guide focuses primarily on the use of building performance simulation in design to reduce building energy use in operations, there are additional benefits.

High-performance buildings support the organizational objectives of global corporations and many clients as we enable direct connections to climate action plans, environmental and social governance programs, and financial market reporting. Overall, high-performance buildings also provide a higher-quality product for our clients, and a commitment to high-performance design consistently raises the profile of a firm.

High-performance buildings are a solid investment in a future in which renewable energy promises to be the fastest-growing and most cost-competitive energy source. Their design, construction, and operation also support economic opportunities by creating new jobs and allowing owners and occupants to invest resources outside of meeting basic energy needs.

High-performance buildings support strong resilient communities, designed to withstand the unprecedented events resulting from climate change and to operate safely while supporting human health, even when electricity from the grid is unavailable. Their design also supports equity and human rights. Everyone should have access to a comfortable, healthy, productive built environment that minimizes energy and its associated cost to consumers and carbon impacts on the environment we all share.

2.2. Building performance simulation for better buildings

Building performance simulation is the use of physics-based software to calculate potential design impacts such as annual energy use and thermal and visual comfort. It includes building energy simulation or building energy modeling such as solar, shading, daylight, glare, thermal comfort, and natural ventilation. The use of building performance simulation by architects in conjunction with third-party professionals is essential to implement and optimize the mix of strategies for high-performance buildings that optimize energy performance and offer occupants better function, enjoyment, and comfort.

It isn't necessary to know how building performance simulation works to understand its benefits, but having some language about it to lead the process is extremely helpful. Figure 2.4 organizes preparatory activities, simulations, and analyses into three categories: early investigations, single aspect simulations, and whole building energy simulation. These three categories can be correlated to stages of the project, from RFP, through the design process, and even into occupancy. To design a truly high-performance building, the architect and the entire design team work together in an integrated design process. Architecture leadership and coordination of simulation efforts, including those that may be performed by the architect, are typically more intensive early in design. They tend to taper off as the activities of a building performance simulation professional (BPS professional) ramp up later in design. The BPS professional is usually, but not always, an engineer (e.g., a member of the MEP team or a specialist), and may perform both single aspect and whole building simulations. Architects may also perform single aspect simulations, but BPS professionals tend to perform whole building energy simulations. (ASHRAE Standard 209, discussed in Part 5.1, describes whole building simulations.)

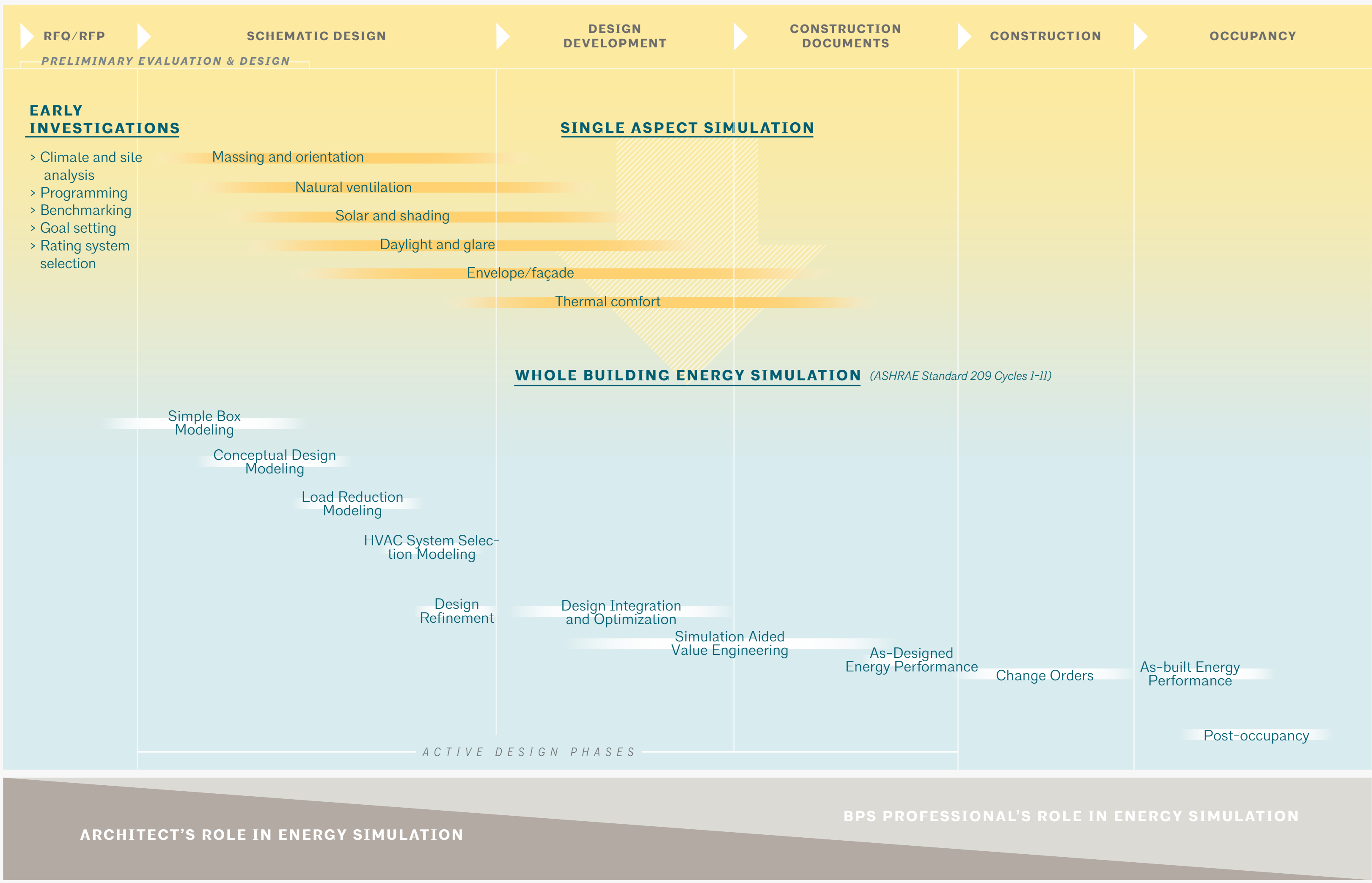
Simulation early and often results in better buildings

Design solutions that are possible in early design, and that affect first costs and operational energy costs, are more expensive to make later on. For example, adjusting building site orientation and massing to minimize solar heat gain in a cooling climate based on simulation results can reduce upfront costs of the mechanical system. Often energy efficiency is labeled as expensive not because it actually *is* expensive, but because energy performance wasn't addressed as a design goal from the beginning and making changes late in the process is much more expensive than if it had been a goal from the beginning. Similarly, if energy efficiency is addressed only in relation to mechanical technologies, lower-cost energy-savings opportunities from passive design are not realized. If energy performance is not considered early in the design process, changes required to address potential energy impacts later are not only more expensive, they may also be impossible. (See Figure 2.5.)

To date, building energy simulation continues to be primarily used as a compliance tool late in the design process, for example, for code compliance or to document efforts toward a LEED rating. Most often compliance modeling is conducted by a BPS professional. Exclusively using performance simulation late in the design process, results in serious missed opportunities. Used early in the design process, building performance simulation can help the architect make crucial decisions that have the possibility of positively impacting first costs, operational costs, and energy-related environmental impacts for the life of the building. Early climate and site analyses—and building

Figure 2.4

Building performance simulation to optimize building energy performance encompasses single aspect simulations with which many architects are familiar and whole building energy simulations that are typically performed by a member of the MEP team or other specialists.



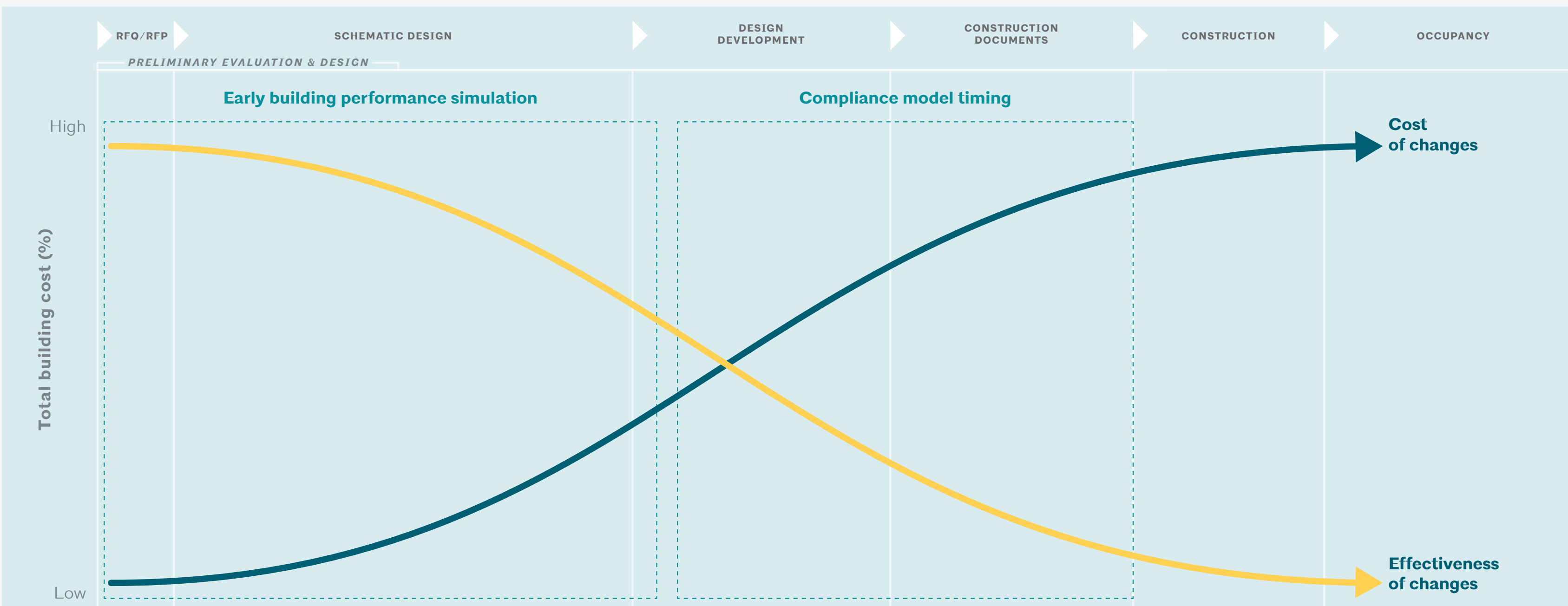
geometry, massing, and orientation—can maximize passive systems not only for better energy efficiency but also for resilience. Maximizing passive systems such as daylighting and passive ventilation, coupled with backup renewable power, increases resilience by improving continuity of building operations for occupants (e.g., water, sanitary waste, essential power, and thermal comfort) in the event of a power outage. Building performance simulation can also help optimize envelope and mechanical systems performance as design progresses. Early simulation and resulting design decisions made by the architect add value to design results and are also valuable to the BPS professional with whom the architect may work on more in-depth whole building energy simulation. Only much later in the design process, after all appropriate design decisions have been made to maximize the performance of the building, should simulation be used to serve as a documentation tool for compliance.

Another tool for designing better buildings

Architects have a long list of responsibilities and tasks, and must make an equally long list of decisions—all with far-reaching impacts on human safety, health, and experience as well as the environment. Architects are deeply involved in a project, from as early as the RFP and preliminary evaluation and schematic design, and are often involved through construction. They must consider a wide variety of factors such as site, building type and use, program, budget and

Figure 2.5: Cost & effectiveness of changes by design phase

When building performance simulation is performed earlier in the design process, design decisions that impact building energy use are less expensive and more effective. Early building performance simulation not only supports the architect in reducing energy costs and environmental impacts, it also enables decisions that impact operational and first costs.



Original graphic by Architecture 2030 for the AIA+2030 Online Series cost, safety, security, code, and materials. There are expertise, strategies, and tools available for all the decisions an architect makes. Energy is a design challenge. Whether architects are aware of it or not, energy is a part—either explicitly or implicitly—of nearly every decision an architect makes. The importance of using appropriate expertise, strategies, and tools to make energy-related decisions—especially early in the design process—cannot be understated.

Architects, like professionals in many fields, rely on judgement and rules of thumb developed through years of personal and shared experience that is often transferred within and across firms. These rules of thumb often encourage the repetition of details and assumptions about performance from project to project and increase production efficiency. Experienced architects may have a go-to wall slab, glazing assembly, roof system, and so on. Building performance simulation can test applicability of rules of thumb on a specific project and inform the development of future details to be applied in a given climate or project type with similar loads. For example, the architect can understand whether added performance of thicker roof insulation or shading devices will be worth the additional cost. If the added performance is minimal, those cost savings can be applied in other areas that might provide more value.

Figure 2.6: Differing terminology; similar goals and principles

Whether aware of it or not, architects make many decisions about design that affect building energy performance. Building performance simulation provides a new lens through which to view these decisions. Whereas building performance terminology may differ from more typical language used in the design process, the underlying goals and principles are often closely aligned or the same.

Design decision	Energy performance design decision
Form and orientation	Solar geometry
Roof form and slope	Solar geometry, natural ventilation, solar ready
Structural system	Thermal mass
Floor-to-floor height	Daylight
Wall design	Thermal mass, insulation, heat transfer
Skin-to-core depth	Daylight and natural ventilation
Façade development	Window-to-wall ratio
Window size	Window-to-wall ratio
Window design, orientation, and size	Passive heating and cooling
	Daylight
	Shading
	Glare control
Window operation	Natural ventilation
Mullion spacing	Thermal bridging
Balcony structure	Thermal bridging

On the other hand, when simulation results vary significantly from existing rules of thumb, these results can signal that the modeler needs to take a second look at the simulation—its inputs and outputs—to be sure the results are credible and reliable. In this way, building performance simulation also establishes a culture of accountability for the design team.

Realizing building performance simulation's full potential, the firm performs post-occupancy evaluation of the project to determine how the building compares to design intent. These evaluations are another important aspect of accountability for the design team and inform ongoing design language and rules of thumb for the firm.

2.3. Putting building performance simulation to work for the firm

Building performance simulation provides economic benefits to each client. And whether it is performed in-house or by a third party, it can also provide market advantages to firms that use it and use it well.

Many architects are concerned about the best way to present the use of building performance simulation in a project to clients. It is often considered an added expense to be carried by the firm because it

Virtual prototyping

Today, virtually every manmade item—from razors to airplanes and potato chips to computer chips—is prototyped virtually (i.e., simulated) before being built physically. Virtual prototyping is less expensive than physical prototyping and supports deeper levels of analyses. Simulation gives us a peek into the future through virtual environments that follow the rules of physics. It allows us to test assumptions and optimize solutions for better outcomes. A computer can evaluate an almost infinite number of variables to find the few options that best meet team goals. Whereas architects are using tools to improve early visualization, we are generally not leading the effort in using tools early to improve building performance.

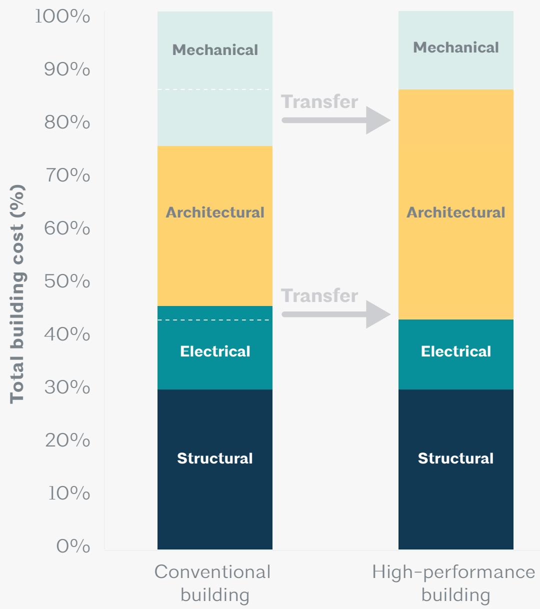
For architects, 3-D digital building information modeling (BIM) is a standard tool. It's complemented by spreadsheet models for cost, fees, and programming. Architects already use a variety of tools to design better buildings and make better decisions. Incorporating the use of building performance simulation, be it from expertise in-house at the firm or by contracting to a third party, is simply another tool—a critically important tool.

Photo credit: National Renewable Energy Laboratory

is perceived as something clients aren't interested in paying for. But energy performance should not be considered an "extra"; it is an integral part of quality architecture and design. Competitive firms include building performance simulation as part of standard practice using integrated design that produces the highest quality and performance. Just as firms educate clients about other aspects of architecture and design, so must they educate clients about the value of simulation to make better buildings. Indeed, this is now part of the professional ethical obligation of AIA members for all projects. (AIA Code of Ethics and Professional Conduct)

Figure 2.7: Integrated design shifts investment

Approaching the design process by incorporating building performance simulation into an integrated design process tends to redistribute costs rather than increase them.



If you must advocate for simulation to a client, consider doing so as a method of controlling first costs as well as reducing operating costs. Building performance simulation allows the architect and client to select only the most effective energy-saving strategies, eliminating those that may add to first costs but don't significantly improve performance. Without the use of simulation, there isn't enough information to make these selections. Whereas use of building performance simulation may add a small amount to the soft costs that represent a small percentage of overall project costs, it can provide insights to reduce project first costs, which represent a much greater percentage of project costs overall.

It is also helpful to add that, when done effectively, including building performance simulation in an integrated design process tends to redistribute labor costs for the design effort while also reducing project first costs for the construction budget. This can result in allowing funds to be allocated to other features that weren't initially considered on the table. (Figure 2.7)

As noted in the introduction, an AIA survey revealed that 41 percent of firms do not use energy modeling. Although the purpose of this guide is to encourage all firms, no matter their size, to use building performance simulation to optimize building energy performance (and hopefully to eventually realize that ideal), there is currently a market advantage for firms that do.

Architects work in a highly competitive environment. Incorporating the use of building performance simulation into the firm's culture and regular practice produces higher-quality buildings for the clients. Use of building performance simulation enables the firm to use analysis and metrics to prove the buildings it designs are, in fact, better buildings. This helps the firm build a reputation for quality, which in turn enables it to win more contracts and more prestigious awards, further raising the profile of the firm with the potential to generate more business.

The 2018 Code of Ethics and Professional Conduct lists five obligations to the environment, the first of which is: "Energy conservation: Members should set ambitious performance targets for greenhouse gas emission reduction with their clients for each project." In its obligations to the public, the code also requires members to inform clients of the "potential environmental consequences or impacts" of the work being performed. The use of building performance simulation in design is key to meeting these obligations. If the client isn't concerned with energy performance, the architect still has a professional obligation to be concerned, and the use of building performance simulation can be promoted as a cost control measure. (Figure 2.8)

Compliance and documentation

Although using building energy simulation solely as a compliance tool late in the design process results in missed opportunities, it is still used as a tool to document compliance with energy codes, financial incentives, and certifications such as Energy Star and LEED. Codes such as ASHRAE 90.1, IECC, and California's Title 24 specify minimum prescriptive requirements, and buildings may comply by meeting each requirement, checklist-style. However, each code also provides a performance path option. To demonstrate compliance with the performance path, simulation results of a building are compared to simulation results of the "same" building designed to meet minimal prescriptive code requirements.

Whether for performance-based energy codes and financial incentives, or certificates, the process for performance-path compliance is the same, with the goal of demonstrating that the building design exceeds minimal energy performance by some percentage. Performance-path compliance is preferred for a large number of building projects because it gives architects and engineers greater flexibility in design.

Virtually all building certifications require the use of building performance simulation. It is the only way to quantify and demonstrate improved performance. For example, the team uses simulation in the exploration of tradeoffs between window-to-wall ratios, glazing materials, and HVAC system sizing to demonstrate that the building is designed overall to perform according to or better than code. The results of that simulation document both the use of simulation and the design decisions necessary to meet certification requirements. Some prescriptive certifications do

Figure 2.8: Building performance simulation for commercial buildings "pays for itself" quickly

HOK and TLC Engineering for Architecture put more than a dozen of their projects through identical analyses and concluded that, for most projects larger than 25,000 square feet, costs associated with investment in building performance simulation can be balanced with operational energy cost savings to the owner within a year.

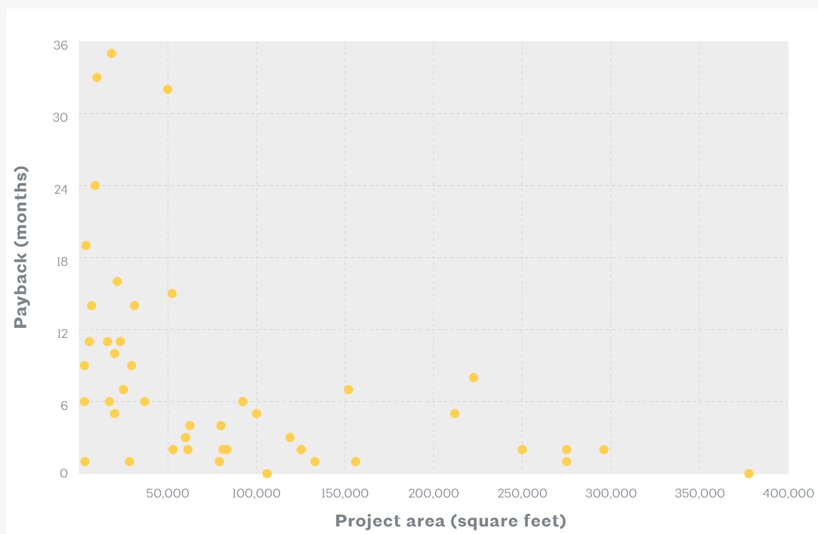


Image credit: Data presented by Kim Shinn, Anica Landreneau, and Vanessa Hostick; Integrated Energy Modeling for First Cost Neutral High-Performance Design at the AIA 2017 Conference on Architecture.

exist, but without using building energy simulation the design team could end up making design choices that meet requirements but are actually unnecessary and have a negative impact on project costs.

Until recently, performance path compliance constituted most of the building performance simulation performed for most projects. Creating a code-minimum building simulation from the model of a proposed building is time-consuming. Because a lot of it involves mechanical systems, it is also primarily done by engineers or modeling consultants. As a result, the simulation is performed only once, at the end of the project—too late to inform design. Recently many software packages have automated the process of creating a code-minimum simulation from a proposed building model. Whereas it used to be wise to allocate some if not most the simulation resources for the end of the project, it now makes more sense to allocate more of them earlier in the project, when they can better inform design. And with performance documentation now coming essentially "for free," building performance simulation early and often can ensure that code compliance, incentive, and certification goals stay on track throughout the project with greater assurance that the project will not encounter expensive surprises or missed opportunities later in design.

2.4. Data with purpose—integrating building performance simulation into firm culture

Within a firm, it is as important to have leadership championing the use of building performance simulation as a part of the firm's regular practice as it is to understand who will actually perform the simulations. And of equal importance is planning how such a cultural shift is carried out. Implementing any change in an organization is challenging, and managing that change intentionally makes the difference between random adoption and consistent execution.

In larger firms, it is important to have a member of executive management champion the change at the highest levels and to ensure adequate resources are committed. A staff member at the director level, for example, is appropriate for setting the tone for process and quality of simulations throughout the design process. This person can both perform simulations as well as guide and mentor other designers to perform single-aspect simulation early in the design process, assisting each design team in asking questions and providing answers using simulation.

In smaller firms, where many people may do some form of simulation, the important thing is to get started. With a willingness to learn and just weeks or months of time investment, an architect in a small firm can know enough about building performance simulation to see immediate results. A good entry point into simulation for architects is daylight, glare, solar, and shading simulations. These single aspect simulations can provide very helpful results to the designer without requiring much complicated work. When these single aspect simulations reach a level of sophistication, more advanced whole building simulations can be investigated.

Using simulation early in design—from preliminary evaluations and preliminary design early in schematic and into early design development—architects both use simulation to improve design outcomes and make important discoveries and decisions that improve communication with a third-party BPS professional, who may come onto the project during design development. If the design team waits until design development to have simulation performed by a BPS professional, the BPS professional can communicate what's wrong with the design, but problems may not be fixable. When the architect performs simulation earlier, the conversation with the BPS professional is more about fine-tuning design decisions than addressing design problems.

Regardless of its size, the firm must consider how its project delivery process supports achievement of the goals integral to high-performance design. If necessary, project delivery methodologies should be changed to intentionally align with performance outcomes. When firms do this, they address who needs to do what and in which sequence to truly align the process with desired performance outcomes. They also address which tools and resources are required when, and embed key items into QA/QC processes to ensure processes are executed consistently.

Culture change also requires communication. To promote a culture of performance, performance needs to become the subject of regular water-cooler conversation. Public display walls that show active projects and their pEUIs (see Part 3.1 for definition)—as well as finished projects and their performance data—encourage literacy and dialogue to make performance a real focus. Regular programs that allow staff to make presentations about project performance are another option. This kind of communication can create an aspirational environment, or friendly competition, as staff start to challenge themselves, wondering why their team reached a pEUI of 49 while another a pEUI of 27 on a similar project. Including project performance in the performance reviews of appropriate staff can also elevate performance as a professional responsibility.

3. Building performance simulation and the design process

This guide is intended to help the architect understand building performance simulation as it relates to the design process and the energy use of the resulting building. It uses the term "building performance simulation" to reflect the fact that building performance encompasses more than energy, and includes thermal and visual comfort, air quality, resiliency, and other metrics. That said, most building performance simulation is actually building energy modeling. This guide also uses the terms "single aspect simulation" and "whole building energy simulation" (see Figure 3.1). Each refers to a process that uses software, and each has a role to play in designing high-performance buildings that use less energy and reduce carbon emissions, but some key differences require an explanation.

Building performance simulation (BPS) uses a virtual replica of a building—a "model"—as well as building physics, weather data, and building usage patterns to determine how energy will be used by the building and its occupants. The model can be run through simulations over a period of time (e.g., one year or a shorter duration). Building performance simulations can also be run with climate change models to support building design that adapts to changing conditions.

Single aspect simulation uses building physics to simultaneously simulate a subset of important aspects of building energy performance. Examples include massing, orientation, daylight, glare, solar, and shading analyses.

Whole building energy simulation uses building physics to simultaneously simulate nearly all of the important aspects of building energy performance.

Whole building energy simulations are usually performed by "BPS professionals." The organization for BPS professionals is the International Building Performance Simulation Association (IBPSA). Whereas architects can receive training to become BPS professionals, that may represent a time-consuming specialty within architectural practice. Architects are likely to perform some, but not all, single aspect simulations. Thermal comfort and natural ventilation simulations, for example, are likely performed by BPS professionals.

This guide does not discuss building information modeling, a process which results in a 3-D digital representation of many aspects of a building and which is also used for work processes to support architects, engineers, and construction professionals in sharing project information more easily and working together more efficiently throughout the entire project lifecycle.

This guide does discuss a set of early investigations that may begin as early as the RFP phase of a project and are critical to the success of single aspect and whole building energy simulation. These activities are discussed further in Part 3.1 and include climate and site analysis, benchmarking, goal setting, and selection of a rating system (e.g., EnergyStar, LEED).

In addition to the term "simulation," this guide uses the terms "modeling/model," "analysis," and "optimize/optimization." A member of the design team engages in *modeling* a building, part of a building, or a process which results in a *model*. This model is then used to run *simulations* that allow the team to *analyze*, refine, and validate design decisions. The whole process of *modeling, simulation,* and *analysis* is used to make good design decisions that *optimize* building and systems designs to make them as functional, effective, and as close to perfect as possible. (See Figure 3.2.)

3.1. A common language for building performance simulation

One of the most daunting aspects for architects learning to engage with BPS professionals is the terminology. Whereas many of the concepts are familiar, there are specific ways that BPS professionals talk about creating and getting results from energy simulation. Understanding these terms can empower teams to evaluate their designs more deeply and discuss them in more nuanced language.

Architects are familiar with concepts involved in modeling, simulation, and analyses for design, but many do not include building performance simulation in the design process. Many models and simulations architects already use are also useful in energy simulation, especially early in the design process. Here are examples of investigations, models, and simulations with which architects may already be familiar and are also used in building performance simulation.

Figure 3.1

Single aspect simulation and whole building energy simulation are two categories of the wider building performance simulation process.

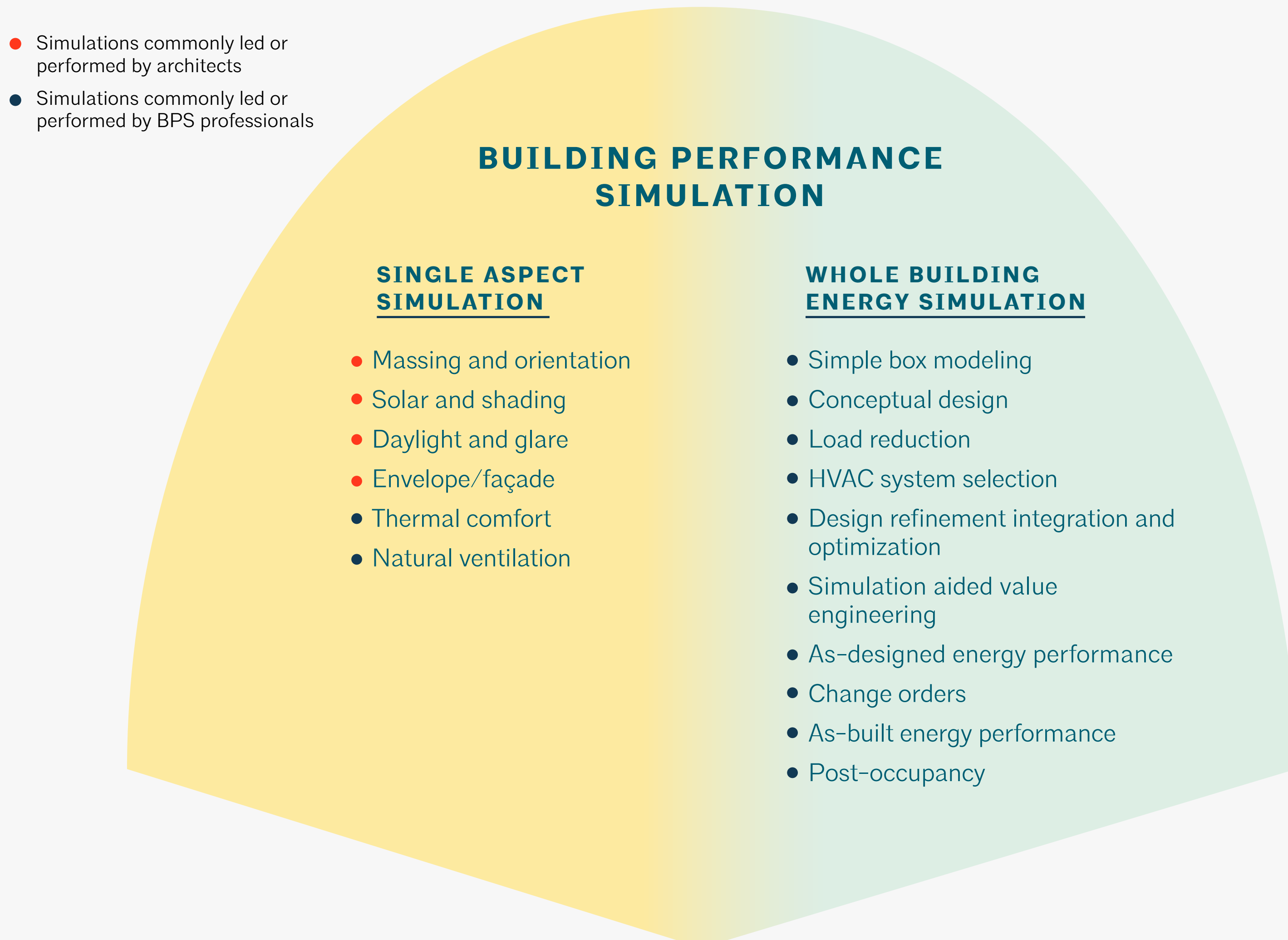
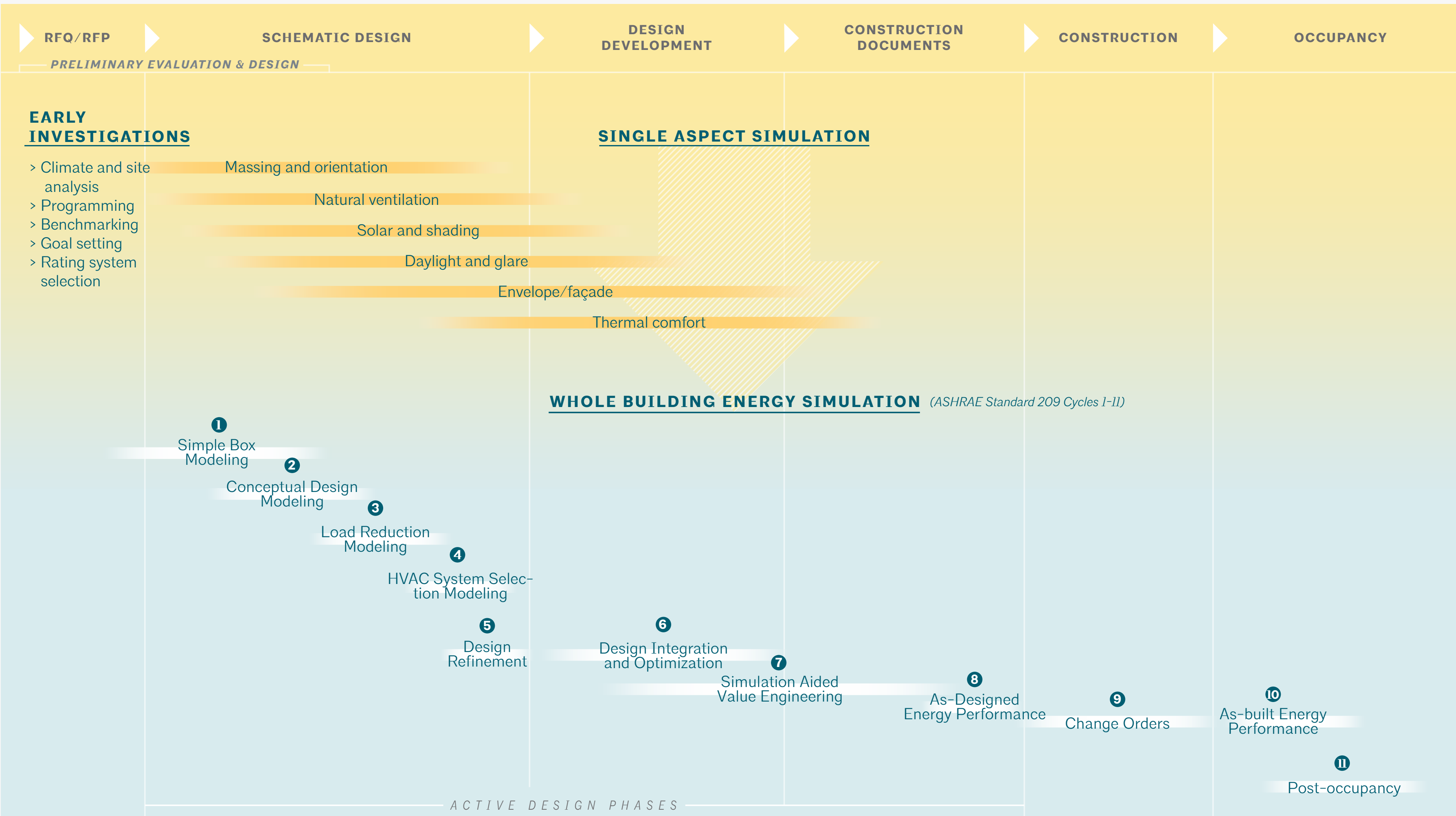


Figure 3.2

Various types of simulations and analyses are organized into three categories: early investigations, single aspect simulation, and whole building energy simulation (see Section 5.1. ASHRAE Standard 209 Building Performance Simulation Framework for more information about whole building energy simulation). These three categories can be roughly correlated to stages of the project and design process, from RFQ/RFP and preliminary evaluations and design early in schematic design through construction administration and occupancy. To design a true high-performance building, the architect and BPS professional work together throughout the project's life cycle. The modeling, simulations, analyses, and optimizations performed or led by the architect, however, are typically more intensive early in design and taper off as the activities of the BPS professional ramp up.



Early investigations

Climate and site analysis. A climate and site analysis consists of many things, including those which have the potential to significantly impact energy use, such as the effects of the sun and wind on the site. Architects and BPS professionals both conduct climate and site analysis, but it is important to note that ASHRAE Standard 209 (see Part 5.1) specifies minimum information collection about the climate variables (e.g., temperature, solar radiation), which may or may not differ from the information typically gathered by the architect. If the project will involve the work of a BPS professional, the design team should refer to the standard to ensure all necessary information is gathered. Climate and site analysis are performed early in the project, potentially in the RFP phase and during preliminary evaluations of the schematic design process. This analysis provides critical inputs to single aspect simulation and whole building energy simulation throughout the entire design process. Climate analysis should consider historical information as well as projections related to climate change.

Programming. Programming for design involves understanding the client's needs and goals for design. It also has energy implications. For example, locating high-intensity energy spaces adjacent to each other, rather than at opposite ends of a building, can significantly impact building energy performance.

Benchmarking. Benchmarking energy use is key to defining project energy targets. ASHRAE Standard 209 (see Part 5.1) defines benchmarking: "Determine the energy use of buildings with the same principal building activities in the same climate and determine their energy costs using applicable local utility rates."

Goal setting. Each project has unique goals and underlying criteria, which depend on project setting and requirements. Often goals inform the types of questions necessary for a particular type of simulation, as well as when to perform it during the design process. Sometimes it is the other way around, that is, the questions may identify the goals and simulation criteria. In either scenario, goal setting is critical to evaluating options down the road. Goals can consist of rating-system-related goals, financial goals, as well as EUI-related targets (see Part 3.1), HVAC design targets (enabling a certain system with a certain capacity), simple reduction targets, comfort targets, and so on, depending on the project.

Selection of rating system. Rating systems for buildings rate or reward building design based on compliance or performance according to specific environmental and energy goals and requirements. Examples include EnergyStar, LEED, Green Globes, Living Building Challenge, and Passive House Institute US. Which rating system the project team chooses depends on a number of factors, including project scope and location, allocation of project budget, and client and project team aspirations.

Single aspect simulations

Massing and orientation. Massing and orientation are critically important to energy performance as they affect the building's ability to take advantage of free passive solar energy and impact heating, cooling, lighting, and natural ventilation. Massing, orientation, and the layout of program within a building massing can be compared very early in design. Different options can be compared for overall solar availability and shading needs, for daylighting potential, for natural ventilation potential, and in other ways. Because options often need to be compared very quickly, a definitive EUI prediction (see Part 3.1), which can take two to three weeks to perform, is often not the best strategy. Instead, the design team should ask more specific questions about energy performance based on their knowledge of the program, climate, precedents, and knowns about the designs so they can be compared. Using building performance simulation software, when the building model information is loaded, it is easy to test multiple orientations with just one command.

Solar and shading. Solar and shading simulation is concerned primarily with radiation heat transfer (as well as daylighting and glare control). The simulation allows the architect to evaluate the impact of the sun on building design and shading strategies that may be used to maximize or minimize solar impacts, depending on the desired goal (e.g., passive heating in the cold season or reduced cooling loads in the warm season). Solar and shading simulations are typically performed by architects early in schematic design, and should result in the effective use of passive strategies to reduce the energy consumed by mechanical equipment (e.g., lighting and HVAC) and even reduce system size for first cost benefits. Part 6.1 provides greater detail about solar and shading simulation.

Daylight and glare. Daylight and glare single aspect simulations are common inputs to whole building energy modeling, especially now that daylight harvesting is often a code requirement. Daylight harvesting is a highly effective energy conservation measure, but glare is a human comfort and productivity concern, thus the two are simulated and analyzed together. Daylight and glare simulation is best performed early in schematic design and no later than design development. Often the simulation is conducted by the architect, but to effectively use the results in whole building energy simulation, the work should be conducted by a person with a keen understanding of building science. The goal is to introduce diffuse natural light into a space without also introducing glare and heat. Part 6.2 provides greater detail about daylight and glare simulation.

Envelope/façade simulation. Envelope simulation uses software to analyze the effective R (or U) value of various assemblies. Studies over the last two decades have shown that R-19 insulation in a metal stud cavity wall provides only about the value of R-9 because of thermal bridging.

More advanced envelope simulation software can also estimate the dew point and the drying potential of a wall assembly to reduce risks associated with moisture. Part 6.4 provides greater detail about envelope simulation.

Thermal comfort. Thermal comfort is one of the greatest sources of complaints in modern office buildings. Often people near under-insulated or highly glazed exterior walls are too hot in the summer or too cold in the winter. To compensate for this, mechanical systems are often asked to provide too much cooling in the summer and too much heating in the winter, leading those who are not near the exterior wall to complain. And, of course, all of those inefficient uses of mechanical systems impact building energy performance. Thermal comfort simulation allows the design team to understand and mitigate problem areas during the design phase. Thermal comfort analysis is especially important in naturally ventilated buildings because there may not be a mechanical system to "turn up" to mitigate complaints. Part 6.3 provides greater detail about thermal comfort simulation.

Natural ventilation appropriateness. This simulation is performed to determine the practicality of using prevailing wind available on the building site and the combination of external and internal air movement for naturally ventilating the building. (Ventilation being the supply and exhaust of fresh air to maintain space comfort and human health, which is separate from heating and cooling.) Natural ventilation can be used to provide ventilation as well as cooling for building occupants. Simulation results influence interior space programming and partition placement as well as window size and location. Part 6.5 provides greater detail about natural ventilation appropriateness simulation.

Whole building energy simulation is described by ASHRAE Standard 209, which is discussed in Part 5.1.

EUI is one example of a commonly used and heard term that has subtle nuances of meaning. From EUI and pEUI to site and source energy, here is a guide to the more common terms and how to tell them apart (See Figure 3.4.)

EUI and building use type

EUI is the primary metric targeted by the 2030 Challenge and tracked by the AIA 2030 Commitment. Performance-based energy codes also express targets in terms of EUI or predicted EUI (pEUI). It is also the metric that DOE uses to benchmark building energy use for the U.S. Energy Information Administration's (EIA) Commercial Buildings Energy Consumption Survey (CBECS).

EUI 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 dataset of metered information for a particular building type at a specific location. Both uses of EUI are based on real measured building energy use data. EUI can be measured in two ways: through site and source energy demand, and through production. (Figure 3.5)

Why do some buildings have much higher EUI 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 schedules, higher process loads, ventilation rates, and

Figure 3.5

Different building types in close proximity can have very different EUIs (kBtu/ft²/yr0).

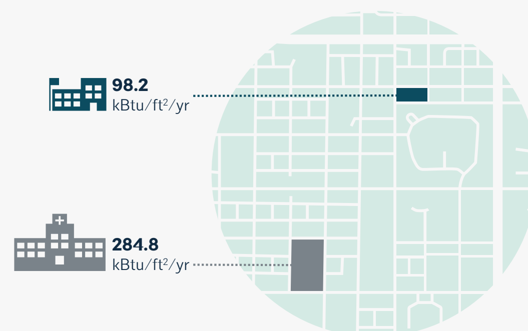


Image credit: Original graphic by Architecture 2030 for the AIA+2030 Online Series

Figure 3.4

Terms associated with common building energy simulation design inputs and metric outputs.

Energy Use Intensity (EUI)	A unit of measure of a building's annual energy consumption normalized by annual consumption relative to the building's area expressed as unit of energy/area/year. In the U.S, EUI is typically measured as total annual energy consumption (kBTU) divided by area in square feet and expressed as (kBTU/ft^2/year). 1 BTU is the amount of energy required to heat 1 pound of water by 1°F. One kBTU is 1,000 BTUs.
Predicted Energy Use Intensity (pEUI)	The modeled predicted energy use for a project, as measured by an energy model. It most often measures site energy consumption but can also account for source energy (see Figure 3.7).
Annual load	The total amount of energy needed to heat and cool a building to meet its setpoints. Annual load is proportional to annual HVAC energy use and energy cost.
Peak load	The maximum amount of energy needed to heat and cool the building over any one hour throughout the year. In the U.S., peak cooliing load usually takes place on summer afternoons while peak heating load takes place on winter nights. Peak loads are proportional to HVAC system "capacity" and first cost.
Site energy	The net energy produced and consumed by a building on the project site. It represents the energy consumed by the building as measured by the utility meter and reflected in utility bills, and is likely a primary driver for the client. It does not represent the energy used to, or the emissions from, providing energy to the building.
Source energy	All utility-provided energy consumed on the building site, which includes the energy consumed to extract, process, and transport primary fuels (e.g., coal, natural gas), the energy losses at power plants, and the energy losses in transmission and distribution to the building.

conditioning requirements. A small office building that supports 80 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.

Figure 3.6

A sample of median EUI scores of different building types from Energy Star Portfolio Manager. It is important to note that these are national median scores for building use types. It is recommended that design teams calculate a baseline EUI for each project using, for example, Energy Star Target Finder or Zero Tool.

Building type	Site EUI (kBtu/ft²/yr)
Bank branch	88.3
Education, K-12 school	48.5
Education, college/university	84.3
Convention center	56.1
Restaurant, fast food	402.7
Restaurant, sit-down	325.6
Grocery store	196.0
Healthcare, hospital (general medical & surgical)	234.3
Medical office	51.2
Hotel	63
Multifamily housing	59.6
Office (not medical)	52.9
Library	71.6
Convenience store	231.4

It is not appropriate to compare the EUI 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 to account for the factors of both climate and grid fuel source. To help understand a building's place on the energy use continuum, the table below provides a sampling of median EUI values (in kBtu/ft^2) in the United States. (Figure 3.6)

Many architects are familiar with EUI, and pEUI is equally important. Building performance simulation is essential to predicting EUI (thus pEUI) throughout the design process to get the best EUI possible while optimizing first costs. It is important to understand that "predicted" doesn't mean "actual" because building operation inevitably varies from the assumptions used in simulations that predict EUI. (See Figure 3.7.)

3.2. Goals, codes, and incentives

Building performance simulation is an important and helpful tool for the project team as they set goals for the project and design to meet relevant code and incentive requirements.

Goal setting

An effective team works closely to establish goals together toward consensus and accountability. Asking questions about project goals is critically important to understanding any high-performance building project. Goals can be direct outcomes of project attributes, such as use type or climate, based on client commitments, such as the 2030 Challenge, or in response to regulatory requirements or certification mandates. They can also focus on desired outcomes such as resilience or health. In those cases, the goal could be continuity of operations or percent of GSF to meet daylighting targets. Some clients are driven by life-cycle costs related to building performance. In regions where electrical rates spike at peak demand, clients may opt to prioritize peak load reduction to avoid peak rates. If the engineer sets a peak load target for the team, designers can evaluate strategies such as shading, chilled beams, stored ice, and load shedding systems that reduce peak load to help reach that target.

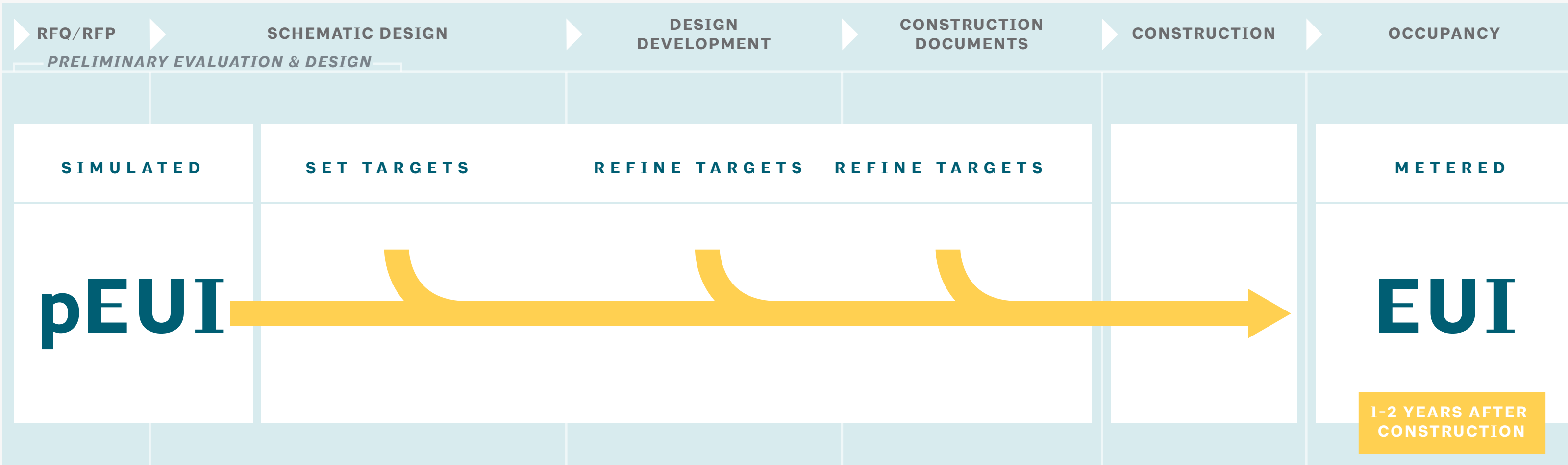
Energy codes

Using building performance simulation to demonstrate code compliance can be a necessity, depending on the project type and location. Using simulation early and throughout the design process can also inform design decisions and performance options to mitigate potential code compliance complications for any project. The architect, BPS professional, or project team member performing simulation should be aware, from the beginning of schematic design, which energy code or standard is adopted for the project and what documentation is required to demonstrate compliance. There are a few items worth consideration regarding code compliance and building energy simulation:

Prescriptive vs. performance codes. In some cases, energy codes offer only a prescriptive path toward compliance, meaning a building must include certain features, as spelled out in code language. Building performance simulation may or may not be important to meeting prescriptive codes. In many other cases, the energy code may offer an option for a performance-based path toward compliance. If the project happens to be in a jurisdiction that provides for performance-based energy code compliance, simulation may be the only viable means to identify the best way to achieve the required level of building performance. Many

Figure 3.7: pEUI throughout the design process

Building performance simulation to optimize energy performance refines the predicted energy use intensity (pEUI) as the design process evolves.



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state and local energy codes, as well as standards such as ASHRAE 90.1 and LEED v4, provide for performance-based approaches. When meeting these kinds of requirements, it makes sense to use building performance simulation to test and compare the impacts of potential design decisions throughout the design process via a series of iterative simulations.

Stretch, overlay, and reach codes. Stretch codes are voluntary appendices to state mandatory minimum energy codes. They allow municipalities to adopt code options to reach greater levels of energy efficiency and reductions of climate impacts. Reach codes are statewide optional standards that exceed minimum mandatory codes. Reach codes offer an optional path to high-performance buildings and cover topic areas such as structural, lighting, mechanical, and plumbing. Both stretch and reach codes are developed through the same public process as other codes, thereby providing consistency, and they may very well forecast changes coming to mandatory code.

Incentives

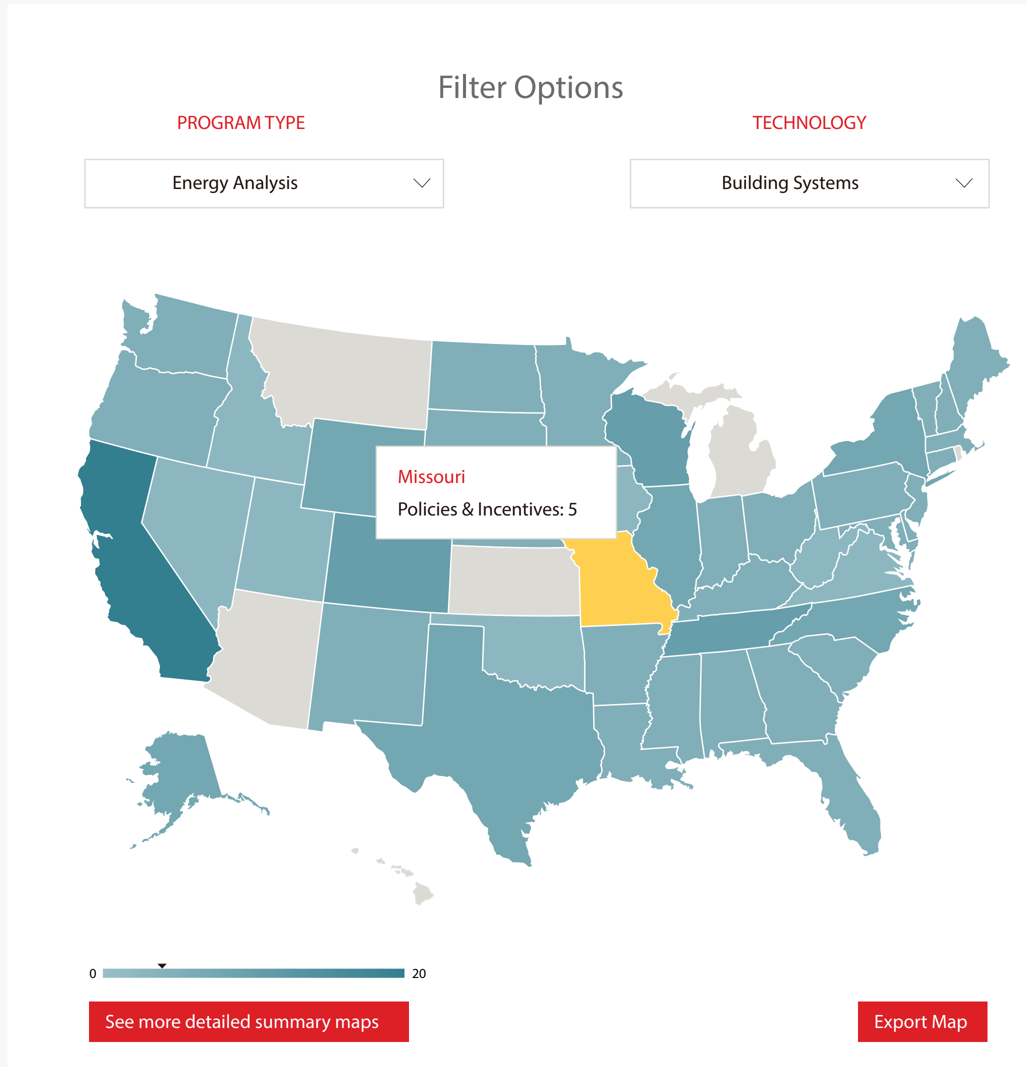
Local energy performance requirements, energy benchmarking, and disclosure ordinances are becoming more common both for new and renovated buildings. This can be a strong motivator for building performance simulation early in the design process. These kinds of incentives are clearly goal-oriented but do not necessarily provide pathways to the objectives. Building performance simulation can always be a critical pathway, but for a lot of reasons may make more sense when more immediate financial incentives are available to catalyze the process. Fortunately, plenty of such incentives exist via national, state, and local programs.

The DSIRE database (Database of State Incentives for Renewables & Efficiency®) is a searchable ZIP code–based compendium of statewide programs available for free, courtesy of a collaboration between DOE and the North Carolina Clean Energy Technology Center. It lists multiple policies, rebates, and other incentives available from federal, state, county, tribal, and local governments as well as utilities. It does not specifically cover incentives for early building performance simulation per se, such as lump sums for early energy simulation or dollar amounts per kilowatt hour of predicted savings. Most of the incentives take the form of grants, tax credits, or other financing strategies that may catalyze the use of building performance simulation for a particular project. Uncovering the pertinent incentives requires some research and drilling down into specific jurisdictional requirements for specific projects.

Checking with your city or county government about the existence of stretch codes may reveal additional incentives to perform building performance simulation. Such incentives often include fast-track permit issuance, reduced fees, or high-profile community relations. (Figure 3.8)

Figure 3.8

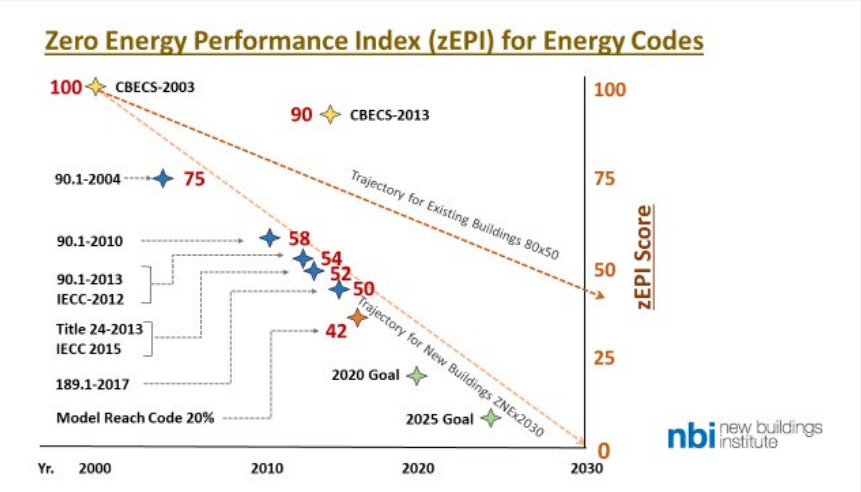
The DSIRE database allows the user to filter building energy performance incentives by specific program criteria and geographic regions.



Zero targets

Architects and clients sometimes set zero-energy-type targets for a project. Zero targets require simulation-aided design iteration. Project teams that achieve these targets work closely together to maximize passive systems and optimize active systems before adding solar or procuring renewable energy. Project teams that seek zero targets should be mindful of climate projections. Here is a guide to commonly used "Z" terms.

Net zero energy (NZE)	The amount of energy demand is equal to the amount of production by renewable sources, annually. Renewable energy production may or may not be generated on-site. It is worth noting that DOE no longer uses the word "net" and considers it implied in the term "zero energy." (See DOE definitions)
Zero net carbon (ZNC)	A zero net carbon building is highly energy efficient and produces on-site, or procures, enough carbon-free renewable energy to meet building operations energy consumption annually. (See Architecture 2030 definition)
Zero energy building (ZEB)	An energy-efficient building where, on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported energy. The ZEB concept has expanded to include definitions for zero energy campuses, communities, and portfolios. With this expansion, the site in "on-site" can now be defined as a group of building sites in a specific locality that have renewable generation and that are owned by a single entity or multiple entities, or that are leased by a single entity. (See DOE definitions)
Zero Energy Performance Index (zEPI)	The score of a proposed building's EUI compared to a reference building model. The scale for measuring commercial building energy performance ranges from zero for a zero-energy building, to 100 for a building that uses the same amount of energy as the baseline model. The zEPI score provides a common language for progress and energy targets over time. The zEPI's absolute scale supports consistent energy code development, which means building performance simulation tools and protocols do not need to be reengineered to adapt to each code revision.



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4. The building performance simulation process

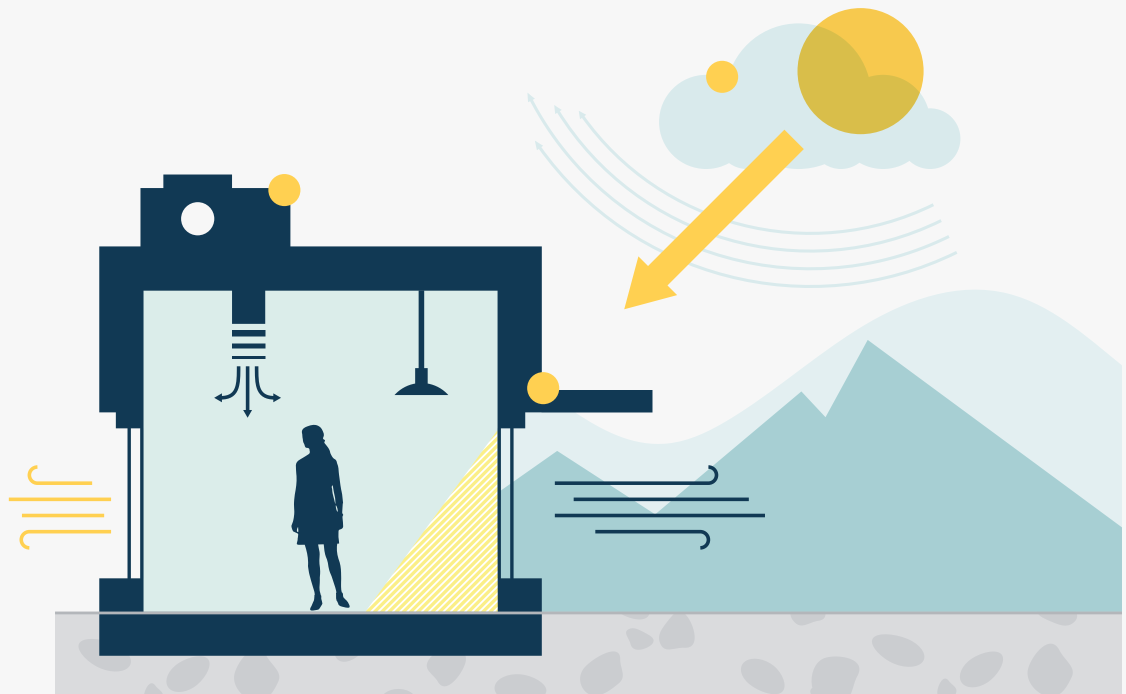
4.1. How building performance simulation works

To perform building energy simulations, the user chooses from a variety of software tools (e.g., Sefaira, Autodesk Insight, EnergyPlus). There are three parts to energy simulation software that can be packaged together or distributed separately:

- An “engine” contains the calculations and algorithms to perform simulations. The engine uses a description of building characteristics, operations, and ambient conditions to simulate physical processes and calculate critical information such as annual building energy use and peak loads.
- A 2-D or 3-D modeler allows geometry to be entered into a software package. This can be done using a separate program to develop a model which is imported into and runs in building performance simulation software. Or the building performance software may have an interface that functions as a plug-in to a 2/3-D modeler. Or the building performance software has a 2/3-D modeler “built-in.”
- A user interface allows the user to work with an engine and 2-D or 3-D modeler to create energy simulations and outputs.

Figure 4.1

Building performance simulation uses a virtual replica of a building—a “model”—as well as multiple aspects of building physics, weather data, and building usage patterns to determine how energy will be used by the building and its occupants. The simulation supports analysis of multiple factors that affect building energy performance, such as local ambient conditions, physical characteristics and processes, and operations of the building design.



Building energy simulation software uses data inputs provided by the user and assumptions about building systems and schedules. The assumptions may be built into the software such that the user has little knowledge or control; or they may be presented as simplified inputs, such as templates with predefined defaults. The user may choose from these defaults as inputs, especially early in design, which can make the software easier and faster to use.

Also, in early design, software may use partial information to perform single aspect simulations that answer questions about specific options such as massing, orientation, solar, shading, daylight, glare, and natural ventilation. The shoebox model is one such example. (Figure 4.2) It represents a small, discrete, and isolated portion of a building and that portion's energy performance. Shoebox models can provide useful information regardless of their simplified inputs such as geometry, internal loads, and HVAC.

Inputs

The accuracy of the energy simulation is directly dependent on the accuracy of inputs. Regardless of who performs simulations, the architect needs to provide inputs associated with the passive design features they control, as well as the building uses they know about. The more information available for the person performing the simulation—whether an architect or BPS professional—the more useful the results.

Tapping into a BPS professional's expertise can help determine if there are other needed inputs. Part of building performance simulation involves the explicit identification of assumptions, such as schedules, comfort standards, window-to-wall ratio, material and insulation characteristics, light-level inputs, and passive strategies.

Figure 4.2

A shoebox model is a type of single aspect simulation and represents an isolated portion of a building.

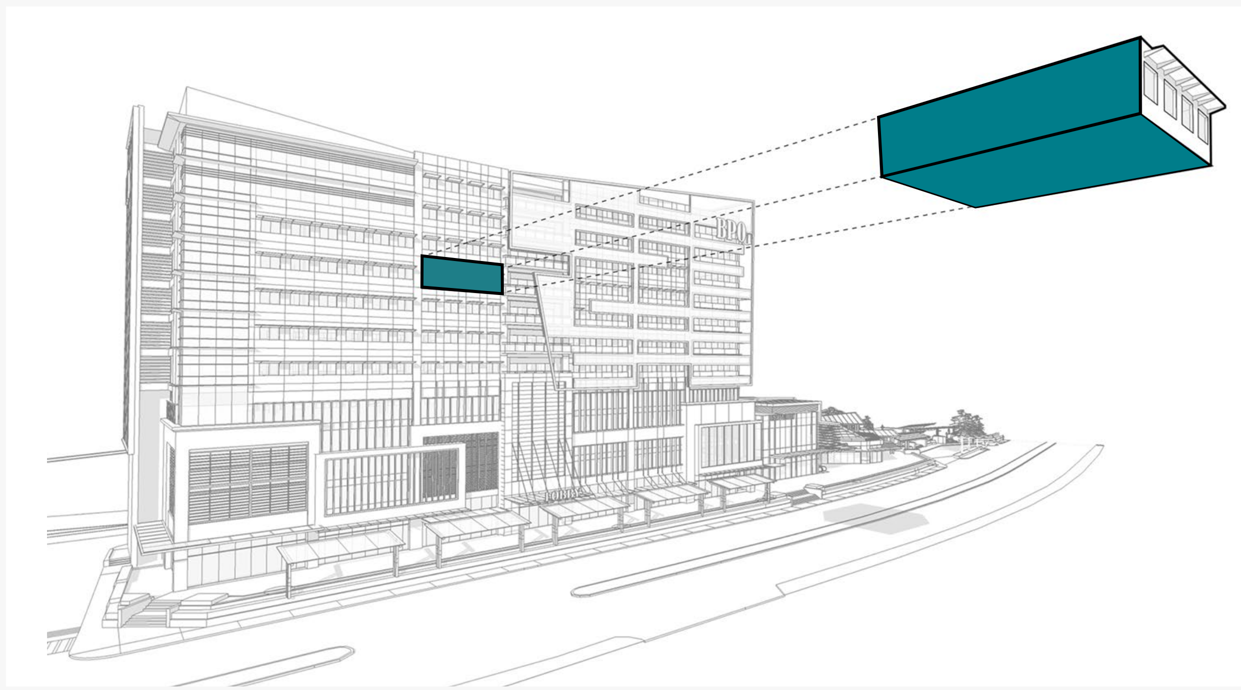


Image credit: Courtsey of CallisonRTKL

Figure 4.3: Design elements and simulation inputs

Common inputs for building performance simulation to optimize energy performance. In many cases, standard default values are available for the variables that are unknown early in design.

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

Common inputs to reach thermal comfort targets (e.g., air temperature, mean radiant temperature, relative humidity) are generally assumed based on ASHRAE Standard 55 – *Thermal Environmental Conditions for Human Occupancy*. For projects using natural ventilation, with an abundance of glass in extreme climates, or with low-energy aspirations, additional conversations are warranted with the design team and the client to consider adjusting the targeted comfort range. Part 6.3 covers thermal comfort in more depth.

As simulations develop, the architect or BPS professional (or both) should review and confirm inputs and outputs. Using simulation iteratively throughout the design process allows opportunities to identify and test additional design decisions that might not have been considered initially and that can improve the performance of the building. (Figure 4.3.)

Location. Building energy use is greatly affected by location, which determines climate and weather impacts. It also has its own effect on a building through geographic features (e.g., mountains, skyscrapers, waterways) that can influence natural forces such as prevailing winds and solar access. Evaluating design based on local geography can help the design team incorporate these natural forces in project design. When carbon is considered in design goals, it's worth noting that location also informs electrical grid fuel mix for emissions tracking. (See Figure 4.4.)

Climate and weather. Most building performance simulation tools require weather files with location-specific climate information to perform analysis. Typical information found in weather files includes air temperature, humidity, prevailing wind speeds and direction, precipitation rates, and solar radiation.

Figure 4.4

EUI can vary significantly by building location.

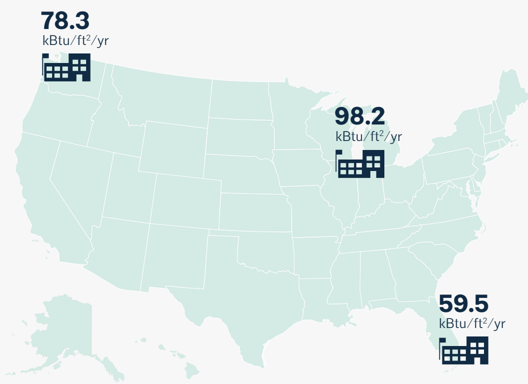


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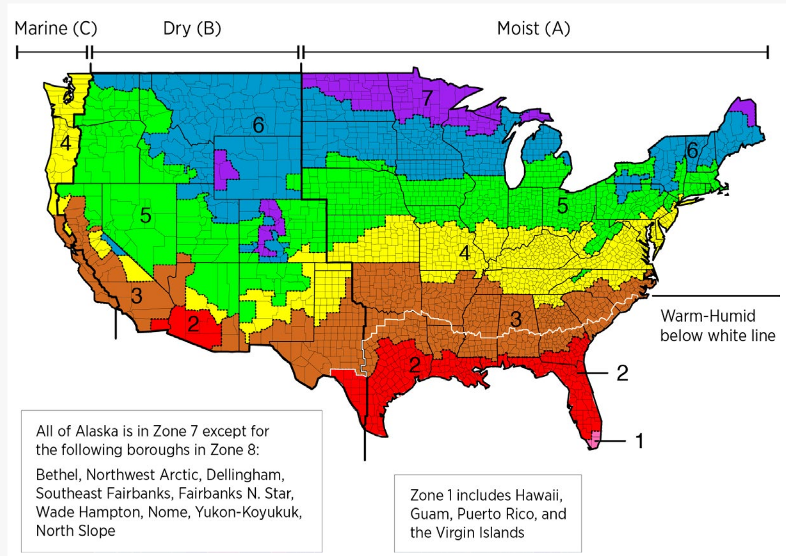
Figure 4.5

Architects may identify a project's climate zone using a map such as this one from the IECC. However, given that climate change continues to alter historic weather patterns, such existing climate region maps may be less reliable. WeatherShift has location-specific maps and analytical data adjusted for more recent and projected climate data. For a fee, the Passive House Institute US also has specific climate datasets available.



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There are several different types of weather files. Typical meteorological year (TMY) files represent typical conditions over a range of years. For example, the current TMY3 files represent weather from 1,200 locations for the years 1991 to 2005 in the United States. TMY3 files are available from the National Solar Radiation Database. International weather data are also available.

Because of the rapidly changing climate, TMY3 files are already outdated. Online services, such as WeatherShift use climate change projections to create approximate weather files for specified future years. Climate projections are especially important when designing for climate adaptability and net zero energy. For buildings that can maintain occupant health without the electrical grid, or produce as much energy as they consume (or both), it is important to understand changing climate conditions and design to more extreme parameters such as higher and lower temperatures, increased or decreased precipitation, and more extreme weather events. The AIAU course "Responding to Climate Change" covers important knowledge and resources. The National Climate Assessment and the Georgetown Climate Center are also excellent resources. Depending on location, a project may need to comply with a local climate adaptation plan. Although architects should design to that plan, a site-specific evaluation is still critical.

Architects should explore tools that can customize weather data to the specific site context. Most weather files are built using data collected at airports. Some of this data, especially wind direction and speed, are not helpful when designing a building in the downtown area of a city the airport serves. Most airport sites are flat, open areas with no trees and far away from densely built areas. Most buildings, however, experience modified local temperature and wind conditions because of tree cover, adjacent buildings, and microclimate effects such as urban canyons and heat islands.

Outputs

Building energy simulation can provide information beyond annual energy use to inform design decisions. Simulations can break down energy use into smaller time increments (e.g., by hour or month). It can provide valuable information on energy end use (e.g., heating, lighting, cooling, ventilation, plug loads, and water heating). Smaller increments of energy use over time and energy end-use detail show how different design options have interrelated effects on energy performance. For example, larger window areas reduce lighting energy use, but they can also increase heating and cooling loads and cause glare. Shading can reduce cooling energy demand, and natural ventilation can reduce cooling and air distribution energy use. Building performance simulation evaluates the building as a system of systems in which adjusting one strategy will produce a variety of outcomes.

Building performance simulation can also produce zone-by-zone temperature profiles for thermal comfort metrics, simple lighting profiles, airflow profiles, and other reports that can be used to evaluate zone conditions. Similarly, single aspect simulation can optimize solar shade sizing to allow solar heat gain in heating months while reducing solar heat gain in cooling months. Understanding some of the questions building energy simulation can analyze is critical to making effective use of these simulations in design.

Ultimately, the true success of building energy simulation depends on the accuracy of inputs. Many things will and should change as the project progresses and the designer uses simulation to test ideas and make good decisions. These informed decisions later become the real and accurate inputs for simulation. This process is similar to cost estimation. In the early stages of the project, the design team uses comparables and gross assumptions about cost to test design ideas and make decisions that provide the team with more specific detail, so they can later identify actual costs.

Single-family residential versus commercial and institutional

Beyond location, energy use varies by typology. In all but the mildest climates, thermal loads dominate the energy demands on single-family residential. Whereas the loads for commercial and institutional projects are most often driven by the internal systems and processes (lights, equipment, people). Most commercial and institutional buildings in the United States, even in northern climates, must be able to cool interior spaces year-round; while most houses, even in southern climates, will experience times when the cooling system is off. Houses are lightly occupied during the day and occupied overnight. The opposite is true for most commercial buildings. These major differences explain why in most cases it is especially critical to optimize the exterior envelope for single-family residential projects and optimize systems and schedules for commercial and institutional projects. (See Figure 4.6.)

Different energy codes apply to the two different types, and they call for different building performance simulation tools to analyze their performance. In general, residential performance simulation programs are relatively simple to use with relatively few user-entered inputs. The opposite is true for commercial building performance simulation software. Many commercial building software programs can model residential building performance, but it is like swatting a housefly with a jackhammer—unwieldy, expensive, and unable to provide much better information than the simpler programs tailored for residential.

4.2. The importance of asking questions

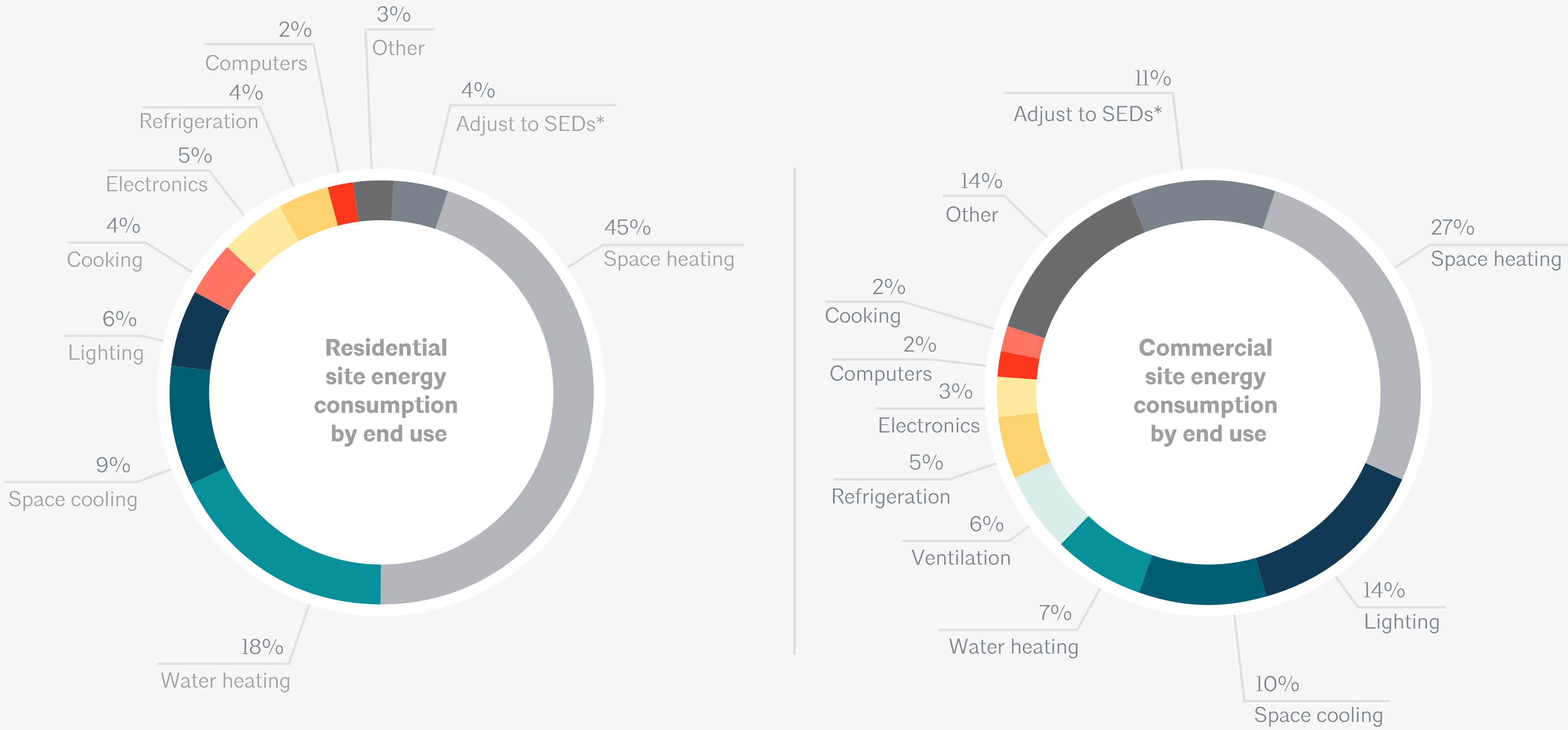
Successful design starts by thoroughly defining design challenges, such as site and budget constraints, or typology adjacencies, which establish parameters for the project to follow. Often the limitations of these parameters define and strengthen the design. Whether it's a tight site, a compressed program, or bold energy-reduction targets, understanding and solving difficult problems brings out the best in any design team.

Designing for high performance is no different. The project team must develop a deep understanding of the client and aspects of the project, such as the building occupants, climate and weather patterns, relevant regulations, the site, and its context. Additional factors such as client or jurisdictional commitments to rating systems or climate change mitigation and firm goals and standards that factor into decision-making must also be clearly understood. Often, as these parameters are being discussed, the design team has questions about building performance. Clarifying these questions is the best way to begin the early building performance simulation process. This deep understanding sets the stage for simulation-driven analysis moving forward by helping to identify which questions to ask as design proceeds.

Asking for building performance simulation is akin to selecting from a menu: The more specific and informed the selection, the fewer surprises in the outcome. In-house staff or third-party consultants are likely to aid the process of figuring out which simulations to order. Considerations such as the type and depth of analysis, design stage, and cost will influence the type of simulation best suited for the project.

Figure 4.6

Energy-efficient design for residential vs. commercial buildings is very different, as the two building types have very different energy use profiles. For this reason, different building performance simulation programs are often better, if not necessary.



*Adjustment made by the Energy Information Agency for it's State Energy Data System (SEDS)
(Recreated from the 2011 Buildings Energy Data Book)

The first step of any energy analysis is to formulate questions about building performance. As simulation is integrated into the design process, a series of questions will guide the overall simulation trajectory. Asking how much energy a building will use is a common question, but the answer doesn't necessarily affect design decisions. More appropriate questions are more specific and reflect the design team's understanding of client, site, typology, and other knowns. For example, what is the comparative energy use of four massing options? Or what are the largest five uses of energy in my building? In general, it is easier to answer questions that compare the performance of multiple options, rather than the absolute performance of a single option during the early design process, because at this stage the design lacks clarity, and it is very time-consuming to provide absolute performance predictions. Questions should be asked only when the answer can affect design.

Ask questions:

- About things the team can change
- About things the team believes are important to performance
- As a group
- Specific enough so that the answer can be acted upon
- That align with the client's goals
- That determine which design aspects are beyond the architect's ability to change because of, for example, program, design vision, or buildability
- That consider annual energy use, peak energy use, and qualitative design aspects such as comfort and daylight

For architects, these questions often involve building-envelope passive systems related to peak cooling and heating loads that are under the architect's control. Peak cooling loads are generally heavily influenced by windows (glazing percentage, shading, and solar heat gain coefficient). Peak heating load reductions generally involve opaque and glazed insulation values, and may involve any passive system or strategy, such as heat storage in thermal mass. Questions about peak demand reductions can lead to cost savings. Similarly, questions about which systems outperform others on a relative basis can prove beneficial.

4.3. Interpreting and communicating results

Simulation results should be intelligible and actionable. If the architect is performing the simulation, this is a self-reflective demand. If a BPS professional is performing the simulation, the architect should request a specific output in a visual format, such as a graph, 3-D diagram, or spreadsheet. Too often results of otherwise useful simulation are sent to the architect as pages of numbers. The numbers make sense to the BPS professional, but they are not always intelligible enough for the architect to understand or explain to the client. In such cases, simulation has not fulfilled its basic goal of informing decision-making. The architect can speak directly with the BPS professional about results and interpretation of the simulation. In many cases the discussion will spur more options to be tested.

Another option is to ask for graphical outputs from the simulation—charts, graphs, or other visualizations that highlight the answer to the question at hand. This takes more time for the BPS professional than talking about the results but is much more comprehensible and useful for most architects and their clients. Sending the BPS professional example graphics can be useful. In any case, trying to communicate complex data to the design team or clients (or both) is critical and takes a deliberate, thoughtful approach. If the person who performed the simulation doesn't provide graphics, the architect often needs to create them. (See Figure 4.7.)

4.4. Choosing the right tools

As with any software solution, not all building performance simulation software is created equal. Much like buying a car, choosing a specific make and model depends on needs, resources, and expertise. There are several important attributes to consider, including:

- Types of inputs the software allows
- When it is appropriate to use the software
- How customizable it is to unique needs
- How it integrates with other 2-D and 3-D design software, such as BIM and CAD systems
- Its visual output capabilities

The decision of which software to use is up to the user; this guide does not advocate for any particular software. Many architects prefer a single 3-D modeling program, so checking that a given software works with that 3-D program is important. The federal government, through DOE and its national laboratories, has developed a suite of software generally available for free. Other software may come from private developers at a price, and others are freely available via open source shareware. Since the first AIA energy modeling guide debuted, the U.S. affiliate of the International Building Performance Simulation Association (IBPSA) took over management of DOE's Building Energy Software Tools web directory (BEST-D). Vendors regularly update this query-based database of software packages and their capabilities.

Figure 4.7

This collection of design and simulation results from a variety of projects by CallisonRTKL demonstrates the wide variety of options for organizing and presenting results in a way that is useful and comprehensible to architects and their clients.

Hotel

Hanoi, Vietnam

The design team wanted to use simple vertical rods in the façade, balancing the need for views from the hotel rooms with the need for shade. An annual solar study was performed during the early design phase to compare two options to a baseline without shade. Average daily values for the summer period are shown. Option 1 provides a 19 percent reduction in solar gains. Option 2 has more rod density located to block the summer afternoon sun and provides a 34 percent reduction in solar gains while still allowing views. Option 2 was selected for further development and analysis with building performance simulation.

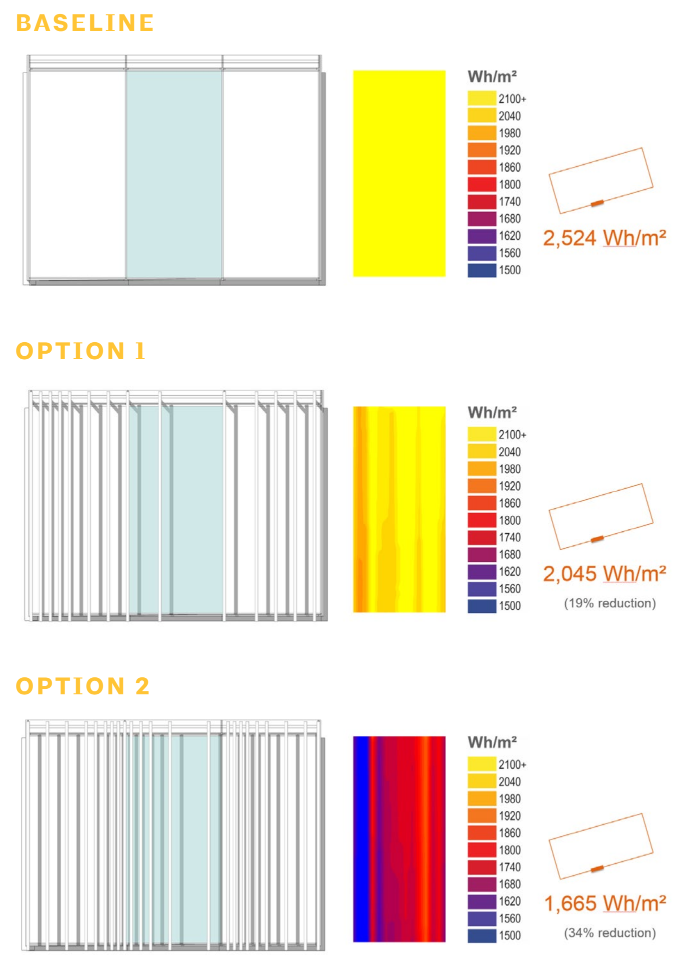


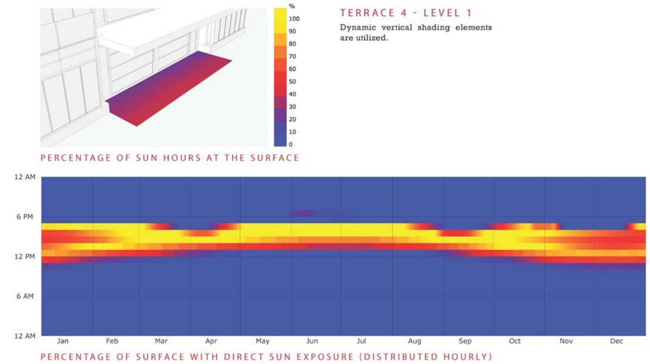
Figure 4.7 cont.

Retail

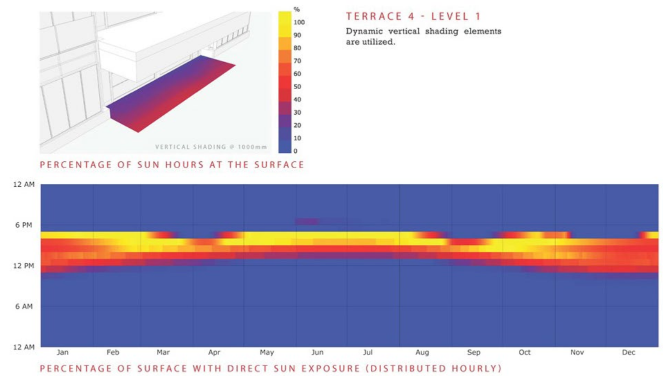
Middle East

The goal was to maximize outdoor comfort in the courtyards of a shopping mall in the middle east. Predicted mean vote (PMV) (see Part 6.3 Thermal Comfort) was calculated at different times and dates. Shade is a known prerequisite to achieve thermal comfort in the seating area during warm days. This study shows three different options: option 1, is a simple overhang; option 2 features a 1000 mm vertical shade; and option 3, a 2000 mm vertical shade. The images show, for each option, both the annual percentage of sun hours on the surface sensors in the terrace and the percentage of the surface with direct sun exposure distributed hourly over the year. With this analysis it is possible to understand the distribution of solar intensity over time and over the surface of the seating area. The study demonstrated that the overhang was not enough to provide shade to this space and additional operable shading was needed.

OPTION 1



OPTION 2



OPTION 3

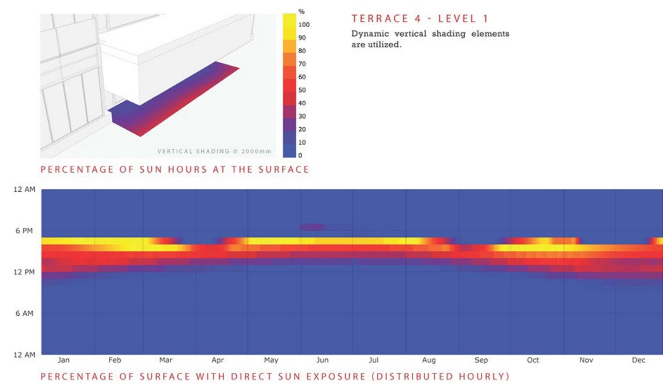


Figure 4.7 cont.

Shopping mall food and beverage area

Melbourne, Australia

The client wanted to minimize direct sun exposure on the food and beverage area located below a glass canopy. Several options for minimizing direct solar gain were studied at the master plan phase. Three options rely on extending the dimension of the structure underneath the glass. The dimensions of the “solar responsive” option are generated parametrically from the centroids of the areas indicated in the summer solar study. Two options are based on sawtooth design, and the most effective is the “30sawtooth.” By angling the sawtooth to minimize summer direct gains, it reduces solar gains by 83 percent. The “30sawtooth” option was selected for further development and testing.

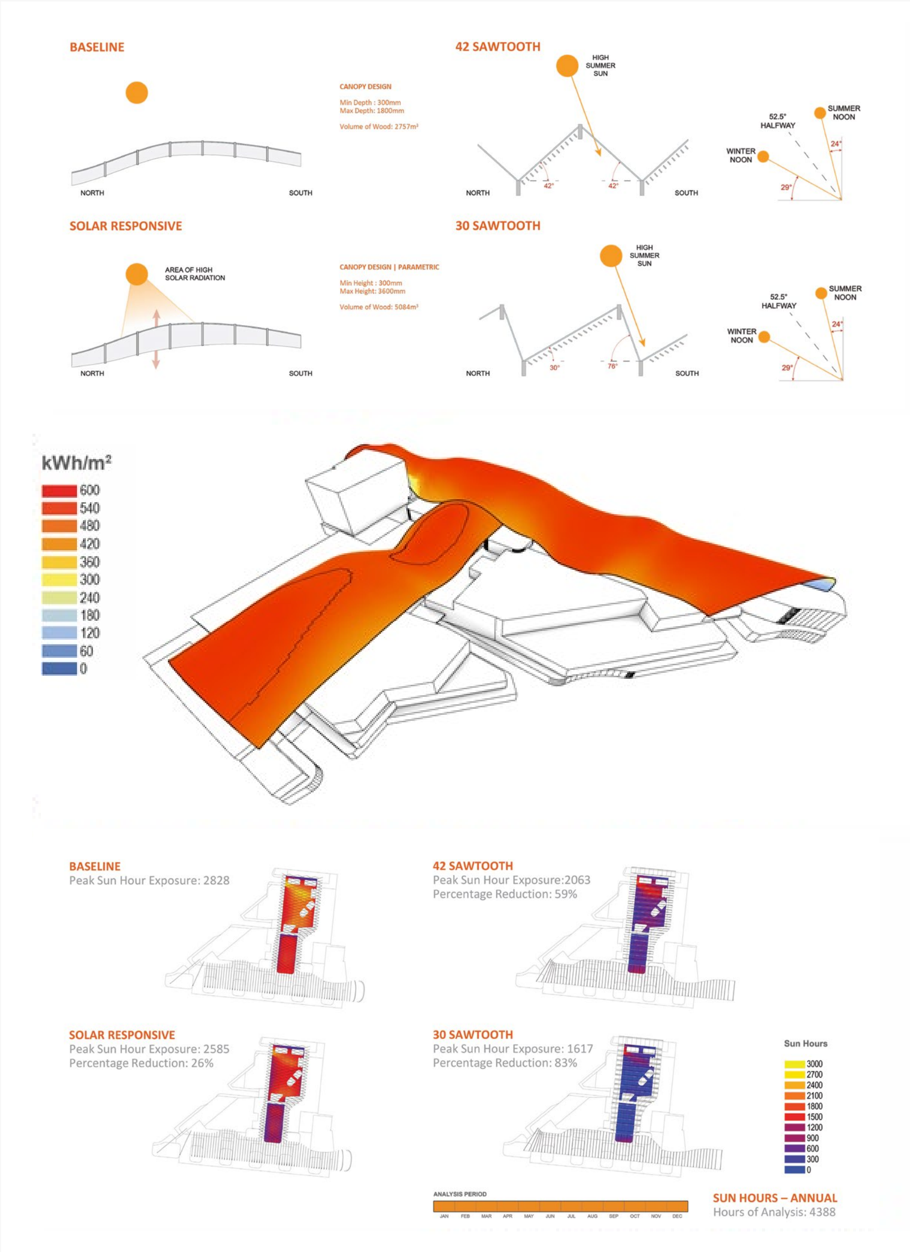


Figure 4.7 cont.

Retail

Abu Dhabi, United Arab Emirates

This shading system was proposed for a glass canopy in a hot, dry and sunny location. The goal was to provide daylight with minimal direct solar gain. Climate analysis indicated it was important to reduce solar gains all year, especially in the summer. Several options were compared during early conceptual design, with annual or seasonal solar studies. One of the summer studies is shown. Option A had the lowest direct sunlight exposure (38 percent), blocking 62 percent of direct sun. Additional reductions in solar gains are achieved when combined with low solar-heat-gain -coefficient (SHGC) glass. Option A was selected for further development and testing for daylight and energy.

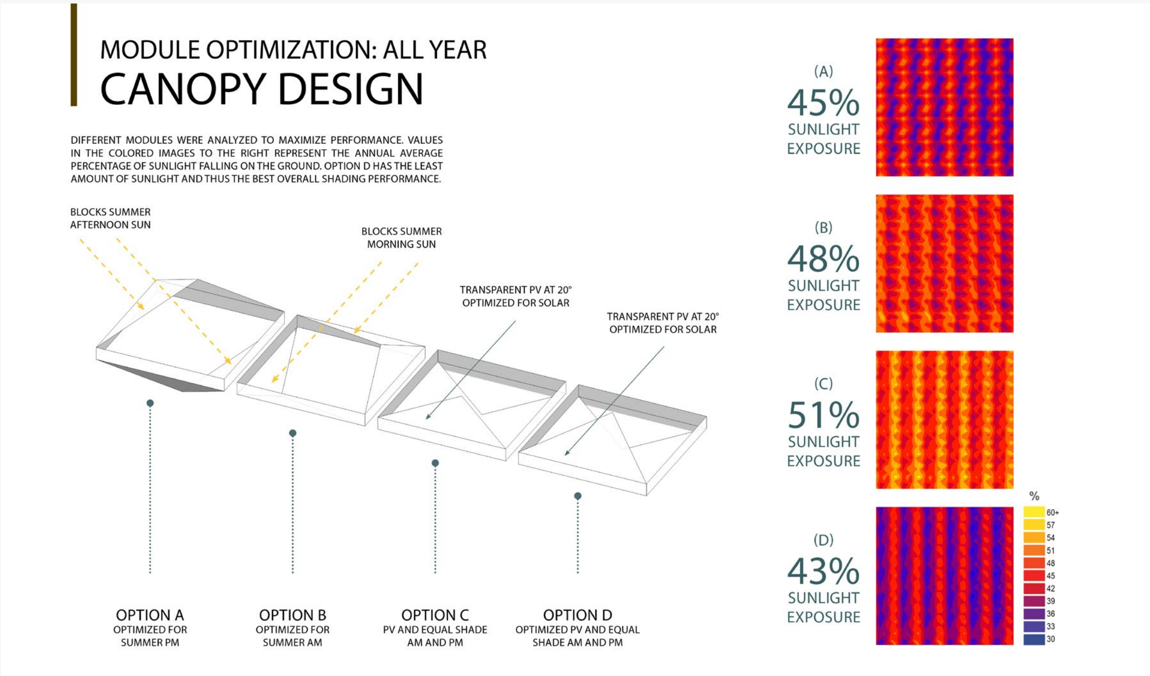
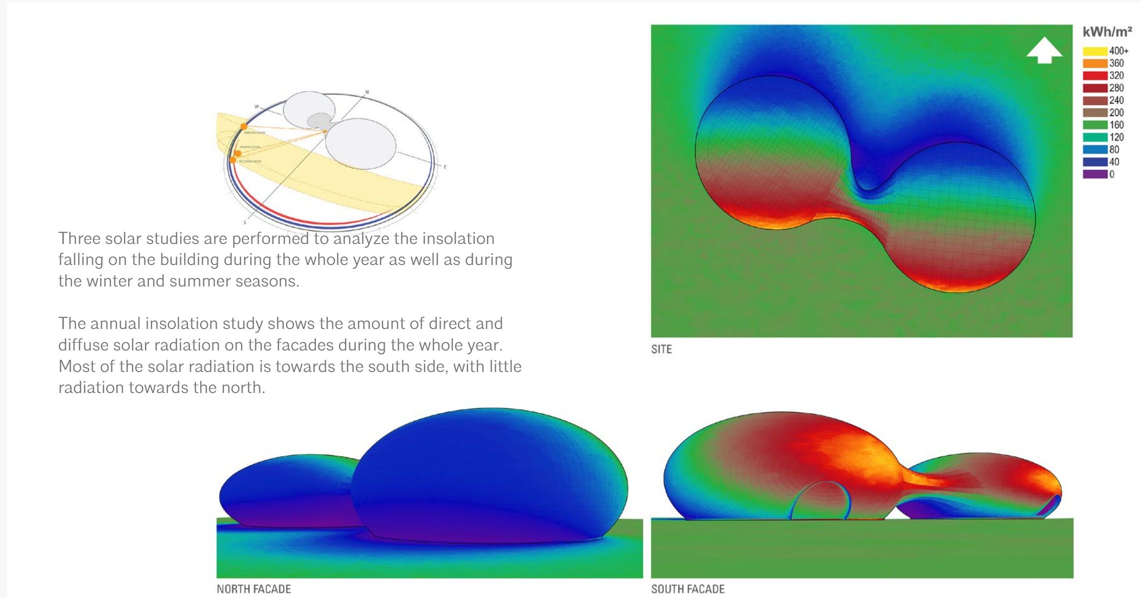


Figure 4.7 cont.

Event space

Harbin, China

The client wanted maximum transparency for an event space in a city with a very cold winter and a warm summer. Control of heat losses and gains through this mostly transparent envelope were very important considerations. Summer and winter solar studies helped define envelope areas that needed more opacity in the summer to block solar gains and more transparency in the winter to provide more solar gains. An operable louver system in key areas to block solar gains in the summer and provide transparency for greater solar gains in the winter is proposed. Additionally, an annual study (not shown here) helped locate PV systems for maximum solar production.



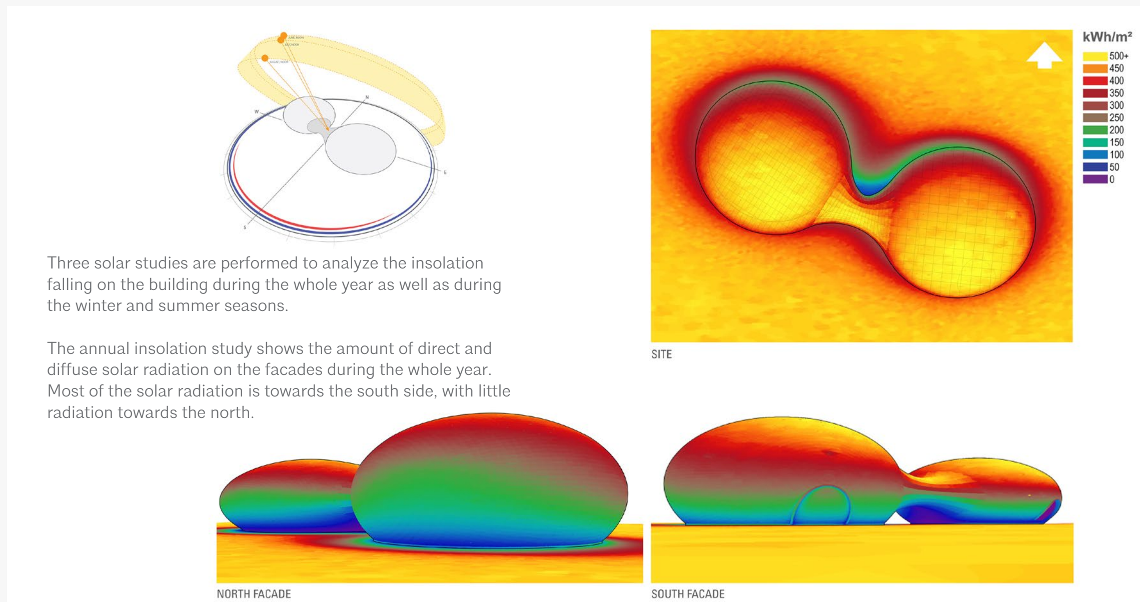
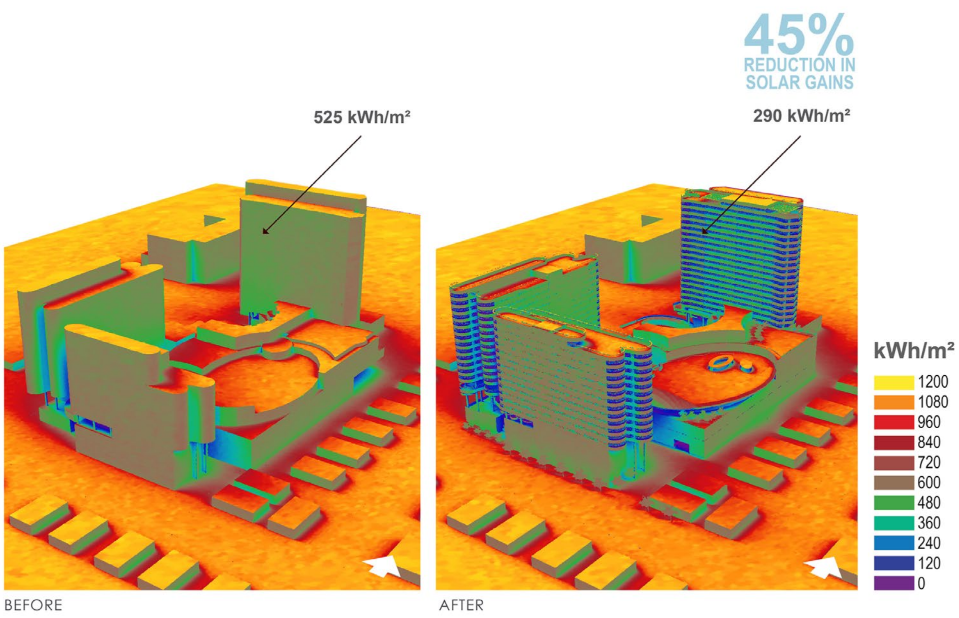


Figure 4.7 cont.

Competition for a hotel and mixed-use development
Anaheim, California

The goal was to determine critical façades and estimate potential reductions in solar gains provided by different shade options on the building. Horizontal fins were designed using the sun shading chart in the Climate Consultant program. The simulation shows 45 percent reduction of solar gains in the south façade with horizontal elements. The result was that shade was implemented for the competition proposal.



In addition to searching by software capabilities, a price-based query is also available. Firms can use the BEST-D site to investigate software that best meets their needs for free or at low cost.

There are many building performance simulation tools available, and it is important that the architect select the tool that will best answer the question at hand. Early-phase single aspect simulation tools should be able to quickly provide an accurate answer using minimum inputs, while more detailed inputs are associated with later-phase whole building energy simulation.

Whether for early-phase analysis by an architect or later-phase analysis by a BPS professional, any software tool selected for use has to be validated to ensure it provides valid results. The software developer should make evidence available that the software has been tested using the Building Energy Simulation Test and Diagnostic (BESTEST) method in accordance with ASHRAE 140-2014 – *Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs*.

Here are some questions to ask when selecting the most appropriate simulation tool for your firm:

Ease of use and support

- What is the learning curve of the program?
- Do new or incoming staff already have knowledge of the program from architecture school or other past experience?
- Is the tool already used in a firm's other divisions or offices?
- Are technical and training support or user groups available from the developer, and at what cost?

Time and cost

- How much time is needed to input required data and for the program to process the information and provide required outputs? Does the amount of time needed correlate with the rate at which design decisions are made? How does this compare with similar tools?
- What is the cost of the tool and how does it compare with similar tools?
- Is the software purchased or rented? Is there a cost each time the software is used (e.g., for cloud-based analytics)?

Interoperability

- Can the program easily import a 3-D architectural model? Does the model have to be created inside the program, or is the program a plug-in that runs inside another program?
- Does the energy simulation program support interoperability with 3-D tools commonly used by the firm and its consultants?
- When importing from a 3-D architectural model, how much cleanup time is needed for the calculation engine to work appropriately?
- Are there opportunities to use the model and results in other simulations, including life-cycle and carbon analysis modeling?
- Is the tool compatible with the tools used by the firm's sustainability and energy simulation consultants?

Input

- Are there default values and assumptions that can be used during the early-phase design? Are these defaults appropriate?
- Is it feasible to quickly change defaults and provide more detailed inputs?
- What is the minimum number of assumptions that this tool needs defined to perform an accurate building energy simulation?

Output

- What type of results does this tool generate (e.g., overall energy use, daylight, glare)?
- Are the results generated by this tool easy to understand, and do they answer the question posed?
- Will this tool generate the requisite code or LEED compliance paperwork?

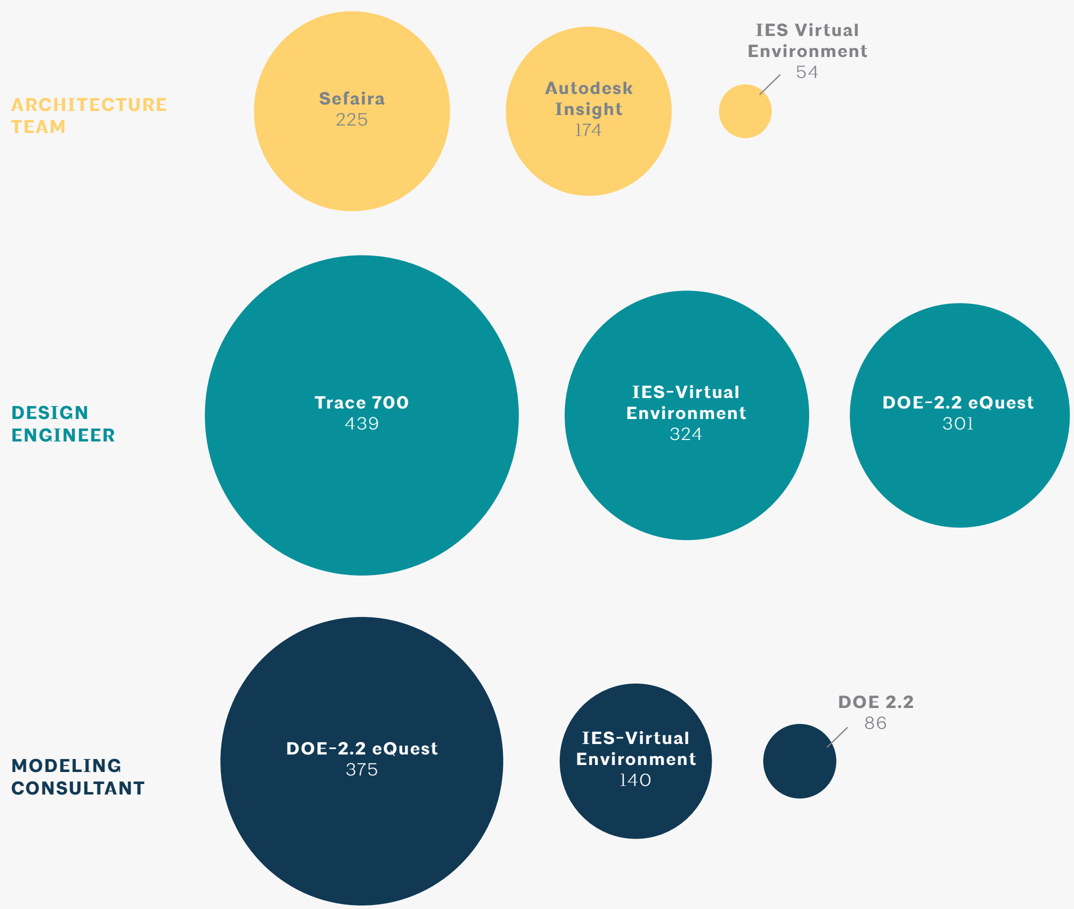
Accuracy

- Do the results provide the required accuracy to answer the problem in the current phase of problem resolution?
- Can this tool be used for final compliance, conceptual modeling, or both?
- Is the simulation engine validated according to a reputable industry standard?

For further assistance, use the AIA's Ask Building Performance resource. (See Figure 4.8 for frequently-used building performance simulation software tools.)

Figure 4.8

Frequently used building performance simulation software.



4.5. Validation in the design process

Validation is critical to understanding whether the completed project is performing according to design intent. As a practice, predicted energy performance should be compared to actual energy performance. The results of this analysis can inform operations as well as refine design approaches on future projects. There are two common forms of validation. LEED requires a commissioning process that includes planning and documentation, commitment of personnel, and commissioning of energy-related systems. The process requires that systems such as HVAC, lighting and daylighting controls, hot water, and renewable energy are installed, calibrated, and performing as designed. Post-occupancy evaluation (POE) covers operations beyond such systems to evaluate performance across a wide array of parameters, including:

Building design function

- layout and organization of space
- accessibility
- lighting
- materials performance
- technology
- aesthetic success
- energy performance
- thermal envelope performance

Facility operations

- effectiveness of program
- occupant satisfaction
- occupant productivity (if applicable)

5. Integrating building performance simulation into the firm

Expectations regarding the role of architects in building energy performance have changed considerably and will continue to change. To create beautiful high-performance twenty-first century buildings that reflect the growing wealth of knowledge about energy as a design opportunity, integrating the use of building performance simulation into practice is an absolute necessity. Whereas this guide focuses more on technical challenges to integrating simulation as a normal part of practice, this integration can also present challenges related to firm culture and personnel resources, no matter its size.

Ideally architects and BPS professionals are part of the same design team from the beginning of the project. Sometimes the architect performs single aspect simulations early in design (from preliminary design and evaluation early in schematic design and into design development), and the BPS professional performs whole building energy simulations at the design development phase and beyond. Whatever the arrangement, it is important to ensure building performance simulation is integrated into the design process and that design decisions that affect energy performance are documented and communicated throughout.

5.1. ASHRAE Standard 209 Building Performance Simulation Framework

ASHRAE Standard 209-2018 – *Energy Simulation Aided Design for Buildings Except Low Rise Residential Buildings* is a companion to ASHRAE Standard 90.1. It defines the terminology, process, and minimal requirements for applying building performance simulation in building design. Standard 209 was developed to both codify process and to create a common language for architects and BPS professionals to use in their work together. It defines common terms that the design team and clients can use to talk to one another, set expectations, specify requirements for inputs and deliverables, and develop scopes of work. ASHRAE also expects that Standard 209 will be adopted by organizations that provide high-performance building certifications and by utilities and other agencies that incentivize using building performance simulation to optimize energy performance in building design.

In this guide simulations have been discussed in two categories: single aspect simulation and whole building energy simulation. Standard 209 does not explicitly include single aspect simulation such as solar, shading, daylight, and glare simulation, but they are still critical tools in optimizing design. Standard 209 does discuss the whole building energy simulation category. It also indicates these simulations must be performed by a certified BPS professional. Ideally then, architects perform (or work with a third party to perform) single aspect simulations early in the design process to establish basic form and massing, orientation, shading, programming, and envelope characteristics. All of these design decisions are the purview of the architect, and all play a central role in building energy use. At the same time, the architect engages the services of a BPS professional who performs whole building energy simulation in accordance with Standard 209.

Standard 209 defines whole building energy simulation in terms of 11 cycles that correspond to architectural design phases as well as general requirements, which include early investigations that precede simulation. The result is a detailed roadmap of what to model, how to incorporate output data for analysis of design decisions, and when simulation is most valuable. Each iterative step throughout the process affords the opportunity to refine previous ideas and options, and improve the specificity and resolution of overall building performance simulation outcomes. However, the only cycle required for compliance with the standard is Cycle 3, load reduction modeling, plus one additional cycle. Load reduction modeling, in which building performance simulation is used to reduce heating and cooling loads from the envelope, lighting, and internal processes, usually takes place early in the design. It is a critical cycle because successful load reduction enables the use of high-efficiency but capacity-limited HVAC systems, which generally set the building up for a lifetime of low-energy use.

Standard 209 is directed toward both BPS professionals and their clients, including architects. Although architects are not necessarily expected to perform simulation at the level required by the standard, it is clear they are critical members of the design team when it comes to making design decisions that impact energy use. Architects must get these design decisions right, and they must use building performance simulation early in the design process to ensure high-performance buildings are the result.

Figure 5.1

ASHRAE Standard 209 defines whole building energy simulation in terms of 11 cycles that correspond to architectural design phases. Single aspect simulations, performed or led by the architect, are important to inform the analyses performed in these cycles.

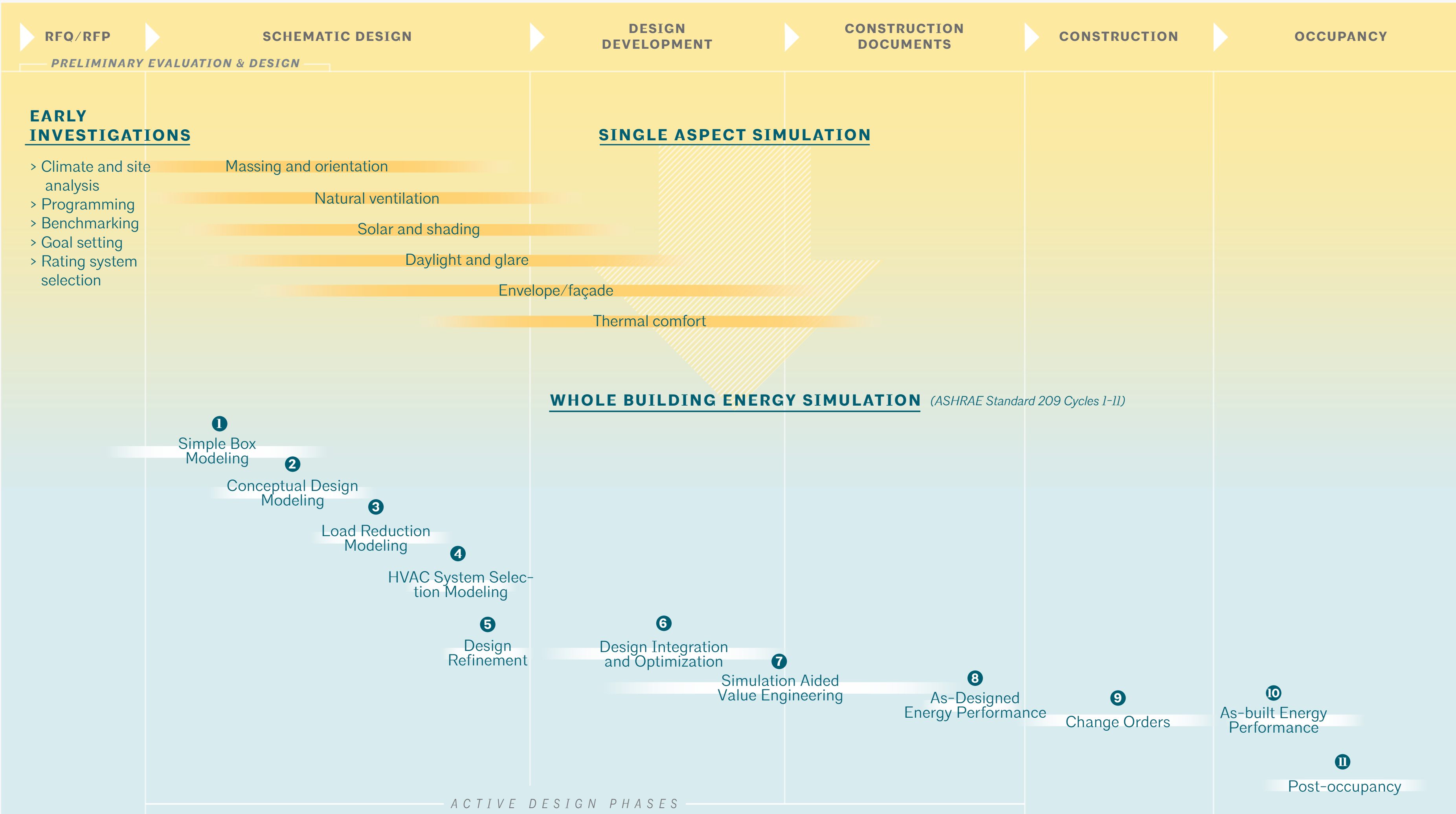


Figure 5.2

ASHRAE Standard 209 includes general requirements, such as early investigations, that precede building performance simulation to optimize energy performance. The simulation process must meet these general requirements to be complaint with the standard.

ASHRAE Standard 209 General Requirements
Simulation Software Requirements. Building performance software used to comply with Standard 209 must meet the minimum requirements of ASHRAE/IES Standard 90.1 (Section G2.2).
Modeler Credentials. The person performing simulations or the person supervising simulations in compliance with Standard 209 must have one of the following credentials: • ASHRAE Building Energy Modeling Professional (BEMP) • Association of Energy Engineer Building Energy Simulation Analyst (BESA) • An equivalent credential
Climate and Site Analysis. Local climate information must be reviewed prior to Cycle 2 (if used for compliance with Standard 209) or prior to Cycle 3 (required by Standard 209). Minimum information such as dry-bulb temperatures, relative humidity or wet-bulb temperature, wind speed and direction, solar insolation, cloud cover, ground temperature, precipitation, and heating and cooling degree days must be recorded.
Benchmarking. Determine the energy use of comparable buildings (i.e., same use type and climate). Determine energy costs based on local utility rates. This information is used in the energy charrette (below).
Energy Charrette. The energy charrette includes representation by the building owner, design team, consultants (including BPS professional), and contractor. Outcomes of the charrette include identification and documentation of critical project information such as the purpose of building performance simulation, defining baselines, establishing performance metrics, and identifying energy conservation measures (ECMs).
Energy Performance Goals in OPR. The architect, BPS professional, client, and other design team members develop energy performance goals and document them in the OPR. Documentation includes any selected rating system, financial criteria for decision-making and life-cycle cost analysis, and performance goals for systems such as envelope, lighting, HVAC, hot water, and plug loads.
General Modeling Cycle Requirements. These requirements apply to all the modeling cycles performed to comply with the standard. They include requirements related to energy baselines and goals, input data, reporting, quality assurance, and quality control.

Figure 5.3

ASHRAE Standard 209 defines whole building energy simulation in terms of 11 cycles. Cycle 3 and one additional cycle are required for compliance. With permission from ASHRAE, the purpose of and analysis intended for each of the cycles are provided here.

ASHRAE Standard 209 Cycles

CYCLE	PURPOSE	ANALYSIS
1 – Simple Box Modeling	Identify the distribution of energy by end use. Evaluate energy end uses and demand characteristics that affect building conceptual design.	Create energy models to calculate annual building energy by end use and peak heating and cooling loads with identical HVAC systems. Perform a sensitivity analysis by varying the following building characteristics: **a.** Building geometry **b.** Window-to-wall ratio, by orientation, and shading options (if applicable) **c.** Orientation **d.** Thermal performance of the envelope and structure
2 – Conceptual Design Modeling	Evaluate energy improvements that are tied to the form and architecture of the building.	Create energy models based on architectural conceptual designs to calculate annual building energy by end use and peak heating and cooling loads with identical HVAC systems. **1.** Perform comparative analyses of the conceptual designs. **2.** Provide recommendations to improve the energy performance of each conceptual design.
3 – Load Reduction	Identify the distribution of energy by end use. Evaluate strategies that will reduce annual energy use and heating and cooling peak loads.	**1.** Create an energy model based on the baseline design, and calculate the annual energy end uses and heating and cooling peak loads **2.** Develop a list of at least three peak load reduction strategies selected from one or more of the following categories: **a.** Building envelope (including, but not limited to, insulation level, window-to-wall ratio, glazing performance, shading, infiltration, phase change materials, and thermal mass) **b.** Lighting and daylighting **c.** Internal equipment loads **d.** Outdoor air (including, but not limited to, outdoor airflow, exhaust air, and energy recovery) **e.** Passive conditioning and natural ventilation **3.** When internal equipment loads exceed 60 percent of the building energy end use, at least two of the strategies shall be selected from the internal equipment loads category. **4.** Use energy modeling to evaluate each load reduction strategy compared to the baseline design using identical HVAC system types.

Figure 5.3 cont.

CYCLE	PURPOSE	ANALYSIS
4 – HVAC System Selection Modeling	Estimate the annual energy and demand impacts of HVAC system options	Use energy modeling to evaluate a minimum of two alternate HVAC systems.
5 – Design Refinement	Use energy modeling to evaluate systems in the building, confirm current design directions, and support further development of the building design.	Use energy modeling to refine and develop the design of at least one building system including, but not limited to, the following: **a.** HVAC systems **b.** Lighting systems **c.** Envelope systems **d.** Service water heating systems **e.** Process and plug-load systems
6 – Design Integration and Optimization	Integrate building systems through an optimization process to assist in meeting one or more of the project performance goals by exploring the complex interactions of multiple variables.	**1.** The energy modeler shall identify one or more optimization objectives for the analysis that relates to the energy performance goals [in the OPR, see Figure 5.2]. **2.** The energy modeler shall identify at least two design variables of interest for a multivariate optimization process. **3.** The energy modeler shall identify the design constraints or test range for each analyzed design variable. **4.** Conduct an optimization analysis using the defined optimization objective or optimization objectives, design variable or design variables, and design constraints.
7 – Energy-Simulation-Aided Value Engineering	To provide information on the holistic implications of value engineering measures on project performance goals to ensure more informed design decisions.	**1.** Identify project alternatives arising from at least one value engineering proposal. **2.** Identify first-cost and operating-cost consequences to building systems directly and indirectly affected by the value engineering proposal. **3.** Use energy modeling to evaluate each project alternative.
8 – As-Designed Energy Performance	Develop an energy model to represent the final design in order to compare as-designed performance to project goals.	Develop an energy model with inputs representing the as-designed configuration.

Figure 5.3 cont.

CYCLE	PURPOSE	ANALYSIS
9 – Change Orders	Provide feedback on all requests for change orders (COs) that impact the project's energy performance goals.	Prior to initiating construction, identify and document the process for addressing COs. The process shall address, at minimum, the topics in the following subsections. **1.** Designated parties and responsibilities. **2.** Timeframe for the energy modeler to respond to COs. For each applicable CO, the energy modeler shall perform one of the following analyses. At least one CO response must be evaluated with a model update: Qualitative review. Energy modeler provides a written description of whether the CO will increase or decrease metrics defined [in the OPR, see Figure 5.2]. Model update. Energy modeler revises the latest proposed design energy model inputs to represent the CO configuration and reports quantitative estimates of how the CO will increase or decrease metrics defined [in the OPR, see Figure 5.2].
10 – As-Built Performance	Develop an energy model to represent the as-built project in order to compare as-built performance to project goals.	**1.** Develop an energy model with inputs representing the as-built conditions, including new design information determined during construction, including, at a minimum, as-built drawings and contractor submittals. **2.** Occupant- and process-dependent schedules and loads shall reflect design phase inputs or be adjusted to reflect new information.
11 – Post-Occupancy Energy Performance Comparison	Compare the modeled performance of the last design- or construction-phase energy model to the actual measured energy use and weather conditions of the building in operation This comparison is intended to inform future energy model assumptions and potentially identify operational energy savings opportunities. The scope of this section does not include adjusting model inputs to calibrate the energy model to the measured energy use, though the comparison described is a fundamental first step to any proposed calibration.	The analysis steps involving measured and simulated energy data shall be performed using the typical weather year simulation results. The same analysis shall also be performed using actual weather year simulation results, except where exceptions apply [these exceptions are noted in the standard].

5.2. Project team structures for successful building performance simulation

Who performs building performance simulation within or for a firm varies by firm. For any firm, there are three basic choices:

- Internal: Develop or add expertise in-house.
- External: Contract the services of a third party to perform simulations.
- Hybrid: A process that combines internal and external resources.

A fundamental question as to whether simulation should be performed in-house, by a third-party consultant, or a hybrid of the two depends on many factors, including available personnel and their expertise, the uniqueness of a project or design question, software, timing and timeframe, and cost. Regardless of who performs simulations, the architect can lead the process by asking the right questions, coordinating input assumptions, and providing design intent sketches and models.

Whereas familiarity with single aspect simulation or whole building energy simulation software (or both) is important, it is even more important to have the theoretical and technical judgement to ask pertinent questions at the right time to be useful to the design problems at hand. This will allow an honest assessment of the analysis problem and the skillset of the available staffing resource to determine which workflow is best for a given project.

Each option has advantages and risks. The key is not necessarily to choose a single workflow type, but to be aware of the opportunities each one provides so the correct pathway can be selected for the project based on the firm's resources.

Internal workflow

Building expertise internally to the firm can be approached through four models: internal consultant, enablers/champions, knowledge experts, and embedded designers.

Internal consultant. This workflow relies on having a "building performance simulation team" as an internal consultant group to the firm. Usually executed by larger firms with the resources to have larger numbers of employees, this workflow solves some of the issues associated with external workflows. Typically, but not always, having the team in-house provides for faster feedback loops and closer collaboration. Having a dedicated simulation team allows the group to have deep technical skillsets and expertise, but its impact can be limited to fewer projects than in the other internal workflows. Despite being within the architecture firm, the work and value of simulation can still be siloed, which precludes opportunities to change the culture of the firm and to have a wider impact overall. This silo effect can also limit professional development and staff satisfaction and retention.

Enablers and champions. Instead of handling the analysis in a separate internal group, this workflow aims to train individuals on the design team to perform building performance simulation. It requires a single individual or small group of "enablers" who work across design teams to support individuals, or "champions" learning this kind of technical analysis. This model can be more transformative to firm culture, allowing a wider impact on more staff and projects, but can result in limited depths of analyses. Each team's champion is closer to the project and can identify opportunities for further or more analyses (or both), provided they are not so junior that they lack design agency. This workflow also requires constant training, which means that the tools chosen, their learning curves, and the regularity with which staff use the tools become important considerations. Oversight and quality assurance and control continue to be provided by the enabler. But even though someone can learn to run a simulation program, it is another skillset altogether to interpret data effectively to produce design insights. That requires a lot of training, reinforcement, and support from all staff levels.

Knowledge experts. This workflow is a variant of the enablers and champions model. It is still a decentralized approach with an "enabler" who works with embedded members of the project team for analysis. This workflow model, however, focuses on developing individual expertise around a single analysis topic, the thought being that the individuals will be able to gain expertise faster if they focus on a single simulation type. They can then share their deeper skillset with other project teams depending on workload and opportunity. This model is still culturally transformative and solves some of the training and learning-curve issues. Availability of these experts can be limited as they commit to projects, and there is a risk of lost institutional knowledge if an expert leaves the firm. Effective simulation knowledge may also require integrative knowledge across multiple simulation types and tools.

Embedded designer. This workflow model represents the highest and most effective state of integration of simulation skillsets within the firm. When high-level designers or project architects are the individuals performing simulation, the lines between design and analysis are blurred. Feedback loops are eliminated while analyses have greater potential to impact the design of the project. Also, if project managers have in-depth knowledge of simulation, they can better coordinate activities amongst their staff while integrating it into the project schedule more effectively than working with an external or internal consultant. However, without careful integration into the schedule and workload, project managers and architects can be too busy for simulation explorations. Additionally, the ability to derive design insight from energy simulation takes a lot of experience and perspective on both the design and technical analysis sides. It is rare to find both strong design and analysis skillsets in the same person. Although this is a very effective workflow model, the level of skill required is hard to develop in a firm and typically needs to be hired.

External workflow

With the external workflow model, building performance simulation is performed by a third-party consultant, such as a BPS professional. The architect's primary role is to help formulate performance-related questions and then provide information to the consultant such as goals and performance criteria and targets; simulation input assumptions; focused investigation questions; and drawings, sketches, and models to communicate design intent and iterations. The consultant confirms that input assumptions are representative of the architect's specifications, leads simulation creation, performs QA/QC on the simulation, and communicates simulation results to the design team and client.

Consultants are usually very well-versed in technical energy analysis and typically provide a higher level of QA/QC for the results. However, if design intent is not understood, the analysis may not be helpful. They can also more easily integrate energy simulation with mechanical engineering, calculations, and sizing programs. This model also requires the least amount of time commitment for the architect, but additional time may be required of the design team to present results to the client that are not overly technical.

The primary challenge with this model is getting feedback often enough, quickly enough, and with the right timing to inform rapidly changing design. Even though consultants are external, they have to be integrated with the design team and design process to ensure investigations have meaningful impact on project design decisions.

Hybrid workflow

Whereas an external workflow model has been the most common, a hybrid workflow is becoming more popular among architects who see the value in engaging directly with the kind of technical analysis that building performance simulation provides. Because many architects at both large and small firms tend to be generalists, the responsibility to perform different types of single aspect simulations may be distributed among staff, and each project includes the services of a third-party BPS professional. The hybrid workflow model attempts to strike a balance between the types of analyses that are best done by the architect in tandem or in sequence with the third party. The key is finding the right balance between in-house and third-party resources, and, more importantly, building and cultivating the necessary expertise within the firm.

In many cases, simulations done externally are more technically rigorous and comprehensive. In-house simulation allows more fluid design response and feedback. Often solar and shading and daylight and glare simulations happen within an architecture firm anyway, allowing many options to be tested without delay. Additionally, in-house simulation has a greater potential of becoming integral to the day-to-day design process.

Many larger firms are seeing the clear benefit of employing an internal model, even if resource constraints require them to sometimes employ third parties. Some larger firms even have the capacity to use an internal model that effectively functions as a hybrid, because the firm is so large. This can be an advantage for multinational firms in particular that are able to commit the resources for building performance simulation in lower-cost labor markets where they have offices.

Whichever workflow model the firm or design team follows, it is important to remember that good design requires time to communicate and process information. In other words, it takes time to "think" deeply about any project.

5.3. Contracts and standard of care

AIA Document D503™-2013 – *Guide for Sustainable Projects, including Commentary on the AIA Sustainable Project Documents*, was developed to help users of AIA contract documents understand contractual considerations unique to sustainable design and construction projects. It describes the relationship between sustainable design practices, such as building performance simulation for energy performance and the architect's standard of care, in the following terms:

> *...[A]s more jurisdictions institute green building standards by code, the Architect's standard of care may include requirements established by newly adopted code or practice. In other words, "standard of care" is an evolving concept; as design professionals begin incorporating sustainable design practices (either voluntarily or through jurisdictional requirements), the*

Architect's standard of care may eventually be construed to include those sustainable design practices as the accepted baseline standard of performance for the Architect. Even in jurisdictions where the International Green Construction Code (IgCC) is not officially adopted, professional practices initially adopted to comply with the IgCC may become part of the general practice of architecture or engineering on a local, regional, or national level and thereby influence the standard of care.

Whether or not building performance simulation is part of the architect's basic services or a supplemental or additional service, it is important to address it in the owner/architect agreement to manage expectations and establish an appropriate process. AIA Contract Documents developed AIA Document E204™-2017 – *Sustainable Projects Exhibit*, to allow parties to address the risks, responsibilities, and opportunities unique to projects involving substantial elements of sustainable design and construction (sustainable projects). A sample of E204-2017 is available free of charge.

E204-2017 is not a standalone document but is intended to be attached as an exhibit to an existing agreement on a project that includes a sustainable objective. E204-2017 is intended to replace the sustainable projects documents included in the conventional (A201) family of AIA Contract Documents. Utilizing E204-2017, the owner and architect should clearly outline the owner's building energy targets as a sustainable objective. The design elements, construction means or methods, and aspects of the project's delivery would be identified as sustainable measures that will be developed as the design evolves. The architect would then document the sustainable measures in the sustainability plan. The sustainability plan 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 sustainability plan should also become a part of the contract documents and connect the sustainable objective and sustainable measures to the contract for construction. Because building performance simulation is a whole building performance-based approach to meeting a sustainable objective, describing specific sustainable measures at the time of contract negotiation is difficult. This is the purpose of incorporating into the contract the deliberate steps of first establishing the sustainable objective, then articulating the sustainable measures, and finally developing the sustainability plan. The sustainability 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™-2017 that addresses additional services. In addition, the agreement between the architect and the owner should acknowledge that building performance simulation early in the design process is considerably less accurate than later in the design because the level of detail early in the design process is inherently lower.

6. Putting theory to practice

This guide has discussed an approach to building performance simulation that consists of three major categories. Early investigations, such as climate and site analysis, benchmarking, goal setting, and selection of rating system, may begin as early as the RFP phase of a project. These investigations are critical to the success of both single aspect and whole building energy simulations performed later. Single aspect simulations are performed during preliminary evaluation and design early in the schematic design phase, and some continue into design development. These include simulations such as massing and orientation, daylight and glare, solar and shading, and envelope/façade modeling. These simulations are often either performed directly by the architect or led by the architect. Thermal comfort, natural ventilation, and simple box modeling are also simulations performed in early stages of design, although they are usually performed by a BPS professional. In addition to simple box modeling, more whole building energy simulations are performed (usually by a BPS professional) during design development through construction documents and into post-occupancy. These categories for describing building performance simulation offer the architect consistent language for discussion with other design team members, be they in-house or third-party contractors.

But now what? Part 6 delves into specific building performance simulations to improve energy performance, providing basic concepts, approaches, inputs, and common questions related to each simulation type. There is also information about how to interpret and communicate the results of each simulation. Project examples are included for further information.

The information in this section makes it clear that many simulations are intertwined and complementary. There are two important design considerations that tie the different simulations together: the building envelope and thermal loads (excess heat or lack of heat that must be added or removed to maintain comfort).

The building envelope most distinguishes the design, and it is the very design element over which the architect has the most control. Building envelope design fundamentally sets the thermal loads that determine the cost and size of the mechanical system used to maintain comfort in the building. Improving energy performance means reducing thermal loads, and architects do this primarily via geometry, massing, and envelope design that minimize, or even exploit, external weather-driven loads. Whereas space planning, scheduling, and careful selection of service equipment also improve energy performance, early architectural decisions are the important factors in designing high-performance buildings. This is where passive architectural strategies are most effective.

Building envelope and passive solar design

Through passive design, architects and designers increase or decrease loads required for heating and cooling the building on every project. Passive heating captures heat from solar radiation during the day and may store it for nighttime use. The simplest method to passively heat a building is to increase solar gains to the interior of the building through a reasonable number of solar-oriented windows. Most building performance simulation tools can calculate the effect of direct solar gains through windows, accounting for different solar heat gain coefficients of glazing and external shading systems (see Part 6.1, Solar studies and shading).

Passive cooling reduces indoor temperature by transferring heat from a building to various natural heat sinks. These systems are typically classified according to the heat sinks they use to store energy: ambient air (sensible or latent), the upper atmosphere, water, and undersurface soil. The applicability of a given cooling system is affected by multiple climate variables, and not all systems can be used in all climates. Natural ventilation (see Part 6.5, Natural ventilation simulation) is one of the most common passive cooling strategies, although it is not strictly designed for cooling. Under appropriate outdoor conditions, it can provide comfort while allowing a mechanical cooling system to be turned off or, in mild climates, eliminated entirely. Some building performance simulation tools provide the ability to include the cooling effects of natural ventilation.

Passive systems must use building materials that perform as a medium to capture, store, and distribute the energy in solar gains. A well-insulated, well-sealed, and well-shaded envelope (see Part 6.4, Envelope simulation) keeps the energy from solar gains inside when heating is required, and outside when cooling is needed. Passive systems can provide thermal comfort under many conditions using a fraction of the energy (and reducing greenhouse gas emissions) that conventional mechanical systems use, while providing thermal comfort with both lower first and operating costs.

Thermal loads

Building performance simulation to optimize energy performance can actually be thought of as two simulations—a load model and an energy model—reflecting an iterative process or "balancing act" between thermal loads and the response of the building to those loads. Load modeling simulates heating and cooling loads: It sums the heat gains (e.g., people, electric lighting, and solar gain) and subtracts the heat losses (primarily conduction through the envelope on cold days) from each space. After thermal loads are calculated, an energy model calculates how the HVAC system responds to these loads to maintain thermal comfort. Note that "peak" thermal loads are calculated for a single day to determine the size of the mechanical system; thermal loads are also calculated at each hour to simulate how the HVAC system will respond as part of an energy model.

There are two primary sources of thermal loads: external and internal. External loads come from the outdoor environment. Cold and warm weather as well as sunshine create loads through the building envelope. Location-specific weather information, including air temperature, humidity, wind, precipitation, and, critically, solar radiation, is found in "weather files," which all building performance simulation software needs and reads.

Internal loads come from the inside the building. Lights, electronics, elevators, refrigerators, cooktops, washing machines, and other equipment all produce waste heat, as do people. A person at rest outputs about 100 watts; if you've ever been in a subway car at rush hour, you are intimately familiar with this. Over the past decade, both lighting and electronics have become significantly more energy efficient, producing less waste heat as a result. In the case of lighting, efficiency gains have been made largely by using technologies that minimize waste heat. Solid-state lighting is highly efficient precisely because it emits most of its radiation at specific visible wavelengths, emitting very little in the infrared spectrum, which is a source of heat. On the other hand, human energy efficiency and waste heat generation have remained flat over the same time period. Because most internal loads are in the form of excess heat, they reduce heating loads and add to cooling loads. Internal loads contribute to overall thermal loads to varying degrees, depending on factors such as occupant density, electrical equipment density, envelope-area-to-floor-space ratios, and weather.

Load baseline and ventilation loads are other important components of a load model. The load baseline is the reference temperature relative to which load is calculated. Load baselines are determined by occupied and unoccupied heating and cooling setpoints. Setpoints are essentially the temperatures at which the heating and cooling systems are turned on. Generally speaking, heating setpoints are several degrees lower than cooling setpoints, creating a narrow range of temperatures that serve as a proxy for comfort. The narrower the range of temperatures, the more energy will be used for heating and cooling. Unoccupied heating and cooling setpoints, often called setbacks, have a wider range of temperatures and thus save energy. Setpoints are subject to the occupancy schedule which itself can be a function of the space plan. Without changing anything about the envelope, lighting, or equipment, heating and cooling loads can be reduced through space programming, locating spaces so they are likely to be occupied during times when they experience low loads. Note that because an unconditioned space constitutes no response, an unconditioned space has no load regardless of the external and internal thermal forces it experiences.

Ventilation is required to remove odors and provide fresh air for people to breathe. For this reason, ventilation is often associated with the human occupancy schedule. Because ventilation air is often required continuously, heating and cooling that air can require significant energy use. Even a highly insulated building with no windows will experience weather-driven heating and cooling loads, because, in accordance with codes and standards, fresh air must be circulated into the building, and that air may have to be heated or cooled to keep interior conditions within specified ranges.

Following are common questions to ask when considering a load model component of building performance simulation to optimize energy performance:

Peak loads and energy use

- What is the total energy use on an annual/monthly/daily basis?

Peak loads and envelope design

- How much does each envelope component contribute to peak loads, annual loads, and energy use?
- What is the optimal amount of insulation in the walls?
- How much can the mechanical system be downsized by installing more insulation, fewer windows, or less glazing?
- What are the ideal performance properties for the windows?
- How much is comfort affected by an improved wall U value?

Peak loads and mechanical system design

- What are the peak loads and rough mechanical costs?

- How much money can I save by reducing mechanical system size through load reduction measures?
- When are the peak loads occurring and how do I reduce them?
- Which zones are driving peak cooling and peak heating loads?

Optimizing loads for effective HVAC system design

- Do perimeter zones meet the cooling load capacity target for high-performance systems such as chilled beams, radiant systems, or natural ventilation?
- How much do heating and cooling demands of different zones occur simultaneously? (Another way to frame this question: Should an HVAC system be used with heat recovery between zones?)

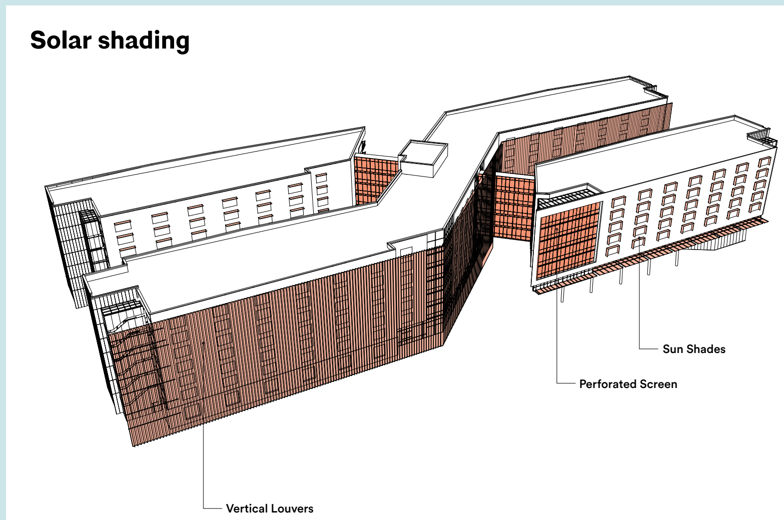
6.1. Solar studies and shading

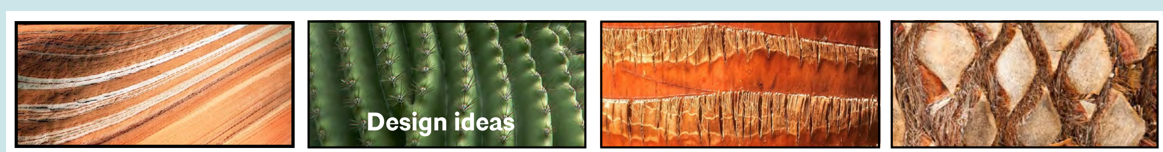
PROJECT EXAMPLE:

Tooker House, Arizona State University

The 458,000-square-foot Tooker House, designed by Solomon Cordwell Buenz (SCB), provides student housing on the Arizona State University campus in Tempe, Arizona. It features double-occupancy suites, dining, community lounges (with kitchens), laundry facilities, a computer lab, and e-Space classrooms.

This project focused heavily on analyzing and evaluating solar loads. Using incident solar radiation analysis, multiple building forms were evaluated for the ability to provide solar control, self-shading potential, and creation of outdoor spaces that provide an oasis from the sun.





This project tells the story of the vertical louver design. When the building form was decided, an initial analysis informed which type of exterior shading devices would be beneficial on critical façades. The design team collected and considered precedents for the vertical louvers. The team developed a set of vertical louver design ideas, including the gradient louver design shown. The incident solar radiation analysis on the façade without louvers set the baseline and the basis of comparison. In addition to evaluating results numerically, it was easy to visually evaluate the results for the louver design option set by assessing the color change. The gradient louver design was the winner. It provides a visually dynamic skin of louvers of varying depth and angle that allows the sun to dance along it over the course of a day, while maintaining a high degree of visual and thermal comfort on the interior.

The set of analyses used to develop the gradient for a portion of this façade is discussed further in Interpreting and Communicating Results for solar studies and shading.

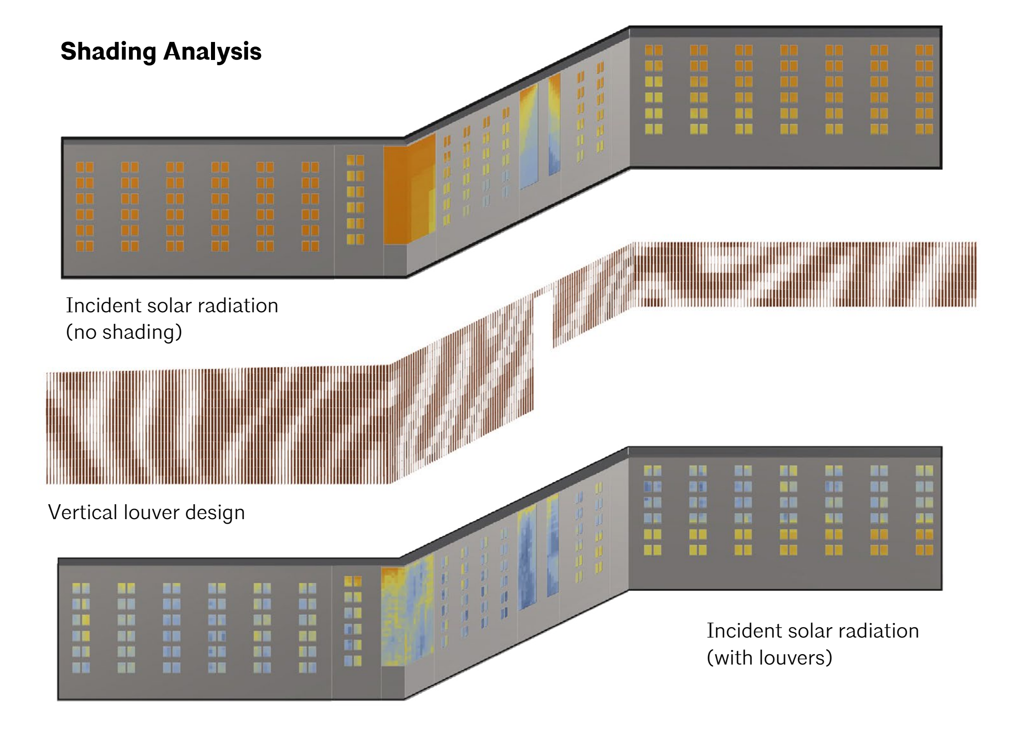


Image credits © Bill Timmerman.

Concepts

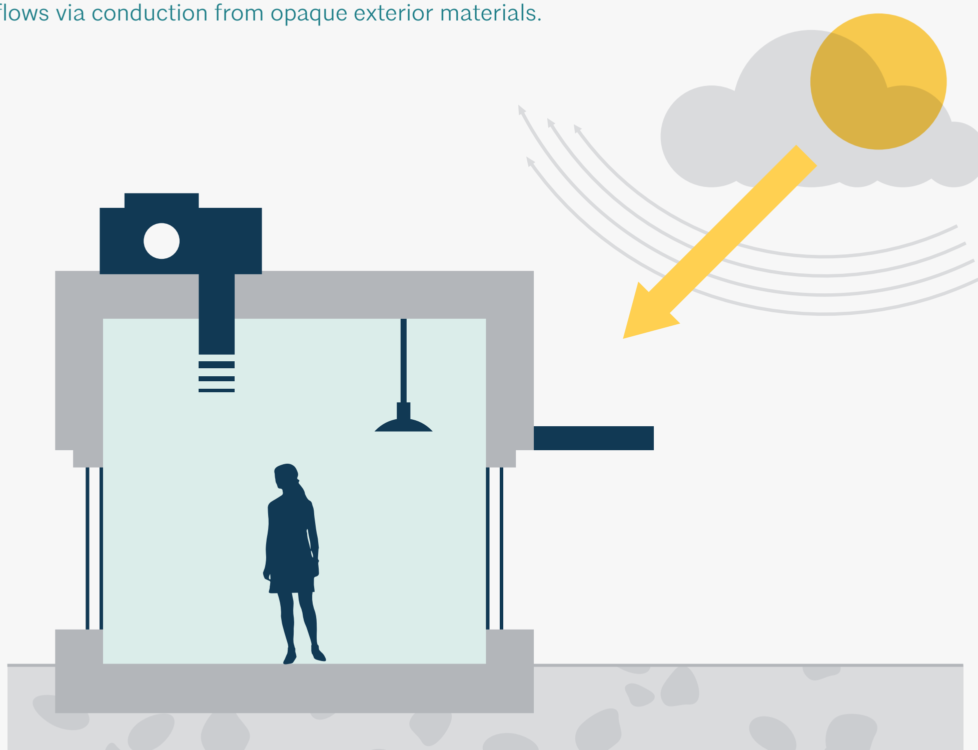
Incident solar radiation (solar radiation that is acting on something) exerts important effects on a building by acting in predictable ways on different building façades at different times of the day and at different times of the year. Solar radiation affects building thermal loads directly when shortwave visible infrared sunlight passes through transparent building materials such as windows and skylights, resulting in increased temperature, or "solar gain." Solar radiation also affects building thermal loads indirectly by increasing the exterior surface temperature of opaque surfaces, which then increases heat flow by conduction through the opaque elements to the interior of the building. That said, much more solar radiation can enter per unit area through a window than through a wall.

The amount of incident solar radiation on a building can be controlled through architectural design strategies such as orientation, geometry, placement of windows, selection of glazing materials, and shading devices. It is important to maximize solar radiation during cool days and minimize solar gains during warm days.

Buildings that control solar gains must be designed appropriately, considering both climate and building type. In general, buildings in the Northern Hemisphere have larger southern façades that maximize the amount of solar radiation absorbed during winter and smaller east- and west-facing façades.

Figure 6.1

Solar studies and shading simulation are critical to building energy performance because solar gains raise interior temperatures when solar radiation passes through transparent materials such as windows or when heat flows via conduction from opaque exterior materials.



Shading. Solar gains should be reduced during the overheated period and promoted during the under-heated period. Shade is also an expressive tool and an architectural design opportunity.

Some rules of thumb for shading in different orientations:

- **Facing the equator (south façade in the U.S.).** Horizontal elements are better because they allow some winter sun and protect when the sun is high in the sky.
- **Facing away from the equator (north façade in the U.S.).** Little or no shade is required. Vertical elements are better for rising and setting sun.
- **East and west.** A combination of horizontal and vertical elements or dynamic elements are preferred. Horizontal elements protect from high-altitude sun while vertical elements block low solar altitudes. Neither is effective when the sun is perpendicular to the façade.

Shading design must be appropriate and consider both climate and building type. Building performance simulation tools add precision beyond rules of thumb, which are helpful but not enough to design the high-performance buildings we need today.

Approach + inputs

There are several methods to design shading devices, which can be fixed or dynamic, internal or external. Shading devices not only reduce thermal loads and energy use; they can also be an expressive architectural design opportunity.

Building performance simulation software enables the determination of cooling and heating loads, while also providing a monthly breakdown of heating and cooling energy, for different window sizes, orientations, and shading systems. These types of investigations can be expanded as options for parametric design and testing in which variables can be modified automatically to determine optimum form and orientation.

The simulation process to design shading devices can include the following steps, also outlined in Figure 6.2. The method is not prescriptive; it is a guide in which different tools can be plugged in and out following the described steps.

1. Climate analysis
2. Solar study
3. Shade design
4. Performance evaluation
5. Solution

Climate analysis. Climate data is used to determine overheated and under-heated periods, and to determine the shade period as defined by a start and end date and a start and end hour to reduce solar gains, reducing cooling loads and overheating.

Solar study. Façade solar studies during the overheated period permit determination of critical orientations that require more solar protection.

Shade design. Shade design is based on seasonal requirements and the orientation and dimensions of the surfaces requiring shade. Vertical and horizontal shadow angles should be calculated, and shadow masks can be used to show annual shading performance in one diagram.

Performance evaluation. Shading options can be tested for overall reduction of incident solar radiation. The option with the least incident radiation during the overheated period and the lowest peak cooling load is the most effective. Energy consumption, illuminance, and luminance levels can also be calculated.

In Figure 6.3, the west façade of a project is being analyzed for incident solar radiation for two cases. The first case (on the left) includes no shading devices, while the second case (on the right) does contain shading devices. In the legend for the figure, yellow is at the top of the scale, meaning high levels of incident solar radiation. Therefore, the façade that is almost all yellow (on the left) does not represent good design. The façade on the right offers a range of oranges, reds, and blues, which are mid- to lower-range on the scale. In this design, the shading devices are having a positive impact, and the shading device design warrants more investigation.

Testing to reach a solution. Testing assists reaching a solution. If testing is satisfactory, the process ends. If testing indicates insufficient shade, shading must be redesigned and reevaluated, assuming the overheated period is correctly calculated.

Figure 6.4 provides an example of effective design resulting from solar studies and shading simulation.

Common questions

- Which massing and orientation options are most suitable for the climate and the program?
- When is solar gain beneficial, and when is it a liability?
- How much do different window-shading options reduce solar gain during the peak hour, day, season, or month?
- What is the optimal shape of shading systems to optimize whole building energy performance (i.e., provide a net benefit between heating, cooling, and lighting energy while still reducing HVAC system size)?

Interpreting and communicating results

Solar studies, and the simulations developed for them, can range from simple to complex, depending on the project and the type of design questions that are being investigated. A solar study may involve evaluating solar radiation on the overall building form to identify areas to investigate further. It may involve evaluating solar radiation and other factors to design exterior shading devices. Or it may involve evaluating the direction and form of skylights to evaluate and reduce internal heat gains. As described earlier, the solar study may involve multiple steps, which means interpreting and communicating results at different stages.

It is important to tell a story when communicating results. A story about exterior shading is typically interesting, and it can include solar studies at the overall building level as well as for façades or portions of façades. To provide context for the target audience, it can be beneficial to include a collection of the studies side by side to tell a more complete story.

Figure 6.2

A design process illustrating inputs and iterative analysis to optimize fixed shading device performance.

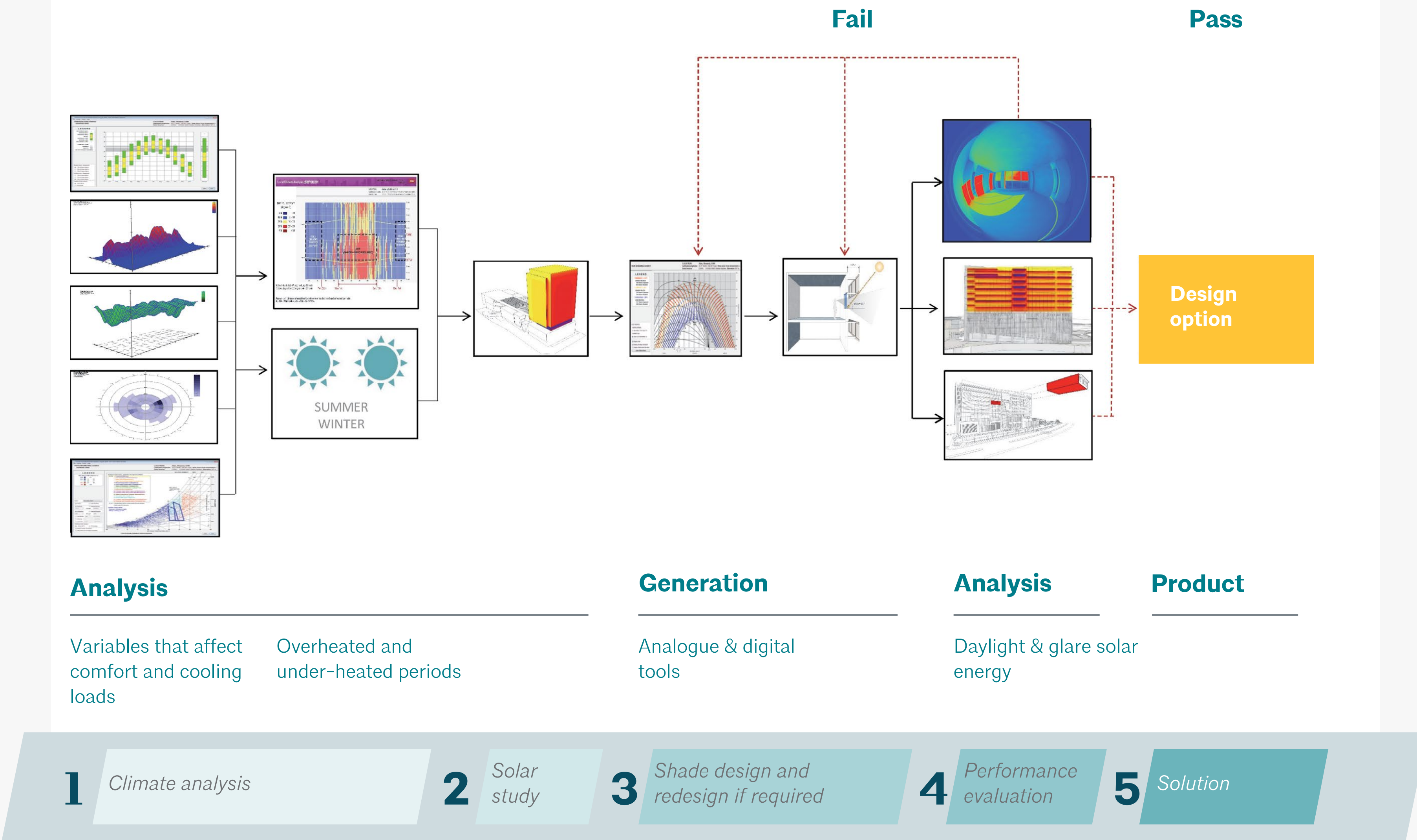


Image credit: CallisonRTKL

Figure 6.3

Incident solar radiation analysis outputs for two design options for a west building façade: The design option on the left does not contain any shading devices. The design on the right includes overhangs and screens. Average daily solar radiation is made visible in color and provides an immediate impression of the difference between the two design options. The option with overhangs and screens provides a 41 percent reduction in solar radiation, compared to the option without shading devices.

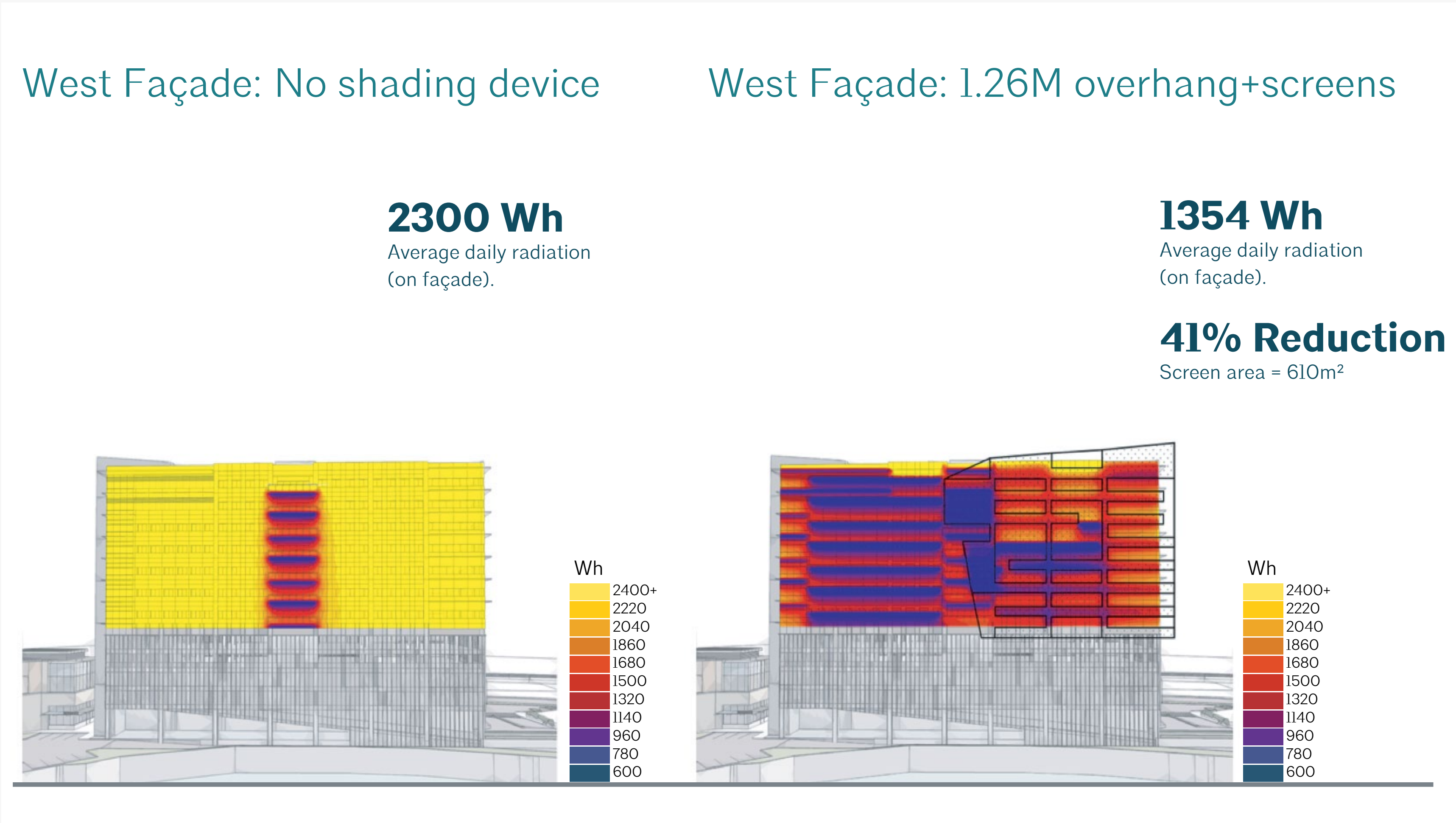


Image credit: CallisonRTKL

Figure 6.4

An example of effective design resulting from solar studies and shading simulation is the CSUMB Business and Technology Building by HMC Architects. This façade uses ceramic baguettes that respond to required shadow angles and the programmatic requirements of use spaces behind the façade. Variation responds to differing programmatic requirements and orientations.

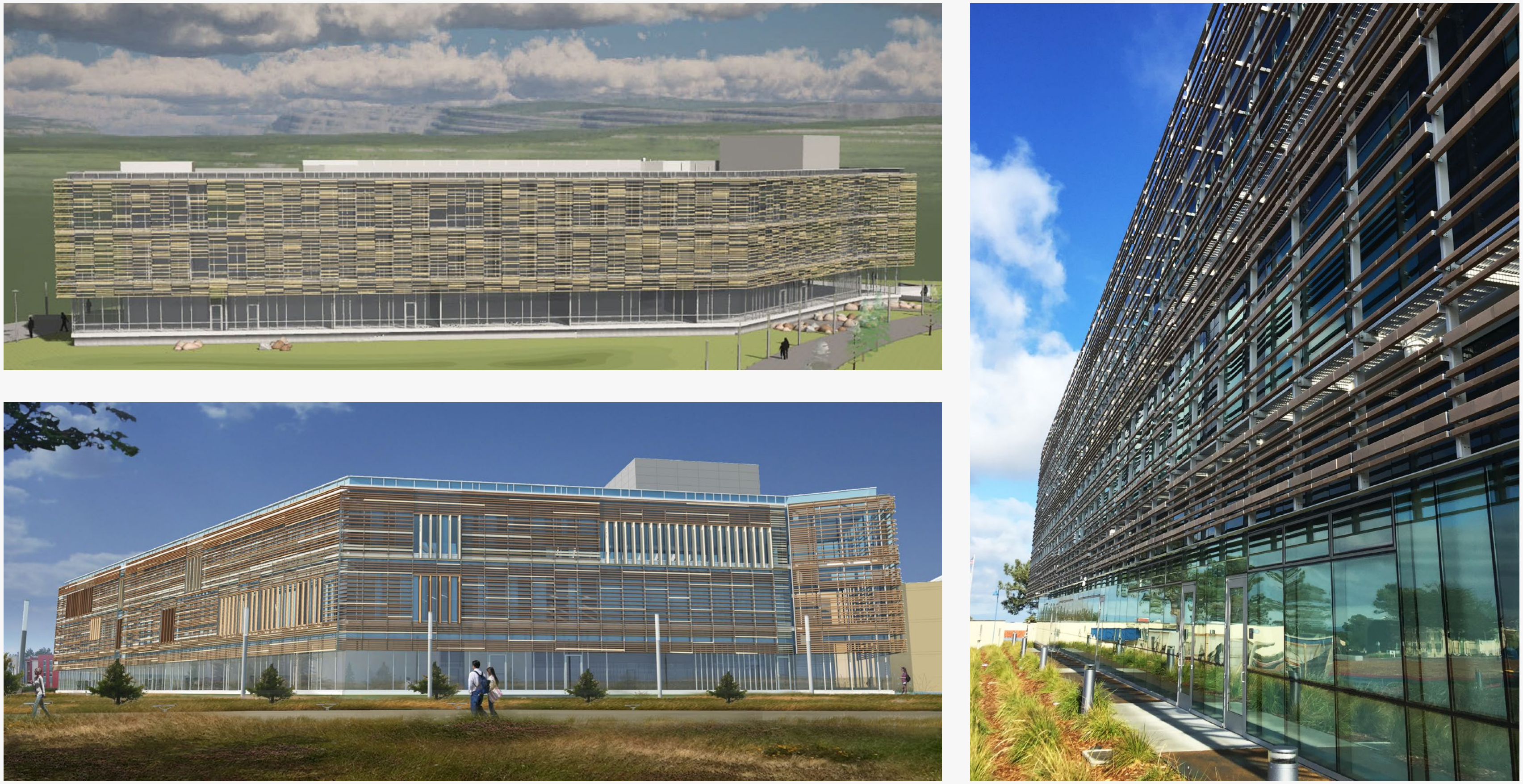


Image Credit: Carbon Neutral Architectural Design

The project example at the beginning of this section tells a story about a façade louver design on Tooker House at Arizona State University. We can build on that story with Figure 6.5, which digs a bit deeper into the louver design for a portion of the larger façade shown. One image provides the results from numerous simulations. Information about location, the analysis period, and the orientation are provided top left. Just below a plan image of the overall project highlights the façades that are part of the analysis. Below the plan is a sun path analysis for the targeted façade, which indicates by color which time periods are of the greatest concern. The color range is defined in a color key below the images and a target color range is identified, so areas of concern can be seen clearly. To assist guiding a discussion of the results, it is useful to reinforce what is considered "good." The portion of the figure labeled "Shading by Louver Orientation" provides "scale-of-analysis" changes, visually displaying the performance of the shapes and sizes of individual louvers. The portion of the figure labeled "Section," provides a geometric representation of the size of the louvers in each row. The deepest louvers are on the top row. Each louver displays the shading it would provide on the façade. The shades of blue and yellow provide insight into the degree of shading provided by the louver. Remember, the color key at the bottom that indicates the target color range is blue. Selecting the louver design with the most blue may seem like a good idea, but other factors should be considered as well, such as whether the project can afford exterior shading devices of this size and shape. However, without a solar study, the ideal answer to "Which type of louver works for this façade?" would not have been clear or possible.

Figure 6.5

A strong example of how results from a solar and shade study can be communicated.

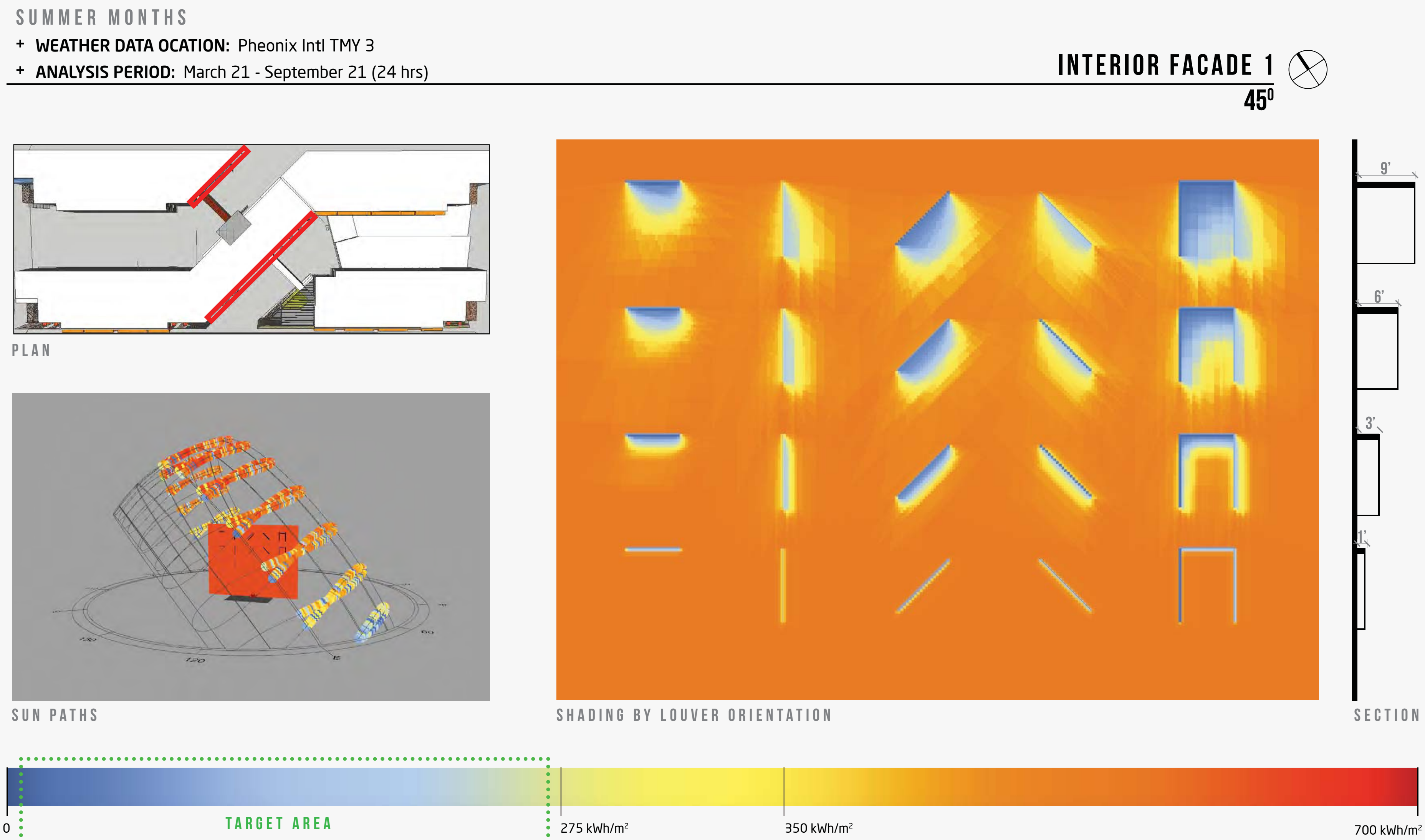


Image credit: MSR in collaboration with JRA Architects

PROJECT EXAMPLE:

Louisville Free Public Library

The Louisville Free Public Library in Louisville, Kentucky, designed by MSR, is a space intended to promote learning at all stages and serves more than 160,000 people. Located in climate zone 4, the 40,000-square-foot library has an energy profile dominated by cooling load.

A daylighting analysis was developed to evaluate the performance of a set of building forms and glazing options for a set of daylighting metrics, loads, and energy use intensity. The building forms were modeled in SketchUp. Sefaira was used to analyze energy. The models were brought into Rhino, so that the DIVA plug-in could be utilized for the daylighting analysis. Combining these metrics into a single graphic clearly and convincingly establishes connections between the influence of the building form and glazing design on daylighting and overall energy. This methodology for integrating and visualizing early design analysis has since become standard practice at the firm. See Interpreting and Communicating Results for additional detail.

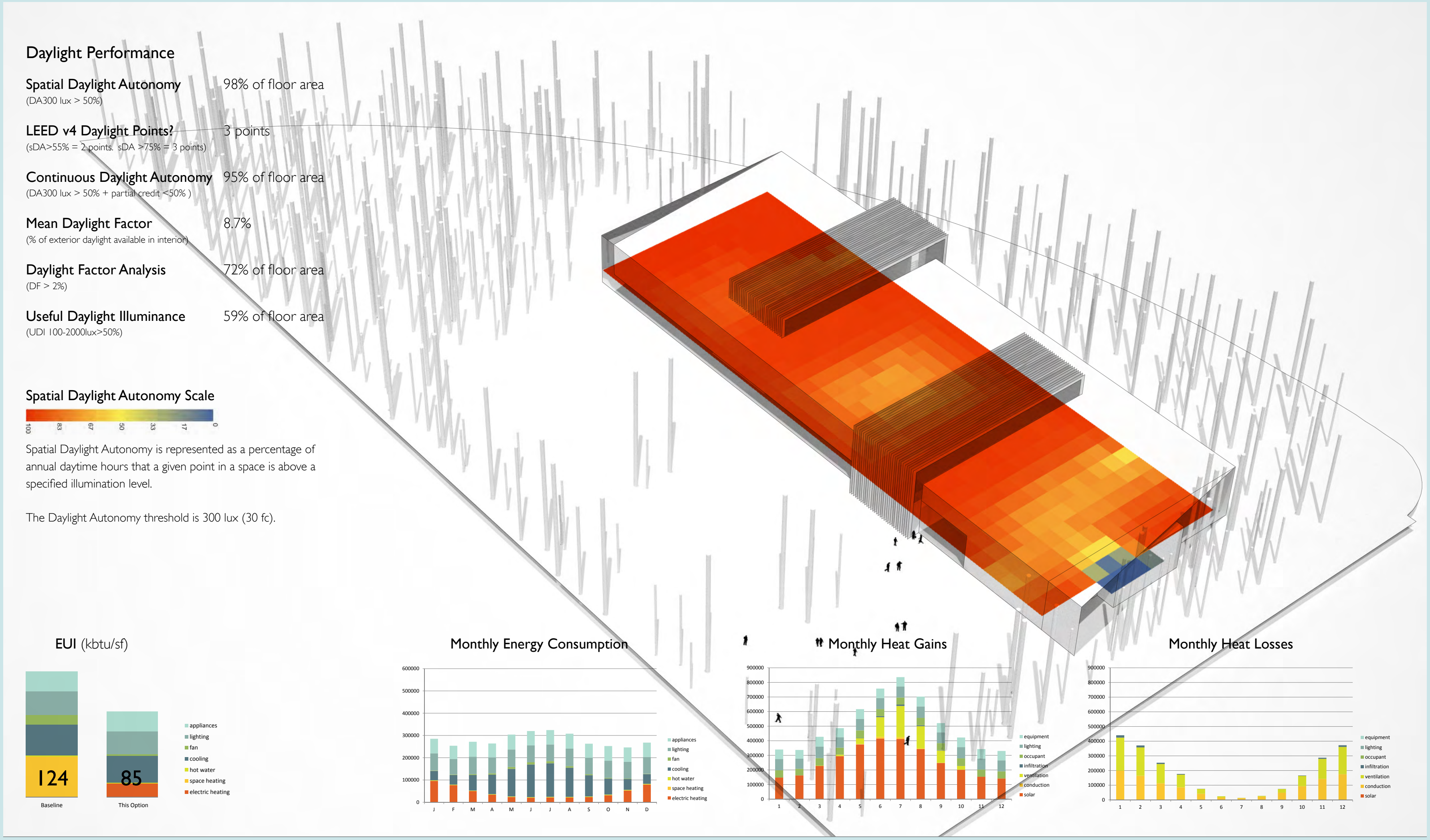


Image credits:. MSR in collaboration with JRA Architects

Concepts

As a strategy, daylighting describes the controlled use of natural light in and around buildings. The daylit area is that part of the building in which there is enough (but not excessive) daylight to provide the required illuminance levels to eliminate or minimize the use of electric lights. Allowing sufficient daylight into interior spaces is integral to the design of every building. Good daylighting benefits occupant productivity and well-being, and encourages energy savings. Many of the wellness and energy savings benefits, however, depend on how often glare occurs in a space. If occupants experience glare, they are likely to close blinds or shades, reducing energy savings from electric lights that could otherwise be dimmed or turned off. Likewise, if electric lights do not use photosensors, daylight-related energy savings may not be realized because the lights are likely to be left on even when plenty of daylight is available. (Figure 6.6)

Illuminance is a measure of the amount of light striking a surface. It describes the luminous flux (the measure of perceived power of light by the human eye) incident on a surface per unit area. The SI unit is "lux" which is the illumination by 1 lumen in 1 square meter. The foot-candle (fc), or lumen per square foot, is also used (1 fc = 10.764 lux). Illuminance is typically used as a quantitative indicator that compares calculated or measured values with requirements for specific activities.

Luminance is a measure of brightness of a surface, when looked at from a given direction. It refers to the amount of light that is reflected off an object's surface and reaches the eye. It is measured as luminous flux density leaving a projected surface in a given direction. This means luminance is affected by both the direction of the light source and its brightness. Luminance is measured in candelas per square meter (cd/m^2) or candelas per square feet (cd/ft^2). In general, brighter luminance, larger source size, and a more centered location in the viewing field increases the probability of experiencing glare. However, an overall brighter average scene luminance (up to a certain level) decreases probability of experiencing glare. There are different glare indices based on different datasets and equations. Two of the most common ones are daylight glare probability and visual comfort probability.

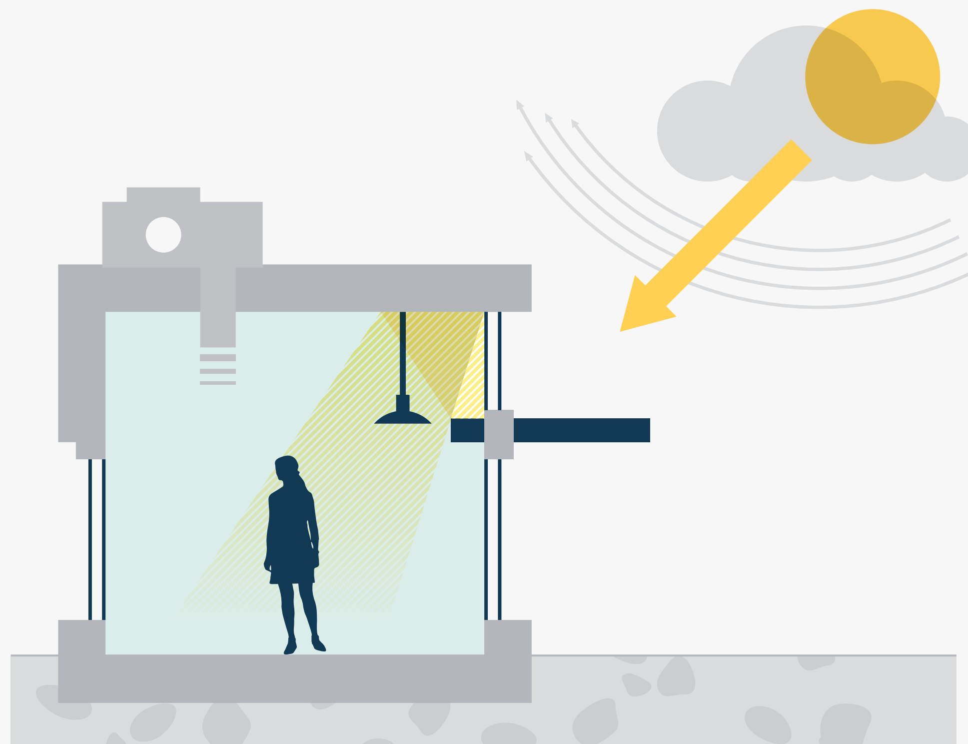
Approach + inputs

Multiple-ray-simulation tools (e.g., Radiance) are recommended to perform daylighting and glare analysis.

Building performance simulation software, in some cases integrated with a BIM tool, can be used for performance-based daylight and glare simulation. Daylight design should aim to achieve required illuminance levels and avoid glare. It should

Figure 6.6

Daylight and glare simulations provide analysis of introducing sufficient daylight into interior spaces with minimal electric lighting and without uncomfortable glare.



also control solar heat gain in the summer and reduce undesirable heat losses through windows during colder seasons, while providing visual balance and a comfortable environment. In fact, without detailed lighting and envelope analyses, available square footage may be effectively reduced because of glare and thermal comfort. The intertwined nature of daylight, glare, and energy savings means that all three are necessary to estimate the energy-related effectiveness of daylighting design.

After geometry has been set up in a 3-D model, glazing properties, reflectances of interior materials, and any shades or blinds are added. It is necessary to include these variables because they affect the properties of daylight by reflection or transmission. Often the amount of light on a so-called work plane, 30 inches above the floor (i.e., desk height) becomes a proxy for the amount of useful daylight within a space. More advanced simulations look at glare that a user might experience from a specific viewpoint, for example from a desk or lying in a hospital bed.

Daylight studies will typically study illuminance level on a work plane and surfaces, and glare from selected viewpoints.

Some of the different types of daylight and glare simulation and workflows (functional and qualitative) are:

Single-point-in-time illuminance analysis.
For this type of study, illuminance is measured at a specific point in time, typically equinoxes during midmorning and midafternoon. It provides actual values at that moment.

Daylight factor (DF).
The ratio of the light level inside a building to the light level outside the building.

Daylight autonomy (DA).
This simulation indicates the percentage of occupied time when the target illuminance in a space is met by daylight. It is indicated in an illuminance grid on the horizontal work plane.

Spatial daylight autonomy (sDA).
This simulation indicates whether a space receives enough daylight during operating hours (8 a.m. to 6 p.m.) on an annual basis using hourly illuminance grids and an algorithm to approximate manual operation of window blinds. Grid points that achieve the target value (typically 300 lux) for at least half of the analysis hours meet the daylighting threshold.

Annual sunlight exposure (ASE).
The intent of this simulation is to help limit excessive sunlight in a space. It measures the presence of sunlight using annual hourly horizontal illuminance grids instead of luminance, so it is technically not a glare metric. ASE uses 1,000 lux as the indicator for sunlight and ranges from zero to 100 percent.

Useful daylight illuminance (UDI) metric .
A metric of daylight availability that corresponds to the percentage of time when a range of illuminances are met by daylight at a specific point in a space. There are three illumination ranges: 0–100 lux, 100–2,000 lux, and over 2,000 lux. The metric provides full credit only to values between 100 lux and 2,000 lux. (Source: New Buildings Institute and Velux).

DGP calculations.
These calculations detect glare sources by contrast ratios, which emphasize direct daylight and specular reflections over dimmer surfaces. The DGP equation has the advantage of being developed from statistical analysis of human factors assessments collected in daylight test facilities.

In this scale, a value above 0.45 is intolerable or disturbing, a value of 0.4 is perceptible, and a value below 0.35 is imperceptible.

Visual comfort probability (VCP).
This index is defined as the percentage of people that will find a certain scene (with a given viewpoint and direction) comfortable with regard to visual glare. According to the Illuminating Engineering Society, it is the rating of a lighting system expressed as the percentage of people who, when viewing from a specified location and in a specified direction, will be expected to find it acceptable in terms of discomfort glare. Visual comfort probability is related to discomfort glare rating (DGR). Higher numbers indicate that more people are in comfort.

For a daylighting and glare simulation, common inputs include:

- Climate zone
- Type of sky
- Window or skylight arrangement and size
- Glazing properties, such as visual light transmittance (VLT)
- Internal or external shading devices, shades, or blinds
- Use type, especially the ability of users to move their bodies or turn their heads if they experience glare
- Interior finish reflectance
- Internal form of the space

Common questions
Some common questions to ask related to daylighting and glare simulations:

Daylighting
- Which directions produce the most solar gains?

- How much energy can be saved by daylighting? How often are the lights dimmed or off?
- Does the client understand that daylight and glare are different, but interrelated?
- What is the daylight balance within a space?
- What is the optimum amount of glass (window-to-wall ratio) for daylighting?
- How many/how large should skylights be for adequate daylighting?
- What is the difference between automated and manual blinds?
- How can the building architecture be designed to help encourage occupants to be more active around interior blinds management, thus improving overall daylighting?
- For interior window treatment, do blinds or shades perform better?
- What is the reduction in annual daylight based on external shading systems?

Glare

- What are key locations where glare should be evaluated?
- Are there particular times of day when glare should be considered?
- Are blinds being deployed manually or as part of a controls system?
- If interior surface reflectances are brighter, how does this affect visual comfort?
- How does a light shelf impact the distribution of daylight and glare in a space?

Which LEED or other green building rating system credits are goals for the project?

Interpreting and communicating results

Daylighting analysis tends to involve numerous simulations. It is beneficial to analyze multiple daylighting metrics and to evaluate a full year, as well as specific days and times. Rather than potentially overwhelming the client or design team members with all the daylight simulation results, it is best to pick and choose which results effectively help tell an effective story. One approach to consider is developing a summary, such as the one in Figure 6.7. This can capture the audience's attention while allowing the design team to go into further areas of detail.

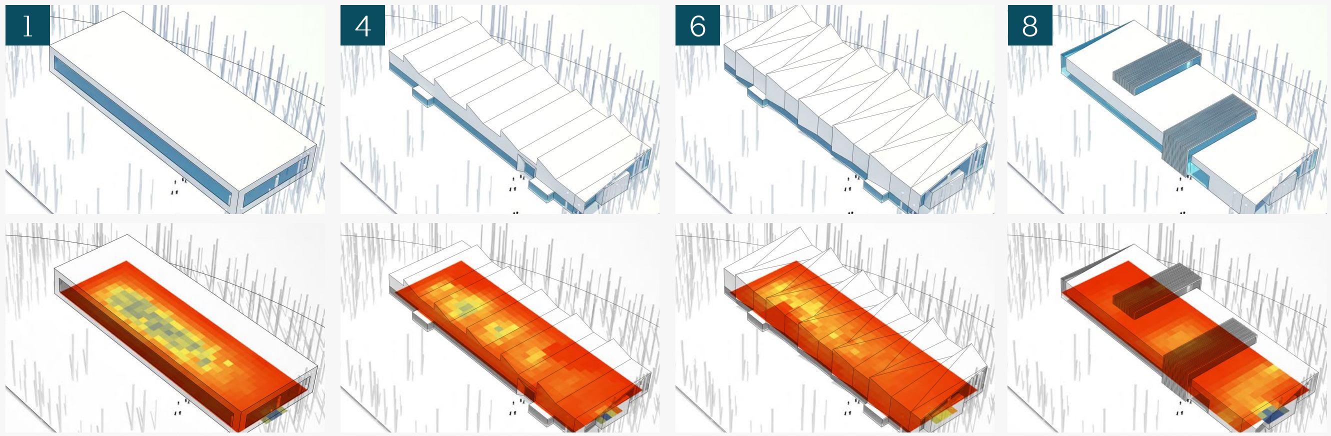
Figure 6.7 shows the results for four early form and glazing options, and the results of their respective spatial daylight autonomy analysis. The image in the project exampe (Part 6.2) represents the presentation of the final results of analysis for the final design alternative. The building form is shown at the top right. The central image presents a visual for the spatial daylight autonomy simulation of the building form. Three graphs at the bottom of the graphic include the set of the daylighting metrics analyzed as well as the energy use intensity. This graphic provides a useful framework to quantify and discuss design ideas and identify potential tradeoffs for design decisions.

Figure 6.7

A summary of results from daylight analysis to compare four different design options for the Louisville Free Public Library.

Design option of building form and glazing

Spatial daylight autonomy analysis result



	1	4	6	8	
Spatial daylight autonomy Lorem ipsum dolor	81%	96%	99%	98%	
Spatial daylight autonomy Lorem ipsum dolor	3.3%	5.8%	4.1%	8.7%	
Daylight factor Lorem ipsum dolor	43%	65%	60%	72%	
Useful daylight illuminance Lorem ipsum dolor	89%	81%	88%	59%	
Energy use intensity Lorem ipsum dolor	73	75	76	85	**104** Baseline

Image Credit: MSR Design

Image Credit: ZGF and PAE Consulting Engineers

PROJECT EXAMPLE:

Rocky Mountain Institute Innovation Center

The Rocky Mountain Institute Innovation Center is a 16,000-square-foot net zero office building located in Basalt, Colorado, one of the coldest climate zones in the United States. The integrated design team included ZGF Architects, PAE Consulting Engineers, and the Rocky Mountain Institute. The building is first and foremost a passive building. It operates with passive-only cooling and a very small electric resistance baseboard system. Individual workspaces feature personal comfort systems that deliver heating and cooling to the people and not the space. This image shows a cross-section of the Innovation Center, highlighting design strategies.

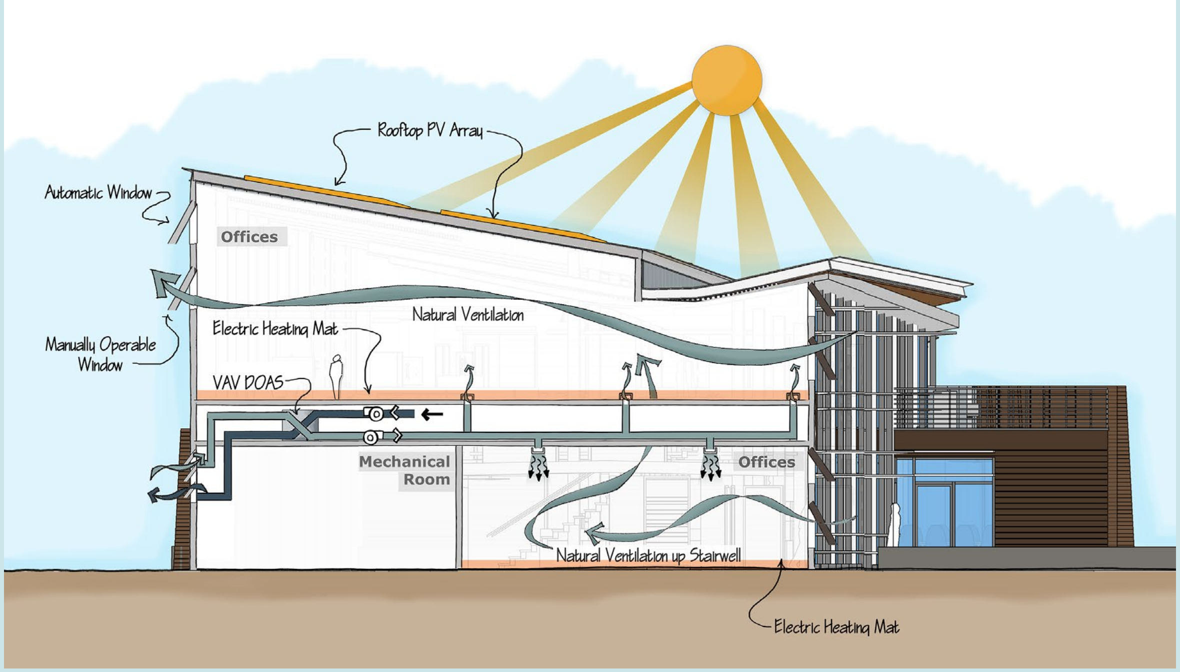
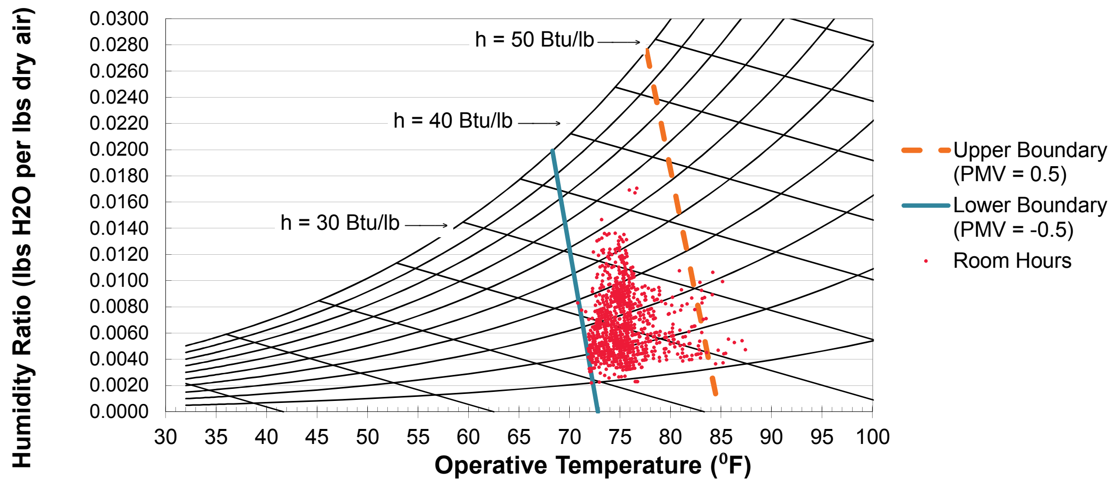


Image Credit: ZGF and PAE Consulting Engineers

Based on elevated air speed model



Detailed energy modeling – Thermal comfort

Room thermal comfort performance

Image credits: ZGF, PAE Consulting Engineers, and RMI

Occupant thermal comfort was central to the design. The design team used the predicted mean vote (PMV) rather than air temperature to establish the desired comfort targets. To determine whether the building would meet comfort targets, the design team relied on energy/comfort modeling to provide analysis at numerous stages of building design.

The team utilized a psychometric chart (above) to provide a summary of the results for each analysis cycle. The internal temperature and humidity ratio for each occupied hour is plotted for the office space. The chart contains upper and lower PMV bounds for too cold and too hot. The design was continuously refined—including envelope optimizations, mechanical system variations, night flush sequences, and even recommended clothing levels for occupants—until only an acceptable number of hours were determined to fall outside of the established comfort range.

The project has now successfully operated for its first full year as a zero energy building. A post-occupancy evaluation revealed that the comfort performance is exceeding industry averages for buildings with traditional heating and cooling systems.

Concepts

A building that is either too hot or too cold and does not provide thermal comfort for occupants is also unlikely to meet its initial energy performance goals. Thermal comfort is influenced by a number of factors at different times of the day, month, and year. Outdoor conditions play a role, as well as ventilation. Where we are in a space, what we are doing, what we are wearing, and how we interact with a space also play a role. The highly subjective nature of human behavior and comfort complicate thermal comfort simulation efforts.

The research of Povi Ole Fanger serves as the foundation for the evaluation of thermal comfort. Two prevailing thermal comfort models are defined in ASHRAE Standard 55-2013: the static whole-body thermal-balance comfort (WBC) model for mechanically conditioned spaces, and the dynamic adaptive thermal comfort (ATC) model for naturally conditioned buildings. The WBC model uses the "PMV-PPD" index to predict the percent of people dissatisfied (PPD) at each predicted mean vote (PMV) for a seven-point thermal-sensation scale based on a design outdoor temperature and the environment inputs described in approach + inputs. The PMV establishes a thermal strain based on steady-state heat transfer between the body and the environment, and assigns a comfort vote to that amount of strain. A simple way to describe the performance target is less than 20 percent PPD of occupants.

The ATC model considers a wider range of impacts on comfort, including the effect of outside conditions (e.g., solar path, solar radiation, and wind levels). The model is based on the assumption that if a change occurs that produces discomfort, occupants will respond to restore comfort. It accounts for the adaptation to climate, behavioral adjustments, and changed expectations based on adaptations. An underlying premise in the model is that the more adaptation opportunities available to occupants for their environment, the less likely they will be to suffer discomfort.

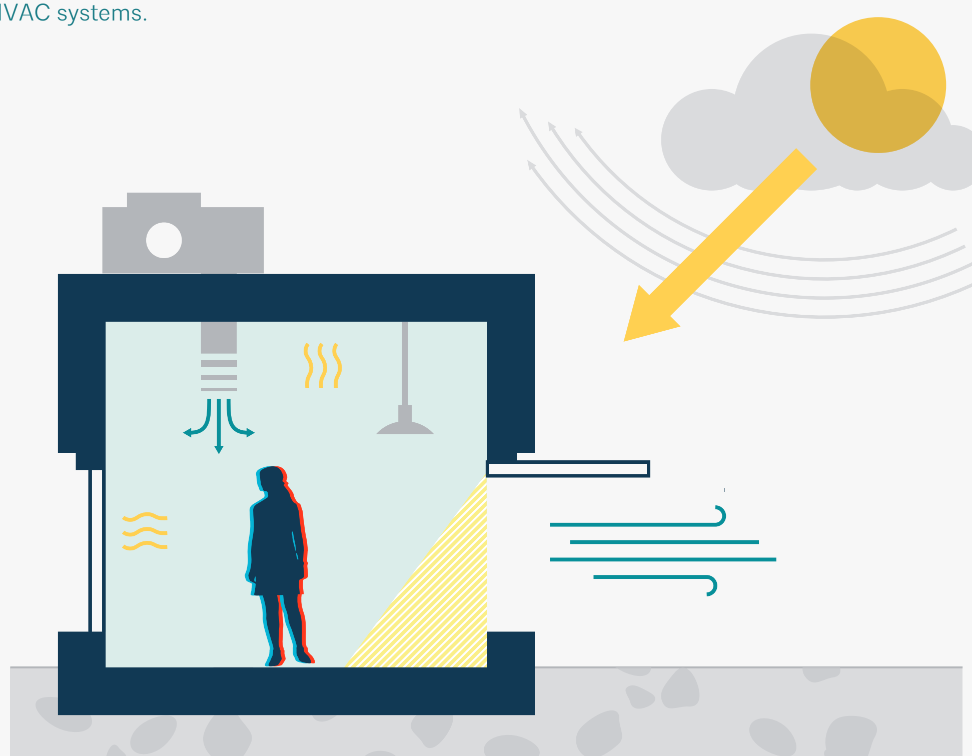
Thermal comfort simulation continues to evolve. The adaptive approach to thermal comfort and thermal comfort simulations resulted from ongoing research about how people experience actual conditions. The more we learn, the better able we are to analyze comfort in more informative ways.

Approach + inputs

Thermal comfort analysis is typically performed by a BPS professional to ensure design compliance or to document green building rating system compliance (or both). However, some tools are enabling architects to evaluate thermal comfort during the design process, too. These tools are design tools, not just tools that provide proof of compliance. They allow designers to see how design decisions about façade and HVAC systems influence the interior

Figure 6.8

Simulations analyzing thermal comfort evaluate the degree of thermal comfort for occupants in an interior environment that is influenced by the way in which design addresses the outdoor environment, and HVAC systems.



environment. They can also provide insight into zonal equipment sizing assumptions and calculations, and provide a fairly quick way to add thermal comfort to the set of performance parameters for evaluating a design. Although analysis can occur at multiple design stages, it typically occurs when active/passive/hybrid conditioning systems and façade systems are being considered in more detail.

There are numerous thermal comfort simulation tools, ranging from spreadsheets, to online tools for ASHRAE 55 compliance, to analysis on BIMs, to computational fluid dynamics. They all typically address the WBC model, and may incorporate aspects of or the entire ATC model to explore the dynamics of indoor and outdoor environments in more detail.

For analysis of mechanically ventilated spaces, identify relevant spaces (typical and unique) and representative occupants for those spaces. Define or model façade geometry and space for each, and determine the outdoor design condition temperatures (typically the hottest and coldest design temperatures). The WBC model assumes the HVAC system is providing a well-mixed supply of air at a uniform temperature. The key six inputs include:

- Metabolic rate (met)—occupant's level of activity
- Clothing insulation (clo)—occupant's level of clothing insulation
- Air temperature (t_o)
- Mean radiant temperature (MRT)
- Average air speed (V_o)
- Relative humidity (RH)

With this information and these inputs, the WBC model analysis can then be performed for the average hottest and coldest outdoor temperatures for the climate zone in question; these are used as the starting point for evaluating the design and testing design alternatives.

For naturally ventilated spaces and evaluation of spaces to other climate dynamics, an additional layer(s) of simulations is necessary, including orientation, daylighting, shading, and natural ventilation, if applicable.

Common questions

Some common questions to ask related to thermal comfort simulation:

- Which climate conditions should be considered?
- Is natural ventilation or mixed ventilation being considered for the building?
- Which are the relevant spaces to analyze, and who are the representative occupants?
- What role is the percentage and type of glazing playing in terms of occupant thermal comfort?
- Will the building be able to maintain comfortable temperatures without power? For how long?

Interpreting and communicating results

Thermal comfort analysis typically involves multiple simulations, evaluating the percent PPD to test the influence of changing the occupant's location; façade or ventilation characteristics (or both); and times of day, month, and year. Simulation tools display the results in different ways, such as a line chart or column graph showing the resulting percent PPD, a psychrometric chart indicating whether the scenario being evaluated falls within or outside the comfort zone, or a computational-fluid-dynamics (CFD) analysis to evaluate select spaces in more detail.

Analyzing the results can inform design decisions for the building envelope, natural- and hybrid-ventilation strategies, HVAC system zone/space equipment sizing, and other low-energy strategies. It enables deeper insight into the interdependencies of performance.

Figure 6.9 provides a summary of a CFD analysis, prepared by Arup, for a typical space in a science building, evaluating the influence of exterior glazing cases and active chilled beams (ACB) on thermal comfort. It is a project of the Northeastern University Interdisciplinary Science and Engineering Complex in Boston. The project team included Payette and Arup.

Case 1 is an insulated double-glazed unit, and Case 2 is a triple-glazed unit. Both exterior glazing cases are the same size, and they have the same 12.4° F design winter temperature applied to them. The additional assumptions are described on the top right of the figure. The difference in surface temperatures between the two cases is shown on the top left (Façade Surface Temperatures). The CFD analysis results for each case represent two cross-sections of the space. The first cross-section (on the left for each case) shows the glazed façade on the right side, two occupants positioned in the space, and the location of the chilled beam indicated above. The result image on the right for each case is just within the space (façade behind) looking toward the other side of the room. A color legend for interior temperatures is provided on the left and between the two cases, to offer interpretation of the color gradients.

The results demonstrate that the triple-glazed façade (Case 2) shows an improvement in resultant temperatures close to the façade as well as overall in the space. In the double-glazed option (Case 1), the darker-blue color indicates colder temperatures near the occupant. Case 2 performs better because

Figure 6.9

Computational fluid dynamics analysis comparing glazing options and active chilled beams for a science building at Northeastern University.

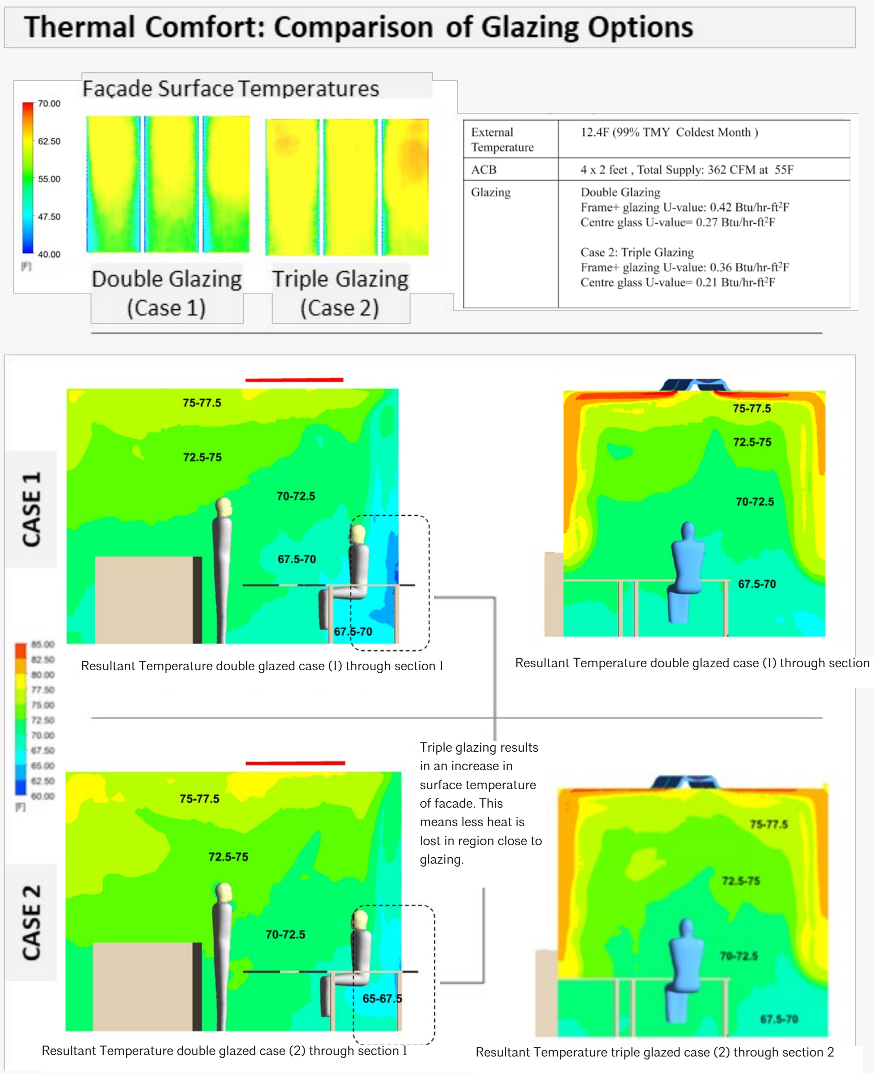
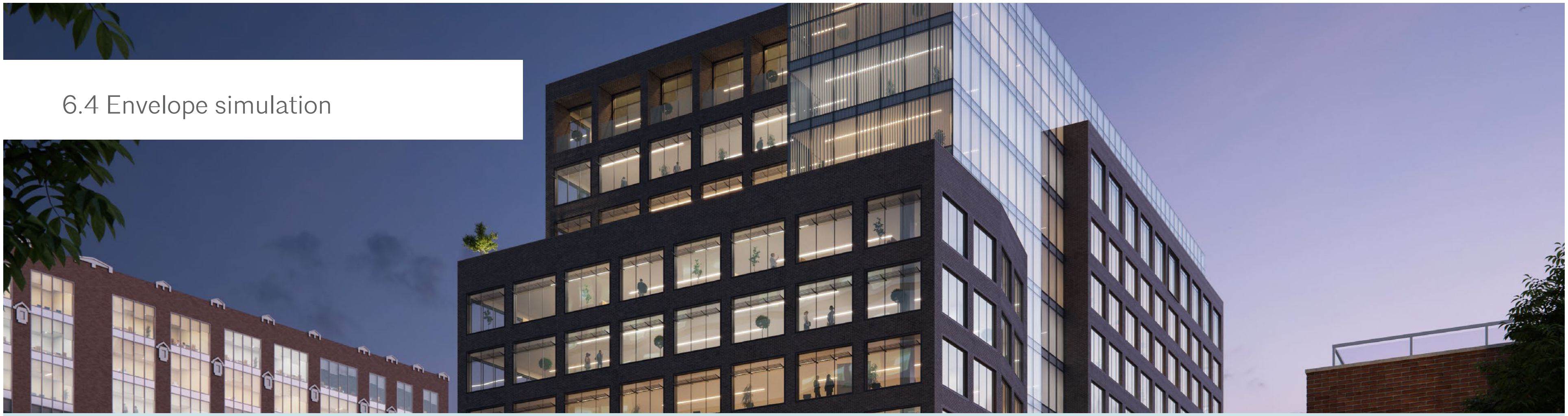


Image credits: Simulations performed by Arup

of the warmer surface temperature on the triple-glazed façade, which results in the space being less exposed to radiant heat loss.

Whereas this example may seem simple and basic, this type of thermal comfort analysis, for a typical space, can inform numerous design decisions—not only for the space but for the overall building. It provides insights on the amount and type of glazing, type and placement of active chilled beams, height and shape of the space, and beneficial workstation locations, to name just a few.

The complex topic of thermal comfort doesn't require complex communication. The percent PPD metric can be a useful way to describe the performance of different scenarios and complement other types of analysis to tell a more comprehensive design performance story.

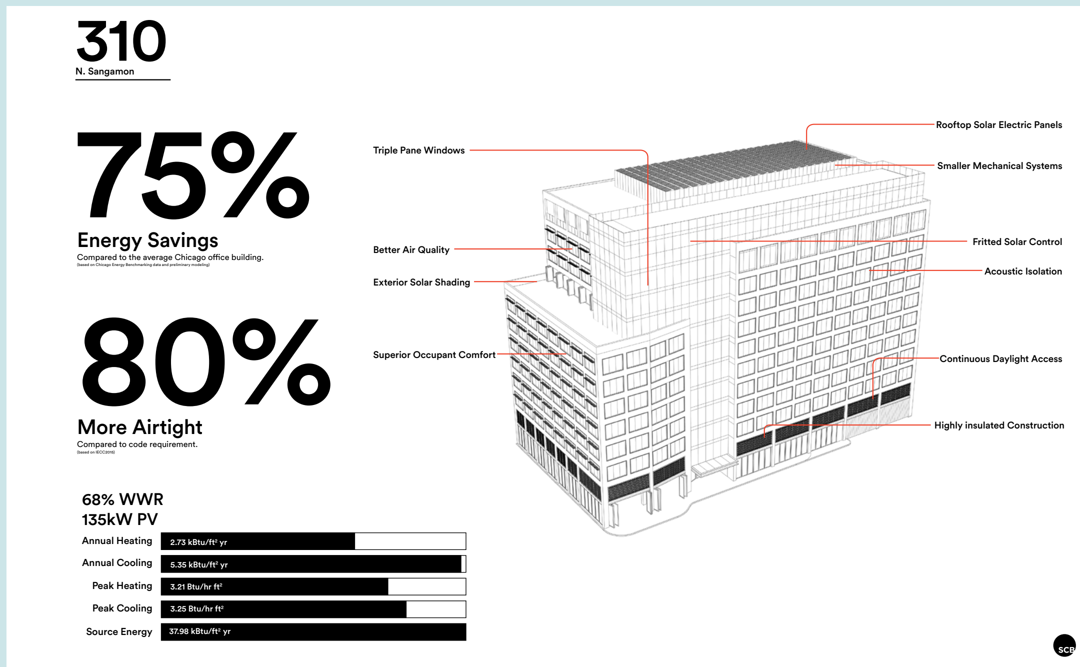


6.4 Envelope simulation

PROJECT EXAMPLE:

310 N. Sangamon Street

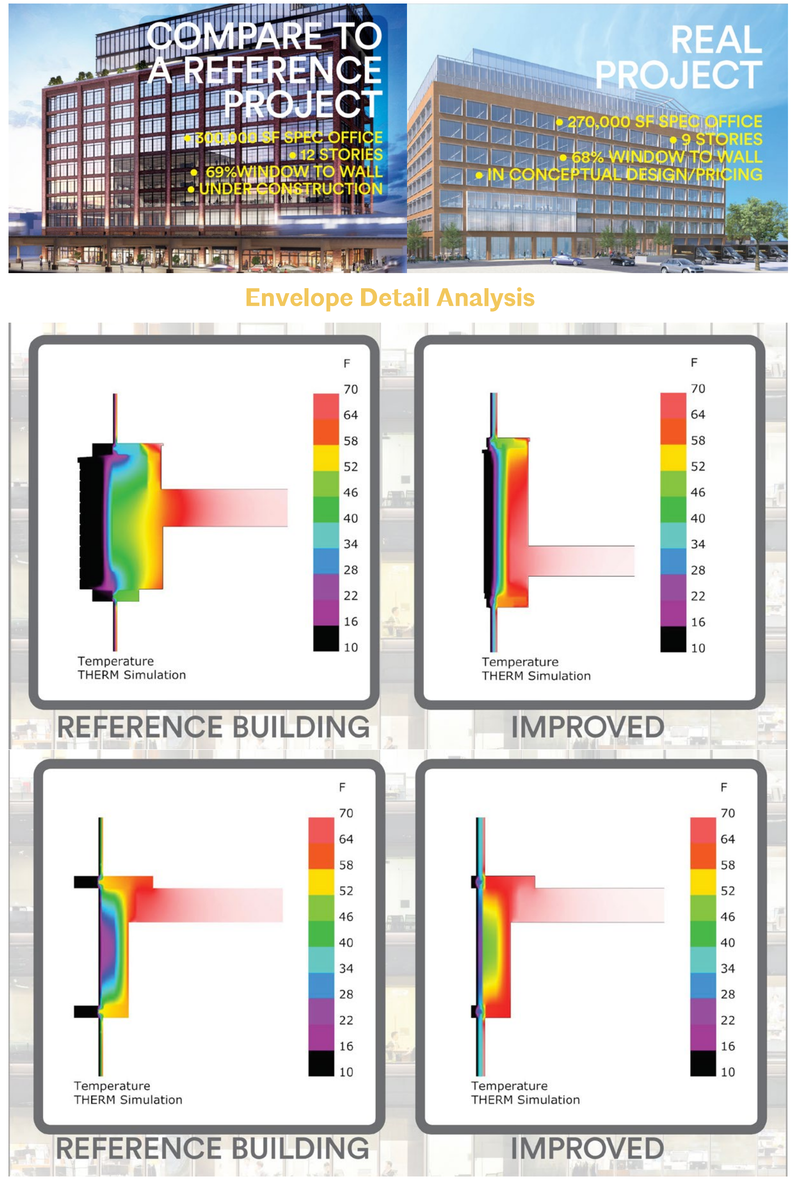
The client for this 270,000-square-foot spec office building in Chicago was interested in maximizing glazing in the design, while also targeting a high level of energy savings and achieving a Passive House Institute US certification. Therefore the envelope needed to be efficient. The design team consisted of Solomon Cordwell Buenz and Mark Goodman & Associates. They performed a heat transfer envelope simulation on a set of building envelope design alternatives in parallel with energy simulation to evaluate which assemblies for the walls, spandrels, and glazing would provide the most benefit. The envelope design alternatives were compared to a reference building to enhance the evaluation.



The image to the right tells the first part of the story. The left side of the image displays the reference project and 2-D heat-transfer simulation results for typical wall and spandrel conditions. The right side of the image shows one of the project envelope designs, which included a window-to-wall ratio of 68 percent. This design option also included R-8, triple glazing with a solar heat gain coefficient (SHGC) of 0.22, and an R-4 frame as well as additional rigid insulation and different detail assemblies. The heat transfer legend for the four details simulated is in the center.

Visual analysis of heat transfer envelope simulations is a great place to start with envelope analysis. The color legend in the image shows the red and pink colors that represent temperatures closest to the indoor design temperature (70° F); the black and purple color represent the cold outdoor design temperature (10°–20° F). Ideally, then, the visual analysis would show a thick band of red toward the interior side, particularly at the interface of the slab, so that cold temperatures don't use the slab as a medium (thermal bridge) to draw cold deeper into the building. On the reference project details (left in the image), the results are very colorful, with a significant amount of green and blue, and a thin band of red. On the real project details (right in the image), the results show a prominent band of red toward the interior on both the wall and spandrel.

There is more information about the analysis of the spandrel detail in Interpreting and Communicating Results.



Comparison of wall and spandrel detail, reference project versus one design option for the 310 N. Sangamon Street project.

Image credits: © Solomon Cordwell Buenz

Concepts

The building envelope is perhaps the most visible mark an architect leaves on a building and, arguably, also the part of the building over which they have the most control. It is the interface between the indoor and outdoor environments. It needs to manage heat gains and losses to conserve energy and maintain thermal comfort. It has to transmit appropriate daylight and control glare while also enabling views. So far in this part of the guide, solar studies and shading, daylight and glare, and thermal comfort simulations have been discussed. The envelope plays a key role in all of these types of analysis, but there is another important level of envelope detail that also needs to be taken into consideration. (Figure 6.10)

Basic facts to consider when thinking about envelope simulation:

- Heat flows from warm to cold
- Moisture flows from warm to cold
- Moisture flows from more to less
- Air flows from higher pressure to lower pressure

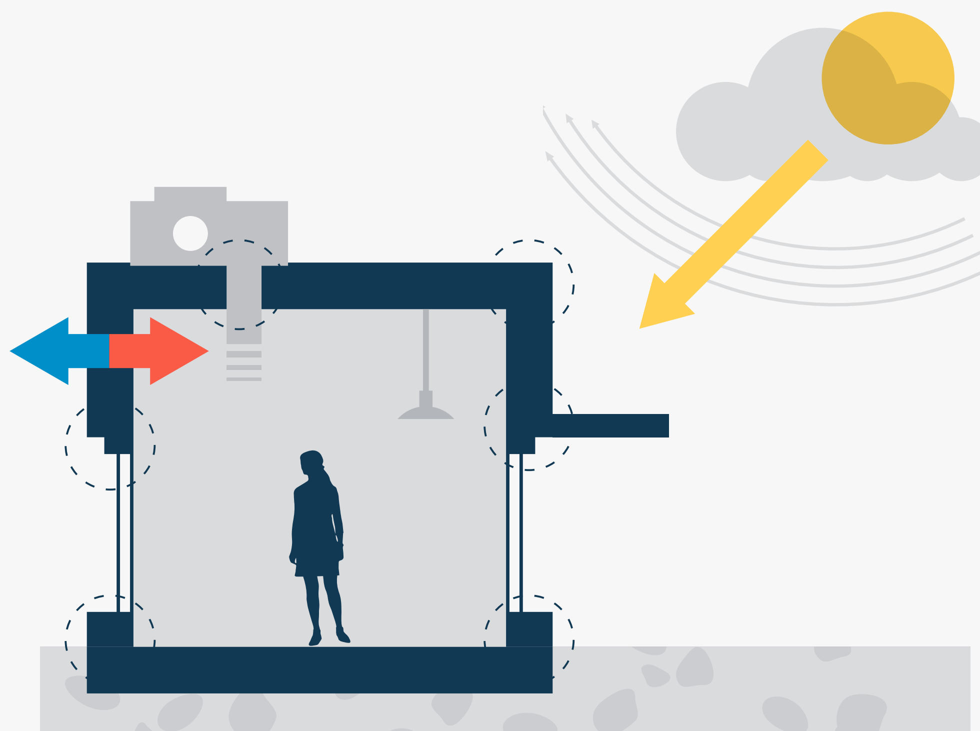
Envelope simulation focuses on heat transfer and hygrothermal transfer (the movement of heat and moisture through buildings) as well as detailing related to both. Whole building energy simulation incorporates the envelope and quantifies its role in the energy performance of the design. However, the input values for walls, roofs, and floors included in the simulations are typically the overall R-Value and U-Value of the assembly. For a wall, for example, this overall value represents the thermal makeup of the sum of the material layers for a typical section of the wall. It does not take into account what is happening at the top or bottom of that wall, how it interfaces with the roof and floor, how window openings are handled, and what connectors are being used to put it all together. Heat transfer and hygrothermal simulation help engineers and façade engineers evaluate whether the assembly compositions for the envelope components will perform as anticipated, and if the detailing of the interface between components will lead to problems.

Approach + inputs

Thermal bridging and heat flow simulation. Thermal bridging can occur where a building component or assembly has a higher thermal conductivity than those surrounding it. This can lead to unwanted heat transfer into or out of a conditioned space. Implications of thermal bridging include increased energy use, reduced occupant comfort, and the appearance of unwanted condensation. Examples of details that are beneficial to investigate include curtain wall assemblies and the interface of a wall to the roof or floor, or both.

Figure 6.10

Envelope simulation provides analysis of the next level of detail to evaluate how the layers of the wall, roof, floor, glazing, and frames handle moisture and heat flow between the indoor and outdoor environments.



Dew point, hygrothermal, and moisture analysis. Eliminating condensation is a key consideration that warrants renewed attention in envelope design and simulation. The most basic level of understanding involves knowing where the dew point lies within envelope assemblies, and whether condensation will be problematic. The dew point is the temperature at which airborne water vapor will condense to form a liquid. If the dew point occurs in the insulation layer of the wall—which causes the insulation to get wet and become less thermally effective—there are going to be multiple problems.

Simulation-aided hygrothermal analysis helps determine moisture content, relative humidity, dew point, and temperatures at the surface of or within each assembly component. Today's highly insulated assemblies can create significant levels of entrapped moisture that go undetected by standard dew point analysis. Consequently, hygrothermal analysis is not only a building performance issue, it's a liability issue as well.

Scales of simulation. Energy simulation is an important tool for any project at the overall building level, but it is also important to consider the role heat transfer and moisture play in how the design performs over time in ever-changing climate conditions. Heat transfer and hygrothermal simulation, in tandem with energy simulation, can help optimize energy efficiency without sacrificing durability.

Simulation approaches. Analyzing each envelope component and its interfaces to determine an effective thermal value for each one is possible. It would be very time-consuming, however, even if building performance simulation programs allowed those values to be incorporated into a whole building energy simulation. A typical approach, therefore, is to look at the design with the engineer/façade engineer and identify a set of typical and unique cases to investigate and analyze.

Some tools provide the ability to analyze both hygrothermal and heat transfer within the same tool, while others focus on one or the other. The analysis can be set up to analyze 1-D, 2-D, and even 3-D flows, but 1-D and 2-D flow analyses are the most typical.

1-D flow refers to the analysis of heat transfer or moisture flow through a wall, roof, floor, or window composition. This analysis is commonly used to identify the dew point, and the comparison of heat transfer results between different assemblies.

2-D flow refers to heat and moisture transfer in two directions. Figure 6.11 provides an example of a 2-D heat transfer analysis comparing the results of two different approaches to the materials used and how they are put together at the interface of a wall and a slab.

These simulations typically require developed building geometry because they are analyzing details, and not larger portions of a BIM or 3-D model. In the detail analysis, each material has a geometry component associated with it. Some tools allow import of underlays (dxf or dwg format), and the user can trace geometry. Tight geometry with contact in all the right places is important because the simulation is analyzing heat transfer.

When the geometry is defined, boundary conditions and appropriate materials can be assigned. Tools typically have a common library of materials to use. Custom materials can be created as well. Materials have to be assigned to each geometry element included in the analysis simulation. The properties

Figure 6.11

A thermal bridging simulation can demonstrate the degree of heat conductivity in various envelope assembly options.

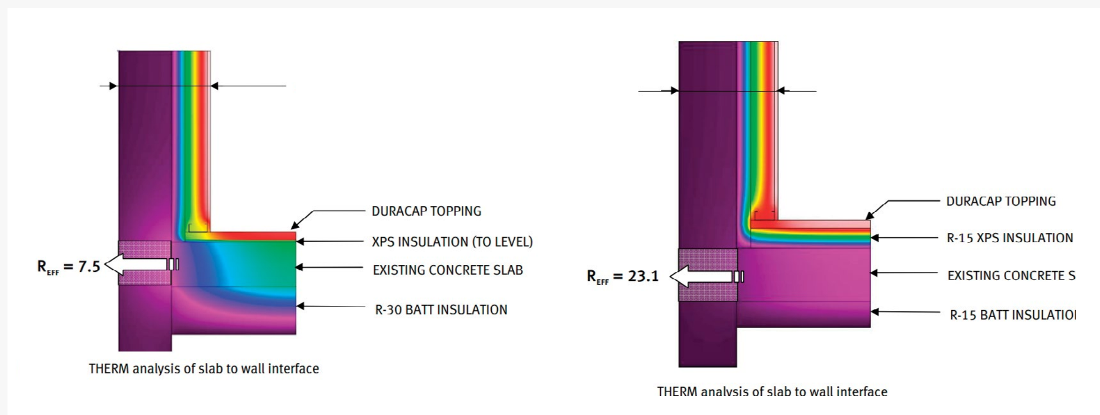


Image Credit: © Solomon Cordwell Buenz

associated with the materials, such as thermal conductance, permeability, and thickness, play key roles in analysis.

Boundary conditions also have to be defined for every edge of the analysis model. The boundary conditions include boundary temperature and film coefficient, which is dependent on the design wind speed and direction that will be included for the analysis. It is important to discuss with the engineer/façade engineer which exterior design temperatures (based on the climate) and internal temperatures are beneficial to include in the analysis. In Figure 6.11, the left edge would have an outdoor boundary condition. The inner edge of the wall and floor would have an interior boundary condition, and the section edges of the wall and slab would have an adiabatic boundary condition in which heat neither enters nor leaves.

Common questions

Some common questions related to envelope simulation:

- Is there a set of wall, roof, floor, and glazing assemblies that would be beneficial to analyze and compare?
- Has moisture flow been considered? What is the dew point for each of the unique wall types?
- Which set of envelope details would be beneficial to analyze?
- What are the right performance properties for the windows? How do they differ from the center of glass values?
- What is the correct amount of insulation in the walls?

Interpreting and communicating results

In the project example image at the beginning of this section, a visual analysis was used to compare the heat transfer envelope simulations between a reference building and one design option for the 310 N. Sangamon Street project. Figure 6.12 provides more information about the spandrel detail, providing further comparison between the reference building and the design option by introducing a description of the detail material composition. For the design option, three key differences are highlighted:

- Triple glazing versus double glazing
- A reduced air space between the glazing and rigid insulation

Figure 6.12

A thermal bridging simulation can demonstrate the degree of heat conductivity in various envelope assembly options.

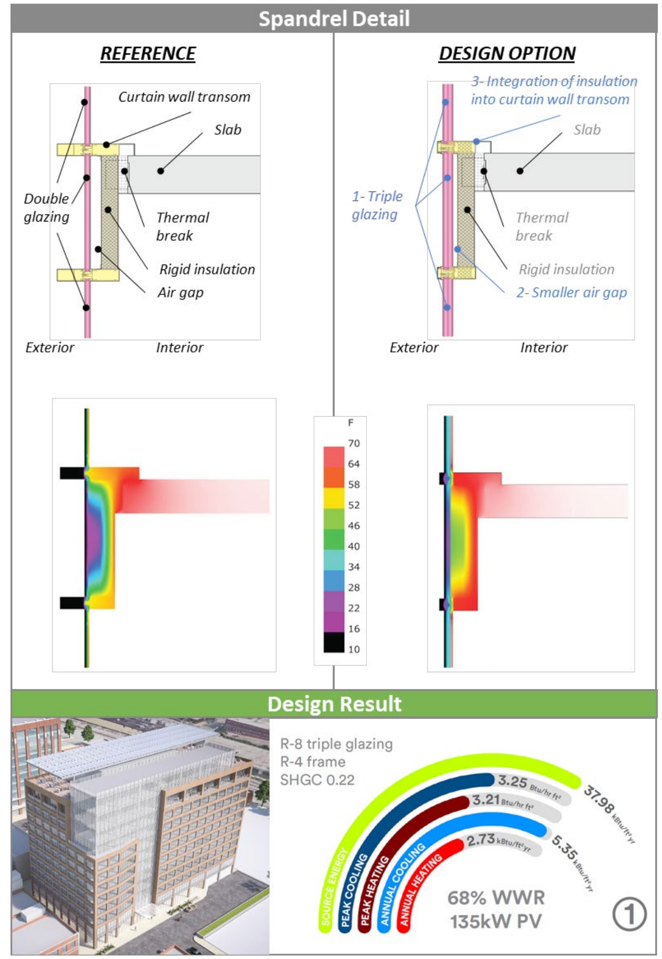


Image Credit: © Solomon Cordwell Buenz

- Insulation integrated into the curtain wall transom

With this information, the heat transfer envelope simulation result becomes more meaningful:

- The triple glazing keeps the coldest temperatures from penetrating the glass layer. Color to the right of the glazing is green (46° F) for triple glazing and purple (22° F) for double glazing.
- The smaller air gap between the triple glazing and rigid insulation keeps the cold from spreading to a large degree, and allows the rigid insulation to do its job, reducing the heat transfer and defining the “red band” visible to the right of the triple glazing.
- The integration of insulation with the curtain wall transom shows that the red zone (64°–70° F) is carried right up to the glazing layer on the design option, versus the predominant yellow and orange bands (52° F) on the reference detail.

The knowledge gained from envelope simulation analyses, enabled effective R-values to be determined for different envelope components, which could be entered with confidence into the energy simulation to assist determining the window-to-wall ratio possible for the design while still meeting energy goals. In this case, the envelope composed of R-8 triple glazing with an SHGC of 0.22 and an R-4 frame allowed the design to incorporate 68 percent window-to-wall ratio, achieving a pEUI of approximately 38 and a 135 kW PV array.

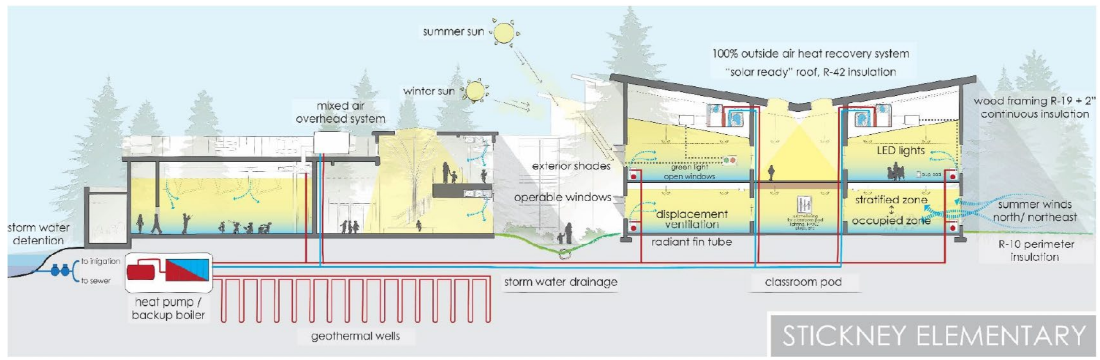
6.5 Natural ventilation simulation

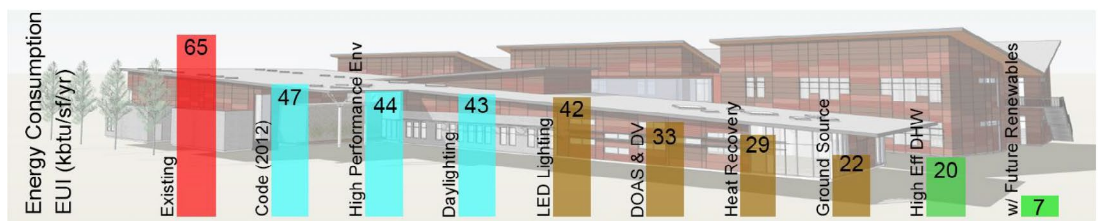
PROJECT EXAMPLE:

Lake Stickney Elementary School

Lake Stickney Elementary School, designed by DLR Group, is a K–5 school in the Mukilteo School District in Lynnwood, Washington. It offers is a great example of what a project team can achieve when it makes the commitment to passive design strategies, utilizing what the local climate has to offer. The image on the right displays the first part of the project's performance story, highlighting how natural ventilation became part of the project, as well as initial strategies to increase the time natural ventilation could be effective that needed further evaluation.

Assessing the feasibility of natural ventilation for a project starts with climate data. The bar graph





in the center of the image displays where each occupied hour of the year falls in terms of outdoor temperature (horizontal axis). The vertical axis is the number of occupied hours. It is easy to see which ranges of outdoor temperature have the largest number of hours. A very useful addition to the graph is the identification of the temperature ranges that can be handled by natural ventilation, those that will require heating and mechanical ventilation, and those that will need mechanical cooling. Additional climate analysis to assess feasibility would involve evaluating wind speed, wind direction and frequency, as well as other factors. However, even at this early stage, the simple takeaway is that natural ventilation can play a significant role.

With this information, thinking can shift to which design strategies assist natural ventilation and can potentially extend the hours natural ventilation can be used. Design strategies such as setting a limit to the width and depth of the building form, using exterior shading to reduce or manage (or both) internal heat gains, utilizing the stack effect in addition to cross ventilation, and incorporating operable windows and signals that let the occupants know when the outdoor conditions are beneficial for open windows. Although a lot of simulation has not been performed at this point, the stage is set to decide which design options it will be beneficial to analyze moving forward, which will require several cycles of simulations of bulk airflow model, computational fluid dynamic models, or more.

Images courtesy of DLR Group.

Concepts

Natural ventilation consists of using natural forces (e.g., buoyancy and wind) to drive air through a space. This air can be used to provide:

- The right amount of fresh air to meet the space's ventilation (indoor air quality/IAQ) requirements
- The right amount of cool air to meet the space's cooling demand (also known as "ventilative cooling")

Because the amount of outdoor air needed to cool a space is often greater than that needed to maintain acceptable indoor air quality, we tend to think of natural ventilation as a cooling strategy only. However, keep in mind that natural ventilation can also be used in the wintertime to maintain adequate indoor air quality (a strategy often known as "trickle ventilation") while using mechanical heating to maintain thermal comfort conditions. Natural ventilation is essentially an engineered HVAC (or at least VAC) system. Despite the challenges this system presents in building performance simulation, it can be used to very effectively reduce energy use and introduce more natural conditions into an indoor space.

Even though natural ventilation is a well-known strategy that has been used in buildings throughout history, it requires a unique set of simulations that tend to be outside the purview of typical energy simulation endeavors. Simulating natural ventilation concerns three main variables:

- Airflow through a space (important for IAQ)
- Indoor temperature in that space (important for thermal comfort)
- Air speed at the window (important to determine whether the air speed may lead to, for example, papers flying off desks)

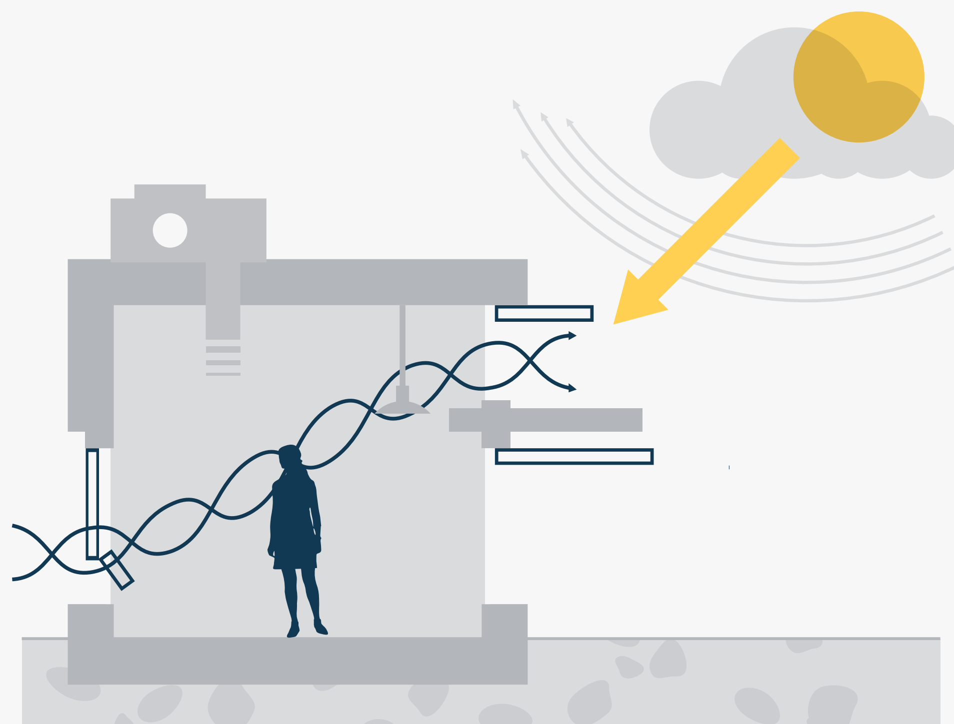
Obtaining information on these variables through simulation can be done through three approaches to natural ventilation simulation.

Hand calculations. Simple spaces that could be treated as a single zone in an energy simulation (ventilated through openings along one or two façades, not connected through shafts or atria to other spaces, and with fairly uniform internal load distributions) can often be simulated with hand calculations (e.g., a single office, an open office, a classroom, all with limited solar gain.) These calculations are for a point-in-time and cannot account for transient effects such as thermal mass but are very useful to determine the adequate size of openings and expected comfort levels in a space.

Bulk airflow models. These simulations calculate pressure differences attributable to buoyancy or wind between two or more spaces or zones, and

Figure 6.12

Natural ventilation uses natural forces such as buoyancy and wind to drive air through space, and can be used for both ventilation and cooling.



estimate the airflow and indoor temperature in each space. These envelope-simulation tools are typically found embedded in building performance simulation packages because they can be used to run hourly annual simulations using the output of the performance simulation. They are ideal for simulating the effects of thermal mass and night flushing. A few standalone tools (i.e., not embedded within building performance simulation) exist and can be very useful in defining a natural ventilation strategy when a simulation of the building hasn't yet been built. These tools are not ideal to simulate wind-driven ventilation because they don't take into account the impact of surrounding buildings or hourly variations of wind patterns when estimating wind pressures.

Computational fluid dynamics (CFD). This approach simulates the movement and temperature of air within or outside buildings, and may be used to evaluate the effectiveness of natural ventilation for a specific point in time. Outdoor CFD simulations are run to evaluate the impact of wind and surroundings on façade pressures. Indoor CFD simulations are used to understand the flow, temperature distribution, and pressure losses within a building but are not ideal for simulating thermal mass effects because of the associated computational requirement. For the sake of accuracy, indoor and outdoor simulations should be run separately, and only to answer questions that other simulation tools cannot. Architects should ensure that the building performance simulation professional they work with to simulate natural ventilation understands this.

Approach + inputs

As with any other HVAC system, the simulation process to design a natural ventilation (NV) system (e.g., size and locate openings, minimize pressure losses) is different than the evaluation of the NV system's annual performance.

Designing an NV system requires the system to work even in a worst-case scenario. This worst-case scenario requires looking at peak loads in the space and a zero-wind condition at one point in time. Hand calculations and standalone bulk airflow models are ideal for this stage. For spaces with concentrated heat gains or multiple spaces connected to a shaft, an indoor CFD simulation may be required to identify ideal opening locations. For areas with high wind conditions, an outdoor CFD may prove useful for understanding the impact of extreme wind on the worst-case condition (and to ensure certain wind conditions won't hinder the flow through the building).

To assess the performance of the NV system and its associated energy savings, a seasonal energy simulation linked to a bulk airflow model is the best approach. As a sanity check, a zero-wind condition with high internal loads should yield airflow and indoor temperature results that are similar to the calculations performed when sizing the system.

Factors that will influence the size of the NV openings:

- Thermal comfort assumptions (if occupants will have control over their clothing levels and some operable windows, an adaptive comfort range per ASHRAE Standard 55 may be assumed)
- Placement of windows, internal partitions, internal shafts
- Window types and dimensions (for spaces ventilated with single-sided ventilation)
- Building orientation, solar and internal gains
- Flow obstructions (windows with insect screens should be about 30 percent larger than windows without them)
- Amount of exposed thermal mass
- Use of fan assist
- Use of ceiling fans

Factors that will affect the energy savings associated with using NV:

- System design
- Climate zone (outdoor temperature, humidity, wind direction and speed)
- Window controls (manual vs. automated)
- Night flushing controls (if any)

Note that if you're pursuing LEED Certification, you can benefit only from the energy performance credit associated with fan energy savings through natural ventilation and not cooling energy savings. This means that most of the energy savings perceived in reality will not be captured within your LEED documentation.

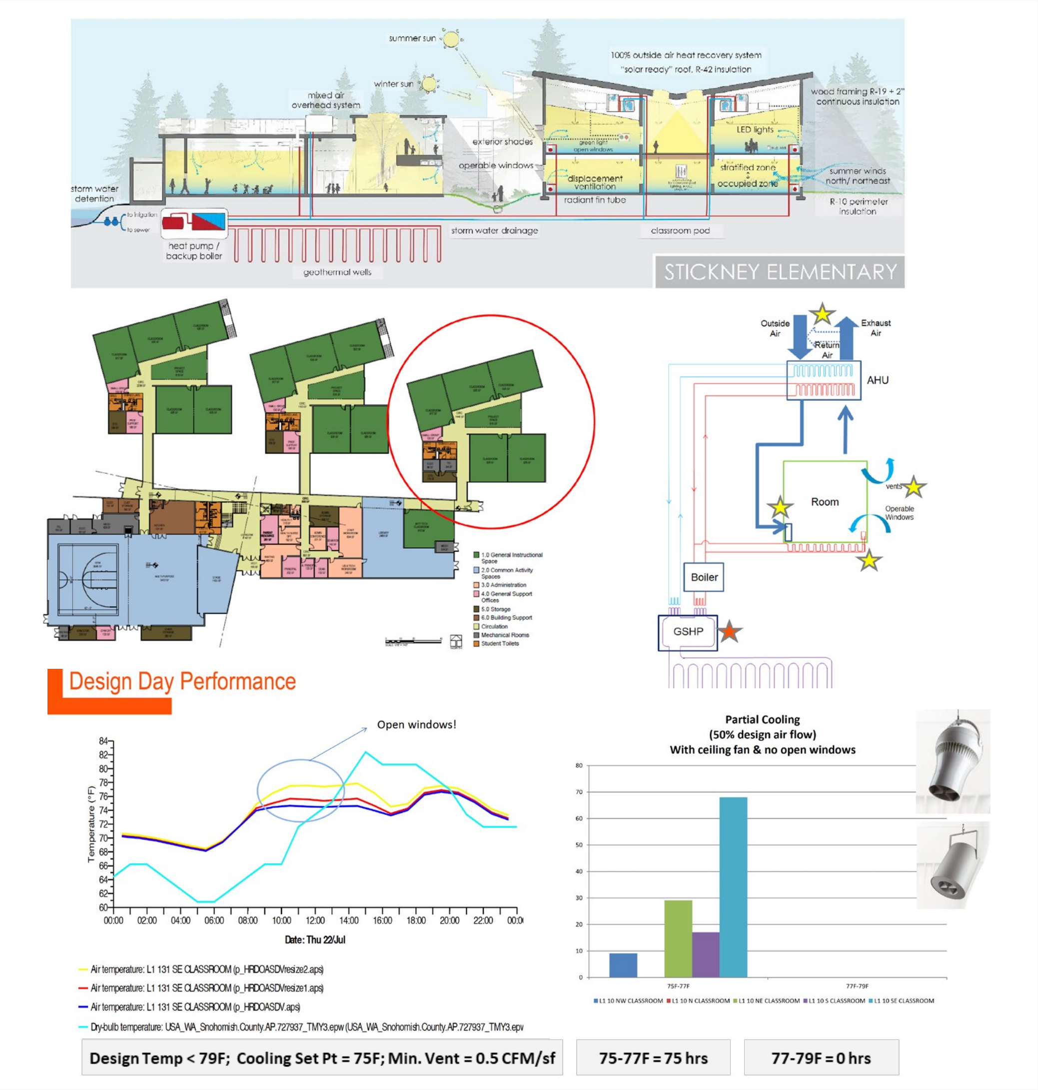
Common questions

Some common questions related to NV simulation:

- Which thermal comfort criteria should be used for a certain building typology? Can adaptive comfort be used? (see ASHRAE Standard 55)
- Will the building use ceiling fans to expand the thermal comfort band?
- Based on indoor comfort assumptions, which outdoor air temperature and humidity ranges are acceptable for natural ventilation?
- What size should windows and interior transfers be? How is this impacted by the use of insect screens? How many windows are needed?
- How will natural ventilation perform in the absence of wind? How will it perform in the presence of unfavorable winds?

Figure 6.13

A summary of natural ventilation being analyzed within overall system options. The images and results were obtained from Lake Stickney Elementary School design performance presentations prepared by DLR Group.



- How many hours of the year is natural ventilation expected to be in use?
- How much cooling and fan energy does natural ventilation save?
- Should the building rely on manual or automatic controls? If manual, what is the best way to provide feedback to users regarding ideal times to open windows?
- What are the optimal night flush schedules and control settings that optimize energy savings?
- Will NV and AC be allowed to operate concurrently in the same floor or building? If so, how will NV be integrated with HVAC controls?

Interpreting and communicating results

Figure 6.13 summarizes a next stage of natural ventilation analyses for the Lake Stickney Elementary School project. As the design moves forward, overall system configuration options (heating and cooling solutions) are being developed and analyzed. This can be confusing, so it is important to clearly communicate which system options are being evaluated and their differences. The middle right of the figure features a one-line diagram of Option 2 for the project. It includes a ground source heat pump (GSHP), a boiler, an air handling unit (AHU) that is part of a dedicated outdoor air system, and natural ventilation (vents and operable windows) at the room level. A key difference for system Option 2 is that it does not include a chiller, which would add additional first cost savings. A strong complement to the single-line diagram is the image at the top of the figure which shows how this system option fits into the context of a cross-section of the project.

Typically, in addition to whole building energy simulation, bulk air flow models have been developed for the overall building as well as CFD models for typical spaces, such as classrooms, to take a closer look at the air flow patterns, temperature, and thermal comfort. The analysis is focused on comparing the performance of the system options in terms of energy savings and thermal comfort, while also answering additional questions about the sizing of the natural ventilation system, and when it can be used.

Analyze the sizing of the natural ventilation system within the overall system for key variables such as:

- Direction of the flow to confirm that the minimum ventilation rate for the desired level of indoor air quality is being met
- Amount of airflow through a zone to confirm that the calculated flowrate is indeed flowing from the outdoors into a zone, rather than backflowing from other occupied zones
- Air speed at the inlet to assess whether there is any risk of high-speed drafts in the space
- Temperature difference between the air entering a zone and that exiting the zone as a direct indicator of when natural ventilation can be used throughout the year

For the Lake Stickney Elementary School project, a set of classrooms (middle left of Figure 6.13) were analyzed in more detail to evaluate sizing, operation, and thermal comfort. The design day (bottom left) was evaluated for the classrooms, and the hours of day that the windows could be opened were quantified. In parallel, the classrooms were analyzed to assess the quantity of occupied hours within certain temperatures for the system option. In this case, the criteria were a design temperature less than 79° F, a cooling set point of 75° F, and a minimum ventilation rate of 0.5 cubic feet per minute per square foot. The bar graph (lower right in Figure 6.13) shows the result of 75 hours in the 75°–77° F range, and zero hours in the 77°–79° F range. This demonstrated the potential of the natural ventilation/partial cooling system option, particularly when it was compared to a natural ventilation only (with ceiling fan) option, which had nearly double the hours in the 75°–77° F range for the classrooms, and had hours reaching all the way to a 85°–87° F range that is well beyond occupant thermal comfort targets.

Results used to quantify energy savings associated with natural ventilation should clearly indicate:

- The thermal comfort model (adaptive or traditional) assumed to decide when the windows can be open
- The control algorithm assumed for window operation (including minimum/maximum outdoor/indoor temperatures, and any periods during which windows are not expected to be open, such as pollen season and nighttime)
- The control algorithm assumed for HVAC operation in conjunction with natural ventilation
- The times of the year when natural ventilation can be used (and how much of that time falls during occupied/unoccupied hours)

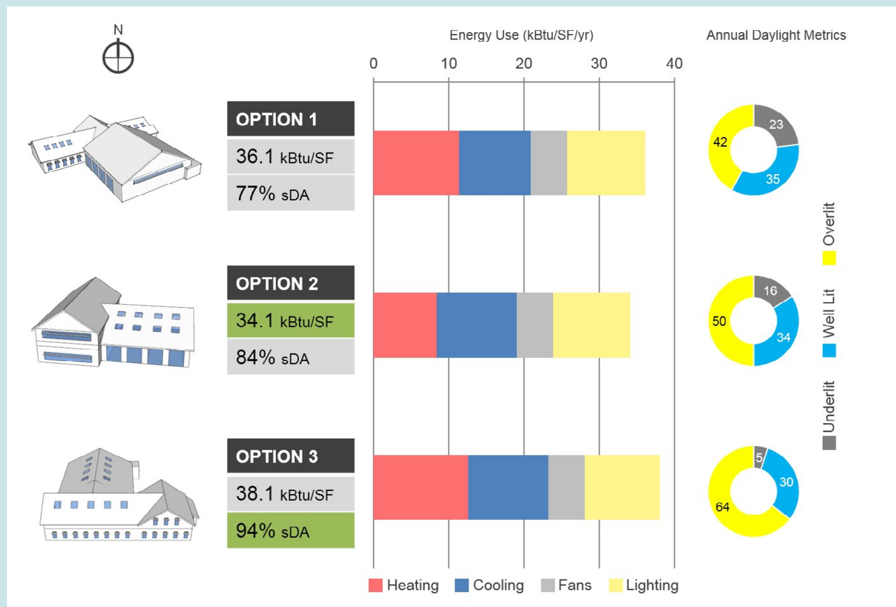
This is only part of any performance story for a project. In a large percentage of project applications, natural ventilation is part of a hybrid system approach. To answer the relevant design questions described above, several simulation models will be used, which means there will be a lot of results. It is wise to opt for quality over quantity, so the performance story can be followed by others. This means it will take more time to put the story together, but it is well worth the time.

PROJECT EXAMPLE:

Lucketts Fire and Rescue Station

Moseley Architects' Lucketts Fire and Rescue Station project in Leesburg, Virginia, drives home how early simple box modeling can be developed. The image to the right shows a summary of simple box model simulations for three design options that were presented by the architect at the project interview. Pause for a moment: The architect was doing simple box modeling simulations even before they had been awarded the project.

This single image provides a rich set of information that can be used to tell numerous stories. It combines the results of simple box modeling and spatial daylight autonomy (sDA—see Part 6.2 Daylight and Glare) in a clear and effective way. Option 2 is the best performer in terms of energy,



Images courtesy of Mosely Architects

while Option 3 leads the way in daylight autonomy. The three options present a range of potential performance for both energy (34–38 kBtu/ft2/yr) and daylighting (77–94 percent sDA), which can trigger interesting and insightful discussions. The energy-use stacked bar chart and the annual daylight metrics donut chart only help to take those discussions further. The energy-use bar chart, which displays the contributions of heating, cooling, fans, and lighting to the pEUI for each of the design options, is information that can be obtained from any energy simulation tool. It opens the door to discussions on load reduction and which strategies could be used to reduce energy use by heating, cooling, fans, and lighting. The annual daylight metrics in the image provide an excellent complement to the energy-use breakdown. They not only provide additional insight into the role daylight is playing in each design option, but also bring aesthetics into the performance discussion in a useful way.

Engaging a potential client in this way may to lead to securing an actual client. Bringing energy performance into the discussion—even at this relatively simple level, and even at the earliest stage of design—can be a persuasive tool. It is well worth noting that Moseley Architects did win the project. Option 3 was selected as the starting point for the design, which was significantly modified to further improve energy and daylight performances.

Concepts

Simple box modeling is a great way to quantify performance early to inform design. It is a whole building energy simulation used to evaluate energy end uses and demand before building geometry and site orientation have been set in the design process. It can assess a number of different single aspect architectural design decisions (e.g., massing, orientation, window-to-wall ratio, and envelope and structure thermal performance). The model does have geometry and massing, so it is a "simple box" only in that each simple box model developed for comparison most often uses the same HVAC system.

In the past, it has been a task for the engineer or BPS professional, if it was done at all. But with the integration of building performance analysis in BIM, as well as the increased accessibility to building performance simulation tools, architects may see the value of this kind of early-stage energy analysis. It is the first "cycle" recommended in ASHRAE Standard 209, and it can serve as an "integration icebreaker" to begin a collaborative dialog with a BPS professional.

There is a common misconception that simulation for energy performance can't begin until design is far enough along. That couldn't be further from the truth. Simple box modeling can begin at the earliest phases of design and inform design as it becomes more detailed. "Simple" is included in the term for a reason. The design team can leverage simple representations of early design ideas to unravel the complexity of building performance and quantify parameters to identify the main performance drivers that deserve attention moving forward.

The design team can use simple box modeling as a "performance sandbox" in which designers can play and quickly develop multiple simulations to test and evaluate ideas. With simple box modeling the results of a single simulation are not the focus. Instead, it is the difference between the results of multiple simulations that identify and quantify the range of influence of performance drivers. Simple box modeling is about comparative analysis and how the design is informed by insight into not only the performance drivers, but the tolerances of those drivers as well.

Approach + inputs

Using a building performance simulation tool, define the form of the building, either through modeling or by selecting a representative form. Select a location and building type. For a number of simulation tools, this is all that is needed to start running simulations. Default values are assigned to the rest of the input parameters, and default core and perimeter zoning are applied, so that simulating the project can start sooner, rather than later. More detail can be added, if it is available.

A simple box model should be simulated often to gain the greatest benefit. The set of simulations to run vary from project to project (see Common questions), but there are some initial strategies that can be pursued.

- Develop a simulation designed to meet performance goals to gain insight into what is needed to get there. Some simulation tools provide the ability to select a target, such as meeting the 2030 Challenge or net zero energy.
- Select a few input parameter values to adjust, run the simulations, and then compare the results to other simulations

Input parameters

Following are some key input parameters and things to consider before performing a simple box model.

Building type. Select from the standard set of ASHRAE building types. In a number of simulation tools, this input defines defaults for internal loads, ventilation, and potentially HVAC systems.

Building form. Some simulation programs will provide a set of forms to choose from, and others allow the user to model the desired form. This is the starting point; it doesn't need to be perfect.

Site location and weather file. This input establishes the climate context for the design. Most simulation programs will automatically associate the weather file with the model when a location is selected. However, if that is not the case the user can download a weather file. It is also possible to associate forward-looking climate files with your simple box model to evaluate changing climate conditions. See Part 4.1 for more information about weather files.

Number of floors. This input assists in establishing the overall conditioned floor area for the design. It can be as easy as defining levels/stories or selecting the number of floors in the building performance simulation tool.

Total conditioned floor area. This input is typically calculated automatically, but it may also be a separate input in some simulation programs.

Window-to-wall ratio. A starting point for this input could be the percentage of glazing for the overall design or per façade.

Envelope assemblies. This input can be as simple as selecting a target R-value for an assembly or a representative assembly. If more detail is known, incorporate it.

Thermal zoning. Perimeter and core zones are handled differently because of the role of fenestration and the envelope. Most simulation tools, by default, assign perimeter and core zoning automatically. The depth of the perimeter zone from the envelope can be altered.

Internal loads. These inputs refer to people, equipment, and lighting loads that are associated with the building type. Watts/per square foot (W/ft^2) are used for lighting and equipment loads. For loads caused by people, inputs may be as simple as selecting a schedule profile or adding more schedule specifics. Quantity of people is typically incorporated as a default, based on building type.

Ventilation. Ventilation inputs are typically a default value associated with the building type, based on ASHRAE Standard 62.1 or ASHRAE/ASHE Standard 170. Exceptions include building types for which outdoor air exchange rates are a key consideration.

HVAC system (optional). Generic HVAC systems are typically included by default. Different HVAC system types can also be incorporated into the model, depending on the tool being used.

Common questions

It is beneficial to consider two tiers of questions for simple box modeling. Tier 1 questions consist of a general set of questions that open the door to establishing performance drivers. Tier 2 questions are dependent on project specifics (e.g., window-to-wall ratio as a performance driver) and they enable the designer to dig into performance drivers to understand more.

Tier 1 questions:

- What are the top three parameters driving performance for the design?
- How does changing the form or orientation of the building design influence performance?

Tier 2 questions:

- If the percent of glazing is increased or decreased by 10 percent, what is the difference in performance?
- If the glazing type is changed to a high-performance product, what is the difference in performance?
- If the envelope insulation level is increased, what is the difference in performance?

Interpreting and communicating results

This section has provided multiple examples of simple box modeling and showed how simple box modeling can be used to complement other single aspect simulations. In the daylight and glare section (Part 6.2), simple box modeling was used to provide another metric to consider in addition to the daylight analysis. A recommended best practice is to incorporate the results of multiple single aspect simulations for a project together. It creates the ability to tell a more comprehensive and interesting performance story for the project, while also opening the door to begin useful design option discussions at an early stage.

For simple box modeling, the focus should be on the result differences, and not on a particular number. Some simulation tools provide the ability to compare multiple simulations within the tool, or the user can capture results and put them in a spreadsheet to compare. Comparisons can be at the overall level to see how the EUI and/or annual energy cost change; or, to look more closely, they can be at the energy-end-use level. Comparisons can also be done with a combination of EUI, annual energy cost, and energy-end-use.

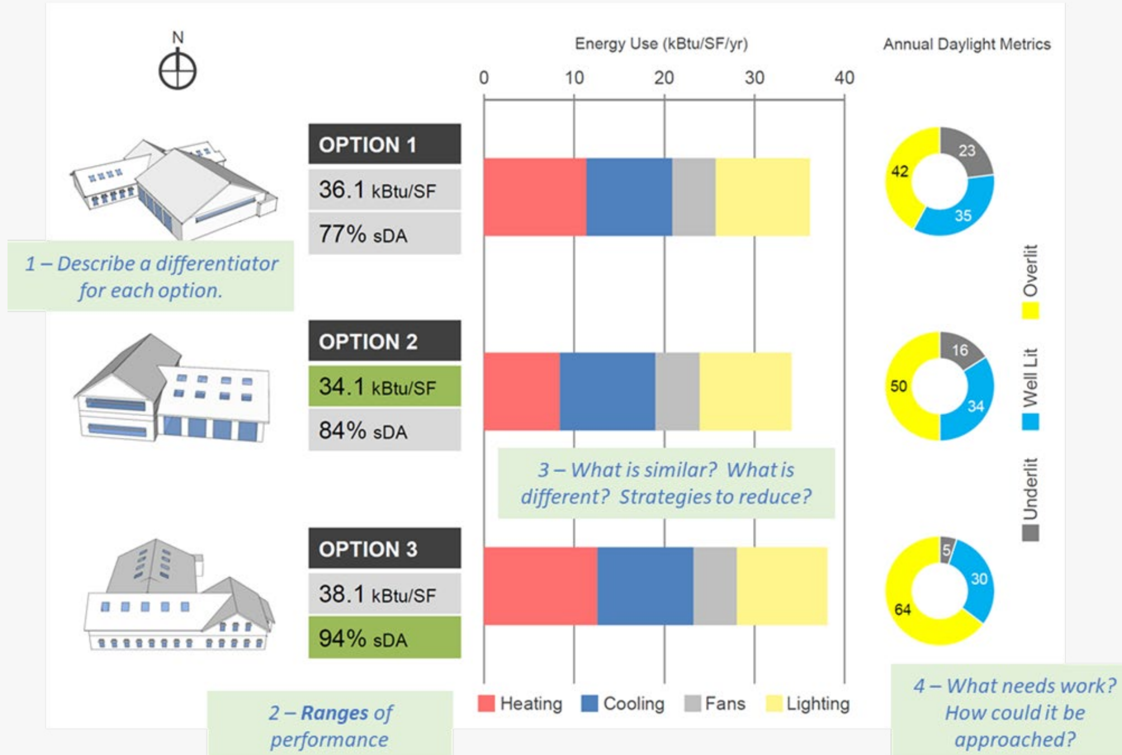
A summary of simple box model comparisons for three design options was introduced at the beginning of this section. Figure 6.14 supports discussion of the possible performance stories that could be told. Notes about what to consider when shaping a performance story are included in the figure, and following is an example of how the performance story could be presented:

- Three design options are presented and compared to ideas to demonstrate design opportunities. The team should describe a key difference between each design option.
- The energy simulations show a range of ~34–38 kBtu/ft^2/yr, which is approximately a 10 percent difference between the presented Options 2 and 3. Bringing daylight into the picture, there is a performance range of 77–94 percent sDA between Options 1 and 3.
- Digging a little deeper into the energy picture, the stacked bar chart shows that the biggest variation in energy use (red bars) is related to heating. The other bars are similar in size.
- What could be contributing to the increase in heating energy for Option 3? Is it related to the increased envelope surface area of this design option or maybe the higher percentage of glazing?The daylight donut graphs show a significant percentage of floor area falling into the "overlit" category. The size and location of windows should be evaluated, because it would be more beneficial to see a higher percentage in the "well lit" category. The performance of the windows should also be evaluated to see how it is influencing annual heating energy. At multiple stages in the project, the team should discuss similar simulation result summaries, so that they can dig deeper into the issues and drivers, and more effectively determine next steps in design.

Finally, note that even at this early stage the design team can start to document the project's design performance on the AIA 2030 DDx. The DDx allows the team to input, compare, and track performance at each design phase, as well as into operations.

Figure 6.14

Simple box model comparisons for three design options with additional notes about what to consider discussing with the design team and client.



7. Conclusion

Incorporating building performance simulation into the design process enables architects to improve building energy performance. Designing for better energy performance provides value to firms, clients, and building occupants by delivering buildings that are healthier, more comfortable, and more resilient while also reducing climate change impacts.

To meet current performance demands, it is essential that all projects, no matter their size, incorporate building performance simulation early and throughout the design process for iterative analysis that informs design decisions. When used correctly, building performance simulation can “pay for itself” by reducing first costs through smart, informed, data-driven design as well as operational costs over the lifetime of the building.

Using building performance simulation throughout the design process empowers architects to take a leading role, working collaboratively with engineers for the best design and performance outcomes. This process—integrative, collaborative, with an emphasis on design solutions for high performance—will push the architectural profession forward toward new notions of function and beauty.

Make the commitment for yourself and your firm. Use building performance simulation to optimize energy performance in all of your projects, and elevate your practice while meeting increasing client demand for high performance. Many simulation tools have evolved to work well for visual thinkers, and using them can stimulate the creativity of the design team. While you’re doing your part to serve clients and save the planet, you may find you’re also having fun in the process.

8. Resources

Useful tools

AIA+2030 Online Series will inspire architects to meet the 2030 Challenge through design strategies, efficient technologies and systems, and applying renewable energy resources.

LEED v4 BD+C Minimum Energy Performance Calculator contains required checks on energy model inputs, based upon ASHRAE 90.1 Appendix G, as well as summary output totals.

ASHRAE Standards:

Standard 209-2018 – Energy Simulation Aided Design for Buildings Except Low-Rise Residential Buildings defines minimum requirements for providing energy design assistance using building performance simulation and analysis.

Standard 90.1-2016 (I-P) – Energy Standard for Buildings Except Low-Rise Residential Buildings provides the minimum requirements for energy-efficient design of most buildings, except low-rise residential buildings. It offers, in detail, the minimum energy-efficient requirements for design and construction of new buildings and their systems, new portions of buildings and their systems, and new systems and equipment in existing buildings, as well as criteria for determining compliance with these requirements.

Standard 55-2017 – Thermal Environmental Conditions for Human Occupancy specifies conditions for acceptable thermal environments and is intended for use in design, operation, and commissioning of buildings and other occupied spaces.

Software tools directory

Building Energy Simulation Tools Directory (BEST-D)

Advances in building performance simulation

IBPSA-USA is the U.S. regional affiliate of the International Building Performance Simulation Association (IBPSA). The mission of IBPSA-USA is to advance and promote the science of building performance simulation in order to improve the design, construction, operation, and maintenance of new and existing buildings in the United States.

Project Stasio – Standard Simulation Inputs & Outputs, in partnership with IBPSA-USA, aims to provide supporting content on inputs, outputs, and case studies around the first three "modeling cycles" defined by the ASHRAE Standard 209.

Building energy codes:

Building Codes Assistance Project (BCAP) facilitates increased communication and collaboration between allies, identifies and navigates past policy and structural pitfalls, and helps state and local decision-makers design strategies to improve building energy efficiency.

Books about building performance simulation and building science:

Carbon-Neutral Architectural Design, 2nd Edition
by Pablo La Roche
CRC Press, 2017

Design Energy Simulation for Architects: Guide to 3-D Graphics
by Kjell Anderson
Routledge, 2014

Heating, Cooling, Lighting: Sustainable Design Methods for Architects, 4th Edition
by Norbert Lechner
Wiley, 2014

Introduction to Architectural Science: The Basis of Sustainable Design, 3rd Edition
by Steven S. Szokolay
Routledge, 2014

Mechanical and Electrical Equipment for Buildings, 12th Edition
by Walter T. Grondzik and Alison G. Kwok
Wiley, 2014

Light reading

"The Shockingly Short Payback of Energy Modeling"
U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy
by Amir Roth
May 23, 2016

"Show Me the Money: Boosting Investor Confidence Through Better Building Energy Efficiency Modeling"
Rocky Mountain Institute
by Ellen Franconi
March 27, 2013

Acknowledgements

This guide was prepared by "Ruby" Theresa Nahan of Nahan Communications.

Special thanks

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