Building energy efficiency from the first decisions

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Abstract

This paper illustrates the energy savings potential embedded in early design decisions for 61 commercial U.S. projects that participated in new construction energy efficiency programs in 2009 and 2010. When energy modelling is used solely to determine how much better than the energy code a particular design is, some opportunities for real energy savings are lost. The modelling protocols of the major energy codes require that each unique design be compared to a corresponding unique baseline. As a result, design alternatives are rarely compared with each other. In some situations, the modelling protocols in these codes actually promote design alternatives with higher absolute energy use for early design decisions. Four utilities in the United States have implemented new construction energy efficiency programs that mitigate this problem by affecting design decisions using contiguous simulations models from the pre-design stage through initial occupancy. These early design decisions are important because they affect the energy use of the building throughout the life of the building. Early decisions that affect energy use, such as building shape or window area, are more persistent than lighting or mechanical efficiency strategies employed later in the design process. Over the life of a building, the lighting system and mechanical system will be replaced several times, but the overall building shape and fenestration will remain unchanged. Consequently, even a 5 % to 10 % annual energy use difference from an opportunity missed early in design has a large effect over 50 or 100 years. This paper also provides policy recommendations that could better support decisions early in the design process that maximize energy savings so that the code recognizes and credits comprehensive whole-building performance for early decisions.

Introduction

The use of energy modelling on building projects has increased substantially over the past 10 years. This coincides with advances in green building rating systems, such as the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED®) Rating System™, and a general increase in awareness of how building energy consumption relates to greenhouse gas emissions. According to the U.S. Environmental Protection Agency (EPA) commercial buildings in the United States are responsible for 27.3 % of the greenhouse gas emissions in the U.S. (EPA, 2010). In the current economic downturn, building owners have become more interested in reducing their utility bills through energy efficiency for newly constructed buildings. Additionally, professional organizations, such as the American Institute of Architects (AIA) and the American Society of Heating Refrigeration and Air conditioning Engineers (ASHRAE), have publicly committed to mass market net-zero energy buildings by the year 2030 (Architecture 2030, 2011).

Current energy codes and their modelling protocols are not as supportive of these goals as they could be. Energy modelling protocols are designed to measure energy savings between a design and a baseline. A well-designed protocol would provide the correct signal by showing more energy savings for more efficient designs when alternative designs are being considered.

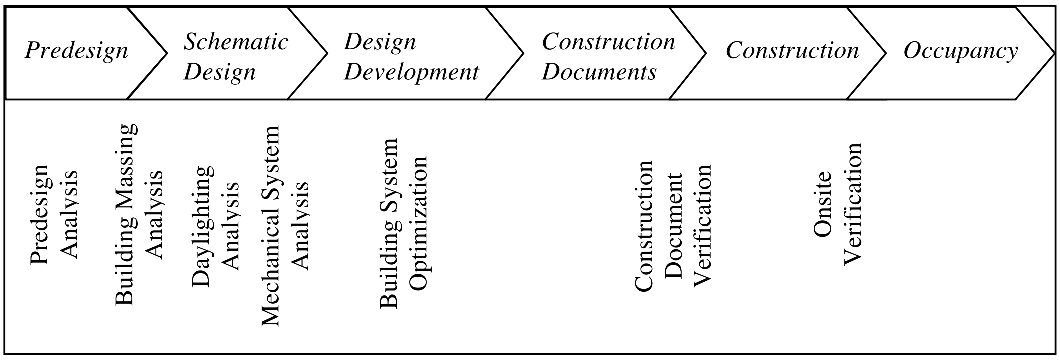


Figure 1: Design Phases and EEDA Analysis Modules.

Current modelling protocols fail to do this for early design decisions. In two-thirds of the projects that participated in utility sponsored demand-side-management (DSM) programs that considered multiple building shapes, the shape with the lowest energy consumption did not have the greatest savings according to the energy code protocol used. The energy analysis showed higher energy savings for a building shape that would consume more energy than another option. This mistaken incentive could be avoided by designing better protocols for modelling and comparison.

In 2009, four utility companies in the United States expanded the Commercial New Construction (CNC) DSM programs offering Energy Design Assistance (EDA) such that the EDA and analysis was available during earlier stages of design for projects with higher energy efficiency goals; this offering was called Enhanced Energy Design Assistance (EEDA). These CNC programs provide comparative analysis of multiple design options to assist design teams in making decisions that will reduce energy consumption. The programs pay for the analysis and pay an incentive to the design team for participating and to the building owner for energy savings beyond those required by code. The incentive is based on peak electric savings for some utilities and percent electricity consumption for other utilities. All funding is provided by rate payer Conservation Improvement Program surcharges. In the first six months, more than 20 buildings enrolled in the EEDA programs, though only six were expected. A total of 61 buildings have participated between January 2009 and December 2010. Of these, 39 have gone through the entire comparative analysis part of the EEDA process and selected all the energy efficiency measures to be installed. These 39 buildings saved an average of 43 % energy compared to the baseline energy code. They have 48 % more savings than projects that participate in the standard EDA program, which starts later in design. The range of savings was for the 39 buildings were 17 % to 79 %.

The EEDA programs consist of five analysis modules and two verification phases:

- Predesign Analysis – for evaluation of opportunities before any design decisions are made
- Building Massing Analysis – for evaluation of building shape options
- Daylighting Analysis – for evaluation of window area, placement and daylight access to occupied spaces
- Mechanical System Analysis – for evaluation of alternative mechanical concepts
- Building System Optimization – for evaluation of over 50 efficiency options on each building

The entire process relies on comparative analysis of viable design alternatives so that design teams can make informed decisions about the future performance of their building. The analysis is done with hourly whole building energy simulation tools for Predesign, Building Massing, Mechanical Systems and Building System Optimization. Daylighting analysis uses both spreadsheet based calculations and backward ray-tracing software.

Current energy codes in the United States do not encourage comparative analysis. Many of the early design decisions, such as building shape or heating energy sources, are used to define the code baseline. This paper demonstrates the importance of using comparative analysis throughout the design process, the lessons learned during the first 61 projects of EEDA programs, and policy changes that could provide recognition of the impact of early design decisions, thus leading to buildings that incorporate energy efficiency measures that have a much greater persistence and lower risk in implementation.

Energy codes and benchmarks

Energy codes play an important role in reducing energy consumption, however, energy codes are designed to apply to all buildings and do not optimize for a specific building. Comparative analysis of multiple options allows a team to optimize energy use for the specific building they are designing. The dominant model energy codes in the U.S., ANSI/ASHRAE/IESNA Standard 90.1 (90.1) and the International Energy Conservation Code (IECC), set minimum attribute levels for individual parameters in a building. They provide a prescriptive and a performance path for compliance. In the prescriptive path, a project achieves code compliance by meeting a long list of attributes[1]. In the performance path, tradeoffs are allowed between attributes and across building systems and compliance is determined by the proposed building using less energy than the baseline—a very similar building with attributes set to the prescriptive code requirements. To measure performance beyond code, a project team would use 90.1's *Informative Appen-*

1. These include insulation, glazing type, lighting and mechanical efficiencies and controls.

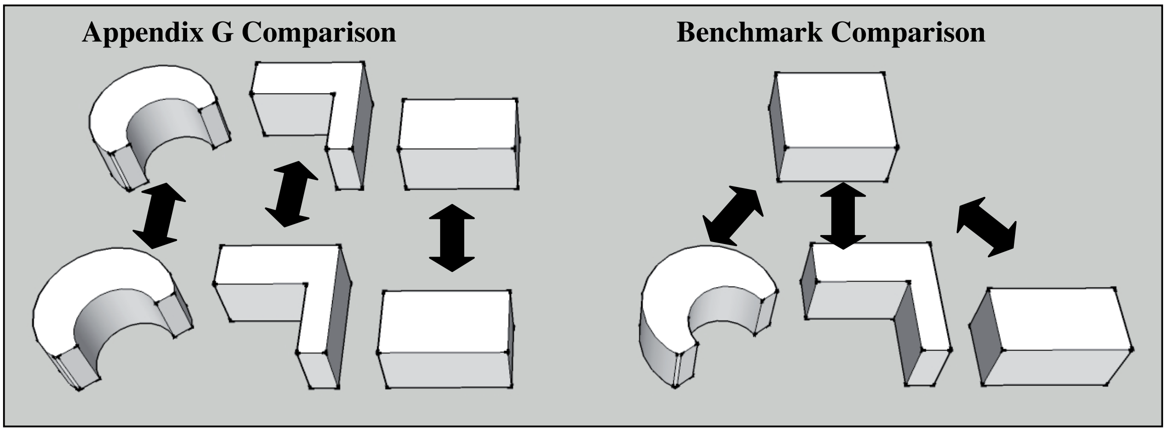


Figure 2. Diagram of Savings versus Code Compared to Savings versus Benchmark.

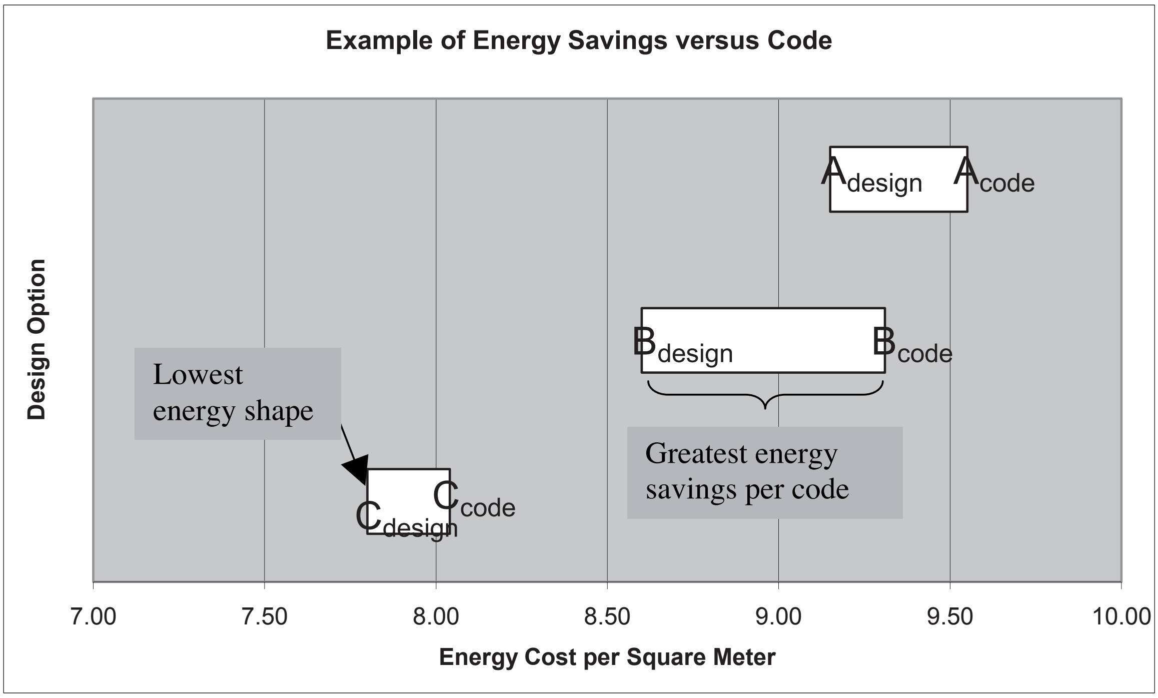


Figure 3: Energy Savings for Different Shapes Compared to Unique Appendix G Baselines or Different Shapes Compared to Unique Appendix G Baselines.

dix G Performance Rating Method, which details how a baseline is derived from a proposed building design. *Appendix G* requires that the building shape of the baseline be the same as the proposed building. This means that each building shape option has its own baseline. This effectively removes building shape from being an energy conservation measure and allows building designers to choose a shape that actually increases the energy consumption without realizing it. In many scenarios, *Appendix G* encourages the designer to choose a higher energy-consuming design.

Because energy savings are calculated as the difference between a design alternative and its unique baseline, one design alternative may have better energy savings not because it uses less energy than another, but because its baseline uses more energy than the other's baseline. As an example of this on an actual project, a design team for a combined city hall and library was considering three different shapes: A; B; and C. The annual energy cost for shape A was 9.15, shape B, 8.60, and shape C, 7.80 Euro per square meter. Shape C uses the least amount of energy per square meter, but the relative savings between the *Appendix G* baseline and the design (which included automatic daylighting controls) was the greatest for shape B. This misalignment of the least energy cost and the greatest energy savings according to code occurred in two-thirds of the 13 projects that looked at building shape alternatives.

Design teams can avoid this perverse outcome by comparing all designs either to each other or to a common benchmark. But if all designs are compared to each other, a design team could increase their "savings" by proposing a particularly energy intensive alternative. If a common benchmark for all the design alternatives is used, their savings would be calculated as the difference between the design and the benchmark.

The protocols in the model energy codes also require the window-to-wall area ratio of the baseline to be the same as the design or 40 %, whichever is less. As Baker, et. al. have shown, *Appendix G* and other protocols in the model energy codes

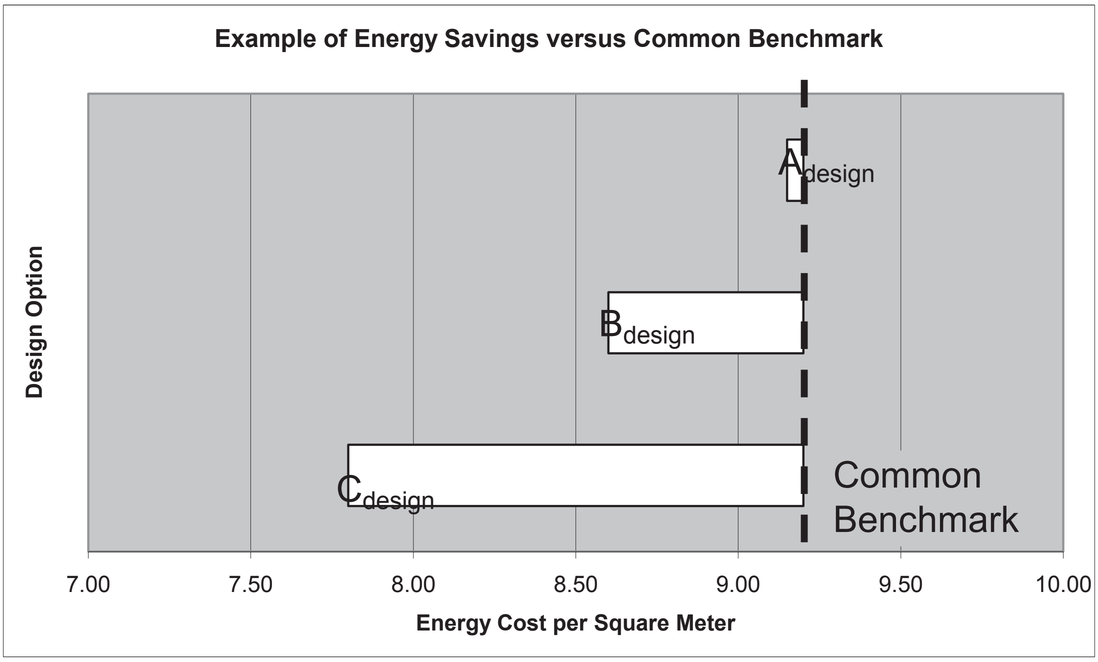


Figure 4: Energy Savings for Different Geometries Compared to Common Benchmark.

reward designs that increase window area up to 40 % WWR by recognizing the positive impact of increased daylighting potential, but fail to penalize them for increased thermal gain and losses (Baker, et. al., 2010). This could be avoided if energy codes were modified so that the baseline was not derived from initial design decisions. Figure 5 shows the energy cost without daylighting in blue diamonds and with automatic daylighting controls in pink squares. The yellow bars below show the energy savings for window-to-wall area ratios between 0.05 and 0.80 relative to their *Appendix G* baselines. As the figure shows, the lowest energy consumption with daylighting happens at 0.10 window- to-wall area, however, *Appendix G* provides the greatest savings to a design.

BENCHMARKS

Benchmarks that are derived from the owner's space-use requirements independent of design decisions, rather than from a specific design, allow multiple designs and even multiple design teams to be compared to a common benchmark. The largest dataset of commercial building energy consumption in the United States is the Commercial Building Energy Consumption Survey (CBECS). CBECS is a periodic survey that looks at energy consumption of over 5,000 buildings (EIA, 2011). This energy consumption is used to define average energy consumption for 44 building types and is the data set for *Target Finder*. *Target Finder* is an online benchmarking tool from the U.S. Environmental Protection Agency that uses regression analysis to set a benchmark for a design; this benchmark is corrected for the local climate, hours of operations, plug load usage and occupant density.

Target Finder covers 13 building types. CBECS publishes national average Energy Use Intensity (EUI) for additional building types but does not have large enough sample sizes for these buildings to be able to correct for regional weather or plug and occupant densities. Without correcting for building use and local climate, buildings with light use in temperate climates will show more energy savings than heavily used buildings in hotter or colder climates.

A benchmark system based on code and additional rules rather than survey data can cover a wider range of buildings without the expense of surveying a statistically significant number of buildings for each building type. This type of benchmarking system has been developed for the State of Minnesota's Buildings, Benchmarking and Beyond (B3) program for existing buildings and the Sustainable Buildings 2030 (SB2030) program for new as well as existing construction. The benchmarks developed for these programs provide EUI goals for the design projects and could be used to establish the baseline for calculating the utility DSM program savings.

COMPARATIVE ANALYSIS BETWEEN OPTIONS

Comparing the energy use of multiple viable options to each other is another way to avoid the pitfalls of comparing each option back to its own code baseline. For early decisions such as window areas and building shape that are held constant between the proposed design and the Baseline models, comparative analysis allows design teams to see which option has the lowest total energy use. It also helps design teams find cost-effective energy efficiency measures by allowing them to compare the energy savings of one strategy to that of another strategy within or across building system types. The cost-effectiveness of lighting power density strategies can be compared to mechanical system selection or envelope insulation.

Research in decision-making shows that looking at multiple viable options at the same time can speed up decision making by making it easier to compare strengths and weaknesses of each option and by providing viable alternatives that can be implemented if the first option does not work out (Eisenhardt, 1990). Eisenhardt has shown that people are more comfortable making a decision to proceed with an option if they have explored multiple options because they know how it compares to other alternatives.

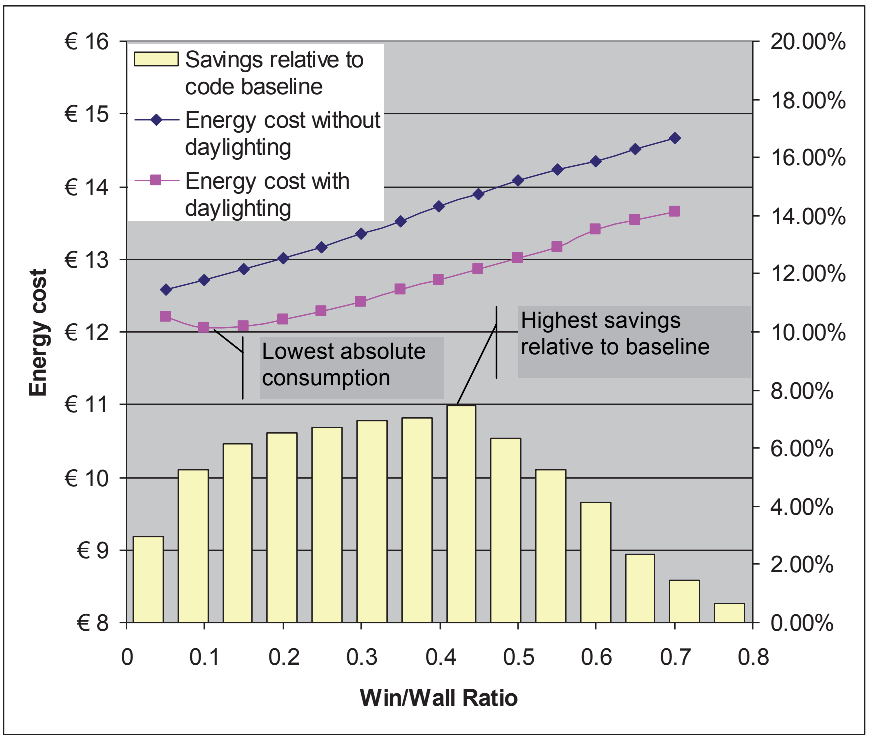


Figure 5: Energy Savings for Automatic Daylighting at Different Window to Wall Area Ratios using 90.1-2007.

Enhanced Energy Design Assistance

In 2009, four utility companies in the United States wanted to achieve higher energy efficiency goals with their commercial new construction DSM programs. At the same time, design teams wanted to have more information earlier in the design process to make decisions that resulted in lower energy consumption in the building being designed. Enhanced Energy Design Assistance (EEDA) programs were created by the authors to meet these goals. Enhanced Energy Design Assistance is a quantitative comparative analysis process that provides design teams with the energy impacts of their decisions from Predesign through Construction Documents. Depending on the utility, a design team needs to commit to either 30 % energy consumption or 15 % peak energy savings to participate in the EEDA program. If a team is initially unsure whether they can commit to the savings goal, they may still be allowed to participate in the Predesign Analysis module. In effect, the Predesign Analysis module is both a planning tool and a screening tool allowing teams and the utilities to test commitments to sets of energy efficiency strategies that would be needed for their building to qualify for the Enhanced Energy Design Assistance program. The programs consist of five analysis modules and two verification modules. The Predesign and the System Optimization Analysis and verification modules are mandatory for all participants and the other three modules are implemented on an as-needed basis.

PREDESIGN ANALYSIS

The Predesign Analysis allows design teams to explore the probable energy impact of different types of efficiency strategies on a simulated analogous building in that climate. For the Predesign Analysis module, the design team looks at the energy use of an analogous building and shows a benchmark energy consumption of that building by end uses (heating, cooling, fans/pumps, service hot water, and equipment), as well as a range of savings potential for typical efficiency strategies for that building type and location. The design team then uses an interactive scenario tool to explore the energy impact of different combinations of energy efficiency measures.

The analogous building uses typical geometries and operation schedules for that building type. The area for each space type and building location are entered into the tool and baseline simulation compliant with the local energy code is generated as well as all of the strategies. Strategies are modelled with typical efficiencies to demonstrate the magnitude of savings that different strategies could provide.

The intent of the module is not necessarily to decide on specific energy efficiency measures, but to give design teams an understanding of where the savings potential lies and the range of efficiency that could be achieved under each scenario. This helps design teams and owners become more realistic about design and budget issues as they relate to energy efficiency before they begin later phase design work where decisions need to be more firmly set. Predesign Analysis is mandatory for participation in EEDA; all 61 projects participated in this module.

BUILDING MASSING ANALYSIS

Design teams often consider alternate building shapes early in schematic design. In the U.S., this process is often called massing studies. This EEDA module allows design teams to see the energy consumption of each shape and weigh them against other non-energy design criteria such as access and circulation priorities. Differences in annual energy consumption between the alternatives are often in the 5-7 % range, but have been as high as 18 %. Although these savings can be lower than those for energy-efficient lighting or mechanical system alternatives, they are more persistent over the life of the building because the building shape is the least likely attribute to be modified. Lighting systems, mechanical systems and windows will be replaced at some point, but the building wall assembly and building shape usually goes without major modification.

The analysis starts with the design team providing up to four geometry options that would meet the owner's requirements and fit on the site. On some projects, these alternatives are developed enough that there are building elevations and actual window-to-wall areas can be calculated, but on other projects, assumptions about window-to-wall areas are made based on suggestions from the design team. Several energy metrics are reported to the design teams, including energy use and energy cost per floor area, total carbon emissions, and energy cost by fuel stream. Potential daylit areas for each design are also reported.

13 of 61 participating EEDA projects used the Building Massing Module. From conversations with design team members, there seem to be three major reasons why participation in this module is lower than the others.

- Some projects had already made design decisions on the building shape. These decisions were made based on other criteria and in the absence of energy analysis results.Some projects were unable to consider significantly different geometries because of site constraints.
- Some architects are reluctant to having rough architectural schemes be analysed for energy implications.

Because the DSM programs base their incentives on savings beyond the local code, these Massing Module savings are not currently counted towards the cumulative savings a project achieves.

DAYLIGHTING ANALYSIS

The goal of the Daylighting Analysis is to maximize the amount of floor area that has access to usable daylight[2] while optimizing the fenestration area needed to provide the daylighting.

Daylighting can be challenging to implement in a project and takes the complementary resolution of the building envelope, interior finishes and furnishings, sensor location, glazing visible transmittance, lighting design and specifications (Vaidya, et. al. 2004). If each of these is slightly suboptimal, it can quickly become a system that is substantially suboptimal.

The Daylighting Analysis looks at the light levels provided by alternative fenestration patterns under different sky conditions and compares that to the light levels needed in the space. This allows design teams to see which design options provide too much light, too little light, or just the right amount of light under different sky conditions.

Forty-two of the projects participated in the Daylighting module, and of those that participated, 86 % selected automatic daylighting controls in the final design.

MECHANICAL SYSTEM ANALYSIS

The Mechanical System Analysis EEDA module is initiated after the team decides on a building shape and fenestration design. This module compares the annual energy cost, consumption, peak loads and carbon emissions for different mechanical system options[3] that the design team is considering. Net-Present-Value (NPV) of life-cycle costs for each of the options is compared to understand the total cost of ownership over time. This enables the owner to look beyond the cash flow for the construction and initial occupancy. The life-cycle costs include mechanical system first costs, additional architectural and/or structural first costs, replacement costs, annual energy costs and estimated maintenance costs. Discount rates and fuel cost escalations rates are defaulted to the U.S. Department of Energy's recommended values for life-cycle cost analysis, but can be adjusted in the meeting if the owner has a preferred discount rate for capital investments.

This is the most used of the voluntary EEDA modules; 53 of the 61 projects completed this module. The energy savings identified through the mechanical system selection eventually comes to represent 30 % to 60 % of the total energy savings that a project selects throughout the EEDA analysis process. We find that, often, the maintenance cost is difficult for owners or engineers to estimate. Maintenance costs on all projects have been an order of magnitude or more less than the other life-cycle cost components. There is often significant concern about setting an appropriate fuel escalation rate. With a tool that can change the escalation rate in the meeting to play what-if scenarios, it is possible to demonstrate that the system selection based on life-cycle cost is not very sensitive to the escalation rate change, albeit within a reasonable range.

BUILDING SYSTEM OPTIMIZATION ANALYSIS

In the Building System Optimization module, the selected geometry, fenestration and mechanical system are used as the starting point for 70 to 120 energy efficiency strategies for optimization of building components across building systems. These systems include envelope insulation levels, glazing properties, lighting controls, lighting design and technologies, mechanical controls, and mechanical components. The energy impact and first cost of each of these strategies is shown in a tool that allows design teams to create several bundles of strategies and then pick one bundle to implement in their design. The estimated cumulative savings and first cost for each bundle of strategies is calculated throughout the meeting so that teams can compare one group of strategies to another. Creating multiple bundles makes design teams more comfortable, considering aggressive strategies in an "upgrade" bundle. Teams are also encouraged to assemble a bundle that maximizes energy efficiency without regard to payback or first cost to see the energy efficiency potential. This often spurs design teams into adding additional energy efficiency strategies into their design to narrow the gap between their design and the maximum savings bundle.

Over the past two years, the projects that participated though EDA in only the Building System Optimization Analysis achieved 29 % savings over the local code. Over the same two-year period, the 61 projects that participated in the EEDA program have had an average of 43 % savings. Admittedly, some of that difference may be due to self-selection of projects

2. Usable daylight means that natural light will be sufficient to turn off or dim the electrical lights for a substantial portion of the hours between sunrise and sunset.

3. The analysis can also compare the energy efficiency of assigning spaces to different air handlers, or having additional air handlers. This can help a design team decide if the savings for separating the different building uses or facades onto different air handlers will be worth the first cost.

Table 1: Energy Savings, First Cost and Other Metrics for a St. Louis, MO Office Building by Category.

	Insulation	Glazing	Lighting	Mechanical
Savings per year	€ 17,820	€ 32,917	€ 78,348	€ 73,848
First cost	€ 295,179	€ 92,576	€ 210,639	€ 674,312
Simple payback	**16.6**	**2.8**	**2.7**	**9.1**
Typical lifespan (years)	73	44	18	20
Cumulative Cash Flow	€ 1,005,650	€ 1,355,757	€ 1,199,620	€ 507,255
Net Present Value (@ 3%)	€ 230,154	€ 705,794	€ 866,917	€ 253,300
Profitability Ratio	**4.4**	**15.6**	**6.7**	**2.2**

with higher energy savings goals or potential choosing to participate in the EEDA program, but the authors believe that the increase from 29 % to 43 % in savings between the programs is substantial.

Importance of early design decisions

LOST OPPORTUNITIES

Some decisions are made only once for a building. It is prohibitively expensive and unusual to change the orientation of a building or its fenestration area after it has been constructed. Those decisions are often literally set in stone. Other decisions, such as occupancy sensors, may be relatively simple to retrofit into a building. If the decisions that are permanent are made without accounting for their energy consumption, their opportunity for energy efficiency will be lost for the entire life of that building. If a building is designed with natural daylight but daylighting controls are not initially put in, they can be installed later. If a design does not have adequate daylight availability, or it has poor orientation for daylighting, the retrofit of controls in the future will not be able to overcome those deficiencies. The opportunity for energy efficiency is lost forever.

THE LIFESPAN OF SAVINGS

The cumulative effect of the annual energy savings due to early design decisions can be significant because those effects tend to be for the life of the building. The median lifespan for an office building in the United States is 73 years (DOE, 2008). The building shape remains the same over its lifespan. The mechanical system has a typical lifespan in the United States of 20 years (DOE, 2008). That means that the mechanical system would need to save 3.6 times as much energy to have the same present value of cumulative lifetime savings as the building geometry. If a design team looks at annual energy savings without considering component lifespan, they may misallocate their energy efficiency investments.

The problem with simple payback as an investment measurement is that it does not say what happens after the payback. If a light bulb pays itself back in 1.9 years and then promptly fails, it is a worse investment than a light bulb that pays itself back in three years but then keeps on working for another six years. The later pays itself back three times over. Early decisions, such as building shape, window size and placement and envelope assembly, tend to be longer lived than later decisions such as lighting fixture spacing or mechanical system control sequences.

To illustrate the effect that lifespan has on different types of components, the energy savings for an 18,000 square meter office building has been divided into four different categories: insulation; glazing; lighting; and mechanical. Table 1 shows savings information by category. First costs shown in the table are the estimated incremental cost for components that go beyond the local energy code; these include any additional material or labour costs.

Lighting and glazing categories are financially attractive from both a simple payback and profitability ratio standpoint. Insulation, with a 16-year simple payback, does not seem attractive at first. But the insulation pays for itself 4.4 times. The mechanical system, on the other hand, only pays for itself 2.2 times over. So, from a simple payback standpoint the mechanical system is more attractive, but when you consider the lifespan of the insulation, it is the more attractive investment. Plotting out the cumulative cash flow over time shows that the longer lifespan overcomes the lower energy savings per year.

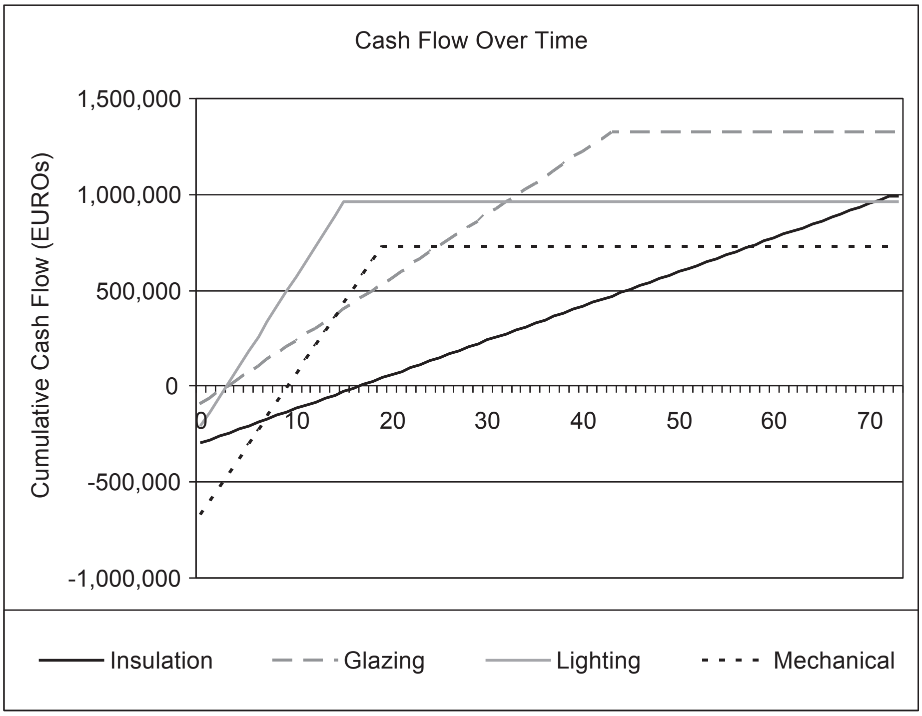
Conclusion and policy recommendations

Energy modelling has the potential to be a tool used for incremental, quantitative, comparative analysis throughout the design of a building to create more energy efficiency options. Demand side management programs that encourage higher energy efficiency goals and that provide comparative analysis starting early in the design process achieve energy efficiency savings of 43 % on average compared to the local energy codes. This is 48 % higher than the 30 % savings for DSM programs that start during Design Development. These savings would be even higher if the energy codes recognized savings due to building geometry or fenestration optimization.

Because current energy modelling protocols within the energy codes derive their baselines from the proposed design, they can provide more "savings" to a design that uses more energy than another design. This false savings is particularly likely because alternative building geometries are required to be compared to their own baselines rather than to each other. Comparing each design to a shared benchmark, or to each other, could eliminate this code anomaly.

Early decisions may have a smaller annual energy savings than some later decisions, but because of their persistence, they have a larger lifetime impact on the building's energy use. To achieve aggressive greenhouse gas emission reduction goals, these early decisions need to be made with quantitative information on energy consumption because they are difficult, if not impossible, to change later.

In the near term, modelling protocols should be developed that set fixed shapes and window-to-wall area ratios so that design teams can take credit for optimizing building shape and fen-



This graph compares the cash flow over time, and illustrates how energy efficiency measures with less savings per year may have greater cumulative energy savings because of longer life spans.

Figure 6: Cumulative Cash Flow Over Time for Different Energy Efficiency Categories.

estration. Longer term, codes and DSM programs should move towards comparing designs to benchmarks that are adjusted for occupancy, plug loads and local weather. Baselines should be derived independent of all design decisions so that all design decisions can be evaluated and credited for their energy impacts.

Glossary

90.1: *ANSI/ASHRAE/IESNA Standard 90.1-2007 Energy Standard for Buildings Except Low-Rise Residential Buildings*
AIA: American Institute of Architects
ANSI: American National Standards Institute
ASHRAE: American Society of Heating Refrigeration and Air Conditioning Engineers
B3: Building Benchmarking and Beyond
CBECS: Commercial Building Energy Consumption Survey
DSM: Demand Side Management
EDA: Energy Design Assistance
EEDA: Enhanced Energy Design Assistance
EPA: Environmental Protection Agency
EUI: Energy Use Intensity (kilowatt-hours per square meter)
IESNA: Illuminating Engineering Society of North America
LEED: Leadership in Energy and Environmental Design
NPV: Net present value
SB2030: Sustainable Buildings 2030

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