Risk calculations for energy conservation technologies: the likelihood of realizing design-phase expectations in new construction

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Abstract

The risk that a technology will not be implemented or operated as designed is a significant barrier that impedes owners from adopting new energy-conserving building technologies. This results in a feedback loop that encourages decision makers to minimize risk by sticking with the status quo, regardless of the environmental impact. Different technology categories have different levels and types of risks associated with them.

This study assigns levels of risk to technologies by tracing a set of envelope systems, lighting designs, lighting controls, HVAC systems, and HVAC controls in a data set of 38 buildings from the design phase through the initial implementation phase. The likelihood that a technology gets implemented and works as expected is assessed, and risk factors for the various technologies are calculated. Explanations for the levels of risk are supported by interviews with third-party reviewers who serve to assist design teams and owners through the construction phase.

Results show that daylighting technologies, including dimming daylighting controls, have the highest risk of not being implemented—when otherwise chosen at the selection phase—while roof insulation and lighting designs are most likely to be fully and correctly implemented. Analysis comparing the risk to the energy conservation opportunity indicates the need for prioritization and support during the design and construction phases to realize expected levels of energy conservation. Overall, the interviewees said the most common reasons for lower than expected energy savings are that energy conservation measures were cut-out during value engineering or cut-out due to later decisions that a technology was functionally risky. This research supports large scale investments in energy conservation technologies for buildings through rebate programs, code improvements, and design guides created by large owners. It identifies technologies that need a higher degree of building management effort and those that need specific designer, contractor and building operator education.

Introduction

As designers, building owners, and developers consider energy conservation goals for new construction projects, they either implicitly or explicitly consider the associated risks and rewards. Their experience with previous attempts at implementing energy conservation and their awareness of available technologies implicitly shapes the set of technologies they will consider. Design teams that use explicit analysis, such as energy simulation, capital cost estimation, and lifecycle costing, along with estimates of the likelihood of successful implementation are able to get a better picture their project's risk/reward profile.

Estimates of likelihood of successful technology implementation provide different information to different parties. For the designer, the risk of adopting a new technology lies in uncertainties in time and cost to ensure successful implementation as well as uncertainty in the final functionality of the system. For owners, the risk stems from uncertainty in the level of realized operational cost savings versus the first costs; developers risk failing to meet the market's expectations for what constitutes a functional building with innovative technologies; and finally, utilities' demand side management (DSM) programs face risks stemming from uncertainty in realized energy reduction as compared to expected levels of reduction. In the absence of quantitative information, all parties are likely to depend on their perception of the risk based on anecdotal information and lean towards making conservative and risk-averse decisions.

This study focuses on the implementation phase of the process of constructing a new building. It starts at the end of design, when energy conservation measures, including envelope, lighting, and mechanical system technologies are selected. It tracks their progress through Construction Document (CD) development and initial site verification. All of the projects in the study were part of a single utility's state regulated Conservation Improvement Program (CIP) and all had the same third-party energy modelling and measurement and verification (M&V) consultant[1].

The guiding motivation of this research is to support adoption of sustainable building design practices and technologies by providing risk information relevant to the design, construction, and M&V phases. As recommended by Bertoldi and Kromer (2005), databases to document energy efficiency results will help program administrators and building owners/developers value investments in energy-efficient technologies and will enable M&V processes to assure functional implementation. The overall objective of the study is to provide quantitative values of the risk, or likelihood, that a technology will be successfully implemented once the design team and owner commit to doing so. The second objective is to provide further understanding of the reasons energy conservation measures are "lost" during the construction phase by conducting interviews with the third-party M&V consultants.

The paper begins with a literature review of risk in the construction and energy efficiency industry. The energy consulting process in which the 38 projects in the study participated is described with particular reference to the information and communication aspects. The methodology and results for technology risk factor calculation and interviewees' responses concerning reasons for technology fall-out are then provided. The paper concludes with discussion of the use of the results by the various parties who assume risk in implementing energy-efficient technologies.

Background

Increased risk is apparent in employing innovative building technologies and architectural designs for a variety of reasons relating to individual responsibilities held by parties within a building's supply chain. Decisions to use innovative building technologies involve three sets of stakeholders (FFC, 1996):

- The development team, consisting of the designer, developer, and construction contractor;
- The tenant and/or owner; and
- The institutional investor (e.g., the bank that provides the construction loan or the utility that provides energy efficiency incentives).

The barriers to adoption of high performance building technologies and building design arise from concerns of each individual stakeholder as well as contractual relations among the parties. For the development team, competition creates pressure to keep first costs low. A developer is likely to make an investment in technical innovation only if it will be visible to the consumer and, therefore, warrant asking for a higher price (OTA, 1992). However, tenants, representing the demand-side of the market, have not yet emerged to demand green building features. Institutional investors tend to reward conservative practices because of the many sources of risk that enter real estate projects (DOE, 2000). In summary, the fragmented nature of the commercial buildings sector means that individual stakeholders are seldom large enough to risk sizeable investments on their own or to capitalize on any resulting innovations.

Architects and engineers find it difficult to specify innovative strategies, such as daylighting controls and natural ventilation, partly due to a lack of credible evidence of efficacy and an overall lack of selection and maintenance information (Vaidya et. al., 2005; PIER, 2003). In addition, building designs that utilize new materials and systems require greater attention by the design professional, as success often depends on proper installation. It is likely that the designer will be held accountable for failure even if they do not have the opportunity to monitor the project to completion (FFC, 1996). Retention of design professionals through the commissioning phases would help reduce the risk of loss to the design professional for potential technology failures.

Davis (2001) identifies two areas of improvement needed to address the financial risks of sustainable, innovative building technologies. First, there is the need to transfer some of the value of long-term benefits to the development team from the tenants or owners (Davis, 2001). The risk that green products or designs do not perform well inhibits their use as it represents a financial risk for *both* the investor and the development team, without reward being properly attributed to either party.

Second, as markets are consumer driven, there is a need for credible evidence of building performance, environmental effects, fiscal performance, occupancy wellness, and productivity impact so as to motivate the tenant/owner side to demand innovative buildings (Davis, 2001). The disconnect between risk and reward brings attention to the need for improved understanding of the nature of building technology uncertainties, which may then lead to contracts, warranties, and information sharing to bridge these barriers. The classes of uncertainty applicable to building design are shown in Table 1 along with the financial categorization (Greden, 2005). The five categories of uncertainty applicable to design are market, climate, regulatory, technological, and future use. Each uncertainty ultimately has a financial impact, but this categorization differentiates the sources of uncertainty. Table lists examples of uncertainties in each class that are relevant to the design of innovative technologies and systems, particularly for energy efficiency and renewable energy. The team that undertakes uncertainty identification should consist of all design disciplines (e.g., both engineers and architects), owners and/or developers, and the building operators. *Table 1* can be used to guide discussion on the major uncertainties and risks pertinent to the design as well as to gather quantifiable information about the uncertainties.

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[1] The projects are from MidAmerican Energy Company's Commercial New Construction Program in the State of Iowa, U.S.A., and The Weidt Group, Inc. served as the consultant.

Table 1. Classes of uncertainty for innovative technologies

Uncertainty class		Examples of uncertainties	Data source or means of quantification
In Finance	*In Design*		
Market risk (i.e., undiversifiable)	Market uncertainty	▪ Demand for product/service provided by system ▪ Price of product/service ▪ Price of inputs (e.g., energy prices)	▪ Historical data (if available) ▪ Expert opinion
	Climate uncertainty (for systems whose performance depends on climate)	▪ Future ambient climate (temperature and solar radiation) ▪ Global climate change and warming trends	▪ Stochastic climate models based on historical data and global climate change inputs
	Regulatory uncertainty	▪ Introduction of new standards for existing facilities ▪ Future availability of tax credits or other incentives	▪ Expert information and opinion
Unique or technical risk (i.e., diversifiable)	Technological uncertainty	▪ Success/failure of a technology (functional, environmental, and productivity impact) ▪ Introduction of new, superior technology	▪ Expert opinion ▪ Historical data ▪ Stochastic models of system performance
	Uncertainty in future use of real estate and/or land	▪ Changes in service type or intensity given initial service intent ▪ Rate of change	▪ Expert opinion ▪ Historical data

Market uncertainties directly impact the financial attractiveness of a project by affecting the costs and revenues. Market risks for a product or service that use innovative technologies include greater uncertainty in the future (sales or rental) value due to uncertainty in market acceptance of the innovative features. Market uncertainties in the energy sector, such as occurred in California's 2001 energy crisis, can provide increased impetus to adopt energy efficiency because financial attractiveness as well as urgency are increased (Payne et. al., 2002). The next four categories of uncertainty—climate, regulatory, technological, and future use—are specific to the project, technology, or location of interest. These categories share the commonality that, if uncertainties evolve unfavourably, expenditures will be needed to correct the problem and bring the system to a productive state. Alternatively, the sub-standard system will not be able to obtain its full profit potential, all other things equal.

Technological uncertainty refers to the functionality of a component, which is partly determined by the system in which it is contained. Another technological risk is that a superior technology will be introduced that competes with the original design; this may also represent an opportunity if upgrades are possible, such as in lamping retrofits. Successful communication of design intent to contractors, sufficient contractor knowledge to correctly install a technology, and sufficient knowledge of the building operator are key aspects to improving the likelihood of proper technology function. Nevertheless, despite all the checks in a typical design and construction process, energy-efficient technologies are still too often poorly specified and implemented. Some of the reasons include the following (Greden, et.al., 2006):

- The design team may lack the expertise to specify and execute certain measures (e.g. daylighting controls) but may not be aware of their shortcoming or may not be willing to disclose it to their client.
- The design team member who attends the initial design meetings may not be the same person who eventually prepares the documentation, and the technology performance goal agreed to in the Energy Design Assistance (EDA) meeting does not reach the final specifier.
- When construction is expected to go over budget, design teams conduct value engineering sessions. These sessions are focused on eliminating items that are not directly related to the function of the building. Unless energy performance is a primary goal for the design, ECMs often fall into this category.

A commissioning process that includes construction document review and M&V help make energy performance a focus during the construction phase. Other studies have addressed the cost effectiveness of M&V programs with respect to the International Performance Measurement and Verificaiton Protocol (Bertoldi and Kromer, 2005; Twombly and Osterholz, 2003). While the cost effectiveness of M&V is outside of the scope of this study, the risk-factor results may be used in conjunction with adminstrative costs to prioritize M&V efforts on a technology basis.

ENERGY DESIGN ASSISTANCE PROCESS

Two key means of assisting market adoption of innovative technologies are providing information to support decisions and technical assistance for implementation. Each of the 38 projects assessed in this study participated in MidAmerican Energy Company's Commercial New Construction Program, in which design teams and owners received free energy consulting and technical assistance. The consulting process, termed Energy Design Assistance, is illustrated in *Figure 1*. During the predesign, schematic design, and/or design development phases, a whole-building consulting approach is used to provide information on energy end-uses, primarily with results from DOE-2 simulations. A series of three meetings is held, where after the third meeting, the owner and design team select a group of strategies for implementation. The "selection" is intended to represent a group of strategies the design team and owner commit to implement. The energy conservation measures fit the construction budget, the design team is confident of implementation success, and the measures show a promise for energy conservation. Likewise, the utility commits to an incentive amount for the mix of selected ECMs based on their annual electric and gas consumption savings. This sets the expectations of the owner in terms of the building energy performance. The design team is then responsible for incorporating the ECMs with the appropriate performance parameters in design documents, and the final payment is based on verified results.

This moves the project into the construction document review and verification phase. The energy consultants review construction documents (CDs), conduct on-site verification, and provide feedback to the design team at each stage. Both the CD review and the on-site verification are done in two stages, a draft and final, with separate reports issued at those stages. When a draft report indicates that technology is missing or that performance expectations are not met, design teams have the opportunity to make corrections, provide further submittals, and/or communicate with their contractors. The CD review focuses on ensuring that the ECMs are incorporated in the construction documents. Field verification of the strategies consists of a combination of approaches that include review of contractor submittals, visual inspection of installed equipment and short-term monitoring using data loggers to observe performance of selected strategies. Dynamic ECMs, such as daylighting controls, variable frequency drives, or equipment efficiencies that vary with part loads, are monitored for up to two weeks to observe their performance over time.

Database

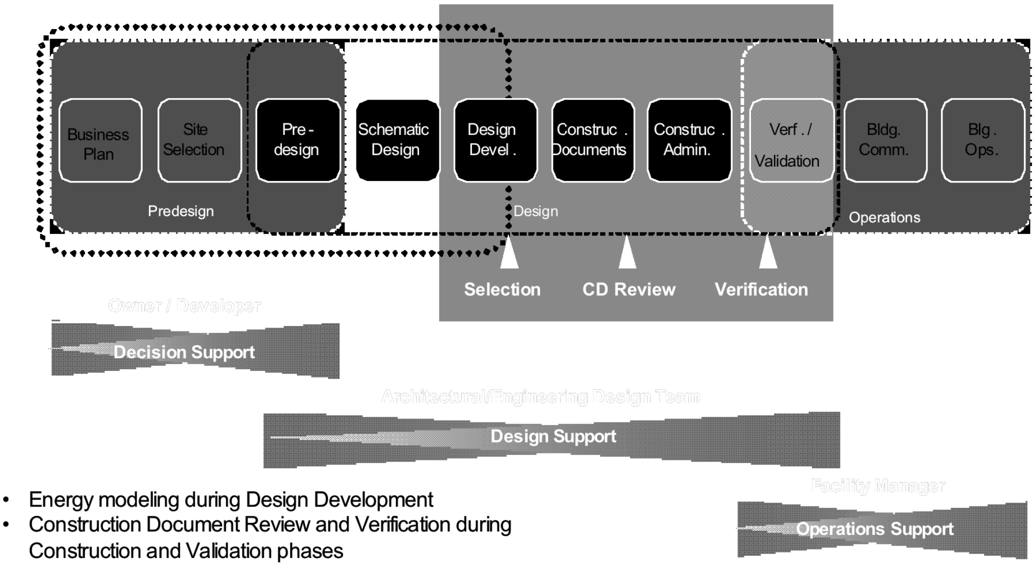
METHODOLOGY

The 38 projects in the overall data set are all located in the State of Iowa (U.S.A.); are greater than 50,000 ft^2 (4,645 m^2); are new construction or addition and major renovation; and all but one was owner occupied. The projects are part of a larger database that was used to assess effectiveness of a review and feedback process for CD review and M&V (Greden et. al., 2006). The energy savings data for each project and each energy conservation measure are derived from DOE-2 energy models of the buildings. The savings amount attributed to a particular strategy is determined by comparing the results of the strategy simulation with those of the code base simulation. ASHRAE 90.1-1989 served as Iowa's State Energy Code for the time period studied (2000-2005). The code was raised to the 2004 version of ASHRAE 90.1 in 2006. At the selection stage, the models predicted that the buildings saved 32 % of electrical (kWh) consumption on average compared to code.

The utility makes the final incentive payment to owners upon final verification of ECMs in the building. Thus, comparison of the energy savings expectations at the selection phase to those determined at the final verification phase provides insight into the level of risk associated with expected energy savings at the end of design.

DATABASE RESULTS

Figure 2 shows the verification findings for the various technology groups. The energy savings are compared relative to the expected electrical (kWh) savings at the Selection phase. Energy savings "achieved," "lost in implementation," and lost due to "later not selected" are shown. Energy savings achieved are greater than 80 % for glazing, roof insulation, lighting power density, occupancy sensor control of lighting, manual control of lighting, and all mechanical categories. For electrical energy savings that are not achieved, as compared to the expectation at the selection phase, the primary reason is a later decision not to implement the strategy, as opposed to difficulties in installing or implementing the strategy. For wall insulation, daylighting controls, manual control of lighting, mechanical equipment, and outside air controls, some projects had reduced electrical energy savings as compared to the selection phase, still achieved some (labelled as "lost in implementation" in the chart). Dimming and switched daylighting control have the highest percentage of savings that are lost in the implementation process, which points to the importance of technical assistance during the construction phase for seeing through successful implementation of daylighting systems. Overall, 17 % of the expected



- Energy modeling during Design Development
- Construction Document Review and Verification during Construction and Validation phases

Figure 1. Energy Design Assistance process illustrating selection, CD Review, and verification points in the timeline

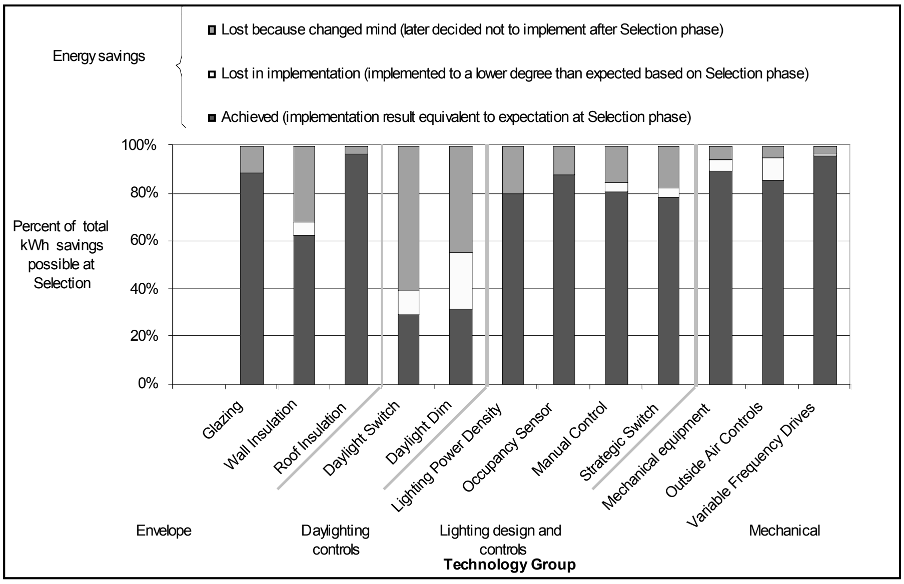


Figure 2. Percentage of electrical energy savings achieved and "lost" as measured between Selection and Verification

electrical savings were lost during the construction phase due to later decisions not to implement (i.e., later not selected) and implementation that did not meet the expected performance parameters.

Risk factors for the technology groups are provided as distributions (*Figure 3*) and as single averages (*Table 2*). Detailed results and numbers of data points are given in the Appendix. Implementation rate is defined as the energy savings of the ECM at a particular phase relative to the energy savings predicted at the selection phase,

$$I_{s,p} = \frac{E_{s,p}}{E_{s,selection}}$$

where $I_{s,p}$ is the implementation rate of energy conservation measure *s* at phase *p*, $E_{s,p}$ is the energy savings of *s* at phase *p*, and $E_{s,\ selection}$ is the energy savings of *s* at the selection phase. Implementation rate can be greater than 100 % if more ECMs, or a higher level of an ECM, are implemented than stated at the selection phase.

The distributions shown in *Figure 3* list the number of strategies on the y-axis and the (successful) implementation rates at the verification phase on the x-axis. Each bar represents the frequency at which the strategy group achieved the associated level of implementation. The distribution for mechanical strategies is the tightest of the various categories and is centered around 90 – 100 % implementation success rate. In contrast, the daylighting distribution is heavy towards the lower end, largely owing to the number of projects that decided *not* to implement the strategy after the selection phase. Six out of 15 projects later decided not to implement the stepped daylighting control, and seven out of 13 later decided not to implement dimming daylighting controls. Other lighting design and control strategies are mainly spread in the 80-120 % range. Glazing and envelope insulation, like daylighting controls, exhibit a mode at the low-end of the distribution, as well as a mode at 90-100 % implementation rate. This suggests that design teams either decide later to reduce insulation and glazing levels to code level, or they stick with the selection phase plan, without much variation between the two possible decisions. The frequency distributions can be used in Monte Carlo simulations for assessing the probability distribution of program-wide energy savings for building sets of similar characteristics.

The risk factors, or the percentage of energy savings that are lost between selection and verification phases, are presented in Table 2. Risk factors are calculated as

$$R_{s,p} = 1 - I_{s,p}$$

where $R_{s,p}$ is the risk factor (energy savings at risk) and $I_{s,p}$ is the successful implementation rate of energy conservation measure *s* at phase *p*. While this data does not account for the potential energy savings pursued for the technology groups, the data are representative of energy savings goals that go beyond code. The risk factors provide indication of the ability of design teams, owners, and contractors in seeing through successful implemetnation of energy conservation technologies, for building sets of similar charcteristics. The risk factors can be multiplied by the expected energy savings at the selection phase to arrive at an expected value of savings that will be achieved at the verification phase.

The strategies in Table 2 are listed in increasing order of risk. The data suggests that roof insulation is the least risky, and the negative value suggests that is implemented to a higher level than expected, on average. Glazing, variable frequency drives, occupancy sensor control of lighting, and manual control of lighting are the next lowest risk strategies at 12-14 %, although all exhibit an increase in likelihood of falling out from the construction document to the verification phase. Mechanical equipment has a risk factor of 17 % for both the construction document and verification phases, implying that the findings during construction document review are generally indiciative of the final finding. Lighting power density's risk factor changes the most from the construction document review to the verification phase (6 % to 28 %), indicating that the final walk-through of the building is important for knowing the true achievement. Outside air controls and daylighting controls are the highest risk technologies for achieving expected energy

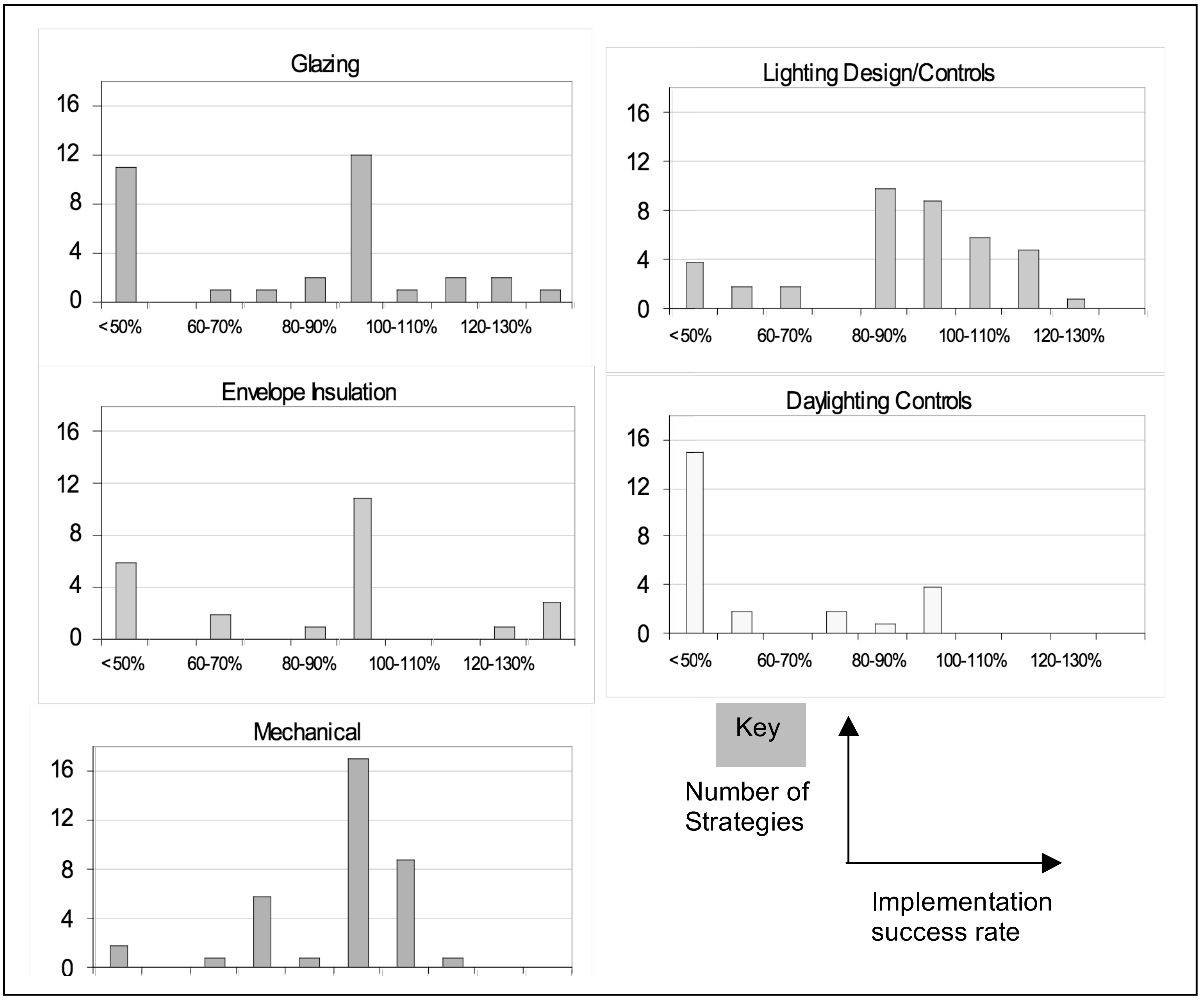


Figure 3. Frequency distribution of success rates for implementation at verification phase

Table 2. Table of risk factors for post-design phase losses in energy conservation (sorted from low to high at verification phase)

	Risk factor at Construction Document Phase	Risk factor at Verification Phase
Roof Insulation	-2 %	-5 %
Glazing	2 %	**12 %**
Variable Frequency Drives	6 %	**12 %**
Occupancy Sensor (lighting)	4 %	**13 %**
Manual Control (lighting)	10 %	**14 %**
Mechanical equipment	17 %	17 %
Strategic Switch (lighting)	**28 %**	21 %
Lighting Power Density	6 %	**28 %**
Wall Insulation	**33 %**	28 %
Outside Air Controls	30 %	**37 %**
Daylight Switching	49 %	50 %
Daylight Dimming	61 %	**68 %**
The risk factors in this table can be used to estimate the level of energy savings that will not be realized by multiplying the values by the energy savings expected at the selection (end of design) phase.		

consrvation as measured from the end of the design phase. The risk factors are already high during the construction document review (30 % to 61 %), and they increase further for the verification phase. These technology groups represent the greatest need in support to reduce implementation risk. Referring back to Figure 2, it is shown that ”lost in implementation” explains the majority of losses for outside air controls, while the reason ”later decided not to implement” accounts for the majority of energy savings fall-out for daylighting controls.

Future work with the database should look at relating the extent of energy savings with the risk factor for implementation. Future studies also should address the relationship between energy savings potential and the risk factors, including likelihood that design teams select a given strategy. This will help prioritize the technologies by identifying where the savings potential lies and what the associated risks are.

Survey and Focus Groups

METHODOLOGY

Surveys and focus group sessions were held with third-party reviewers at the energy consulting firm. The surveys were conducted as a precursor to the focus group discussions so as to reduce the bias associated with group dynamics. However, bias will still be present in these results as all nine participants work in the same firm. Furthermore, respondents' answers are likely to be biased towards their most recent experiences and those that required the largest time commitments, as those memories will be strongest. Nonetheless, this research was conducted to see if patterns emerged. From those patterns, conclusions can be drawn as to future courses of action that would help improve the implementation rates of technologies.

A total of nine energy consultants completed the surveys and participated in the focus groups. The respondents completed surveys individually in which they were asked to respond on how often 13 different reasons were the cause of strategies being dropped in six different technology categories: envelope, lighting design, lighting controls, daylighting controls, outside air controls, and mechanical systems. The questions pertained to the construction document review process, later design decisions, communication, and construction or contractor issues (as found during M&V). The survey questions are listed in the Appendix.

The one-hour focus group sessions were held in groups of two, three, and four. The sessions were aimed at understanding collective experience with the "Why?" of implementation success rates as observed during the CD review and M&V phases of the Energy Design Assistance process. The types of questions discussed included:

- What are some explanations for why a strategy is not found during the CD review and M&V process?
- What are some common responses from design team members and/or owners when reports indicate that ECMs are not found?
- What are the primary barriers and potential solutions for getting to 100 % implementation rate?

SURVEY AND FOCUS GROUPS RESULTS

The results of the surveys and subsequent focus group discussions are presented in this section and relate to the data findings in the previous section. For the surveys, the average response for each reason in each category was calculated. The responses are on a scale of 1 to 5, where 1 indicates "not a common reason," and 5 indicates "a very common reason" for a technology not being implemented to the goal-level at selection. Standard deviations are used to assess which factors have high agreement between the interviewees and which ones have low agreement. A summary table of the results is given in the Appendix. The two most common and the two least common reasons for each technology category are shown in the following tables. Those with a high level of agreement (a standard deviation of 1.00 or less) and those with a low level of agreement (a standard deviation of 1.50 or greater) are highlighted.

Before discussing results for each technology category, a few generalized observations are made. In general there was more agreement about what was *not* identified as a reason than what *was* identified as a reason. Furthermore, the respondents tended to agree more than they disagreed, as judged by the standard deviations of average scores. A few scores fell near the middle of the scale, but with a relatively high standard deviation.

For envelope insulation, the top reason for fall-out was value engineering. The second highest average response was that the technology was considered implicit in the documents according to the designer, but not documented well enough for a third party to be able to identify it (but with low agreement); this is the only category that this reason was a prevalent cause. Lack of coordination and lack of installation knowledge were the least cited problems in the survey for insulation. The average answers across all of the reasons were lowest in this category. In the focus groups, a participant noted that the metric of R-value is sometimes not understood by design teams in that they do not account for thermal bridging. Group discussion also noted that value engineering is often the reason for an envelope insulation strategy to fall-back to an earlier level.

Table 3. Envelope insulation survey results

Top reasons for not implementing the strategy		
Value engineering	3.00	1.22
Documents incomplete	2.89	1.54
Not a factor for this technology group		
Lack of coordination	2.11	0.33
Installation knowledge	1.11	0.33
*1 = not a reason to 5 = a very common reason ■ High agreement (Std Dev < 1.0), ▨ Low agreement (Std Dev > 1.5)		

Table 4. Lighting design survey results

	Average Response*	Standard Deviation
Top reasons for not implementing the strategy		
Miscommunication	2.67	1.41
Functionally Risky	2.44	1.42
Specification knowledge	2.44	1.51
Not a factor for this technology group		
Lack of coordination	1.56	1.01
Installation knowledge	1.44	1.01
*1 = not a reason to 5 = a very common reason ■ High agreement (Std Dev < 1.0), ▨ Low agreement (Std Dev > 1.5)		

The survey results found the top reasons for not implementing lighting design goals are "miscommunication," "functionally risky," and "lack of specification knowledge." Discussion groups noted problems primarily arise with the intended use of Super T8 lamps. Price, inventory, and miscommunication with specification writers are all reasons for not following through with Super T8 lamp strategies.

Discussion groups noted one of the biggest areas of variability between selection and CD review is lighting power density because designers get accustomed to designing certain lighting fixture layouts over a period of time and they find it difficult to change these for design goals to reduce the lighting power density. This indicates an opportunity to assist design teams with sample lighting design layouts for reduced lighting power densities and target footcandle (lux) levels.

The survey results found that, for lighting controls, documentation is usually not a problem. The survey finds lighting controls are most often eliminated because of a perceived functional risk and value engineering after selection. The discussion group backed-up the functionally risky finding by commenting on unfamiliarity with occupancy sensor technology. Furthermore, it was suggested that later stage decisions not to place an occupancy sensor in spaces such as restrooms, mechanical/electrical rooms, and storage rooms could be avoided by more attention to these space-types during the selection phase.

For daylighting controls, the survey respondents on average said that “value engineering” is a top reason for no longer deciding to implement the strategy. The next top reasons are “lack of specification knowledge” and “later decided was functionally risky,” according to the survey. Daylighting in general received the highest scores for almost all reasons as compared to other technology categories. In speaking with design teams, focus group participants suggested that “lack of knowledge” and “functional risk” may be root causes for later decisions to remove daylighting when budgets become squeezed.

Focus group participants noted they very rarely find daylighting specifications to the level that they expect so as to ensure proper function. A lack of knowledge is often observed for how to specify daylighting control algorithms and calibration requirements. Design teams have provided feedback on several projects that manufacturers do not provide enough help with calibration. Overall, the energy consultants noted it is their M&V feedback that reveals to facility managers and design teams that daylighting controls are not working.

For control of outdoor air technologies, “value engineering” and perceived “functional risk” received the highest average survey responses. The survey found that a variety of reasons were not usually applicable to control of outdoor air technologies as indicated by average responses of 2.0 or less, including “not sent a full set of documents,” “miscommunication,” “installation knowledge,” and “contractor omission.”

Focus group participants noted that variable frequency drives (VFDs) are a common area of incomplete implementation. The components may be installed, but datalogging trends reveal that they are not calibrated correctly. Overall, dynamically varying strategies, such as minimum pump flows, variable air volume (VAV) control sequences, CO_2 controls, VFDs, and daylighting controls, are the least likely to be implemented correctly, according to focus group participants. This was generally demonstrated by the data shown in the previous section, where the highest risk factors were found for daylighting controls (49 and 68 %) and control of outdoor air flows (35 %). The one exception is VFDs, which had the third lowest risk factor at 15 %. This is attributed to the ease in correcting VFD operation once the problem is identified.

In the Mechanical Equipment category, the survey results show that “value engineering” is by far the most significant reason that strategies were dropped. The next most common reason, “difficult to find in CDs, but design team later points it out” was very close to the center of the scale. This is the only category for which this reason had an average score above 2.5. However, even if not found in CDs, the technology may still be implemented successfully as verified during M&V. “Lack of coordination” had the lowest score for this category, which is expected since these technologies fall wholly within the mechanical designers’ responsibilities.

Focus group participants noted that chillers are often specified at differing operating conditions from the modelling assumptions. Another common reason found during discussion is that the efficiency level of a technology, as modelled, may not be available. Premium efficiency motors are sometimes

Table 5. Lighting Controls survey results

	Average Response*	Standard Deviation
Top reasons for not implementing the strategy		
Value engineering	3.22	1.48
Functionally risky	3.00	1.32
Not a factor for this technology group		
Documents incomplete	1.78	0.83
Not sent full documents	1.56	0.72
*1 = not a reason to 5 = a very common reason ■ High agreement (Std Dev < 1.0), ▨ Low agreement (Std Dev > 1.5)		

Table 6. Daylighting Controls survey results

	Average Response *	Standard Deviation
Top reasons for not implementing the strategy		
Value engineering	4.67	1.00
Specification knowledge	4.44	1.33
Not a factor for this technology group		
Documents incomplete	1.89	1.27
Not sent a full set of documents	1.67	1.00
*1 = not a reason to 5 = a very common reason ■ High agreement (Std Dev < 1.0), ▨ Low agreement (Std Dev > 1.5)		

Table 7. Control of Outside Air survey results

	Average Response *	Standard Deviation
Top reasons for not implementing the strategy		
Value engineering	3.44	1.67
Functionally risky	2.56	1.33
Not a factor for this technology group		
Not sent a full set of documents	1.67	1.00
Miscommunications	1.89	1.27
Installation knowledge	1.89	1.05
Contractor omitted	1.89	1.17
*1 = not a reason to 5 = a very common reason ■ High agreement (Std Dev < 1.0), ▨ Low agreement (Std Dev > 1.5)		

Table 8. Mechanical Equipment survey results

	Average Response *	Standard Deviation
Top reasons for not implementing the strategy		
Value engineering	3.78	1.39
Difficult to find in CDs (design team later points it out)	2.67	1.32
Not a factor for this technology group		
Lack of coordination	1.11	0.33
Installation knowledge	1.44	0.73
*1 = not a reason to 5 = a very common reason ■ High agreement (Std Dev < 1.0), ▨ Low agreement (Std Dev > 1.5)		

Table 9. Summary table of reasons

	Envelope	Lighting design	Lighting controls	Daylighting controls	Outside air controls	HVAC systems
Often a factor (Average score)	Documents incomplete 3.00	Miscommunication 2.67	Value engineering 3.22	Value engineering 4.67	Value engineering 3.44	Value engineering 3.78
	Value engineering 2.89	Functionally risky / Specification knowledge 2.44	Functionally risky 3.00	Specification knowledge 4.44	Functionally risky 2.56	Not seen in CDs (but was there) 2.67
Seldom a factor (Average score)	Lack of coordination 1.11	Calibration 1.11	Not sent a full set of CDs 1.56	Not sent a full set of CDs 1.67	Lack of coordination 1.11	Lack of coordination 1.11
	Installation knowledge 1.11	Installation knowledge 1.44	Documents incomplete 1.78	Documents incomplete 1.89	Not sent a full set of CDs 1.67	Installation knowledge 1.44

not properly specified, even though designers think they have specified them correctly.

Generalized results across technology categories

Value engineering was the single most cited reason for a strategy category being removed in five out of six of the categories. The only exception is lighting design where lower lighting levels are often less expensive because of fewer fixtures. "The design team or owner later deciding a strategy was functionally risky" also is a top reason in all categories other than envelope and HVAC systems. This suggests that greater assistance in a) understanding the long-term value of the energy conservation measure and b) specifying and commissioning the technology would be helpful pathways to achieving increased implementation rates. "Getting a full set of drawings" was not a common reason for lack of implementation, which means that the third-party reviewers receive the drawings that would go to the contractors. In all categories except daylighting, the survey results suggest that contractor-related reasons are the lowest cause of strategies not being implemented. For daylighting controls, poor documentation is likely a contributing factor to contractor related issues, including "contractor not implementing a strategy correctly," "not being calibrated or tested" and "contractor omission." HVAC systems is the only category where either of the construction document related reasons was a common problem, which is likely due to difficulty in identifying the specified efficiencies.

Conclusion

This study focused on the construction phase persistence of energy conservation measures in new buildings. The study is motivated by the observation that even after design teams and owners invest time and effort in a process to analyze and choose energy conservation measures for their building, there is still a risk that energy savings are not realized due to subsequent decisions to remove a design element or due to partial or incorrect implementation of a technology. The study assessed data for projects that had design phase energy modeling, CD review and M&V consultants. The role of the CD review and M&V professional is one of identifying errors and omissions and providing feedback and technical assistance.

The data set of 38 projects indicated that 17 % of electrical energy savings are lost as compared to those expected at the end of the design phase. Of the individual technology categories, lighting design and roof insulation are most often implemented correctly, and thus have low risk factors. Conversely, dynamic control strategies including daylighting and outdoor air flow are most likely to be lost either due to later decisions not to implement the strategy or due to incorrect implementation, such as calibration. Surveys of the CD review and M&V consultants revealed that value engineering, later decisions that an ECM is functionally risky and miscommunication between design team members are top reasons for not implementing a strategy or for it to not be fully functional. The results indicate that, in addition to design phase assistance, the construction-phase assistance is important for helping design teams and owners with decisions related to energy conservation. When value-engineering occurs during the construction phase, increased informational support on the value of energy strategies, including integrated cost savings, and increased technical assistance to reduce concern that a technology will not function properly would help to raise the level of verified energy savings closer to those expected at the selection phase.

Additionally, incentive programs could be structured to provide economic assistance relative to the risk that the technology entails, such as found in this study. While communication barriers continue to be a challenge to the multi-party design and construction industry, the results further demonstrate the importance of ensuring that all decision-makers are involved as early as possible in the building's design process. When team members change, communication of the energy goals and design history will help them buy-into the energy conservation features thus included in the design. Finally, with dynamic control strategies showing the highest risk and with their potential to provide operational life savings throughout the lifecycle of the building, more training is needed in documentation, specification writing, calibration, and coordination amongst design disciplines and construction members to ensure their successful implementation.

Future work in this area is to build the database to encompass a wider geographical area to understand implementation success and the role of M&V with respect to geographical differences in product availability, regional differences in design processes and building codes, and design-build firms vs. a more typical supply chain of separate design. Future work will also include data on ECMs that were considered but not chosen during the design phase and their relative opportunity for energy savings. This greater picture will serve market transformation by helping prioritize provision of funding to technologies and M&V areas that have high reward potential, but also currently have high associated risks.

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Appendices

DATA TABLE FOR IMPLEMENTATION RATE BY TECHNOLOGY

			No. datapoints	
Average implementation rate	CD	V	CD	V
Glazing	89%	85%	35	34
Wall Insulation	66%	71%	13	13
Roof Insulation	97%	99%	20	18
Daylight Switch	49%	51%	15	15
Daylight Dim	39%	32%	13	13
Lighting Power Density	93%	91%	52	52
Occupancy Sensor	85%	79%	37	37
Manual Control	87%	80%	36	36
Strategic Switch	74%	81%	11	11
Outside Air Controls	70%	65%	22	22
Variable Frequency Drives	88%	85%	25	25
Mechanical equipment	72%	71%	102	102

GROUP

SURVEY (RATING FORM) GIVEN TO FOCUS GROUP PARTICIPANTS

For each technology category, how would you rate the following explanations for why a strategy is not found during the CD Review and verification process?

	Envelope	Lighting design	Lighting Controls	Daylighting Controls	Outside air	HVAC systems	Notes for discussion
CD Review Process							
We did not see it in the CDs, but it was actually there							
Documents incomplete, still under development							
We were not sent a full set of documents, they existed but were not sent							
Later Decisions							
Value engineering							
The design team decided the strategy was functionally risky							
Communication							
Miscommunication amid design team and EDA							
Lack of coordination between the design disciplines							
Lack of knowledge in selection, specification							
Informal documentation							
Construction							
Contractor did not do it right and strategy was not otherwise checked by a design team member							
Lack of knowledge in installation							
Not calibrated/ balanced/ commissioned/ tested adequately							
Contractor omitted it (did not understand energy/incentive impacts of what might otherwise be perceived as a small exclusion)							

Rate each reason for each category from 1-5, where 1 = not a common reason, 3 = somewhat common, and 5 = very common reason for not finding strategy during CD review or M&V.

DATA TABLE OF SURVEY RESULTS

		Envelope (insulation, glazing, design)				Lighting design				Lighting Controls				Daylighting Controls			
		Avg	Std Dev	Low	High	Avg	Std Dev	Low	High	Avg	Std Dev	Low	High	Avg	Std Dev	Low	High
CD Review Process	We did not see it in the CDs, but it was actually there	2.00	1.32	1	5	1.67	1.32	1	5	1.89	1.36	1	5	2.00	1.32	1	5
	Documents incomplete, but designer said they are under development and we get them later	2.89	1.54	1	5	1.67	0.87	1	3	1.78	0.83	1	3	1.89	1.27	1	4
	We were not sent a full set of documents (existed but not sent)	2.11	1.27	1	4	1.89	0.78	1	3	1.56	0.73	1	3	1.67	1.00	1	4
Later Decisions	Value engineering (the design team tells you that they decided not to go ahead with it for budget reasons)	3.00	1.22	1	5	2.22	1.39	1	5	3.22	1.48	1	5	4.67	1.00	2	5
	Later decided the strategy was functionally risk (had high goals at end of design, but thought more about it and decided it was functionally risky)	1.33	0.71	1	3	2.44	1.42	1	5	3.00	1.32	1	5	4.22	1.39	1	5
Communication	Miscommunication (e.g. the design team member completing the documents was not at EDA meetings and did not know about the strategy parameters)	1.56	0.88	1	3	2.67	1.41	1	5	2.00	1.32	1	4	3.22	1.56	1	5
	Lack of coordination between disciplines (e.g., lighting contractor installed controls, mechanical contractor then came in and blocked with ducts; e.g., mechanical and electrical examples?)	1.11	0.33	1	2	1.56	1.01	1	4	2.00	1.22	1	4	2.56	1.59	1	5
	Lack of knowledge in selection, specification	1.56	1.01	1	4	2.44	1.51	1	5	2.11	1.36	1	5	4.44	1.33	1	5
Construction	Informal documentation (they actually have it, but it is not formally documented in the plans or specifications)	1.89	1.17	1	4	1.67	0.87	1	3	1.89	0.93	1	3	2.00	1.32	1	5
	Contractor did not do it right and strategy was not otherwise checked by a design team member	1.22	0.67	1	3	1.89	1.54	1	5	2.00	1.12	1	4	3.56	1.33	1	5
	Lack of knowledge in installation	1.11	0.33	1	2	1.44	1.01	1	4	1.89	1.27	1	5	3.78	1.39	1	5
	Not calibrated/ balanced/ commissioned/ tested adequately	1.00	0.00	1	1	1.11	0.33	1	2	2.33	1.32	1	5	4.11	1.36	1	5
	Contractor ommitted it (did not understand energy/incentive impacts of what might otherwise be perceived as a small exclusion)	1.44	0.88	1	3	2.00	1.32	1	4	2.22	1.39	1	5	2.44	1.67	1	5