Characterizing the Microeconomic Decision Factors of Energy Efficient Commercial Building Retrofits

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Michael A. Hamilton

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Dr. Patrick Gurian (advisor)

Dr. Jin Wen (thesis committee member)

Dr. Patricia Gallagher (thesis committee member)

Dr. Charles N. Haas (department head)

Liam Hendricken

Jared Langevin

Pat Casey

UTRC

EEB HUB

Table of Contents

List of Tables

List of Figures

Abstract

Characterizing the Microeconomic Decision Factors of Energy Efficient Commercial Building Retrofits

Michael A. Hamilton
Patrick L. Gurian, Ph.D.

Engineering analyses have claimed that the implementation of retrofits in existing buildings can significantly reduce their energy consumption and generate cost savings for owners – yet such investment in energy efficiency has been minimal by many standards. The primary goal of this thesis is to identify and quantify the factors affecting stakeholders' decisions to adopt (or not adopt) energy conservation measures during commercial building retrofits, and then to suggest ways in which these decision processes can be improved through policy instruments. Chapter I presents a literature review of previous research on the subject and explains the theoretical basis of the "energy-efficiency gap." Chapter II presents findings from a set of surveys in order to clarify the major determinants of the commercial energy-efficient building retrofit decision – and uses these data to make observations of differences in retrofit investment preferences between different types of organizations and leasing structures. Chapter III summarizes the implications of the first two chapters and suggests possible policy-based solutions to encourage increased attention to energy efficiency in the commercial building sector. Results from the surveys conducted for this study are shown to be generally in agreement with a third data source, the Johnson Controls Energy Efficiency

2011 Indicator survey. The relative importance of various financial metrics (such as simple payback period) in stakeholders' decision processes is quantified and the ability to alter the outcomes of these processes via the addition of new financial information is documented. It is found that stakeholders' behavior may be partially explained by their beliefs in the future cost of energy, which they expect will decrease in real terms over the next 20 years (though significant variation does exist in these perceptions). An approximate quantitative measure of "split incentives" is obtained and differences in its effect between different organization ownership structures are outlined. Together, the data presented in this thesis suggest that an "energy efficiency gap" does exist, though to a smaller degree than have been suggested by some. Specific policy solutions to increase investment in energy efficiency are recommended, including 1) targeting non-profit and government organizations to act as "early adopters," 2) the creation of a third-party database with cost and performance information for ECMs, and 3) the widespread adoption of on-bill financing.

CHAPTER I : LITERATURE REVIEW

1. BACKGROUND

The “energy efficiency gap” is a highly-politicized term originating in engineering analyses indicating that there may exist a set of net present value (NPV) positive energy conservation investments in the market which for some reason have gone unrealized. A steady stream of papers over the past thirty years have addressed (and questioned) the existence, magnitude, and persistence of such a gap. An early argument for the existence of a gap appeared in a 1979 report detailing the results of the Harvard Business School Energy Project, in which authors concluded that if government were to make conservation a priority, the possibility of reducing energy consumption by 30 or 40 percent while maintaining the current standards of living was not an unreasonable proposition [1].

Any discussion about the existence, magnitude, and nature of an energy efficiency gap must define what the “gap” actually is and how it is to be measured. Jaffe *et al*. (1994) identified five separate and distinct notions of optimality: the economists' economic potential, the technologists' economic potential, hypothetical potential, the narrow social optimum and the true social optimum. The paper cautions that any analysis of the “gap” must be specific with regards to which definition of optimality is being used. Figure 1 represents these different levels diagrammatically. Following is a brief explanation of each of these levels:

- *The economists' economic potential* may be achieved by eliminating existing market failures in the energy efficient technology market.
- To attain *the technologists' economic potential*, additional (non-market failure) barriers such as high discount rates and organizational inertia must be eliminated.
- Approaching the problem from a practical point of view, the *narrow social optimum* may be achieved by eliminating those market failures whose solutions pass a societal cost-benefit test (but without accounting for any externalities).
- Once the narrow social optimum has been achieved, the *true social optimum* may be achieved by internalizing any existing externalities. Any difference between the narrow social optimum or the true social optimum and the hypothetical potential exists because there may be market failures for which there are no cost-effective solutions.
- *The hypothetical potential* may only be achieved when *all* market failures in the broader energy market are eliminated. Achieving this potential is not only impossible, the authors say, but undesirable (if it is assumed that some market failures are most costly to correct than to leave in place).

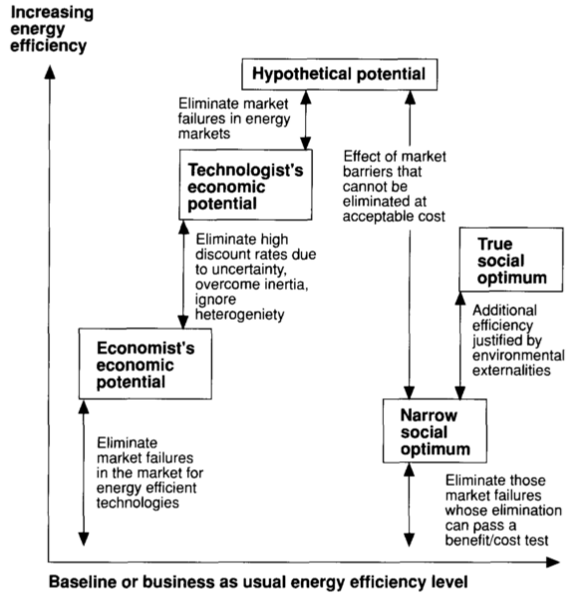


Figure 1. Notions of energy-efficiency optimality (from Jaffe and Stavins, 1994).

Many studies use the *technologists' economic potential* as their "ideal level" of energy efficiency. From a policy analysis perspective, however, this is not necessarily the correct level to target – the *narrow social optimum* seems like an achievable goal while the *true social optimum* would provide additional positive benefits. The authors proceed to note that whether or not an energy gap exists, the diffusion of economically superior technologies is typically gradual. Thus "… if the purpose of measuring the efficiency gap is to identify desirable government policy interventions, then what we need to know is whether the market barriers that cause slow diffusion can be mitigated by government intervention in such a way that overall resource allocation is improved." [2]

2. BARRIERS

Keeping in mind that the terminology for an energy-efficiency gap is not consistent across studies, it remains possible to list the potential barriers which have been put forth by these studies and then to classify these barriers according to different classification schemes. We will begin by looking at each of the proposed barriers individually.

Information: Problems stemming from a lack of information or the uneven dissemination of information are frequently cited as forms of market failure. It is critical to distinguish between different types of information problems, which in some cases have been confused in the literature. Weimer and Vining make the distinction between imperfect information and information asymmetry, both of which are considered forms of market failure. [3]

- Imperfect information refers to a lack of information provision and may be considered a public goods problem, since information itself may be considered a public good. Public goods (in contract to pure private goods) are neither rivalrous nor excludable and thus will tend not to be supplied by the market. A common example of a public good is a lighthouse – the benefits of a lighthouse accrue to multiple parties in a non-rivalrous and non-excludable manner – thus lighthouses must typically be provided by governments. Similarly, information (for instance, data about technologies' performance) may benefit multiple parties in a way that is non-rivalrous and non-excludable, and thus may not be provided by the market of its own accord.
- Information asymmetry, on the other hand, refers to the uneven possession of information between different parties. For example, if a seller has better

> information about a product than a buyer, there exists an information asymmetry between the two actors and this may lead the buyer to purchase more or less of the product than under the alternative condition of symmetric information.

To understand how problems related to information may affect the market for energy efficient technologies, it is useful to classify goods into search goods, experience goods, and post-experience (or credence) goods. Search goods allow evaluation by the consumer prior to purchase. Experience goods only allow evaluation through use or consumption. Post-experience or credence goods are difficult to evaluate, even after consumption. [3] It has been suggested that the energy efficient technology market falls into this final category, given that many consumers lack the education or the means to make the necessary evaluation of performance even after using the good. [4], [5] Pharmaceuticals are another oft-cited example of post-experience goods.

Adverse selection: The problem of *adverse selection* is closely related to information asymmetry. In a 1970 paper, Akerlof demonstrated how sales of "bad" used cars (a.k.a., "lemons") in the used car market will tend to drive out "good" cars since it is typically impossible for the buyer to distinguish between the two types prior to purchase and because the rate of return for selling a "lemon" is higher than that of a "good" car. This situation exists because a "lemon" can be considered an experience good, one whose quality can only be determined after using it for some period of time. Thus, information asymmetry encourages the sales of "lemons," eventually crowding the market with inferior goods – hence the phenomenon of adverse selection. This situation is also dependent on the willingness of the seller opportunistically sell a "lemon" at the same price of good car. [5], [6] It is not hard to translate this to the market for energy efficient technologies, especially if one accepts the hypothesis that such technologies are post-experience goods (thus making it even more difficult to evaluate their performance).

Principal-agent relationships: The problem of principal-agent relationships also has roots in the lack of perfect information held by all parties. Such relationships exist because the objectives of employers (or principals) and their employees (agents) are not always in perfect alignment. In a world of perfect information, principals would know everything known by their agents. This situation is unlikely to obtain because there are costs associated with monitoring agents. Thus there remains the possibility that *agency loss*, or the costs associated with discrepancies in the supervisory relationship, will occur. [3]

A corollary of the principal-agent problem is the requirement that investments will satisfy either short payback periods or high internal rates of return (or "hurdle rates") within a firm. Such rates are set by the principal as a litmus test to ensure that investments undertaken by the agent carry a minimal amount of risk and are at least at profitable as the set minimum. The result is that investments with lower returns (as is typical of energy-efficient retrofits) are passed by in favor of more profitable investments – for example, the expansion of production facilities. It must also be noted that a firm's decision to set higher hurdle rates is not itself a barrier to energy efficiency, but rather a response to address existing conditions in the market.

Hurdle rates are also related to the complexity of interactions within a firm. Decanio (1993) pointed out that corporations are not individuals and therefore cannot be expected to behave as such. In the author's words: "The individuals making up a business firm may all be rational seekers after their own interest, but the outcome of their collective action may be suboptimal." The structure, organization, and a myriad of other internal factors influence the decisions of a corporation, which cannot realize every profitable investment available. A corporation's decision to set hurdle rates higher than the cost of capital can be interpreted as a response to the principal-agent problem in that it increases the chance of an acceptable return on investment. This relates to the phenomenon that corporations may tolerate some degree of management inefficiency as long as the bottom line remains profitable [7].

In a later paper, Decanio and Watkins (1998) further explored the notion that the characteristics of a corporate entity will affect its energy efficiency investment decisions. By using the choice to participate or not participate in the EPA's Green Lights program as a proxy for willingness to invest in energy efficiency, the authors attempted to show that certain properties of a corporation will affect their investment decisions. By estimating a discrete choice regression over firms with the choice of joining the program, results revealed that a firm's number of employees, earnings per share, the historical rate of growth of industry earnings, expected future earnings growth, price/earnings ratio, industrial sector, and EPA region all had an influence on the dependent variable. In general, there was a positive correlation between a firm's performance and its likelihood of joining the Green Lights program. The authors concluded that this "… is evidence that the conventional model of investment decision making is inadequate in this case." In other words, there exists a heterogeneity among firms which limits them from being lumped into the single orthodox notion of a *firm* [8].

More recently, Martin et al. (2012) found that among manufacturing plants in the UK, the adoption of "climate-friendly management practices" correlate with the presence of an energy or environmental manager. The correlation is strongest when this manager's position is close to that of the CEO, but drops precipitously when the CEO assumes this responsibility. The study also found that such management practices are associated with higher productivity and less energy usage. [9]

Split or misaligned incentives: The problem of split incentives assumes its most common form in a landlord-tenant relationship in which the landlord owns a building and leases space out to a tenant or tenants. These tenants are responsible for paying their own energy bills while the landlord is responsible for the building infrastructure. The tenants have little incentive to improve the building's energy systems since they do not own the building, while the landlord has little incentive to improve the energy systems since the tenants pay the rent. Thus any possible investment in energy efficiency is left in stalemate.

The landlord-tenant relationship is not the only instance of split or misaligned incentives. Hirst and Brown (1990) note that there many different parties involved in the design, construction, and operation of buildings – including owners, engineers, architects, builders, contractors, and others. The involvement of these "intermediaries" leads to more weight being placed on first cost rather than life cycle costs, thus limiting investment in higher cost, more energy-efficient options. [10]

There have been several policy tools targeted at overcoming problems associated with split incentives. One example is "on-bill financing," a financial arrangement in which a utility company (or a third party lender) will provide financing to a building owner with the specific intent of performing an energy-efficient building retrofit. The loan is then paid back to the lender through the energy cost savings generated by the retrofit. This payment is integrated with the owner's utility bills (hence the name "on-bill financing"), which simplifies the transaction and reduces the chance of the owner defaulting on the repayment. An important property of most on-bill financing arrangements is the provision that the responsibility for repaying the loan is tied to the building and not to the building owner. Thus if the building owner sells the building, the loan moves with the building to the new owner.

Risk and uncertainty: Any projections of energy cost savings due to retrofit investment will include some degree of uncertainty. Contributing factors may include the performance of the technology, the future cost of energy, and the length of ownership of the building in question. Such uncertainty produces a corresponding degree of risk in the investment. Several studies have demonstrated that certainty is a highly-valued determinant in making decisions. It has been observed that people must be compensated disproportionately more to give up something they already have than to obtain something they do not. [11] It has also been shown that residential consumers increase their discount rates 5-6 percentage points when dealing with energy-efficient investments in their residences even when the risks are relatively small. [12] Samuelson and Zeckhauser refer to this phenomenon as the "status quo bias." [13]

Hidden costs: Some have argued that there is not an "energy efficiency gap" because the engineering models which were used to estimate the gap somehow failed to account for hidden costs. [14] Such costs may include the cost of information gathering, the assessment of alternative strategies, decrements in productivity due to the implementation of new equipment and procedures, and managerial costs. [15] Hein and Blok (1994) found that hidden costs represented a non-negligible portion of total investment costs within firms, and that this percentage increased for more advanced retrofits or for smaller firms. [16] The same trend was reported by Kulakowski. [17]

Hidden costs should not be confused with *transaction costs*, which some have argued represent an often-overlooked though substantial contribution to the economics of energy efficiency. [5], [18] It is the case, however, that some transaction costs may be hidden, and that some hidden costs may be transaction costs.

Heterogeneity: Not all buildings are the same. This simple statement also implies that not all building owners are the same, nor are building operators or facilities managers. While heterogeneity is rarely used to explain the energy-efficiency gap by itself, it is commonly used to explain why other barriers are so difficult to surmount; that is, it is an important factor in economic models focused on the macro-level but not in engineering models focused on the micro-level. As a simple example, consider two identical buildings with the same rooftop solar array. A building located in Los Angeles will experience a very different energy savings than a building located in Alaska. Heterogeneity is also used to describe differences in consumers and their preferences for energy-efficient technologies.

Access to capital or financing: It has been suggested that the rules governing the use of capital preclude investment in energy-efficient technologies because they are typically more expensive than their less efficient counterparts. Some of these rules, particularly those governing payback periods and hurdle rates discussed previously, are imposed by the firms themselves and may be aimed at preventing agency loss (also discussed previously).

Bounded rationality: Herbert Simon's concept of "bounded rationality" suggests that consumers do not have the necessary cognitive capacity to process all the information available on a specific topic, and therefore must resort to heuristic approaches which require less computation. The term "bounded rationality" thus reflects the notion that consumers are rational up to a certain point, but that limits on the ability to process data set restrictions on such behavior. When presented with a difficult decision, actors may first try to simplify the choices available before choosing in a rational manner. Simon referred to this process as "satisficing," in which individuals attempt to arrive at a satisfactory solution instead of (necessarily) the optimal solution. [19]

In accordance with this theory, several studies on residential consumers have shown that they do not always make decisions based purely on economic considerations, or that they make incorrect calculations. There is evidence that residential householders frequently make inefficient decisions related to energy consumption [20] and that consumers exhibit systematically incorrect biases when comparing the fuel economy of different cars (i.e., by failing to recognize that a fuel economy increase from 15 MPG to 20 MPG is equivalent to an increase from 30 MPG to 40 MPG). [21] Neij *et al.* (2009) argued that residential consumers' investment decisions cannot be predicted solely by economic variables. Their review of existing literature suggested that consumers largely ignore operating costs when making decisions about household appliances. This may be attributed either to a lack of understanding of how to calculate operating cost savings, or to consumers' weighting of non-financial criteria as more important (e.g., comfort, aesthetics, reliability, etc.). [22]

Other studies have looked at whether or not consumers may take environmental considerations in to account when making decisions about residential conservations measures. Achnicht (2011) performed a choice experiment on residential consumers in Germany regarding their decision to invest in a new heating system or improved thermal insulation for their home. They found environmental benefits (i.e., CO_2 emissions) to have a significant effect on choices of heating systems but not for choices of insulation type. This was interpreted to mean that consumers may find it easier to associate the reduction of CO_2 emissions with a new heating system than with new insulation.

Credibility and trust: This refers to consumers' attitudes toward information providers. In an important study by Craig and McCann (1978), pamphlets on how to request energy conservation information were sent to consumers by one of two sources: the New York State Public Service Commission (high credibility) or the local utility company (low credibility). Except for the source, the information presented was identical. Consumers receiving the pamphlet from the high credibility source were twice as likely to request more information. [23]

Form of information: Studies have shown that the form of information has an important effect on how much impact it has on the target audience. In general, it has been suggested that people will evaluate information differently depending on how it is presented, which is one of the tenets of "prospect theory" put forth by Kahneman and Tversky. [24] More specifically, DuPont (1998) looked at consumers' ability to interpret energy labels on household appliances in the U.S. and Thailand and found that while Thai labels more effectively conveyed data about energy efficiency, consumers in both countries had difficulty interpreting the information properly. In most cases, the end result is that consumers place an inordinate weighting on first cost, often to the detriment of other metrics such as long term cost savings. [25] It has also been observed that the timing and format of how television sets' energy use information is presented will affect consumers' choice of products. [26]

Impact of Social Norms: Values and social norms are difficult to quantify, and research has suggested that they only play an important role in energy conservation behaviors when they do not cost more than more energy intensive alternatives. Limited changes in residential energy use behavior have been observed when presented with information comparing one household's consumption with that of neighboring houses. [27]

Inertia: Inertia is an acknowledgment that human beings prefer to have set ways of doing things. When applied to the energy efficiency gap, this term may refer to organizational inertia, in which entrenched ways of doing something prevent new and innovative methods from being used. One example resides with the actual construction of buildings – building codes and existing methods have been suggested as hindrances to increased use of newer and more energy-efficient technologies. [28]

Power: A notion taken from behavioral economics, the term *power* in the context of energy efficiency refers to the lack of influence of energy management employees within an organization. In some ways this barrier is similar to the split incentives and asymmetric information barriers (discusses previously), in that agency loss may occur in an organization because those individuals with the relevant knowledge have limited power to implement changes. [5]

Organizational culture: Organizational culture is defined as the sum of each constituent member's values. The influence of a member's values is directly proportional to the rank of that individual within the organization. [5], [8] This is another concept that may be difficult to quantify. However, an obvious example where the leadership exerted influence over the direction of the organization is Apple, Inc., under the late Steve Jobs.

Discount Rates: The topic of discount rates used by consumers has been a popular avenue for exploration since the late 1970s. In a 1979 article examining discount rates used when considering the purchase of an air conditioner, Hausman found that consumers were utilizing annual discount rates as high as 26.4 percent. Such values are much higher than discount rates typically used in engineering analyses and much higher than values commonly used for the cost of capital. Hausman noted that such a finding does not surprise many economists, citing the "defective telescopic faculty," or the tendency to discount at a rate much higher than the corresponding opportunity costs of investment in credit markets. A possible solution to this "defect" is to directly incentivize the purchase of energy efficient equipment through tax subsidies or other similar policies. The paper also noted that the discount rate varies inversely with income, with higher income classes using an implied discount rate much closer to the value derived from existing lending opportunities. [29]

Hassett and Metcalf (1993) argue that such high discount rates are not unreasonable when sunk costs and uncertainty are factored into the consumer's decision. Drawing on their own previous work, they suggest that the appropriate hurdle rates for energy efficient investments are four to five times the hurdle rate without uncertainty. Because the hurdle rates are so high, the authors conclude it is unlikely that tax subsidies will increase investment in energy conservation measures, instead citing mandatory energy efficiency standards and consumption taxes as more effective methods. [30]

Other studies have clarified that high discount rates used by consumers are not themselves a barrier, but rather a reaction to (or restatement of) other barriers. It is thus fruitless to argue for a specific discount rate. [2], [5], [31]

3. TAXONOMIES OF BARRIERS TO ENERGY EFFICIENCY

Before proceeding, we must first define the term "market failure." A market failure is described by Weimer and Vining as a "situation in which decentralized behavior does not lead to Pareto efficiency. [These are] circumstances in which social surplus is larger under some alternative allocation to that resulting under the market equilibrium." [3] The four types of market failure include: public goods, externalities (both positive and negative), natural monopolies, and information asymmetries. The majority of the barriers discussed in relation to energy efficiency do not fall into one of these categories, thus any analysis must be careful to distinguish between those barriers which are recognized as traditional market failures and those which are not. Depending on the taxonomy being applied, there are additional distinctions (besides market failure vs. non-market failure) that should be made between barriers. Although not an exhaustive list, the potential barriers discussed in the previous heading represent the most frequently-cited examples of each group. We will next discuss the various taxonomies which have been developed to classify such barriers.

Orthodox economics offers perhaps the simplest taxonomy of barriers to energy-efficiency – a binary "yes or no" approach which recognizes the validity of some barriers but not others. Barriers considered valid by this school of thought include market externalities, imperfect information, adverse selection, principal-agent problems, misaligned incentives, hidden costs, access to financing, and risk. "Invalid" barriers include any notions that deviate from the orthodox economic assumptions of rational market actors making profit-maximizing decisions under perfect information without transaction costs or market externalities. These include a number of "behavioral" and "organizational" barriers (discussed below).

Hirst and Brown (1993) offer a slightly different way of grouping barriers to increased energy efficiency. Barriers are *structural* or *behavioral*. Structural barriers include limited access to capital, government fiscal and regulatory policies, codes and standards, and supply infrastructure limitations. Behavioral barriers include attitudes toward energy efficiency, perceived risk of energy-efficiency investments, information gaps, and misplaced incentives. [10]

Weber (2007) expands on this taxonomy to include four groups of barriers: *Institutional, market, organizational, or behavioral*. This classification system widens the narrow approach afforded by orthodox economics (by recognizing that real markets may violate traditional assumptions of firms), and simultaneously distinguishes between subgroups of the Hirst and Brown system.

- *Institutional barriers* are created by political institutions (Weber gives state government and local authorities as examples). Such barriers are large and lumbering – they may be very influential but also hard to describe in a clear-cut manner, and typically have great inertia.

- *Market barriers* result from macro-level glitches in the market as a whole, which in turn reflect existing institutional barriers. Market barriers mostly affect rational actors (i.e., individuals and firms) attempting to increase their utilities.
- *Organizational barriers* represent problems within the firms that constitute the market. As discussed previously, there may exist the possibility for moral hazard and agency loss within organizations, and these may have adverse effects on a firm's decisions and actions. These barriers are not recognized by orthodox economics.
- *Behavioral barriers* represent individuals' decisions related to energy consumption. Weber cites "social norms and lifestyle patterns" as being important members of this category, and may include lack of attention toward energy conservation or a perceived inability to influence the level of consumption. These barriers are not recognized by orthodox economics.

Weber notes that care must be taken when talking about barriers: "*What* is an obstacle to *whom* reaching *what* in energy conservation?" There are four important caveats which must be remembered when utilizing the barrier approach.

- The first caveat is that barriers map outcomes only to positive actions by actors. This means that changes which result from *not* doing something are not recognized by this model. Thus conservation efforts, or the act of reducing consumption of energy without the expansion of existing inputs, are not considered.

- The second is the focus on only actions as a means to an end. The purpose of the action is not questioned. Ultimately, this leads to an emphasis on technical solutions.
- Thirdly, the barrier framework implies an "ideal level of efficiency." As noted by Jaffe and Stavins (discussed previously), this level must be specified according to some baseline.
- Lastly, Weber explains that the notion of "energy efficiency potential" carries normative assumptions: that less energy consumption is better for society because it reduces waste (in an economic sense).

Weber's key point is that barrier models only record positive actions. When considered in conjunction with the Jaffe and Stavins framework shown in Figure 1, this shows that inputs into a barrier model of energy efficiency must be precisely defined. [32]

Thollander *et al.* (2010) suggested a simplified three-group taxonomy which categorizes barriers by their relationship to the system they affect. The *technical* (or micro level) *regime* includes economic barriers which are not considered traditional market failures, including hidden costs, access to capital, risk, and heterogeneity. The technical regime applies to specific technologies and their associated costs. The second group, the *technological* (or meso level) *regime*, still pertains to specific technologies but also adds in the dimension of human use of such technologies. Members of this group include imperfect information, adverse selection, misaligned incentives, and form of information, which except for the final member, are all economic barriers which are also considered traditional market failures. The third and final group is the *socio-technical* (or macro) *regime*, which places more emphasis on the human-centered barriers, including bounded rationality, inertia, power, and culture. This category matches closely to Weber's behavioral barriers category.

An alternative way of incorporating non-orthodox economic ideas into the analysis of barriers to energy-efficiency is suggested by Sorrell (2004). He criticizes the Jaffe-Stavins framework on the grounds that it ignores contributions from transaction cost economics (TCE) and behavioral economics and thus cannot adequately describe decision-making in the real world. Instead, he suggests that this framework must be modified to include inputs from both of these fields. This approach is shown diagrammatically in Figure 2.

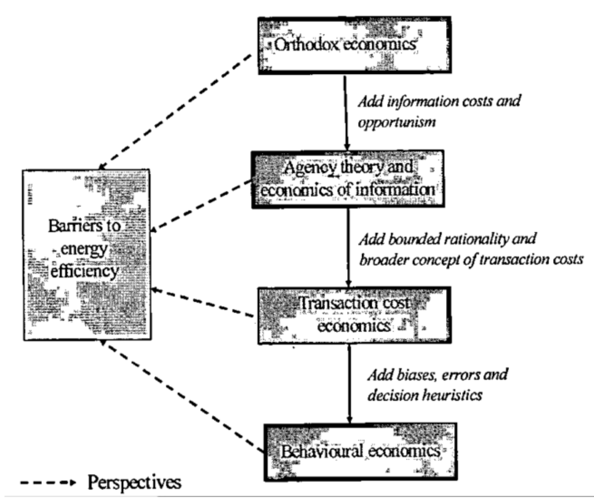


Figure 2. Extending the orthodox model to include inputs from agency/information theory, transaction cost economics, and behavioral economics (from Sorrell, 2004)

According to this modified view, the more traditional notion of market failure falls short for several reasons: 1) It treats market failures as absolute rather than relative, 2) It does not allow for *organizational* failure, and 3) It relies too heavily on orthodox economic assumptions (such as perfect information). This leads to a broad, three-part classification system of barriers:

- *Market failures* (in the traditional sense, which may include externalities or asymmetric information) which may be corrected by government intervention,
- *Organization failures*, or management failures on a firm-specific level, where the barrier may be overcome through task restructuring or proper managerial incentives within the firm, and
- *Non-failures*, in which a firm is reacting to risk and hidden costs in a rational manner (for instance, by setting high internal hurdle rates to deal with uncertainty).

The key contribution TCE toward understanding energy efficiency investments is the concept of bounded rationality (discussed previously). There are two important corollaries to this idea: 1) That contracts are not complete, and 2) Transaction costs are unavoidable. These corollaries encapsulate deficiencies of the orthodox approach. Yet despite advancing our understanding of decision-making in the real world, TCE still falls short by failing to incorporate the true extent of limits in human judgment and cognitive processes. In order to capture these individual shortcomings, Sorrell argues that elements from behavioral economics must be considered.

One popular formulation of behavioral economics is "prospect theory," put forth by Kahneman and Tversky (1979) as an alternative to orthodox economic theory. Instead of relying on an expected utility function, prospect theory attempts to describe human decision-making under risk through the use of a *value function*. The value function differs from the expected utility function in that it replaces probabilities with "decision weights," allowing for losses to be treated separately from gains. The slope of the function is typically steeper for losses. [24] Sorrell cites two important features of the theory that bring to bear on energy efficiency decisions: 1) The *certainty effect*, in which certain outcomes are weighted more heavily than uncertain outcomes, and 2) *Loss aversion*, or the observation that the value function slope is more pronounced for negative outcomes. [5]

Recently, Allcott and Greenstone (2012b) have questioned whether or not the energy efficiency gap exists to the extent that others have claimed (the authors cite two estimates which place the "gap" between 20% and 40% [1], [33]). The paper clarifies that there are in fact two distinct forms of market failure at play, but that often they are inadvertently rolled into one. The first possible market failure takes the form of energy use externalities that keep the price of energy artificially low. The second possible market failure is information asymmetry, in which consumers do not have sufficient information to make educated decisions about investment in energy conservation. If energy use externalities represent the only market barrier, then the proper government response is to apply a tax or a cap-and-trade system to force market actors to internalize those costs. If the only market barrier is information asymmetry, however, then the government's first reaction should be to provide the appropriate information to the market through some sort of information provision mechanism (such as mandatory disclosure). If this does not correct the failure, then more forceful policies (such as subsidies) may be applicable. [14]

Allcott/Greenstone and Sorrell agree that the separation of potential market failures is critical to understanding the energy efficiency gap. Both explain that artificially low energy prices do not completely explain the existence of economic inefficiencies in the building retrofit market. Both groups also argue that any policies targeting the gap must be custom-tailored to specific groups in order to address the heterogeneity that exists among different consumers. Where these authors differ is their estimates of the magnitude of the energy efficiency gap – in contrast to Sorrell's estimates, Allcott and Greenstone argue that the magnitude is actually quite small. Sorrell, on the other hand, does not rule out the possibility that significantly higher levels of economic and energy efficiency are possible.

A final framework which must be mentioned is the theory of "diffusion of innovations" put forth by Rogers (1962). The theory describes how new ideas and technologies (i.e., innovations) are adopted (or not adopted) by members of a society. Rogers' framework comprises five different groups of adopters in any society: Innovators, early adopters, the early majority, the late majority, and the laggards. [34] This framework has been applied to the diffusion of energy efficient technologies in the building industry. Based on the premise that building designers do not make energy efficiency a guiding principle in their projects, some researchers have argued that a fundamental element impeding wider diffusion of many ECMs is a lack of knowledge and experience on the part of the architects and engineers. Because new designs are often based on the precedent of previous designs, this lack of information or understanding may serve to hinder diffusion of a certain technology. [35], [36] This relates closely to specific barriers such as information asymmetry and inertia (both discussed previously).

4. THE IMPORTANCE OF BUILDING RETROFITS

We have so far discussed specific barriers to increased energy efficiency, classification systems to categorize these barriers, and considerations related to how an energy efficiency gap is measured. We now turn to one specific area in which an energy efficiency gap may have important consequences: existing buildings.

The Energy Efficiency Buildings (EEB) HUB, a Department of Energy-sponsored research consortium headquartered at the Navy Yard in Philadelphia, The primary goals of the consortium are to stimulate private investment in energy-efficient measures in new and existing buildings in the Greater Philadelphia region in order to reduce carbon emissions and create a market environment that incentivizes such investment. As part of this effort, researchers were tasked with determining policy, market, and behavioral (PMB) barriers preventing the adoption of energy efficient building system technologies and how these barriers may be surmounted by modifying the existing financial, policy, and regulatory framework.

In a report commissioned by the EEB HUB, eConsult Corporation (2011) noted that "… 47% of the commercial and industrial space in the Philadelphia area is identified as potential candidates for energy retrofits," covering 4,201 buildings with 154 million square feet of space. eConsult estimates this retrofit potential could generate $618 million in local spending and support 23,500 jobs.

Several recent publications have highlighted the importance of stimulating such investment in energy efficiency in the built environment. In a report by McKinsey and Company (2009), researchers estimated that the US could reduce its non-transportation energy consumption by 23% by the year 2020 by investing in energy efficient programs and technologies. [33] An analysis by the American Council for an Energy-Efficiency Economy suggested a 45%-69% reduction in energy consumption across residential and commercial buildings in the US is possible by 2050. [37] The US Energy Information Administration, in its Annual Energy Outlook 2012, projects a possible 83% energy reduction in the commercial sector by 2035 in a best case scenario compared to a reference case. [38]

5. THE MICROECONOMIC RETROFIT DECISION

Moving away from the theoretical underpinnings of energy efficiency and its barriers, we begin a discussion of research that has been performed on actual decision-making processes related to building retrofits. These studies are important because in many cases they substantiate the ideas which have been described above and provide an empirical foundation to further our understanding of the market mechanisms being discussed. Specifically, such examples may illustrate where barriers actually affect the decision process and where there may be room for policies to improve existing market, organizational, and behavioral tendencies.

Parker *et al.* (2000) examined the energy efficiency investment criteria of 26 corporate decision-makers in the Pacific Northwest. The decision-makers were responsible for making decisions about a range of building categories, including healthcare, retail spaces, and office spaces. Results of the interviews suggested that a majority of corporate decision-makers budget in advance for energy efficient investments and that the typical decision process is "bottom up," where the decision is initiated at the lower levels of an organization and consequently makes its way up the internal management hierarchy until it is ultimately approved or rejected by a senior manager. The funds for investment are typically considered to be a capital outlay rather than an operating expense. The rank ordering of criteria applied to energy efficiency investment decisions are:

- the technology's track record
- financial performance estimates
- perceived effects on tenant comfort and satisfaction
- defined investment priorities

The authors found that the technical and financial assessments of an investment, two critical components of the decision-making process, tend to occur at a very early stage. If the investment opportunity passes muster in both of these dimensions, the final approval from the senior manager may be relatively quick. However, this does not mean that the process is simple or straightforward. Instead, the process involves a number of steps, typically in this order:

- tracking of problems and needs
- investigation and technical assessment of equipment options
- financial analysis
- selection of a preferred option
- approval
- procurement

The most common financial criterion used by respondents was simple payback period, with a fairly short acceptable payback period of 2 years. The next most common measure used was rate of return (ROR), with an average minimum acceptable value of 12%, although these ranged from 8% up to 12%. Net present value was only reported to be used by 3 of the 26 firms interviewed. Overall, there was a wide range of investment priorities among respondents. Energy efficiency was cited by some firms as a high priority, though most rated it somewhere in the middle or bottom end. [39] These results provide additional evidence for the existence of several barriers previously mentioned, particularly those based on transaction cost economics and behavioral economics.

In the Deloitte survey of organizations that had undergone at least one LEED-certified building retrofit, it was found that "greater indoor environmental air quality" and "corporate environmental commitment" ranked as the two highest motivations for pursuing such a green retrofit. "Operational cost savings from energy efficiency" was tied for third along with “value of public relations and free publicity” and “attraction and retention of corporate workforce.” The authors found it surprising that cost considerations did not rank higher in this list. When asked to rank the top impacts of undergoing an EER, the greatest increases were reported as “goodwill/brand equity” and “employee comfort.” [40] These findings are generally different from most other studies, which have found environmental principles to reside near the bottom of the priority list. This difference is likely explained by the fact that inclusion required the organization to have undergone a LEED-certified retrofit, biasing the sample in a certain direction.

Jones (2009) used semi-structured interviews of 12 decision-makers and a meta-analysis of existing literature to review energy conservation decisions by different organizations. By using a case study approach, Jones was able to generate an optimal decision process for evaluating and implementing energy conservation measure in buildings. He cited a general “lack of understanding at all levels” as an important barrier to increased adoption of energy efficiency technologies. [41] This generalization seems to include pieces of many different theoretical barriers previously discussed, including imperfect information and bounded rationality.

Similarly, Levitsky *et al.* (2011) found that that the common barriers to investment include a lack of understanding on the part of decision-makers, a scarcity of financial modeling tools, and the need for increased transparency of building energy consumption data. These data came from a review of secondary research on various value delivery systems and delivery models for energy efficient retrofits. [42] In general, these findings match closely to the findings of Parker (2000) and Jones (2009) while giving some additional details on the specifics of contractual relations and possible misaligned incentives.

Other efforts have suggested that a general lack of education and awareness are important detractors from the retrofit decision process. Sachs *et al.* (2006) found that building owners may be ill-informed about the different options they have to make their buildings more efficient [43]. Danfoss (2010) conducted surveys with owners, architects, engineers, mechanical contractors, and OEM manufacturers, and obtained results which acknowledged the persistent importance of first cost considerations as a barrier to wider implementation of many ECMs. One way to surmount this barrier is not to create "more and better products," but to educate and train the people that use existing products. A related problem is the concern of building operators regarding the complexity of new technologies. One respondent was cited as saying:

> **"The drawbacks are that the end users have a large learning curve on maintaining these facilities. There are a lot of practices that been in place for the last 50 years that the building engineers know backwards and forwards and there are a lot of things that could be taken for granted that could affect health. The costs can be debated, but the concern I have is for the end user to properly maintain these things so that you get the long-term efficiency that you are promised upfront."**

In general, these studies affirm the existence of several previously-mentioned barriers, including lack of information, the presence of uncertainty, bounded rationality, and inertia. [44]

Decision support tools have been developed to help guide decisions on energy management, though statistics on the use of these tools is scarce [45–48]. In a Master's thesis, Estes (2011) reported that use of payback period as a criterion is frequently used by organizations when considering investment in ECMs, and developed a spreadsheet to help users calculate more sophisticated financial metrics. [49] Sayce and Ellison (2007) proposed a set of criteria which, when taken together, form the basis of a property-specific sustainability index. These criteria include energy efficiency, climate control, pollutants, waste and water, adaptability, accessibility, occupier, and contextual fit. [50] Hendricken *et al.* (2012) modeled the performance of packages of ECMs for commercial retrofits and determined the least cost alternatives for a given energy consumption reduction level. [51]

Several recent papers have proffered multi-criteria and multi-objective optimization models related to energy decisions and building retrofits. Greening and Bernow (2004) presented an overview of multi-criteria decision-making models of energy and environmental policies. [52] Diakaki *et al.* (2008) applied multi-objective optimization techniques to the problem of choosing the most appropriate ECMs for a building retrofit and found that while the technique may work in a simplified hypothetical situation, the technique was inadequate when applied to a real world situation due to “competitiveness between constraints.” [53] Asadi *et* al. (2012) applied a multi-objective optimization model to a residential building, showing that although complicated, the approach is a viable way to help stakeholders assess the tradeoffs of alternative ECMs. [54] Kumbaroglu and Madlener (2012) evaluated both the technical and economic merits of retrofit alternatives for an office building in Germany. They found that not only does the price of energy have a significant effect on the value of a retrofit investment, but that widely-fluctuating energy prices often make it worthwhile to simply wait to invest. [55] It seems, however, that the commercial importance of these relatively sophisticated tools and approaches is minor.

CHAPTER II : SURVEYING THE MAJOR FACTORS AFFECTING THE COMMERCIAL BUILDING RETROFIT DECISION

1. INTRODUCTION

1.1 The importance of commercial building retrofits

Primary energy consumption in the United States has roughly tripled in the last 50 years, from approximately 30 quadrillion BTU in 1949 to approximately 98 quadrillion BTU in 2010 [56], and the U.S. Energy Information Administration (EIA) projects that energy consumption will continue to grow at 0.3% annually between 2010 and 2035 [38]. In the United States, the buildings sector accounted for about 41% of primary energy consumption in 2010, 44% more than the transportation sector and 36% more than the industrial sector [57]. Within the building sector, commercial buildings alone represent just under 20% of U.S. primary energy consumption, and thus have become prime candidates for policies targeted at reducing energy use. Newer buildings tend to be more energy-efficient than older buildings. But in urban areas where a large number of older buildings are still in use, such improvements in new construction may not combat high energy use by existing structures. Within the greater Philadelphia area, it is estimated that 77% of the existing building stock was built prior to 1990 and that 47% of the existing commercial and industrial building stock is eligible for an energy-efficient retrofit [58]. Such statistics highlight the importance of building retrofits in reducing energy consumption and lead to the question of how to encourage investment in this area.

1.2 The "energy-efficiency gap"

The term "energy efficiency gap" originated in engineering analyses indicating that there may exist a set of net present value (NPV) positive energy conservation investments in the market which for some reason have gone unrealized. A steady stream of papers over the past thirty years have addressed (and questioned) the existence, magnitude, and persistence of such a gap [2], [7], [10], [29–31], [59], [60]. Any discussion of a "gap" – and also of potential solutions to correct it – is made complex by virtue of the economic assumptions made regarding markets and market actors' behavior in such a situation. The politicization of climate change has further complicated matters. Regardless of how a "gap" is defined, it seems useful to identify corrective actions that will encourage not only energy efficiency, but also encourage economic efficiency. A number of potential barriers to increased investment in energy efficiency have been identified, and several taxonomies for classifying these barriers have been proposed [15], [31], [32], [59], [61]. Information asymmetry, uncertainty, and "split incentives" emerge as the more common examples of such barriers.

1.3 The Energy Efficient Buildings HUB

The Energy Efficient Buildings Hub (EEB Hub, formerly known as the Greater Philadelphia Innovation Cluster, or GPIC) was established in Philadelphia by the U.S. Department of Energy (DOE) as an Energy-Regional Innovation Cluster in 2011. EEB Hub was tasked with the following mission:

1. Develop and deploy to the building industry a state-of-the-art modeling platform to integrate design, construction, commissioning, and operation;
2. Demonstrate the market viability of integrating energy saving technologies for whole building solutions at the Philadelphia Navy Yard and elsewhere in the region;
3. Identify policies that accelerate market adoption of energy efficient retrofits of commercial buildings and support policy makers in the development of such policies in the Greater Philadelphia region;
4. Inform, train, and educate people who design, own, construct, maintain, or occupy buildings about proven energy saving strategies and technologies;
5. Help launch ventures with new and existing companies that will exploit market opportunities for providing whole building energy saving solutions.

To accomplish these goals, the Hub's research efforts were divided into the following major subject areas: Design Tools, Integrated Technologies and Systems, Policy, Markets and Behavior, Education and Workforce, and Demonstration and Deployment. As part of the Policy, Markets and Behavior (PMB) team, Drexel University was tasked with bridging the space between technologies and the markets which use them.

1.4 The microeconomics of the retrofit decision process

In accordance with EEB's goal to encourage greater investment in energy efficient technologies, it is necessary to first look at how market actors choose to adopt (or not adopt) such technologies. It is difficult to broadly characterize all such decision processes since there is significant heterogeneity in the specifics of each decision, however, it should be possible to make some observations that are generally applicable to a wide range of these decisions. Such observations may illustrate where barriers actually affect the decision process and where there may be room for policies to improve existing market, organizational, and behavioral tendencies.

Several analyses have cited a "lack of understanding" or "lack of information" as important barriers to increased adoption of energy efficiency technologies [43], [44]. This generalization seems to include pieces of many different theoretical barriers previously discussed, including imperfect information and bounded rationality. Other studies have reported that decision-makers commonly use "rule of thumb" metrics such as simple payback period to evaluate retrofit investment options even though this metric does not provide accurate information on the worth of the investment [39], [42], [49]. In one study, net present value (a more appropriate metric to use) was only reported by 3 of the 26 firms interviewed [39]. The predominance of simple payback period as a "metric" is examined in this study.

1.5 "Split incentives"

The term "split incentives" is commonly used to refer to principal-agent problems in the rental market and is commonly mentioned as a barrier to increased energy efficiency in the building sector [8], [10], [33], [60], [62]. A typical situation involves a building owner who chooses to not invest in a rental property because it is the tenant who would realize the energy cost savings (with the assumption that this would not lead to a higher rent for the owner). By the same token, the tenant will not invest in the building because they do not own it. In terms of energy efficiency, the end result is an investment stalemate. While the phenomenon of split incentives is commonly cited as a barrier to greater energy efficiency, few efforts have been made to characterize its precise nature and quantify the size of its effect.

1.6 Research basis and goals

The basis and directives of this survey research were provided by several other research efforts being done as part of the EEB Hub effort. The most important of these is the Advanced Energy Retrofit market model (AER model) designed by researchers at United Technologies Research Corporation. This model is designed to predict energy consumption (and energy savings) for a given region and building stock at five-year increments into the future. The model contains a library of 26 individual ECMs (shown in Table 1) bundled into 103 unique combinations, or "packages," which can then be selected as retrofit options (Appendix 1 shows the different combinations of specific calculating changes in energy consumption by the building stock over time). **Error! Reference source not found.** shows a schematic representation of the AER model and its inputs, including a set of decision parameters used to decide which ECM packages would be selected by a "virtual decision-maker" (i.e., a building owner or property manager). As discussed in the methods section, the semi-structured and structured survey instruments were designed so that the results could help tune these decision parameters.

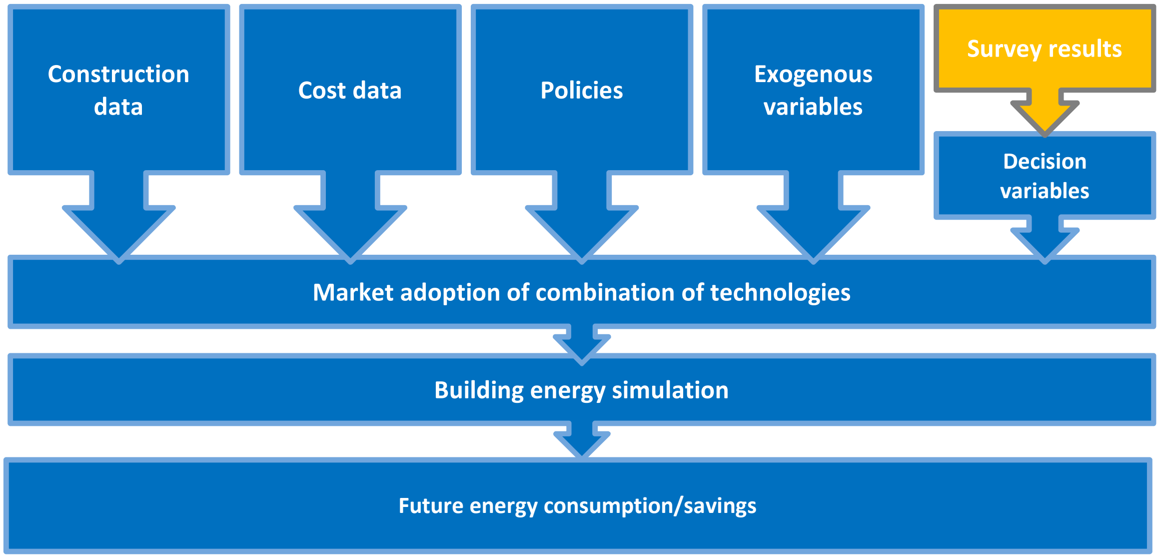


Figure 3. Schematic of AER market model and role of the survey results

Table 1. Individual ECMs considered in energy modeling/surveying (see questions 10A-10D in Appendix 3 for detailed descriptions of each ECM and associated assumptions)

T-5 lighting upgrade from T-8 lighting
LED (light emitting diode) lighting upgrade
High efficiency elevator upgrade
Double pane window upgrade
White roof upgrade
Insulated roof upgrade from R-15 to R-30
Green roof upgrade
Insulated walls upgrade from R-6 to R-11
High-efficiency cooling upgrade
High-efficiency heating upgrade
Variable-air-volume (VAV) system upgrade
Radiant Heating/Cooling and Dedicated Outdoor Air System
Switching to a heat pump
Switching to a ground-source heat pump
Central boiler upgrade from 70% to 95%
Photovoltaic (solar) installation
Smart grid controls / metering
Central chiller plant upgrade
Temperature Reset Strategy
Daylighting
Combined heat and power (CHP) system
Plug load control (more efficient equipment, better management of equipment, etc.)
Weatherization (reduce air exchange through sealing cracks, etc.)
Occupancy sensors
Shading (screens or overhangs to reduce solar gain during summer)
Commissioning

2. METHODS

In an effort to better characterize the microeconomic decision process used for evaluating energy efficient buildings retrofits, and specifically to provide a closer examination of the effect of "split incentives" on this process, we relied on three sources of data:

- The 2011 Energy Efficiency Indicator (EEI) survey conducted by the Johnson Controls Institute for Building Efficiency,
- A series of semi-structured, extensive one-on-one interviews with decision-makers, and
- A structured online survey designed to further explore the findings from the semi-structured interviews.

The results from each of these three data sources are examined and then cross-referenced with each other in order to provide a more holistic picture of the decision factors affecting EER investment. Details of each source are described below.

2.1 The 2011 Energy Efficiency Indicator (EEI) survey

The 2011 EEI survey was the fifth annual survey conducted online by the Johnson Controls Institute for Building Efficiency in partnership with the International Facility Management Association (IFMA) and the Urban Land Institute (ULI). The survey was international in scope, covering 13 different countries, and asked business executives about "their management practices, investment plans, technology integration and financing approaches" pertaining to energy-efficiency and real estate decisions [63]. For the purposes of this analysis, the data was filtered to include only those responses from the United States in which answers were given in terms of US dollars.

2.2 *Semi-structured interviews*

To better characterize the key factors that contribute to decisions regarding the energy retrofit of commercial office space, researchers from Drexel University conducted two stages of stakeholder surveying: in the first stage, a series of semi-structured interviews allowed for open-ended responses from the subjects to uncover factors that might be overlooked by a more rigid interview format. In the second stage, a structured, stated preference survey was conducted to better characterize the findings from the semi-structured interviews (described in the next section). The semi-structured interviews examined the key factors that influence decisions regarding the use of energy-saving measures, their relative weight in the decision-making process, and how these factors may or may not differ across stakeholder groups (i.e., building owners vs. architects).

The interview was administered to 16 stakeholders from 15 different organizations over the course of approximately six weeks. Each of the organizations was located either within the Philadelphia metropolitan region or the surrounding suburban areas. The breakdown of respondents by primary role was 36% owner/developer, 43% architect/engineer/consultant, and 21% property/facility managers. Interview subjects were recruited through email and by word of mouth. Respondents included building owners and managers, architects, engineers, developers, and consultants. The interviews were administered in person or by phone and lasted between 30 minutes and 1.5 hours per respondent. The interview consisted of two primary sections:

- **Background Information**: Includes questions about the individual's role in the building design/development/retrofit process, what type of buildings they typically work with, and the area in which their buildings are located.
- **Retrofit Decision Factors:** Includes questions about specific triggers for building retrofits, the barriers that must be considered, what types of efficiency measures are targeted, and what metrics or models are used to assist in making the decisions. When possible, specific target values were elicited for the various metrics. Questions covered the many general areas regarding building retrofit decisions. For this analysis we chose to focus on a small selection of those areas:
    - ➢ Factors affecting the choice of a new or non-standard technology in the retrofit process.
    - ➢ How the performance of new technologies is estimated prior to installation.
    - ➢ Metrics used in making decisions about retrofits (both financial and non-financial).
    - ➢ Acceptable or target values for these metrics.

Following subject approval, responses to these questions were recorded with a digital audio device. In cases where subjects preferred not to have their responses recorded, notes were taken and interviews were scored during or immediately following the conversation. The full survey instrument is shown in Appendix 2. Responses to each question were scored and tabulated into a single database for analysis.

2.3 Structured stated-preference surveys

Lastly, a structured stated-preference survey was conducted to more precisely quantify the decision factors identified during the semi-structured interviews. This survey was administered to 206 stakeholders from a wide range of different organizations over the course of approximately two months. A convenience sample of survey respondents was recruited through email, word of mouth, and through a paper mailing to a mailing list of attendees from a local facilities management tradeshow. Respondents included building owners, facilities managers, architects, engineers, developers, vendors, maintenance personnel and consultants. While respondents were allowed to answer the questions based on any experience within the United States, the majority of respondents were from the Mid-Atlantic region.

Survey design and development was a lengthy and intensive process, requiring approximately four months to complete the final product. As discussed in subheading 1.6 above, the design basis for the survey was informed by three main sources:

- ***The AER market model***. A primary set of goals for the structured survey was to generate data that could later be used to fine-tune parameters in the market model. These include acceptable values for payback periods, perceptions of individual ECMs, as well as the *relative* weights of financial and non-financial factors (addressed by the conjoint question). The specifics of the AER market model internals is proprietary information and is thus not discussed here in detail, however, it may be understood that each question in the structured survey was designed in a way to produce data that can be “plugged in” to the market model.

- ***Energy modeling.*** The modeling work of Hendricken et al. (2012) was used as a basis for many of the questions related to the hypothetical building retrofit. The Hendricken effort, in turn, was partially informed by data in the AER market model. Thus there was a three-way interdependency between the survey instrument, the energy modeling, and the market model.

- ***The semi-structured interviews.*** The semi-structured interviews were designed to elicit factors that might not otherwise be considered in a more formal survey. One benefit of having done the semi-structured interviews first was the recognition that building owners willing to take a survey are difficult to find. Thus the structured survey was designed so that the respondent pool could include not just building owners, but also the architects, engineers, consultants, property managers and other who advise them in their decisions.

The survey was administered either as an online format, using the proprietary web platform Qualtrics, or in a paper and pencil format. The survey was designed to take approximately 20 minutes to complete. Recruitment of subjects relied on multiple approaches, including word of mouth, a dedicated table at the GreenBuild 2012 conference in San Francisco, email lists through EEB Hub, and a paper mailing to roughly 600 attendees from a local facilities management trade show in November 2012. While the precise breakdown of subjects from each source was not tracked, it is estimated that a majority of subjects were recruited from the paper mailing (~100 subjects), followed by the Greenbuild conference (~40-50 subjects).

The instrument (shown in Appendix 3) consisted of the following primary sections:

- ***Background Information***: This section included questions about the individual's role in the building design/development/retrofit process, what type of buildings they typically work with, years of experience related to EERs, and the portion of working time devoted to EERs.
- ***Retrofit Package Selection for a Hypothetical Office Building***: This section presented respondents with a hypothetical three-story office building and asked them to make certain assumptions about its location, tenancy type (owner-occupied vs. leased to tenants), responsibility for paying the utility bills, and the type of organization that owns the building (e.g., private sector vs. non-profit institution). Building owners were requested to answer these questions from their own (or their organization's) point of view. Other respondents (non-owners) were asked to answer the questions from the point of view of a building owner they had previously worked with. Specific questions in this section included those on:

- Perceived attractiveness of individual retrofit technologies for the hypothetical building, such as double-pane windows or white roof upgrades.
- The length of simple payback period for a retrofit package most likely to be considered for adoption.
- The effect that an additional metric (incremental internal rate of return) has on this decision.

As previously discussed, the specifics of a number of questions for this survey were based on building energy simulation work done by Hendricken et al. (2012), which was also done in conjunction with the EEB work on the AER market model. Figure 4 shows data from the Hendricken et al. effort in which modeled values for energy use intensity by each of the 103 retrofit packages are plotted against their respective first cost values and an efficient frontier is generated. Those packages lying on the Pareto frontier are denoted in red.

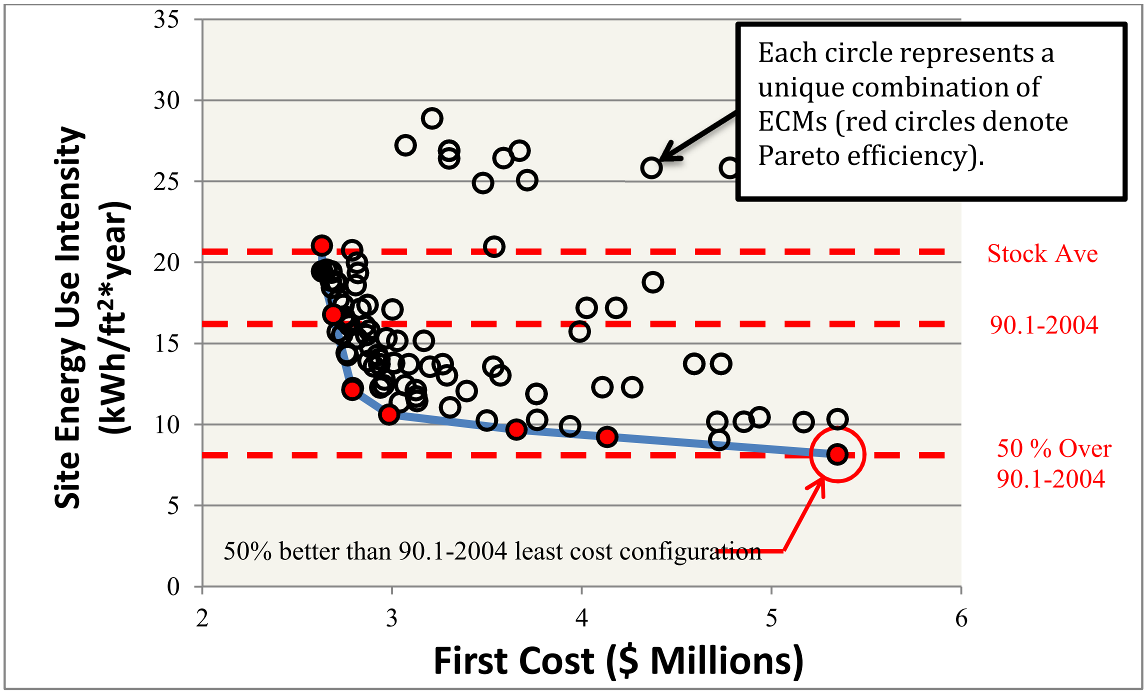


Figure 4. Pareto frontier for ECM packages (from Hendricken et al., 2012)

It now became a task for the survey to determine which of these packages would most likely be selected by real market actors. Thus the characteristics of those packages lying on the Pareto curve were used to create the retrofit packages shown to respondents as part of the hypothetical building retrofit scenario (shown in Table 2). In other words, a primary goal was to determine at which point along the Pareto curve would the market place itself. In an effort to isolate the financial components of the retrofit decision, the decision was made to present each retrofit package as a generic option – meaning only the relevant financial information was presented for each option. The component technologies were not specified as this would likely bring other subjective factors to bear on the selection process (e.g., building-specific considerations that may alter the effect of the financial metrics).

Data from pencil and paper surveys were entered into the online form and combined with the data previously obtained from the online format. Statistical tests and graphs were done in SPSS and Microsoft Excel 2010.

3. RESULTS

3.1 Analysis of the Energy Efficiency Indicator survey data

After filtering the data to look only at commercial office buildings within the United States, some important differences in acceptable payback period emerged between different types of organization ownership. Figure 5 shows a graph of longest acceptable payback period for investment in energy efficiency as a function of organization ownership, revealing a spectrum of acceptable payback periods between private-sector, publicly-traded organizations on one end and government-owned organizations on the other end. A chi-square test of independence revealed the differences to be statistically significant, χ^2 (24, N = 1453) = 267.70, p = .000). To test the hypothesis that differences in allowable payback period between types of ownership is a function of how frequently energy usage data is reviewed within an organization, a second chi-square test of independence was performed on frequency of energy usage data review and organization ownership. Results were significant, χ^2 (32, N = 1472) = 56.51, p = .005). Figure 6 shows a comparison of how frequently members of an organization review energy usage data by organization ownership. It is interesting to note that while these data generally follow the same trend as longest allowable payback period, a key difference is that government-owned organizations reported a frequency of energy usage data review that was very similar to the value reported by private-sector, privately-held organizations.

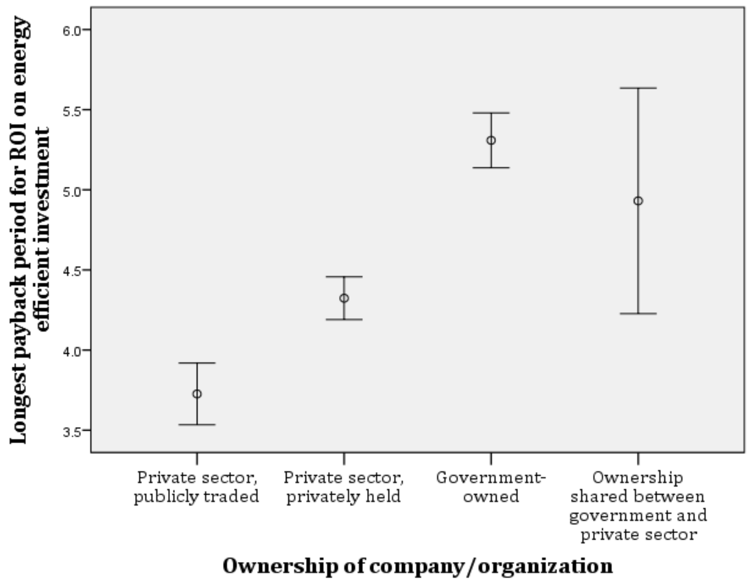


Figure 5. Longest allowable payback period by organization ownership (EEI data) (N=1452)

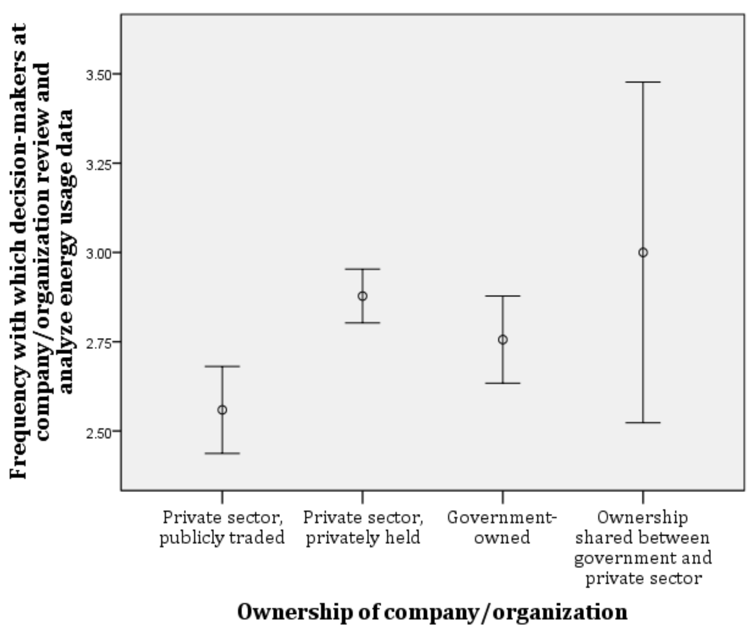


Figure 6. Frequency of review of energy usage data by organization ownership (EEI data) (N=1452)

Together, these results suggest that the ownership of an organization has an important effect on the longest allowable payback period for investments in energy efficiency, and that these values are not simply due to a lack of review of energy consumption data by the organization. The finding that government-owned organizations are willing to accept longer payback periods for investment in energy efficiency despite their relatively frequent analysis of energy usage data, along with the finding that private-sector, publicly-traded organizations review their energy consumption data comparatively frequently and yet still have shorter allowable payback periods, suggest that review of energy consumption data is not enough to increase investment in energy efficiency and that these organizations may have inherently different planning horizons.

3.2 Results of the semi-structured interviews

3.2.1 Metrics Used to Make Decisions Regarding Building Retrofit Investments

Simple payback was cited by interview participants as the dominant metric by which retrofit investments are considered (Figure 7). In addition to simple payback, several respondents reported using more sophisticated financial metrics such as net present value (NPV), internal rate of return (IRR), savings-to-investment ratio (SIR, mentioned by one respondent), or a combination of these metrics. Additionally, approximately 12% of respondents factored tax rebates and government incentives into their metric calculations; however, this category was most commonly given less weight than other categories. Non-financial performance ratings such as LEED or EnergyStar ratings were cited by approximately 21% of respondents as playing a role in decisions regarding retrofits, though in most cases this appears to be a secondary consideration after an acceptable payback period has been achieved. The finding that more advanced financial metrics were cited much less frequently than simple payback period supports the notion that any retrofit investment must first pass a "simple payback period" test before it is given additional consideration. Coupled with the results from the EEI data, these results affirm the importance for an investment to adhere to restrictions on payback period.

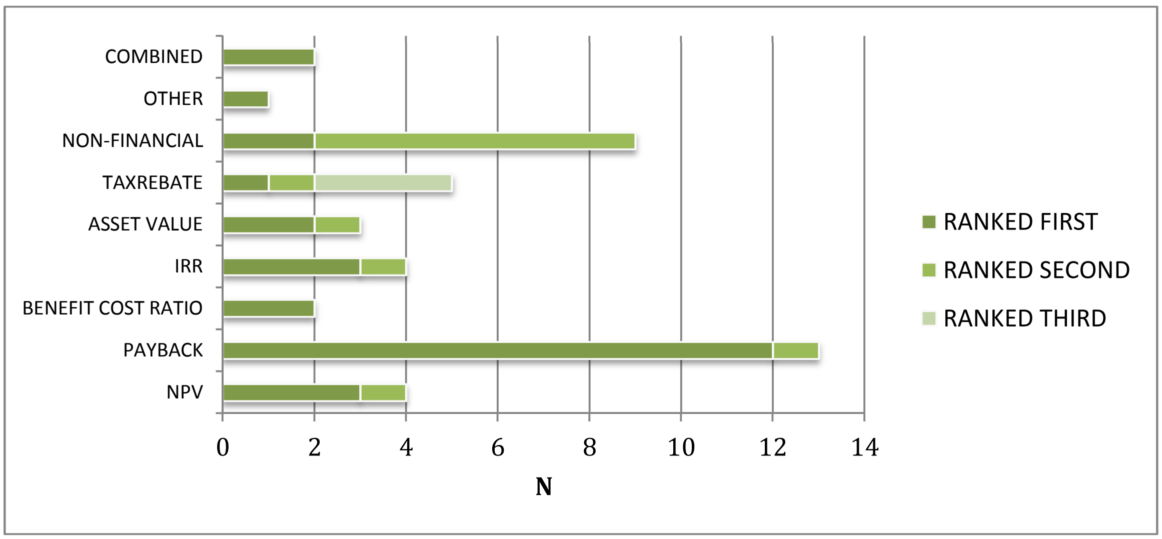


Figure 7. Top three metrics used to make decisions about retrofit investments (N=16)

3.2.2 *Value of Metrics*

For simple payback, the average payback period acceptable to respondents was 5.4 years with a standard deviation of 4.86 years (one value was reported at 20 years). Assuming a lifespan of 10 years, this would correspond to an annual rate of return of approximately 15%. The mean of 5.4 years is slightly higher than the mean payback period for all organizations from the EEI data (the mean range chosen was between 3 and 4 years) but is of a similar magnitude. Because of the small sample size, differences in acceptable payback period were not broken down between different organization types in the semi-structured interview data, as was done with EEI data.

3.2.3 *Factors Affecting Decision to Adopt New or Nonstandard Technologies*

"Payback/Energy service company (ESCO) guarantee," along with "An example of local success" were cited by respondents as the most important factors affecting the decision to adopt a new or non-standard technology for a building retrofit (Figure 8). However, several respondents noted that they either did not understand or did not fully trust performance contract guarantees offered by energy ESCOs. Building simulation modeling was ranked by only 8% of respondents as being one of the top three tools affecting retrofit decisions. This may suggest that the complexity of some models allows only those with expert knowledge to capitalize on the projections afforded by these tools, or that the modeling results are used as a "point of departure" but are not in themselves sufficient to sway a major retrofit decision. Coupled with the results of the previous question, these data suggest that while computer modeling is an important initial step in the retrofit decision-making process, stakeholders place more weight on actually seeing the technology in operation and that such operation must be convincing from a cost-benefit perspective.

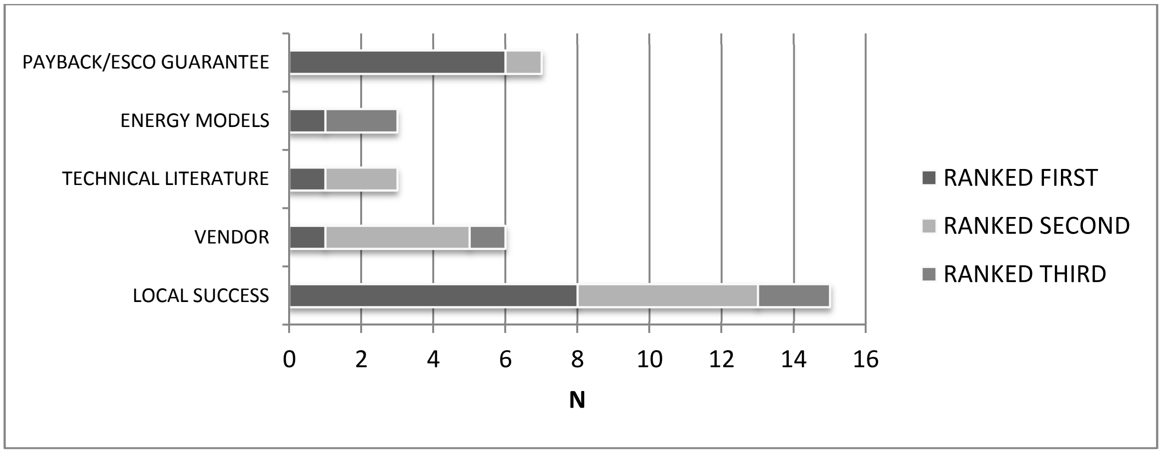


Figure 8. Factors affecting the decision to adopt new or non-standard technologies. (N=16)

3.3 Results of the structured surveys

The results of the structured surveys provided more in-depth information on many of the decision factors identified in the semi-structured interviews. In particular, they afforded a chance to further explore the importance of simple payback period as an evaluation metric and to test if it is possible to alter this behavior.

3.3.1 Characteristics of the respondent pool

From experience with the semi-structured interviews, it was believed that finding enough building owners to constitute a sufficient survey sample would be difficult. Thus a strategic decision was made to expand the eligibility pool to include professionals that regularly work with building owners and can answer questions from these owners' points of view. This group of advisors was asked to answer the questions from the point of view of the last commercial building owner they had worked with. Respondents who said they were unable to answer from a building owner's perspective were instantly disqualified. Figure 9 shows how respondents chose to answer the survey questions. Figure 10 shows the breakdown of respondents by job function.

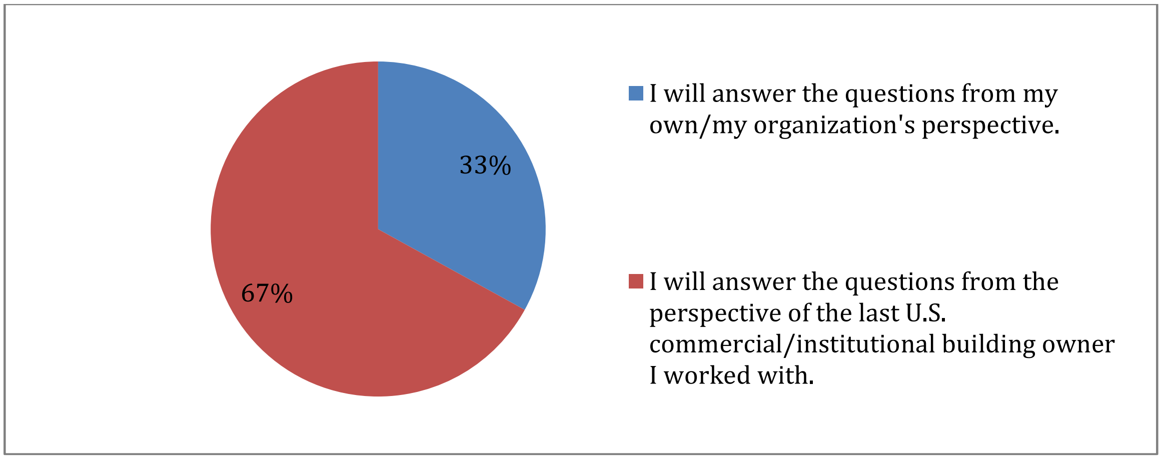


Figure 9. Perspective of survey respondents.

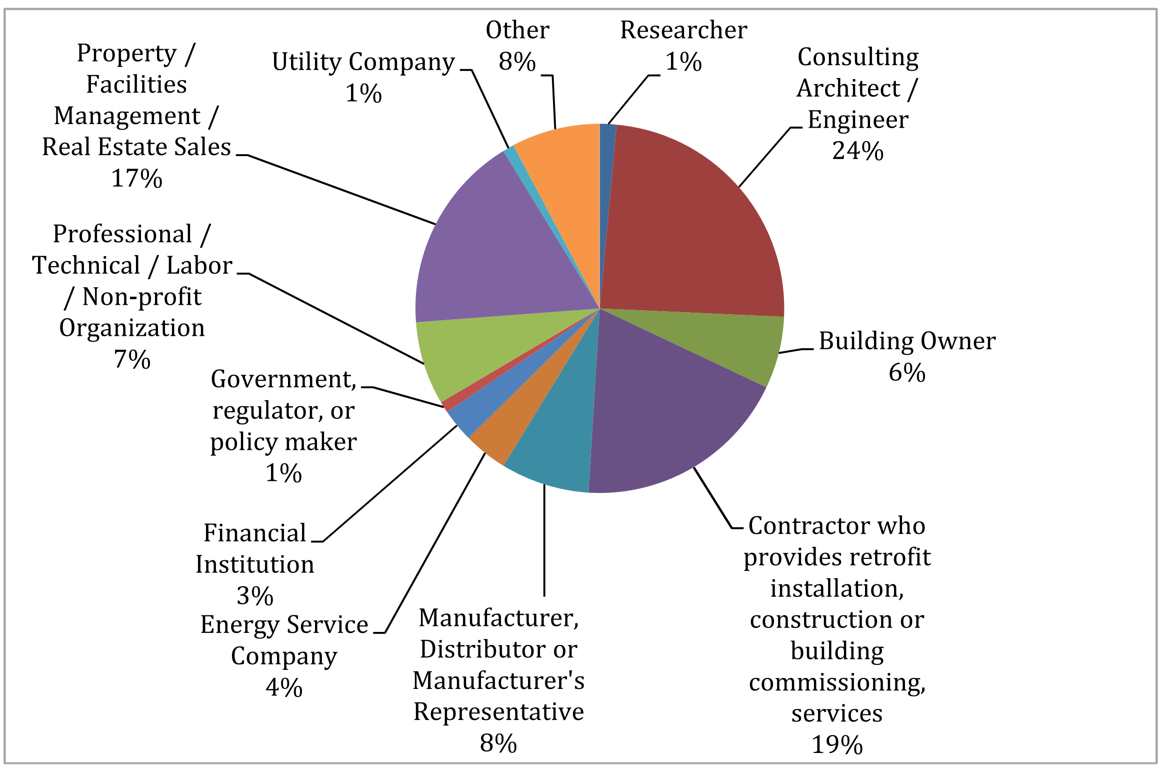


Figure 10. Breakdown of respondents' job function.

Respondents were also asked about which party (owner vs. tenant) was responsible for paying the utility bills in their hypothetical building. Figure 11 shows how respondents chose to answer this question. Approximately half of the scenarios involved building space occupied by the owner and half of the scenarios involved building space leased to a tenant. In roughly one quarter of the scenarios (half of the leased cases) the building owner paid utility bills for a tenant using the space.

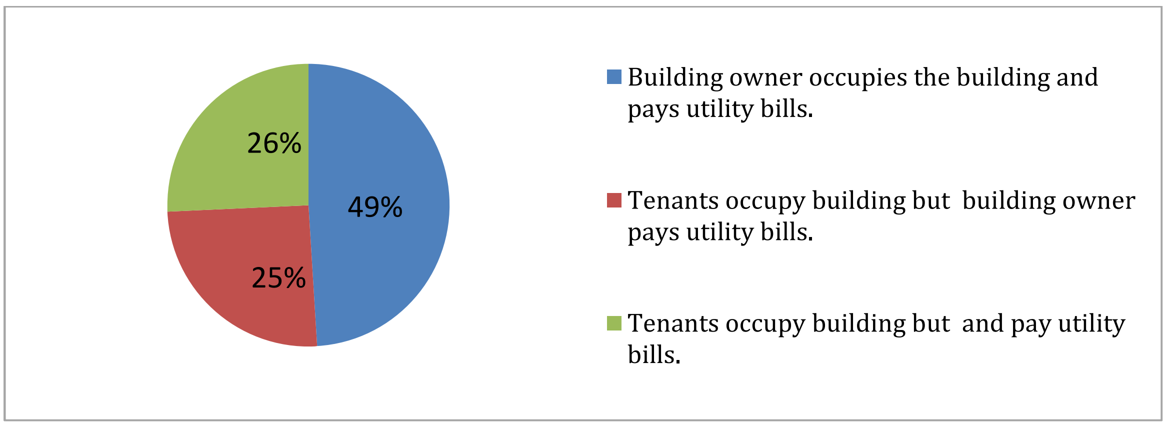


Figure 11. Respondents' assumptions for utility bill-paying responsibilities.

Given that the geographic location of a building may be important when making decisions about a retrofit, respondents were asked to report the state where their building existed. Figure 12 shows how respondents chose to locate their buildings.

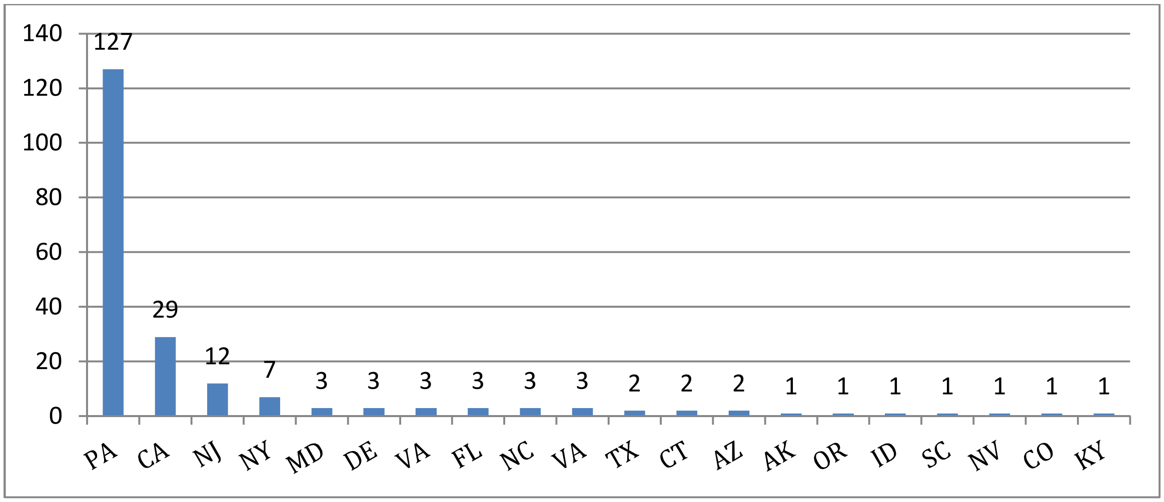


Figure 12. States where respondents chose to locate their buildings.

Lastly, respondents were asked to characterize the type of organization that owns the building. This breakdown is shown in Figure 13.

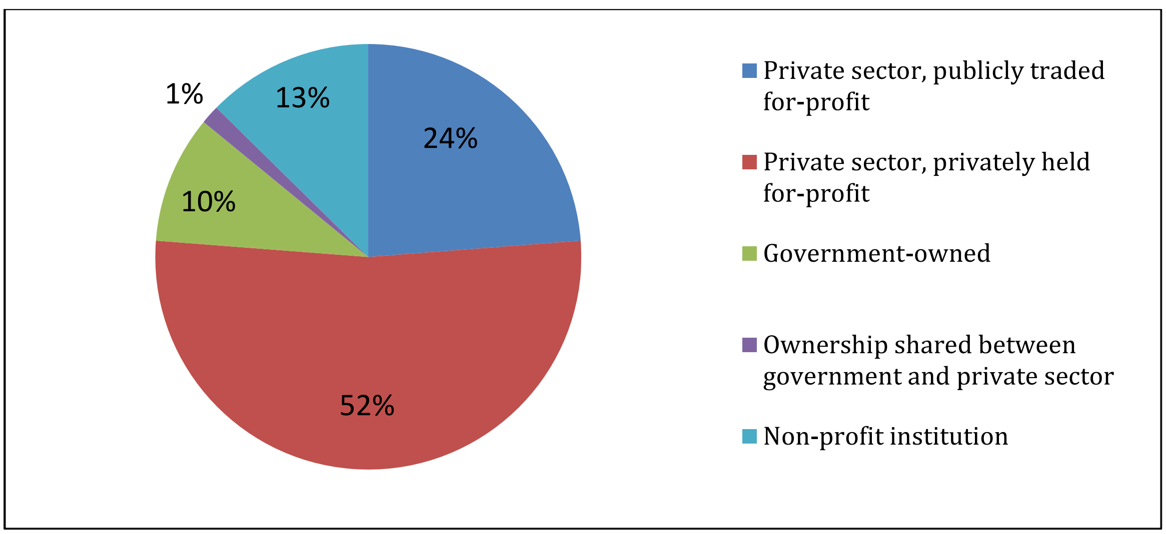


Figure 13. Building owner organization classification.

3.3.2 Respondents' perceptions of specific retrofit technologies

Respondents were asked to rate the attractiveness of 26 individual ECMs for their hypothetical building. As discussed previously, the list of ECMs was designed to represent a majority of retrofit technologies currently available on the market, and match with energy modeling done by Hendricken *et al*. (2012). Each ECM was rated on a Likert scale from 1 to 5, with 1 representing "very unattractive" and 5 representing "very attractive." Respondents were also given the ability to answer "no experience" for each ECM. Such responses did not affect the final results. The scores for each ECM were averaged. These results are shown in Figure 14. Generally speaking, respondents expressed positive views of less capital-intensive ECMs such as temperature reset strategies, weatherization, and occupancy sensors. ECMs requiring longer payback periods, such as green roof upgrades, switching to a heat pump system, and radiant heating/cooling, were ranked near the bottom of the list.

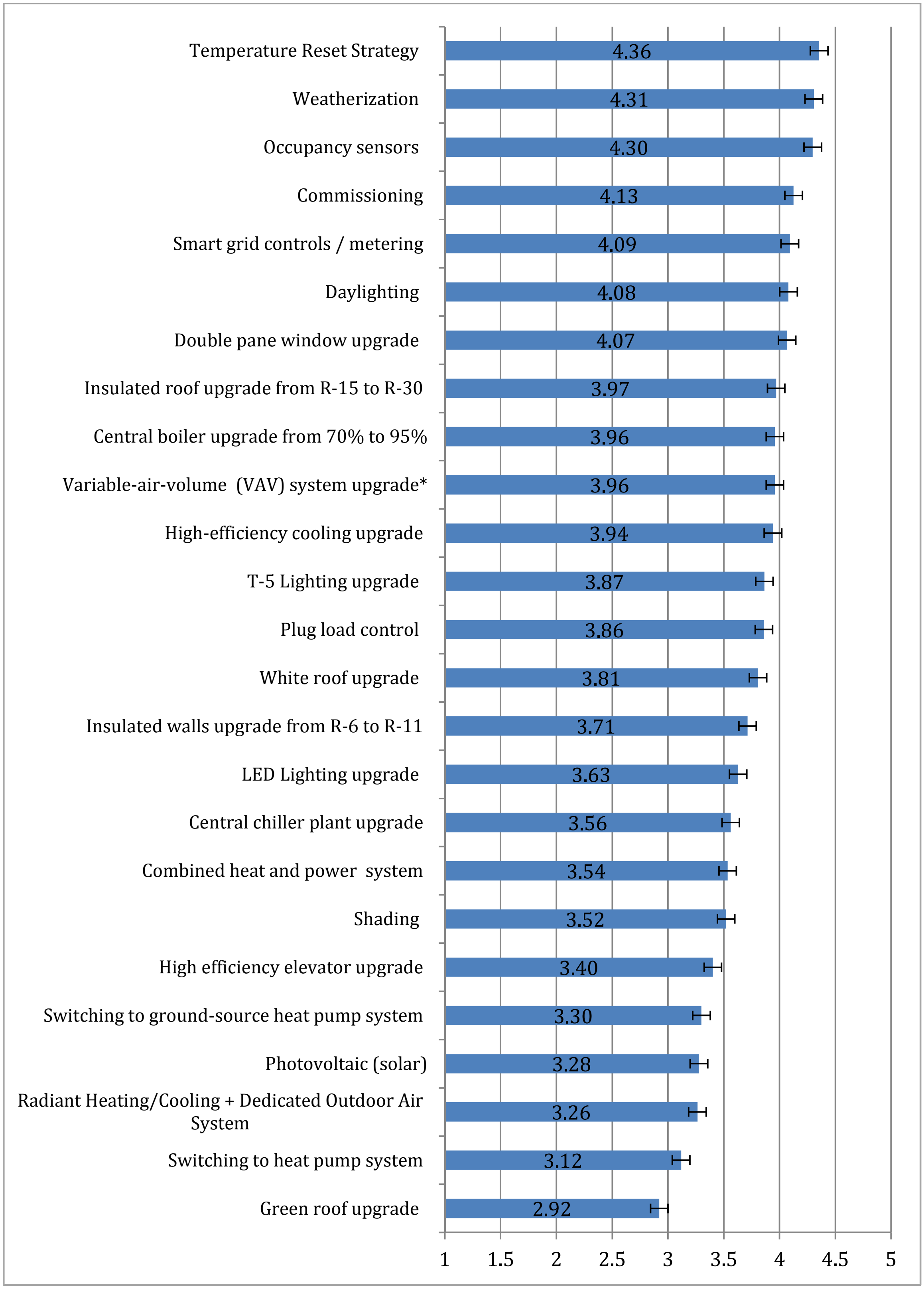


Figure 14. Respondents' mean perceptions of specific technologies (5=very attractive, 1=very unattractive)

3.3.3 Use of simple payback period as a financial metric

Simple payback period is defined as the amount of time required to recoup the costs of an investment [64]. The calculation is easy to perform and easy to understand, however, there are three problems with using SPP as an investment metric: (1) it does not consider the time value of money, (2) it does not account for savings which occur after the initial expenses have been recouped, and (3) it does not take into account marginal returns on competing investment options. On the other hand, incremental rate of return may serve as a "comparison" metric when competing investments are being considered, and is able to distinguish between investments that SPP could not. For instance, consider two competing investment options, Option A and Option B, which have equal first costs but Option A has a SPP of 1 year and Option B has a SPP of 2 years. In the case the incremental rate of return for the investment with the longer payback period is negative and there is no benefit to pursuing this option. In this situation, the two metrics (SPP and incremental IRR) would agree on Option A. But consider the case where Option A has a first cost and cost savings that are both significantly lower than for Option B. Here, the incremental rate of return for Option B would be both positive and significant, indicating that investment in Option B is desirable. Hence the incremental rate of return takes into account the benefits offered by alternative investment options with shorter SPPs, as well as the amount of additional capital required for the investment with a longer SPP. The incremental rate of return can be thought of as the rate of return on all monies spent above and beyond the next cheapest option.

Again, the investment options presented in the survey were based on the work of Hendricken *et al*. (2012), in which different retrofit packages of specific ECMs were developed and their associated costs estimated. There is some degree of uncertainty in projections of energy savings (and their associated rates of return); thus, the values for SPP and incremental rate of return were presented as fairly wide ranges to reflect realistic market conditions. Though based on the specific results of Hendricken *et al*. (2012), these values may applied in other scenarios provided that: (1) five or six options can be developed with payback periods spaced over the range from roughly 2-20 years, and (2) the capital investment for each incrementally longer payback period is substantially (1.5 to 3 times) larger than the next lowest payback period option.

To assess the effect that providing additional financial information (i.e., incremental rate of return) has on the retrofit investment decision, respondents were first asked to select a retrofit package based solely on its estimated simple payback period (they were given only the information in the "Simple Payback Period" column in Table 2). For this survey question, choices were given as ranges in order to incorporate an element of uncertainty in the projections and thus to make the options more realistic. Table 2 shows the packages presented to respondents, each shown with its associated simple payback period and incremental rate of return.

Table 2. Information presented to respondents regarding retrofit package selection

Retrofit Package	Simple Payback Period	Incremental Rate of Return for Package
Option 1	No upgrades (baseline)	
Option 2	2.3 – 3.9 years	25% to 43% (relative to Option 1)
Option 3	3.1 – 5.2 years	13% to 23% (relative to Option 2)
Option 4	4.6 – 7.8 years	7% to 15% (relative to Option 3)
Option 5	5.4 – 9.1 years	3% to 10% (relative to Option 4)
Option 6	7.7 – 13.0 years	-3% to 2% (relative to Option 5)
Option 7	11.5 – 19.5 years	-9% to -13% (relative to Option 6)

In order to compare these findings with the payback periods in the EEI data, the distributions of acceptable payback period were converted to cumulative distributions by using the midpoint from the ranges of values given and plotted on a single graph (Figure 15). Although the comparison is only an approximate one since two surveys did not use the same bins, it appears that there is general agreement between them.

As the second part of this question, respondents were given the incremental rates of return for each option (shown in column 3 of Table 2) and asked again to select the package most likely to be adopted. The distributions of responses to both parts of this question are shown in Figure 16.

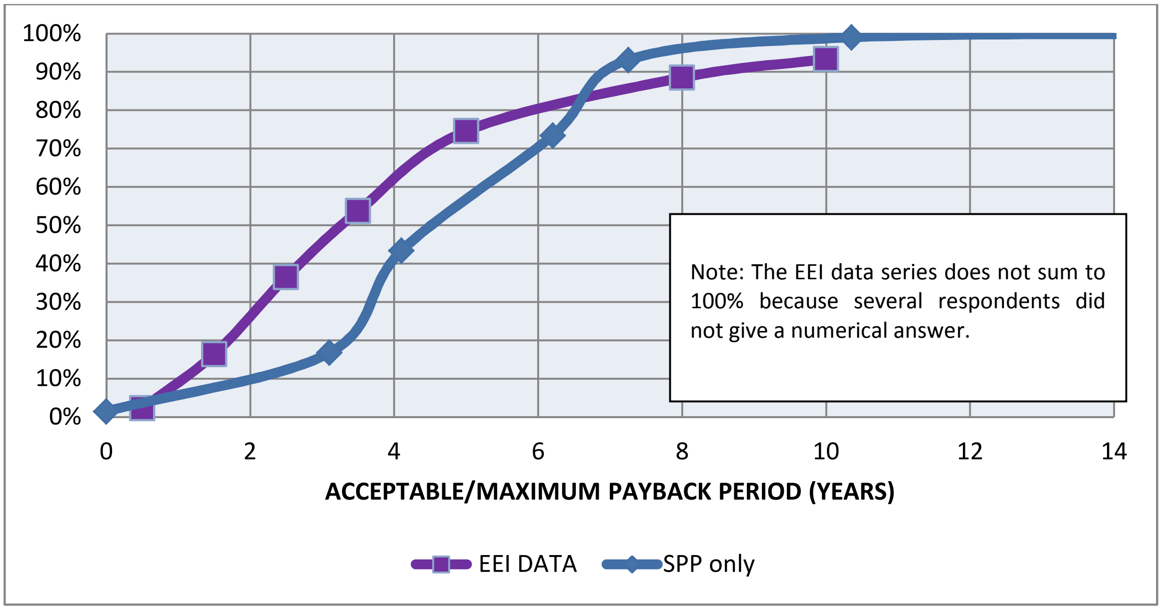
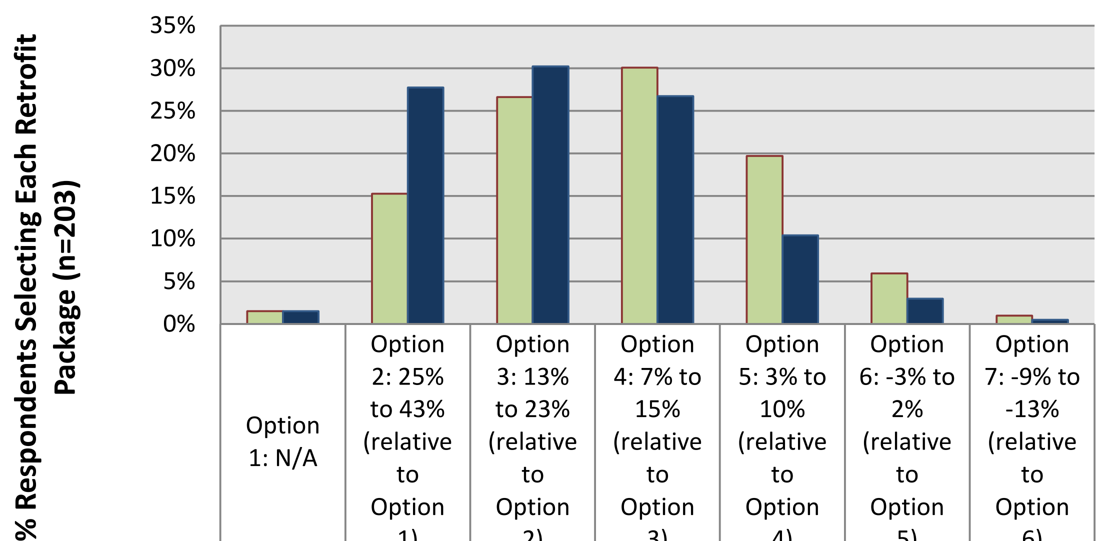


Figure 15. Comparison of cumulative % (midpoint) payback periods between EEI data and Drexel data.



	Option 1: N/A	Option 2: 25% to 43% (relative to Option 1)	Option 3: 13% to 23% (relative to Option 2)	Option 4: 7% to 15% (relative to Option 3)	Option 5: 3% to 10% (relative to Option 4)	Option 6: -3% to 2% (relative to Option 5)	Option 7: -9% to -13% (relative to Option 6)
SPP only	1%	15%	27%	30%	20%	6%	1%
SPP + Incr. ROR	1%	28%	30%	27%	10%	3%	0%

Figure 16. Respondents' selection of retrofit packages based on simple payback period alone and when combined with incremental rate of return

The response distributions show that while Option 4 (4.6 - 7.8 years) was the most commonly-selected option when only information on simple payback period was given, the addition of the data on incremental rate of return caused the distribution to shift toward the options with faster payback periods. The net result was a movement toward Options 2 and 3, which had break-even times of 2.3 – 3.9 years and 3.1 – 5.2 years, respectively. Figure 17 shows that overall, respondents made a significant change in their EER package selection when given the additional data on incremental rate of return, tending to choose an option with a slightly faster payback period. It is notable that the addition of data on incremental rate of return caused a net movement towards packages with shorter payback periods, particularly that over a quarter of respondents selected Options 1 or 2, indicating a required incremental rate of return of greater than 25%. It is possible that some respondents did not understand how to properly interpret this metric; it is also possible that better understanding of the incremental gain in financial returns shifted respondents away from longer payback periods. Matching the results from this question to the Pareto curve (Figure 4), it is evident that the preferences of decision-makers would make it difficult to achieve an energy use intensity of less than 9 kWh/ft2 * year.

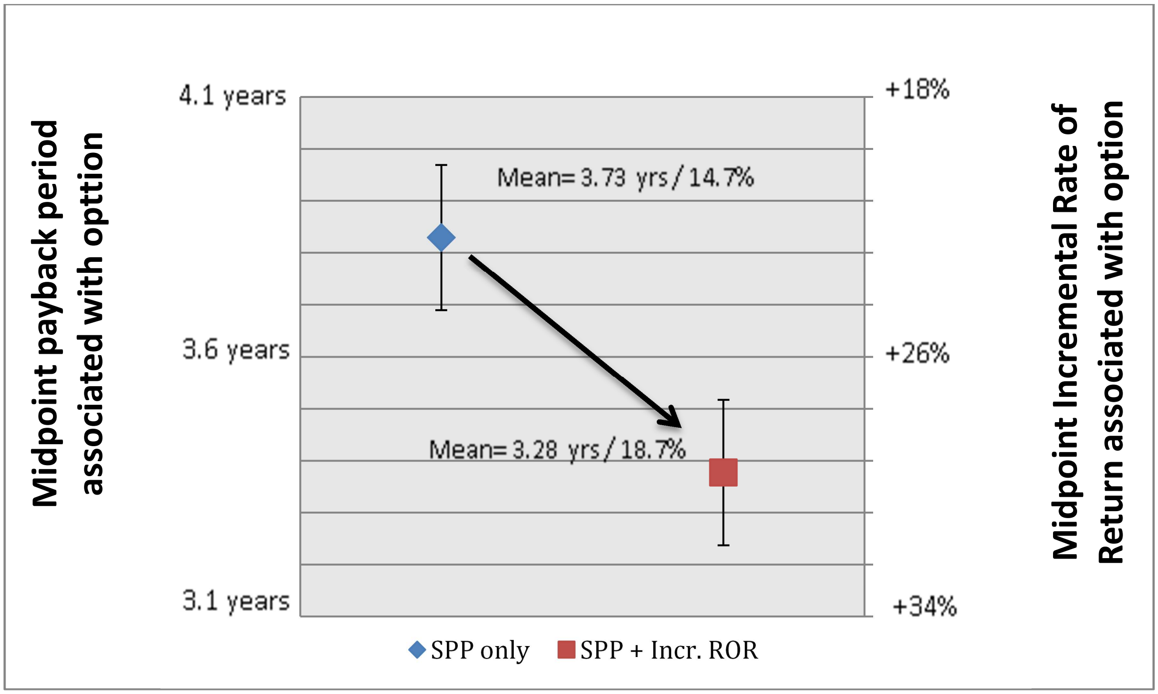


Figure 17. Mean preferred retrofit package based on additional information given.

Other group differences in acceptable payback period are reported in Table 3. It should be noted that while some trends may exist, none of the group differences shown in this table were significant. In particular, it should be noted that there were not any significant differences in preferred BET and IRR between respondents who answered the questions from their own (or their organization's) point of view and respondents who answered from a previous client's point of view.

Table 3. Acceptable payback period by group.

GROUPING	MEAN PREFERRED PACKAGE BASED ONLY ON PAYBACK PERIOD				MEAN PREFERRED PACKAGE BASED ON PAYBACK PERIOD & INCREMENTAL IRR			
	SPP (yrs)		Incr. IRR		SPP (yrs)		Incr. IRR	
	mean	*std. dev.*	mean	*std. dev.*	mean	*std. dev.*	mean	*std. dev.*
All respondents	5.62	*2.23*	14.65	*9.96*	4.89	*1.98*	18.69	*10.67*
Answer from own perspective	5.60	*2.51*	13.72	*9.95*	4.88	*2.43*	17.72	*10.63*
Answer from client's perspective	5.67	*2.09*	15.09	*9.98*	4.90	*1.72*	19.16	*10.70*
Private sector	5.54	*2.16*	15.02	*10.02*	4.89	*2.03*	18.71	*10.69*
Public sector	5.86	*2.44*	13.46	*9.76*	4.91	*1.84*	18.6	*10.72*
Publicly-traded	5.64	*2.14*	15.99	*11.1*	4.82	*1.86*	20.28	*11.34*
Not publicly-traded	5.56	*2.51*	14.21	*9.56*	4.91	*2.03*	18.17	*10.43*
In HUB region	5.68	*2.21*	14.84	*10.11*	4.78	*1.73*	19.31	*10.47*
Not in HUB region	5.47	*2.3*	14.16	*9.65*	5.14	*2.48*	17.16	*11.11*
Owner pays bills	5.71	*2.36*	14.2	*10.06*	4.86	*1.99*	18.47	*10.45*
Tenant pays bills	5.35	*1.8*	15.91	*9.64*	4.96	*1.99*	19.31	*11.37*
Democrats	5.5	*2.18*	14.46	*9.76*	4.91	*2.27*	18.81	*11.23*
Republicans	5.79	*2.23*	14.14	*9.78*	5.23	*1.93*	17.26	*10.65*
Independents	5.38	*1.84*	15.8	*9.7*	4.49	*1.41*	20.64	*9.93*

When asked which metric most affected their decision, approximately 60% of respondents reported basing their decision primarily on payback period even when presented with additional information on incremental rate of return. Figure 18 shows which additional metrics (if any) respondents would have liked to see presented. Approximately 35% of respondents said they would have liked to been given a benefit-cost ratio of each option, and 33% of respondents claimed they would have liked to see the first cost value. Only 17% of respondents wished they had been given the net present value (NPV), and 11% indicated they required no additional metrics. Overall, these results provide additional evidence that decision-makers continue to make suboptimal decisions when evaluating energy-efficient investment by placing too much weight on first cost and not enough weight on more appropriate metrics, such as NPV. These findings are significant because they suggest that any retrofit investments must fall within a range of acceptable payback periods before receiving much consideration from decision-makers. They also suggest that metrics such as incremental rate of return may have little effect in convincing decision-makers to increase their acceptable payback periods. It should be noted that neither “energy savings” nor “energy savings costs” was prompted as part of this question, thus it is impossible to say to what degree the presentation of this information would have an effect on respondents’ choices.

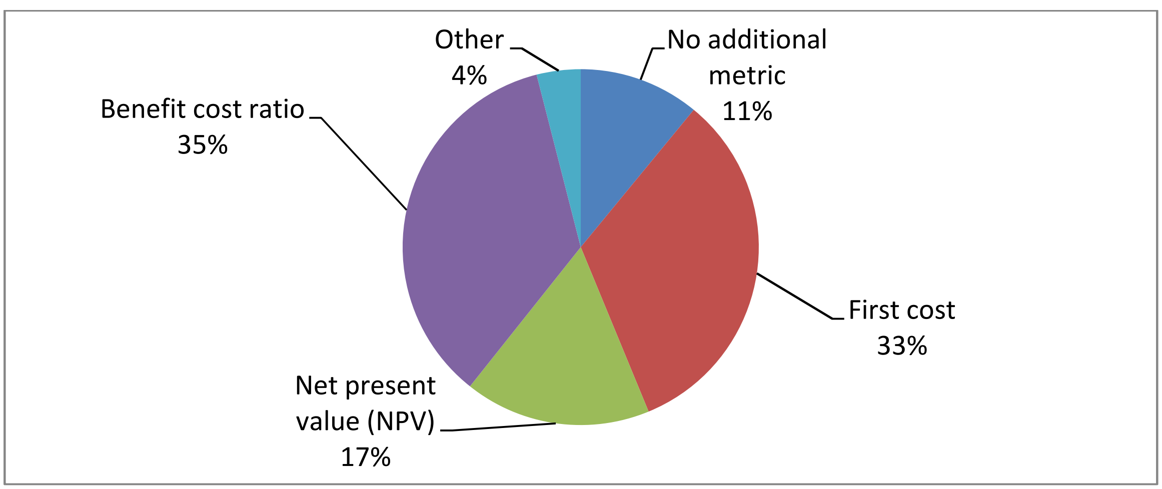


Figure 18. Additional metrics respondents would have liked to see for hypothetical retrofit package selection.

In retrospect, it is possible that some portion of the respondents did not understand the information being presented to them in the latter half of this question. Incremental rate of return is a comparatively sophisticated financial metrics; thus, it would not be surprising if some respondents misinterpreted the information. It is recommended that future survey work on this issue include a question to make sure the information is being properly interpreted by respondents. This could be accomplished with something as simple as "Have you ever encountered this concept before? Do you feel comfortable utilizing this information to make decisions?" An alternative approach would be to include an example with actual numerical data to show how the information should be used.

3.3.4 Respondents' perceptions of the future cost of energy

Respondents believe that the cost of goods and services (as measured by the Consumer Price Index) and the cost of energy will both increase slightly over the next 20 years. However, respondents expect that the increase in the cost of energy will not keep pace with the overall increase in the cost of goods and services (see Table 4), implying that the cost of energy (in real terms) will *decrease* over the next 20 years. Such perceptions are very important when considering why owners are not keen on investing in energy-efficiency projects with 20 years payback periods. However, it must be noted that there was significant variation in respondents' perceptions of the future cost of energy (the standard deviations are shown in parentheses below). This variability indicates a lack of consensus as to what future energy costs will be.

Table 4. Respondents' beliefs in the future cost of energy compared to inflation.

Index	Mean annual change in nominal cost	Mean annual change in real cost	Energy Information Agency prediction [65]
Cost of goods/services – 5 years	+4.2% *(9.4%)*	--	
Cost of goods/services – 20 years	+8.4% *(15.9%)*	--	
Cost of energy – 5 years	+3.5% *(9.3%)*	-0.7%	
Cost of energy – 20 years	+6.8% *(16.1%)*	-1.6%	~+1.1%*

*Note: EIA forecast is average real increase in all types of energy for the commercial sector through 2035.

3.3.5 Do "split incentives" have a measurable effect on retrofit investment decisions?

To test the hypothesis that split incentives (as defined by which party is responsible for paying the utility bills) have a measurable effect on which retrofit package is likely to be selected, a series of one-way ANOVA tests were run on preferred retrofit package by utility-paying party. To accomplish this, the tenancy structure variable was collapsed to create a binary variable indicating whether or not the building owner pays the utility bills. Group differences were not significant when the test was run on the entire sample or when the sample was filtered to contain only private-sector organizations. However, when the sample was restricted to privately-owned, publicly-traded organizations, the results were significant ($F(1, 47) = 4.760$, $p = .03$, see Figure 19). This lines up closely with the finding from the EEI data that among any type of organization ownership, private-sector, publicly traded organizations have the lowest acceptable payback period for retrofit investments (Figure 5).

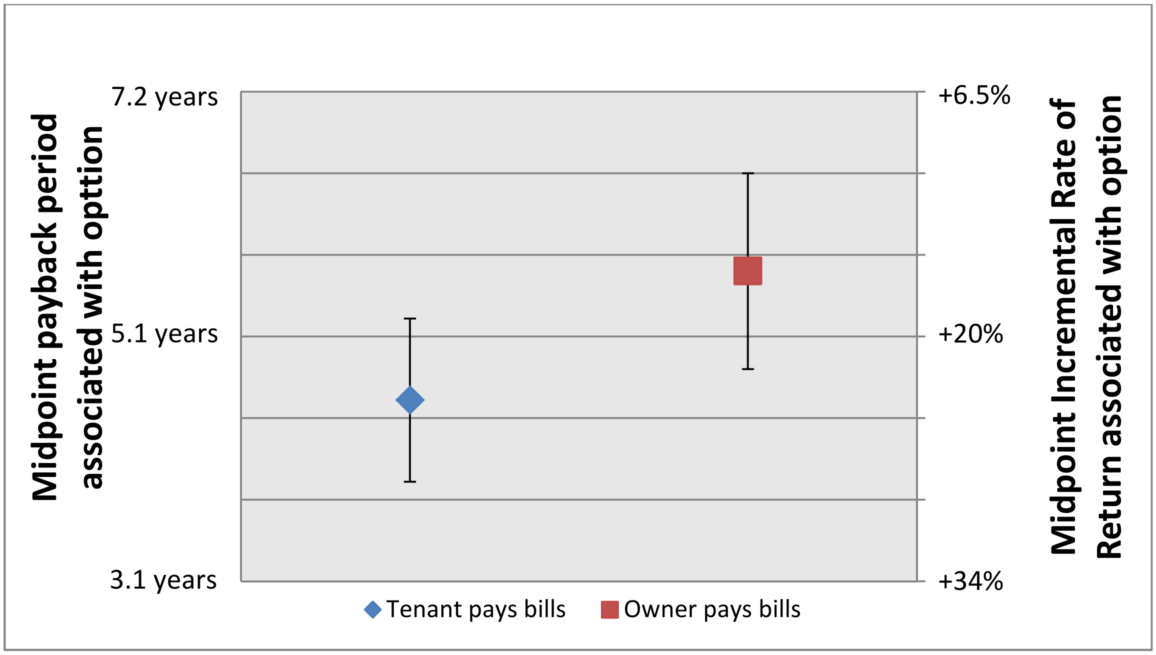


Figure 19. Preferred retrofit package characteristics for tenants-pay-bills vs. owner-pays-bills (for privately-owned, publicly-traded organizations only).

Probing this relationship a bit further, assumptions regarding the type of bill-paying scenario among different types of organization ownership type were examined. Figure 20 shows that responses for buildings owned by private-sector, publicly-traded organizations had the lowest number of instances in which the building owner is responsible for paying the utility bills, while non-profits had the highest. When the "ownership shared between government and private sector" was removed, a one-way ANOVA reveals these differences are statistically significant, $F(3, 202) = 3.02$, $p = 0.031$.

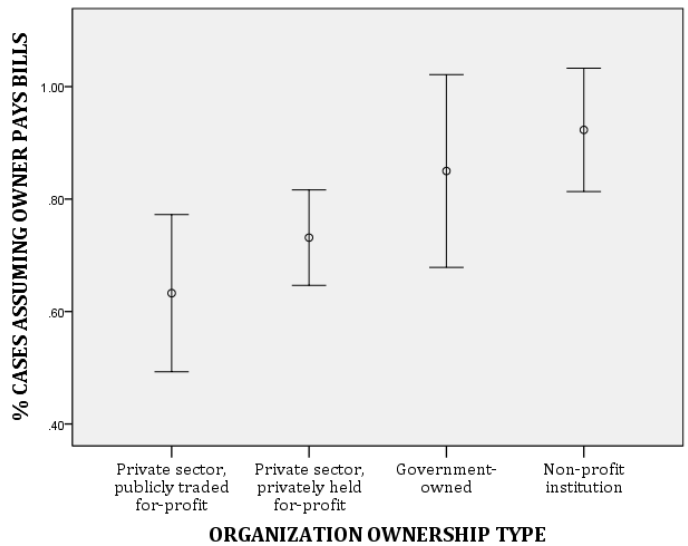


Figure 20. Differences in assumptions for bill-paying scenario by owner organization type

Pursuing further this line of inquiry, a multivariate regression was run on simple payback period using the binary dummy variables "publicly-traded" (1 if publicly-traded, 0 otherwise) and "split incentives" (1 if the building pays the tenant's utility bills, 0 otherwise) as predictors. By themselves, neither "publicly-traded" nor "split incentives" had a significant effect on SPP. However, the interaction of both variables was significant (p=.03), as shown in Figure 21.

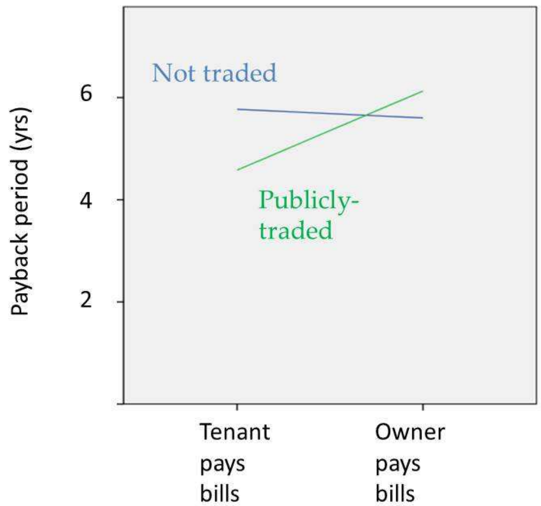


Figure 21. The interactive effect of trading status and split incentives on payback period

Lastly, when the data were filtered to include only those scenarios in which the "split incentives" was not a factor, Figure 22 shows there was virtually no difference in acceptable payback periods between owner organization type. So while other factors cannot be ruled out as underlying reasons for differences in acceptable payback period between owner organization types, it is clear that "split incentives" represents a significant barrier to energy efficiency, and is most keenly felt by private-sector, publicly-traded companies.

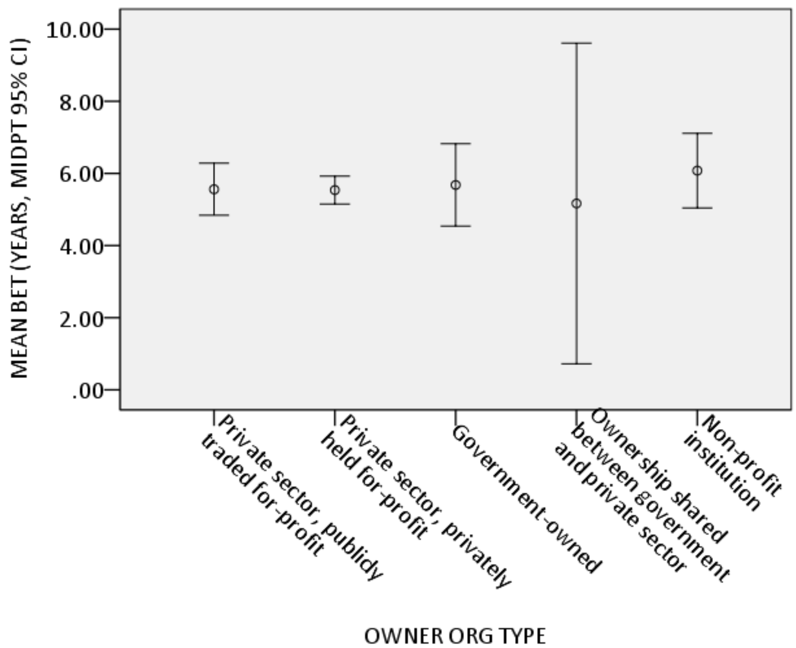


Figure 22. Mean SPP by owner organization type for scenarios in which split incentives do not exist

3.3.6 Conjoint Question Results

Originally developed in mathematical psychology, conjoint methods provide a way to determine which attributes of a multi-attribute package are perceived by consumers as the most important. By forcing respondents to make tradeoffs between different attributes of a generic retrofit package, we were able to derive relative weights in the decision process of the following four dimensions:

- Break-even time for the investment in the EER (based only on projected energy cost savings)
- Change in employee productivity as a result of the EER
- Change in pollutant emissions of the building due to reduced energy consumption

- The presence/absence of a performance contract guarantee (which does not affect first cost)

The conjoint structure yielded a set of "part-worth" utility scores for each attribute. Such scores are calculated based on the ranking of a defined set of combinations of attribute values, and may serve as regression coefficients for each attribute level in a linear equation. The part-worth utilities are additive, meaning they may be added together to obtain the total utility for a specific combination of attribute levels. Higher utility values indicate a greater preference for a given attribute level, with less negative values considered greater than more negative values [66]. The part-worth utilities are shown in Table 5. As expected, shorter break-even times were preferred to longer break-even times. Similarly, a greater increase in employee productivity was preferred to both the static productivity level (0% change) and a slight decrease in productivity (-2%). Surprisingly, respondents seemed to have greater preference for lesser reductions in pollutant emissions, as well as little regard for the presence of a performance contract guarantee, as evidenced by higher utility scores for presumably less desirable values of these factors.

Table 5. Part-worth utility scores for each level of all factors.

FACTOR	LEVEL	PART-WORTH UTILITY
Break-even time for retrofit investment	3.0 years	-.534
	6.0 years	-1.069
	10.0 years	-1.603
Change in employee productivity	+10%	-.279
	0% (no change)	-.558
	-2%	-.838
Change in pollutant emissions	-50%	.062
	-25%	.124
	-5%	.186
Presence of performance contract guarantee	Yes	.049
	No	.098
(constant)		*6.438*

Additionally, the conjoint questions yielded relative weights for each of the four main attributes (categories). Because respondents were given no additional information besides the attribute levels shown above, comparisons can only be made between these dimensions relative to one another. The relative weights for each of them are shown in Figure 23. As expected, “break-even time for the retrofit investment” was weighted most heavily at 59%, followed by “change in employee productivity” at 31%. “Change in pollutant emissions” and “presence of a performance contract guarantee” carried much less weight in the retrofit decision (7% and 3%, respectively). However, performance guarantees may be important in specific contexts, such as novel technologies, that were not explicitly considered here.

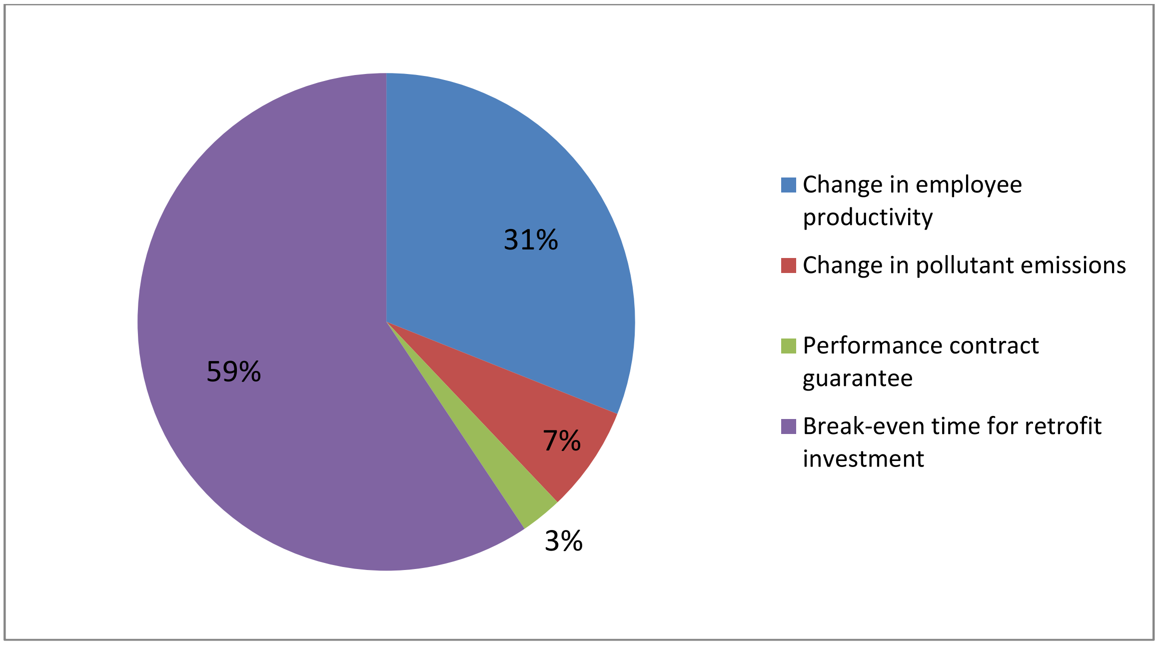


Figure 23. Relative importance scores for conjoint factors.

4. DISCUSSION

By cross-referencing the results of three separate data sources on energy-efficient retrofit investment in commercial buildings, this chapter has attempted to better characterize several important factors in the retrofit investment process. These include the continued use of simple metrics (such as simple payback period) in place of more accurate financial metrics (such as NPV or incremental rate of return), and the precise nature that "split incentives" has on an owner's investment decisions. These results, along with some recommendations to help market mechanisms operate successfully, are detailed below.

- ***Decision-makers believe that the overall cost of energy over the next 20 years will not keep pace with inflation.*** This is important because it may explain why building owners are not eager to make investments in energy efficiency that extend beyond several years. Additionally, there was a significant degree of variability in respondents' perceptions of the future cost of energy. As noted in Chapter I, such beliefs may have the effect of convincing decision-makers to simply *wait* to invest in any sort of retrofits.

- ***Investment choices made solely on the basis of simple payback period are not set in stone and can be changed by presenting the decision-maker with additional financial information.*** When presented only with information on the break-even time of a retrofit investment, a majority of respondents chose the option corresponding to a simple payback period of 4.6-7.8 years. However, when presented with additional information on the incremental rate of return for these same options, there was a net movement away from retrofit options with greater payback periods and toward options with payback periods of 3.1-5.2 years and less. While a shift to packages with shorter payback periods may not be desirable from an energy-efficiency standpoint, it does show that while decision-makers' investment choices are guided by payback period, these choices are not written in stone. These results also lend credence to the idea that some decision-makers are not making investment choices on sound financial principles, but instead using "rules of thumb" as a decision heuristic. The net change was a substantial shift away from Option #5 and toward Option #2, with more than a quarter of respondents indicating a preference for hurdle rates exceeding 25%, a rate much greater than typical borrowing costs. These findings suggest that a greater degree of general financial literacy may be important in encouraging greater adoption of energy efficiency measures. Failing this, it is again recommended that financial data for local examples of success are made available for public view.

- ***"Split incentives," the responsibility for paying the utility bills, does have a measurable effect on retrofit investment decisions for private-sector, publicly-traded organizations.*** The effect may also be felt in other areas, but not to the same degree. The cause of this disproportionate effect may be due to a higher percentage of cases in this sector in which the building owner does not pay the utility bills; however, other reasons cannot be ruled out (such as more stringent internal investment criteria, e.g., "higher hurdle rates"). It does appear that frequency of review of energy consumption data by an organization is not the primary reason why some types of organization are willing to accept longer payback periods than others. Taken as a whole, these results reinforce the need to realign "split incentives" so that market mechanisms may operate successfully. This also suggests that correcting such mechanisms will have its greatest impact among publicly-traded organizations. While "green leases" may be able to correct some of the problems associated with "split incentives," the importance of disclosure of financial information from local retrofit projects cannot be overlooked. Some larger cities have already begun to adopt mandatory energy consumption disclosure laws, and these are likely to have a strong impact on the commercial building retrofit market in the US.

- ***Purely financial concerns still outweigh more indirect measures of asset worth, though many building owners recognize the importance of employee productivity.*** The results of the conjoint portion of the structured survey reveal that decision-makers continue to place a significant amount of weight on payback period while at the same time recognizing that employee productivity has an important effect on a building's bottom line. It is not surprising that decision-makers placed comparatively less emphasis on environmental aspects since these are typically not tied to financial return. Although little emphasis was also placed on performance guarantee considerations, it cannot be ruled out that these may exert great influence over some retrofit investment decisions.

CHAPTER III : TOWARD A MORE ENERGY-EFFICIENT COMMERCIAL BUILDING MARKET

This final chapter presents a broader discussion of barriers to increased energy efficiency in the building retrofit market and possible ways in which they may be surmounted.

1. SYNTHESIS

The first chapter of this thesis presented an overview of potential barriers to increased investment in energy efficiency. Some of these barriers can be classified as "market failures" (such as imperfect information and split incentives) while others (such as the use of high discount rates by decision-makers) may considered to be reactions to underlying problems but are not in themselves market failures. A significant degree of heterogeneity in the market further obfuscates the decision processes commonly pursued during retrofit projects and makes it difficult to ascertain the relative importance of decision factors.

The second chapter detailed the results of analyses on three data sources in an effort to better characterize the barriers that were discussed in Chapter I. A measurable effect of a recognized market failure (i.e., "split incentives") on retrofit decision-making was documented and a possible source of market failure (the tendency of decision-makers to base decisions on simple payback period rather than more theoretically justified metrics) was observed. In their text on policy analysis, Weimer and Vining (2011) explain that when there is evidence of market failure in an operational market and an absence of government intervention, the correct path is to assess possible interventions and compare their costs to the cost of the market failure. Together, these results suggest that increased energy (and economic) efficiency in the retrofit market could be achieved via a government intervention to realign investment incentives and provide information to relevant stakeholders. In such an instance, one would expect a net increase in demand for energy efficient technologies and overall gain in social surplus. Specific mechanisms to achieve these goals are discussed in Section 2 below.

Recognizing that the term "energy efficiency gap" is not a well-defined economic concept (see Chapter I for details), it may be possible to generate a very rough measure of the difference between our current level of energy efficiency and some ideal level. To do this, we simply compare the hurdle rate for investment in energy efficiency reported by survey respondents to an accepted value of the social discount rate. The reported acceptable hurdle rate reported by respondents based only on simple payback period was 14.65%. If we use 5% as the social discount rate [67], then it becomes evident that a discrepancy of 9.65% exists between the two values. Looking at it from a different angle, the acceptable hurdle rate reported by survey respondents is nearly 3 times the social discount rate. By matching these rates to ECM packages along the Pareto curve shown in Figure 5, it should be possible to derive an approximate value for the difference in energy consumption between the highest level of efficiency that is technically feasible and the level of energy efficiency that would be adopted by the market. A hurdle rate of 14.65% falls somewhere between package #3 and package #4, suggesting an energy use intensity of approximately 12 kWh/ft^2*year. A rate of 5% falls somewhere between package #5 and package #6, which corresponds to an energy use intensity of approximately 9.5 kWh/ft^2*year. The difference between the two is 2.5 kWh/ft^2*year, which is roughly 12% of the stock average energy use intensity of 21 kWh/ft^2*year. This measure represents one possible approach to measuring the "gap."

2. DATA USE CONSIDERATIONS

Several important caveats must be considered when interpreting these results or using them for further research:

- The results of the semi-structured interviews and online surveys are mainly applicable to mid-sized commercial office buildings. While they may in some instances also be applicable to other building types, care should be taken when applying values from this study to other building types.
- Even among mid-sized office buildings, there is significant variability in massing, construction, subsystems, and end uses. So care must be taken even when generalizing these findings to mid-size commercial office buildings. While the survey was developed to minimize variation due to building characteristics, it is very likely that the influence of other factors enters into the decision equation when other building types are considered.
- Results may vary across different regions, particularly for the ratings of specific ECMs. This survey was not designed to identify regional differences but such differences may exist.

3. POLICY RECOMMENDATIONS

As mentioned previously in this paper, improvement in energy efficiency is a moving target – and it seems there is no "silver bullet" solution short of allowing the price of energy to properly internalize all applicable environmental and health externalities associated with its use and production and then letting the market react accordingly. The next best thing to "self internalization," from a theoretical standpoint, would be the introduction of a carbon tax or similar policy [14]. Such taxes have been implemented with some degree of success in other countries, including Ireland and Sweden [68], [69]. However, the introduction of a carbon tax is a complicated political and engineering problem and would likely take years to implement. If cities such as Philadelphia hope to reduce their building energy use 20% by the year 2020 (a goal put forth by the EEB HUB), a more expedient set of solutions should be adopted. In this chapter I argue in favor of three specific policy solutions that should be able to address all of the aforementioned barriers and should be able to be implemented with relative ease.

3.1 Recommendation #1: Incentivize non-profit and government organizations to act as "early adopters"

Recognizing that non-profit and government organizations tend to accept longer payback periods than their private sector counterparts, it may be possible to convince these organizations to invest in newer retrofit technologies that have the potential to reduce energy consumption but do not have the track record to justify the expense to more risk-averse investors. Certain non-profit and government institutions are also in a unique position to reap the rewards of such investment since they do not experience the same problems of "split incentives" to the same extent as felt by publicly-traded firms in the private sector. If new technologies are adopted and perform well, this information could be documented in a third-party database (discussed in Recommendation #2 below) with the idea that private-sector organizations would then adopt them. The provision of empirical data would serve to reduce uncertainty associated with the operation of the retrofit technologies and the knowledge that it can be done locally would mitigate problems created by bounded rationality (for instance, by letting potential investors view the retrofitted building). On the other hand, if certain ECMs are adopted and perform poorly, this would send a strong signal to the market indicating those technologies should be avoided. Several efforts of this nature are already underway in the Philadelphia area, including demonstration projects by EEB Hub at the Navy Yard and work at the Friends' Center in Center City.

3.2 Recommendation #2: Third-party database showcasing local examples of success

The second recommendation is the creation of a third-party database containing information on retrofits that have been performed in a given region and including building energy consumption, which specific subsystems are in use, the installation and operating costs of these subsystems, and the building's overall utility bills over time. This solution goes a step beyond the standard "mandatory disclosure" solution in that it would include data on the prevalence and performance of specific building subsystems, thus acting as an inventory of local examples of success (or failure). By making this database both public and *searchable*, the performance of specific technologies could be easily evaluated by decision-makers by looking at their performance in buildings of a similar size. The Department of Energy has begun implementing a very similar database called the Buildings Performance Database [70], though the level of detail that will be included remains to be seen. In creating a database of this nature, it would be critical to maintain transparency in the presentation of energy data while at the same time respecting personal and proprietary information of the building owners. This is closely related to the problem of "credibility and trust" discussed in Chapter I – if this trust is ever betrayed, the efficacy of the database will likely decrease. An analog of such a database does exist in other markets – for instance, the service provided by Consumer Reports to potential car-buyers can have an important effect on the market via the provision of standardized information to consumers.

3.3 Recommendation #3: Widespread promotion of on-bill financing

The third recommendation is the promotion of on-bill financing for energy-efficient retrofits. On-bill financing is an idea initially put forth by the Energy Efficiency Institute as a way to promote energy efficiency in the rental housing market and has now been adopted by utility companies in at least 23 states around the country [71]. Although much variability exists between utility companies on-bill finance offerings, a typical setup will allow the building owner to obtain a loan directly from their utility company or a third-party lender in order to install certain energy-efficient retrofit measures in a building. Responsibility for repaying the loan is tied to the building that received the upgrade rather than the building owner, thus removing an element of risk for the building owner. The loan is eventually repaid as part of the utility bill through energy cost savings resulting from the upgrade [72]. Given the findings reported in Chapter II on the effect of "split incentives" on retrofit investment, it is clear that this barrier remains one of the most important hurdles to achieving greater energy efficiency in the commercial office building market. In a scenario in which a tenant pays the utility bills but does not own the building, the other recommendations (given above) will streamline the process for increased investment in energy efficiency, but not provide the initial incentive to do so. The ability of a building owner to profit from investments in tenant-leased spaces, along with the reduction of risk that goes along with pinning the investment to the building itself, are important difficulties that would be simultaneously addressed by on-bill financing.

3.4 Addressing existing barriers

Table 6 presents a matrix of existing barriers and how each potential barrier is addressed or not addressed by these two mechanisms. It can be argued that the few barriers which are not directly addressed can be categorized as "secondary" barriers in that they are merely more specific forms of "primary" barriers. Specifically, the barriers described as *values*, *inertia*, *power*, and *culture* may be seen as outgrowths of *imperfect information* manifested in different ways within an organization [5]. As values are informed by information, it follows that values can be altered by providing (more or better) information. If the problem of asymmetric information could be properly addressed, then in this view these secondary barriers would also be addressed.

4. THIS THESIS' CONTRIBUTION

This thesis has presented the most pertinent findings from two sets of surveys aimed at characterizing the commercial building energy retrofit process and found them to be generally in agreement with a third data source, the Johnson Controls Energy Efficiency 2011 Indicator survey. The relative importance of various financial metrics (such as simple payback period) in stakeholders' decision processes was quantified and the ability to alter the outcomes of these processes via the addition of new financial information was documented. It was found that stakeholders' behavior may be partially explained by their beliefs in the future cost of energy, which they expect will decrease in real terms over the next 20 years (though significant variation does exist in these perceptions). An approximate quantitative measure of "split incentives" was obtained and differences in its effect between different organization ownership structures were outlined. Specific policy solutions to increase investment in energy efficiency – targeting non-profit and government organizations to act as "early adopters," the creation of a third-party database with cost and performance information for ECMs, and the widespread adoption of on-bill financing – were recommended.

Table 6. Existing barriers to energy efficiency and recommended solutions

Theoretical Barrier	Addressed by targeted adoption of ECMs	Addressed by third-party database with cost data	Addressed by on-bill financing
Imperfect information		●	
Adverse selection		●	
Principal-agent relationships		●	◐
Split incentives			●
Hidden costs		●	
Access to capital			●
Risk / Uncertainty	●	◐	◐
Heterogeneity		◐	
Form of information		◐	
Credibility and trust		◐	
Bounded rationality	◐	◐	
Values *		secondary	
Inertia *		secondary	
Power *		secondary	
Culture *		secondary	
KEY	● = addressed	◐ = partially addressed	

* This is a secondary barrier and is addressed via "Imperfect information."

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APPENDIX 1: COMBINATIONS OF ECMS USED IN ENERGY MODELING

#	Component ECMs
1	Uncommissioned Baseline 1: 25% Window Area
6	Uncommissioned Baseline 1 + Lighting Improvement
7	Uncommissioned Baseline 1 + HE Elevators + LED Lighting
8	Uncommissioned Baseline 1 + DP Windows
9	Baseline 1 (Commissioned)
10	Baseline 1 + Temp Reset Strategy
11	Baseline 1 + Lighting Improvement + Temp Reset Strategy
12	Baseline 1 + HE Elevators + LED Lighting + Temp Reset Strategy
13	Baseline 1 + DP Windows + Temp Reset Strategy
14	Baseline 1 + HE Boiler + Temp Reset Strategy
15	Baseline 1 + HE Cooling + Temp Reset Strategy
16	Baseline 1 + HE Cooling + HE Boiler + Temp Reset Strategy
17	Baseline 1 + HE Elevators + Lighting Improvement + DP Windows + Temp Reset Strategy
18	Baseline 1 + HE Elevators + LED Lighting + DP Windows + Temp Reset Strategy
19	Baseline 1 + Lighting Improvement + HE Cooling + HE Boiler + Temp Reset Strategy
20	Baseline 1 + HE Elevators + LED Lighting + HE Cooling + HE Boiler + Temp Reset Strategy
21	Baseline 1 + DP Windows + HE Cooling + HE Boiler + Temp Reset Strategy
22	Baseline 1 + HE Elevators + Lighting Improvement + DP Windows + HE Cooling + HE Boiler + Temp Reset Strategy
23	Baseline 1 + HE Elevators + LED Lighting + DP Windows + HE Cooling + HE Boiler + Temp Reset Strategy
24	Baseline 1 + VAV upgrade no DCV + HE Cooling + HE Boiler
25	Baseline 1 + VAV upgrade + HE Cooling + HE Boiler
26	Baseline 1 + VAV upgrade + HE Cooling + HE Boiler + Lighting Improvement
27	Baseline 1 + VAV upgrade + HE Cooling + HE Boiler + HE Elevators + LED Lighting
28	Baseline 1 + VAV upgrade + HE Cooling + HE Boiler + DP Windows
29	Baseline 1 + VAV upgrade + HE Cooling + HE Boiler + HE Elevators + Lighting Improvement + DP Windows
30	Baseline 1 + VAV upgrade + HE Cooling + HE Boiler + HE Elevators + LED Lighting + DP Windows
31	Baseline 1 + Heat Pump + VAV upgrade
32	Baseline 1 + Heat Pump + VAV upgrade + Lighting Improvement
33	Baseline 1 + Heat Pump + VAV upgrade + HE Elevators + LED Lighting
34	Baseline 1 + Heat Pump + VAV upgrade + DP Windows
35	Baseline 1 + Heat Pump + VAV upgrade + HE Elevators + Lighting Improvement + DP Windows
36	Baseline 1 + Heat Pump + VAV upgrade + HE Elevators + LED Lighting + DP Windows
37	Baseline 1 + Central chiller + HE Boiler + VAV upgrade
38	Baseline 1 + Central chiller + HE Boiler + VAV upgrade + Lighting Improvement
39	Baseline 1 + Central chiller + HE Boiler + VAV upgrade + HE Elevators + LED Lighting
40	Baseline 1 + Central chiller + HE Boiler + VAV upgrade + DP Windows

41	Baseline 1 + Central chiller + HE Boiler + VAV upgrade + HE Elevators + Lighting Improvement + DP Windows
42	Baseline 1 + Central chiller + HE Boiler + VAV upgrade + HE Elevators + LED Lighting + DP Windows
43	Baseline 1 + White Roof + Temp Reset Strategy
44	Baseline 1 + Insulated Roof + Temp Reset Strategy
45	Baseline 1 + White Roof + VAV upgrade + HE Cooling + HE Boiler + HE Elevators + Lighting Improvement + DP Windows
46	Baseline 1 + White Roof + Heat Pump + VAV upgrade + HE Elevators + Lighting Improvement + DP Windows
47	Baseline 1 + White Roof + Heat Pump + VAV upgrade + HE Elevators + LED Lighting + DP Windows
48	Baseline 1 + White Roof + Central chiller + HE Boiler + VAV upgrade + HE Elevators + Lighting Improvement + DP Windows
49	Baseline 1 + White Roof + Central chiller + HE Boiler + VAV upgrade + HE Elevators + LED Lighting + DP Windows
50	Baseline 1 + Walls + VAV upgrade + HE Cooling + HE Boiler + HE Elevators + Lighting Improvement + DP Windows
51	Baseline 1 + Walls + Insulated Roof + Heat Pump + VAV upgrade + HE Elevators + Lighting Improvement + DP Windows
52	Baseline 1 + Walls + Insulated Roof + Heat Pump + VAV upgrade + HE Elevators + LED Lighting + DP Windows
53	Baseline 1 + Walls + Insulated Roof + Central chiller + HE Boiler + VAV upgrade + HE Elevators + Lighting Improvement + DP Windows
54	Baseline 1 + Walls + Insulated Roof + Central chiller + HE Boiler + VAV upgrade + HE Elevators + LED Lighting + DP Windows
55	Baseline 1 + White Roof + GSHP COP 6 + VAV upgrade + Lighting Improvement
56	Baseline 1 + White Roof + GSHP COP 6 + VAV upgrade + HE Elevators + Lighting Improvement + DP Windows
57	Baseline 1 + White Roof + GSHP COP 6 + VAV upgrade + HE Elevators + LED Lighting + DP Windows
58	Baseline 1 + White Roof + GSHP COP 6 + VAV upgrade + HE Elevators + LED Lighting + DP Windows + Walls
59	Baseline 1 + Insulated Roof + GSHP COP 6 + VAV upgrade + HE Elevators + LED Lighting + DP Windows + Walls
60	Baseline 1 + Ice Tank + White Roof + Central chiller + HE Boiler + VAV upgrade + HE Elevators + Lighting Improvement + DP Windows
61	Baseline 1 + Ice Tank + White Roof + Central chiller + HE Boiler + VAV upgrade + HE Elevators + LED Lighting + DP Windows
62	Baseline 1 + Chilled Beams & DOAS + White Roof + Central chiller + HE Boiler + HE Elevators + Lighting Improvement + DP Windows
63	Baseline 1 + Chilled Beams & DOAS + White Roof + Heat Pump + HE Elevators + Lighting Improvement + DP Windows
64	Baseline 1 + Chilled Beams & DOAS + Walls + Insulated Roof + Central chiller + HE Boiler + HE Elevators + LED Lighting + DP Windows
65	Baseline 1 + Chilled Beams & DOAS + White Roof + GSHP COP 6 + HE Elevators + Lighting Improvement + DP Windows
66	Baseline 1 + Chilled Beams & DOAS + Walls + Insulated Roof + GSHP COP 6 + HE Elevators + LED Lighting + DP Windows
67	Baseline 1 + Chilled Beams & DOAS + Ice Tank + Walls + Insulated Roof + GSHP COP 6 + HE Elevators + LED Lighting + DP Windows
68	Baseline 1 + Smart Grid + VAV upgrade + HE Cooling + HE Boiler + Lighting Improvement
69	Baseline 1 + Smart Grid + VAV upgrade + HE Cooling + HE Boiler + HE Elevators + LED Lighting + DP Windows
70	Baseline 1 + Smart Grid + Heat Pump + VAV upgrade + HE Elevators + Lighting Improvement + DP Windows
71	Baseline 1 + Smart Grid + White Roof + Central chiller + HE Boiler + VAV upgrade + HE Elevators + LED Lighting + DP Windows
72	Baseline 1 + Smart Grid + Walls + Insulated Roof + Heat Pump + VAV upgrade + HE Elevators + LED Lighting + DP Windows
73	Baseline 1 + Smart Grid + White Roof + GSHP COP 6 + VAV upgrade + HE Elevators + LED Lighting + DP Windows
74	Baseline 1 + Smart Grid + Walls + Insulated Roof + GSHP COP 6 + VAV upgrade + HE Elevators + LED Lighting + DP Windows
75	Baseline 1 + Smart Grid + Ice Tank + White Roof + Central chiller + HE Boiler + VAV upgrade + HE Elevators + Lighting Improvement + DP Windows
76	Baseline 1 + Smart Grid + Chilled Beams & DOAS + White Roof + Central chiller + HE Boiler + HE Elevators + Lighting Improvement + DP Windows
77	Baseline 1 + Smart Grid + Chilled Beams & DOAS + White Roof + Heat Pump + HE Elevators + Lighting Improvement + DP Windows
78	Baseline 1 + Smart Grid + Chilled Beams & DOAS + Walls + Insulated Roof + Central chiller + HE Boiler + HE Elevators + LED Lighting + DP Windows
79	Baseline 1 + Smart Grid + Chilled Beams & DOAS + White Roof + GSHP COP 6 + HE Elevators + Lighting Improvement + DP Windows
80	Baseline 1 + Smart Grid + Chilled Beams & DOAS + Walls + Insulated Roof + GSHP COP 6 + HE Elevators + LED Lighting + DP Windows
81	Baseline 1 + Smart Grid + Chilled Beams & DOAS + Ice Tank + Walls + Insulated Roof + GSHP COP 6 + HE Elevators + LED Lighting + DP Windows

82	Baseline 1 + CCHP + Smart Grid + White Roof + Abs Chiller + VAV upgrade + HE Elevators + Lighting Improvement + DP Windows
83	Baseline 1 + CCHP + Smart Grid + Walls + Insulated Roof + Abs Chiller + VAV upgrade + HE Elevators + Lighting Improvement + DP Windows
84	Baseline 1 + CCHP + Smart Grid + White Roof + Abs Chiller + VAV upgrade + HE Elevators + LED Lighting + DP Windows
85	Baseline 1 + CCHP + Smart Grid + White Roof + Abs Chiller + VAV upgrade + HE Elevators + Lighting Improvement + DP Windows
86	Baseline 1 + CCHP + Smart Grid + Ice Tank + White Roof + Abs Chiller + VAV upgrade + HE Elevators + Lighting Improvement + DP Windows
87	Baseline 1 + CCHP + Smart Grid + Chilled Beams & DOAS + White Roof + Abs Chiller + HE Elevators + Lighting Improvement + DP Windows
88	Baseline 1 + CHP + Smart Grid + White Roof + HE Cooling + VAV upgrade + HE Elevators + Lighting Improvement + DP Windows
89	Baseline 1 + CCHP + Smart Grid + Chilled Beams & DOAS + Walls + Insulated Roof + Abs Chiller + HE Elevators + Lighting Improvement + DP Windows
90	Baseline 1 + CHP + Smart Grid + White Roof + Abs Chiller + VAV upgrade + HE Elevators + LED Lighting + DP Windows
91	Baseline 1 + CHP + Smart Grid + White Roof + Central chiller + VAV upgrade + HE Elevators + Lighting Improvement + DP Windows
92	Baseline 1 + CHP + Smart Grid + Walls + Insulated Roof + Central chiller + VAV upgrade + HE Elevators + Lighting Improvement + DP Windows
93	Baseline 1 + PV + Smart Grid + White Roof + Central chiller + HE Boiler + VAV upgrade + HE Elevators + Lighting Improvement + DP Windows
94	Baseline 1 + PV + Smart Grid + Walls + Insulated Roof + Central chiller + HE Boiler + VAV upgrade + HE Elevators + Lighting Improvement + DP Windows
95	Baseline 1 + PV + Smart Grid + White Roof + Central chiller + HE Boiler + VAV upgrade + HE Elevators + LED Lighting + DP Windows
96	Baseline 1 + PV + Smart Grid + White Roof + Central chiller + HE Boiler + VAV upgrade + HE Elevators + Lighting Improvement + DP Windows
97	Baseline 1 + PV + Smart Grid + Ice Tank + White Roof + Central chiller + HE Boiler + VAV upgrade + HE Elevators + Lighting Improvement + DP Windows
98	Baseline 1 + PV + Smart Grid + Chilled Beams & DOAS + White Roof + Central chiller + HE Boiler + HE Elevators + Lighting Improvement + DP Windows
99	Baseline 1 + PV + Smart Grid + Chilled Beams & DOAS + Walls + Insulated Roof + Central chiller + HE Boiler + HE Elevators + Lighting Improvement + DP Windows
100	Baseline 1 + PV + Smart Grid + White Roof + GSHP COP 6 + VAV upgrade + HE Elevators + Lighting Improvement + DP Windows
101	Baseline 1 + PV + Smart Grid + Chilled Beams & DOAS + White Roof + GSHP COP 6 + HE Elevators + Lighting Improvement + DP Windows
102	Baseline 1 + PV + Smart Grid + Chilled Beams & DOAS + Walls + Insulated Roof + GSHP COP 6 + HE Elevators + Lighting Improvement + DP Windows
103	Baseline 1 + PV + Smart Grid + Chilled Beams & DOAS + Walls + Insulated Roof + GSHP COP 6 + HE Elevators + LED Lighting + DP Windows

APPENDIX 2: SEMI-STRUCTURED INTERVIEW INSTRUMENT

Semi-Structured Interview for Decision Makers

Greater Philadelphia Innovation Cluster (GPIC) Task 4: Policy, Markets, and Behavior

We would like to talk to you about decision making for retrofits for small commercial buildings. We are particularly interested in buildings that are less than 100,000 square feet.

1. **What triggers the decision to retrofit a small commercial building?**

   Prompts

   Owner/Tenant Needs
   Architectural Considerations
   - o Programming (spatial adjustments to better support primary activities)
   - o Aesthetics
   - o Draw in more customers
   - o Other
     - ▪ Structural/material improvements

   Occupant Variables
   - o Improved Comfort
     - ▪ Thermal only or are there other variables of concern for comfort?
   - o Improved Productivity
   - o Improved Health/Well-Being

   Energy Efficiency
   - o What generally prompts the desire to be energy efficient?
     - ▪ Longer term financial goals (i.e. energy savings, payback)
     - ▪ Improved company image ("green" conscious, innovative, etc.)
     - ▪ Tax breaks/local, state, and federal incentives?
     - ▪ High energy costs?
     - ▪ Personal sense of environmental responsibility?

- Increased asset value of property?

Facility Maintenance

- Mandatory upgrade to prevent failure?

Code Requirements

- Which entity's requirements? Federal government? State government?

2. Currently, what potential barriers must be considered as a part of this decision?

Prompts

Initial costs and/or projected maintenance costs?
Capital available / allocated for work?
Loss of operating revenue?

- Displacement of workers
- Suspension of services (if large retrofit)

Legal barriers (i.e. zoning requirements, building codes, etc.)?
Lack of knowledge about/familiarity with retrofit process?
Design challenges?

- Building size & complexity
- Communication between client and architect
- Keeping design decisions under budget
- Community feedback

Uncertainty about outcomes?
Timing of retrofit process?

3. Once the building retrofit process is underway, what specific efficiency measures are targeted?

Prompts

Building Energy Sources

- Solar
  - PV

        - Solar Hot Water
    - Ground source heat pump
    - Combined Heat & Power
    - Wind
- Building Orientation & Massing
- Building Envelope
    - Glazing
    - Envelope material and detailing
        - Insulation type
    - Shading
    - Shape & porosity
- Building Environmental Conditioning Systems
    - Active HVAC systems
        - Choice of system type
        - Equipment efficiency
    - Passive systems
        - Solar gains/thermal mass
        - Natural ventilation
        - Occupant considerations (i.e. improved perceived control)
- Building Lighting, Appliances, Plug Loads
    - Lighting
        - LED vs. lower efficiency lighting
    - Other major appliance improvements?
- Interior design
    - Colors/textures
    - Furniture/office accessories
    - Spatial layout (esp. in open plan offices)
- Energy demand/pricing
    - Demand-response
    - Determining how tenants will be charged

Do you see certain of these retrofit opportunities being pursued more heavily in current commercial projects than others? If so, why?

4. Who is most responsible for making each of these key design decisions?

Prompts

Owner
Architect
Engineer
General Contractor
Tenant
Code/Zoning
Energy Services Company

5. **What factors go into the decision to adopt a new or non-standard technology for a building retrofit? (please specify what technology this would be)**

Prompts

Do there need to be local examples of success?
- Willing to invest in an unproven, higher risk technology if the benefits are potentially greater than for alternative, safer options?

Vendor recommendation?
Does technical literature matter?
Energy models or cost calculators?
- Anticipated payback/Net Present Value?

What about vendor or Energy Service company performance guarantees?
Are the "image" implications of adopting novel technologies over more traditional ones considered?

6. **How is the performance of these new technologies estimated? (prior to installation)**

Prompts

Vendor claims/guarantees
Engineer/architect experience
General contractor estimates
Owner experience

Technical literature information/Previous case studies (describe source)
Computer models (describe model and who runs it)
Anecdotal information

7. **What metrics are used in decision making about energy efficiency upgrades?**

Prompts

First Cost
Net Present Value
Payback period (simple or discounted)
Benefit cost ratio
Internal rate of return/return on invested capital
Increased asset value / rent

Non-financial metrics, such as LEED rating, IEQ, increased productivity.

8. **What values of these metrics must be achieved? Over what time period at what interest rate?**

9. **What are the primary sources of uncertainty to consider when making decisions about a retrofit building design?**

Prompts

Operational uncertainties
- o Projected monthly/annual energy savings
- o System/equipment maintenance and life span
- o Occupant variables
  - ▪ Uncertainty in comfort/productivity/health outcomes?

Cost-benefit analysis uncertainties
- o Length of estimated payback period (can it be guaranteed?)
- o Interest rate
- o Energy costs

- o Costs to society (included or not?)
- o Regulatory risk / policy uncertainties regarding long-term availability of government incentives

Structural uncertainties?

- o Right financial/energy model choices?

Value uncertainties?

- o What bounds do you put on the analysis? (i.e., are externalities considered, etc.)

Other assumptions?

10. How are these uncertainties normally considered in the decision making process?

Prompts

Bounded sensitivity analysis (explore a range of different assumptions or input values?)

Monte Carlo (repeated simulation of outcome based on uncertainties in parameters?)

Are there ways to establish particular values/ranges of inputs for use in these analyses?

- o Examples of values/distributions you might typically use for these analyses?
  - ▪ Example: Energy costs (what source is used to project into future?)

11. Do decision makers view energy efficiency as a way to protect against energy cost volatility and/or other uncertainties that can adversely affect the expense and effectiveness of building operation?

Prompts

Why or why not?

Is so, how is this factor incorporated in decision making?

Formally with risk-metrics or informally?

APPENDIX 3: STRUCTURED SURVEY INSTRUMENT

BUILDING RETROFIT SURVEY

Drexel University, in conjunction with the Energy Efficient Buildings (EEB) HUB, is conducting research on how people make decisions related to energy efficiency in building retrofits.

To qualify for this survey, you must have some experience with building energy retrofits in a commercial or institutional (i.e., non-residential) setting within the United States.

The entire survey takes about 20 minutes to complete.

If you have any questions about this survey, please email mah364@drexel.edu.

*** THIS SURVEY MAY ALSO BE COMPLETED ONLINE AT http://tinyurl.com/drexel-retrofit-survey ***

Completed paper copies may be mailed to:

M. Hamilton

Drexel University CAEE

3141 Chestnut Street

251 Curtis

Philadelphia, PA 19104

Q1 Are you a Drexel University student or employee?

No. Please proceed with survey.

Yes. You must provide your Drexel ID number in order to receive a gift card. What is your Drexel ID? ____________________

Q2 Sector or Industry (Check the one that best describes your sector or industry.)

- ❍ - Academic Researcher (1)
- ❍ - Consulting Architect (2)
- ❍ - Building Owner (3)
- ❍ - Contractor who provides retrofit installation, construction or building commissioning, services (4)
- ❍ - Manufacturer, Distributor or Manufacturer's Representative (5)
- ❍ - Energy Service Company (6)
- ❍ - Consulting Engineer (7)
- ❍ - Financial Institution (8)
- ❍ - Government, regulator, or policy maker (9)
- ❍ - Labor Organization (10)
- ❍ - Non-profit professional, trade, energy, development, or environmental organization (11)
- ❍ - Professional or Technical Association (12)
- ❍ - Property Management (13)
- ❍ - Real Estate Sales (14)
- ❍ - Researcher or Technology Developer (not affiliated with an academic institution) (15)
- ❍ - Urban Planning Consulting (16)
- ❍ - Utility Company (17)
- ❍ - Facilities Management (18)
- ❍ -Other (19) ____________________

Q3 Are you LEED accredited?

- ❍ Yes (1)
- ❍ No (2)

Q4 How many years you have you worked in any field related to building energy efficiency, including design, operation, maintenance, management, construction/installation, auditing, investment decision making, etc. ?

Years of experience: ______

Q5 Average % of work time spent on energy-efficient retrofits: ______ % work time

Q6 If you are a commercial/institutional building owner or work for a commercial/institutional building owner, please answer the following questions from your own perspective or your organization's perspective.

If you are not a commercial/institutional building owner but work with commercial/institutional building owners, consider a commercial/institutional building owner similar to the U.S. commercial/institutional building owner that you most recently worked with and answer the questions from their point of view.

- ❍ I am a U.S. commercial/institutional building owner or work for a U.S. commercial/institutional building owner and **will answer the questions from my own/my organization's perspective**.
- ❍ I work with U.S. commercial/institutional building owners and will answer the questions from the **perspective of the last U.S. commercial/institutional building owner I worked with.**
- ❍ I cannot answer these questions from a U.S. commercial/institutional building owner's perspective.

Q7 Retrofit Package Selection for a Hypothetical Office Building

Please consider a hypothetical 3-story, 60,000 square foot masonry commercial/institutional office building with 25% glazing (i.e., window area). It was last refurbished about 20 years ago. It has single pane windows, and three roof-top, constant-air-volume units (RTUs) with electric cooling (COP 3) and hydronic heating (by a central boiler with 70% efficiency). The envelope meets ASHRAE 90.1-1989 code requirements. Interior lighting is a mixture of incandescent lighting and T-8 fluorescent lighting. The building undergoes periodic commissioning. Accordingly the HVAC system is well balanced and otherwise well maintained.

Assume the subsystems in this building need to be replaced as they are nearing the end of their useful life. Assume that for the baseline, you replace all energy-related subsystems with the most inexpensive up-to-date counterparts. Other options allow you to selectively make upgrades to some of these subsystems.

Q9 You must assume that this building is either occupied by the owner, or that it is leased by the owner to a tenant or tenants. Which will you assume?

- ❍ I will assume that the building owner occupies the building.
- ❍ I will assume that the building owner leases out space in the building to other tenants but that the building owner pays the utility bills.
- ❍ I will assume that the building owner leases out the space in the building to other tenants and that those tenants pay their own utility bills.

Q9B You must assume this building is located in a specific state and city:

In what state is the hypothetical building you are considering located? (for example, "FL" or "Florida"):

State:_______________

In what city or metropolitan area is the hypothetical building you are considering located in?

City/metro area:__________________

Q9C Which category best describes the organization that owns this building?

- ❍ Private sector, publicly traded for-profit
- ❍ Private sector, privately held for-profit
- ❍ Government-owned
- ❍ Ownership shared between government and private sector
- ❍ Non-profit institution

Q10A For the building previously described, please rate each of the following retrofit technologies in terms of potential attractiveness for inclusion in an energy-efficient retrofit on a scale from 1 to 5 where 1=very unattractive (should not be included in a retrofit for any of a variety of reasons, such as, will not produce energy savings that justify initial cost, will not be reliable, will cause problems for occupants, etc.) and 5=very attractive (should be included in retrofit, will produce energy savings justifying initial cost, will be reliable, will provide benefits to occupant productivity or comfort, etc.).

	No experience	1. Very unattractive	2. Unattractive	3. Neutral	4. Attractive	5. Very attractive
T-5 Lighting upgrade (replace T-8 lighting with T-5 lighting) (1)	❍	❍	❍	❍	❍	❍
LED Lighting upgrade (replace T-8 lighting with light emitting diode lighting) (2)	❍	❍	❍	❍	❍	❍
Shading (screens or overhangs to reduce solar gain during summer) (3)	❍	❍	❍	❍	❍	❍
Double pane window upgrade (replacing single-pane glazing with double-pane glazing which has an air-gap) (4)	❍	❍	❍	❍	❍	❍
White roof upgrade (applying a white, reflective coating to the existing roof) (5)	❍	❍	❍	❍	❍	❍
Green roof upgrade (applying a fairly-adiabatic vegetative structure to the existing roof) (6)	❍	❍	❍	❍	❍	❍
Insulated roof upgrade from R-15 to R-30 (7)	❍	❍	❍	❍	❍	❍
Insulated walls upgrade from R-6 to R-11 (8)	❍	❍	❍	❍	❍	❍
Weatherization (reducing envelope leakage through sealing cracks, etc.) (9)	❍	❍	❍	❍	❍	❍

Q10B For the building previously described, please rate each of the following retrofit technologies in terms of potential attractiveness for inclusion in an energy-efficient retrofit on a scale from 1 to 5 where 1=very unattractive (should not be included in a retrofit for any of a variety of reasons, such as, will not produce energy savings that justify initial cost, will not be reliable, will cause problems for occupants, etc.) and 5=very attractive (should be included in retrofit, will produce energy savings justifying initial cost, will be reliable, will provide benefits to occupant productivity or comfort, etc.).

	No experience	1. Very unattractive	2. Unattractive	3. Neutral	4. Attractive	5. Very attractive
Variable-air-volume (VAV) system upgrade plus associated control system (including replacing existing CAV boxes to be VAV boxes, equipping the supply fans with VFDs, and upgrading the control systems accordingly)	❍	❍	❍	❍	❍	❍
Radiant Heating/Cooling and Dedicated Outdoor Air System (completely replacing the HVAC and duct systems with a system employing radiant heating and cooling subsystems and a duct system designed for transporting ventilation air only.)	❍	❍	❍	❍	❍	❍
Switching to heat pump system (heating and cooling is replaced with air-to-air heat pumps with a COP of 4 in cooling mode)	❍	❍	❍	❍	❍	❍
Switching to ground-source heat pump system (replacing existing heating and cooling systems with geothermal heat pumps with a cooling COP of 6 and electrical auxiliary heating system)	❍	❍	❍	❍	❍	❍
High-efficiency cooling upgrade (upgrading current RTUs to have a COP of 5)	❍	❍	❍	❍	❍	❍

Q10C For the building previously described, please rate each of the following retrofit technologies in terms of potential attractiveness for inclusion in an energy-efficient retrofit on a scale from 1 to 5 where 1=very unattractive (should not be included in a retrofit for any of a variety of reasons, such as, will not produce energy savings that justify initial cost, will not be reliable, will cause problems for occupants, etc.) and 5=very attractive (should be included in retrofit, will produce energy savings justifying initial cost, will be reliable, will provide benefits to occupant productivity or comfort, etc.).

	No experience	1. Very unattractive	2. Unattractive	3. Neutral	4. Attractive	5. Very attractive
Central boiler upgrade from 70% to 95%	❍	❍	❍	❍	❍	❍
Central chiller plant upgrade (replacing existing RTU systems with chiller + AHU systems with a central chiller having a COP of 5)	❍	❍	❍	❍	❍	❍
Combined heat and power (CHP) system (combined heat and power system which is sized so that heat generated can meet peak heating demand)	❍	❍	❍	❍	❍	❍
Commissioning (a one-time process of examining the whole building systems including recalibrating sensors and balancing air systems)	❍	❍	❍	❍	❍	❍
Smart grid controls / metering (assumes that the building level demand energy will be reduced by 15% through measures such as dimming lights during times of peak demand)	❍	❍	❍	❍	❍	❍

Q10D For the building previously described, please rate each of the following retrofit technologies in terms of potential attractiveness for inclusion in an energy-efficient retrofit on a scale from 1 to 5 where 1=very unattractive (should not be included in a retrofit for any of a variety of reasons, such as, will not produce energy savings that justify initial cost, will not be reliable, will cause problems for occupants, etc.) and 5=very attractive (should be included in retrofit, will produce energy savings justifying initial cost, will be reliable, will provide benefits to occupant productivity or comfort, etc.).

	No experience	1. Very unattractive	2. Unattractive	3. Neutral	4. Attractive	5. Very attractive
Temperature Reset Strategy (thermostat is programmed to minimize heating and cooling during unoccupied times and is adjusted higher in summer and lower in winter) (1)	❍	❍	❍	❍	❍	❍
Daylighting (add a lighting control system to dim perimeter lighting when outdoor lighting is sufficient) (2)	❍	❍	❍	❍	❍	❍
Plug load control (more efficient equipment, better management of equipment, etc.) (3)	❍	❍	❍	❍	❍	❍
Occupancy sensors (implementing occupancy sensors for use in lighting management and thermostat control) (4)	❍	❍	❍	❍	❍	❍
High efficiency elevator upgrade (using new variable speed drives that consume 50% less power)	❍	❍	❍	❍	❍	❍
Photovoltaic (solar) installation (assumes system covers 50% of the roof area by fixed (non-tracking) panels)	❍	❍	❍	❍	❍	❍

Q11 Based on the information on Break-even Time in the matrix below, please choose the retrofit package you think would be most likely to be selected for an energy-efficient retrofit of the hypothetical building previously described. Choose one option only.

	Break-even time for investment in energy-efficient upgrades (range reflects uncertainty in projections)
Option 1 (baseline)	N/A (no upgrades)
Option 2	2.3 - 3.9 yrs
Option 3	3.1 - 5.2 yrs
Option 4	4.6 - 7.8 yrs
Option 5	5.4 - 9.1 yrs
Option 6	7.7 - 13.0 yrs
Option 7	11.5 - 19.5 yrs

- ❍ Option 1 (baseline -- no upgrades)
- ❍ Option 2
- ❍ Option 3
- ❍ Option 4
- ❍ Option 5
- ❍ Option 6
- ❍ Option 7

Q12 Given the additional information on Incremental Return on Investment in the matrix below, please choose the retrofit package you think would be most likely to be selected for an energy-efficient retrofit of the hypothetical building previously described. All other information is the same. Choose one option only.

	Break-even time for investment in energy-efficient upgrades (range reflects uncertainty in projections)	**Incremental rate of return** (on additional money relative to previous option)
Option 1 (baseline)	N/A (no upgrades)	N/A (no upgrades)
Option 2	2.3 - 3.9 yrs	25% to 43% (relative to Option 1)
Option 3	3.1 - 5.2 yrs	13% to 23% (relative to Option 2)
Option 4	4.6 - 7.8 yrs	7% to 15% (relative to Option 3)
Option 5	5.4 - 9.1 yrs	3% to 10% (relative to Option 4)
Option 6	7.7 - 13.0 yrs	-3% to 2% (relative to Option 5)
Option 7	11.5 - 19.5 yrs	-9% to -13% (relative to Option 6)

Q13 Of the metrics given in the previous question, which metric most influenced your upgrade package decision?

- ❍ Break-even time for investment in energy-efficient upgrades
- ❍ Incremental rate of return on investment

Q14 Please select the additional financial metric, if any, you would most like to see for the previous upgrade package selection decision.

- ❍ No additional metrics
- ❍ First cost
- ❍ Net present value (NPV)
- ❍ Benefit cost ratio
- ❍ Other (please specify) ____________________

Q15 Please rank-order the following retrofit packages from 1 to 9 **(1=most desirable, 9=least desirable)** in terms of which would most merit consideration and evaluation for the hypothetical building previously described.

Use each number only once!

Your ranking	**Break-even time for investment in energy-efficient upgrades** (based only on projected energy cost savings)	**Change in Employee Productivity** (increased proficiency, less absenteeism)	**Change in Pollutant Emissions due to energy consumption** (airborne, waterborne, fine dust) (negative sign implies a reduction)	**Performance Contract Guarantee** (does not affect first cost)
	10.0 years	0% (no change)	-5%	Yes
	10.0 years	-2%	-50%	No
	6.0 years	+10%	-5%	No
	6.0 years	-2%	-25%	Yes
	6.0 years	0% (no change)	-50%	Yes
	3.0 years	-2%	-5%	Yes
	3.0 years	+10%	-50%	Yes
	10.0 years	+10%	-25%	Yes
	3.0 years	0% (no change)	-25%	No

Q16 How do you expect the **overall cost of goods and services** (for example, the cost of living as estimated by the Consumer Price Index) to change in the future?

Over the next 5 years, I expect the overall cost of goods and services (as represented by the Consumer Price Index) to ***increase/decrease (circle one)*** by ____% per year on average.

Over the next 20 years, I expect the overall cost of goods and services (as represented by the Consumer Price Index) to ***increase/decrease (circle one)*** by ____% per year on average.

Q17 How do you expect the **cost of energy** (natural gas, oil, electricity, etc.) to change in the future?

Over the next 5 years, I expect the **overall cost of energy** (natural gas, oil, electricity, etc.) to ***increase/decrease (circle one)*** by ____% per year on average.

Over the next 20 years, I expect the **overall cost energy** (natural gas, oil, electricity, etc.) to ***increase/decrease (circle one)*** by ____% per year on average.

Please answer the following questions from your own point of view. The information in these questions does not relate to any information given previously in this survey.

Q18 For the following questions, people consider two buildings, Building A and Building B. They are identical, except that Building B is more energy efficient than Building A. For two otherwise identical units in Buildings A and B, what do you think is the most tenants would be willing to pay in additional monthly rent for a unit in Building B if their monthly energy costs in Building B would be $100 lower than for an otherwise identical unit in Building A?

- $0 more a month (1)
- $25 more a month (2)
- $50 more a month (3)
- $75 more a month (4)
- $100 more a month (5)
- $125 more a month (6)
- $150 more a month (7)
- $175 more a month (8)
- $200 more a month (9)

Q19 If the energy efficiency of Building B was advertised as **good for American energy independence and the reduction of dependence on foreign oil**, what do you think is the most tenants would be willing to pay in additional monthly rent for a unit in Building B if their monthly energy costs in Building B would be $100 lower than for an otherwise identical unit in Building A?

- $0 more a month (1)
- $25 more a month (2)
- $50 more a month (3)
- $75 more a month (4)
- $100 more a month (5)
- $125 more a month (6)
- $150 more a month (7)
- $175 more a month (8)
- $200 more a month (9)

Q20 If the energy efficiency of Building B was advertised as **good for the environment and the reduction of carbon emissions**, what do you think is the most tenants would be willing to pay in additional monthly rent for a unit in Building B if their monthly energy costs in Building B would be $100 lower than for an otherwise identical unit in Building A?

- $0 more a month (1)
- $25 more a month (2)
- $50 more a month (3)
- $75 more a month (4)
- $100 more a month (5)
- $125 more a month (6)
- $150 more a month (7)
- $175 more a month (8)
- $200 more a month (9)

Q21 If the energy efficiency of Building B was advertised as **good for lowering the cost of energy use and the reduction of tenant's energy bills**, what do you think is the most tenants would be willing to pay in additional monthly rent for a unit in Building B if their monthly energy costs in Building B would be $100 lower than for an otherwise identical unit in Building A?

- $0 more a month (1)
- $25 more a month (2)
- $50 more a month (3)
- $75 more a month (4)
- $100 more a month (5)
- $125 more a month (6)
- $150 more a month (7)
- $175 more a month (8)
- $200 more a month (9)

Q22 In general, politically I consider myself:
- Very Liberal (1)
- Liberal (2)
- Somewhat Liberal (3)
- Moderate (4)
- Somewhat Conservative (5)
- Conservative (6)
- Very Conservative (7)

Q23 On economic issues, politically I consider myself:
- Very Liberal (1)
- Liberal (2)
- Somewhat Liberal (3)
- Moderate (4)
- Somewhat Conservative (5)
- Conservative (6)
- Very Conservative (7)

Q24 On social issues, politically I consider myself:
- Very Liberal (1)
- Liberal (2)
- Somewhat Liberal (3)
- Moderate (4)
- Somewhat Conservative (5)
- Conservative (6)
- Very Conservative (7)

Q25 Politically, which group do you most identify with:
- The Democratic Party (1)
- The Republican Party (2)
- Independents (3)
- Other; Please Specify: (4) ____________________

Q26 Please select which gift card type you would like.
- Target (1)
- Amazon (2)

- ❍ Starbucks (3)

Q27 Please provide your mailing address to have the gift card mailed to you. Your address will not be linked to your survey responses and will not be shared or made public, per IRB regulations.

Recipient name:____________________________________

Street address:_____________________________________

Unit number, suite number:___________________________

City:____

State/Province:_____________________________________

Zip code:____

Email address:______________________________________

Q28 Thank you for participating in our survey. We appreciate any comments you may have:

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