Energy Research & Social Science 47 (2019) 37–45

Contents lists available at ScienceDirect

Energy Research & Social Science

journal homepage: www.elsevier.com/locate/erss

Original research article

Neither a borrower nor a lender be: Beyond cost in energy efficiency decision-making among office buildings in the United States

Alexander Davis*, Gabrielle Wong-Parodi, Tamar Krishnamurti

Department of Engineering and Public Policy, Carnegie Mellon University, 5000 Forbes Avenue, United States

ARTICLE INFO

Keywords:
Energy efficiency
Decision-science
Debt aversion
Uncertainty

ABSTRACT

Even when the benefits seem to outweigh the costs, many building owners do not invest in energy efficiency. Here a framework is presented for understanding energy efficiency investment decisions drawing on methods from behavioral decision research. The approach begins with a normative analysis that characterizes how building owners should behave, compares this to interview and survey data from decision-makers, then concludes with policy recommendations suggesting how to bridge that gap. The framework is demonstrated with a sample of class B and C office building owners in Pittsburgh, a population believed to under-invest in energy efficiency. Interviews (n = 16) and a survey (n = 132) found that while uncertainty and a lack of information about costs and energy savings play a critical role in decision-making, a significant proportion of the respondents also express aversion to debt and a lack of sensitivity to split incentives. Based on the results, providing owners of class B and C offices cost–benefit information and resolving energy savings uncertainty through guarantees, trial periods, or grants that fully subsidize energy efficiency for a small part of a building may be a way to enhance investment. The approach can be applied to other energy efficiency decision-making contexts by anyone with training in behavioral research.

1. Introduction

Energy efficiency is one of the most important tools for mitigating climate change [1], and the commercial buildings sector has a large potential for implementing cost-effective energy efficiency improvements (e.g., occupancy sensors) [2]. Unfortunately, this sector also has a track record of slow market diffusion of energy efficiency improvements [3–5]. To better understand the causes of this slow diffusion, researchers have examined the barriers faced by owners of commercial buildings. However, work has solely focused on larger commercial buildings, that face very different constraints (e.g., corporate social responsibility [6,7]) than smaller commercial buildings, that are informally rated as class B or C according to their value, amenities, and expected rental price.[1]

To understand the decision-making of owners of class B and C offices, the present paper uses the tripartite analytical approach of behavioral decision research [8], an approach that has been applied across a variety of domains, from health decisions [9] to energy policies [10] and decisions related to climate and energy systems [11,12]. von Winterfeldt and Edwards [8] divide the approach into three components: (1) a *normative analysis*, considering when and why a building owner with economically focused and well-constructed preferences should invest in energy efficiency,[2] (2) a *descriptive analysis*, complementing existing behavioral findings by using interviews and a survey to identify the concerns that actually matter to building owners, and (3) a *prescriptive analysis* that suggests how energy efficiency program designers, such as utilities or regulators, might use the results to improve program performance. The approach embraces both the formalism of decision analysis [13] and the empiricism of complementary social sciences (e.g., psychology, anthropology, sociology), using normative analyses to carefully specify the decision problem, and descriptive analyses to test that characterization and allow new results to emerge. The approach is illustrated using the energy efficiency investment decisions of owners of class B and C offices in Pittsburgh PA.

1.1. Normative analysis

The normative analysis in this work draws on previous research

* Corresponding author.
E-mail addresses: alexdavis@cmu.edu (A. Davis), gwongpar@cmu.edu (G. Wong-Parodi), tamar@cmu.edu (T. Krishnamurti).

[1] http://www.boma.org/research/pages/building-class-definitions.aspx.

[2] While the meaning of the term "normative" varies across contexts, here normative means the analyst's conception of what a rational decision-maker should do given a description of the decision problem.

https://doi.org/10.1016/j.erss.2018.08.008
Received 15 July 2017; Received in revised form 4 August 2018; Accepted 11 August 2018

investigating influences on energy efficiency decision making [14–20]. It focuses on four factors that have substantial theoretical and empirical support, and were relevant from informal discussions with experts familiar with class B and C offices. These four factors are necessary conditions for investment by building owners with economically focused preferences: (1) low uncertainty in energy savings, (2) capital availability, (3) time preference, and (4) incentive alignment between landlord and tenant. These are normative influences on decision-making because they are consistent with the axioms of rational preferences [21], and how those preferences should be related over time [22].

First, building owners should be wary about investing in energy efficiency if the energy savings are uncertain, depending on the occupancy patterns of the building, weather, and technology performance [14,23]. For example, in one study of 447 commercial buildings retrofitted with energy saving measures, Greely *et al.* [24] found that most (two-thirds) of the actual energy savings deviated from the predicted energy savings by more than 20%. Investing in energy efficiency means that the building owner accepts this uncertainty, with its potential downside. As expected from this analysis, homeowners in the residential sector [25,26] who are more risk averse are less likely to invest in energy efficiency. Second, building owners may not purchase energy efficient equipment because they simply do not have enough money to pay the up front capital costs [27]. There is evidence that some firms are unwilling (or unable) to use debt to finance energy efficiency investments [28]. Third, rewards in the future are often discounted, tipping the balance against energy efficiency, that promises delayed rewards (energy savings) in exchange for immediate capital costs [27]. Previous economic studies have found that the discounting of energy savings is both large and variable [29,30]. Finally, building owners do not always directly benefit from investments that make their building more energy efficient because in many buildings tenants pay the utility bills. For example, Schleich [31] conducted a cross-sectional survey of 2000 organizations in the commercial and services building sector in Germany and found that buildings with renters tended to be less likely to adopt at least half of the relevant energy efficiency measures for their building compared to owners that also occupied the building.

To characterize these normative issues we present the following simple mathematical model of an idealized energy efficiency investment decision. According to this model, building owners should invest if the annual time-discounted and uncertainty-adjusted sum of the energy savings (ES) from an investment is greater than the annual time-discounted (but certain) sum of the annual cost (AC) of that investment:

$$\sum_{j=1}^{J} \frac{\mathrm{ES}_j}{(1+\delta^*+\delta^o)^j} > \sum_{j=1}^{Q} \frac{\mathrm{AC}}{(1+\delta^*)^j} \tag{1}$$

Here, ES_j is the annual energy savings in year $j \in \{1, 2, \dots J\}$ that accrue to the building owner (not the tenants), δ^* is the risk-free discount rate (the market interest rate that would provide building owners a rate of return of δ^* per year for sure), δ^o (where "o" stands for "other") is the rate at which the energy savings are discounted above and beyond the risk-free rate (e.g., taking other factors into account, such as uncertainty). AC is the annual cost of a fully amortized loan (or building owner's capital if self-financed) over $j \in \{1, 2, \dots Q\}$ years:

$$\mathrm{AC} = P \times \frac{i(1+i)^q}{(1+i)^q - 1} \tag{2}$$

where P is the capital cost, i is the effective annual interest rate, and q is the number of years of the loan. The normative analysis holds that an energy efficiency investment must: (1) provide a rate of return greater than market alternatives (time discounting, δ^*), (2) provide that rate of return with enough certainty (uncertainty aversion, δ^o), (3) be within the budget or financing constraints of the building owner (capital constraints, AC), and (4) provide financial benefit to the building owner, not just the tenants (split incentives). Further, the analysis considers only narrow self interest, as opposed to broader altruistic environmental concerns, as well as assumes that the building does not face other regulatory constraints such as new building codes.

1.2. Descriptive analysis

The normative analysis specifies what building owners should care about, if their preferences adhere to the axioms of rational choice and they value only economic outcomes. In reality, descriptive studies have demonstrated violations of these axioms, reflecting the use of a number of simplifying choice heuristics [32–34], and concerns other than the economics of investments, such as social and organizational factors [35]. For example, cognitive studies in the decision sciences find that decision processes are swayed by the characteristics of available options and salient reference points [36,37]; that people are often uncertain about what they want [38–40] and give different responses to choice tasks that are logically identical but described differently [41]; and that decisions made over time reflect more than pure time preferences [22]. Studies looking at social factors have found that people are influenced by social norms, doing what they think others do, or following social rules that they believe society prescribes [42]; that people care about things other than money, such as the harm done to others by air pollution [43–45]; and that subtle cues about what is expected of them can change energy conservation behavior [46]. Thus, the normative analysis is contrasted with descriptive research using interviews and a survey of class B and C office building owners in Pittsburgh, to determine whether and to what extent the normative analysis captured their concerns. Our descriptive analysis focuses on individual decision-making (rather than group or organizational decisions), because individuals are the dominant owners of class B and C offices in our sample (both from the database we compiled and their self-reports).

To conduct the descriptive analysis, data were obtained on building class and owner contact information from a combination of sources, including the commercial real estate database firm CoStar,[3] real estate searches using the Allegheny County Assessment, deed searches in the Allegheny County records, and other internet sources (e.g., Googling). Our sample frame included the entire population of class B and C offices in Pittsburgh, including 327 owners of 504 buildings.

2. Interviews

The descriptive analysis began with 16 semi-structured interviews [47,10] conducted in-person or by phone. These interviews started with an unstructured section, giving us an opportunity to learn what building owners had on their mind, followed by a structured section, where specific topics of the normative analysis were examined in greater detail.

2.1. Interview recruitment and participants

Interviewees were recruited by cold-calling building owners for whom contact information was publicly available. The interviews lasted about an hour and interviewees were compensated with $50 in cash or a gift card. Interviewee ages ranged from 38 to 91 years; the majority of interviewees were male, and one was female, reflecting the skew toward male owners in the population; they had a variety of professions including business owner, marketing professional, real estate manager, physician, school teacher, financial advisor, and engineer; their education levels spanned a wide range, from bachelor's degree to PhD; their reported gross annual income from the building ranged from $−40, 000 (a loss) to a $2, 000, 000 gain; their buildings ranged in size from 2500 ft^2 to 150,000 ft^2; about half were class B and half were class C

[3] http://www.costar.com/.

buildings; and 10/16 interviewees also occupied space in the building they owned.

2.2. Interview results

The interviews began with an unstructured section, where owners were asked to talk about their buildings and energy systems in general, then focused sections on energy efficiency getting at normative issues, including a hypothetical heating system replacement scenario, and hypothetical choices among programs designed to help them replace their heating systems. The interviews were coded and analyzed using a formal coding scheme implemented by three research assistants. Below are those findings most relevant to the normative analysis.

First, no interviewee spontaneously mentioned uncertainty in the energy savings as an issue of concern. Furthermore, when asked whether they would want a guarantee of the energy savings, a few said that they did not want one because guarantees were not possible in this domain.

Second, no interviewee specifically mentioned the time value of money (a discount rate), although a few who purchased the building as an investment property mentioned specific thresholds for return on investments that they would consider attractive. For example, Owner 9 said:

> "My criteria for my return is very simple: I look at the safe investment return available on the market, and the safe investment return in the market today is generally in a S&P 500 stock fund, that could be 5%, or in a certificate of deposit, that could be 2.5%. If I could double that … I'm willing to do it." (Owner 9)

Third, when asked about how they paid for improvements to their building in the past, about half of the interviewees (which constituted 7/10 owner-occupiers) tended to use their own financing for improvements. They said things like:

- "I didn't borrow any money." (Owner 6)
- "… everything has been cash." (Owner 7)
- "… well basically I paid cash for it." (Owner 10)

Fourth, when asked about who pays the energy bills in their building and whether that matters, interviewees did not consider it a big issue. Instead, many spontaneously mentioned that their main goal was tenant retention. Additionally, many interviewees relied on their contractors for information, and had strong ties with them:

- "… you pretty much go with what the people selling it to you tell you, or someone who gives you advice on that … A lot has to do with the person you're dealing with and the person he deals with … So if the guy is a Lennox dealer, then you go with a Lennox unit." (Owner 4)
- "These are people that, for the most part, people we have worked with for many many years." (Owner 16)

In sum, the semi-structured interviews revealed that interviewees: (1) did not spontaneously consider uncertainty in energy savings, (2) infrequently considered the time value of their money, (3) rarely used financing for improvements to their buildings, (4) were more concerned about tenant retention than energy bills, and (5) often had relationships with contractors that helped them scope potential projects. These initial findings highlight the strength of the normative analysis to raise issues that might be otherwise overlooked, as reflected in issues of uncertainty and time preference. One surprise was that interviewees rarely used financing, in contrast to our normative analysis where building owners should use financing if the cost of the financing is less than the building owner's cost of capital. Although suggestive, the interview results are limited by the small sample size, so we explored these issues further in a follow-up survey.

3. Survey methods

Following these initial interviews, a survey was conducted to evaluate whether the views that emerged from the interviews were reflected in the broader population. The survey was pretested with 10 members of the population to determine whether they understood the questions and interpreted them as intended. Using the building owner database, an attempt was made to recruit all 327 building owners to participate in the survey. They were sent an initial recruitment mailing in early November 2014, including the survey, cover letter, an addressed stamped return envelope, and a $10 cash incentive. The cover letter included the building owner's name or the name of the building owner's holding company if the name could not be determined. If owners had not responded in two weeks they were sent a follow-up postcard reminding them to return the survey. The postcard also provided them a link to participate online. Two weeks after the postcard was sent, attempts were made to contact owners in person. After these in-person visits, attempts were made to contact non-responders by phone or email. Approximately one month after the in-person contacts we sent a second mailing wave with the survey, cover letter, an addressed stamped return envelope, and a $10 cash incentive. In total, 132 of 327 (40%) building owners responded to the survey. Characteristics of the population and sample are described in detail in the SI section 1. One notable sample selection limitation was that, even though owner-occupiers accounted for the majority of the population, the sample was biased toward owner-occupiers, likely because their contact information was easier to obtain from county records and other sources. Because most (74% or 72/97 that answered the question) of the respondents were owner-occupiers, comparisons of the responses of this group to building owners who did not occupy the building were not possible.

4. Survey results

4.1. Choices

The survey began with two hypothetical choices about energy efficient lighting improvements to respondents' buildings. Lighting was chosen because it accounts for about one-third of energy used in offices, many lighting improvements are cost-effective, and lighting is the most frequent target for energy efficiency improvements [48].[4] Each choice provided respondents with information about the costs and benefits of a new energy efficient technology (see SI section 2 for calculations), and asked whether they would prefer the new technology or the status quo. While the normative analysis does not dictate any particular response to these questions, responses were used in later comparisons and to measure interest in energy efficiency, finding a high level. The choices are shown in Tables 1 and 2, with the number of respondents choosing each option shown in brackets below each table.

Table 1 shows that, of the 117 responses to the question about occupancy sensors (89% responding), 67 respondents indicated they would invest in occupancy sensors (57% of respondents). At the end of the survey, respondents were asked whether they had already installed occupancy sensors, with 34 indicating that they had already made that upgrade (26%). Table 2 shows that, of the 116 responses to this question (88% responding), a substantial majority (76) indicated that they would upgrade the linear fluorescents (66% of respondents). Individuals' choices for the two lighting upgrades were also correlated (Pearson's $r = .47$, $p < .01$). In sum, most respondents were favorable toward investing in their building's lighting systems yet had not made

[4] We also included a heating system choice task that produced very similar results to the lighting task. Out of 97 respondents, 88% (=85/97) chose a more expensive higher energy saving option and 12% (12/97) chose a less expensive lower energy saving option.

Table 1
Information shown to respondents about investing in occupancy sensors, and the number stating they would invest (in brackets below).

	Option A Occupancy sensors	Option B No change
Installed cost	$125 per sensor	$0
Annual energy cost savings	$52 per year, per sensor	$0
Lifetime	14 years	
Time to pay back	2.40 years	
	[67]	[50]

Table 2
Information shown to respondents about investing in linear fluorescents, and the number stating they would invest (in brackets below).

	Option A New linear fluorescent	Option B No change
Installed cost	$55 per fixture	$0
Annual energy cost savings	$11 per year, per fixture	$0
Lifetime	14 years	
Time to pay back	5 years	
	[76]	[40]

the investment, suggesting that other issues (e.g., uncertainty) stood in the way of making that choice. Those issues are explored in the next sections.

4.2. Uncertainty and information

To better understand whether uncertainty was one of those issues, respondent attitudes were measured with respect to a number of services that could help make it easier for them to invest in energy efficient lighting systems. Consistent with the normative analysis, but contrasting with the interviews, uncertainty played a critical role in their decision-making. Respondents were asked the following question:

> "Suppose the following services could be provided to help you improve the energy use of your building's lighting systems. Tell us what you think about each of them using a rating from −3 to +3 described in the scale below."

The scale was 7 points with labels "very unhelpful" (−3), "moderately unhelpful" (−2), "slightly unhelpful" (−1), "neither helpful nor unhelpful" (0), "slightly helpful" (+1), "moderately helpful" (+2), and "very helpful" (+3). The services were described in the following order:

- *Energy Saving Comparables*: Data on the energy savings in buildings comparable to yours that improved their lighting systems.
- *Energy Savings Assessment*: Assessment by an engineer or architect about the energy saving potential of improved lighting systems.
- *Economic Assessment*: A cost–benefit analysis of lighting system improvements most relevant for your building.
- *Contractor Vetting*: Vetting of potential contractors based on quality, reliability, and customer satisfaction.
- *Energy Tracking*: Assistance in tracking your building's energy use with energy management software.
- *Contractor Scorecard*: A public scorecard showing how well potential lighting contractors have performed in the past.
- *Guarantee*: A guarantee that you will save a certain percent on your electricity bills if you improve your lighting systems.
- *Lease Structuring*: Assistance in creating a lease structure that allows tenants to pay for part of the cost of the lighting systems (skip this question if your building does not have tenants).

Table 3
Attitudes toward decision-making services. Items with different superscripts denote $p < .05$ according to the Wilcoxon Signed Ranks Test.

Service	−3	−2	−1	0	+1	+2	+3	Mean	SD	*n*
Guarantee	1	1	1	14	12	27	69	2.1^a	1.2	125
Economic Assessment	1	1	0	12	13	39	61	2.1^a	1.1	127
Energy Assessment	1	1	1	13	25	34	52	1.9^b	1.2	127
Energy Comparables	4	2	0	19	25	29	47	1.7^c	1.5	126
Energy Tracking	1	3	1	35	28	20	38	1.4^d	1.4	126
Contractor Vetting	2	3	3	36	20	22	38	1.3^d	1.5	124
Contractor Scorecard	1	1	1	41	29	21	33	1.3^d	1.3	127
Lease Structuring	5	4	1	33	12	14	23	1.3^e	1.3	92

As seen in Table 3, respondents were most favorable toward the energy savings guarantee, which would reduce the uncertainty associated with project benefits (in the form of energy savings). They were equally favorable toward an economic assessment that would provide information about the costs and benefits of energy efficiency investments. Both were rated significantly higher (according to a Wilcoxon Signed Ranks Test,[5] W_{sr}) than the next highest service, an energy assessment.

To see whether the guarantee reflected the same concern as the economic assessment, a maximum likelihood factor analysis with varimax rotation was used (see SI section 3) [51]. A two factor solution provided two grouping factors [52], with the economic assessment, energy assessment, and energy comparables all loading on the first factor, while the guarantee, contractor vetting, and contractor scorecard loaded on the second factor. As expected from the normative analysis, these results suggest that respondents were concerned about how much energy they would actually save. Interestingly, this concern reflected uncertainty about project performance more broadly (not just the technology), as indicated by the high correlations of contractor vetting and contractor scorecard on the second factor (along with the guarantee). Furthermore, they also wanted information about the costs and benefits of those investments, and that uncertainty about project performance and information about costs and benefits are separable concerns.

4.3. Capital constraints

The next section explored whether respondents faced capital constraints, finding that most could pay for energy efficiency investments themselves. Specifically, respondents were asked:

1. "How much do you think it would cost to buy and install new linear fluorescent lamps, ballasts, and fixtures in your entire building?"
2. "Could you pay for that without getting external financing?"

Out of 110 responses to the second question, 87 (79%) indicated they could pay for the lighting improvements out of pocket, while 22 said they could not, suggesting capital constraints were a problem for only a minority of the sample (Table 4).

4.4. Time discounting

Although most respondents could pay for the improvements themselves, whether they prefer to pay themselves (or use debt) should

[5] The Wilcoxon Signed Ranks Test subtracts the ratings each participant gave to one item (e.g., Guarantee) from another item (e.g., Energy Assessment), finds the magnitude of that difference, ranks the magnitudes, then signs the ranks based on whether the rating given to the first item or second item was greater. Under the null hypothesis that the two items come from population distributions with paired differences normally distributed around zero, the sum of the negative and positive ranks should be equal [49,50].

Table 4
Factor analysis of decision-making service attitudes. Bold items indicate that the item-factor correlation is greater than 0.4.

Item	Factor 1	Factor 2	Uniqueness
Guarantee	0.11	**0.50**	0.74
Economic Assessment	**0.88**	0.14	0.21
Energy Assessment	**0.86**	0.16	0.23
Energy Comparables	**0.53**	0.37	0.58
Energy Tracking	**0.42**	0.35	0.70
Contractor Vetting	0.27	**0.60**	0.57
Contractor Scorecard	0.15	**0.90**	0.18
Eigenvalue	2.1	1.7	
% Variance Explained	0.3	0.24	
Cumulative Variance	0.3	0.54	

normatively depend on their time preferences. This was explored with the following question:

> "Suppose you could lend that same amount of money to a commercial bank. The bank would pay you back in monthly installments, plus interest. What is the minimum annual interest rate you would have to be paid to lend this money? Assume the bank will definitely pay you back (there is no risk)."

The answer to this question can be used to identify the next best investment respondents can make with their money, as those who require a higher interest rate to lend money should also require a higher rate of return on an energy efficiency investment, to compensate for the lost opportunity to invest elsewhere. Because there was no risk in this investment it is denoted δ^*, the respondent's risk-free discount rate. Of the 132 respondents, 79 answered this question. Respondents' δ^* ranged from 0% to 15% (median = 5%, mean = 5.3%, SD = 2.8%). Because the rate of return from the linear fluorescents and occupancy sensors was above the risk-free discount rate for all respondents (20% and 42%, respectively), every respondent who could pay for the lighting improvement themselves should (if they perceived the energy savings as risk free). However, 26 of the 76 respondents (34%) who could pay for the linear fluorescents and 34 of the 77 respondents (44%) who could pay for the occupancy sensors indicated they would not invest.

The finding that respondents did not invest purely based on their risk-free discount rate suggests that an investment in energy efficiency was not seen as the same thing as a certain return from a bank. To capture the characteristics of energy efficiency that might account for this discrepancy, we asked respondents about their willingness to pay interest on a loan for energy efficiency:

> "If you were to take out a loan from a commercial bank to finance this, what is the maximum annual interest rate that you would be willing to pay?"

Respondents should only be willing to take out a loan (paying some annual amount for sure) in exchange for energy efficiency if they think the annual benefits are greater than the annual costs. Thus, the maximum annual interest rate at which respondents are willing to borrow estimates where these annual benefits and costs are perceived to be equal. There were 82 responses to this question with respondents giving a range of maximum borrowing interest rates from 0% to 10% (median = 4%, mean = 3.63%, SD = 1.8%). Using a Wilcoxon Rank Sum Test[6] (W_{rs}), those who rejected the occupancy sensors gave lower annual interest rates, suggesting they expected lower economic benefits (W_{rs} = 2.6, p = .01). A similar pattern held for linear fluorescents (W_{rs} = 1.8, p = .08).

Using the measured risk-free discount rate δ^* and the maximum interest rate respondents indicated they were willing to pay on a loan, we compare the contribution of the rate of pure time preference relative to other factors that might reduce the perceived value of the energy savings, denoted δ^o (see SI section 4 for details). It was possible to estimate δ^o for 63 respondents, with Fig. 1 showing the bivariate scatterplot of δ^* and δ^o. As can be seen, δ^o varied from 13% to 25%, with a mean of 16% (SD = 2.3%). For almost all respondents δ^* was smaller than δ^o (W_{sr} = 2013, $p < .01$), suggesting that other factors mattered more than the time-value of respondents' money. Respondents with higher δ^o were also less likely to invest. The median δ^o was 15% among those who chose linear fluorescents (mean = 15%, SD = 2%, N = 40) and 16% among those who did not (mean = 17%, SD = 3%, N = 17). The difference in means was small (2%, Cohen's d = .8), and was statistically significant using the signed ranks test (W_{rs} = 220, p = .04), but not according to a t-test ($t(20)$ = 2, p = .10). Note that discount rates in the private sector are typically assumed to be 10-15% [48], while in the sample, taking both risk free and risk-adjusted discounting into account, the discount rates range from 17 to 35% for linear fluorescents (mean = 21%, SD = 4%).

4.5. Debt aversion

The time discounting analyses suggested respondents were considering more than the time value of money when discounting the energy savings from an energy efficiency investment. However, because of the non-response patterns in the data (with more than half not responding to all three questions about loans and loan length), these results should be interpreted carefully. Here some explanation is provided of the other issues that respondents considered and the non-response pattern, using a question that was designed to explore an extreme aversion to debt, in that choosing to pay the full cost up front implies the complete rejection of the use of debt to finance building improvements (and a negative discount rate):

> "Imagine that you have enough money to pay the full cost of the lighting improvements up front, but also have the option of making payments evenly divided across a fixed number of years. Assume there is 0% interest on the delayed payments. Which would you prefer? (Full cost up front or even payments over several years)."

- Full cost up front [$\frac{35}{115}$]
- Even payments over several years [$\frac{80}{115}$]

As can be seen, approximately one-third of respondents preferred to pay the full cost of the improvement up front (implying a zero or negative discount rate). Those who rejected the loan outright also tended to not respond to the interest rate question. Overall, of the 80 who indicated they wanted the delayed payment, 26 did not respond to both questions about interest rates (33%). In contrast, of the 35 who indicated they wanted to pay the cost up front, 22 did not respond to both interest rate questions (63%) ($\chi^2(1)$ = 8, p = .005). Thus, a substantial proportion of respondents (32 % = 42/132) refused to specify an interest rate at which they would be willing to borrow or lend money. Confirming this, respondents were also asked about their support for lower interest rates on a loan, finding that those who preferred to pay up front gave a lower median rating of 0 than those who preferred the delayed payment, with a median rating of 1 (W_{rs} = 1682, p = .04). Likewise, respondents were asked about how comfortable they felt borrowing money from a number of different organizations, again finding that those who refused loans also felt less comfortable borrowing from large banks (W_{rs} = 1752, p = .003). In sum, respondents that expressed debt aversion by rejecting the equivalent of a zero interest loan also made responses on the survey consistent with that aversion to debt, by not wanting support for lower interest loans and

[6] The Wilcoxon Ranked Sum Test ranks the interest rates ignoring which group (accepted vs. rejected the investment) the rates came from. The ranks of each of the groups are then summed. Under the null hypothesis that the two groups come from population distributions with the same mean, the sum of the ranks of the two groups should be equal [49,50].

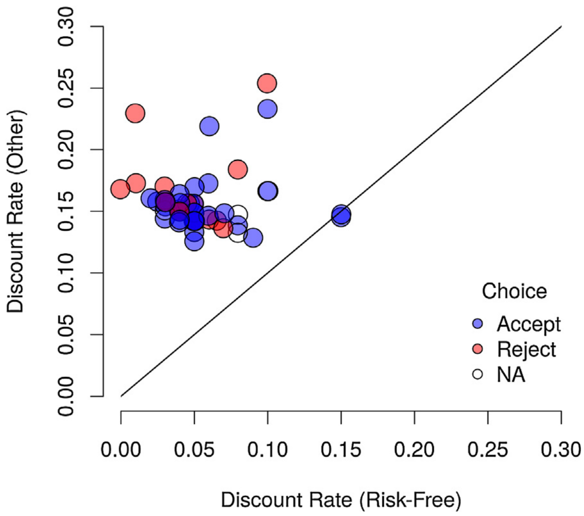

Fig. 1. Risk-free and other discount rate. The risk-free discount rate is shown on the horizontal axis, and the discount rate from other factors is shown on the vertical axis. Blue versus red circles indicate whether respondents accepted or rejected the linear fluorescents in the hypothetical choice (respectively). (For interpretation of the references to color in text/this figure legend, the reader is referred to the web version of the article.)

expressing discomfort with borrowing from large banks.

In addition, measures were included to elicit respondent attitudes toward debt that did not assume respondents knew the precise interest rates they would be willing to accept or pay [38,53]. Specifically, respondents were asked to:

> "Tell us what you think about using each of the following financing methods to pay for improving the energy use of your building's lighting systems using a rating from −3 to +3 described in the scale below."

The scale was 7 points with labels "very undesirable" (−3), "moderately undesirable" (−2), "slightly undesirable" (−1), "neither undesirable nor desirable" (0), "slightly desirable" (+1), "moderately desirable" (+2), and "very desirable" (+3). The financing mechanisms were described as follows:

- Self-funding: Pay for the lighting systems yourself. No financing.
- Commercial loan: A loan from a federally regulated for-profit commercial bank.
- Small bank loan: A loan from a not-for-profit small bank or credit union that is not federally regulated.
- Local government financing: The local government loans you the money, then increases your building's property taxes for a fixed time period, until the money is paid back.
- Utility financing: A local utility company loans you the money and takes a portion of the energy savings for a fixed time period, until it has recovered the cost.
- Energy contract: A private energy service company loans you the money and takes a portion of the energy savings for a fixed time period, until it has recovered the cost.

As seen in Table 5, self-funding was the most preferred financing method. There were 122 responses to both questions about self-financing and the commercial loan, with 54 rating the loan higher than self-financing, and 68 rating the self-financing higher than the loan. Of the 76 respondents who indicated they would accept the 0% interest loan, 38 rated self-financing higher than the commercial loan (50%). In contrast, of the 35 respondents who indicated they would reject the 0% interest loan, 25 rated self-financing higher than the commercial loan (71%), ($\chi^2(1) = 3.7$, $p = .056$). These results indicate that respondents were not merely confused by the question or responding randomly, but that they systematically preferred to avoid debt in a way that is consistent with other stated attitudes (lack of support for better financing, discomfort with borrowing from banks, preference to self finance).

Table 5
Attitudes toward financing and debt. Items with different superscripts denote $p < .05$ according to the Wilcoxon Signed Ranks Test.

Financing Mechanism	−3	−2	−1	0	+1	+2	+3	Mean	SD	*n*
Self-funding	16	6	7	17	17	15	46	0.95^a	2.1	124
Utility financing	24	10	5	29	21	16	19	0.1^b	2	124
Energy contract	28	13	8	22	21	20	12	-0.17^c	2.1	124
Small bank loan	30	11	8	43	18	8	6	-0.55^d	1.8	124
Commercial loan	35	13	6	38	18	8	6	-0.69^d	1.8	124
Local govt. financing	58	6	12	21	13	4	10	-1.2^e	2	124

4.6. Split incentives

The last factor from the normative analysis was split incentives. Because these building owners are primarily individuals (as opposed to organizations), and most respondents do not have building or facilities managers, the landlord-tenant split incentive is most relevant. A respondent is classified as facing a split incentive if the respondent has tenants that pay all the electric bills, meaning the respondent had no financial incentive to invest in energy efficiency. We found little relationship between split incentives and respondents' hypothetical decision to invest. The 58% (= 19/(19 + 14)) of respondents who faced split incentives indicated they would invest in occupancy sensors, as did 57% (= 48/(48 + 36)) of respondents who did not face split incentives, suggesting no relationship between split incentives and the decision to invest. Similarly, 71% (= 22/(22 + 9)) of respondents who faced split incentives indicated they would invest in linear fluorescents, as did 64% (= 54/(54 + 31)) of respondents who did not face split incentives. Neither differences were statistically significant using logistic regression ($t(115) = 0.04$, $p = .97$ and $t(114) = 0.74$, $p = .74$, respectively), and if anything, the result suggests that those facing split incentives were slightly more likely to invest in linear fluorescents.

4.7. Tenant retention

The interviews revealed that tenant retention was more important than saving operating costs through energy efficiency. This issue was explored with the following question:

> "To what degree would improving a building's energy performance help retain tenants in that building?"

The scale was 5 points, with labels "Not at all" (0), "Slightly" (+1), "Moderately" (+2), "Very" (+3), "Extremely" (+4). Confirming the interview findings, the 42 building owners who said they would invest in occupancy sensors tended to believe that energy performance could increase tenant retention to a greater degree (mean = 1.6, SD = 1.1) than the 30 respondents who said they would not invest in occupancy sensors (mean = 1.1, SD = 1.0), ($t(70) = 2.0$, $p = .03$, $d = 0.6$). A similar result emerged for linear fluorescents, where the 45 building owners who said they would invest in linear fluorescents tended to believe that energy performance could increase tenant retention to a greater degree (mean = 1.6, SD = 1.1) than the 37 respondents who said they would not invest in linear fluorescents (mean = 1.0, SD = 1.0), ($t(60) = 2.0$, $p = .02$, $d = 0.6$).

5. Discussion

It is a long-standing puzzle why building owners do not invest in energy efficiency when those investments appear to be more economically attractive than available alternatives. In this work a method was demonstrated for understanding when and why such investments occur. Drawing on behavioral decision research, the study began with a normative analysis of energy efficiency investment decisions, finding they should depend on uncertainty in the energy savings, capital availability, the degree to which the future energy savings of investments are discounted, and whether the tenant pays the energy bills. This helped frame descriptive research that included interviews and a survey of owners of class B and C offices in Pittsburgh, revealing that respondents: (1) were concerned about uncertainty in the energy savings and desired measures to reduce that uncertainty (a guarantee), (2) discounted the future energy savings of energy efficiency investments, but only a minority of this discounting was due to time preferences, (3) had enough capital to pay for the investments themselves, and preferred to pay themselves, with some respondents even rejecting a no interest loan, and (4) rarely cared about landlord-tenant split incentives but did care about energy efficiency if it could improve tenant retention.

The finding that respondents most strongly supported an energy savings guarantee is consistent with the work of Farsi [25] who found that Swiss apartment renters viewed energy savings from efficiency (e.g., triple glazed windows, ventilation with an air renewal system) as uncertain, and Qiu [26] who measured the risk aversion of homeowners in Arizona and California and found that individuals with greater risk aversion were less likely to make energy efficiency retrofits and buy energy efficient appliances, but were no different in their use of energy efficient AC units. The results of the present research provide a twist on this prior work, as a factor analysis suggested that an energy savings guarantee and an economic assessment reflected different underlying concerns, with the guarantee reflecting skepticism about the performance of energy efficiency investments, as indicated by its positive correlation with ratings of contractor vetting and a contractor scorecard, and the economic assessment reflecting a desire for information about the energy saving potential of these investments.

The desire for a guarantee above other potential services suggests that programs that ensure the performance of new technologies (e.g., by allowing experimentation or "trial periods" with these technologies) are likely to be more effective than merely reducing up-front costs (or offering more attractive financing). Research on the diffusion of medical guidelines suggests that such trial periods are effective at reducing this uncertainty [54]. Alternatively, insurance programs and energy service contracts may be able to provide guarantees of the energy savings directly, but the challenges to scale, profitability, and complexity must be addressed [23]. For example, one problem with performance contracts provided by energy service companies (ESCOs) is that the revenue generated from a building is proportional to the size of the building, and transaction costs per performance contract are high [48,55]. For example, a 1,000 square foot building might generate $1/sqft/year in revenue for the ESCO, so the ESCO would need 100 contracts with small buildings to equal the revenue from a single 100,000 square foot building, but would incur significantly more transaction costs in the former scenario than the latter. Because the majority of class B and C offices are also small (see SI section 1), without some form of policy intervention, it is unlikely that the market will produce the mechanisms for uncertainty reduction required by these building owners to invest.

Consistent with the desire for more information, in the hypothetical choices more than half of respondents were willing to invest in cost-effective energy efficient lighting measures such as occupancy sensors and linear fluorescents. The survey's summary tables might have provided the information respondents needed to make their decision. If true, the survey reveals a general willingness to invest among owners of class B and C offices along with a lack of knowledge about where to turn to get the right information. This result is consistent with the work of Min et al. [29] who found that providing lifetime energy savings information strongly swayed decisions to favor more energy efficient CFLs over incandescents. How that information is delivered is critical, as it must come from trusted, credible, and non-persuasive sources [56]. The initial interviews and additional survey analyses in the SI (section 5) find that this source might be a contractor that the building owner has previously worked with, as building owners seek information from contractors and trust them more than other sources of information.

Second, the discount rates measured in the survey reflect more than pure time preference, with rates significantly higher than assumed in other work on the private sector [48]. Many studies have looked at how people discount the future rewards of energy efficiency investments, using methods that include market behavior, hypothetical choices, and experiments. For example, Min et al. [29] found that respondents making hypothetical choices on a survey discounted the future savings of compact fluorescent lightbulbs 100% on average ($\delta = 1$) when provided information about the lifetime cost of lightbulbs, and 506% on average ($\delta = 5.06$) without information. Despite their large magnitude, these discount rates were consistent with the large variability in measured discount rates from previous studies looking at individual choices among energy saving technologies [30]. Our study further supports the idea that choices about energy efficiency reflect more than impatience and the ability to reinvest, leading to variation in these factors across people, and whether measurement methods capture them [22].

Third, when asked about their preferences for financing mechanisms, respondents preferred to self-finance, and some respondents indicated that they would reject the use of debt even if offered at no interest. This result highlights the fact that looking at stated preferences for interest rates alone will overstate the effectiveness of financing policy by masking debt aversion. While this research is the first to highlight the existence of debt aversion in energy efficiency decision-making, the cause is still an open question. From a normative perspective, it does not make sense to prefer self-financing to a zero interest loan, as this implies a negative discount rate, and bizarre behavior (e.g., putting off all consumption until the end of one's life). One possibility is that respondents who refused debt also felt skeptical about banks, as indicated by their survey ratings of feeling uncomfortable borrowing money from large banks. Another explanation was provided by the work of Ross [28], who interviewed twelve large firms in the steel, paper, and aluminum industries, finding that firms with lower debt carrying capacity (higher debt to income ratio) required higher rates of return on investments (including energy efficiency) than firms with less constrained capital. One reason given by respondents for not using debt to finance profitable projects was that using debt would reflect negatively on the firm, reducing their market value and ability to take on additional debt or issue bonds to institutional lenders. In other words, many of these firms believed that there was a shadow price to financing, making them reluctant to use financing for energy efficiency investments. The current research cannot separate these explanations, but does highlight directions for future research.

Fourth, the tenant-landlord split incentive occurs when tenants pay the energy bills (in a net lease) while the landlord controls the level of building efficiency, meaning the landlord has no incentive to invest in energy efficiency measures unless the landlord expects future tenants to know that the building is inefficient. Instead, the landlord can attract new tenants with lower rents, passing the energy bills on to the tenant. For example, a developer of small commercial buildings interviewed by Blumstein [20] found that tenants tended to be more sensitive to rental price than utility costs. Although often cited in the literature on barriers to energy efficiency diffusion, split incentives were not a primary concern for respondents in our study in both the interviews and surveys. One reason was that the sample of building owners studied was heavily skewed toward building owners who also occupied the building, meaning the building owner was also a tenant. Another may have been that those who did have tenants were more concerned about retaining those tenants as an important source of income than cutting their own costs. This is consistent with the finding that building owners who believed energy efficiency could help tenant retention were also more likely to indicate that they would invest in lighting retrofits for their building.

Although best efforts were made to minimize validity threats in the study, there are several limitations that represent considerable challenges to this study's conclusions. A major limitation of the study is the use of self-reported attitudes and intentions rather than more objective measures of behavior. For example, one explanation for the finding that many respondents indicated they would invest in new lighting systems may have been that respondents merely said they would do something that they would not actually do, either because they were telling us what they thought the researchers wanted to hear [57], or because they knew they did not have to do what they said. In addition to being hypothetical, many of the questions were quite abstract, such as the question about willingness to lend to a commercial bank. Supporting this, many respondents either could not respond to this question or refused to respond (as indicated by the lower response rate), and those who refused to respond were also more likely to exhibit debt aversion (rejecting loans at *any* rate). There were also several issues with the study that limit its generalizability. Although significant attempts were made to recruit the entire population of class B and C office building owners in Pittsburgh into the survey, the study achieved only a 40% response rate, with over-representation from owner-occupiers. This over-representation was due to the difficulty in determining who owned the building, with owner-occupiers being much more easy to identify.[7] Furthermore, given the lack of data on class B and C office building owners in other cities, the conclusions are necessarily limited to Pittsburgh. As a result, although the approach outlined in this paper is generally applicable for developing energy efficiency programs, the specific results that apply to class B and C office building owners in Pittsburgh are unlikely to generalize to other populations (e.g., class A office building owners, class B/C office building owners in San Francisco).

Given these reservations, the following program for owner-occupiers of class B and C offices in Pittsburgh could be effective. First, to help reduce the uncertainty in energy savings, a local utility, government, or non-governmental organization would offer seed grants that fully subsidized small projects, such as making a single floor of a building energy efficient. This would allow building owners to gain valuable information about project uncertainties without risking their own money. While grants are fairly straightforward, other uncertainty mitigation strategies, such as the use of financial instruments [23] or trial periods, might be viable alternatives. Second, respondents desired information about the costs and benefits of energy efficiency. That information should be provided in a non-persuasive manner, providing the facts and uncertainties candidly [56]. Based on the interviews and the survey (see SI section 5), local contractors were the most trusted source of information, and might be a viable channel for providing that information.

The only way to know whether such an approach would work is for future research to evaluate each recommendation with an intervention, testing under what conditions the insights work in field experiments. There are also several other areas for future research. Based on the result that the risk free discount rate only accounts for the minority of discounting of energy efficiency savings, studies could further try to separate the different determinants of discounting for energy efficiency. Separating discounting due to uncertainty about the technology and its performance from discounting due to uncertainty about the implementers of the technology (e.g., contractors) would be an important contribution. Further work could also explore debt aversion, for example by comparing larger organizations (e.g., those that own class A buildings) who are quite comfortable using debt to finance investments with owners of small commercial buildings, small businesses, and residential buildings, who are quite unwilling to accept debt to finance energy efficiency. Some promising avenues for comparison would include skepticism of banks, debt carrying capacity, and bad prior experiences with debt.

To summarize our application of behavioral decision research to energy efficiency investment decisions, consider the following four issues. First, normative and descriptive analyses of decision-making can strongly complement each other. Normative analyses help researchers develop well-formed questions, and help respondents reflect on issues that they might overlook. Descriptive analyses let respondents speak in their own words and contrast those concerns with normative expectations, highlighting disagreement between researcher and respondent on how decision-making should proceed. Second, it is possible for the same respondent to behave normatively in some respects (expressed as concerns about uncertainty and information) and violate normative considerations in others (rejecting debt and ignoring split incentives). Approaches that characterize individuals as totally rational (or irrational) will miss much of the picture. Third, previous studies have been almost exclusively limited to the residential sector or large organizations. Here this study looks at a unique type of decision-maker, whose sophistication (and biases) lay somewhere between a large institution (in class A buildings) and an individual layperson (in residential buildings). Finally, the approach described in this paper risks errors of believing what people say when they may not be able to express (or know) what they want, or may not be candid. This work accepts this risk and holds that it is the lesser of two, the other assuming people can't (or won't) tell us what they want. By listening to what people have to say, the approach outlined builds goodwill, trust, and a chance for future collaboration through a systematic and inclusive energy efficiency program design process.

6. Conclusion

Policy-makers and program designers can encourage owners of class B and C offices to invest in energy efficiency. One way to do this is by reducing uncertainty about the savings from energy efficiency by using mechanisms such as trial periods, performance-based guarantees, grants, or insurance contracts that shift investment risk away from individual building owners. Another way is by providing information about the costs and benefits of investments through trusted local contractors and their networks to help building owners make their decision. Field experiments that test uncertainty reduction and information provision approaches through contractor networks would produce the evidence policy-makers and program designers need to choose the most effective approaches to encourage energy efficiency investments.

Author contributions

A.D. conceived and designed the data collection, performed the interview and survey data collection, analyzed the data, contributed data collection materials, and wrote the paper. G.W.P. conceived and designed the data collection, performed interview data collection, and wrote the paper. T.K. conceived and designed the data collection, performed the interview data collection, and wrote the paper.

Competing financial interests

The authors declare no competing financial interest.

Acknowledgements

Anonymized data and R code are available on the Open Science Framework.[8] This work was supported by the Richard King Mellon Foundation and by the Center for Climate and Energy Decision Making

[7] Although the response rate is low in absolute terms, in relative terms it is reasonable compared to typical survey studies [58,59].

[8] osf.io/2u8m9.

under a cooperative agreement between Carnegie Mellon University and the National Science Foundation (SES-0949710 and SES-1463492). We thank Xiyu Wang, Yuvraj Kumar, Isabelle Jiang, Dan Hochman, and Ranan Tannenbaum for help collecting the data. We also thank CoStar for sharing their database.

Appendix A. { [(Supplementary information)] }

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.erss.2018.08.008.

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Supplementary Information for Neither a borrower nor a lender be: Energy efficiency decision-making among class B and C offices in Pittsburgh

June 26, 2018

1 Sample and Population

Carnegie Mellon University obtained a university license from the commercial real estate information company CoStar to identify all class B and C offices in the Pittsburgh downtown and Oakland areas (including ZIP codes 15222, 15219, 15213). Data provided by CoStar included building address, building owner name, building floor-to-area ratio, tenancy, typical floor square footage, number of stories, year built, percent of building leased, rental price per square foot per year, gross leasable area, and building class (B or C). CoStar's primary methods of data collection were contacting the building's listing broker and accessing public records through Allegheny County and the City of Pittsburgh. We augmented these data with publicly available information provided by Allegheny County on the date and price of last building sale, the current taxable market value of the land and building, and permitting data from 2012-2014 for each building made available by the City of Pittsburgh's Bureau of Building Inspection. We then cross-referenced CoStar's building owner information with that provided by Allegheny County.

From these data we identified 500 buildings that were potential class B and C offices. Upon further inspection of county records, we found that some buildings changed use since CoStar last updated their database. These included 26 buildings that were converted to residential or sold as condos, 3 buildings that were now vacant lots, and 1 building that was demolished. This left a total of 470 buildings, which constituted our final building population.

Cross-referencing revealed missing data from both sources, the most important being the name of each building owner. In these cases, both databases included names of holding companies (e.g., "400 Avenue LP") with address information that could not be linked to an individual. For these buildings we attempted to determine the building owner's name using the building's deed obtained from the County. Using this approach we identified a total of 327 unique building owners, of which we could identify 182 by name.

From this building and owner population we attempted to determine, for each building, whether it was owner-occupied. For each building we checked whether the owner's mailing address (as indicated by the CoStar and county databases) was the same as the building's address. If that was the case, we attempted to determine whether some business or organization could be found through a Google search that had an address at that location, with a name associated with the owner. The clearest cut case was when a tenant had the same name as the owner of the building, and this could be verified by a Google search.

There were also cases where there was some uncertainty surrounding the owner-occupy classification. For example, there were cases where the last name on the public record matched the name found on a business in the building, but not the first name. We assumed that the building and business were owned by the same family. Second, there were cases where a large company owned the building, had offices in the building, but clearly the entire company did not occupy the building. In both cases we treated the building as being owner-occupied.

There were two sets of cases where we could not determine whether the building owner was an owner-occupier. In one set we simply could not determine, using either CoStar's data, the public record, or deeds, who the owner was (aside from the name of the holding company listed on the county records). In a final set the owner's name was listed as a tenant, but we could not verify that the owner actually had an office there.

Here we briefly describe the characteristics of the building population, including building class, gross leasable area, date of last sale, owner-occupy status, and owner type. We find that there are more class B than class C buildings in the population. Of the 470 buildings in the population, 268 are class B and 200 are class C, with 2 buildings lacking classification. Most of the buildings were small, with a few very large outliers. The gross leasable areas of the office buildings ranged from 691 to 820000 ft^2, with a median of 14000 ft^2 and a mean of 45200 ft^2. To check the internal consistency of these measurements, we compared the gross leasable area to the total building square footage found by multiplying the typical floor square footage by the number of floors for each building, finding almost perfect agreement between the two indicators ($R^2 = 0.97$).

Table 1: Quintiles of Gross Leasable Area (1000 ft^2) by Building Class

Class	0%	20%	40%	60%	80%	100%
B	0.9	8.0	20	38	83	820
C	0.7	3.6	6.5	9.8	19	450

As expected, there were very few energy efficiency certifications among these buildings (less than 1% of the building population combined), with 3 ENERGY STAR certified buildings, and 4 with LEED certification. Similarly, based on data provided by the local Green Building Alliance, 26 buildings had joined the Pittsburgh 2030 district ($\sim$ 6% of the building population). Next, we found that 249 buildings were owner-occupied (53%), 153 buildings did not have an owner that also occupied space in the building (33%), and we were unable to determine the owner-occupancy status for 68 buildings (14%). These proportions were almost identical across class B and C offices.

Unidentified investors (those who owned the building who could not otherwise be classified) accounted for the largest share of ownership, with 139 buildings, followed by small businesses with 136 buildings. Other types of building owners accounted for far fewer buildings, including 38 owned by universities, 36 owned by other 501(c)3 organizations, 18 by government, 18 by hospitals, and 12 by religious organizations, with developers, property management companies and 501(c)4 (unions) accounting for less than 10 buildings total. It is very likely that many developers and property management companies were classified as otherwise unidentified investors.

Table 2: Building Owner Type by Building Class

Class	Inv.	Sm.Business	Univ.	501(c)3	Gov.	Hosp.	Rel.	Other	Unk.
B	87	66	28	15	10	10	10	9	33
C	52	70	9	21	8	8	2	2	28

Information from Allegheny County on the last sale date of the building was available for 367 buildings (78%). The median ownership length was 9 years, with a mean of 19.2 years, with 75% of ownership lengths greater than 4 years. We also found that 190 sold for less than $100. Thus, these sale dates will underestimate true ownership lengths, as many buildings were passed between family members or common organizations.

Using this database we attempted to recruit all 327 building owners to participate in the survey. Building owners were sent an initial recruitment mailing in early November 2014, including the survey, cover letter, an addressed stamped return envelope, and a $10 cash incentive. The cover letter included the building owner's name or the name of the building owner's holding company if the name could not be determined. If owners had not responded in two weeks they were sent a follow-up postcard reminding them to return the survey. The postcard also provided them a link to participate online. Two weeks after the postcard was sent, we attempted to contact owners who had mailing addresses in the 15222, 15219, and 15213 areas in person. After these in-person visits, we attempted to contact non-responders by phone or email. Approximately one month after the in-person contacts we sent a second mailing wave with the survey, cover letter, an addressed stamped return envelope, and a $10 cash incentive. In total, 132 of 327 building owners responded to the survey (40%).

We begin by describing some basic characteristics of the building owners, dividing these characteristics into those that relate to the owner and those that define the relationship between the owner and the building. The former set of characteristics include age, gender, political affiliation, and education (occupation). The latter include whether the owner occupies the building, reasons for acquiring the building, the type of building owner, and planned ownership duration of the building. As previously mentioned, there were a total of 132 responses to the survey. However, some respondents decided not to answer some questions (item non-response), so for each question we include the total number of responses and the percent responding.

1.0.1 General Owner Characteristics

The first question asked owners about their age, yielding 122 responses (92% responding). The median age of respondents was 56 with a range of 26 to 86 years. Interestingly, the age of the respondent at the first quartile was 50 years, indicating that 75% of respondents were older than 50. If we consider the "baby boomer" generation to be those who were born between 1946 and 1964 (between ages 50 and 68 in 2014), roughly 61% of respondents fit into this category.

There were 123 responses to the question about gender (93% responding). Consistent with a male dominated workforce and ownership culture of the baby boomer cohort, 112 respondents were male, with 11 female respondents. The sample thus does not reflect the balancing effect on building ownership of women's participation in the labor force that may show up in the future. Because of this lack of variation, we are not able to detect any gender differences that may be present in decision-making.

There were 117 responses to the question about political affiliation (89%

Table 3: Sample Building Owner Characteristics

Characteristic	Sample Value
Age (n = 122)	
Median	56
Range	26 - 86
Gender (n = 123)	
Male	112
Female	11
Political Affiliation (n = 117)	
Democrat	48
Republican	38
Independent	24
Other	7
Highest Education (n = 125)	
Bachelor's	51
Advanced (MD, JD, PhD)	35
Masters/Professional	25
Associate's	6
High School Graduate or Less	8
Occupation (n = 117)	
Attorney	20
Business Owner	10

responding). Of these respondents, 48 indicated that they were Democrats (41%), 38 Republicans (32%), and 24 Independents (21%). The majority of the remaining respondents indicated that they were not political. Although there were more Democrats than Republicans, this lack of balance is weaker than in the local general population. As of December 15, 2015, in Allegheny County there were 527K registered Democratic Voters (60%), 238K registered Republican voters (27%), 68K voters with no affiliation (7.7%), 5K registered Libertarian voters (0.57%), and 45K (5.1%) voters of all other types. Thus, our sample overrepresents Republican and Independent views relative to the local population, but may be representative of owners of class B and C offices in Pittsburgh (assuming those who responded to the survey are like those who did not respond).

There were 125 responses to the question about highest level of education (95% responding). Of those responses, 51 respondents indicated they had a bachelor's degree, representing the most frequent response. This was followed by 35 with advanced degrees (MD, JD, Phd), 25 with masters or professional degrees, and 6 with associate's degrees. There were some respondents without some college-level education, including 7 who completed high school and 1 with some high school education. The sample was on average well-educated relative to the local population (census data).

1.0.2 Owner Characteristics in Relation to the Building

Next we explore a number of characteristics that define the relationship between the owner and the building, including whether the owner occupies the building, reasons for acquiring the building, the planned ownership duration of the building, and the type of building owner.

First, there were 120 responses to the question about whether the owner or the owner's organization occupied the building (91% responding). Of those respondents, 98 indicated that they occupied the building in some way (82%), whereas 22 said they did not occupy the building at all. This differs from the characteristics in the population, where our research indicated that 249 owners occupied the building, 153 did not, and 68 could not be determined. Thus, of the buildings where occupancy status could be determined in the population, owner-occupiers accounted for 62% of the buildings. If the remaining 68 buildings that could not be classified in the population were all owner-occupiers, owner-occupiers would account for 67% of the population, still well below the rate of owner-occupiers in the sample. Thus, our results need to be adjusted to reflect the overrepresentation of owner-occupiers in the sample. We address this issue later in our inference section with post-stratification, giving greater weight to non-occupiers.

Next, there were 124 responses to the question about the owner's reasons for acquiring the building (94% responding). The most frequent reason for owning the building was that the owner needed space for their business or organization, indicated by 66 respondents (53%). The next most frequent response was that the owner planned to lease the building for income, given by 26 respondents (21%). The third most frequent response was both needing space and leasing for income, given by 12 respondents (9.7%). Only 2 respondents indicated that their primary reason for acquiring the building was to sell it for profit. An additional 2 respondent indicated that they both planned to sell it for profit and lease it for income. These reasons, which focus mostly on using rather than profiting from the building, likely reflect the sample's overrepresentation of owner-occupiers, who tend to be businesses or other organizations that plan to buy and hold the building for their own use.

Table 4: Sample Building Owner Characteristics

Characteristic	Sample Value
Owner-Occupied Status (n = 120)	
Owner-Occupied	98
Not Owner-Occupied	22
Primary Reasons for Acquiring Building (n = 124)	
Needed Space	66
Lease for Income	26
Needed Space & Lease for Income	12
Profit from Sale	2
Other	18
Planned Duration of Ownership (n = 95)	
# $\leq$ 5 years	7
# $>$ 5 years	71
# $>$ 10 years	57
# $>$ 15 years	48
# $>$ 20 years	48
Until Death	8
Unknown	9

Respondents were next asked how long they planned to own their building. This question had a lower response rate, with 111 responses (84% responding). Based on pretesting, we believe that part of the reason for the higher non-response rate was that owners had no plans to sell the building, and thus did not know how to respond to the question (or felt that it did not apply). Supporting this were numerous write-in answers telling us that the building would be held "indefinitely," "infinitely," "forever," or "unknown." Only 7 respondents indicated that they planned to own the building for less than 5 years, with about half (48) indicating that they planned to own the building for more than 15 years.

There were 126 responses to the question about who owns the building (95% responding). The building owners were most frequently a single person, with 37 respondents answering "Just Me" (29%). The next most frequent category was business partners, indicated by 23 respondents (18%), followed by private corporations, indicated by 16 respondents (13%). There were 32 respondents (25%) that indicated that the building was owned by some combination of private investors, real estate developers, business partners, private corporations, and property management companies.

1.0.3 Building Characteristics

Next, we look at energy efficiency measures already taken by building owners and the energy intensity of their buildings. Of the 132 respondents, 79 indicated that their building had a programmable thermostat (60%), 54 indicated that they had improved their HVAC motors (41%), 44 indicated that they had used sealing to reduce air leaks (33%), 39 indicated that they had increased their roof's insulation (30%), and 34 indicated that they had installed occupancy sensors (26%). To assess the likelihood of buildings having T8 linear fluorescents with electronic ballasts, we asked respondents how long it has been since they replaced the ballasts on their linear fluorescents. There were 78 responses to this question (59% responding), likely reflecting unfamiliarity with ballast technology. Respondents had replaced their ballasts a median of 10 years ago, with a range of 1 to 50 years. There were 57 respondents with ballasts older than 5 years (73%) when EPACT began the phase-out of magnetic ballasts in 2009, indicating that most respondents probably did not have T8 linear fluorescents with electronic ballasts.

According to the most recent Commercial Building Energy Consumption Survey, based on a sample size of 152 the annual expenditures per square foot for office buildings in the mid-atlantic region are $1.63 for electricity, $0.26 for natural gas, $0.03 for fuel oil, totaling $2.03 for all major fuels. We compare these results to the self-reported annual cost of electricity and natural gas from our survey, dividing by the gross leasable area of the building provided by CoStar to find the use intensity per square foot.

Of the 132 respondents, we could calculate electricity intensities for 51 buildings. Those in our sample had a median electricity intensity of $1.1 per square foot, with a mean of $1.5. Based on the interquartile interval, 50% of electricity intensities were from $0.69 to $1.6. Of the 132 respondents, we could calculate the intensity of natural gas use for 42 buildings. Those in our sample had a median natural gas intensity of $0.37 per square foot, with a mean of $0.52. Based on the interquartile interval, 50% of natural gas intensities were from $0.24 to $0.54. Of the 132 respondents, we could calculate total energy intensity for 42 buildings. Those in our sample had a median total intensity of $1.5 per square foot, with a mean of $1.9. Based on the interquartile interval, 50% of total intensities were from $0.97 to $2.2.

1.0.4 Population Building Information

However, building class is not a reliable indicator of building value, with median taxable market value (land and building) for class B buildings of $\$59/\text{ft}^2$ versus $\$62/\text{ft}^2$ for class C buildings. A similar result holds for the recorded price of the building's last sale (B = \$32/ft^2 vs. C = \$37/ft^2). However, the median listed annual rental price per square foot is higher for class B (\$16/ft^2) than class C offices (\$14/ft^2), although there are only 97 buildings with rental prices available.

Table 5: Indicators of building value by building class

Class	Number	Taxable Market Value	Last Sale Price	Rental Price
B	268	\$59/ft^2	\$32/ft^2	\$16/ft^2
C	200	\$62/ft^2	\$37/ft^2	\$14/ft^2

2 Lighting Cost and Savings Estimates

Quantitative information for the occupancy sensors table was taken from the Pennsylvania Act 129 Statewide Evaluator Market Potential Study, Commercial and Industrial Sector Appendix 3. Details about the methodology are provided in the 2014 Pennsylvania Act 129 Technical Reference Manual Office FIE2. The assumed Lighting Power Density was 1.0 for offices. Annualized energy savings (kWh) was defined as follows:

$$kW_{controlled} \times HOU \times (SVG_{ee} - SVG_{base}) \times (1 + IF_{energy}) \tag{1}$$

where $kW_{controlled}$ is the total lighting load connected to the control (fixture wattage (in kW) times number of fixtures per control) with default values of 0.350 for wall-mounted occupancy sensors and 0.587 for remote mounted occupancy sensors, SVG is the savings factor (percent of time lights are off) for the new controls (SVG_{ee}) and manual switch (SVG_{base}) with default values 24%, HOU is the average annual operating hours of the baseline equipment, taken as 2,567 hours for offices (which would be roughly 10 hours a day 5 days a week), and CF is the coincidence factor accounting for heating losses due to reduced light use taken to be 0.61 for offices. Assumes the fixture is 0.61 kW (=1578kWh/2567h). Baseline building equipment and house of use were based on surveys of utility customers in Pennsylvania.

Quantitative information for the linear fluorescents table was again taken from the Pennsylvania Statewide Evaluation and Technical Reference Manual. From the Technical Reference Manual, annualized energy savings (kWh) was the change in power multiplied by the equivalent annual full load hours of operation for the installed measure:

$$(kW_{base} - kW_{EE}) \times [HOU \times (1 - SVG_{base})] \times (1 + IF_{energy}) \tag{2}$$

where HOU is the average annual operating house of the baseline lighting equipment before lighting controls, and IF is the interactive HVAC energy factor which represents secondary energy savings in cooling required from decreased indoor lighting wattage. From the Commercial and Industrial Appendix 3, we used measure Office FIE1 which was a fixture replacement of T12 lamps with premium efficiency T8 32W lamps and electronic ballasts. Building assumptions were a base load of 394 kWh and a reduction of 97 kWh, a savings of 25%.

3 Factor Analysis Estimation

Our approach assumes that responses to each question reflect an underlying structure that takes the following form [1]:

$$x_i = \sum_{r=1}^{k} l_{ir} f_r + e_i \tag{3}$$

In this formulation, each x is an attitude question and there are i of them (in our case there are 7, excluding the lease structuring question because of missing data). The model holds that x_i is a linear combination of a set of unobserved factors f_r, with the correlation between each x_i and the factor captured in the loading l_{ir}. The model also assumes that there is some measurement error e_i for each x_i that follows a normal distribution, with $e_i \sim N(0, v_i)$. Thus, the seven attitude questions form a multivariate normal distribution where each question is related to other questions only through the loading on common factors, that is $x \sim MVN(0, C)$, where $C = [c_{ij}]$ is the covariance matrix between questions. Our goal is to explain as much of the covariance between attitude questions as possible with a limited number of factors. Considering:

$$Var(x_i) = c_{ii} = \sum_{r=1}^{k} l_{ir}^2 + v_i \tag{4}$$

and

$$Cov(x_i, x_j) = c_{ij} = \sum_{r=1}^{k} l_{ir} l_{jr} \tag{5}$$

The covariance matrix can thus be written as:

$$C = LL^T + V \tag{6}$$

where $L = [l_{ir}]$ is a $p \times k$ matrix of loadings and V is a diagonal matrix with elements v_i. Let $A = [a_{ij}]$ be the sample covariance matrix. Because the x_i are normally distributed, the covariance matrix $C = X^T X$ has a Wishart distribution with mean equal to the variance matrix V. Thus, the log likelihood of C given A is:

$$\ln L(\mathrm{L}, \mathrm{V}|A) = -\frac{n}{2} \ln |\mathrm{LL}^T + \mathrm{V}| - \frac{n}{2} \mathrm{tr}(\mathrm{A}(\mathrm{LL}^T + \mathrm{V})^{-1}) \tag{7}$$

4 Solving for the discount rate

To solution for δ^0 must satisfy:

$$0 = -\sum_{j=1}^{q} \frac{AC}{(1+\delta^*)^j} + \sum_{j=1}^{14} \frac{ES_j}{(1+\delta^* + \delta^o)^j} \tag{8}$$

Where AC is the annual cost of the investment, ES_j are the annual savings in year j, and δ^* is the risk-free discount rate. This can be simplified noting that $\sum_{j=1}^{q} \frac{AC}{(1+\delta^*)^j}$ is equal to the present value of the annual cost (denoted $PVAC$, the annual costs discounted by the risk-free discount rate δ^*), and that the energy savings are the same in each time period (\$11):

$$0 = -PVAC + 11 \times \sum_{j=1}^{14} \frac{1}{(1+\delta^* + \delta^o)^j} \tag{9}$$

Expanding this yields:

$$0 = -PVAC + 11 \times \frac{1}{(1+\delta^* + \delta^o)^1} + 11 \times \frac{1}{(1+\delta^* + \delta^o)^2} + \ldots 11 \times \frac{1}{(1+\delta^* + \delta^o)^{14}} \tag{10}$$

Substituting $x = \frac{1}{(1+\delta^*+\delta^o)^1}$ and $c_0 = PVAC, c_1 = 11, c_2 = 11, \ldots c_{14} = 11$ gives:

$$0 = c_0 + c_1 x + c_2 x^2 + \ldots c_{14} x^{14} \tag{11}$$

Using the Jenkins-Traub algorithm [2], a unique positive real solution for x exists if $c_0 < 0$ and $c_j x > 0$ for all subsequent time periods j, which is the case for the current problem.[1] The risk-adjusted discount rate δ^r can then be obtained using:

$$\delta^o = \frac{1}{x} - 1 - \delta^* \tag{12}$$

[1] The Jenkins-Traub algorithm was implemented using the *polyroot* function in R, retaining only the unique positive real root x.

5 Information Sources and Contractors

To learn more about how respondents acquired information about energy efficiency options for their building's energy systems, respondents were asked to:

> "Imagine that your building's primary heating system has reached the end of its useful life and you've decided to replace it . . . Below are professionals you might consult with when replacing your building's primary heating system. Circle all that you would talk to (if any)."

1. Contractor (HVAC) [99]
2. Engineer [65]
3. Architect [36]
4. Facilities Manager [32]
5. Utility Company [29]
6. Financial Analyst [18]

There were 116 responses to this question, with the large majority of respondents (99) indicating they would consult with an HVAC contractor, indicating that contractors were the primary point of contact for consultation about the building's heating system. To explore the relationship with their contractor further, respondents were then asked to answer the following question:

> "If you had specific contractor[s] in mind, about how long have you known them?"

There were 82 responses to this question. Of those responses, 5 indicated that they knew a contractor for 0 years. The remaining respondents who did not answer the question likely did not have a specific contractor in mind. Of the remaining 77 respondents who gave a duration longer than zero years, the range was between 1 and 30 years, with a median of 10 years. Thus, most respondents had existing relationships with contractors, many of them for long periods of time.

Confirming this result, we also asked respondents about the degree to which they trust different organizations, with the goal of understanding which organizations could be most effective at working with building owners to implement energy efficiency programs. Respondents were asked:

"To what extent do you disagree or agree that these entities have your best interests in mind?"

The ratings were made on a scale from "strongly disagree" (-2), "disagree" (-1), "neither disagree nor agree" (0), "agree" ($+1$), and "strongly agree" ($+2$).

Table 6: Trust in organizations

Organization	-2	-1	0	$+1$	$+2$	Mean	SD	n
A contractor you choose	7	13	22	56	24	0.63[a]	1.1	122
A local non-profit	10	10	40	44	16	0.38[a]	1.1	120
A small bank or credit union	12	20	44	38	8	0.082[b]	1.1	122
An energy service company	22	28	43	26	3	-0.33[c]	1.1	122
Your local government	18	35	44	21	4	-0.34[c]	1	122
A large commercial bank	27	24	54	13	4	-0.47[c]	1.1	122
Your utility company	29	34	45	10	3	-0.63[c]	1	121

From the interviews we heard that building owners tended to rely on contractors for information fairly extensively, and that they tended to have long, even friendly, relationships with contractors. It is thus not surprising that contractors were rated as the most trustworthy, with the modal response being agreement ($+1$) that a contractor chosen by the owner would have the owner's best interest in mind. In contrast, it was very surprising that a local non-profit was, on average, seen as trustworthy, as we frequently heard in interviews negative attitudes toward non-profits. The modal response for the remaining entities was at the neutral point of neither disagree nor agree (0). Surprisingly, the utility company was rated the least trustworthy, with very few respondents agreeing that the utility company has their best interests in mind. This is particularly surprising given that respondents felt most comfortable receiving rebates from the utility company as an incentive.

References

[1] Lawley, D.N. and Maxwell, A.E. Factor analysis as a statistical method. *Journal of the Royal Statistical Society. Series D*, **12,** 209–229 (1962).

[2] Jenkins, M.A. and Traub, J.F. Algorithm 419: Zeros of a complex polynomial. *Communications of the ACM*, **15,** 97–99 (1972).