

Rutgers Center for **GREENBUILDING**



Energy Efficiency and Occupant Behavior

**Greater Philadelphia Innovation Cluster (GPIC)
for Energy-Efficient Buildings, a U.S. DOE Energy
Innovation Hub Repository Case Study**

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Executive Summary

This research on energy efficiency and occupant behavior in multi-tenanted buildings provides valuable insights into the challenges that confront the goal of achieving a 50% energy reduction in commercial buildings in the Greater Philadelphia region by 2014 (gpichub.org). Our research questions are grounded in a framework that investigates both direct and indirect effects on energy use taking into account such factors as developer/owner requirements, building design and systems, construction outcomes, and building operator and occupant behavior. Research design and methods are drawn from the tradition of post occupancy evaluation (POE) research and entail both primary and secondary data collection via semi-structured interviews of tenants and members of the developer/owner team, an occupant survey, building walk-throughs, focus groups, utility bill and building automation system sensor log analyses, and building performance benchmarking.

Probably the most obvious conclusion we can offer is that multi-tenanted buildings are complex. All too often buildings (and their occupants) are treated as a black box, as if the organization of tenants within made no difference. Multi-tenanted commercial office buildings house tenants with diverse business objectives and, often, diverse energy needs. Moreover, the manner in which the occupants of multi-tenanted buildings interact with building systems and design may be influenced by their workplace objectives, in addition to work styles and personal preferences for comfort. While good building design and operation can help to mitigate these challenges, additional factors such as fragmented responsibilities/ locus of control issues, split incentives along with inadequate flow of information, and other related issues such as a lack of coordination between building design and interior design each may be especially relevant to a multi-tenanted context, given its heterogeneous population. These factors make can make energy management in multi-tenanted buildings highly challenging and helps explain shortfalls in realization of building performance objectives. Conversely, successful resolution of these factors could lead to joint benefits for building developer/owners and tenants/occupants. The developer/owner of the two buildings comprising this study has instituted an energy efficiency objective to reduce energy consumption by 23% across its portfolio by 2012. The challenges of reaching this objective, as illustrated in this report, are informative for the GPIC mission of obtaining approximately double the reduction in energy consumption in a slightly longer time frame.

Three findings of this research stand out as most actionable by GPIC investigators, the building design community, developer/owners and tenants and their occupants.

1. Disconnect between core and shell design/construction and interior fit-out of tenanted spaces

The first of these concerns a reoccurring disconnect between building design intent as represented in architectural choices and interior design (fit-out). In these buildings, as well as numerous others we have studied, the intent of the design— e.g., maximization of daylighting — is counteracted by interior organization of workspace. Sometimes the conflicts are unintentional and unrecognized. At other times it is intentional and reflects additional design needs and priorities — such as avoidance of glare, enhanced privacy or acoustical control. Moreover, some design strategies (in these buildings, central atria and a northerly glass curtain wall) balance energy efficiency with other factors such as overall appearance and spectacular views. This study, for example, confirmed just how much occupants like the northerly curtain wall for its views, while reinforcing the principle that exposure plays a critical role in energy consumption. In this case, workspaces located along the northern glass curtain wall not only demonstrated cooler temperatures in building performance evaluations (and echoed in occupant comments) but heating to the spaces was found to be triggered by outside air temperature during off-hours, for which a retrofit is being designed by building management. This disconnect is a prime example of an on-going challenge for building designers to acknowledge the extent to which energy efficient design strategies are affected by a dynamic occupant workforce and result in compromised outcomes in energy efficiency. Concurrently, they render the building less usable by both building occupants and the building operator.

In our interviews of tenants it also became clear that the objectives for a tenant-fit out and the extent to which it takes architecture into account can vary within an organization. Program guidance (such as LEED) has been unable to overcome the disjointed nature of building design and interior design with separate rating systems for building core and shell (LEED C&S) and interior fit-out (LEED CI) targeted towards different organizations entities (respectively, building developer/owners and tenants). Building codes pay little attention to this issue. Lease terms do address construction and maintenance within tenanted space and often specify aspects of the interior design program. However, even in the rare cases where energy efficiency as an objective is mentioned, enforce-

ment can be awkward given the over-riding need of a building developer/owner to satisfy its tenants. In this study even concerted effort by the building developer/owner to work with tenants during their fit-out and successful pursuit of LEED CI by two tenants has not proven sufficient to overcome subsequent operational challenges.

A different approach is needed that simultaneously can satisfy energy objectives and occupants' workplace preferences. This could be accomplished through increased coordination between core and shell and interior fit-out in a manner that takes the mediating role of occupant behavior more fully into account, at all levels of organization. From a policy perspective, GPIC investigators can then take this knowledge about occupant behavior and tie it into the development of better, more integrated design process and best practices that are incorporated into building programs within the GPIC region and nationally. Performance-based codes and tying incentives for energy efficiency to actual performance would also be expected to advance the GPIC energy agenda.

2. Diffused and confused locus of control

A second actionable finding concerns the reality in commercial building operation that control over property management and function is diffused among the building developer/owner, manager, and tenants/occupants. A level of cooperation among these parties is therefore required to meet energy efficiency and related objectives. Additionally, in this study as in others, some level of confusion exists regarding control over key building functions such as lighting and HVAC. Diffused and confused loci of control in these areas can have detrimental impacts on building performance. This is especially the case given that individual preference regarding such things as thermal comfort and lighting conditions are heterogeneous to begin with and that their responses to unfavorable conditions can be as diverse. A variety of remedies may be available ranging from a program of tenant/occupant education to new design approaches and operating systems that help to assuage the inherent tension between centralized and local control. An important component of instilling these fixes is more accurate portrayal of occupant behavior. To this end, GPIC investigators of building occupant behavior can assist in finding solutions by formalizing the results of POE into models of more realistic occupant behavior that the building and real estate industries can, in turn, use in designing, construction and operating buildings with more predictable performance.

3. The role of direct feedback and a new view of split incentives; is economic motivation sufficient?

A third actionable finding, which needs to be confirmed by additional research, is that there are situations in which the occupants of commercial office space may not care all that much about savings that can result from increased energy efficiency. We observed situations in which direct feedback on energy consumption is not readily available to tenants; the tenant is in a satellite office which is not made responsible for its energy use by the home office, and/or energy is a relatively small part of the cost of doing business. None of these situations are conducive to an enhanced energy conservation regime. From the standpoint of economic motivation, employee occupants appear to care even less. Thus, while direct feedback on energy use no doubt remains an important tool in promoting energy efficient behavior, it is a necessary but not sufficient condition. This raises the question of what other approaches or interventions could be made available to tenants and building occupants that would capture their interest and bond them to a mission of steep energy reduction. Developers/owners of buildings already comprehend the importance of direct feedback even while costs to sub-meter a multi-tenanted building can be prohibitive and technically complicated for a mix of tenants such as represented in this study. Next in line for GPIC research in Year 2 is exploration of the effects of customized feedback mechanisms (individual dashboards) in conjunction with serious games/social media-like interventionist approaches in these or similar buildings. This is an undertaking to be executed at all levels of organization – developer/owner, building manager, tenant, and employee/occupant. Overall, the individuals we spoke with in this study or who answered our survey perceived these buildings very positively, were supportive of its energy efficiency features and proud to work in a green building. Our objective, therefore, is to discover ways of leveraging these helpful attitudes to accomplish a shared energy reduction agenda.

Introduction

Study Objectives

This case study is prepared by the Rutgers Center for Green Building (RCGB) and was commissioned as part of a grant from the Greater Philadelphia Innovation Cluster (GPIC). The goal of the study is to contribute to a knowledge base for the improved integration of design, building operations, occupant activities and public policy, with the ultimate goal of commercial market adoption and diffusion towards a 50% reduction of energy use in buildings by 2014 with an 80% reduction target set for 2050 (gpichub.org). The partnership between the developer/ building owner of the two subject properties, GPIC and Rutgers University creates an important opportunity for evaluation of green, high performance commercial buildings while benefitting from the input of industry stakeholders on topics of green building post occupancy evaluation (POE) and energy efficient building design. Research in these areas is essential for identification of strengths and weaknesses in design strategies related to energy efficiency performance and savings, as well as to promote market diffusion of effective green building operating practices through a “lessons learned” framework.

An important component of this objective is to understand the role of occupants in affecting energy use in buildings. A better understanding of the transactions between occupant activities in the building and building design and operation can lead to strategies for maximizing benefits to companies and industries while reducing energy demand. The two case study buildings, located within the GPIC region, are LEED certified multi-tenanted ‘spec’ office buildings. Multi-tenanted commercial buildings are ubiquitous in the GPIC region, and energy management in multi-tenanted buildings is notoriously challenging. The literature shows that split incentives, fragmented responsibilities, lack of localized control, poor usability, and inadequate information flows hinder the pursuit of energy efficiency in this building type. As such, the results of this study are expected to find an eager audience among building designers, owners, operators, tenants and policy makers who desire to learn more about best energy management practices in multi-tenanted buildings and to promote their diffusion.

Research Questions

The research questions of interest for this case study focus on how the interaction among building occupants and the design and operational systems of multi-tenanted buildings affects energy efficiency. We have developed a model based on the assumption that

there are multiple factors that affect energy use that are internal to building design, operation and use (independent of external factors such as the availability and cost of fuels). This model organizes these factors into those that have direct versus indirect effects on energy use, as is shown in Figure 1.

Direct Effects on Energy Use: A number of design factors influence energy use directly, and are largely unaffected by building operation or the action of occupants. These are largely determined by regulation (building code) and associated design decisions about the building structure, materials, orientation and systems. These can include, but are not limited to the level of insulation provided by cladding, windows, and insulating materials, the degree of heat gain and loss as determined by building orientation and design elements, and the design and efficiency of HVAC and lighting systems and controls. The impacts of these are the direct result of the regulatory environment, architectural design and engineering decisions, and quality of construction which are again, largely unaffected by actions of building occupants.

Indirect, Mediated and Moderated Effects on Energy Use: Other aspects of the building design and systems also affect energy use through the actions of the individuals who manage or work in the building, building operators, and occupants. For instance, these building features may include some aspects of HVAC and lighting controls (such as how well their use and optimal operation are understood by the building operators, how appropriately and easily are they accessed by occupants, what kinds of feedback results from their use). Energy use may also be affected by the ease and ability of occupants to manipulate windows, shades, etc., especially as it relates to the control of daylighting; and the quality and adjustability of electrical lighting. Still other mediating factors may rely on occupants’ sense of responsibility for energy management, confidence in their ability to make changes in their environments, and belief that their actions make a difference in resource conservation.

Those factors that have direct effects on energy efficiency are largely fixed once the facility is in place, and typically can only be modified at great expenditure of time, effort and cost. Indirect effects, however, are worthy of attention because many building features that affect energy efficiency are amenable to change, through environmental modification, changes in system interfaces, or education. Indirect effects are influenced at different organizational scales of the building environment and thus energy interventions require an understanding of the all influencing factors at the each level – centralized management, building level opera-

Direct & Indirect Effects of Building Design on Energy Efficiency

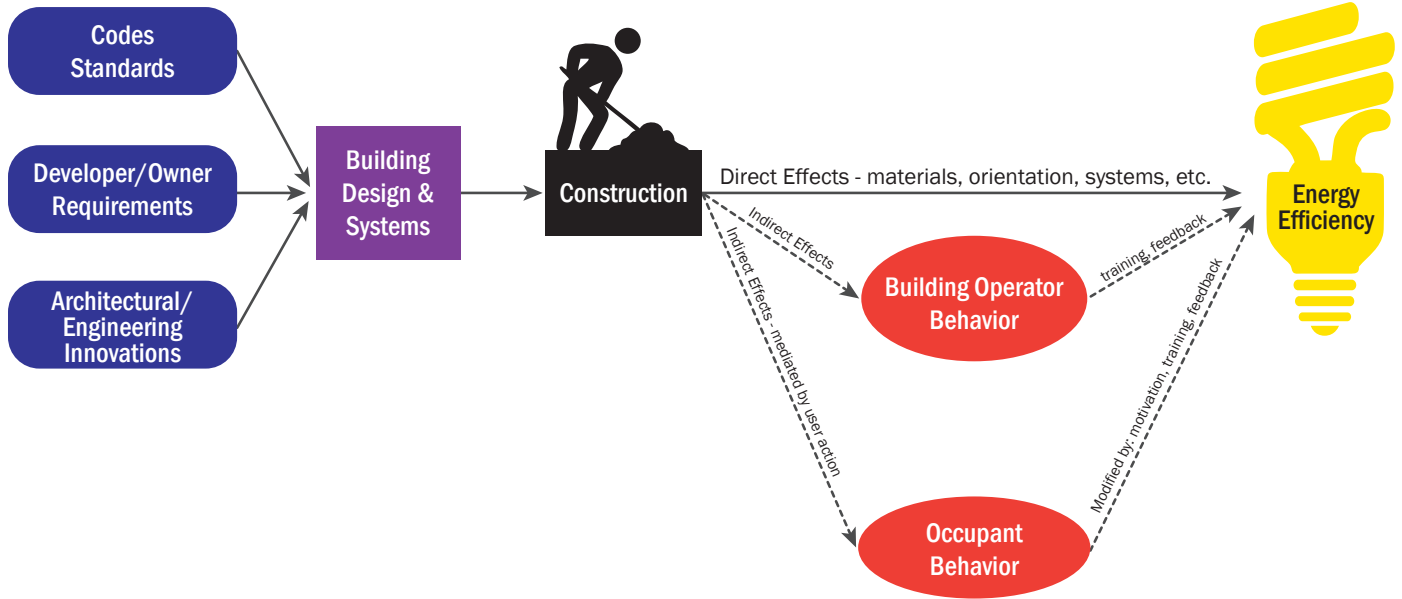


Figure 1 Building Design and Energy Efficiency

tions, tenant level interests, and individual occupant characteristics.

The nature of human interactions with buildings is often defined by individuals' work responsibilities as well as their personal preferences. Occupants interact with building design and systems in order to achieve personal levels of comfort and workplace productivity by adjusting or attempting to adjust building systems to changing environmental demands. Operators interact with the building design and systems to maintain a program set by the building owner while accommodating occupant comfort and needs without excess energy and expense. Accommodating occupant behavior in this regard may be as simple as providing a way to open window blinds to allow in more light when needed, which in return reduces the amount of electric light needed, or to close them to reduce heat gain, again with positive energy use consequences.

The success of this simple function is inextricably related to the orientation, quality and amount of glazed surfaces, ease of use of adjustable window treatments - and the ability of occupant to understand how and when to use them, and correspondingly adjust electric lighting and thermostat settings. That is, keeping room lights off when daylight is sufficient and glare is controlled reduces energy expenditure without restricting productivity or comfort. Occupant motivation also plays a role in the success of this interaction in his or her desire to save energy because of personal values or corporate requirements, a sense of satisfac-

tion and approval of general work conditions, and the degree to which systems provide timely and accurate feedback about the success of occupant actions.

Support by the building management/operations team. The central management team plays an important role in bringing tenants/occupants into the fold of the building's energy objectives. This can include providing training and equipment to the building manager/operator, placing clauses in the lease contract that define either voluntary actions or required responsibilities of occupants toward energy efficiency, instituting regular or frequent onsite visits and independent audits of systems, and offering educational workshops and even incentive-based competitions among tenants/occupants. Providing motivation to occupants to conserve energy may also help to counter some well-known impulses of building users that can run counter towards an agenda of energy conservation and increased efficiency. For instance, occupants have a tendency to overcompensate in their reactions for relatively minor annoyances, and to consciously or otherwise, leave systems in their switched state, rather than altering them back again later, at least until another crisis of discomfort is reached.¹

¹ Leaman - Raymond J. Cole and Michelle Steiger. (1999). "Green Buildings-Grey Occupants. Web-Proceedings: American Institute of Architects/US Green Building Council - Mainstreaming Green Conference, Chattanooga, TN, 14-19th October 1999 "

Correspondingly, our main research questions/study objectives for this work are:

- What are the design features and systems that were put in place in the subject buildings to increase energy efficiency and how well do they achieve their goals and work for occupants?
- How useable are these energy efficiency systems for the building manager/operator, and are they being used as intended?
- How do users perceive the building? How well do they understand how the building systems are meant to be used and can be adjusted to increase energy efficiency? How satisfied are occupants with their physical working conditions?
- How does the behavior of building occupants affect energy outcomes?

Our expectations are that if building energy systems and practices are available and user friendly, if occupants understand the purpose and function of these systems, if they are motivated to use them in a way that satisfies their needs and conserves energy, and if they receive appropriate feedback on their actions, they can achieve high levels of satisfaction with their setting along with energy efficiency. This, in turn, would enhance the ability of the building manager/operator to achieve targeted levels of energy efficiency.

Background

The developer/owner with whom Rutgers is partnered in this work is a leading commercial developer of high-performance green buildings. Many of this organization's properties are newly constructed or retrofitted LEED or ENERGY STAR certified green design. Moreover, the organization has put in place an energy efficiency objective to reduce energy consumption by 23% across its portfolio by 2012. The challenges of reaching this objective, as illustrated in this report, are informative for the GPIC mission of obtaining approximately double the reduction in energy consumption in a slightly longer time frame.

Building and Site Descriptions

Built in 2005, Building One was initiated as a sustainable, speculative multi-tenant office development. It consists of 76,350 square feet. It achieved LEED Platinum Certification – Core and Shell v 1.0 pilot in 2006² and its current ENERGY STAR Portfolio Manager Score is 79.³ The building has been over 90% occupied during the period of this evaluation.

In addition to its sustainable characteristics, its energy savings features include:

- Positioning the building for the most favorable solar orientation with sun shades on the south façade and a glass curtain wall system on the north side to minimize solar heat gain;
- A four-story day-lit atrium;
- Occupancy sensors in some areas along with daylight harvesting;
- Tenant design guidelines;
- A high efficiency HVAC system;
- Fundamental commissioning of the buildings' systems; and
- Measurement and verification of the base building.

² LEED for Core & Shell is used in projects wherein the developer controls the design and construction of the base building – mechanical, electrical, plumbing, and fire protection systems – but has no control over the design and construction of tenant fit out.

³ This national energy performance rating is a type of external benchmark that helps energy managers assess how efficiently their buildings use energy, relative to similar buildings nationwide. The rating system's 1–100 scale allows everyone to quickly understand how a building is performing — a rating of 50 indicates average energy performance, while a rating of 75 or better indicates top performance.

Built in 2009, Building 2 was initiated as a sustainable, speculative multi-tenant office development. It consists of 95,621 square feet. It achieved LEED Gold Certification – Core and Shell v 1.2 in 2009 and receives a current ENERGY STAR Portfolio Manager score of 78 once a major energy user (healthcare facility) is removed from the tally. The building leased up over a period from April 2009 through March 2010. It was 100% occupied during most of this evaluation.

In addition to its sustainable characteristics, its energy savings features include:

- A sophisticated utility monitoring and metering system to evaluate real time performance;
- A high efficiency HVAC system;
- A four-story day-lit atrium;
- 10' ceilings with expansive daylight views;
- Daylight in 75% of the spaces;
- Occupancy sensors and daylight harvesting;
- Tenant design guidelines;
- Fundamental and enhanced commissioning of the buildings' energy systems; and
- Measurement and verification of the base building.

Energy Savings Measures – On-going Monitoring and Evaluation

Both buildings are subject to a regime of on-going monitoring and periodic evaluation for energy efficiency opportunities. Specifically, the building operations are reviewed regularly in accordance with an Energy Savings Tracker which focuses on the following items:

- Light – turn off when not in use;
- Time of day scheduling for HVAC;
- Confirming building operating hours;
- Optimize start-up time and demand management;
- Plan for seasonal weather changes;
- Review damper and building leaks;
- Adjust ventilation;
- De-lamp and disconnect unused ballasts;
- High efficiency LED exit signs;

- Vending machine controllers; and
- Use of kill-a-watt equipment to monitor energy consumption of office equipment.

Additionally, systems are checked for communication failures on a daily basis as are static pressure trends to make sure air conditioning units are not running during unoccupied times (during the conditioning season). On a bi-weekly basis, variable air volume (VAV) zone set points are checked to make sure they are not set out of established parameters. Zone trends are checked during unoccupied times to make sure heat is not on when not called for. Unoccupied walk-throughs are conducted of tenant spaces to identify any motion sensor or timer problems quarterly. Finally, sensors are checked for accuracy (static pressure, CO₂ and temperature) on an annual basis.

These buildings also differ in key ways that are expected to affect the findings of this study.

1. Different (sub) metering strategies.

Building 1 is not sub-metered except for 3 meters that are tied into healthcare and data operations. Building 2 is sub-metered. Because direct feedback to tenants regarding energy consumption is hypothesized to affect an inclination to conserve on its use the different (as is provided for energy costs monthly by meters) sub-metering strategies might be expected to produce different outcomes.

2. Different tenant mix and therefore different energy load profiles.

While the tenant mix in the two buildings is broadly similar – containing professional, scientific or technical services, healthcare, construction management firms -- Building 2 contains a healthcare tenant who, by the nature of their business, is very energy intensive, and which accounts for 50% of that building's load. This tenant's core operations are centrally managed by the building's BAS.

Research Design

Comparative Post-Occupancy Evaluation

This study is a comparative post-occupancy evaluation of two multi-tenanted office buildings in the GPIC region. As noted above, the two subject buildings offer common features that support an evaluation across two related structures while also permitting some comparisons between the buildings and among tenanted spaces, based upon differences in design, tenancy, and to a lesser degree, management operations. Our model of direct and indirect effects on energy use further informs this comparative evaluation.

The practice of Post Occupancy Evaluation (POE) has been steadily increasing among private sector corporations since the 1970s and 1980s at which time it was largely an academic focus and became required by public agencies.⁴ POE refers to study of the operation, status, and usability of a physical setting at some point after construction is completed and users move in (Wener, 2002)⁵, and are intended to complete otherwise missing aspects of feedback loops that check how well the building's operation fits initial intentions, goals, program and design (see Figure 2).

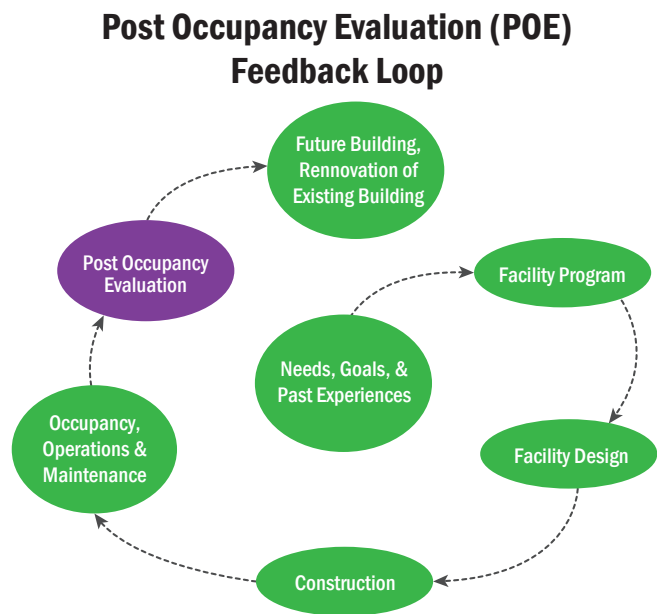


Figure 2 Post Occupancy Evaluation (POE) Feedback Loop. Adapted from Zeisel, J. (1981). *Inquiry by Design: Tools for Environment-Behavior Research*, Brooks/Cole Publishers, Monterey, CA

⁴ Senate Public Buildings Act of 1980, section 108, required the use of POE to: “determine and improve effectiveness of existing and planned public buildings providing a safe, healthful, economical, conveniently located, energy efficient and architecturally distinguished accommodations for federal agency offices.”

⁵ Wener, R. (2002). “Post Occupancy Evaluation,” in *The Encyclopedia of Psychological Assessment*, Rocio Fernandez-Ballesteros (ed.) Thousand Oaks: Sage Publications.

POE can include technical assessments of engineering systems (lighting, HVAC, etc.) and look at the energy usage or water consumption of a building compared to its design intentions. POE is distinctive, however, in its focus on building occupants and their needs and often includes surveys that ask about occupant satisfaction in key building areas.

Methods

As a case study this report provides a descriptive assessment of the two subject facilities with some comparisons among the case study buildings and their tenants, and also and between them and industry accepted measures. Toward these objectives, a series of methodologies were selected to increase understanding of the impact of design, systems and, especially, occupant behavior on building performance outcomes. In POE as with other studies, the use of multiple methods and types of data increases confidence in the validity of findings on the premise of data triangulation (Zimring & Reizenstein, 1980). The data sources employed in this study include:

Secondary Data

- Review of Archival Sources - LEED documentation, ENERGY STAR Portfolio Manager analyses, various consultant reports
- Building Performance Evaluation -utility bill analysis and Building Automation System (BAS) sensor logs
- Primary Data
- Walk-through observations of common spaces and a sample of tenant spaces in the two buildings
- Photo documentation of some of these spaces
- Semi-structured interviews with
 - Design, Construction, and Engineering Team members and; representatives of building developer/owner to review design intentions, performance expectations, and features aimed at energy efficiency
 - Facility Manager (FM) to gather detailed information about the building and FM practices
 - Tenant Representatives for a sample of occupied spaces to understand their expectations and views of the building and any specific office policies regarding energy use

- Focus Groups of
 - Tenant representatives (also a tenant recruitment strategy)
 - Office occupants for a sample of participating tenants
- Survey of
 - Building occupants to assess perceptions, satisfaction and use of the buildings such as may impact building energy performance
 - Facility Manager in conjunction with a Building Performance Evaluation (BPE) tool to assist in gathering both quantitative and qualitative data in such areas as energy, water, building cost and waste

Findings And Discussion

In keeping with the comparative POE research design and methods associated with this approach, this section presents empirical data drawn from various sources and levels of organization. It includes findings from our building performance evaluation utilizing utility data, industry benchmarks and building automation system sensor logs for tenanted conditions, data drawn from interviews focus groups and walk-throughs data of tenanted spaces and survey data of individual building occupants.

Building Performance Evaluation

Utility Bill Analysis

The purpose of a building performance evaluation is to develop objective, quantitative measures of resource use and indoor conditions for comparison with performance benchmarks and with subjective measures of occupant perceptions. Utility bills provide an objective basis for assessing energy efficiency. Based on findings from such an analysis, it is possible to determine:

- Whether there are energy savings in buildings;
- Which buildings in a comparison are using excess energy; and
- Whether energy management efforts are succeeding.

Building 1

Building 1 is primarily electricity driven. Natural gas is only used for backup re-heating of the building and to fuel an emergency generator. The total annual energy bill averages about \$180,000 of which only about \$1,600 is for natural gas. An analysis of the utility bills (electricity and natural gas) for Building 1 reveals that the building is functioning without any major irregularities.

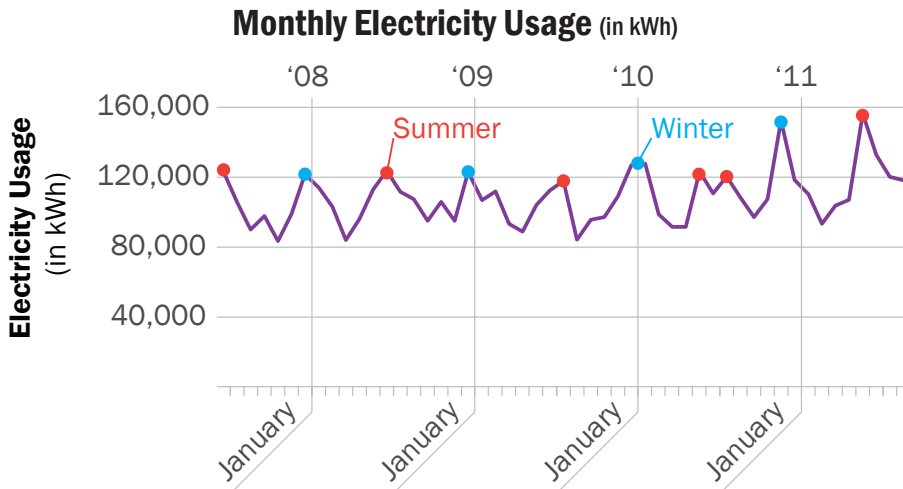


Figure 3: Build 1 electricity consumption patterns by month

Electricity Usage: Electricity consumption shows a regular seasonal pattern, with peaks formed during the summer (May-June) and winter (December-January) months (Fig 3). These peaks result from the heavy electricity use of the heating and cooling systems in their respective seasons.

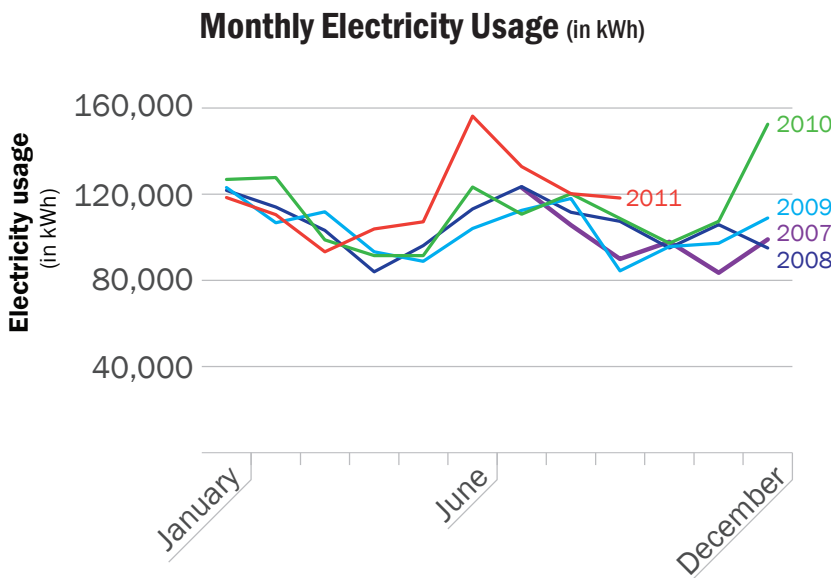


Figure 4 Building 1 Seasonal Electricity Usage

Trends: Figure 4 overlays monthly data for several years to illustrate its seasonality and to investigate whether there is a long-term trend. The winter of 2010 and summer of 2011 show unusually high usage but this is within the range of possible inter-annual variation in weather patterns and cannot yet be considered a secular trend.

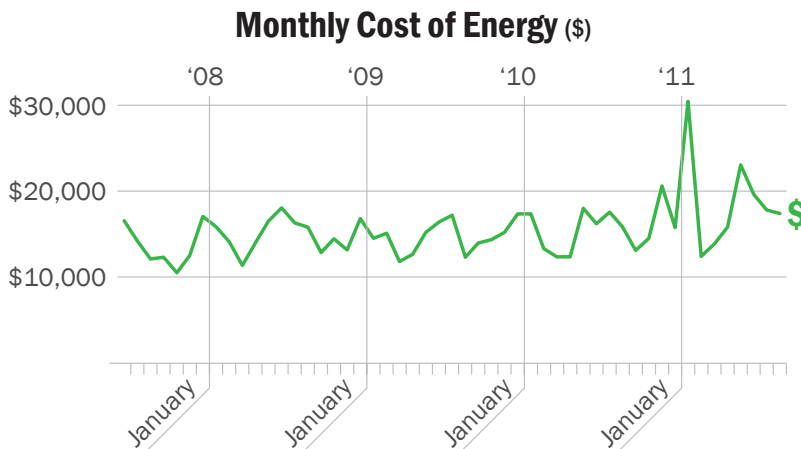


Figure 5 Building Monthly Energy Costs

Energy Cost: As the building is electricity intensive, the monthly total cost of energy echoes the pattern of electricity usage. This is illustrated in Figure 5 and Figure 6. Figure 5 confirms the seasonality of energy costs.

Electricity Intensity: Electricity intensity is measured in terms of annual kilowatt-hours per square foot of total floor area (79,034 sq.ft.)

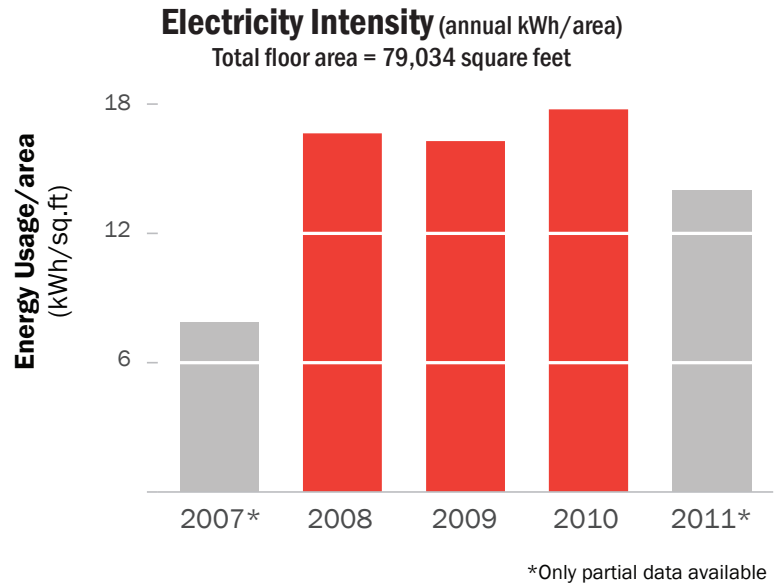


Figure 6 Build 1 Electricity Intensity by square foot

Intensity Over Time: As shown in Figure. 7, over the years the electricity intensity of the building has not changed dramatically. Note that years 2007 and 2011 have partial data.

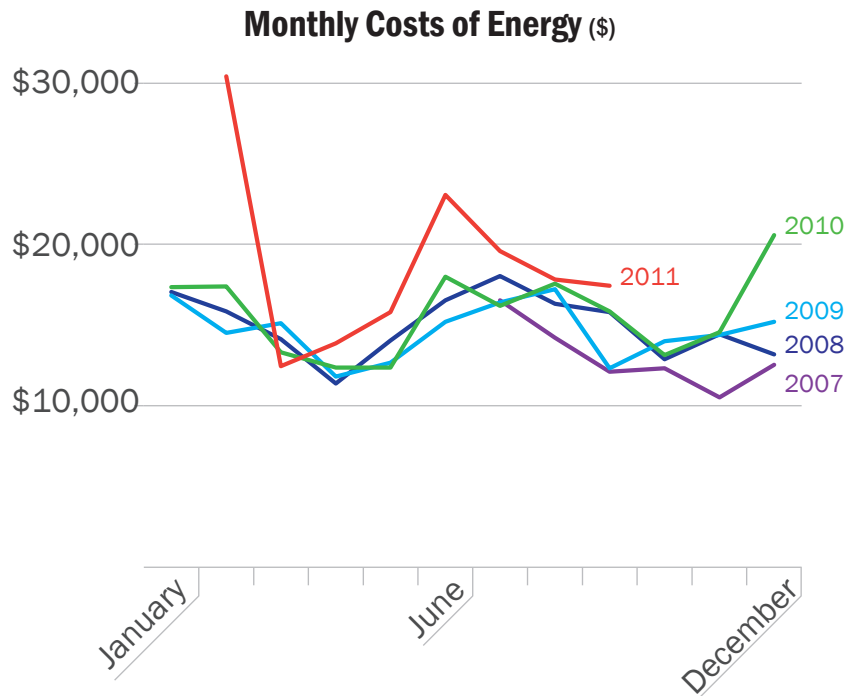


Figure 7 Building 1 Energy Costs

Total Energy Expenditure: As the building is electricity intensive, the total energy expenditure is heavily influenced by electricity expenses. Figure 8 shows the resulting pattern of total energy expenses.

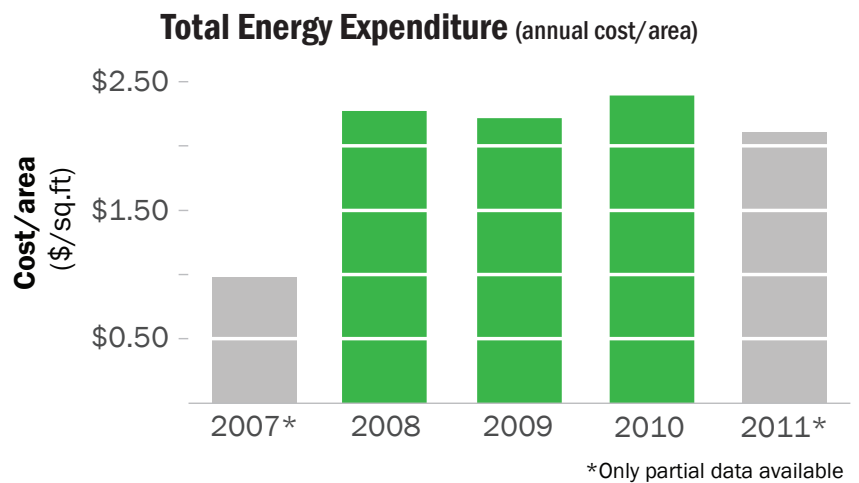


Figure 8 Building 1 Energy Expenditure Intensity Cost by square foot

Building 2

Building 2 is also primarily electricity driven. Natural gas is used only to start up the emergency generator. The total annual energy bill for this building averages about \$330,000 of which only about \$600 is for natural gas. An analysis of the utility bills (electricity and natural gas) of Building 2 reveals some interesting findings.

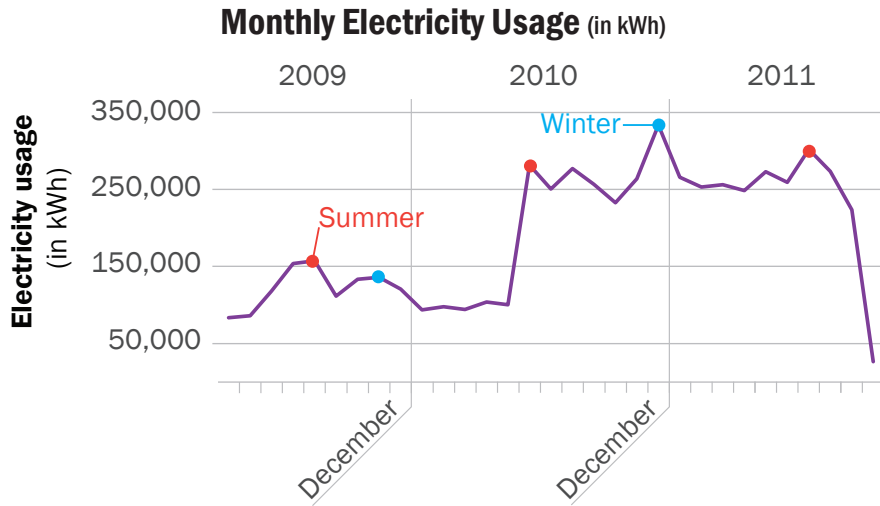


Figure 9 Building 2 Monthly Electricity Usage

Electricity Usage: We observed an irregular pattern in the pattern electricity usage over the 2.5 years of operation. A sudden and dramatic increase in electricity use is seen from May 2010, as clearly illustrated in Figure 9. The owner of the building attributes this anomaly to a change in the multiplier used to translate the meter readings into kWh of electricity usage. The utility recognized that its multiplier was inaccurate and is now making adjustments. Figures 9-10 show how this problem affects our ability to estimate energy costs and energy intensity.

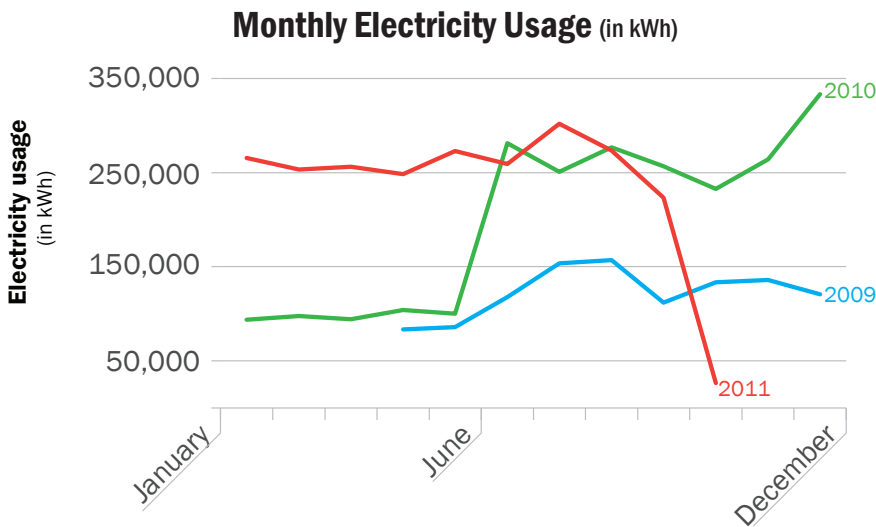
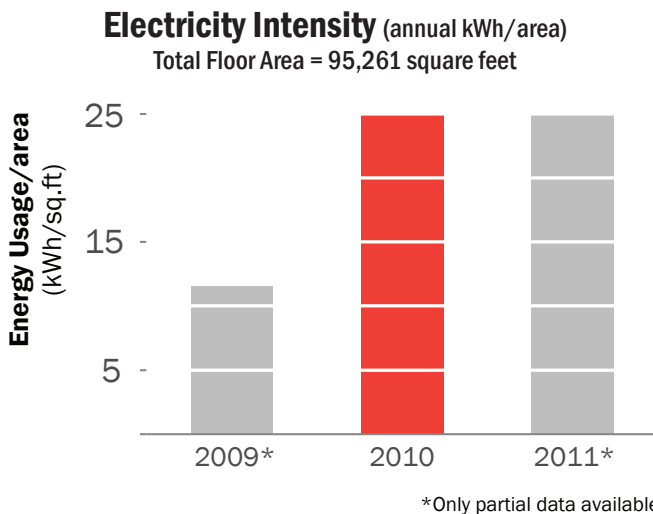


Figure 10 Building 2 Seasonal Electricity Usage



*Only partial data available

Electricity Intensity: Electricity intensity is measured in terms of annual kilowatt-hour per total floor area (95,261 sq.ft.). Figure 11 illustrates the level of electricity intensity (only partial data are available for years 2009 and 2011).

Figure 11 Building 2 Electricity Intensity

Total Energy Expenditure: Because of electricity-intensive nature of this building, the total energy expenditure is heavily influenced by electricity expenses. Figure 12 shows the normalized total energy expenses.

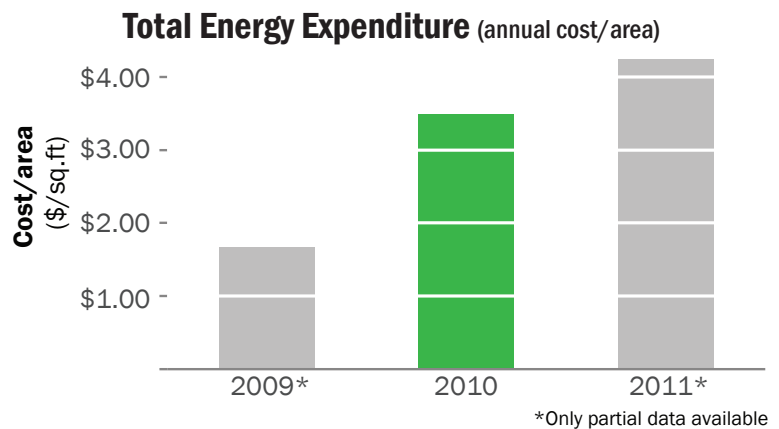


Figure 12 Building 1 Energy Expenditure Intensity Cost by square foot

ENERGY STAR Portfolio Manager

This national energy performance rating is a type of external benchmark that helps energy managers assess how efficiently their buildings use energy, relative to similar buildings nationwide. The rating system’s 1–100 scale allows everyone to quickly understand how a building is performing — a rating of 50 indicates average energy performance, while a rating of 75 or better indicates top performance. Based on the information entered about a building, such as its size, location, number of occupants, and number of appliances, the rating system estimates how much energy the building would use if it were the best performing, the worst performing, and every level in between. To estimate the amount of energy used by a building at each level of performance, EPA conducts statistical analysis on the data gathered by the Department of Energy’s Energy Information Administration during its quadrennial Commercial Building Energy Consumption Survey (CBECS). The system then compares the actual energy data entered to the estimate in order to determine where the building ranks relative to its peers. (www.energystar.gov)

The owner/developer of both Building 1 and Building 2 regularly conducts an energy performance evaluation using ENERGY STAR Portfolio Manager. The performance data for both buildings during the 2010-2011 time frame are provided below:

ENERGY STAR Statement of Energy Performance: Building 1

- Site Energy Intensity: 62 kBtu/sq.ft/yr
- Energy Performance rating of 79

ENERGY STAR Statement of Energy Performance: Building 2

- Site Energy Intensity: 77 kBtu/sq.ft/yr
- Energy Performance rating of 78

Discussion of Building Performance Evaluation

It is important to note that the “Statement of energy performance” for Building 2 was prepared after excluding the energy usage of their most energy intensive tenant, which uses the building for medical purposes. The amount of energy used in medical settings is strikingly higher than in those that do white collar office work, and it was felt that including this tenant would have been inappropriate for comparisons with office baseline data.

As part of our analysis, we calculated the site energy intensity of Building 2 including all tenants, for the period 2010-2011 and found it to be 107.03 kBtu/sq.ft. With these utility bills, an office building would have received an energy performance rating of 22, and a medical office would receive a 33. In other words, the actual performance of Building 2 indicates that it is relatively energy intensive, although much of the cause is due to its mix of tenants rather than the building envelope or systems.

On calculating the site energy intensity after excluding the most energy intensive tenant of Building 2, we found it to be 79.73 kBtu/sq.ft, showing a 2-3% error in the data provided to the rating system.

We also calculated the site energy intensity of Building 1 and found it to be 61.36 kBtu/sq.ft which corresponds with the data previously provided.

Figure 13 compares the Site Energy Intensity of Building 1 and Building 2 based on total-building utility bills.

Comparing Site Energy Intensity for 2010-2011 (in kBtu/sq.ft.)

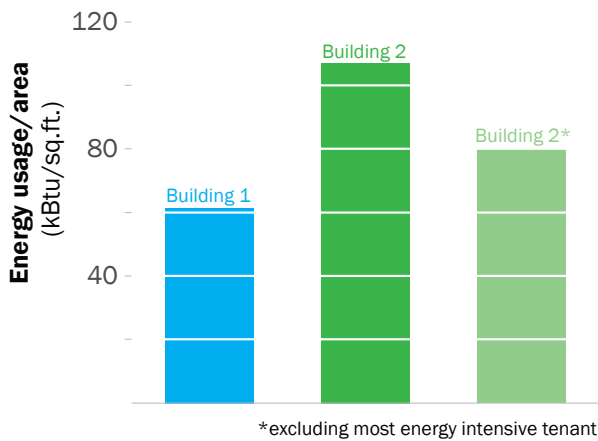


Figure 13 Site Energy Intensity Comparison of Building 1 and Building 2. Data based on utility bills.

Energy Analysis

We also compared the performance of Building 1 and Building 2 to benchmarks drawn directly (rather than indirectly through ENERGY STAR Portfolio Manager) from the Commercial Buildings Energy Consumption Survey (CBECS), which is based on a national survey of 5,215 buildings, as shown in the following energy analysis. Specifically, we extracted average values for both office buildings and healthcare operations in the Mid Atlantic region. In evaluating the following comparisons, it is important to note that CBECS data is only available up to 2003. Since then plug loads in most buildings have increased significantly because of the number of electrically powered devices in use. A more recent CBECS survey was conducted (for 2007), but because of an inadequate response rate, the US DOE has not released it.

Electricity Intensity: These data show that Building 1 performs approximately at or better than the CBECS 2003 benchmarks for office and healthcare buildings while Building 2 (all tenants included) appears to be more electricity intensive than either.

Natural Gas Intensity: Both Building 1 and Building 2 have been performing exceedingly well in terms of natural gas intensity.

Total Energy Expenditure (in \$/sq.ft.): Because Building 1 and Building 2 are electricity intensive; the total energy expenditure is heavily influenced by the electricity expenditure.

The total energy expenditure of these buildings exceed the value suggested by CBECS which seems largely due to the fact that the unit cost of electric power provided to Building 1 and Building 2 is higher than either CBECS estimate.

Discussion of Energy Analysis

There are a variety of possible inferences to draw from these analyses regarding the performance of Building 1 and Building 2. First, it is reasonable to assume that the buildings' design balances energy efficiency with other factors such as overall appearance and spectacular views, which may offer tenants a higher quality experience than in a typical office building. In our interviews with the building management team about these buildings, we also learned that they have faced a number of challenges in energy management that are common to multi-tenanted buildings including: the value-engineering of certain control sequences which were written but not implemented; start-up issues such as incorrect commissioning of VAV boxes; and, partial tenancy and thereby partial load conditions.

Most important, the fact that both buildings have healthcare tenants seems to have a significant impact on overall energy performance, particularly in the case of Building 2 where one healthcare tenant uses up to 50% of the building's energy. Benchmarking of building performance becomes challenging in the multi-tenanted case because actual tenants' energy use profiles often diverge from those assumed during design. Also, most of the energy operations of this tenant are not controlled by the building manager thereby presenting a real challenge for meeting energy efficient objectives of this building.

Building Automation System (BAS) Sensor Logs Analysis

Another line of inquiry into the performance of these buildings draws us deeper into the building systems – into tenanted spaces and thus the Building Automation System (BAS) sensor logs. Below, are three sample analyses for three tenants in Building 1. They serve to illustrate the indoor thermal conditions prevalent in three different spaces while revealing that good energy saving practices such as setting temperature setbacks during nights and weekends are being followed. In interpreting these findings it is helpful to bear in mind that the HVAC system is centrally controlled. However, tenants do have the option of manually adjusting the thermostat within a +/- 2 degree range. Some tenants have this option enabled and some do not; the decision is left up to each office manager who, based on our interviews, may not understand that s/he has this control.

The following figures illustrate in detail the relationship between the interior room temperature and the heating and cooling setpoints, found in various parts of the building:

Tenant 1

Building Exposure: North and East facing facade

Floor: 3

It also should be noted that even during weekends there is not a significant decrease in room temperature.

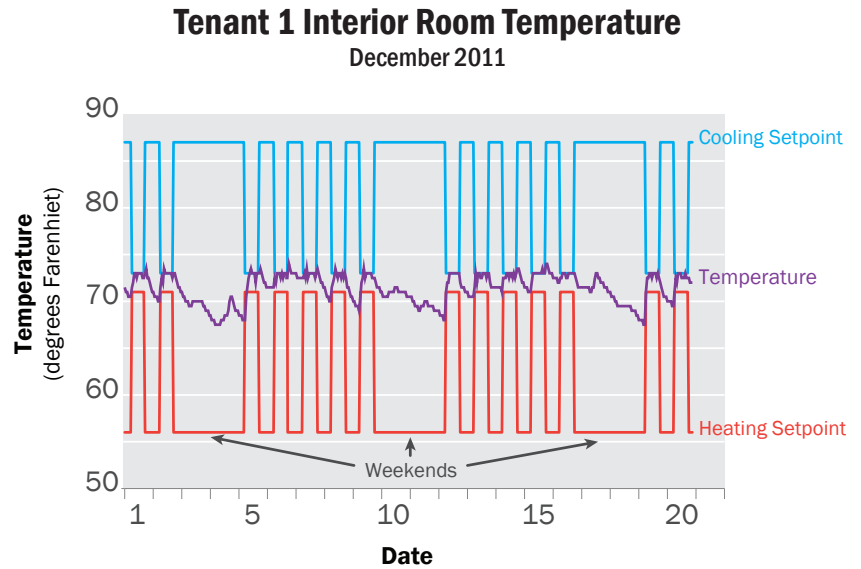


Figure 14 Setbacks in Temperature for Nights and Weekends

Tenant 2

Building exposure: West facade

Floor: 2

Again, note that even during weekends, as depicted in Figure 15 there is not a significant decrease in room temperature.

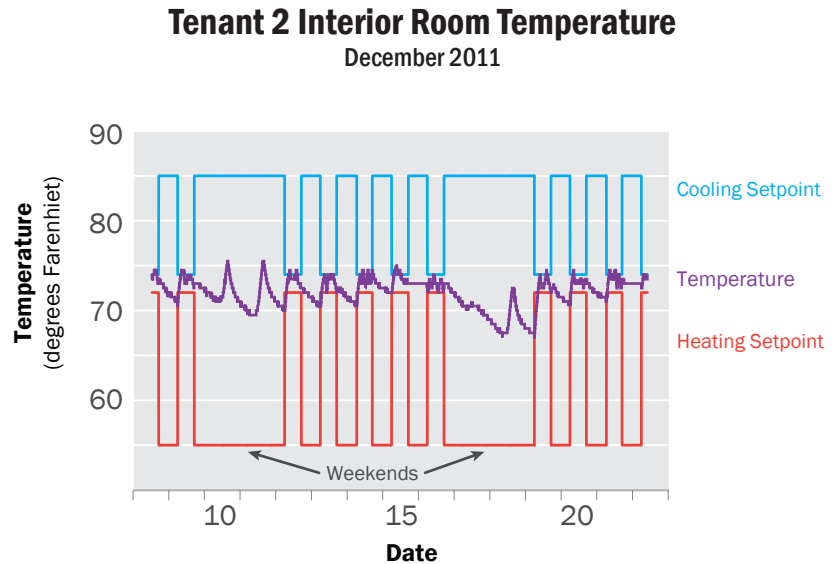


Figure 15 Setbacks in Temperature for Nights and Weekends

Tenant 3

Building orientation: North and West facing facade

Floor: 2

It is interesting to note however that during the weekends in spite of these setbacks as depicted in Figure 16 the actual room temperature seems to be equal to and at times even higher than the weekday temperature.

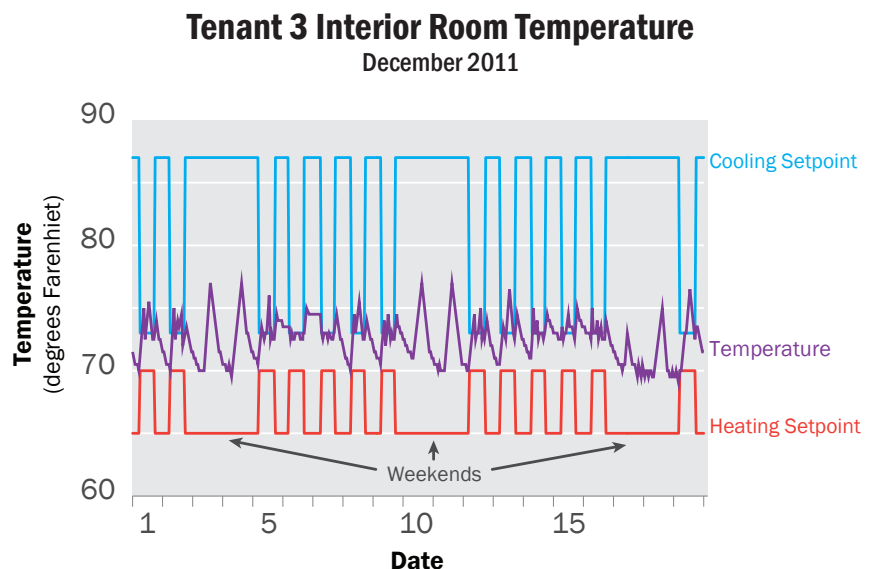


Figure 16 Setbacks in Temperature for Nights and Weekends

Discussion of BAS Analysis

Tenants' trended conditions add useful information to the analysis of multi-tenanted buildings. All of the tenants depicted in our analysis have either full or partial control over their thermostats (all zones versus some zones), so these samples tell us little about the effect of differences in thermostat adjustability. Rather, they demonstrate how a difference a key design parameter – exposure – can matter in energy usage. Tenant 3 occupies space along a large stretch of the northern curtain wall. This is significant due to its relatively colder temperatures, and also because the curtain wall heating that is provided has no time schedule but rather is triggered by outside air temperature. This heating system, then, runs on the weekends and night-time if it is cold enough outside. Building management is aware of this problem and is implementing a plan to overcome it.

Occupant Perceptions and Behavior

As earlier explained, information from occupants is an integral component of developing an explanation of building performance. Focus groups, interviews and surveys of building occupants, including an interactive walk-through of tenanted spaces, can help to confirm and identify indirect effects of human interactions with the building on energy and water usage, and related occupant satisfaction. During the course of this study, we conducted two (2) formal focus groups and approximately a dozen semi-structured interviews. We also completed several walk-throughs of tenanted spaces, some of which entailed interactions with a variety of office occupants along the way. Photo documentation of these spaces was sometimes permitted and completed, but because this is a confidential study, photos that could provide identifying information are not included here.

Online Survey

To complement data obtained from site visits, an online 65 item survey was completed by 48 respondents, or approximately 10% of the buildings' population, all of whom work for organizations leasing space in these buildings. The survey was a self-administered, online tool. The building owner/manager distributed notice of the survey's purpose and link via an email blast to all tenants in both buildings simultaneously with one follow-up reminder. A cover page was provided by the research team to ensure uniform and systematic directions to prospective participants. The survey was posted for 2 weeks and then removed from the building occupants' access. The survey, taken in the winter season, asked respondents to base many of their answers on their experiences for the prior week. Because of the small numbers on the completed survey,

associated statistics should be thought of primarily for descriptive purposes and to further illustrate responses obtained by qualitative/interview measures.

The people who were interviewed and who responded to our survey were a mix of new and long standing employees (most had been with their company between 1 and 3 years but over 40% had been employed longer than 3 years); and many had been in these buildings since they had opened and in their current workspace for more than one year. All but 1 participant were full-time employees; most (almost 61%) spent little time (1/2 day to 1 day) working outside of their primary building site of employment. The lessees are, for the most part, satellite offices for larger organizations, and most are engaged in some form of technical services (professional, scientific or technical services, healthcare, and construction management). Our respondents were overwhelmingly professional, upper level management and administrators, almost exclusively full-time employees who spend most of their workweek in these buildings. There were nearly twice as many respondents for one building over the other, which was not unexpected given tenancy and for other reasons.

Of the 35 survey participants responding to the question about the geographic orientation of their work space orientation, there was a relatively equal number working in spaces with northeastern, northwestern, southeastern, and southwestern exposures. Sixteen respondents reported working in cubicles with either low or high (five or more feet) partitions while 20 reported occupying offices either alone or with others (See Figure. 17). More than 73% of the survey respondents (28) had window views. Respondents on floors 1-3 were pretty equally represented with the fourth floor being under - represented in our sample.

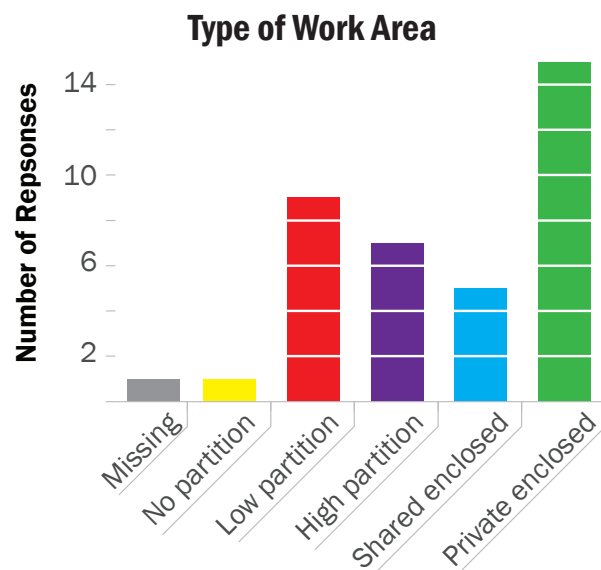


Figure 17 Description of Respondents' Work Area

Semi-structured interviews also gave us access to experiences on all orientations of the two buildings and also to a variety of office layouts and configurations. Illustratively, one tenant we visited with occupies an entire floor, another occupies large spaces on more than one floor and several occupy smaller spaces with one or two exposures.

General Response to the Sites

Overall, the individuals we spoke with or who answered our survey perceived these buildings very positively and saw them as very attractive and very clean work environments, good places to work productively, good places for feeling healthful. They saw these buildings as good examples of environmentally friendly design and were proud to be working in such an environment. The sites were rated very positively for the quality and comfort of the public areas, the landscape, convenience of location and parking. Other comments below should be read within the context of an overall strong positive rating for the facilities as a whole. Only convenience of public transportation was not rated well.

Respondents, as noted in focus groups, interviews and surveys, further indicated that the building met their needs for space issues they felt were most important. This was true for the highest rated issue - the amount of workspace available, and for the most part for noise, privacy, and lighting, although there were some problems in these areas. HVAC issues (temperature control, air flow) rated somewhat less well. Energy efficiency relates most strongly to behavior connected to temperature control and lighting. Thus we focus on providing detailed occupancy data for these two areas, below.

Thermal Comfort/Temperature Control

Since heating and cooling is the most significant use of energy, occupant response to these systems and attempts to adjust for comfort are particularly important. Thermal comfort was rated as very important by occupants for their ability to work well. Survey and interview respondents were generally positive about the level of thermal comfort provided in these buildings, although there was considerable variation among individual responses. Concerns were especially prominent in the period soon after occupancy when some occupants, especially those near broad northern exposures of glass, indicated that they used portable electric resistance heaters in the winter. This particular problem may have been related to the need for better communication with the building managers and may be less prevalent now.

Even so, many respondents (more than 50%) reported occasionally having too cool a work environment with about 15% reporting the same experience every, or almost every, day (see Figure 18). Approximately 35% of respondents reported the temperatures too high on occasion (see Figure 19) and 10% every, or almost every, day. Airflow was reported as inadequate at least occasionally by approximately 22% of respondents (Figure 20).

Temperature too Cold

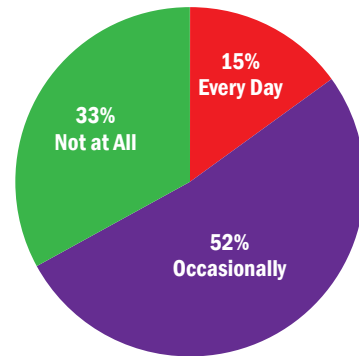


Figure 18 Reports of Workspace Temperatures during Previous Week

Temperature too Hot

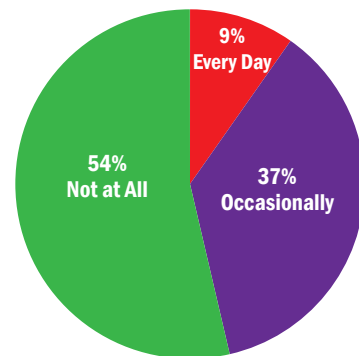


Figure 19 Reports of Workspace Temperatures during Previous Week

Too Little Airflow

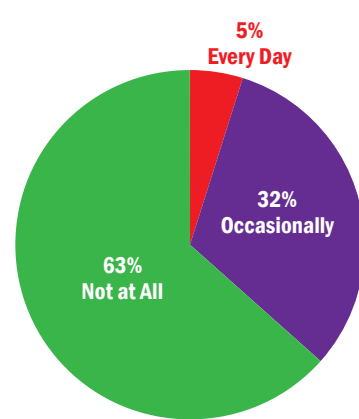


Figure 20 Reports of Workspace Airflow during Previous Week

Regarding actions taken in response to these perceptions, respondents indicated that they mostly respond by adjusting clothing (such as putting on sweaters), or by manipulating window shades, presumably to let in heat, or attempting to adjust the thermostat. When air flow is an issue for occupants of either of these buildings they may call management and feel the problem is handled well. Calls to management with a work request, however, seem to be relatively rare. Based on our interviews we suspect that relatively few calls to the building manager for a variety of reasons including that the buildings work quite well, occupant discomfort is not great enough to bother, adaptive actions are sufficient, individual tenants are unwilling to “bother” the building manager, and the tenant wishes to avoid paying the after-hours fee for turning office lights back on, opting rather for task lighting or going home.

As regards thermal comfort, it is interesting to note that most building users do not have control over thermostats beyond a +2 degree range, whereas the building manager can vary it widely in response to measured conditions or complaints. We met with office managers who had different beliefs about the adjustability of zoned thermostats in the same building. One was convinced that the thermostats are not at all adjustable, while the other claimed to adjust them regularly within a narrow range. We also spoke with two office managers who had such an intense interest in the thermal quality of their space that they regularly monitored temperature and, in one case, humidity.

Daylighting

Daylighting, or indirect lighting by the sun, is a central design feature of these buildings. It is viewed positively by survey, interview and focus group respondents alike. Daylight is available in most parts of the building and occupants mention it unprompted and appreciate it. Just as often they refer to the large expanses of glazed façade as facilitating views.

Glare is sometimes a side effect of daylighting and can be a challenge to manage on various exposures and in different seasons with the sun’s rays hitting the building at different angles. Almost 45% of respondents reported having experienced daylighting conditions as too bright, with glare anywhere from an occasional to an everyday occurrence (n=16). This was reported by respondents across all exposures (see Figure 21).

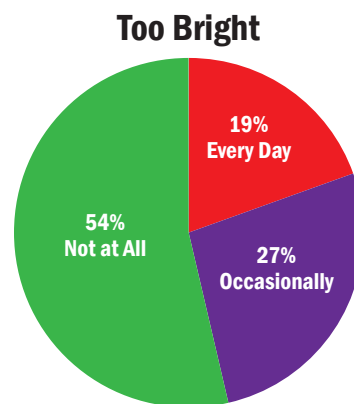


Figure 21 Reports of Workspace Airflow during Previous Week

Anecdotally, individuals have commented that the significant levels of daylight enable them to reduce use of electrical lights during daytime work hours although others have commented that manually switched office lights stay on all day even if there is enough daylight to do without them for a portion of the day.

In our walk-through of tenant spaces we did observe apparent operation of blinds, in combination with manually switched lights, mainly in private offices. We also observed situations in which blinds could not be operated due to the configuration of office furniture, which again points to the importance of tenant fit-out and how this relates to daylighting and other potentially energy saving features. Our interviews and walk-throughs exposed us to situations in which tenants deliberately arranged the office so as to maximize daylight penetration (i.e., by using high cubicles for privacy but with clear glass on top), others in which cubicles that were inherited from a prior tenant blocked daylight penetration across an otherwise open floor plan, and yet another in which glare and building configuration (curvature of the curtain wall on the one hand and atrium on the other) made it very challenging to situate a CEO’s desk such that he could command the office and face entrants, as was said to be customary.

We also observed varied responses to over-lit/glare conditions in our interviews/walk-throughs. In one case, the response was to lower shades and add screens to computers that cut the glare, although it was noted that these actions were also taken out of concern for privacy. In another case, an occupant of a private office responded to periodic glare by operating his blinds and turning on a switched light. Both of these cases are along the western wall – in one case of Building One, in the other of Building 2.

Electric Lighting

User ratings for electric lighting were generally positive, though with some concerns, with approximately 12% rating it as below average. There were indications

that available electric lighting is sometimes perceived as too bright (potentially causing glare) or too dim. Moreover concern over lighting is affected by the less than complete level of control occupants have over its setting and some feel that they have no options when lighting needs adjustment (70% of respondents are either unsure about how to control the lights or feel that they are not easy to understand, see Figure 22). Indeed, not all lights in these buildings are controlled at the office level. Individuals at desks may feel relatively little control over setting their lighting levels, except where task lights are available.

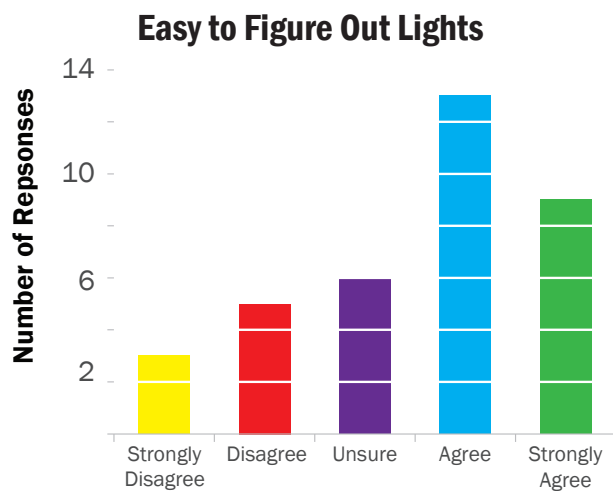


Figure 22 Respondents' Reports Reflect Ease in Understanding Electric Lighting Controls

Our semi-structured interviews and office observations amplify and add dimension to this last finding – there is confusion about who controls which lights and actual control over lighting is quite diffuse. At the same time, there is a surprising amount of diversity in lighting configurations and control across tenanted spaces.

In one office, the building facility manager has sole control of approximately $\frac{3}{4}$ of the lights, which are always on in a large workspace filled with cubicles adjacent to the curtain wall. These lights double as night-lights to meet the Philadelphia building code even though the building is not occupied at night. In this same office lights remain on in an under-utilized space along the southern side of the office/building. Whereas occupancy sensors could create a more efficient outcome in this space, there is no direct incentive for the tenant to install these in a building without sub-metering. If total building electric use shrank, this tenant would receive a only small credit (utilities are charged on a per SF pro rata basis), while the inefficiency of leaving the lights on is diffused across the tenant base.

The tenant controls the remaining lights some of which are in private offices, although we also learned

from the facility manager that the lights in the private offices are actually on a time clock. After 7 PM (lights out time) office occupants cannot turn them back on themselves, but rather must call him to change the program and incur a fee. This may help to explain the relative prevalence of task lighting we encountered in private offices in this and similarly configured spaces.

In other office spaces, almost all lights are on occupancy sensors or otherwise controlled by the facility manager. We also encountered occupancy sensors that can be manually operated and lights that have been retrofit with lighting sensors by row and cubicle, although this level of precision in lighting management seemed to be rare. In contrast, we also were told of situations in which occupancy sensors have been removed since lights would go off when occupants sat at desks quietly, or when it otherwise created awkward situations.

Other lighting retrofits that have been made to tenanted spaces in order to adjust lighting to meet workplace needs and individuals' preferences include the addition of sconces to areas perceived to be underlit and the addition of under-cabinet lighting for close-up work. At times, these lighting changes to support a particular work environment have been made despite the intent of the building design to make increased use of daylight and despite LEED-CI driven requirements, to which two tenants currently reportedly adhere having attained LEED CI certification.

Other Issues

Building Occupants' Attitudes and Values. As evidenced in the survey, the occupants of these buildings seem to be environmentally conscious and concerned; 92% of respondents (n=34) indicated that they thought it was important to save energy (see Figure 23).

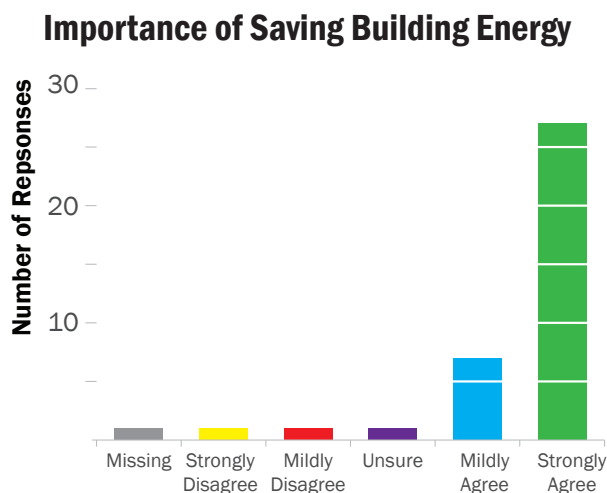


Figure 23 Number of Occupant Respondents' Agreeing on Importance of Saving Building Energy

Most respondents did not feel that the energy saving features of these buildings are an inconvenience to them, although a significant minority (26.3%) did find the energy savings features to be inconvenient. A contingent did feel that the water saving features were inconvenient. Survey (84%) and interview respondents alike recognized these buildings as “green buildings” and reported being proud of this status.

Notwithstanding these data, respondents to our semi-structured interviews and office walk-throughs rarely mentioned energy efficiency as a business priority. Indeed, only one interview respondent had ever seen a utility bill for his office space. Most respondents felt that if the bill was an issue they would have heard about it from the home office; but again, it ranked low on their list of concerns. The lack of direct contact of onsite administrators with electric and gas bills, which often are paid by personnel at other sites, is another organization factor that limits motivation to conserve.

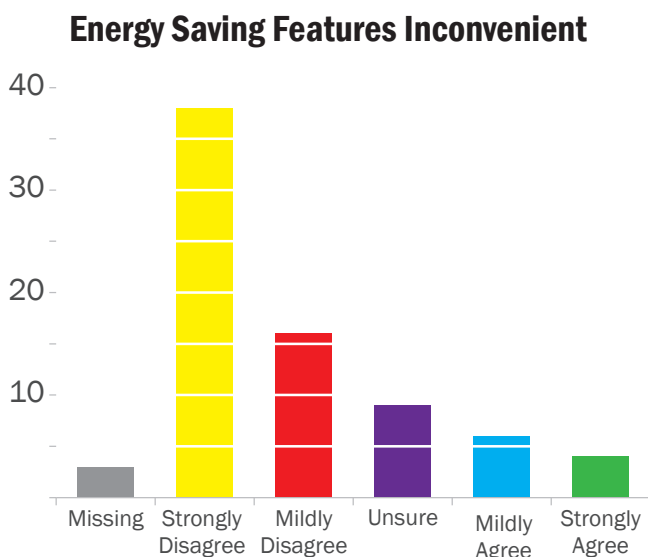


Figure 24 Number of Occupant Respondents Reporting Inconvenient Energy Saving Features in the Building

Discussion

Integration of Building Design, Operation, and Occupant Activities

Both buildings in this study have been designed as high-performance buildings to maximize energy efficiency and other sustainability objectives. The actual performance of green design for effective energy efficiency is the result of the combination of planning, construction, design strategies as built, operations management, and occupant experiences and behavior in the spaces, and also regulatory, economic and other constraints. Exterior considerations including site characteristics and building envelope design and maintenance can produce independent effects on energy consumption and can interact with interior environments to produce synergistic conditions that

either favor or detract from energy efficiency objectives. Interior design (fit-out), mechanical system operation, and maintenance practices also affect the efficient operation of energy systems while building management performance provide the leadership to guide all aspects of the building’s energy objectives.

At all levels of management and occupancy there are a variety of perspectives about what constitutes effective energy management. In addition, the benefits of energy efficiency or, more broadly, sustainability do not accrue equally across all entities, e.g., savings on energy use. Effort is not always met with direct reward. As we have seen, no one entity has complete control over managing the space and so a level of cooperation is required to meet energy efficiency and related objectives. In the literature it has been noted that this is particularly the case when improvements are being made to already occupied space (Pivo, 2010),⁶ which has interesting implications for the objectives of the GPIC.

Furthermore, while green buildings, i.e., buildings with an objective to reduce environmental impact, tend to be more efficient in energy and resource use with concomitant savings, they also may require additional effort and expense to operate. This may be because of the need for more intensive management of these buildings or because of a steeper learning curve for their efficient operation (Miller, Pogue, Saville, Tu, 2010).⁷ This is complicated by findings indicating that newer buildings are more energy intensive due to increasing plugload (Andrews and Krogmann, 2009).⁸

⁶ Pivo, G. (2010). Owner-tenant engagement in sustainable property investing *Journal of Sustainable Real Estate*, 2(1), pp. 183-199.

⁷ Miller, N., Pogue, D.; Saville, J.; Tu, C. (2010). The operations and management of green buildings in the United States. *Journal of Sustainable Real Estate*, 2(1), pp. 51-66.

⁸ Clinton Andrews and Uta Krogmann, “Technology diffusion and energy intensity in U.S. commercial buildings,” *Energy Policy* 37(2009): 541-553.

Conclusions/Recommendations

The multiple sources of data collected for this case study of two multi-tenanted buildings reflect the challenges in managing energy use in multi-tenanted office space that go well beyond the direct effects of design strategies. These additional factors include fragmented responsibilities/locus of control issues, split incentives along with inadequate information flows, and other related issues such as a lack of coordination between building design and interior fit-out. All of these are examples of indirect effects of design upon energy efficiency as mediated and moderated by the actions of building occupants which, in some instances, influence the outcomes for energy efficiency in this building type.

Locus of Control

As is detailed in the sections above, the ability to control energy use via thermostats and lighting controls is diffused over various levels of organization. Control over daylighting and glare and workspace temperature were common themes. At the same time, individual preferences regarding thermal comfort and lighting conditions (both natural and electric) can be quite heterogeneous and their response to unfavorable conditions can be as diverse, often resulting in changes in the intended building performance. A variety of fixes may be available ranging from a program of tenant/occupant education (on an on-going basis) to design approaches that assuage a tension between centralized and local control. For instance, flexible light switches each containing fewer ballasts and lamps and that are coordinated with sources of daylighting can instill in the educated occupant a sense of ability and responsibility to use lights as needed. Similarly, HVAC diffuser vent systems that are accessible to occupants may be managed with the objectives of reducing the need for portables (i.e., electric heaters, fans). The development and coordination of advanced building automation systems with opportunities for local overrides and flexible application can also help merge the interests for both centralized and local systems control.

Inadequate Feedback Information and Split Incentives

Related to the locus of control theme is the well-documented finding that a lack of direct feedback runs counter to the ability of an individual or organization to enhance building performance using key information, in this case feedback on energy consumption. The information may be cost or use-based, but nevertheless is important as local benchmarks for management of consumption patterns. The fact that the two buildings studied are only partially sub-metered and/

or tied into the building automation system controls limits the kind of information that can be used to monitor and respond to energy consumption. Furthermore, even with sub-metering, any information that is available is often sent off site, i.e., to headquarters locations where the feedback typically is not made available to local occupants. Some of the companies we interviewed indicated a general disinterest in their energy usage as compared to other business considerations. In these cases, perhaps more direct feedback would encourage energy conservation, but feedback is only effective when it provides information about relevant consequences of behavior. Feedback about use in the absence of connection to costs would likely be an insufficient motivator. This raises the question of what kind of motivation will prove successful in working with tenants to save energy. Motivation can be a mediating factor that varies among individual occupants and may be defined in terms of one's beliefs about resource conservation, their ability to effect a change in energy consumption or in office conditions, or the importance of their actions. For other companies, the lack of an apparent share of the direct financial benefit for conserving energy was seen as a barrier, a version of the split incentive problem that can exist between building owners and tenants. The form in which feedback is provided may also vary with the organizational level of the desired intervention, i.e., building operators, tenants, and rank and file occupants may be motivated by different kinds of feedback relevant to operations at the building level, the tenant office space, or to the specific workspace.

Design and Fit-Out for a Diverse Tenant Base

Both buildings studied contain a mix of industries with varying energy needs, including health care providers. Health care providers have on-site energy intensive equipment such as x-ray and other diagnostic machines and monitors and have been known to contribute substantially to energy loads. It can be difficult to design and operate a building for maximal energy efficiency with a combination of large and smaller loads, although modern building automation systems certainly assist in this task. It may, however, be even more difficult to try to control building occupancy patterns given the apparent trend for satellite offices and decentralized and off-site services. A remarkably wide variety of tenant fit-out (type of furniture, etc.) further results in varied outcomes of lighting, daylighting and electric consumption and response patterns. While tenanted spaces obviously need to meet the needs of the specific office culture, a reoccurring theme in our studies of multi-tenanted green buildings is the need for strategies toward better integration of the design intent of the building and the fit-out of the space of different office uses. Continued evaluations of

the kinds of industries that populate multi-tenanted buildings may help owners and designers more closely specify system designs and management to more accurately reflect energy needs. Enhanced understanding of tenant occupancy patterns can help designers better integrate core and shell design with interior design, and create spaces that support office programs that are synergistic with energy efficient strategies. An example of such coordination may include designated spaces at the curtain wall that support work areas with built-in glare and temperature controls.

Risks of Using Benchmarks

As a result of diverse tenancy generally, and the inclusion of high-load facilities, in particular, the risk of centralized or universal benchmarking is that operations will be compared to unrealistic or inappropriate use levels. Again, a feedback loop that offers general guidelines for similarly tenanted buildings along with local energy performance indicators and education on energy performance can provide helpful information where occupants have control over their energy consumption. Owner representatives and the building manager of these buildings are well aware of the need to be cautious about benchmarking given these features. The priority of core business operations in the healthcare tenants over energy efficiency was a recurring theme among multiple stakeholders we interviewed. That said, a tendency to treat high-energy uses as outliers and to thereby exempt them from a benchmarking analysis does not help to advance the energy efficiency objective. To complement the design, motivational and coordination recommendations above, better benchmarking tools/methodologies are needed that reflect the growing reality of mixed uses and energy loads.

Site vs. Source Energy and First Costs

A related issue concerns the site versus source energy for these building types. The two buildings studies here represent a growing trend towards all electric buildings combined with high-performance design that emphasizes a tight envelope, daylighting strategies and efficient mechanical equipment. Even while these buildings may perform well in terms of their site energy, achieving scores that put them in the top 20% of their peers, their source energy remains high. Alternative approaches would incorporate more renewable energy and advanced energy systems such as solar and geothermal on-site. Additionally, these same systems could help to balance variable energy loads. However, the first costs associated with these systems discourage their incorporation into building projects, as was confirmed by our interviews of members of these buildings' developer/owner team and others like

them. This is a well-studied problem in policy circles that nevertheless continues to be a barrier to greater dissemination of energy efficiency and sustainability features, technologies and, to a lesser extent, practices.

Areas for Future Research

This research has advanced our understanding of how building occupants interface with specific building systems and features, and therefore how behavior may affect energy outcomes. It has supported established wisdom about the relationship of occupants and energy efficiency and also provides some new insights that challenge the established wisdom. More work along these lines is needed in order to solidify an understanding of the dynamic relationship between occupant behavior and energy efficiency, including attempts to affect it through technological and behavioral interventions. As such, an interventionist framework is our team's focus for the second year of GPIC work. Specifically, Rutgers University along with colleagues at Penn State University, Carnegie Mellon University and the Princeton Plasma Physics Laboratory will advance the field's understanding of relevant occupant behavior through a set of detailed pre- and post-occupancy evaluations supported by lighting and HVAC retrofits and a series of behavioral interventions that include testing innovative approaches for user control and feedback. We will formalize our findings in a variety of ways, including through an agent-based modeling framework that represents occupant and operator behavior in multi-tenanted buildings under several scenarios for individual incentives, organizational incentives, information feedback and design features affecting usability and local controllability of energy systems. Our over-arching objective is to link knowledge of occupant behavior to improved building performance, energy modeling practices, and energy management best practices in organizations as part of a reconfigured systems delivery for more energy efficient buildings.

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