WHY ENERGY-SAVING MEASURES IN COMMERCIAL OFFICE BUILDINGS FAIL: DEEP VERSUS SHALLOW USE STRUCTURES

by

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ABSTRACT OF THE DISSERTATION

Why Energy-Saving Measures in Commercial Office Buildings Fail:
Deep versus Shallow Use Structures

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Buildings consume large amounts of energy and other natural resources. The green building movement is a response to associated impacts; however the failure of these buildings to perform as intended is a persistent challenge. This is most apparent regarding energy use, which has continued to grow despite decades of public policy and investment to the contrary. In this dissertation, I demonstrate that underperformance is linked to poor usability and that building-level Energy Conservation Measures (ECMs) often are misaligned with the functions and use structures they are meant to support. In particular, I conclude that: 1) the social nature of workplace-based lighting and HVAC energy measures is not well understood by designers who conceptualize their use structures as narrow and shallow, when they are wide and deep; 2) innovation in energy-saving technologies has not kept pace with popular workplace organizational contexts – e.g., flex time, telecommuting and collaborative/activity-based design; and 3) the organizational implications of the convergence of advanced energy conservation technologies and IT is only beginning to become clear to adopting organizations, who have not implemented organizational protocols that empower decentralized users.

These usability shortcomings in turn negatively impact the case for greater diffusion of workplace-based energy conservation measures.

Acknowledgements

Over the past decade I have benefitted from the support of many individuals, too numerous to mention here. I would especially like to thank my dissertation chair, Dr. Clinton Andrews, whose international fame as a scholar of green building innovation continues to grow. I am grateful also to the other members of my committee – Dr. David Listokin, Dr. Julia Rubin and Dr. Rich Wener, who each in his or her own way has conveyed to me valuable skills and knowledge – and also to Dr. Krueckeberg, whose early influence on this work is found in its opening phrases. For the unwavering support of my colleagues at the Rutgers Center for Green Building – Dr. MaryAnn Sorensen Allacci and Deborah Plotnik – there are no words great enough. The amount and quality of data presented herein is the result of a large-scale team effort, which we endured in a spirit of mutual support and professional growth. I similarly owe a note of gratitude to the building owners and tenants who have so graciously tolerated and supported our research inquiries. In particular, a handful of highly dedicated employees of a leading real estate investment trust have contributed much time and insight to this thesis. They know who they are.

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Glossary of Terms

AIR EXCHANGE RATE

The rate at which outside air replaces indoor air in a space. Expressed in one of two ways: the number of changes of outside air per unit of time air changes per hour (ACH); or the rate at which a volume of outside air enters per unit of time - cubic feet per minute (cfm). (EPA Glossary of Terms, http://www.epa.gov/iaq/glossary.html#I, accessed October 18, 2014)

AIR HANDLING UNIT, or AHU

For purposes here, refers to equipment that includes a blower or fan, heating and/or cooling coils, and related equipment such as controls, condensate drain pans, and air filters. Does not include ductwork, registers or grilles, or boilers and chillers. (EPA Glossary of Terms, http://www.epa.gov/iaq/glossary.html#I, accessed October 18, 2014)

AUTO SENSOR

Automatic controls or sensors that increase or reduce lighting in response to level of natural light. (CBECS, 2003)

BUILDING ENVELOPE

Elements of the building, including all external building materials, windows, and walls, that enclose the internal space. (EPA Glossary of Terms)

CBECS

Commercial Buildings Energy Consumption Survey: a national sample survey on the stock of U.S. commercial buildings, including their energy-related building characteristics and energy usage data. (U.S. Energy Information Administration)

COMMISSIONING

Start-up of a building that includes testing and adjusting HVAC, electrical, plumbing, and other systems to assure proper functioning and adherence to design criteria. Commissioning also includes the instruction of building representatives in the use of the building systems. (EPA Glossary of Terms)

COSTAR

Leading provider of building-specific information through a proprietary database of commercial transactions in the U.S., U.K. and beyond. (http://www.costar.com/, accessed October 23, 2014)

DAMPERS

Controls that vary airflow through an air outlet, inlet, or duct. A damper position may be immovable, manually adjustable or part of an automated control system. (EPA Glossary of Terms)

DAYLIGHTING

Building features designed to reduce the amount of energy consumed by the lighting system. These include skylights or atriums, daylighting sensors, specular reflectors, electronic ballasts, and an Energy Management and Control System (EMCS) that controls the lighting in the building. (CBECS, 2003)

DIFFUSERS AND GRILLES

Components of the ventilation system that distribute and return air to promote air circulation in the occupied space. (EPA Glossary of Terms)

ECONOMIZER CYCLE

A heating, ventilation, and air-conditioning (HVAC) conservation feature consisting of indoor and outdoor temperature and humidity sensors, dampers, motors, and motor controls for the ventilation system to reduce the air-conditioning load. Wherever the temperature and humidity of the outdoor air are more favorable (lower heat content) than the temperature and humidity of the return air, more outdoor air is brought into the building. (CBECS, 2003)

ENERGY CONSERVATION MEASURE

A technology or practice that is implemented in a building or other physical asset with the intent to reduce (or conserve) energy use.

ENERGY MANAGEMENT CONSERVATION SYSTEM (EMCS)

An energy management feature that uses mini/microcomputers, instrumentation, control equipment, and software to manage a building's use of energy for heating, ventilation, air conditioning, lighting, and/or business-related processes. These systems may also manage fire control, safety, and security. Not included as an EMCS are time-clock thermostats. (CBECS, 2003)

ENERGY STAR (Commercial Buildings)

A U.S. Environmental Protection Agency (EPA) voluntary rating program for comparing similar building facilities nationwide on a scale of 1-100. A score of 50 represents typical performance, while a score of 75 indicates that a facility performs better than 75 percent of all similar facilities nationwide. (ENERGY STAR, United States Environmental Protection Agency)

ENERGY STAR PORTFOLIO MANAGER

EPA's online energy management and tracking tool that calculates 1 – 100 ENERGY STAR scores for eligible commercial and institutional buildings.

Portfolio Manager also facilitates the tracking of improvements over time. (ENERGY STAR, United States Environmental Protection Agency)

GRESB

The Global Real Estate Sustainability Benchmark, known as GRESB, solicits voluntary information from building owners to provide to institutional investors, with the aim of improving the sustainability performance of the global property sector at large. (https://www.gresb.com/about, accessed October 25, 2014)

INDOOR AIR QUALITY

Indoor air quality (IAQ) is a term referring to the air quality within and around buildings and structures, especially as it relates to the health and comfort of building occupants. (EPA Glossary of Terms)

INDOOR ENVIRONMENTAL QUALITY

Indoor environmental quality (IEQ) refers to the quality of a building's environment in relation to the health and wellbeing of those who occupy space within it (CDC Topics) and includes thermal comfort, indoor air quality, sound and vibration, and non-ionizing electromagnetic radiation (including visible light). (ASHRAE Guideline 10-2011)

ILLUMINANCE

The incident luminous flux density on a differential element of surface located at a point and oriented in a particular direction, expressed in lumens per unit area. Since the area involved is differential, it is customary to refer to this as illuminance at a point. The unit name depends on the unit of measurement for area: footcandles if square feet are used for area, and lux if square meters are used. (Adapted from IES) In lay terms, illuminance is a measurement of light striking a surface. It is expressed in footcandles in the U.S. (based on square feet) and in lux in most other countries (based on square meters). (USGBC Glossary)

LEADERSHIP IN ENERGY AND ENVIRONMENTAL DESIGN

Leadership in Energy and Environmental Design (LEED) is a set of rating systems developed by the US. Green Building Council (USGBC) for the design, construction, operation, and maintenance of green buildings, homes and neighborhoods. (USGBC)

LOAD SHEDDING

An intentional action by a utility to reduce the load on the system. Load shedding is usually conducted during emergency periods, such as capacity shortages, system instability, or voltage control. (USGBC Glossary)

MINIMU7M EFFICIENCY REPORTING VALUE, or MERV

Consumers can select a particle removal air filter by looking at its efficiency in removing airborne particles from the air stream that passes through it. This efficiency is measured by the minimum efficiency reporting value (MERV) for air filters installed in the ductwork of HVAC systems. The American Society of Heating, Refrigerating and Air-Conditioning Engineers, or ASHRAE developed this measurement method. MERV ratings (ranging from a low of 1 to a high of 20) also allow comparison of air filters made by different companies. (EPA Glossary of Terms)

MISCELLANEOUS ELECTRIC LOADS (MELs)

In buildings are electric loads resulting from electronic devices not responsible for space heating, cooling, water heating, or lighting. *(*Roth et al, ASHRAE Journal)

SICK BUILDING SYNDROME, or SBS

Term that refers to a set of symptoms that affect some number of building occupants during the time they spend in the building and diminish or go away during periods when they leave the building. Cannot be traced to specific pollutants or sources within the building. (EPA Glossary of Terms)

VARIABLE-AIRVOLUME SYSTEM

An HVAC conservation feature usually referred to as "VAV" that supplies varying quantities of conditioned (heated or cooled) air to different parts of a building according to the heating and cooling needs of those specific areas. (CBECS, 2003)

VARIABLE-FREQUENCY DRIVE (vfd)

also termed *adjustable-frequency drive*, *variable-speed drive*, *AC drive*, *micro drive* or *inverter drive* is a type of adjustable-speed drive used in electro-mechanical drive systems to control AC motor speed and torque by varying motor input frequency and voltage (CBECs, 2003)

List of Glossary Sources:
CDC, http://www.cdc.gov/niosh/topics/indoorenv/
ENERGY STAR, http://www.energystar.gov/buildings/about-us
EPA Glossary of Terms, http://www.epa.gov/iaq/glossary.html#I
Roth K., McKenney, K., Brodrick, J. "Small Devices, Big Loads." ASHRAE Journal. Vol. 60 No. 6. June 2008.
U.S. Energy Information Administration, http://www.eia.gov/consumption/commercial/about.cfm)
USGBC, http://www.usgbc.org/about
USGBC Glossary, http://www.usgbc.org/glossary/39#letterl

Introduction: Why Energy Conservation Measures in U.S. Office Buildings Fail and Roadmap of the Dissertation

Tragedy of the Commons

The promise of a super efficient car has long fascinated both the scientist and lay person. In contrast, energy use in commercial office buildings is the basis for a stimulating conversation among very few. In most U.S. office buildings, rank-and-file workers are not concerned with energy use – they never see a bill, bear no economic consequences for its use, lack direct control over building energy systems and played no role in designing the building let alone its energy features. From the perspective of the tenant, energy costs are very minor, especially in comparison to labor costs and therefore are a very distant or nonexistent concern. On account of how most commercial leases are structured, the building owner also bears little or no consequence of building energy use (the tenant pays). Commercial office building energy use is a variant of the social-economic dilemma known as the tragedy of the commons (Hardin, 1968). Direct accountability for building energy use, or corresponding environmental pollution, does not exist and thus no one has a strong incentive to decrease building energy use.

In the U.S., there is more than 16 billion square feet of office floor space, which is equal to 18 percent of total commercial floor space, *the most of any building type* (U.S. Energy Information Agency (EIA), Commercial Building Energy Survey (CBECS) 2012 Preliminary Results). The most recent data available shows that office buildings consumed more than 17 percent of energy use in the commercial sector (EIA, 2003 Office Report) and that energy use in the commercial sector is growing at a rate of 2.9% a year, *faster than any other sector of the economy* (EIA, 2011). Building energy use is a public policy concern because buildings intensify global warming by releasing carbon dioxide into the atmosphere through the use of electricity generated by the burning of non-renewable fossil fuels, and because extraction and procurement of fossil fuels additionally have geopolitical consequences. Buildings further impact their occupants through indoor environmental quality (IEQ) – air quality, ergonomics, noise levels, privacy – which in turn affect satisfaction, productivity and health.

Newer commercial buildings, including office buildings, are larger than older ones (EIA, CBECS 2012), which partially explains growth in total energy demand. A propensity towards increased glazing (window area) in new buildings and disregard of solar orientation strategies or an inability to implement them in buildings are additional design factors that result in suboptimal energy performance. Form – a pleasing or popular look and also desired attributes of the floor plan – trumps building energy performance. Increased plug load, as generated by mainly standard office and smaller consumer electronics such as computers and cell phones, has offset efficiency gains in major building energy end uses such as space conditioning, heating and lighting (EIA, 2013). Given the relatively low cost of energy to labor, the functional use of the building –its economic value in contributing a space that is conducive to the production of work – is prioritized over building energy use.

Traditional and Alternate Approaches to Reducing Building Energy Use

Efforts to influence building energy use have tended to focus at the early part of the building life cycle, when major decisions about building design are made. These take place with direct input limited to just a few individuals, typically owners and designers. Governmental organizations, including the U.S. Department of Energy, along with building professional advocacy groups, work to reduce barriers related to budget (e.g., first costs, value engineering), lack of design knowledge, and to improve building code and other regulations. Green building and energy efficiency policies mainly target these direct influences on building energy use, and this limited set of agents. After more than two decades of investment in this approach, it has proven largely ineffective.

An alternative explanation for poor building performance is that buildings are not user-friendly. This relationship, which has not received much focus, directs us to examine the indirect influence that building users have on energy outcomes as depicted in Figure 1. Building users can and do adjust building energy systems to achieve individual preferences – e.g., regarding thermal comfort, desired lighting quantity or quality – which additionally may impact co-workers and building energy performance. While sometimes abject technology failure is to blame, this research demonstrates it is mostly recalcitrant, difficult-to-use building systems which fail to achieve an intended or satisfactory result, frustrating and prompting building occupants to take action.

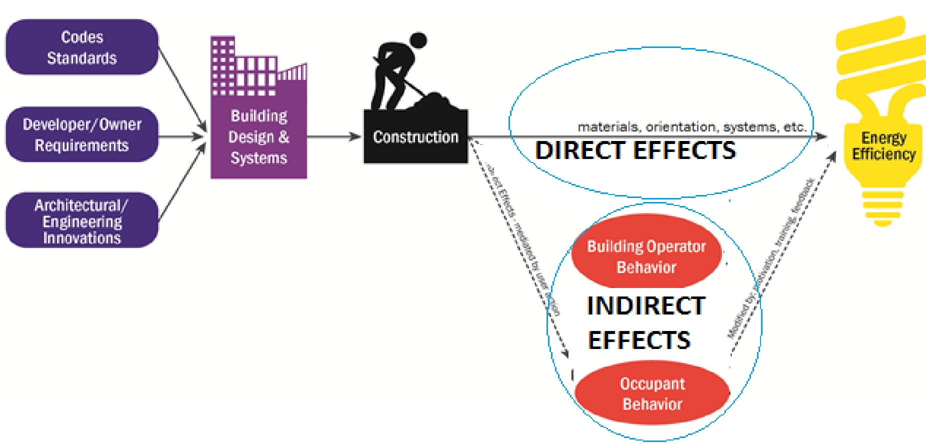


Figure 1. Direct and Indirect Effects on Energy Efficiency.
Building occupant and operator behavior mediate building outcomes. Source: RCGB Archive, 2012

Building users – e.g., office workers, operators, service providers, and visitors -- regularly transact with the building and each other in a specific building context. Their use experience and its context are inseparable, as the former is constrained or enabled by the latter. In this sense, usability is the property of the overall system: it is the quality of use in a context" (Bevan and Macleod, 4.2, 1994). This framework guides my fieldwork and analyses and motivates the following high-level hypotheses:

H1) Under-performance of building energy conservation measures is caused in some measure by usability failures.

H2) Innovations that are not compatible with organizational context (use structures) will result in negative quality of use.

Framing the challenge of building performance in an organizational context, which further defines its use structure (Norman, 1988), draws attention to the social nature of energy technologies. A better understanding of the technology-society linkage inherent in the use of building energy technologies is critical for improving the usability of these innovations, and for helping organizations to adapt their management practices to accommodate them.

Control rights over these technologies emerge as a major theme in this research. Within work organizations, as within other social constructs, control is a moderated, often contested affair. Lessons learned about how building occupants respond to changing control conditions over building environment may have implications for control concepts more broadly. In the ensuing case study, overly diffuse control over lighting leads to confusion and an inability to maintain building lighting at all, while overly restricted control over information about and actual lighting settings leads to a series of mostly counter-productive/energy wasting adaptive behaviors by building occupants. In today's debate over privacy rights, the struggle to find an acceptable middle ground regarding information sharing is somewhat analogous. Powerful government principals and citizen agents debate the extent to which privacy policies should be centrally commanded or devolved as an individual choice.

Concurrently, a number of broader social trends have fairly direct implications for usability successes and shortcomings in the design and operation of building energy technologies. These include increasing rates of telework, which grew nearly 80% between 2005 and 2012 (Global Workplace Analytics, 2013) and an associated design movement that shrinks workspace per employee through so-called options for hoteling, non-territorial offices, free address offices (in which there are no proprietary workspaces), activity-based design and various hybrid arrangements that encourage and support fluid occupancy patterns within proto typical office suites. As this work suggests, there is a gap between current design and implementation strategies for building energy systems and these broader societal trends.

Throughout this thesis I argue that usability determines the success of an innovation. Much as consumers influence whether electric vehicles, ipads, foldout beds in planes and other innovations become commercially successful, this research identifies the experiences and actions of building users as instrumental in understanding building energy performance and as a source of information to improve energy systems. Specifically, users' experiences elucidate how technologies measure up against classic innovation concepts – compatibility of the technology with its use setting, the relative simplicity or complexity of integrating its use into an existing routines, whether the technology provides sufficient user feedback regarding its operation and others as advanced by Rogers (1962) and Norman (op cit). The collection of mid-sized multi-tenanted buildings that are the subject of this research provide a rich laboratory for analyzing how and why energy conservation measures fail, and for developing grounded hypotheses linking usability and innovation diffusion concepts. These buildings are characterized by a large number of stakeholders and their organizations whose interactions exhibit wide and deep use structures. Building energy systems ideally would accommodate varying user needs through flexible and scalable features, but often do not.

Overview of Findings and Implications

In the following pages I present the results, and reflect on the process, of multi-year comparative case study research in high-performance (LEED and ENERGY STAR) and conventional commercial buildings that have been outfitted by their owner – a REIT -- with lighting and HVAC energy conservation technologies. A REIT is a company that owns and, often, operates income-producing real estate. The assets of (equity) REITs account for an estimated 15 percent of total U.S. commercial real estate assets. (https://www.reit.com/investing/reit-basics/guide-equity-reits). Thus, while the findings of this research may not apply to all real estate sectors, they are likely to be informative for the portion of commercial real estate that is concentrated in its ownership by REITs and who therefore have ability, if motivated, to enact portfolio-level change.

The limitations of this research are in some degree its strengths. Case study research allows for deeper exploration than would otherwise be the case, but produces a smaller ‘n’ study. Drawing case study buildings from mainly one owner conveys the ability to control for some organizational influences along with climate and other structural factors. However, it simultaneously risks oversights related to the role of different forms, and cultures, of property ownership. In this study, differences among tenants are characterized and very much form a basis of analysis.

Similarly, I believe that the control and other building user behaviors noted in the case study generally apply to corporate America, but they probably would do less well in explaining building-level organizational phenomena in a more hierarchically-ordered society, such as Japan. This research is concerned mainly with existing commercial buildings, and the difficulty of introducing energy retrofits into occupied spaces. I am able to demonstrate that my main insights apply to both retrofits and new buildings, especially multi-tenanted ones. As depicted in Chapter 2, even new LEED certified buildings can suffer usability challenges.

In summary, I find that organizational contexts and use structures significantly influence energy retrofit outcomes in terms of key usability metrics – the effectiveness of the energy retrofit compared to the projected result, the efficiency of its use (effort, cost) and user satisfaction. Re-occurring themes across a dozen building studies – nine retrofits and supporting observations from four new buildings converge on the following:

It is difficult to design and fit-out buildings in conditions of a diverse, changeable tenant base. One design does not fit all and yet multi-tenanted buildings are subject to constant change. For this reason, the role of communication during the design phase is elevated such that maximally compatible and, hopefully, flexible design results. The goal is to produce interior fit-outs that are compatible not only with an existing tenant, but hopefully can also accommodate future ones through flexible features.

Control over building operations (e.g., local vs. centralized lighting/HVAC) can be highly variable and confusing, often violating key predictive innovation factors such as the ease (simplicity) with which an innovation is integrated into an existing workflow or use setting.

The split incentives of stakeholders, including disinterest by a building owner in losing a tenant, is difficult to overcome. Tenant comfort will be prioritized over energy conservation even if it means undoing recently installed energy technologies. Also, some organizations seem unwilling or are unprepared to trust their employees with greater control over decentralized, flexible building energy systems. A promising exception to the split-incentive problem was demonstrated through the REIT's experimentation with load shedding (reduction of building energy use during times of grid strain). The imperative to reduce load on an as-needed basis seemed to resonate with building occupants; this experience may be leveragable in communicating about daily energy use.

There are on-going technical challenges in interpreting building energy performance data such that even well-trained building operators and engineers have a hard time evaluating the success or failure of energy retrofits. Further frustrating the imperative to understand building energy performance is the frequency with which building energy models turn out to be inaccurate. The development of more accurate building energy models, based partly on more accurate representations of human behavior, and increased competency in interpreting building energy data are related strategies for achieving better performing and more satisfying buildings.

This thesis also brings to light a number of policy drivers that stand to improve the record of commercial building retrofits. These include:

Benchmarking Disclosure Ordinances, which is regulation requiring building owners to disclose building-level energy use. This approach is based partially on shaming – the Scarlet letter of being known publically as an energy laggard –and, also, bragging rights – for top performers. While it is still early in the benchmarking disclosure movement, there is some evidence that it is beginning to change building owner behavior towards energy use.

Slow, but increasing, interest in ISO 50001 and other enterprise-level energy management processes by building owners. ISO 50001 and similar standards (e.g., the new Tenant Star certification offered through the U.S. EPA) represent an attempt to instill in organizations an energy discipline reminiscent of the early quality control movement by U.S. firms. Correspondingly, some sustainability certification programs (e.g., GRESB) now reward the implementation of an energy management system by portfolio owners, who highlight certification in their shareholder responsibility reports.

Increased prevalence of post-occupancy evaluation (POE) wherein organizations internally or through consultants undertake a user-based evaluation of building design and operation. LEED now requires some aspects of POE, with an emphasis on occupant thermal comfort. There may be an opportunity to use POE to help “unfreeze” a stuck organization with respect to changes in managerial/communications protocols that would benefit energy conservation practice.

Organization of the Thesis

The remainder of this thesis is organized as follows. In Chapter 1, I address the environmental, economic and social impacts of buildings and review the history of the green building movement, and energy conservation trends in commercial buildings. Chapter 2 presents summary findings from earlier exploratory research in new green buildings, which informed the hypotheses of this research. Chapters 3 and 4 cover, respectively, the research framework and supporting literatures, and methods and data. Chapters 5-10 comprise the retrofit case study. Starting in Chapter 8, I introduce an organizational schematic to guide the reader through the more meaty empirical content.

In Chapter 5, I further provide the organizational context of the energy retrofit program undertaken in the study buildings followed by specific predictions that result from a mapping of the usability attributes of specific energy conservation measures (ECMs) to Bevan and MacCleod's usability metrics and Rogers' innovation concepts. In Chapter 6, I present the energy savings results of the ECMs applied to the set of subject retrofit buildings. Chapter 7 presents an introduction to the post occupancy evaluation component of the case study, the basis for explaining where, how and why the energy retrofits fell short of their intended outcomes. It is followed by Chapter 8, which assesses *pre-retrofit* contexts and usability in the buildings and Chapters 9 and 10, which evaluate *post-retrofit* usability conditions. In wrapping up, Chapter 11 contains discussion of the case study, with a return to the earlier predictions regarding building user reactions and response to the energy retrofit measures. Finally, in Chapter 12, I offer a number of attendant policy prescriptions, and include suggestions for future research.

Chapter 1: Why Buildings Matter: Environmental, Economic and Social Impacts

In recent years, increasing emphasis has been placed on the significant impact buildings have on the environment and what to do about it. Buildings (and their human occupants) account for 40% of total energy consumed in the U.S. and 71% of its electricity (EIA 2013, 2014). Buildings intensify global warming by releasing carbon dioxide into the atmosphere through the use of electricity generated by the burning of non-renewable fossil fuels, accounting for 38% of greenhouse gas emissions (U.S. EIA, 2008). Buildings further account for 68% of raw material use through construction and demolition activities (U.S. EPA, 2009), and also 13.6% of potable water consumption (US Geological Survey, 2000).

Buildings also directly impact the people who occupy them, primarily through indoor environmental quality (IEQ). Multiple components comprise IEQ; these include air quality, ergonomics, noise levels and privacy, and other design factors that contribute to occupant comfort, satisfaction, productivity, stress levels and other facets of health. As poor indoor air quality (IAQ) is believed to affect as many as 30% of new and renovated buildings (Yeang, 1999), its impacts on productivity and health have received much focus (Wargocki, Wyon, & Fanger, 2000; Wargocki, Wyon, Sundell Clausen, & Fanger, 2000; Milton et al, 2000, and Fang, Wyon, Clausen, & Fanger, 2004). Poor IAQ is estimated to result in billions of dollars in lost productivity and hours of illness and discomfort, annually (U.S. EPA, 2009).

Other IEQ factors have also been found to be responsible for discomfort or illness, and may reduce building occupants' ability to concentrate or to remain at work (Heerwagen, 2000; Heerwagen & Zagreus, 2005; Miller et al 2006; Singh, Syal, Grady,

& Korkmaz, 2010, Deuble and de Dear 2012). Exposure to stressful conditions, particularly when the causes are perceived to be beyond the occupant's control, has been shown to have negative consequences on mood, motivation, and satisfaction, which in turn may impact productivity and health (Evans & Johnson, 2000). These relationships, however, are not straightforward and often trade-offs exist in trying to achieve optimal IEQ conditions (Stanton, Hedge et al, 2004).

The Green Building Movement

The green or high-performance building movement was established to remedy the negative impacts of buildings, with an initial focus on decoupling material use from economic growth (1987 Bruntland Commission Report). In 2003, the Office of the Federal Environmental Executive published specific objectives: 1) increasing the efficiency with which buildings and their sites use energy, water, and materials; and, 2) reducing impacts on human health and the environment, through better siting, design, construction, operation, maintenance, removal. These objectives have been adopted by building labeling programs that provide guidance for realizing better buildings.

In the U.S., the green building program with the highest market recognition is LEED (Leadership in Energy and Environmental Design). Developed by the U.S. Green Building Council in the 1990s, this labeling program encourages the adoption of green building through the commoditization of established performance criteria. These include site location, water and energy conservation and efficiency, sustainability, conservation and recycling of construction materials, and indoor environmental quality. There are LEED modules for residential and commercial buildings; however, the commercial building sector has proven the more receptive target. Although LEED is neither a building code nor a zoning ordinance, a number of municipalities and other governmental jurisdictions have adopted LEED requirements for projects receiving public financing, for public buildings, for larger private commercial buildings and, in rare cases, for single-family homes. These requirements range from certification to providing evidence that a LEED checklist was consulted and that green building measures were pursued in good faith (USGBC LEED Ordinances, accessed on-line July 13, 2014).

The other well diffused building labeling program in the U.S. is ENERGY STAR, developed and maintained by the U.S. EPA. This program almost exclusively is concerned with energy performance and has been marketed to residential and commercial builders and consumers. In some locations, ENERGY STAR requirements are an alternative pathway for residential building code compliance and there are instances in which certification for residential and commercial properties is required by utility incentive programs (ENERGY STAR State and Local Fact Sheet, 2013). ENERGY STAR Portfolio Manager additionally provides the framework for rapidly diffusing energy benchmarking programs. As of 2013, more than 325,000 commercial buildings reported using Portfolio Manager to measure, track, assess and report on energy and water consumption. This is equivalent to 40% of the nation's commercial building space (ENERGY STAR, Overview of 2013 Achievements).

In 2005, LEED and ENERGY STAR certified buildings accounted for approximately 2% of nonresidential construction, valued at a total $10 billion by McGraw Hill Construction's 2009 Green Outlook: Trends Driving Change report. Between 2005 and 2008, the value of green construction increased five-fold from $10 to

$49 billion, according to this same source. Two years later, the value of green building construction starts was up 50% from a revised figure of $42 billion to $55 billion-$71 billion, accounting for 25% of all new construction activity in 2010. Translated into new building starts, a third of all nonresidential construction is reported by McGraw Hill to be green (McGraw Hill Construction, 2011).

Given that new construction represents only 1-2% of total stock per annum (Dixon et al, 2009), much concern exists about how to reduce energy use and greenhouse gas emissions in existing buildings (Eichholtz et al, 2012; Jaffe and Stavins, 1994; Long et al, 2011; Martin et al, 2012). The square footage of LEED-certified existing buildings recently surpassed LEED-certified new construction by 15 million square feet on a cumulative basis (USGBC Green Building Facts, accessed July 17, 2014). When ENERGY STAR certifications are included, approximately 61% of all construction projects are green retrofits (McGraw Hill, 2010 Smart Market Report), a share that is projected to rise 20-30% by the end of 2014 (McGraw Hill, 2009, Green Building Retrofits). By 2015, the green share of the largest nonresidential retrofit and renovation activity is expected to more than triple, growing to 25-33% of the activity by value (McGraw Hill, 2010, Green Outlook).

Across building uses, the highest penetration of green building is in education, followed by health care and then by office (McGraw Hill, 2010, Green Outlook). As with the early days of LEED, adherents dominantly represent larger, more costly and/or owner-occupied properties, and organizations with explicit sustainability objectives. This is evidence that the split-economic incentive problem – wherein the tenant is responsible for utilities and the building owner for capital investment -- continues to be a barrier as does concerns over first costs (Kleindorfer et al 1993; Panayotou and Zinnes, 1994; Cortese et al, 2010; Prindle and Finlison 2011).

On the one hand, it can be argued that investments by the USGBC and others in green building education and marketing have paid off. Evolving data on the financial benefits of efficient buildings demonstrating instances of lower utility bills, faster absorption rates and also higher rents and resale value (Kats, 2003; Dixon et al 2009; Pivo and Fisher, 2010; Eichholtz et al 2009, 2012; Fuerst and McAllister, 2011) is helping to motivate increased adoption of green and efficiently-branded buildings. The split-incentive problem is being addressed through promotion of environmental best practices in leasing, often known as 'green leases' and other revenue sharing arrangements, even if progress is slow (Institute for Market Transformation, Green Lease Library, accessed July 24, 2014).

On the other hand, the failure of these designated green, smart, or otherwise high-performing buildings to meet their design criteria is a stubbornly persistent problem, particularly concerning energy use. These short-comings, coupled with an apparent reluctance to adopt more innovative energy measures, suggests that a rosy conclusion about the green building movement, and the ease of being green, may be premature.

Energy Conservation Measures in U.S. Office Buildings

In the U.S., there is more than 16 billion square feet of office floor space, which is equal to 18 percent of total commercial floor space, the most of any building type (U.S. Energy Information Agency (EIA), Commercial Building Energy Survey (CBECS) 2012 Preliminary Results). The most recent available data shows that office buildings consumed more than 17 percent of energy use in the commercial sector, which includes also warehouses, health care facilities, restaurants and a number of other commercial uses (EIA, 2003 Office Report). Energy use in the commercial sector is growing at a rate of 2.9% a year, faster than any other sector of the economy (EIA, 2011). Newer commercial buildings are larger than older ones (EIA, CBECS 2012), which partially explains growth in total energy demand. Also, increased plug load (or, Miscellaneous Electric Loads (MELs) has offset efficiency gains in major building energy end uses such as space conditioning, heating and lighting (EIA, 2013). The adoption of energy conservation measures (ECMs) in commercial buildings –as defined in Table 1-- has not kept pace with the rising curve of total building energy use, a particular challenge in existing buildings whose lifespan tends to greatly exceed technology cycles.

Illustratively, in an economy-wide survey resulting in data on 5,215 buildings built before 1920 through 2003 (EIA, CBECs 2003), Andrews and Krogmann (2009) found that HVAC systems with a variable-air-volume configuration or the ability to switch into an economizer mode when outdoor conditions permit are found in no more than 50% of buildings. They also found that auto sensors and daylighting have particularly low penetration rates – an average of 5% and 10%, respectively, over these same time periods. The presence of an energy management system (EMCS), adopted at rates ranging from 25-40%, signals a more comprehensive and also centralized approach towards energy use in buildings, and therefore inclines towards less individual control by building occupants.

As expected, adoption rates for these technologies favor larger more energy intensive buildings and owner-occupied ones (Andrews and Krogmann, op cit). An analysis of the top adopters of these technologies by principal use conveys additional nuance. *Nongovernmental administrative/professional buildings* category ranks first for presence of VAV, economizer mode, EMCS, auto sensor and daylighting. This use group makes up the largest and also most diverse use group in the CBECS data; thus, a more in-depth understanding of whether and how these ECMs meet their objectives among this group stands to make a difference. Ranking 2^{nd} for VAV, economizer mode, EMCS and daylighting is the relatively more homogenous *religious worship* principal use, which is followed by *elementary/middle school*, which ranks 2^{nd} in auto sensors, 3^{rd} for VAV, EMCS and daylighting and 4^{th} for economizer mode. *Retail store* ranks 3^{rd} in economizer mode and 4^{th} in sensors, VAV and EMCS. Other use types with relatively stronger adoption records include *distribution/ shipping centers*, *hospital/inpatient health centers*, *mixed-use office*, and *restaurant/cafeteria* uses as depicted in Table 2.

Energy Conservation Measure	CBECs Definition
VAV	**Variable Air-Volume (VAV) System:** An HVAC conservation feature usually referred to as “VAV” that supplies varying quantities of conditioned (heated or cooled) air to different parts of a building according to the heating and cooling needs of those specific areas.
Economizer cycle	A heating, ventilation, and air-conditioning (HVAC) conservation feature consisting of indoor and outdoor temperature and humidity sensors, dampers, motors, and motor controls for the ventilation system to reduce the air-conditioning load. Wherever the temperature and humidity of the outdoor air are more favorable (lower heat content) than the temperature and humidity of the return air, more outdoor air is brought into the building.
EMCS	**Energy Management Conservation System (EMCS)**: An energy management feature that uses mini/microcomputers, instrumentation, control equipment, and software to manage a building’s use of energy for heating, ventilation, air conditioning, lighting, and/or business-related processes. These systems may also manage fire control, safety, and security. Not included as an EMCS are time-clock thermostats.
Auto Sensor	Automatic controls or sensors that increase or reduce lighting in response to level of natural light
Daylighting	Building features designed to reduce the amount of energy consumed by the lighting system. These include skylights or atriums, daylighting sensors, specular reflectors, electronic ballasts, and an Energy Management and Control System (EMCS) that controls the lighting in the building.

Table 1. Definition of Energy Conservation Measures Presented in this Analysis.
Source: CBECs glossary for 1999 and 2003 Survey. Also, comparisons between 1992, 1995, 1999 and 2003 CBECs, http://www.eia.gov/consumption/commercial/comparison-between-years.cfm

	Rank of				
Principal Use	**VAV**	**Economizer**	**EMCS**	**Auto Sensor**	**Daylighting**
Administrative/professional office	1	1	1	1	1
Religious worship	2	2	2	3	2
Elementary/middle school	3	4	3	2	3
Retail store	4	3	4	4	10
Government office	9	9	11	9	16
Distribution/shipping center	5	5	5	5	4
Hospital/inpatient health	6	6	12	6	9
Mixed-use office	7	7	6	7	11
Restaurant/cafeteria	8	8	7	8	8
Non-refrigerated warehouse	10	10	10	10	6
High school	12	11	9	12	17
Motel or inn	14	17	14	14	5

Table 2. Select Energy Conservation Measure Rank by Principal Building Use.
Note 1st place of Administrative/professional office buildings. See Table 1 and text for definitions.
Source: CBECs 2003 data, Tables 1, 2, 3 and 7.

In an analysis drawn from a database of 302 commercial buildings that received LEED certification through December 2005, Kawecki (2009) also found low adoption rates for advanced energy technologies. Less than 20% of the associated design teams elected the more difficult/expensive program targets such as the optimization of energy performance by 20% or greater, or the use of renewable energy to meet or exceed 5% of building energy use. Instead, close to 40% of the sample elected to purchase green power from non-building generated sources which is a purchasing not a design decision. The majority of the sample (60-100%) chose options such as use of a LEED Accredited Professional (which has since become a pre-requisite), low emitting materials, 20% use of local/regional materials, use of 5% recycled content in building materials, and recycling of construction material. In other words, an earlier generation of green buildings achieved certification by harvesting the proverbial low-hanging fruit (of the LEED scoring matrix) and by employing conventional approaches rather than more ambitious and potentially innovative ones.

A recent evaluation comparing total LEED points and LEED categories across two time periods (2006-2008 and 2009-2011) suggests both progress and challenges in adoption of energy technologies and practices (Pyke et al, 2012). On average, newer projects scored a higher fraction of available LEED points, and all LEED categories show improvement notwithstanding the somewhat tougher standards of newer LEED versions. However, in the Energy & Atmosphere (E&A) category, the results have a long rightward tail indicating that few projects manage a large number of LEED E&A points. The average in the 2009-2011 time period is 7 points, up from 6.3 points in the earlier one, an improvement but not remarkable. Compared to the other categories, adoption of E&A measures continue to lag.

Moreover, many LEED buildings have failed to achieve their projected energy savings. In a pivotal work that has engendered much attention and debate, Turner and Frankel (2008) employed three metrics of building energy performance (Energy Use Intensity comparison of LEED and national building stock (CBECs), ENERGY STAR ratings of LEED buildings, and measured results compared to initial design and base modeling) to model the performance of a sample of approximately 90 LEED buildings. They found that LEED commercial and institutional buildings, on average, deliver anticipated energy savings in the range of 25-30% less than the national average. However, there is wide scatter among the individual results. Within measured performance in relation to the modeling metric, some buildings perform significantly better than anticipated but some buildings are performing much worse than predicted, with some using more energy than the predicted code baseline modeling.

A more recent, preliminary analysis by the USGBC considered 195 projects of which the majority were certified under the LEED for Existing Buildings system. From this data it was determined that the average building had attained an average ENERGY STAR score of 89 out of 100 possible points and was therefore performing in the 11th percentile of peer buildings (USGBC, 2012). A second sample considered 7,100 LEED for New Construction projects, of which 92.2% allegedly were improving energy performance by 10.5%, while 89% were improving by 14% USGBC, op cit). Yet, in other cases, the performance of these buildings was still shy of the 25-30% anticipated savings indicated by their design.

Over time, green building programs, building codes and other drivers of building design have become more stringent, particularly in the area of energy efficiency where requirements have increased. Possibly in the future, we will bear witness to a more virtuous pattern of ECM adoption and improved more predictable building energy performance. Presently, it appears that diffusion of green or otherwise high-performing buildings does not predictably lead to better building performance, or the innovative/transformative results that policy-makers seek.

Explanations of Poor Building Performance

There are several plausible explanations for underperformance in green, high-performance buildings, as well as conventional ones. The default one is poor building design or faulty operations. Windows may be exposed to late afternoon sun and not properly shaded to prevent glare, or, artificial lighting levels may not be calibrated with daylighting design features. HVAC control systems supplied by different vendors or from different vintages may be incompatible. In addition, cost considerations by developers/owners and lack of familiarity by architects, engineers and the construction trades are acknowledged barriers to the adoption and performance of innovative building technologies and designs. For the past 20 years since the USGBC introduced LEED, public policies to encourage better buildings have been aimed mainly at adopters and have sought to address these types of informational and financial gaps.

An alternative explanation for poor building performance is that these buildings are not user-friendly, that interactions between building systems and users do not produce intended or satisfactory results. More formally, users' experiences in green buildings –

the effectiveness, efficiency and satisfaction with which they achieve IEQ related goals (adapted from Bevan and Macleod, 1994, 4.3 and ISO 9241-11) -- are suboptimal. As presented in Andrews, Yi, Krogmann, Senick, and Wener (2011), these terms may be defined as follows:

Effectiveness is the extent to which the intended use-related goals of an overall system are achieved. It can be measured as the percentage of time a building system achieves its target performance level, such as a temperature set point or workplane illuminance standard or more generally as to whether a green building meets its energy goals.

Efficiency is a function of the expenditure of resources and effort to achieve the intended goals. This may refer to the resources required to deliver thermal comfort or illumination, for example, and may include natural resources such as energy and human resources such as building occupant or operator effort.

The extent to which the user finds the overall system acceptable comprises satisfaction, which in building-level studies is measured through a combination of surveys, focus groups, structured interviews and observational protocols.

Satisfaction, efficiency and effectiveness are interdependent metrics – e.g., the required expenditure of human effort (efficiency) for a system to be effective affects user satisfaction, especially as relates to control over key functions of the system. It is possible for a technology to satisfy one or two usability dimensions without necessarily satisfying all three, due to trade-offs or unwillingness to trade across users or usability factors. A building owner may decline to incur additional cost to improve the functioning of a system even if it would increase occupant satisfaction. A user may not want to make additional effort for the sake of being more comfortable/satisfied.

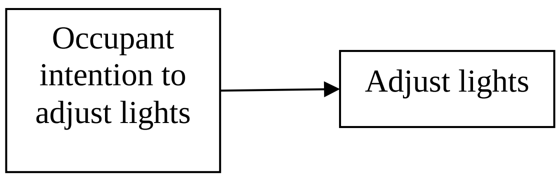
Within this system are located the users, tasks, equipment, and mediating physical and organizational environments (Bevan and Macleod, op cit). Usability challenges also arise at multiple scales and may be deceptive or difficult to interpret. What may appear initially to be an individual problem with lighting, may in reality reflect unclear or contested decision-making about lighting locus of control. The use structure within which a user accomplishes a task is shaped by its social context; "usability is a property of the overall system: it is the quality of use in a context" (Bevan and Macleod, 4.2, 1994). Based on this thesis' findings, designers of building energy systems seem not to fully appreciate the critical role of use structure and context.

As characterized by Norman (op cit), everyday activities enjoy use structures that are narrow and/or shallow. A lack of choices means that decisions are conceptually simple and their results predictable. As an example of a narrow structure, Norman points to a cookbook recipe (p. 121). Although there may be many steps to follow in a recipe (depth), there are few lateral choices. As an example of a shallow use structure, Norman presents the menu of an ice cream store (p. 121). There may be many top-level choices, but few decisions to entertain after that.

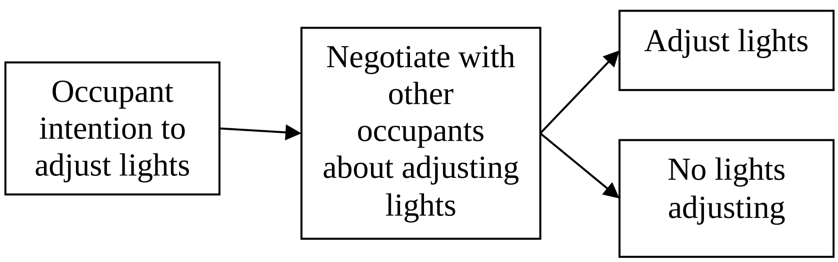
Figure 2 illustrates five lighting locus of control situations in a progression that evidences the most simple use structure (narrow, shallow) to the most complex (wide, deep). In Situation 1, an occupant of a private office wants to adjust the lights. With 100% control over this action (e.g., a dedicated on/off or dimmer switch) the occupant makes the adjustment – an example of a narrow and, also, shallow use structure for which the technology fits. However, a desire to adjust lights by an occupant in an open plan office reveals a use structure that has grown both wider and deeper (Situation 2), with the occupant sharing decision-making control with other office occupants. As a result, the outcome is more ambiguous. In Situation 3, the social nature of the intended action (adjust lights) has expanded with the added hierarchical element of the office manager. In Situations 4 and 5, the technology has changed in that the occupant no longer can adjust lights, as lighting control is centralized at the level of the office manager and/or building manager. If occupants are satisfied with the quality and quantity of lighting, this may not be a problem. However, if occupants are dissatisfied with lighting quantity or quality, then this lighting design is more likely to degrade quality of use, especially if occupants feel too constrained by social or organizational precepts to request a lighting adjustment.

These depictions of lighting use structures and quality of use consequences are further complicated by the addition of occupant adaptive response. When a given occupant is dissatisfied with overhead lighting and cannot adjust these lights, s/he may take adaptive action. Depending on the context, these adaptations can negatively impact building energy performance while improving occupant satisfaction or productivity. Common adaptations that have little or no impact on building energy use include turning on a task light (while uncontrollable overhead lights also remain on), adjusting blinds or shades (if possible), working in a different area, or going home. When daylight sensors are present and tied into lighting dimmers, the adjusting of blinds can have fairly dramatic impact on interior lighting levels and energy use. A similar situation exists regarding HVAC, wherein personal adaptive strategies such as (de)layering of clothing do not have negative impact on building performance while use of a space heater significantly increases building electricity use.

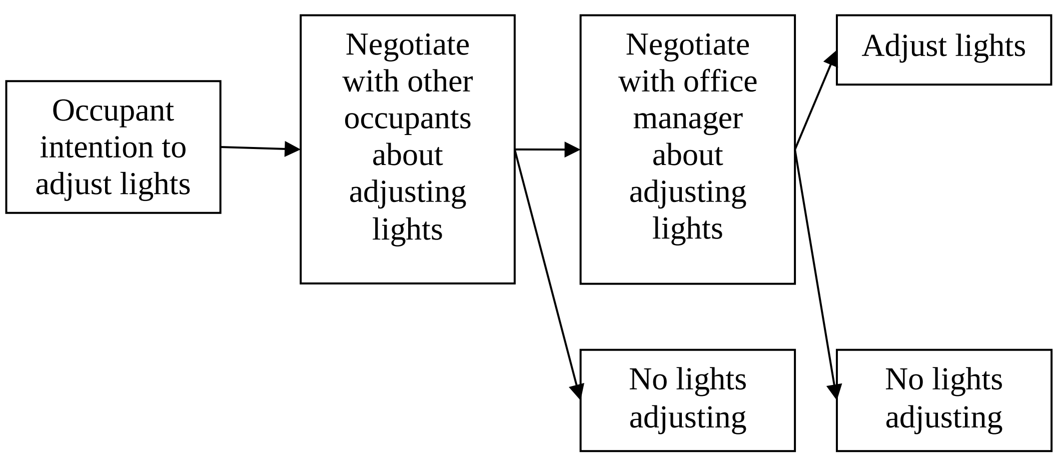
Situation 1: Occupant has 100% locus of control



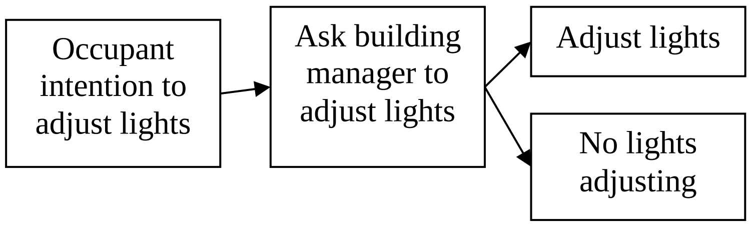
Situation 2: Occupant has shared locus of control with other occupants e.g. coworkers



Situation 3: Occupant has shared locus of control with other occupants and office manager



Situation 4: Occupant has no locus of control. Only building manager is able to adjust lights.



Situation 5: Occupant has no locus of control. Office manager and building manager are only able to adjust lights.

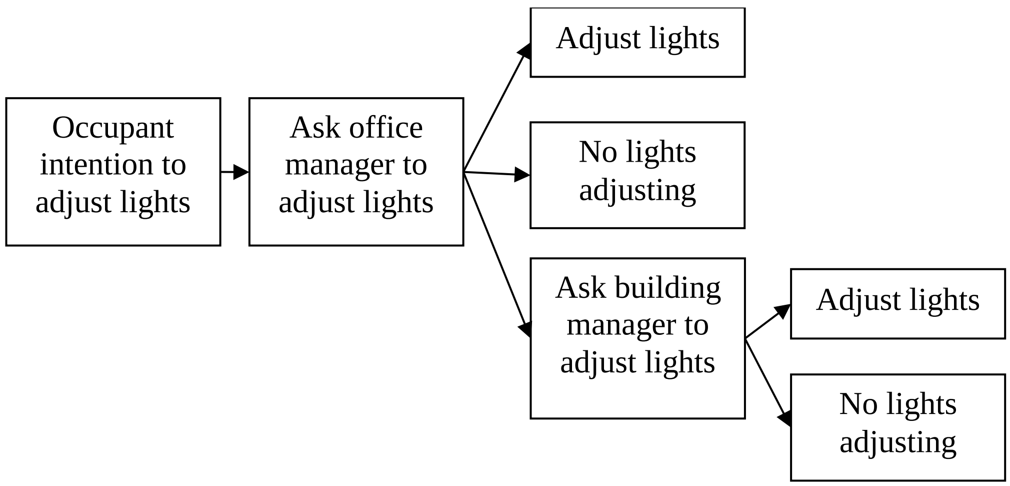


Figure 2. Lighting Locus of Control Depicting Increasingly Complex Use Structures.
Source: Senick et al, Rutgers Center for Green Building.

These loci of control insights, along with the organizational focus of this thesis, were inspired by previous building occupant-technology research conducted with the faculty and staff of the Rutgers Center for Green Building. In the following chapter, I present summary findings from investigations into four first generation LEED buildings. These suggest that even new, green designated buildings suffer from systemic usability challenges regarding the application of some lighting and HVAC designs to multi-tenanted and multi-purposed settings. I return to associated findings later in the conclusion of this thesis in order to compare them to a case study of existing commercial buildings that underwent energy efficiency retrofits.

Chapter 2: Findings from Exploratory Research in New Green Buildings

Between 2009 and 2012, the Rutgers Center for Green Building undertook exploratory post occupancy evaluations (POE) of four LEED certified buildings to assess how building occupant and operator behavior might influence building performance outcomes, with specific attention to the usability of lighting and HVAC systems. All of the subject buildings are located in the mid-Atlantic region. Three of them were initiated as speculative multi-tenanted offices (LEED 1-3) ranging in size from 76,350-98,225 SF. LEED 4 was constructed as a dedicated multi-purpose facility for a municipal police force and to support municipal court functions. It is the smallest of the set, at 41,850SF. LEED 1 and 2 are managed by an on-site facilities team and have dedicated property managers. LEED 3 and 4, being institutionally owned buildings, are overseen by the building owner if not exactly "managed" and have varying degrees of facilities support.

The three speculative buildings, LEED 1-3, pursued and attained certification under the Core and Shell (C&S) LEED rating system, achieving the Platinum (top honors), and Gold designations, respectively. The C&S option most closely approximates the delivery of the "plain vanilla box", earlier noted as the industry development standard for speculative buildings. In the case of LEED 3, all tenant spaces subsequently were certified under the LEED-Commercial Interiors standard (Gold), with the active assistance of the building owner. LEED 4 achieved the Gold level under the New Construction (NC) rating system, generally applied to owner occupied buildings.

Common to all of the buildings were designs emphasizing energy conservation through daylighting measures and high efficiency HVAC coupled with sophisticated building energy management systems.

We conducted case study research of these buildings after construction was completed and users had settled in, in keeping with the standard for POE, (Wener, 2002). Similar methods were applied in each building case study – review of archival data, photo documentation and formal and informal observations, building performance engineering analysis, structured and semi-structured interviews, and surveys. More information about the history and application of POE is located in Chapter 4, Methods. More information about these particular POEs is found in the following three reports:

Rutgers Center for Green Building. (2012). *Investigating Opportunities for Improving Building Performance Through Simulation of Occupant and Operator Behavior*. Prepared for the U.S. Green Building Council.

Senick, J., Andrews, C.J., Haus, M.L., Wener, R., Kornitas, M., Bolen, M., Samat, P., Krogmann, U. and Jordan, F. (2011). *Waterfront Technology Center Study: A New Jersey Economic Development Authority Building.* Prepared by Rutgers Center for Green Building for USGBC – NJ Chapter.

Senick, J., Andrews, C.J., Haus, M.L., Wener, R., Kornitas, M., Bolen, M., Samat, P., Jordan, F., Plotnik, D. and Kwak, G.(2010). *Maplewood Police and Court Building: A Post Occupancy Evaluation*. Prepared by Rutgers Center for Green Building for USGBC – NJ Chapter.

Overview of Respondents

In LEED 1 and 2, a joint on-line survey netted 48 replies, by about 10% of the building occupants. Respondents tended to be mainly upper echelon (managerial, professional, administrative) employees of the various tenants that chose to participate in the study, and to occupy private offices where they spent most or all of the work week. Many had worked in these offices since the buildings had opened, although 40% had been there 1-3 years. For 82% of respondents, this location was a satellite office.

Twenty-seven on-line surveys were returned in LEED 3, representing the participation of 2 tenants. In one of the tenanted spaces (Tenant 2), respondents were mainly those that had been employed for a longer period (mode: 4-10 years) as compared to respondents from Tenant 1 who were more recent hires. Respondents ranged from 20-50 years old and were diverse in terms of job types and levels.

Information on occupant responses to LEED 4 was attained through individual and group interviews and a paper survey that was completed by 25 participants. This sample represented a cross-section of court and police staff, with distinction made between administrative and patrol officers as users of this multi-purpose building. More than 50% of respondents had been employed by this organization for between 4-10 years and were aged 20-69. Over 70% of survey respondents were male.

Summary of Building Performance Evaluation and Usability Outcomes

The realized energy performance of these buildings draws attention to the difficulty of managing energy use in multi-tenanted and multi-purposed buildings. Across a 2-3 year period, we found that the buildings performed at or better than peer-based comparisons of conventional buildings; however, they each fell short of expected energy outcomes. While detailed explanations for performance shortcomings vary by building, we discerned common organizational themes that appear to have resulted in compromised building usability: 1) unclear or socially contested loci of control (lighting); and, 2) interior fit-outs that were discordant with building envelope design objectives, predominantly the combination of high partitioning walls adjacent to windowed spaces meant to facilitate daylight harvesting; and, 3) the challenge of pairing complex HVAC systems with organizational structures lacking for full-time continuous facilities management. Additionally, we found control and usability of building systems to be affected by the assignment of costs and benefits of building performance (efficiency), and whose satisfaction matters most. These themes are further explored, below.

Example 1: Lighting System Usability in conditions of Diffused and Unclear Control

Users' ratings of the electric lighting in LEED 1 and 2 generally were positive, with only a small number of survey respondents (12%) rating it as below average. More concern, however, was expressed over the level of control users had over lighting settings. In particular, a strong majority of respondents reported that the lighting system in these buildings was not easy to use or to adjust (Figure 6).

Structured interviews and observational data provided insight into lighting use structures within these buildings and how diffused lighting control, even when it is local, can lead to operational confusion. In a tenanted suite in LEED 1, the facility manager had sole control of approximately three-quarter of the lights. These were set to be always on during the workday, including in a large workspace we observed to be filled with cubicles adjacent to a glass curtain wall. This area had periodic although uneven access to daylight, given the cubicle-to-curtain wall design; those in the row closest to the wall experienced the brightest conditions and those towards the back the dimmest. In this same office, lights controlled by the Facility Manager remained on in an under-utilized space along the southern side of the office.

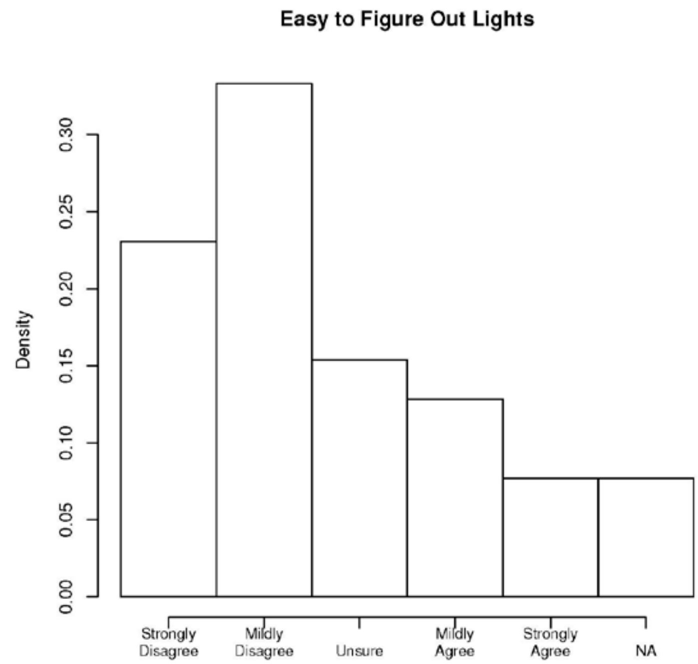


Figure 3. Respondents' Reports of Ease in Understanding Electric Lighting Controls
Few agree that it is easy to figure out how to use the lights. Density refers to percent of respondents. n=36. Source: Rutgers Center for Green Building

The tenant had control over the remaining lights, mainly located in enclosed offices; however, the facility manager also told us that these lights were on a time clock. While several office occupants operated their lights so as to turn them off when daylight was plentiful, after 7 PM (lights out time), if office occupants wanted their overhead lights on they needed to call facilities to change the program, incurring a fee. In practice, we found that occupants in this suite and in others with a similar set-up were unwilling to do this, resorting instead to task lighting or working in the dark. These occupants also were unwilling to leave the doors to their private offices open for daylight to penetrate the interior cubicle space, evidencing the limits of socialability in affording increased daylight for other occupants.

Programming the lights to go off at 7PM, by which point most occupants have left the premises, implements an energy savings opportunity. However, inability to control these lights locally, at least during the day, suggests a missed energy savings opportunity (diminished effectiveness). Given the assignment of energy costs and benefits in this particular context, there is no direct incentive for either the tenant or building owner to undertake lighting efficiency measures. Tenants pay for electricity use in LEED 1 and 2, but not in direct correspondence to its use. Rather, their share of total building electricity cost is calculated on a SF pro rata basis and any energy savings (or increased cost) is spread across the tenant base. Moreover, many of the tenants we interviewed were satellite offices with the headquarters based elsewhere. In these cases, office managers were not only unaware of energy use, but also of contractual terms and lease costs generally. The exceptions were the few sub metered tenants in LEED 1 and 2, which are healthcare facilities (2) and a data center.

Example 2: HVAC Control by Off-site and Part-time Facilities Management

In LEED 3 and 4, HVAC was the hot button. In LEED 3, dissatisfaction with temperature comfort and control was reported by 47.4% of respondents. Those on upper floors seemed particularly dissatisfied with temperature (p<000). Unlike in LEED 1 and 2, facilities management for this building is routinely out-sourced based on price and other public contracting imperatives. While off-site facilities management need not result in unsatisfactory conditions – and most building facilities in the U.S. are managed by off-site contractors, if at all –associated comfort actions are less observable to building occupants, while wait times for responses to comfort requests tend to be longer.

In LEED 4, an inability of occupants to improve thermal comfort similarly had negative impact on satisfaction and perceptions of building usability. In particular, occupants became frustrated with thermostats that they perceived as irresponsive. A frequent response to this situation was to contact the dedicated facilities manager, who "made adjustments daily." Beyond comfort considerations, a level of confusion existed about the extent to which building design supported both 24/7 use and any variant less than that. While staff and administrators we spoke with felt that the building could only run according to a 24/7 design – with unused spaces being heated and cooled in off-hours – in fact, every zone is adjustable. This misunderstanding about design and use apparently pervaded everyday users and facilities management, alike.

Towards the end of our study period, budget cuts removed the full-time position of facilities manager, replacing it with a new staff member responsible for multiple buildings and unfamiliar with the idiosyncrasies of this one. As a result of the multiple charges, facilities then had less time to correct HVAC issues in LEED 4 or any given building. Similarly, of LEED 3, it was clear to our team that building knowledge was lost with each facilities contract change. Along with building occupants and their organizational contexts, facilities and property managers influence use structures.

Figure 4. Disagreement in Cubicle Design and Daylighting.
(A-C) Under-utilized Office Space Lacking Local Lighting Control (D). Such disagreement tends to result in higher electric lighting use than predicted by design parameters, and natural daylight is available to few occupants.
Source: Rutgers Center for Green Building Archive.

Chapter 3: Framework of this Research

Much as consumers influence whether electric vehicles, ipads, foldout beds in planes and other innovations become commercially successful, this research identifies the experiences and actions of building occupants, operators, owners and other stakeholders as instrumental in building energy performance. However, unlike in the case of consumer goods, building energy technologies and associated energy conservation measures are not designed for end users but rather for purchasers whose primary interest is price. The influences of building users on building performance is mostly indirect, while a direct feedback loop from these end users to designers does not exist. Thus, a disconnect exists between building user's experience and innovation.

Reframing the challenge of building performance in an organizational context draws our attention to the social nature of energy technologies in various use settings, a better understanding of which is critical for increasing the usability of these innovations. As in the examples above, the actions, inactions and interactions of building users and operators mediate technology outcomes. Mid-sized office buildings, especially multi-tenanted ones, provide a rich laboratory for analyzing how and why energy conservation measures fail. This sector is characterized by a large number of stakeholders -- building owners, managers, tenants, service companies, financial brokers and others. Within tenanted office buildings, multi-agency challenges concerning energy conservation measures (ECMs) are transacted in a manner that reveals wide and deep use structures. This research complements macro-level organizational studies of the adoption and diffusion of ECMs, with a greater understanding of how "buildings as communities"

(Axon et al, 2012) function regarding energy conservation objectives. It also offers insight into how the designs of energy technologies and also their implementation might better respect the social side of their nature, leading them to become more 'behaviorally robust' (Wener, 1984). If building energy technologies were more usable, transformative improvement in building energy performance would be more likely.

Usability Premise of Innovation Diffusion

An underlying premise of this thesis is that usability determines the success of an innovation. The expectation is that high quality of use leads to continued and expanded use of the innovation, here: energy technologies, while a lack of usability – entailing dissatisfied users and poor performance -- hinders innovation diffusion through reputational effects, future purchasing decisions, or simply lack of promotion (Blumstein, Krieg, Schipper, & York, 1980; Case, 1984; Wener, 1984; Volink, Meertens, &Midden, 2002). The context in which technological or behavioral change is attempted is critical given the mediating role of organization on the process of change. A clear understanding of context is also important in undertaking organizational change to attempt to optimize the end result. A similar experience characterized a movement by U.S. firms to improve quality control over production. Early institutions that existed to help guide these decisions were insufficient in mirroring the complexity of the task. Eventually, an augmented institutional framework was created, which both helped firms in their organizational learning about quality control methods and facilitated dissemination of this learning to other firms (Cole, 1999).

Prior studies in other disciplines from which this research program draws inspiration include Norman (1988), who characterized usability for consumer products and the linkage to commercial success, and von Hippel (1988, 2005), who focused on users (consumers) and lead users as a source of innovation. The work of Saetnan et al (2000), whereby "lay end users" may lack knowledge to participate effectively in technology discussions also has strong implications for my research.

Building Usability and Users

In the past, the usability of buildings did not receive much attention. One reason may be that over several centuries of environmental building practice, as depicted by Gissen (2002), the dominant trend has been to de-emphasize the role of the building user. Passive environments gave way to mechanical ones, with an increasing emphasis on centralized systems for heating, cooling, ventilation, and lighting and for delivering occupant comfort.

Today's green buildings cover a spectrum of usability with some associated innovations inclining towards greater occupant involvement and others stripping away control from building users. The conventional wisdom is that satisfaction improves when building occupants have personal control over important systems so that they can, for instance, improve thermal comfort and adjust air flow by opening windows or adjusting a thermostat (Michelson, 1977; Weidemann, & Anderson, 1985; Francescato, Weidemann, & Anderson 1989,; Bonaiuto et al, 1999). In both lab and field studies, researchers have shown that occupants will accept varied environmental conditions (e.g., wider temperature range than is typical), if occupants have access to a personal environmental control (PEC) system (Arens et al, 2009; Hoyt et al, 2009). A long-term study of office buildings in Austria (Mahdavi & Proglhof, 2008) was able to demonstrate patterns of occupant control behavior that helped to predict building system outcomes (i.e., the probability of building occupants switching on a light upon arrival and minimum work plane illuminance). Ajzen (2005), in the Theory of Planned Behavior, explains that an element of control over the behavior in question can be a strong predictor of individual action, mediating the link between an intention and a behavior. Occupants also report satisfaction in knowing that somebody is in charge of building systems relating to key environmental functions, even if it is not them (Evans and Stecker, 2004; also, Kay et al, 2009), and occupants are happier when they understand how the building is supposed to work (Deuble and de Dear, 2012).

Occupant satisfaction and productivity are negatively impacted when occupants waste time and become unhappy dealing with recalcitrant or otherwise unusable building features (Cole & Steiger, 1999; Heerwagen, 2000). Frustration with unusable controls is exacerbated by confusion over who is in control in distributed control systems. People respond negatively to perceived chaos (Evans and Stecker, op cit) and users want prompt feedback showing whether the building is responding to their actions (Darby, 2001). User responses to unusable building systems may include doing nothing, logging a complaint, or seeking to directly correct discomfort or dissatisfaction through an individual adaptive response. Depending on the form the latter takes (e.g., plugging in a space heater versus putting on a sweater, or, turning on overhead lighting versus using a task light), building performance may be negatively impacted even while occupant satisfaction has, at least temporarily, improved.

A number of recent studies further explicate this multi-agent, multi-level dynamic. Agha-Hossein et al (2013) link office building energy performance with occupant (dis) satisfaction and ensuing actions. Fabi et al (2012) and Liu et al (2012) find that adaptive actions taken by occupants to adjust air quality can greatly impact energy use. Fabi et al. (2012) also propose that building occupants take action because of one of a number of "drivers" or "triggers" of behavior, including physical factors (temperature, climate, building design, etc.), psychological and social factors (personal needs and preferences, as well as social interactions among and between occupants) and physiological factors (individual occupant conditions, such as age, health, etc.). While these factors do not necessarily correspond to an unusable technology or device, they do suggest that the building is failing to meet a basic human need. In an attempt to depict more realistic building occupant behavior, Andrews et al (op cit) develop and validate an agent-based lighting model with articulated user preferences, utility functions, actions and building system (lighting and energy) performance. A continuum of personal control is implicitly incorporated through the specification of different lighting systems, some of which (e.g., task lighting) are easily controlled by building occupants.

A recent survey of 30 green buildings worldwide on satisfaction with personal control over key building systems (Baird, 2010), offers mixed evidence at best. Average satisfaction with lighting control barely exceeded the mid-point of a 7-point scale, and average satisfaction values for other environmental conditions such as acoustical and cooling and heating control were worse (2.48 to 2.82). In an earlier study, Huizenga et al (2006) also sought to link occupant satisfaction in green buildings with control over the indoor environment, and produced mixed results. The authors found that occupants in green buildings, on average, are more satisfied with thermal comfort and air quality in their workspaces than those in comparable conventional ones, but that average scores for lighting and acoustics were similar across the two building types. In many of the green buildings surveyed, occupant control over environmental conditions including lighting was limited due to the high percentages of peoples in cubicles with low partitions or in so-called bull-pen settings (i.e., open plan, no partitions). Open-plan and low partitioned cubicles, a favored workplace design by management if not by the rank-and-file, are sometimes paired with glass curtain walls and/or clerestory windows as a means to facilitate natural daylight penetration. However, results are mixed regarding glare control and standard workplace issues of acoustics and privacy.

Building Usability and Organizational Context

To the extent that personal control in the design intent and operation of building systems has waned, other factors affecting building system usability may play a larger role. This thesis explores how usability and energy performance might be improved with intentional matching of organizational contexts and the design and implementation of energy conservation measures. Organizational context is a broad concept; thus, it is helpful to parse it into manageable pieces -- organizational characteristics, which describe attributes of people, protocols over which they have agency, and organizational structures, which are relatively more determinate.

Organizational characteristics that predict adoption decisions, and which may similarly influence the quality of use of an adopted technology, include familiarity with the technology, managerial attitude towards change, and communications protocols both for acquiring and disseminating knowledge to affected participants (Dewar and Dutton 1986, Cohen and Levinthal, 1990). Familiarity favors adoption and should also favor better use experiences. In TOE (technology-organization-environment) studies of innovation adoption, familiarity and firm size are often related; larger firms have more ability to dedicate personnel to overseeing the process of technological change (Tornatzky and Fleischer, 1990). It is unclear, a priori, whether larger size is positively related to higher quality of use. In the Lighting Locus of Control examples given earlier (Figure 6), increased organizational complexity, often a function of size, was associated with more complex use structures.

An embracing attitude and more open communications protocols should have a favorable impact on the use experience of an adopted technology. Another consideration may be the extent of managerial centralization, which along with firm ownership, has unclear impacts on the adoption of new practices and generally is regarded as one of the more contentious issues in organizations (MacLean, 2012). While a more centralized managerial structure may convey an ability to prevent or counter resistance to change, this form of organization may also prove less responsive to users' poor experiences with a building technology (assuming management even learns about them thereby gaining the opportunity to correct them). Regarding ownership type, managers of non publicly traded firms may feel less constrained by popular opinion. However, associated managers and/or owners may be motivated by cultural and legitimacy-directed activities (DiMaggio and Powell 1983), particularly in the case of energy conservation wherein the dividing line between private and public benefits is blurred.

Organizational structures of interest include geographical settings and political-economic conditions (Wejnert 2002) – e.g., climate, regulatory and regimes, and characteristics of the local real estate market. To these previously established structures, I would add workplace trends in organizing physical space. Between 2005 and 2012, telework grew nearly 80% (Global Workplace Analytics, 2013), in turn, facilitated by advances in information technology. Accompanying this trend, has emerged a collective vision for the workplace that entails shrinking space allocations for workers – from a peak of 370 SF per worker in the 2nd quarter of 2009 to 305 SF per worker in the 2nd quarter of 2013 (Miller, Forthcoming in the Journal of Corporate Real Estate, accessed on-line February 1, 2014). Design features that favor common and collaborative workspaces over dedicated workspace (Barber et al, 2005) is the 3rd leg of this aspect of changing workplace contexts. There are many variants of this vision, with hoteling, non-territorial offices, free address offices (in which there are no proprietary workspaces), activity-based design and various hybrid arrangements supporting and also further encouraging increasingly fluid occupancy patterns within proto typical office suites.

Workplace design strongly affects worker satisfaction and also how these users experience the building environment. In workplace-based usability studies, the realized use of space -- furniture design and layout, and visual environment are acknowledged variables of interest (Maissel et al, 1991). In this thesis, the question is how the structure of these workplaces affects users' experiences with lighting and HVAC technologies.

In a related vein, recent studies in energy and environmental research have explored the interrelationship of organizations and technology. Schelly et al (2013) in a study of energy conservation measures in a school district evaluate the dynamic of building infrastructure and organizational culture. They find that leadership qualities (charisma) and competition among users are important in realizing successful outcomes. Pellegrini-Masini and Leishman (2011), demonstrate that organizational culture can be leveraged to encourage energy conserving behavior, which is similar to the more general explanation by Teixeira and Werther (2013) for how organizational culture – unique histories, beliefs, actions -- conditions outcomes. Janda (2013) posits energy conservation opportunities in commercial buildings as an intersection of "organizational factors, occupant behavior and technology adoption" (p.2), in the belief that treating these realms separately does not paint a true picture. Jain, Taylor, and Culligan, 2013 and Prindle and Finlinson (2011) urge greater attention to the "meso-level" for exploring interdependencies and interactions between building occupants, organizations and macro-level outcomes. Similarly, several scholars associated with the UK's Usable Buildings Trust earlier studied *how* buildings --organizations and discrete stakeholders-- learn and adapt, and how these pathways produce societal-level outcomes (Stewart Brand, 1994; Blackmore, 1991; Cooper, 1988).

In applying an organizational model to processes of building-level innovation, Kleindorfer, Kunreuther and Schoemaker (1993) emphasize the manner in which tasks relating to building functions are divided among various hierarchical and also lateral participants, how information on building uses, needs and performance is processed, and how decisions are implemented. The authors draw on the work of Thompson (1967) to formalize relationships between different technologies and task types and attendant managerial requirements – with a result that is similar to Norman's (op cit) conceptualization of use structures. Simpler technologies and tasks place lower demands on organizational communications and coordination (according to Norman, their use structures are narrow and shallow), whereas more complex technologies and tasks have broader and often iterative demands (wider and deeper use structures). Correspondingly, complex organizational contexts (e.g., multi-tenanted office buildings) may require robust and adaptive technologies and controls, which nevertheless must be straightforward in their use as perceived by the lay end-user.

Synthesis of Usability Metrics and Innovation Concepts

A contribution of this research is to connect building-level usability metrics with innovation outcomes (i.e., their energy performance). As there is no agreed upon usability framework in relation to green building innovation (Heerwagen and Wise 1998; Heerwagen, 2000; Cole and Steiger, 1999; Turner, 2006), it is necessary to synthesize a theoretical approach. To do this, I draw on well vetted innovation concepts by Rogers (1962) – i.e., relative advantage, trialability, complexity or simplicity, compatibility and observability -- to help characterize user-technology interactions in workplace settings and to explain their outcomes. In relation to Bevan and Macleod's depiction of usability factors – Context of Use Components (the users, task, equipment and environment) inform Quality of Use Measures (effectiveness, efficiency, satisfaction) -- Roger's concepts offer innovation success criteria for generalization of results.

Relative advantage – refers to how improved an innovation is over the previous generation and is a criterion for evaluating the outcomes of the technology in question. Are newer HVAC or lighting controls more flexible than earlier ones in accommodating varied building use schedules? If so, quality of use should improve, leading to better, or at least not worse, measures of satisfaction, efficiency and effectiveness. Communications and managerial structure may influence how the relative advantage of an innovation is perceived.

Trialability -- the ability to experiment with an innovation as it is being installed/adopted by users. Is management supportive of technology trials? Does management share passwords for controlling dimmable lighting ballasts with employees or co-workers and if not is this a missed opportunity to at least improve user satisfaction and possibly also system performance?

Complexity or simplicity -- is attributable to technology and context. If the innovation is too difficult to use then quality of use will suffer, potentially resulting in dissatisfied users who may furthermore take adaptive actions that are sometimes detrimental to building performance. Norman's usability dimensions of an innovation, especially affordances, conceptual models for use, feedback, and constraints, are close analogies. They describe preferred attributes for designs that optimize use, while also anticipating the importance of context.

A relationship also exists between the complexity of the technology and the complexity of the organizational setting (Kleindorfer et al, op cit). In simplistic terms, correspondence is good and divergence is not. If the design of a workplace requires extensive social negotiation, or even excessive communication, to make an adjustment to lighting or temperature, there is a divergence in the complexity of the de facto use structure and the technology's intended design. In this example, per Norman, the use structure is wide and deep whereas the design of the technology anticipates a more narrow and shallow use structure. Per Thompson, wide and deep use structures present higher degrees of interdependence, placing high demands on management decision-making and communications and a more intensive/reciprocal technology type/task design.

Compatibility and observability also are tightly linked to social context. *Compatibility* refers to the extent to which the innovation is easily assimilated into a pre-existing situation, while *observability* is the extent to which an innovation -- its function and results -- are visible to a community of users. The introduction of a new technology or design (e.g., daylighting) may be *incompatible* (non communicative) with the interior organization of workspace (high-walled cubicles), or with work schedules and the objectives of job functions/tasks. A utility bill may be paid off-site and not accessible to on-site managers or the space may not be sub metered, all of which are detrimental to *observability* and consequently truncate the desired feedback loop.

Motivating Hypotheses

Of greatest interest in this thesis are *how* and *why* building occupants interact with HVAC and lighting technologies within multi-tenanted offices, in order to help explain ECM outcomes. I proceed according to the following motivating hypotheses:

H1) Under-performance of building energy conservation measures is caused in some measure by usability failures.

H2) Innovations that are not compatible with organizational context (use structures) will result in negative quality of use (effectiveness, efficiency and satisfaction).

The null hypothesis is that there is no relationship usability and performance, on the one hand, and between organizational context and usable HVAC or lighting design.

Chapter 4: Methods and Data

This dissertation employs multi-site longitudinal case study research to uncover the richness of the proposed relationships between usability and energy use. It facilitates an exploration of usability perceptions by individuals in varying organizational contexts, and enables systematic comparisons of established usability factors and innovation concepts. The evaluation protocols I utilize support comparative as well as generative case study as drawn from the traditions of building performance evaluation (BPE) and, especially, post occupancy evaluation (POE).

Building Performance Evaluation

BPE is a process for evaluating the performance or effectiveness of one or more building systems on criteria such as cost, functionality, satisfaction, productivity, safety (Zimring, Rashid & Kampschroer, 2010). It begins with a specification of the building systems (innovations) to be evaluated. BPE may include objective as well as subjective measures. Examples of objective measures include: utility bills, building management systems (BMS) data that charts environmental conditions within the building, complaint logs relating to one or more building systems and also detailed data about building or appliance usage obtained from occupancy sensors, plug load, water and light meters, and air quality tests. Some studies also include formal behavioral observations and recorded productivity measures and employee absentee records. Subjective measures are obtained from occupant surveys, structured interviews and focus groups.

Post-Occupancy Evaluation

Information obtained directly from building occupants and other building users is commonly referred to as post-occupancy evaluation (POE). The terms POE and BPE sometimes are used interchangeably; yet, POE is more targeted in scope than BPE. Its main objective is to "complete otherwise missing aspects of feedback loops" as to whether, why and how the operation of the building successfully meets "initial intentions, goals, program and design" (Wener, McCunn, Senick, 2014). POE offers diagnostic and/or prognostic information by focusing upon the needs and interests of building occupants (Zeisel, 1981; Preiser et al., 1988; Wener, 1989; Zimmerman and Martin, 2001). Preiser (2001) additionally suggests that POE should take account of the political, economic and social forces that shape building operation. Both BPE and POE occur at some point after a building has been populated by its occupants. Most often, POEs are performed on newer, typically more ambitious building designs, and POE is now included as an IEQ credit in LEED for New Construction (LEED-NC 2.2). POEs of existing buildings are few, which is unfortunate given buildings' environmental and human impacts and the apparent difficulty of retrofitting these buildings successfully.

There are various types of POE with corresponding research designs and techniques. Two prominent types, relating to different intended uses of the findings, are summarized by Wener (1989). This research draws on comparative POE to assist in differentiating occupant reactions and responses to energy retrofits within and across buildings engaged in this study and generative POE to assist in grounded theory building (Yin, 1994) about how organizational and building-level contexts may inform broader outcomes. This hybrid approach facilitates a deep understanding of user-technology dynamics in an embedded context (Orlikowski and Iacono, 2001), while conveying an ability to sort findings according to innovation concepts and related themes. A blend of quantitative and qualitative research techniques facilitates “triangulation” of these data (Marshall and Rossman, 1999, p.110). Qualitative data provide key themes, or “interpretative constructs” (Rubin and Rubin, 2005, p. 29) with which survey and measured building data are joined in reaching conclusions and/or grounded hypotheses for evaluation in future research.

POE traditionally has been a one-off exercise. Examples of multi-site and longitudinal POE are rare, although becoming more common as their value is increasingly recognized by some designers and owners, and outside funders. Recent multi-site POE studies have incorporated both subjective and objective data, while also seeking to develop standard measures for this data. Choi, Loftness and Aziz (2012) evaluated over 400 workstations in 20 Federal office buildings across the U.S. and, in addition to occupant satisfaction surveys, collected data on temperature, relative humidity, carbon dioxide and carbon monoxide concentrations, total particulates, volatile organic compounds, light levels, radiant temperature, and air velocity as a basis for future IEQ standards and guidelines. A group of UK PROBE researchers who investigated the post-occupancy energy performance of 23 office buildings in 1995-2002 used this larger data set to help develop CIBSE TM22 (Chartered Institution of Building Services Technical Memorandum 22) methodology for estimating building energy use. Menezes et al. built upon this standard in 2012, in a case study of a London office building using CIBSE TM 22 entailing close monitoring of small loads and occupancy patterns and by then using the results to improve energy modeling accuracy.

Examples of multi-site studies, exploring factors that influence occupant comfort include: the European HOPE project (Bluyssen et al, 2011) representing 59 buildings in 8 countries; the Canadian COPE project (Veitch et al, 2007) which evaluated occupant satisfaction with open plan designed space in a questionnaire of 779 occupants in 9 buildings; and the works of Kim and de Dear (2012) assessing the relationship between satisfaction with individual IEQ factors and overall workplace satisfaction drawing on data from 351 different office buildings from the Centre for the Built Environment database at the University of California.

While usability, ceteris paribus, has not been the main focus of POE research, many of the methods and protocols commonly used in POE are well suited to such an investigation (Wener, McCunn, Senick, op cit). In addition, meta-level analyses of POE have been conducted with the objective of organizational learning in hopes of closing the loop more routinely between building design and the user experience.

Empirical Basis for Field Work

The empirical basis for my field work is a collection of high-performance and conventional commercial buildings that have been outfitted with energy conservation technologies, drawn mainly from the portfolio of a mid-Atlantic-based real estate investment trust (REIT). In particular, I develop a case study of user-technology interactions, and their contexts, in 9 multi-tenanted office buildings as they were under-going energy efficiency retrofits of lighting and HVAC technologies. This case study advances the themes of the LEED new building studies that contributed an organizational interest to this work.

A real estate investment trust (REIT) is a company that owns and, often, operates income-producing real estate. REITs can be publicly traded or privately held. Listed equity REITs own more than $1 trillion of real estate assets in the U.S. (15% of total U.S. commercial real estate assets), which includes more than 40,000 properties. (https://www.reit.com/investing/reit-basics/guide-equity-reits, accessed March 7, 2015). As of January 31, 2014, there were 204 REITs registered with the Securities and Exchange Commission having a combined equity market capitalization of $719 billion.

In July 2014, the REIT to which the subject buildings belong had a market value of approximately $9 billion and owned 750 buildings (or 101 million square feet) of industrial and office space in the United States and the United Kingdom, occupied by 2,300 tenants (subject REIT website, August 2014). Founded in 1972, this REIT develops, acquires, leases and manages properties with a mission "to enhance people's lives through extraordinary work environments." It began to market itself as a leading developer of "high-performance green buildings" within the last decade, and was an early adopter of the LEED standard for new office construction, within the REIT community.

The decision to concentrate field study within the building portfolio of one owner reflects both theoretic and pragmatic factors. The organizational environment of a REIT provides a rich context within which to assess how organizational factors shape usability interactions and results. The ability to hold constant possible impacts due to ownership allows a more concentrated focus on varying building-level contexts -- different facility operational policies or administrative involvement, leasing arrangements, operating hours, different numbers and types of tenants with varying operational policies, and, also, variability among building occupants. The organizational structure of a REIT is very flat;

property managers often are more influential in setting and maintaining building policy than REIT officers or others at REIT 'central'. Similarly, the accounting locus within a REIT is the building; thus, organization-wide green building programs within REITs are rare and REITs generally have been slow to embrace sustainability. In the same sense that the POEs of the early LEED buildings provided insight into early occupant experiences with green building settings and technologies, this research of a pioneering REIT's attempts to retrofit existing tenanted buildings with energy efficient measures is an opportunity to evaluate organizational determinants of usability while refining and generating new hypotheses about building occupant-technology behavior.

All of the buildings owned by the REIT in which field work was carried out are located in a major mid-Atlantic metropolitan region, subject to similar pricing and policy impacts. The buildings represent a mixture of Class A and B office space, weighted towards the former, and are mainly multi-tenanted. Selection of buildings with multiple tenants replicates complex real-world occupancy patterns while affording opportunities to more effectively identify technology-user patterns that either undermine energy efficiency objectives or contribute to effective management of energy conservation. Finally, because REITs own large collections of buildings, policy recommendations resulting from this research carry high potential leverage.

Selection of these buildings was also opportunistic. The initial relationship with this REIT was formed on the basis of a mutual acquaintance who thought there might be a shared interest in POE. While the majority of this research was supported by an independent grant from the U.S. Department of Energy (Award Number DE-EE000426), the fact that at least some of it was conducted as a work-for-hire leaves it open to claims of bias – e.g. the researcher may refrain from presenting poor or critical results. As should become obvious in the following chapters, this was not the case here. Moreover, a close relationship between the REIT and the research team at the Rutgers Center for Green Building facilitated deeper understanding of the factors that motivate the REIT/subject's behavior and actions than would have otherwise been possible (Miller, 1999; Lather, 1992; Robottom, 1993).

Funding for two of the early LEED POEs was provided through a grant from the New Jersey Chapter of the US Green Building Council. Permission to conduct research activities in all of the buildings referenced in this study was granted by the respective building owners and approval was given by the IRB (IRB# E09-015).

Categories and Contexts of Investigation

A multi-layered case study approach supports inquiry at various units of analysis, which in my research includes: the building, the technology, its users, and organizational contexts. This approach for understanding user-technology behavior is both robust and forgiving. Data is compared across and within unit levels to help paint the most complete picture given the inevitability of missing and confounding data in field research.

Thematically, I focus on three main categories and contexts of user behavior that impact energy consumption in commercial office buildings – thermal comfort, lighting and, to a lesser extent, plug load as a consequence of adaptive actions related to the other two categories. I adopt a comprehensive data approach to support this inquiry (Table 3). These data requirements are, in turn, mapped to the data protocols deployed in my field work concerning the nine buildings undergoing energy efficient retrofits.

EQUIPMENT/TASK	USERS	ENVIRONMENT
Basic description, specifications Major function: building-level performance objective Task goal(s) and outputs Task frequency, duration, percent of time relative to other tasks Task dependencies	Personal details (user type, location of workspace, type of workspace – private office, shared, etc., tenure and work status (full, part) Skills and knowledge: familiarity with the innovation, organizational experience, general knowledge of 'green', feedback mechanisms to which a party Experience of use: effort, satisfaction, results Personal attributes: age, gender, attitude, motivation	Structure: hours of work, level of flexibility, management and communications structures Attitudes and culture: organizational aims, EE/sustainability policies Workplace conditions: thermal, visual, auditory Workplace design: space and furniture, location Transactional terms: lease structure, building rules, facilities management, property management

Table 3. Equipment/Task, Users, Environment: Factors of Usability Study.
Based on concepts from Bevan and MacCleod, Table 1 Breakdown of Context, p.12

Data Protocols

Building performance data provides a basis for judging the effectiveness of energy conservation measures (against industry standard benchmarks and stated or modeled intent). Performance data is available for all buildings that form this study, in most cases broken down by energy conservation measure. Against this data are paired a series of causal predictions/ hypotheses about user-technology interactions and outcomes. Behavioral data results from a combination of structured and intercept interviews, walk-throughs and observations, surveys, and in limited instances, focus groups.

Throughout the period of fieldwork semi-structured interviews were conducted of tenant representatives – e.g., the office manager, human resources manager, quality control manager, and a divisional manager, CEO or COO, along with the building owner, designer, operator and property manager. Potential interviewees were contacted either by email or phone and invited to participate in a face-to-face interview about their experiences in these buildings. I have drawn upon the resulting transcripts and complementary archival data, where these were available (e.g., company mission statements, lease samples, etc.), to characterize organizational context, and other identifying themes and patterns (Liamputtong and Ezzy, 2005).

Intercept interviews were conducted of individual building users, often in concert with the taking of lighting and thermal comfort measures in their workspaces. An attempt to stratify across building floors and exposures was made, both for the intercepts and the measurements, although the success of this strategy was constrained by building occupancy patterns and subject willingness and availability.

A Konica Minolta T-10A Illuminance Light Meter was used to measure work surface in front of the computer monitor, other desk work surfaces, including at center, at a window, when applicable, and in common or circulation areas based on Illuminating Engineer Society of North America – IESNA - photometry guidelines. A Fisher Scientific Traceable® Temperature and Humidity Meter was used to measure temperature and humidity at the center of the work space, 1.0 m in from the center of the window, at window, 24" from floor where occupant sits, as suggested by ANSI/ASHRAE Standard 55-2010 guidelines. While these measures were not intended to be used conclusively, as a complementary data stream they work to help characterize building IEQ along with occupants' reports of lighting and thermal comfort. Where it was practical to do so, these measurements were recorded on office floor plans.

An observational protocol was used to provide further insight into how building occupants interact with building systems and technologies. Recorded data includes workspace configurations and evidence of adaptive responses (i.e., presence of space heaters, a sweater, task lighting). Photo documentation accompanies this protocol and was carried out in a manner that avoided capturing subject's faces or other identifiers.

At different phases of this study, anonymous online surveys were sent to building occupants through tenant representatives and, depending on the phase of study, included baseline questionnaires, short questionnaires to be administered 2-3 times per week, and a follow-up survey. Survey questions are both original and drawn from existing scales including those developed by the Center for the Built Environment at Berkeley (series on IEQ), the National Research Council of Canada, AUDE in the UK, the HOPE project, and Aeries (2010, windows, view and office characteristics). Additionally, to help ascertain physical and mental responses by building occupants to load shedding activities, the research team utilized select survey scales from the PROMIS (Patient-reported outcomes measurement information system) instrument as validated by Hays et al (2009), and from the World Health and Work Performance Questionnaire [HPQ], which were validated during a pilot phase of research. Original survey questions probed more directly the quality of use experience of building occupants with various energy technologies – e.g., effort (efficiency of use) and perception of performance (effectiveness of use) along with satisfaction. These also were validated in a pilot phase.

Appendix A contains copies of the observational, interview and survey instruments used to collect data.

A Further Note on Recruitment

Subject recruitment was a multi-step process, with subjects self-selecting into the study. As previously noted, an attempt was made to develop a stratified random sample for the intercept interviews, and sometimes this effort was successful. In the aggregate, this study does not enjoy the statistical properties of a randomized research design. While there is currently much talk of introducing randomized controls into energy behavior research – e.g., this topic was a main theme at the recent American Academy of Arts & Sciences Conference I attended (*Beyond Technology: Strengthening Energy Policy through Social Science.* June 18-19 2014, Pace University, New York) -- it is not always possible to do so. In this case, recruitment was dependent on the building owner or the property manager making an initial request to tenants to consider participating in the study. Neither the building owner nor the property manager(s) were willing to push the issue and there were some tenants who were excluded from consideration by the building owner. The building owner/property managers opened the door and successful recruitment from there became the responsibility of the research team. After initial introductions, tenants were re-contacted by email or phone to set up appointments to conduct interviews, measurements, and observations in tenant suites. The tenants, in turn, controlled access to their employees although their influence was limited to permitting the intercept interviews and forwarding the invitation to take the survey via a confidential link to a Rutgers' server. Some office managers were more supportive of the study than others and the distribution of collected data reflects this.

Organization of the Data

The ensuing data are organized into a comprehensive case study of the nine retrofit buildings, broken into parts in a manner that elucidates usability hypotheses and findings.

In Chapter 5, I provide the organizational context of the energy retrofit program. Subsections focus on the "equipment and tasks" and "users and the environment" as guided by Bevan and MacCleod (op cit, Table 4) to realize a contextual understanding of usability processes and outcomes. These data are followed by specific predictions that result from a mapping of the usability attributes of specific energy conservation measures (ECMs) to Bevan and MacCleod's usability metrics and Norman's innovation concepts.

Next, in Chapter 6, I present the energy savings results of the ECMs applied to the set of buildings (e.g., their effectiveness), in total and also subdivided by general load (lighting) and HVAC components of the retrofit against modeled projections.

Chapter 7 presents an introduction to the post occupancy evaluation component of the case study, the basis for explaining where, how and why the energy retrofits fell short of their intended outcomes. It is followed by Chapter 8, which assesses *pre-retrofit* contexts and usability in the buildings. Chapters 9 and 10 evaluate *post-retrofit* usability conditions. More specifically, in Chapter 9 the experiences of three buildings that underwent retrofits in the earlier phases of the program are systematically assessed for evidence relating to the usability predictions. In Chapter 10, the experiences of the later phase buildings and also longitudinal experiences of the earlier ones are evaluated for evidence of organizational learning. In Chapters 8-10, a graphical device summarizing the contents of these chapters is presented in the chapters' introductions in order to help with reader orientation.

In wrapping up, Chapter 11 contains discussion of the case study, with a return to the earlier predictions regarding building user reactions and response to the energy retrofit measures. Finally, in Chapter 12, I offer a number of attendant policy prescriptions, and include suggestions for future research.

Chapter 5: Turning Existing Buildings into "Smart" Buildings
The Organizational Context of an Energy Retrofit Program

In 2009, a mid-Atlantic based REIT (Real Estate Development Trust) applied with its local utility to the U.S. Department of Energy's Smart Grid Infrastructure Grant (SGIG), an ARRA (American Recovery and Reinvestment Act) program for building energy retrofit funding. The REIT proposed to test the value proposition of a bundle of energy conservation measures that would be linked through a BWAN, building-wide area network, in 10 out of its 700+ buildings (SGIG Application, 2009, Appendix 4). The BWAN would facilitate centralized remote monitoring of energy use and grid system interoperability (e.g., 2-way communication between the building and the electric grid). These buildings therefore would be capable of participating in an activity known as load shedding, wherein light level reductions, power demand limiters, reduced variable speed drives, electric demand reduction, and other equipment and strategies are made subject to utility demands for reducing strain on the electrical grid during times of peak load (SGIG application, op cit). The total cost of the proposed program was approximately $4,250,000, to be split equally by the U.S DOE and the REIT.

The proposed energy conservation measures (ECMs) were the following:

- Installation of advanced lighting controls with upgrades to fully dimmable network addressable electronic ballasts and low wattage bulbs
- Web-accessible open protocol intelligent energy management systems to monitor power use, lighting and HVAC systems
- Smart metering and real time monitoring of energy usage, with control integration of major building systems
- Retro-commissioning of building HVAC system

These measures would complement other, low cost energy conservation measures previously identified by comprehensive energy audits conducted on all of the REIT's managed office buildings as part of its sustainability initiative one year prior, which also included installation of the BWANs. Through these measures, the REIT believed it could attain energy savings of 20-30% in each building.

The SGIG application was successful and in February of 2011 the REIT commenced the first phase of retrofits, consisting of two buildings. Two additional phases followed, of four buildings each. Each phase consisted of engineering, construction, and commissioning/reporting phases. (Milestone Matrix, revised, Appendix B). The program was completed June 2014.

Equipment and Tasks

The SGIG application detailed the energy technologies (equipment) and their functions (tasks). In the descriptions below I have retained the exact wording, and added underling to emphasize projected quality of use outcomes. Retrofit details, by building, appear in Appendix C.

> "**Advanced Lighting Controls:** This proposed system seamlessly integrates and simultaneously deploys 6 energy management strategies. Those 6 strategies are: Smart Time of day Scheduling, Daylight Harvesting, Task Tuning, Occupancy Control, Personal Control, and Variable Load Shedding. The cumulative effect of these strategies equates to significant energy savings. Additional benefits include:
>
> - Eliminate Wasted Energy - Addressable fixture level dimming and switching <u>controls coupled with easy to use control software allow the system to respond dynamically to the ever-changing characteristics of a building</u>. <u>By achieving the right amount of light when and where required, wasted energy is eliminated.</u> This technology is also used for automated energy load shaving or demand response strategies.

- Three Methods of Control - Occupants have control of their own work environment, facility managers are able to control every facet of their lighting system, and energy managers can control lighting as part of a facility wide energy management strategy to maximize savings.
- Improved Worker Productivity – This system improves workplace ergonomics, occupant productivity and tenant satisfaction by optimizing lighting quality and providing individuals with the ability to have complete control of light levels in their workspace from their PC.
- Enhanced ability to achieve LEED Existing Building certification - This solution contributes between 12 and 22 points to LEED certification, depending on the specific application and other factors.
- Dynamically adapts lighting system to changing building uses – This system is able to change to workspace use. Varying lighting requirements or internal reconstruction are easily addressed through the control software without ever having to physically alter wiring or move luminaries. The result is that control zones become completely independent of electrical circuiting.
- Lighting control becomes a major component of a facility wide energy management strategy. With the ability to shed lighting load, this system will be used for energy peak shaving or demand response strategies. It constantly monitors energy usage and can predict and avoid sharp increases in energy demand without affecting lighting quality. It will also share data and seamlessly integrate with our building "Smart Metering" system.
- Included with the advanced lighting controls is an upgrade to dimmable ballasts and more efficient light bulbs where needed, including parking lot lights.

Web-accessible non-proprietary open intelligent energy management system: This intelligent building energy management system will be the backbone or nerve center of this smart building project. The system will be a fully open non-propriety LON based system equipped with wireless communications to allow the new network to be seamlessly accessed by the building occupants and owners through a web-base IP protected address. It will employ Cisco network management and a Tridium Niagra Jace intelligent network. The individual roof top units, terminal units, lighting systems and metering devices will all be integrated through this LON open protocol. Energy Conservation strategies such as Time of Day Scheduling, comfort control optimization, reduction of simultaneous heating and cooling, Demand Control Ventilation utilizing CO2 sensors, Economizer optimization, lighting control integration, night setback and demand response will be incorporated into the intelligent building solution.

Smart Metering: The old adage of "what you can't measure, you can't manage" is appropriate to describe the current state of energy management of the U.S. commercial real estate industry. Most buildings pay their utilities without any idea whether the consumption charges accurately reflect the actual building consumption. Effective energy conservation can only be accomplished through the knowledge of how, why and when energy is being consumed. This proposed system provides the following:

- Electrical utility meter readings will be integrated into the smart building network where instantaneous usage can be tracked and monitored. Specific sub-metering locations will also be integrated to track large user loads.
- This information will be communicated to a centralized utility management software database where the information will be collected, inventoried and formatted into charts and graphs which can be modified by the user to identify usage anomalies.
- The system will integrate the building systems so that it can reduce load in response to peak demand reduction requests instituted by [name removed] or PJM.
- Near real time monitoring and data capture of energy usage of each building
- Integration with the application of open standard based interoperability technologies on the existing Building Automation System (BAS) to provide remote monitoring and alarm notification.
- Unification with [name removed] internal network portal to provide consumption trend transparency and visibility of utility/energy utilization for each building
- Dash-board profiles that provide a comparative overview of the energy performance to improve operations, building controls, reduce utility consumption and monitor environmental footprint.

Retro-commissioning: Retro-commissioning is a systematic, documented process that identifies important operational and maintenance improvements in existing buildings and brings the buildings up to the design intentions of its current usage. Building systems that do not perform as intended will consume significantly more resources over their lifetime. By retro-commissioning the HVAC system, not only will it perform better and use less energy, it will reduce operating expenses, require fewer maintenance callbacks, and improve occupant comfort and productivity."

Users and Environment

The REIT's introduction of energy retrofit technologies to tenants of the ten buildings emphasized the potential to save energy, money and emissions. (Source: REIT to tenant flyer, distributed by email to tenants, April/May 2010.) The flyer repeatedly emphasized the 'smart' nature of the proposed ECMs, the attainment of optimal or maximal efficiency, and occupant comfort. The flyer also stated that work would be performed after hours and set the expectation that tenants would not be disrupted. Finally, this communication emphasized the broader societal benefit of the retrofits, suggesting that taking part in them was commendable to friends and family and part of an important step forward in the future energy management of commercial buildings.

The business model of a REIT revolves around its tenants, so a REIT is unlikely to impose workplace-based sustainability measures on unwilling tenants. As previously noted, REITs generally have been slow to embrace sustainability and this REIT is the only one I know of that has undertaken energy efficiency retrofits in occupied tenanted spaces. It is also the only one of which I am aware that has implemented load shedding activities via a tenant opt-out system; in general, load shedding by non owner-occupied properties is rare. By way of comparison, I recently interviewed the VP of Sustainability of another office local REIT with a strong reputation for pro sustainability measures and learned that while they load shed, they do so in common areas with some tenants opting-in to do more on their own. (Source: Interviews by author at 2014 NAREIT Leader in the Light Working Forum January 8-9, 2014 San Francisco, CA and follow-up interview, July 7, 2014, New York City.) The President of a 3rd REIT, also based in the mid-

Atlantic area, has focused its sustainability efforts on partnering with tenants to install PV panels on roofs and on energy efficiency upgrades to its multi-tenanted headquarters. (Source: Monthly participation in sustainability committee meetings of this REIT over a period of 2 years and on-going communications).

The ten buildings selected for the retrofits are representative of the subject REIT's managed office building portfolio. They are full-service buildings and thus the REIT is the utility account holder. With few exceptions, tenants' gas/electric usage is not individually metered and payment is calculated pro rata based on square footage. Recalling the split-incentive problem earlier described, this arrangement favors capital investment by the REIT while still leaving open the possibility that tenants' utility costs could be reduced if total costs decline. However, the lack of direct correspondence and transparency between energy use and savings could also impede tenants' motivation to conserve. The planned retrofits called for the installation of a few additional sub meters, to account for the disproportional impacts of larger energy users.

The fact that these buildings are "managed" means that they have dedicated property managers. This is not the same as having a dedicated facilities manager, which in these buildings is not the case. Rather, the property manager works with tenants to call in various service providers as needed to address equipment or other problems if s/he cannot address them directly. As was demonstrated through the earlier exploratory case study, the specific function of facilities and property management mediates building performance and occupant satisfaction. Across the three phases of this retrofit program, a total of five different property managers were involved. Their roles and potential influence on building tenant level outcomes are evaluated later on.

Finally, all ten buildings are low-rise office structures located in the same metropolitan area and sited in suburban office parks bearing Co-star assigned class ratings of A or B. They were built between 1971 and 2005 and range in size from 50,000-100,000 SF. Construction type is consistent with building age; the newer buildings have more glass atria and/or curtain walls. Approximately a quarter of the buildings had already achieved higher ENERGY STAR scores prior to retrofit, and thus would be consider higher-performing buildings.

Use schedule is an important contextual variable that influences use structure. These were found to include a high percentage of fixed weekend hours -- sometimes under minimal occupancy conditions, late hours, variable hours and, rarely, standard office hours (Company building-level energy audits, 2008, Table 5). In multi-tenanted commercial buildings, use schedules frequently change. One of the original ten buildings remained vacant throughout the time of the retrofit program. A second building was only lightly tenanted and faced high tenant turnover during the period of the POE. Although all buildings were multi-tenanted at the time of the SGIG application, one became single-tenanted at around the start of this POE. Variety in tenant activities also suggests complex use structures. At the time of our study, tenant activities in these buildings included sales, professional services, product development, government functions and a lab/clinical setting. A summary of building tenancy is provided in Table 4.

Building Address	Year Built	SF	Number of Tenants/ Occupancy % (2011)*	Pre-Retrofit Energy Star Score (2/11)**	Work Phase/Property Mgr
Building 1	2004	76,692	1 (prev. 2) 87.6%	71	1/A
Building 2	2005	100,000	6 99.54%	76	1/B
Building 3	1982	54,623	9 78.08%	74	2/C
Building 4	1985	60,645	10 35%	64	2/B
Building 5	1983	46,697	3 100%	51	2/ D
Building 6	1971	100,000	5 100%	58	2/ E
Building 7	2000	108,675	9 86.63%	65	3/D
Building 8	2001	89,165	4 68.22%	79	3/ E
Building 9	1977	58,835	4 75.86%	53	3/D
Building 10	1988	49,526	vacant	--	3

Table 4. Building and Tenancy Physical and Organizational Characteristics.
Source: Assembled from data provided by the REIT.
*Per REIT rent roll for this time period. ** Per ESPM calculations of REIT sustainability department during this time period

Building	Monday-Friday	Saturday	Sunday
Building 1			
HVAC	5AM-6PM	OFF	OFF
Lighting	5AM-7PM	OFF	OFF
Occupancy	8AM-6PM	OFF	OFF
Building 2			
HVAC*	6AM-6PM	OFF	OFF
Lighting	6AM-9PM	OFF	OFF
Occupancy	6AM-6PM	OFF	OFF
*6 AM – 10 PM on Tuesday and Thursdays			
Building 3			
HVAC	7AM-6PM	OFF	OFF
Lighting	24/7	24/7	24/7
Occupancy	8AM-6PM	OFF	OFF
Building 4			
HVAC	8AM-8PM	Varies	Varies
Lighting	8AM-8PM	Varies	Varies
Occupancy	8AM-6PM	OFF	OFF
Building 5			
HVAC	6AM-6PM	6AM-6PM	6AM-6PM
Lighting	8AM-8PM	9AM-7PM	OFF
Occupancy	8AM-6PM	9AM-5PM	OFF
Building 6			
HVAC	5AM-10PM	Varies	Varies
Lighting	6AM-10PM	Minimal	Minimal
Occupancy	6AM-10PM	Minimal	Minimal
Building 7			
HVAC	6AM-7PM	OFF	OFF
Lighting	6AM-10PM	OFF	OFF
Occupancy	6AM-7PM	OFF	OFF
Building 8			
HVAC	6AM-7PM	6AM-2PM	11AM-3PM
Lighting	7AM-10PM	OFF	OFF
Occupancy	6AM-6PM	Minimal	OFF
Building 9			
HVAC	24/7	24/7	24/7
Lighting	8AM-6PM	OFF	OFF
Occupancy	8AM-6PM	OFF	OFF
Building 10			
HVAC	8AM-6PM	8AM-6PM	8AM-6PM
Lighting	8AM-6PM	8AM-6PM	8AM-6PM
Occupancy	8AM-6PM	8AM-6PM	8AM-6PM

Table 5. Energy Audit Data Produced Prior to Retrofit of the Office Buildings.
Source: Company energy audits from 2008.

Usability Factors and Innovation Concepts

Aligning Bevan et al's context of use components -- equipment/tasks and users/environment -- with Roger's innovation concepts, leads to the following quality-of-use predictions about the planned retrofits (Tables 6-8). In this framework, the innovation concepts provide the basis to judge (a priori) whether the application of these energy technologies and measures meet threshold criteria for innovation diffusion in the organizational settings found in multi-tenanted office buildings.

As billed, the advanced lighting controls should lead to a high quality of use experience on all three usability metrics (satisfaction, efficiency, effectiveness), and would qualify as an innovation wonder. Promising strong relative advantage across use metrics, an observability benefit via smart metering and monitoring, and the suggestion of trialability via personalized control, the advanced lighting package potentially matches the complex use structures of these tenanted office buildings. Its attributes are intended to meet varying schedules and energy profiles. It is further suggested that configuration of the system according to internal reconstruction of workspace is easily accomplished. The lighting retrofits, therefore, should accommodate existing workspace configurations, although this is not explicitly stated.

The usability case for the proposed web-accessible/open Energy Management System and Smart Metering system is less well articulated. It is noted that the EMS will be accessible to building occupants and owners, but it is not clear whether this means that rank-and-file workers can make adjustments or that this can be done only by tenant management (greater/lesser trialability). Dash board profiles of energy use will also be on view (observability), but again it is not clear who will have access to these. Generally, these features would be expected to help ensure proper functioning of energy technologies (effectiveness), and to economize on the effort required to achieve these outcomes (efficiency) – a relative advantage. To the extent to which the technologies perform well, in a predictable (not overly complex) fashion, and are compatible with occupant preferences and workplace needs, occupant satisfaction and efficiency also should be enhanced.

Retro-commissioning is a process not a product, and not particularly innovative either, although less than 5% of existing buildings are retro/commissioned (Mills (LBNL), 2009, p.6). It typically consists of a series of trial-and-error adjustments to underlying technologies (in this case, HVAC). Outcomes of retro-commissioning could be said to result or benefit from its trialable nature. Retro-commissioning of the HVAC systems in the ten buildings, including replacement of some component parts, is anticipated to result in better thermal comfort performance (a measure of effectiveness), improved occupant comfort (satisfaction) and "reduced operating expenses and fewer maintenance callbacks" (efficiency and/or effectiveness depending on stakeholder perspective). However, the ultimate ability to improve HVAC quality of use in these buildings through retro-commissioning is constrained by the existing HVAC system, the performance of the building's envelope and other relatively fixed factors.

There may be plausible alternatives to the predictions I have presented. However, I believe these to be reasonable, supported by the literature on usability, innovation diffusion and organizations, and to provide a solid basis against which to align empirical data collected from these buildings. I return to these predictions in the discussion of the case study, in Chapter 11.

	Relative Advantage	**Trialability**	**Observability**	**Complexity/ Simplicity**	**Compatibility**
Advanced lighting controls	**X**	**X**	**X**	**X**	**X**
Eliminate wasted energy	+Effectiveness				
Three methods of control	+ Satisfaction	+Satisfaction		+Satisfaction	+ Satisfaction
Improved worker productivity	+ Efficiency	+Satisfaction + Efficiency			+ Efficiency
Seamlessly integrates and deploys technologies	+Efficiency			+Efficiency	+Efficiency
Dynamically adjusts to uses	+Effectiveness	+Satisfaction		+Efficiency	+Efficiency + Satisfaction
Integrated with smart metering, monitoring	+Efficiency +Effectiveness		+Efficiency	+Efficiency	

Table 6. Quality of Use Predictions for Advanced Lighting Controls Aligned with Innovation Concepts. These predictions suggest that the advanced lighting retrofits, in particular, would produce favorable usability and innovation results.

	Relative Advantage	**Trialability**	**Observability**	**Complexity/ Simplicity**	**Compatibility**
Web-accessible, open EMS/Smart Metering	**X**	**X**	**X**	**X**	**X**
Seamlessly accessible by building occupants through an IP protected address	+Efficiency +Satisfaction	+Efficiency	+Efficiency	+Satisfaction	+Satisfaction
Near real time monitoring and data capture	+Effectiveness		+Effectiveness	+Efficiency	+Efficiency
Dash-board profiles; formatted data for future usage	+Effectiveness			+Efficiency	+Efficiency

Table 7. Quality of Use Predictions for EMS/Smart Metering Aligned with Innovation Concepts.

	Relative Advantage	**Trialability**	**Observability**	**Complexity/ Simplicity**	**Compatibility**
Retro-commissioning HVAC	**X**	**X**	**N/A resulting changes should be invisible to the building occupant**	**N/A, depends on existing HVAC technology**	**N/A, depends on existing HVAC technology**
Better energy performance, reduced op expenses, fewer callbacks	+Efficiency +Effectiveness				
Improved occupant comfort and productivity	+Effectives +Satisfaction +Efficiency	+Satisfaction +Efficiency			

Table 8. Quality of Use Predictions for HVAC Retro-Commissioning Aligned with Innovation Concepts.

Chapter 6: Energy Savings Results of the Retrofits

By the conclusion of the retrofit program, each of the ten buildings was retrofitted with all or most of the following ECMs (Wagner et al, 2014).

1. Dimmable ballasts were installed in lighting fixtures.
2. Wireless, ceiling-mounted daylighting sensors were installed to reduce fixture output in perimeter areas.
3. Occupancy sensors were installed in office areas to automatically turn lighting on and off based on occupant activities.
4. Variable frequency drives (VFD) were installed on exhaust fans inside the RTU units.
5. Supply air temperature reset was programmed into the building automation systems (BAS).
6. Duct static pressure reset was programmed into the BAS
7. Demand control ventilation utilizing CO2 sensors

Additionally, control sequences were written and implemented to tie building lighting and HVAC into the BWAN system for building-wide management. As a result of the ECMs, building energy use as measured by ENERGY STAR Portfolio Manager improved for the nine buildings for which this analysis was performed, even if very slightly. However, the sought after savings of 20-30% per building has yet to be achieved. Based upon a Measurement and Verification (M&V) exercise conducted for the REIT by researchers from the U.S. Department of Energy's Consortium for Building Energy Innovation (CBEI), the two best performing buildings returned energy savings of 24.8% and 16.4%, with others showing either single digit savings or, in one case, virtually no savings (Wagner et al, op cit). As can be seen in Table 9, there is significant variance in the savings achieved across the eight buildings for which the M&V was performed. Of the original ten buildings, one (Building 10) remained vacant throughout the course of the retrofit program. Another (Building 4) experienced occupancy changes considered too great to make evaluation of the energy measures feasible. A companion analysis (Table 10) presents building performance disaggregated into general (lighting) and HVAC load.

Building	Bldg sq. ft.	Fuel Type	Overall Energy Savings						
			Energy Savings		Predicted Total Energy Consumption for Post-Retrofit Period		% Energy Savings	Cost Savings	Savings per sq. ft.
			kWh	kBtu	kWh	kBtu			
Building 1	76,692	all-electric	141,721		1,509,680		9.4%	$13,506	$0.18
Building 2	103,024	all-electric	150,380		2,093,244		7.2%	$15,540	$0.15
Building 3	56,535	electric and gas		68,755		1,470,535	4.7%	$2,141	$0.04
Building 5	48,331	all-electric	144,224		880,238		16.4%	$13,283	$0.27
Building 6	103,500	all-electric	140,613		2,587,083		5.4%	$14,108	$0.14
Building 7	108,675	all-electric	240,540		971,155		24.8%	$27,958	$0.26
Building 8	89,165	all-electric	**Savings were not significant**						
Building 9	58,835	electric and gas		404,293		4,230,698	9.6%	$11,420	$0.19

Table 9. Overall Energy Savings and Cost Savings for the Buildings Evaluated.
The retrofit buildings generally under-performed energy savings expectations of 20- 30%; most by a large measure.
Source: Energy calculations by Wagner et al in 2014, within the context of parallel work with the subject REIT as funded by DOE (see acknowledgements). Added original analyses. Note: Buildings 4 and 10 were not part of this analysis.

Building	Total Savings			EEM Savings								Post-Retrofit Evaluation Period
				General Load Related				HVAC Load Related				
	kWh	kBtu	$ Savings	kWh	kBtu	% of Total Savings	$ Savings	kWh	kBtu	% of Total Savings	$ Savings	
Building 1	141,721		$13,506	68,026		48%	$6,483	73,695		52%	$7,023	Most Recent 12 Month Period; 1/19/2012 to 1/17/2013
Building 2	150,380		$15,540	34,587		23%	$3,574	115,793		77%	$11,966	Most Recent 12 Month Period; 1/23/2012 to 1/22/2013
Building 3		68,755	$2,141		56,404	82%	$1,489		12,351	18%	$652	Most Recent 12 Month Period; 8/9/2013 to 1/21/2014
Building 5	144,224		$13,283									11 Month, 1 Week; 3/4/2013 to 2/14/2014
Building 6	140,613		$14,108	95,193		68%	$9,551	45,421		32%	$4,557	Most Recent 12 Month Period; 4/20/2013 to 4/21/2014
Building 7	240,540		$27,958	113,304		47%	$13,064	127,236		53%	$14,894	6 Month Period; 9/4/2013 to 2/28/2014
Building 8	Savings were not significant											
Building 9		404,293	$11,420		387,934	96%	$10,054		16,359	4%	$1,366	10 Month Period; 4/11/2013 to 2/11/2014

Table 10. Disaggregation of Energy Savings by General and HVAC Loads.
This view helps to isolate energy savings results by technology – lighting (contained within the General Load category) and HVAC.
Source: Energy calculations by Wagner et al, 2014. Note: Buildings 4 and 10 were not part of this analysis.

While the report's authors state in several places that they are unable to offer explanations for these results, they do note that the following issues encountered during the M&V process may have had an impact: (Wagner et al p.2)

1. Irregular building usage during the pre-retrofit and/or post-retrofit periods. [*in other words, complex use structures, emphasis added*]
2. Difficulty in evaluating only one measure or ECM and not the conflation of multiple measures. For example, some ECMs depended on programming of a building's BAS system, which was done correctly for workweek periods, but may have inadvertently changed weekend scheduling. [*elements of use structure complexity*]
3. Limitations in data availability; in some cases only monthly energy consumption data was available for analysis, which can produce erroneous results. [*lack of observability*]. For example, disaggregated savings for Building 5 were not calculated by the authors as no pre-retrofit disaggregated data was available.

A quick explanation of the underlying calculations for Building 9, wherein the disaggregated savings appear to be severely weighted towards general load, is useful for illustrating the extent to which interpretation of building performance data depends on an understanding of behavioral issues. As it turned, out, gas savings were actually found to be -588 ccf, believed to be due to the fact that the outside air dampers were locked down into the minimum position (which probably meant the building was being under-ventilated), as discovered during the install of the DCV system. The outside air damper was then made operational, which had the impact of actually increasing natural gas use in the post-retrofit, while perhaps also increasing occupant comfort. On the electric side, the authors' analysis showed there was both GS and HVAC savings, but the electric HVAC savings were heavily masked by the negative natural gas savings (which were normalized to kBtu and combined). The result was that almost all of the savings occurred on the GS electric side – presumably, a result of more efficient lighting. (Source: email correspondence with Wagner). An additional puzzle related to energy savings in this building presented in the form of decreased energy use intensity in 2012 in parallel with increased building occupancy. As it turned out, in three tenanted spaces of this building large areas were vacant – a fact that the POE research team, myself included, was able to observe in a building walk-through and to document. However, this information was not known by our CBEI colleagues at the time they completed their building performance evaluation. To the extent to which energy analysis and behavioral study in buildings continue to exist in silos, incomplete understandings of building use structures and their performance characteristics result.

Chapter 7: Energy Retrofits in Tenanted Office Buildings

Introduction to the POE

The desired result of the retrofits was given as, “A successful program that maintains tenant comfort and proves significant energy savings, environmental savings, and operating expense reductions at an acceptable return on investment [that] could then become the model for existing buildings across the country.” (SGIG Application, op cit). The subject REIT was aware of potential pitfalls and alluded to a potential trade-off between the reduction of peak demand usage and tenant comfort, essentially constraining the former by the latter.

The primary objective of this POE was to determine user reaction and responses to the newly installed energy conservation measures (ECMs). Survey and interview instruments developed for this purpose incorporated usability as a major theme and included specific questions to ascertain user satisfaction, effort and self-relevant assessments of the effectiveness of the energy technologies. Depending on the question, the context was framed for the respondent as being either more proximate (personal workspace) or general (common areas, the office building), with differing timeframes for evaluation (i.e., at this moment, in the last year and points in between). A dedicated set of questions was employed to ascertain building occupant responses to building load shedding activities, in an attempt to locate the threshold at which building occupants notice temperature and/or lighting changes. These questions were administered as part of a series of surveys: a baseline survey, a daily survey (given on load shed and control days), and a follow-up survey employed in the first year of the POE only. Measured data was collected to help to characterize building IEQ, and physical trace observations of building occupant behavior also were recorded.

Description of Fieldwork and Collected Data

Between 2012 and 2013, I directed and participated in a research project of the Rutgers Center for Green Building that entailed collecting data from nine of the retrofit buildings (excluding the vacant one). In these settings, as a team of 2-5 researchers, we collected data through walk-through observations, semi-structured and also focused, intercept interviews, lighting and temperature measurements, photographs, archival data, and online surveys, of which some provide a longitudinal perspective. Where it was possible due to timing, data was collected in both pre- and post-retrofit contexts, including during load shedding trials and actual events. All buildings were visited one or more times between January 2012 and September 30, 2013.

Our fieldwork efforts were broken down into two phases, referred to in this section as Year 1 of the POE (2012), which roughly corresponds to the 1st year, or pilot phase of the retrofit program, and Year 2 of the POE (2013), which approximately corresponds to the 2nd and 3rd retrofit program phases. Correspondingly, a survey series was administered twice, once in Year 1 of the POE (2012) and again in Year 2 (2013). The chronological nature of this POE enables a dynamic understanding of how the quality of use experiences of the energy retrofits might have changed at various levels – individual, tenant, building, the REIT – including any evidence of organizational learning across the retrofit phases. These relationships and our building visits are depicted in Table 11, below.

Building	Retrofit Phase	Building Owner Pre-retrofit Survey 2011	Pre-retrofit Site Visit* 2012	Post-retrofit Site Visit 2012	Baseline (pre-load shedding) Survey 2012	Daily Load Shedding Surveys 2012	Follow-up Survey 2012	Post-retrofit Site Visit 2013	Baseline (pre-load shedding) Survey 2013	Daily Load Shedding Surveys 2013
1	1	X		X	X	X	X	X	X	X
2	1	X						X	X	X
3	2	X	X	X					X	X
4	2	X	X	X					X	X
5	2							X	X	X
6	2							X	X	X
7	3	X						X	X	X
8	3	X						X	X	X
9	3	X						X	X	X

Table 11. Roadmap of POE Phases and Data Activities.
While data collection activities were conducted in all 9 buildings, more data points were collected in Building 1 than any other building. In Buildings 3 and 4, five different measures were collected, whereas in the remaining buildings longitudinal collection consisted of 3-4 points during the same year.

In Year 1 (2012), 47 baseline, 287 daily and 33 follow-up surveys were collected from a building in the first (pilot) phase of the retrofit program, and 2 additional buildings scheduled to be retrofit in Phase 2 were visited for pre-retrofit interviews and observations. In Year 2 of the POE (2013), 81 baselines and 554 daily surveys were collected from 9 buildings. Over the course of the two years, interviews were conducted with 27 tenants and more than 100 intercept interviews were completed in tenanted suites within the nine buildings.

Other data activities included periodic review of archival data (timelines, building plans, building performance specs etc.) and my bi-weekly participation in team-based project calls led by the REIT. A number of manuscripts have been developed drawing on aspects of these data, although none have been published formally. In the following pages, I draw on these data, adding to them with the inclusion of additional data and analyses, and interpret them in a unique manner.

Senick, J.A., R.E. Wener, I. Feygina, M. Sorensen Allacci, and C.J. Andrews. 2013. *Occupant Behavior in Response to Energy-Saving Retrofits and Operations*. Prepared by the Center for Green Building at Rutgers University for the Energy Efficient Buildings Hub, Philadelphia, PA.

Senick, J.A., M. Sorensen Allacci, R.E. Wener, C.J. Andrews, D. Plotnik, P. Shinde, and S. Malenchak. 2013. *Post-Retrofit Assessment of Lighting & HVAC Conditions in Three Tenanted Buildings- Liberty – PECO Smart Grid Investment Grant Program*. Prepared by the Center for Green Building at Rutgers University for the Energy Efficient Buildings Hub, Philadelphia, PA.

Malenchak, S., Sorensen Allacci, M., and Andrews, C.J. 2014. *Preliminary experimental evaluations of occupant behavior during load shedding*. Prepared by the Center for Green Building at Rutgers University for the Energy Efficient Buildings Hub, Philadelphia, PA.

Rutgers Center for Green Building, 2014. Advanced Energy Retrofits (AER) Evaluation and Recommendations.

Overview of Findings

The POE produced a number of lighting and HVAC quality of use findings that are consistent with earlier presented predictions of organizational and use-oriented behavior. In spite of disappointing energy savings results, occupants' average ratings of lighting, air quality (related to HVAC function) and overall satisfaction with the buildings across the three retrofit phases distinctly improved. This is an interesting result for a program that was aimed primarily at energy savings. Although the sample size is small, these results achieved statistical significance (Figure 5). Not only were occupants more satisfied with lighting and thermal comfort outcomes (a measure of effectiveness), less effort (a measure of efficiency) to achieve these results was reported in interviews of office managers and others whose spaces were retrofit in the 3rd phase.

These results I attribute, at least in part, to in-field adjustments in communications protocols and vendor contracting changes made by the REIT across retrofit phases, a dimension of organizational learning that took place. Among these was a change the REIT instituted following the Phase 1 retrofits to facilitate more return visits by vendors for adjustments to the newly installed technologies. As well, relatively better energy performance in select buildings appears to have occurred as a result of greater documented collaboration between the REITs' property manager(s) and tenants on establishing compatibility in workplace organization and the implementation of lighting and, less often, HVAC designs.

Building occupant experiences with load shedding gave perhaps the brightest result of the study, while highlighting how the building owner's increased familiarity with the Energy Management/Smart Metering system (one of the installed innovations) contributed to positive quality of use results. Mostly, building occupants did not notice load shedding activities, were more thermally comfortable during them, and/or were supportive of the need for them. These findings held across almost all buildings and tenanted spaces.

Overall, this POE serves to illustrate the challenge of managing energy use in multi-tenanted. The diversity of sub-cases and results further highlights the mediating role of organizational context, especially such factors as the organization of workspace, familiarity with innovations and the extent to which knowledge of an innovative technology is shared laterally and hierarchically within workplaces and the building eco-system that includes also property managers and service vendors.

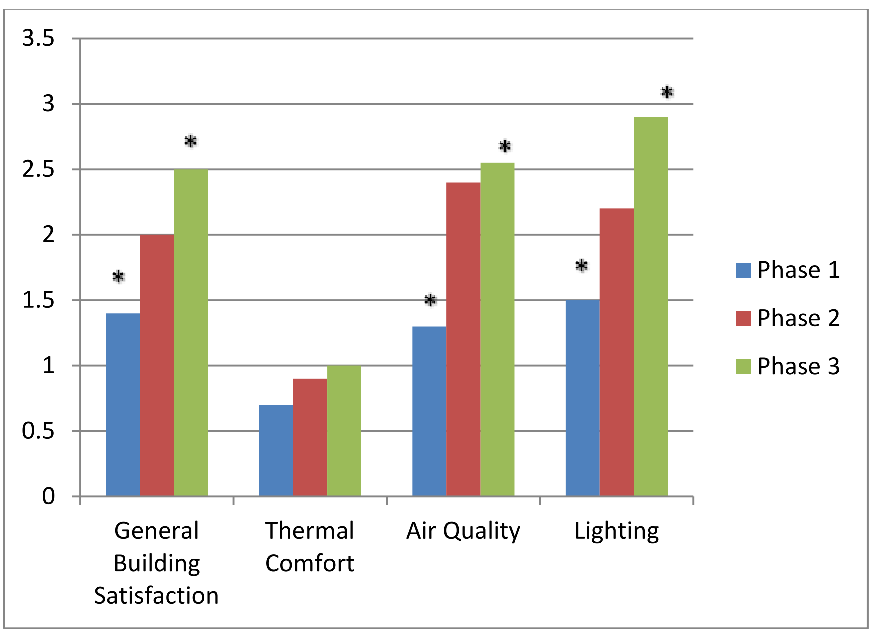


Figure 5. Occupant Satisfaction Across Phases (2012-2013) Evidencing Significant Increases in Lighting, Air Quality and General Satisfaction among Building Occupants. 7-point Likert scale, baseline survey data for all buildings. [1]n ranges from 42-45 between the variables; [2]n ranges from 8 to 9; [3]n ranges from 21 to 25. *Denotes significance at the 5% level.
Chart source: Rutgers Center for Green Building (Rich Wener, Steve Malenchek).

Chapter 8: Pre-retrofit Context and Usability

During the first year of the POE, in February 2012, our team conducted a pre-retrofit baseline assessment of HVAC and lighting conditions in two buildings that were scheduled for the 2nd phase of the retrofit program (Buildings 3 & 4). During the pre-retrofit evaluations of these buildings, we collected data in a subset of all office spaces. We aggregated comments from interviews and observations for each building and evaluated these for common themes or topics. A complicating factor in this pre-retrofit evaluation was that in some office suites aspects of the retrofits had already taken place, more so regarding HVAC than lighting. In the cases where the retrofits had occurred or were occurring, the early experiences with these changes were observed and recorded.

Additional supporting data regarding pre-retrofit context and HVAC and lighting usability in these and five additional buildings is gleaned from the building owner's brief pre-retrofit on-line survey of these properties. For Buildings 3 & 4, these results are integrated into our on-site findings. For the remaining five buildings, key results of the REIT's own pre-retrofit survey are presented in a separate section. These data collection activities are depicted in Figure 6.

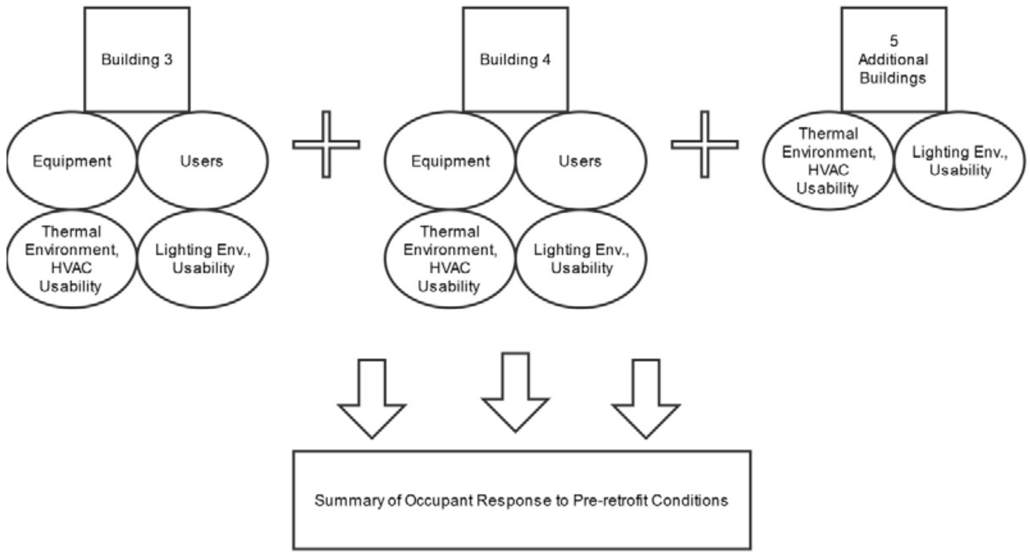


Figure 6. Flowchart of Data Collection Activities in Chapter 8: Pre-retrofit Context and Usability.

Building 3 Pre-retrofit Evaluation

Building 3. Equipment

By the time of our visit, new Variable Air Volume (VAV) boxes had replaced Constant Volume (CV) boxes in the air distribution system in the largest, sub metered office. New controls would be added in the upcoming phase of work. Lighting fixtures had been retrofit in this suite, although controls were just going live. In the upcoming phase of work, HVAC fan motors would be replaced with Variable Frequency Drives (VFDs), Lutron IP addressable dimmable ballasts with integrated daylight and occupancy sensors would be extended to additional tenants, and controls for both lighting and HVAC would be implemented and re/commissioned as necessary, including so as to facilitate eventual load shedding.

Building 3.Users

At the time of our pre-retrofit evaluation, nine tenants occupied Building 3, including a government and lab/clinical office that were excluded from the study by the

REIT. Of these, a sample of 5 tenants (3A-E) was engaged for pre-retrofit baseline assessment. The largest tenant that we met with was sub metered, such that a direct correspondence between energy use and its cost theoretically is established. The other tenant representatives we spoke with were aware that they did not pay the electricity bill directly, and were unaware of any (observable) measure of their electricity use.

In the literature chapter, a potential relationship was posited between ‘green’ knowledge/sustainability values and quality of use. As to whether sustainability values might influence attitudes towards the retrofits, none of the tenants we visited reported having a comprehensive company sustainability policy. Some mentioned recycling and/or use of washable dishes and utensils. One office manager of a very sparsely populated (satellite) office reported turning down thermostats when a room was unoccupied and that computers were turned off at night.

With one exception, the tenants we visited were on the small side, so face-to-face interviewing provided a very high degree of coverage. We conducted an interview of either the office manager or another tenant representative and visited 29 individual workspaces or locations throughout the building -- perimeter (15) and core locations (14), enclosed offices (14), circulation areas (2), common spaces (9), and cubicles (4).

Building 3. Thermal Environment and HVAC Usability

According to the REIT’s pre-retrofit survey conducted just prior to our visits in early February, 2012, the majority of respondents (74% , n=17) felt that overall temperature comfort in Building 3 “could be better or was terrible”. A noteworthy 91%

of respondents (n=20) found the temperature to be too cold in winter; 47% (n=8) found winter conditions to be too dry.

During our February 15, 2012 visit, Building 3 occupants reported variable thermal conditions by time of day, day of week and location within the building – e.g., “it is always TOO COLD, TOO HOT”, “the temperature in the office fluctuates greatly for different parts of the office area” – and also expressed dissatisfaction with the Monday am start-up sequence and temperature variability during the shoulder-seasons (Spring, Fall). We were told that thermostats were limited in their usefulness (effectiveness) – e.g., “sometimes…it seems to be responsive” -- and learned that building occupants responded through a range of adaptive behaviors (effort). These included personal strategies (e.g., dressing in layers), managing blinds to block heat gain, posting notes to other building users regarding proper or, at least, desired thermostatic use, contacting management, and using portable heaters and fans.

Some of these strategies have greater implications for energy use than others, while others may require more significant effort including negotiation with co-workers. The frequency with which occupants find it necessary to engage these strategies (efficiency) may have impacts on their levels of satisfaction with buildings environmental conditions. In some cases, adaptive strategies failed to work to achieve satisfaction, as portrayed in this quotation, “[I] keep dressing wrong based as guesses [about] likely temperature. …dress in layers. ...thermostat is far away [and has] little effect.”

In one office we visited (3A), all occupants wore jackets (the outside temperature this day was 43°F, skies were overcast). In this same office, the manager kept the thermostat literally hidden behind a heavy file cabinet so that others would not adjust it.

On the day we visited, it was set to 80°F, although the office did not feel warm. From Tenant 3C, we learned that it had simply assumed the fit-out arrangement that was left behind by a prior tenant as the company had “moved in on a shoestring” budget. While this person was aware of potential disagreements between workspaces and HVAC vents and lighting fixtures, investing in a fix was not in the cards.

In the sub metered office (3B), the thermostat for controlling a conference room and private office was located in the women’s restroom, along with a note to stop turning it off. This particular office suite, with 30 employees, had been re-partitioned several times and its layout was sufficiently incoherent that we became disoriented while taking measurements and conducting intercept interviews. The compatibility of fixture locations and workspaces was not optimal and HVAC zoning was unclear. Although the company officer we interviewed was vaguely aware of the monthly electricity bill, she was not particularly concerned about it.

Of 29 workspaces we visited throughout the building, we were able to access 6 thermostats that showed temperature settings between 72^0 and 80^0 F. Most of the thermostats we saw had very few affordances, offering only choices of - ‘on/off’ or ‘c(ool)/w(arm).’ We subsequently learned from the property manager that the “man in the house” setting (present on some of the on/off types) had been disabled in favor of centralized controls. He also informed us that the offset for the thermostats had been programmed to 6 degrees from 68F, meaning they permitted a range in temperature from 62-76^0 F, which at least one building occupant reported was “more than adequate”.

Apparently, HVAC settings were not known to the vast majority of office occupants we encountered, who like the office manager of 3A attempted to set the thermostat at its highest (warmest) setting whether this meant “W” or in excess of 76^0 F. In our walk-throughs we encountered numerous portable heaters, including in the sub metered space. The property manager told us he was surprised at the extent of space heating use, as represented by the REIT’s pre-retrofit survey; 52% of respondents (n=11) used a space heater in their workspace in the last 12 months, 33% (n=7) had worn a blanket or gloves, 24% (n=5) had used a portable fan and 19% (n=4) had done nothing. He took these results as an indication that better communication about thermal comfort and how to achieve it was needed between him and designated tenant representatives. However, he also pointed out the difficulty inherent in a communications strategy that relies on a singular point-of-contact who may not share information with office co-workers, a challenge that we also experienced in our data collection efforts.

The tenants we met with praised their landlord and were generally satisfied with service vendors’ responses to reported HVAC problems, even if repeat visits were sometimes necessary (5 during the winter of 2012 in the sub metered suite).

Building 3. Lighting Environment and Usability

Based on the REIT’s pre-retrofit survey, occupants found lighting to be “fine”, and had few or “no complaints”. Seventy percent (n=16) of Building 3 respondents rated the overall lighting condition in their work area as just right. During our team’s pre-retrofit visit, we conducted lighting measurements and observations in each of the 29 workspace settings. We found varied lighting conditions with levels in enclosed offices ranges from 200 to 800 lux, in circulation spaces from 100 to 1150 lux and in cubicles and open ‘bull pen’ settings from 260-720 lux. Illuminance in common spaces (e.g., conference rooms) adhered to a more narrow range, between 650 and 704 lux; general recommendations for desk work surface lighting are 400-500 lux and are dependent on the task to be performed (Newsham, Veitch, Reinhart and Sander, 2004; also, the 2011 IES Lighting Handbook). Of the 29 spaces, 6 had task lighting. Four of these task lights were on while 2 were off at the time of our visit.

While occupants generally reported to us that they were satisfied with lighting conditions in the pre-retrofit spaces – e.g., "fine", "adequate", kind of acceptable" -- some found lighting to be overly bright and there were reported instances of glare. Several occupants operated blinds when available and on occasion responded by removing or covering bulbs. One tenant was very specific about how lighting was "not situated properly over cubes" and further called the lighting design "hodegepodge". In the physically larger sub metered suite, where the sensor controls had recently begun to operate, reaction was mixed. Occupancy sensors were either too sensitive or insensitive to movement and seemingly never just right, meaning that their effectiveness for these respondents was low. Whereas executives in private offices had retained their light switches, and were more satisfied with ability to control lighting conditions, occupants in cubicle settings or smaller core private offices found themselves at the mercy of adjacent or strolling coworkers who triggered the sensors. Nor did they did not have PC control over lighting levels or seem to know who if anybody had this control. Conversely, in a different suite the office manager claimed to have learned only recently about the impending lighting retrofits and was aware of the online controllability feature.

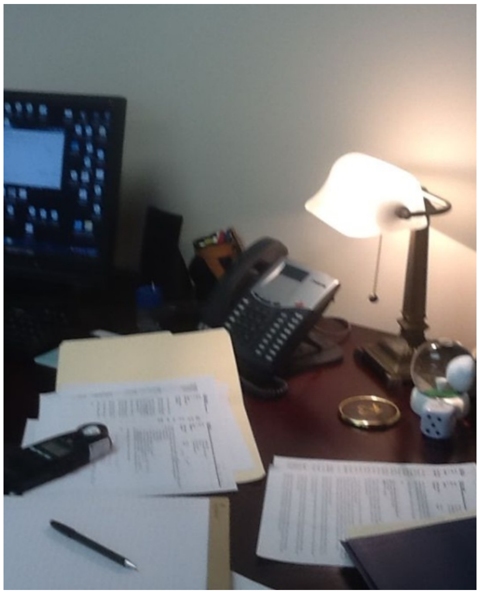


Figure 7. Task Light On, Overhead Light Off.
In modeled projections, this combination is the most energy efficient and may also produce satisfactory results.
Source: Rutgers Center for Green Building Photo Archive

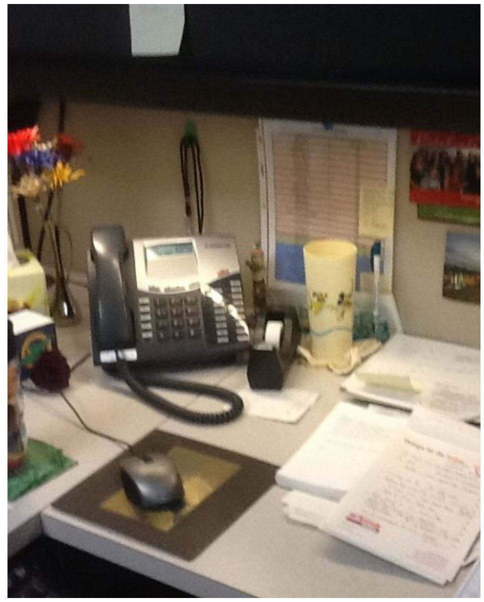


Figure 8. Under cabinet Lighting with Overhead Light Off.
In modeled projections, this combination is the most energy efficient and may also produce satisfactory results.
Source: Rutgers Center for Green Building Photo Archive

Figure 9. Misalignment of High Cubicles and Lighting Fixtures.
This arrangement is less efficient and effective and likely less satisfactory to office occupants.
Source: Rutgers Center for Green Building Photo Archive

Figure 10. Blinds in Drawn Position with Louvers Partially Open.
These allow both privacy and lighting. The operation of shades and blinds in office settings is often overlooked as a valuable and mediating user adaptation to environmental conditions.
Source: Rutgers Center for Green Building Photo Archive

Figure 11. On/off "Man in the House Thermostat Type.
This interface is meant to afford on/off and also variable temperature settings.
Source: Rutgers Center for Green Building Photo Archive

Figure 12. Unclear Locus of Control/Social Negotiation of Thermal Comfort.
This sign was posted in a womens' bathroom that was zoned with adjacent workspace.
Source: Rutgers Center for Green Building Photo Archive

Figure 13. "What Temperature is C?"
This thermostat type has few affordances or conceptual models to guide occupants as to its use.
Source: Rutgers Center for Green Building Photo Archive

Figure 14. "Don't Touch the Themostat!"
As in many office settings, use of this thermostat is off limits to building occupants.
Source: Rutgers Center for Green Building Photo Archive

Building 4 Pre-retrofit Evaluation

Building 4. Equipment

The scheduled retrofits to Building 4 were nearly identical to those for Building 3. HVAC improvements were to include added controls and CO2 sensors (variable speed drives had been added under a separate project) and the conversion of lighting ballasts to the Lutron IP addressable dimmable ones with associated daylighting and occupancy sensors, along with new lighting control zones for the lobby and exterior of the building. All would be connected through a building wide area network (BWAN) to support load shedding and so-called smart metering generally. Compared to Building 3, Building 4 entered this process with poorer energy performance. Its ENERGY STAR Portfolio Manager score was 64 versus 74. In other words, Building 4 ranked at the 64th percentile of a peer group whereas Building 3 ranked higher/better in the 74th percentile.

Building 4. Users

At the time of our initial engagement, Building 4 housed 10 tenants, although at least 1 was on its way out and there was generally high turnover in the rent roll between 2012-2014. Building 4 tenants also were on the smaller side (4-30) and, on any given day, few employees were on site. Also, the entire 3rd floor of the building was empty, along with other vacant pockets and much under-utilized space.

In February 2012, we visited 6 offices in Building 4. As with Building 3, we met with the property manager on-site and again later at a nearby office of the REIT for an opportunity to go over the planned retrofits in more detail. This particular PM had been on the job for only 6 weeks and so was just coming up to speed himself. He characterized the retrofit program as intended for electricity demand peak shaving (load shedding) rather than, for example, comfort improvement.

Most Building 4 occupants we interviewed were aware of the upcoming retrofits. Some had attended a recent on-site meeting about the upcoming changes, which had included an opportunity to preview the new lighting fixtures. However, their recollections about the details varied on matters such as how much control individual occupants would have over new systems. At least one tenant expected the retrofits to result in greater HVAC control, "being able to adjust will be great; now we have to call." Building occupants generally were positive about their communications with the building owner and associated service calls – "24 hours service is excellent" at the same time noting that "calling someone is inconvenient – there is a wait time." None of the tenants we interviewed in Building 4 reported having a company sustainability policy. One noted that the building owner did not offer a recycling service.

The 31 workspaces we observed included enclosed offices (15), circulation areas (2), common space (12), and cubicles (2). Seventeen (17) of these were located on the perimeter of the buildings, and 14 were located in the core.

Building 4. Thermal Environment and HVAC Usability

Pursuant to the REIT's pre-retrofit survey of Building 4, 50% of respondents (n=5) were dissatisfied with temperature comfort in their work area; 78% (n=7) were too cold in winter and 56% (n=5) found the air too dry. Building 4 occupants indicated similarly variable thermal comfort conditions to our team. While some interviewees found conditions comfortable – e.g., "it is cool now; I prefer it cooler than hot", others were frustrated by fluctuating temperatures – e.g., “in the dead of winter it gets hot, turn down the heat and the vents blast cold air”, and overly cool temperatures – e.g., “gets extremely cold.” The use of both portable heaters and fans was common, and several people reported frequent donning of sweaters, coats, hats and boots in the office to increase comfort. More than one respondent noted that in some cases air blowers would not shut off, and in one office reports of draftiness was a dominant theme – “especially by windows”, “awful drafts in office down hall.” On the day of our site visit some thermostats were set at the highest level, in conditions that we experienced as quite cool. Some interviewees told us that thermostats were not connected/operational.

Thermostats were typically few in number (i.e., 2) per office suite and offered only ‘on-off’ or ‘c(old)-h(ot)’ options. In several instances, interviewees did not know where thermostats that controlled their office temperature were located or if they even existed. In the suite of Tenant 4A, we searched together for the thermostat and eventually found it, set to the top of the range marked “warm”. Similarly, a representative of Tenant 4B, who had been in the space since 2009, told that she was not sure where the thermostat was located, that she “never dealt with it”. In both of these cases, the office manager did not demonstrate particular interest in playing a role in managing thermal comfort nor much knowledge thereof.

Building 4. Lighting Environment and Usability

Building 4 occupants reported a high degree of satisfaction with pre-retrofit lighting conditions. According to the REIT’s pre-retrofit survey, 70% of respondents rated the overall lighting condition in their work area as just right (n=7). This was the same percentage as in Building 3, but based on a smaller sample size.

When we asked respondents about lighting, building occupants typically responded that it was "fine." Some added that there were spaces that were over-lit; the recently renovated lobby was mentioned a few times (according to our measurements, 1100 lux). Of their workspaces, respondents noted some problems with computer screen glare and several also indicated that work station location and lighting fixtures often were misaligned, leading to under-lit desktop conditions. Of the 31 spaces, we observed that all of the lights were "on" in 24 of them. Some of the corridor or common spaces we visited appeared to be over-lit with multiple fixtures illuminating areas in which there would typically not be intense work activity or reading. The light switches for some of these areas were tied into lighting for cubicles and could not be switched off separately.

Pre-retrofit Conditions and Usability in Five Additional Buildings

Pre-retrofit conditions and HVAC and lighting usability in five additional buildings that eventually underwent the same or very similar energy efficiency retrofits were characterized by the REIT's pre-retrofit survey. As our team did not visit or interview at these buildings during this phase, this analysis relies on the REIT's data as presented below and as confirmed, in some cases, in discussions with REIT employees. In January 2011, the REIT conducted the survey in Buildings 1 and 2. These buildings comprised the first phase of retrofits, considered by the REIT to be a pilot of the retrofit program. In February 2013, Buildings 7-9 were surveyed by the REIT, prior to the 3rd phase of scheduled retrofits. No surveys are available for Buildings 5 and 6 and results of this survey for Buildings 3 and 4 were reported in the sections just above.

Five Additional Buildings. Thermal Environment and HVAC Usability

As with Buildings 3 and 4, thermal discomfort continued to be a primary theme as can be seen in Figure 20. Seasonal issues also were a dominant theme. The most commonly reported seasonal condition was that temperatures were too cold in the winter, although many also found their buildings to be too cold in the summer. Building 1 occupants, in particular, offered a large number of written comments at the conclusion of the survey about thermal comfort. There were comments about the complexity of thermostatic controls ("nonfunctional sometimes"), the noise of the HVAC system, and the need for separate zones for the perimeter south facing offices. In response to thermal discomfort, building occupants employed a variety of adaptive strategies. In Building 2, space heater usage was reportedly very low (n=7, 5%), although blankets and/or gloves were reportedly worn by 24% of respondents (n=37). Building 9 was similar in this regard in that few people used a space heater (n=3, 10%), while 23% (n=7) wore blankets/gloves. In other buildings the use of portable heaters was greater – e.g., in Building 1, 13% (n=14) used a space heater while in Building 8 16% (n=7) did.

Five Additional Buildings. Lighting Environment and Usability

Regarding pre-retrofit lighting conditions and their usability, building occupants in these five buildings often were satisfied with lighting conditions, although considerable numbers also were dissatisfied to varying degrees (Figure 21). Moreover, respondents often found lighting to be either too bright or too dim (Figure 22).

Generally, task light usage was low -- e.g., 80% (n=36) of respondents in Building 8 reported never using one and 75% (n=24) of respondents in Building 9 never used one either. In Buildings 1, 2, and 7, task use lighting was higher with 41% (n=46), 50% (n=79) and 42% (n=33), respectively, always or sometimes using one.

Respondents' comments about lighting included the desire for a lower lighting setting, fewer lighting fixtures or bulbs, dislike of direct fluorescent lighting and a corresponding desire for reflected light, and an assertion that more light switches could result in more energy saved. A number of usability challenges related to zoning control were given through more extensive descriptions as in the following two examples.

> "My cube is on the west side of the build second floor). I sit with my back to the windows. I have to ask for the blinds to be put down at 4PM because the sun streams in and I can't see the monitor on my desk. The issue is that the person who I have to ask sits in the next aisle over against the window."
> "Reason for answers to #5&6. Work by task light at night. Would be nice if you could turn lights on for a few rows vs. whole building when applicable." (Building 2 respondent)

> "It would be nice if the lighting was controlled by zoned dimmer switches in the main areas, so lighting could be controlled that way rather than the need to pull out tubes. (Building 7 respondent)

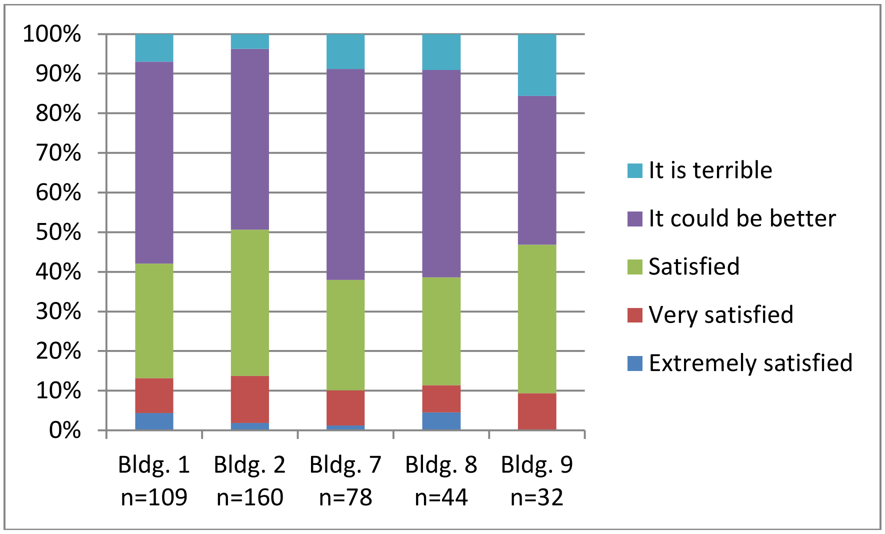


Figure 15. Comparison of 5 Buildings Thermal Satisfaction.
In all buildings, at least half of respondents are dissatisfied. Source: REIT Pre-retrofit survey.

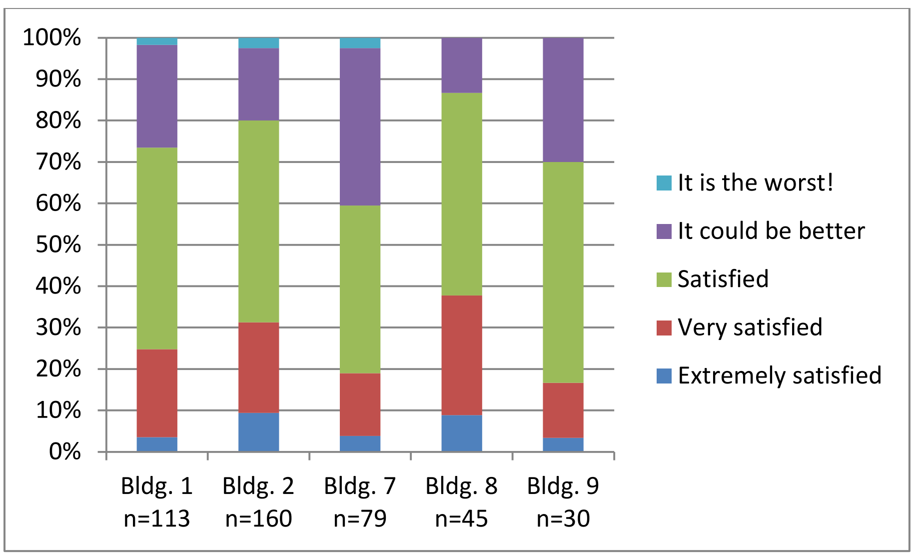


Figure 16. Comparison of 5 Buildings Lighting Satisfaction.
In all buildings, a majority of respondents are satisfied with lighting. Source: REIT Pre-retrofit survey.

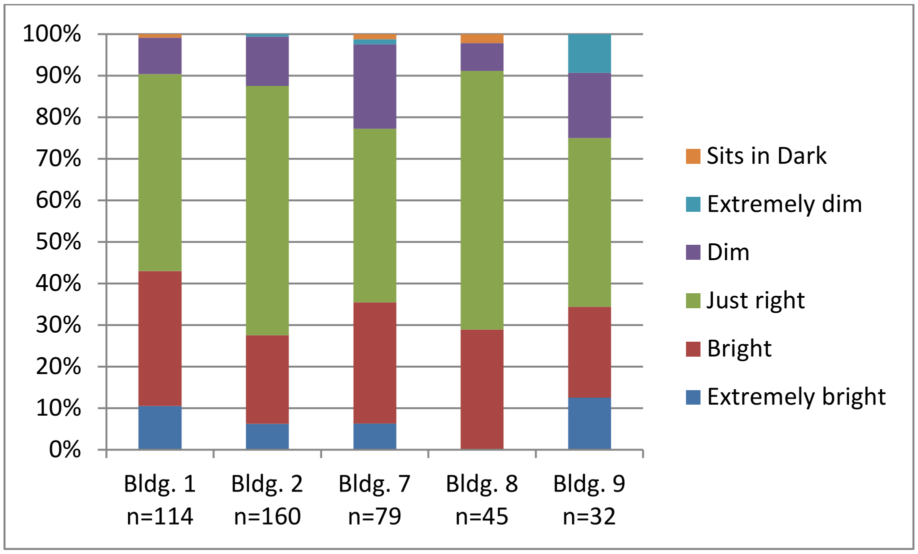


Figure 17. Comparison of 5 Buildings Lighting Conditions.
Most respondents find lighting conditions to be just right, although many also find them to be overly bright and in fewer cases overly dim.
Source: REIT Pre-retrofit survey.

Summary of Occupant Response to Pre-retrofit Conditions

The dominant theme that emerged from our assessment of pre-retrofit conditions was thermal discomfort. This was the case across all buildings considered, including those in which some HVAC-related measures already had been installed. However, HVAC retro-commissioning measures were on-going – e.g., re-balancing and program scheduling controls work, as is typical in a retro-commissioning phase. It would be reasonable to expect more predictable thermal conditions in the future, leading to efficiency, effectiveness and satisfaction gains. Conversely, occupant satisfaction with lighting, while varied, was not overly problematic. In this sense, the lighting retrofits risked existing levels of occupant satisfaction in the pursuit of greater lighting efficiency and effectiveness.

Usability themes that emerged from our fieldwork in Buildings 3 and 4, and which also were evident in the REIT's pre-retrofit survey, centered on the detrimental influence on user-technology interactions of an unclear mapping of technology function to use structures. One recurrent situation was found in HVAC zoning and control. There were several cases in which building occupants did not know what physical areas a thermostat controlled (or if it worked). Also, thermostatic control was sometimes contentious requiring various forms of social negotiation among building occupants. In some cases, occupants were unwilling to approach another occupant with thermostatic control (typically a supervisor) to request an adjustment. Occupants also were unhappy with building environmental conditions during "off" hours such as in the case of working late or on weekends. While tenants generally have the ability to request additional heating or cooling during off hours, for a charge, the lack of individual zoning control for both the retrofit lighting and HVAC technologies tended to result in one of two situations: the entire suite or large portions of it being “on” for 1-2 occupants, or occupants foregoing heating/cooling. This situation exemplifies how work schedules, along with locations for work, have become more complex and variable than is technology flexible.

Another contextual issue relates to use of blinds, employed not only for glare control but frequently also for hiding unwanted views and for helping to ensure privacy. Window tinting served this dual purpose as well, although it also may have resulted in overly dim conditions in some offices. Occupants’ use of shades and blinds, especially for privacy purposes, raises the concern that occupant comfort behavior and expected energy savings from the lighting retrofit might be oppositional.

An additional compatibility factor, we observed physical disagreement in several office suites between the organization of workspace and the locations of lighting fixtures, which generally were not slated to be relocated during the impending retrofit. Failure to address such disagreement potentially results in sub optimal use conditions. Collectively, these pre-retrofit conditions draw our attention to the importance of several innovation factors – i.e., observability, compatibility and also the complexity of use structures in tenanted office settings (Table 11).

	Relative Advantage	**Trialability**	**Observability**	**Complexity/ Simplicity**	**Compatibility**
HVAC			**Area of Concern**	**Area of Concern**	**Area of Concern**
Lighting				**Area of Concern**	**Area of Concern**

Table 12. Pre-retrofit Conditions, Areas of Concern in HVAC and Lighting Usability in Relation to Use Structures.

Chapter 9: Post-retrofit Usability Evaluation of Three Buildings

In order to assess building occupants' initial experiences with the energy retrofits, our team visited three retrofit buildings in December 2012 -- Buildings 1, 3 and 4. In addition to interview and observational data collected during these visits, the Building 1 post-retrofit evaluation additionally included the deployment of a survey series comprising a baseline survey, brief daily load shedding surveys and a follow-up survey. Baseline and daily surveys would be later engaged in all nine buildings, in 2013, once their load shedding abilities as tied to the EMS/smart metering systems came fully on-line. The follow-up survey was dropped, not because it wasn't useful but because requesting participants to endure a 2nd 20-30 minute survey, mirroring the baseline, was not realistic, and because we were able to evaluate key hypothesized relationships based on the baseline and daily survey series. Figure 18 depicts these data collection activities in a flowchart paralleling the development of data in this chapter.

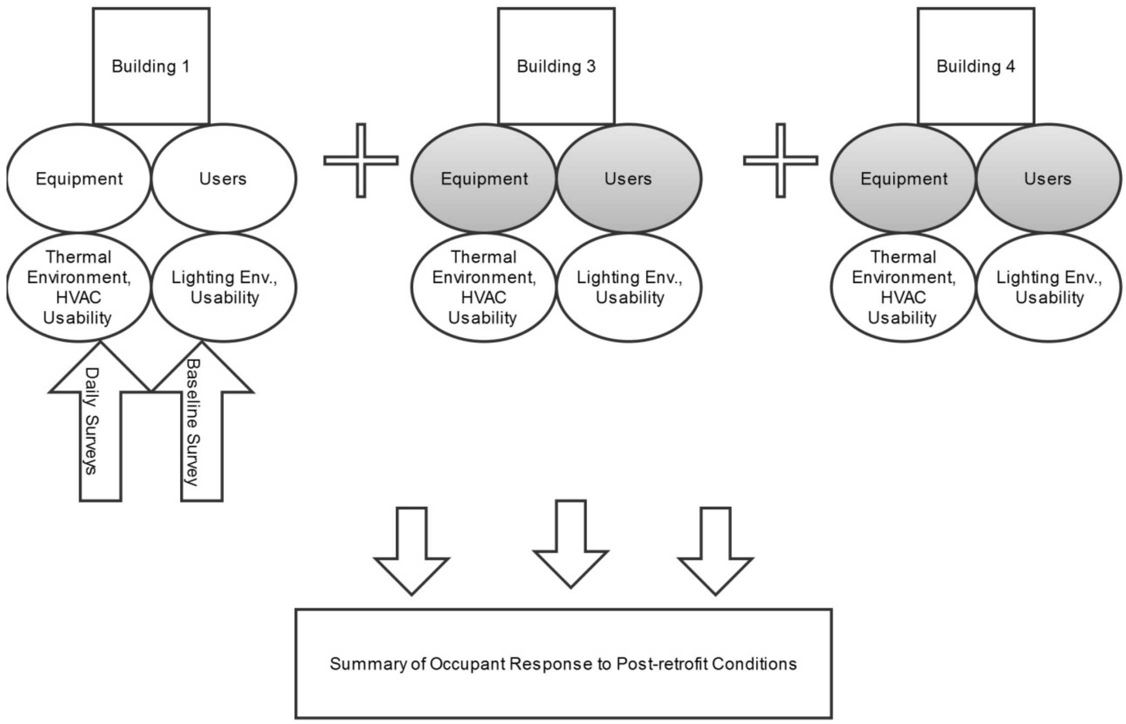


Figure 18. Flowchart of Data Collection Activities in Chapter 9; Post-retrofit Usability Evaluation of Three Buildings.

Work on the HVAC and lighting retrofits had been completed in all three buildings by the time of the follow-up site visits. As previously noted, the HVAC program included the addition of Variable Frequency Drives, controls work and rebalancing measures as a result of prior retro-commissioning reports. The lighting retrofit program included ballast replacement (to enable dimming), new fixtures in some office spaces, the installation of integrated occupancy, dimming and daylight sensor systems, and corresponding removal of most light switches.

As with the pre-retrofit site visits, post-retrofit data were collected in a subset of office spaces. During these visits, we took lighting measurements and added temperature and humidity readings to our measurement protocol for all buildings.

Building 1 Post-retrofit Evaluation

Building 1. Equipment

The energy retrofits to Building 1 consisted of HVAC improvements -- an upgrade of existing Trane controls, added CO2 sensors, the replacement of 2 roof top unit variable speed fans, and lighting improvements – conversion of ballasts to enable dimming capabilities, installation of occupancy and daylight sensors, and the addition of some additional lighting zones. Considered but not implemented was the installation of auto shades, which would go up/down based on measured daylight. Also, in Building 1 as in all 9 retrofit buildings, metered tie-ins to the Building Wide Area Network were made so as to facilitate load shedding.

Building 1. Users

At the time of our engagement, Building 1 was occupied by a single tenant and had 227 on-site employees. Due to the recent departure of a 2nd tenant, the remaining one (Tenant 1A) was in the process of occupying additional space on the 2nd floor so as to eventually fully occupy all 3 floors. In so doing, the tenant was reconfiguring the vacated space contemporaneously with an on-going effort by the REIT to improve occupants' post-retrofit experiences.

In Building 1, a lengthy period of adjustment had ensued prior to our involvement. During this time, the REIT issued a number of change orders to contractors to extend their services in the building and agreed to re-install light switches in some private offices and conference rooms. The adjustment experience in Building 1 also differed from the other two buildings in the resources provided by the remaining tenant to help oversee the retrofit program. In particular, Tenant 1A, an engineering firm, had on staff a dedicated sustainability/building engineer who became deeply involved in reporting and also helping to address needed adjustments. Rank-and-file employees in Building 1 also were interested and actively engaged in the retrofit process.

Although we were unable to visit this tenant on a pre-retrofit basis, the REIT's pre-retrofit survey from January 2011 offered insight into quality of use experiences with the pre-existing HVAC and lighting systems, as reported in Chapter 8. Recall that many Building 1 respondents to this survey were dissatisfied with temperature; in particular, they found conditions to be too cold in both winter and summer (62% and 52%). Lighting satisfaction was fairly well distributed, but still 43% found lighting conditions to be bright or extremely bright as opposed to just right or dim. Some building occupants reported dissatisfaction with the existing location and function of thermostats and the on/off nature of large banks of lights and thermal zones for weekend work. The retrofits (and an extensive period of retrofit commissioning by the REIT and its contractors) presented an opportunity to try and address at least some quality of use issues.

In advance of our site work at Building 1, we sought to characterize post-retrofit conditions through a building-wide survey we administered to building occupants prior to the start of load shedding activities. The baseline survey was administered between September 21 and October 1, 2012, took approximately 15 minutes to complete, and included questions relating to building environment satisfaction, control over environmental factors in the workplace, adaptive behaviors and perceived productivity and overall job satisfaction in addition to demographic questions.

The baseline survey further served as a point of comparison for building occupants' reactions and responses to environmental conditions during subsequent load shedding trials, orchestrated by the REIT as six load shedding events/days and control days. The load shedding surveys we administered took a few minutes to complete and were given in both the AM and PM on the specified days. Although load shedding is more typically engaged during the summer months, during the Fall of 2012 the REIT experimented with load shedding events in the two Phase 1 buildings (Building 1 and Building 2). During some of the load shedding and/or control days, our team was on-site to gather interview, observational and measured data. At the end of the load shedding test period, a follow-up survey was administered. These data are reported below in the order in which they were drawn, beginning with the baseline survey and culminating with our on-site work.

Building1. Fall-Winter 2012 Baseline Survey Results

Forty-seven (47) Building 1 employees participated in the baseline survey during the Fall of 2012. Mostly these participants served in professional and technical (85%) positions, worked full-time (94%), and been with the organization for at least three years (67%). About a third had been there for more than 10 years. Respondents' locations throughout the building represented a fairly even distribution among exposures with the southwest less well represented. Approximately half of the survey respondents (51%) sat next to a window, while just over 40% occupied a private office, with the balance distributed among various types of cubicles – individual, shared, with high and low partitions. Three people reported working in an open plan setting or public workspace. Many (45%) had occupied the same workspace for at least three years.

Satisfaction with Environmental Conditions

Building 1 occupants, on average, rated temperature and privacy of workspace lower than other workplace environmental conditions. (Figure 23). Even lower, were ratings regarding the ease of use of building HVAC and lighting systems, particularly for electric lighting (Figure 24). Occupancy sensors performed the worst according to building users, which was not surprising given what we had learned from the building owner about an extensive period of such difficulties.

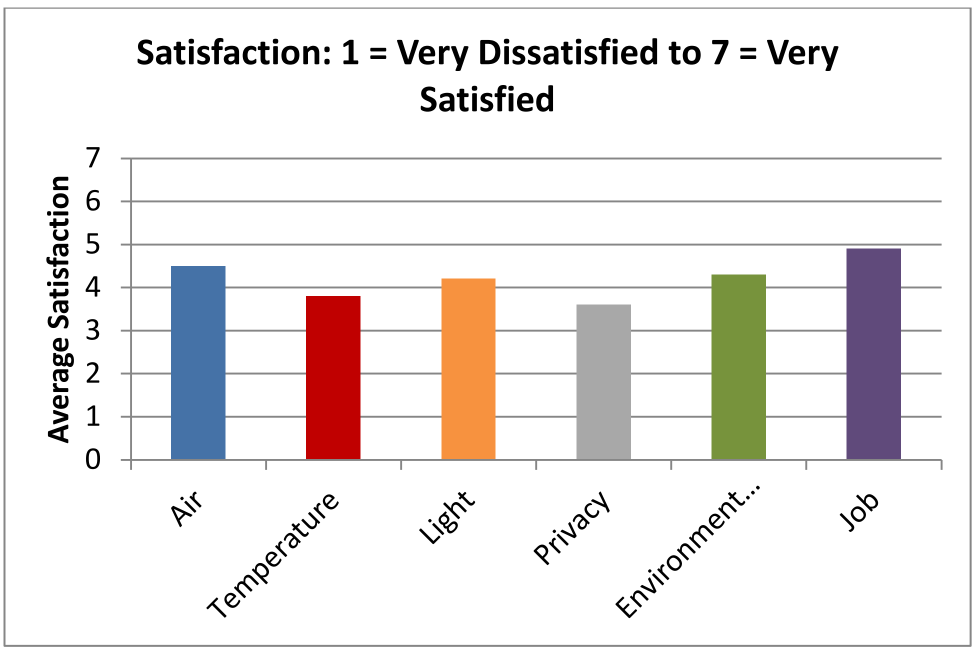
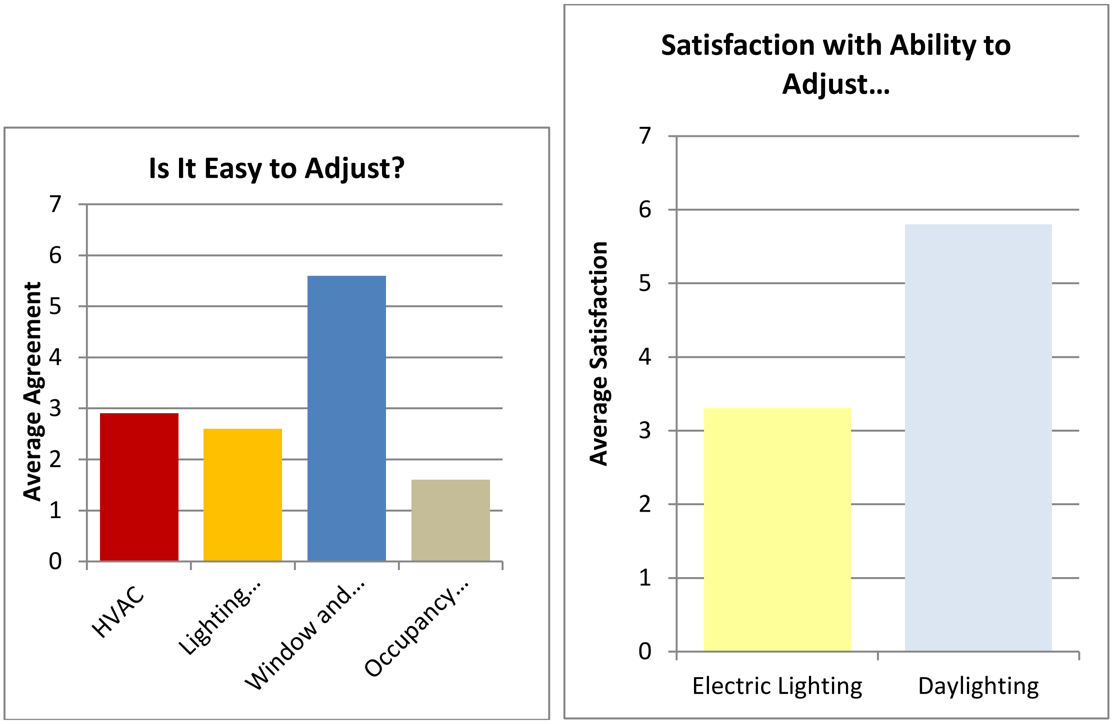


Figure 19. Satisfaction with Environmental Conditions (Building 1).
"Air" and "Temperature" are composites with Cronbach's Alpha of .863 and .870, respectively. n=47 except for job (n=46) Source: Senick, J.A., R.E. Wener, I. Feygina, M. Sorensen Allacci, and C.J. Andrews. 2013b. Occupant Behavior in Response to Energy-Saving Retrofits and Operations. Prepared by the Center for Green Building at Rutgers University for the Energy Efficient Buildings Hub, Phil., PA.



1 = Very Strongly Disagree to
7 = Very Strongly Agree

1 = Very Dissatisfied to
7 = Very Satisfied

Figure 20. Ease and Satisfaction with Adjusting Environmental Factors (Building 1).
"Is it easy to adjust?" n ranges from 37-41. "Satisfaction with ability to adjust electric lighting, n=25; daylighting, n=26. Source: Senick, J.A., R.E. Wener, I. Feygina, M. Sorensen Allacci, and C.J. Andrews. 2013b. *Occupant Behavior in Response to Energy-Saving Retrofits and Operations*. Prepared by the Center for Green Building at Rutgers University for the Energy Efficient Buildings Hub, Philadelphia, PA.

Occupants in enclosed offices were more satisfied than those in cubicles or elsewhere on virtually all aspects of IEQ, along with an ability to control workspace conditions. In particular, they were more satisfied with heating (p=.06), difference between their perceived and desired temperature (p=.003) and, unsurprisingly, visual privacy (p=.04). They were also more satisfied with their ability to adjust daylighting, but this relationship did not achieve statistical significance. Also, occupants regardless of workspace type located in the NE quadrant of the building were least satisfied with heating (also in the SE), cooling, lighting, air quality and overall environmental conditions; however, these relationships were not significant (based on ANOVA for which purposes the one respondent reporting a location in the "center" was removed).

Nine percent (9%, n=4) of survey respondents reported having control over a thermostat tied only to their workspace, whereas 23% (n=11) had shared control and an additional 4% reported that the thermostat controlling their workspace is controlled by their supervisor. Forty-three percent (n=20) and 21% (n=n=10), respectively, said that the thermostat is controlled by the building manager or that there is no thermostat controlling their workplace. Only 6% (n=3) reported use of a portable heater, 66% (n=31) dressed in layers or made adjustments to clothing and 25% (n=12) notified management. Respondents commented:

> "The thermometers always read higher than it feels." "Too much air flow – overloads air conditioning coils." "I was told that if the thermostats were left at 75 then the system would adjust the temperature as necessary and everyone should be comfort-able but I have found the thermostat turned down to 55 a few times." "The AC is often too cold. There is some control in the enclosed conference rooms (but not all conference areas have doors). The thermostat that controls my office is in the next office over and my supervisor sets it at whats comfortable for him." "The inability to override temp-erature and ventilation features causes a decrease in work productivity. This is very apparent during off-hours i.e. working on weekends. Overriding the climate controls in off-hours is non-existent."

Regarding lighting, 24% (n=11) of survey participants reported at least occasional operation of a light switch controlling overhead electric lighting of their workspace: of these, 4% (n=2) operated the switch daily, 4% operated it 1-3times/week and 16% (n=7) had not operated it within the last month. Most respondents reported either that they did not have a light switch (40%, n=18) or that overhead lighting could not be adjusted (36%, n=16). Asked how often they adjusted lighting using the dimming feature, one individual reported doing so 1-3/week, 2 individuals had not done so in the last month, while 56% (n=25) reported not having this feature and 37.8% (n=17) reported that this lighting aspect could not be adjusted. Further knowledge about dimming was scant: 4% of respondents (n=2) reported a dimming switch on a wall within the respondent's workspace, 2% (n=1) said it was on a wall outside the workspace, 2% indicated it was on the respondent's computer screen, while 2% said it was on a computer screen not belonging to the respondent. Adaptive strategies included adjusting blinds for about a quarter of respondents (22%, n=10), combining those who adjust blinds more and less regularly, and using task lighting, regularly and also less regularly, for about two-thirds (67%, n=31), a seemingly higher percent than in the REIT's pre-retrofit survey (16%, n=18 always used task lighting, 25%, n=28 sometimes did). Twenty-four percent (24%, n=11) reported either daily or weekly task lighting use. Of the building's lighting systems, respondents commented:

> "Motion activated lights in office cannot be controlled - very bad for employee satisfaction, loss of a simple control of an environmental factor, loss of the ability to turn off lights and use natural daylight, loss of the ability to lower lighting and us[e] task lighting, not well suited to personal office space." "Lack of control of my individual office lighting was a major mistake. I always turned off my lights when exiting the building and the cleaning crew always did the same. Any cost savings are far outweighed by employee dissatisfaction, feeling of lack of control. The automated lighting system is appropriate for common and high traffic areas, or low-traffic storage spaces - but not for individual private offices." "T[h]e override buttons for the lighting in the conference rooms is not intuitive (e.g., push and wait) so most people just push a lot of buttons quickly and mess up the system. Why can't there just be a regular switch so that you can turn on the lights when [y]ou are in there and turn them off when you are done? There was a whole page instruction sheet on how to override the lights! That means it's too complicated." "The workplace environment definitely affects work productivity. It would be nice to have some control over some of the settings, so that these can [be]adjusted as per individual needs."

Building 1. Occupant Perceptions of Smart Building Operations

In the fall of 2012, the REIT began to trial load shedding capabilities of the web-accessible EMS/Smart Metering systems in the two Phase 1 buildings. Scheduled trials included a 5% reduction in lighting and HVAC reductions (Shed Level 1), a 10% reduction in HVAC and lighting reductions (Shed Level 2), and a 15% reduction in lighting only (Shed Level 3), with corresponding cooling and heating set points as depicted in Table 12. The REIT was unwilling to trial a Level 3 reduction in HVAC, reserving this for emergency situations. The load shed schedule for the trial period for Building 1 appears in Table 13, along with the schedule for deployment of our daily surveys. An example of the EMS dashboard for programming load shedding activity appears in Figure 21.

Shed Level	***Lighting Reduction***	***Cooling Setpoint***	***Heating Setpoint***
0	*0%*	*74.5 ⁰F*	*71.5 ⁰F*
1	*5%*	*76.5 ⁰F*	*69.5 ⁰F*
2	*10%*	*78 ⁰F*	*67.5 ⁰F*
3	*15%*	*N/A*	*N/A*

Table 13. Pre-determined Load Shed Levels with associated Lighting Reductions and Cooling and Heating Setpoints.

Survey Distribution	***Week of***	***Date***	***Comment***	***Load Shedding / Building Condition Shifting***	***Comment***
Baseline	9/24/12-9/28/12	9/25/2012		-	
Daily am & pm	10/1/12 - 10/5/12				
Morning Daily		10/5/2012	control / placebo	-	
Afternoon Daily		10/5/2012	control / placebo		
Daily am & pm	10/8/12-10/12/12			-	
Morning Daily		10/10/2012	control / placebo		
Afternoon Daily		10/10/2012	control / placebo		
Daily am & pm	10/15/12-10/19/12			-	
Morning Daily		10/17/2012	control / placebo		
Afternoon Daily		10/17/2012	control / placebo		
Daily am & pm	10/15/12-10/19/12				SCREEN SHOTS AVAILABLE
Morning Daily		10/18/2012	no notice to tenants	Building Intervention (load shedding / DR)	Level 1 DR, Lights and HVAC 9-11am;
Afternoon Daily		10/18/2012	no notice to tenants	Building Intervention (load shedding / DR)	Level 1 DR, Lights and HVAC 1-3pm
Daily am & pm	10/22/12-10/26/12			-	
Morning Daily		10/25/2012	control / placebo		
Afternoon Daily		10/25/2012	control / placebo		
Daily am & pm	10/22/12-10/26/12			-	
Morning Daily		10/26/2012		Building Intervention (load shedding / DR)	10% with open space lighting, HVAC
Afternoon Daily		10/26/2012		Building Intervention (load shedding / DR)	10% with open space lighting, HVAC
Daily am & pm	12/3/12-12/7/12			-	
Morning Daily		12/6/2012	control / placebo		
Afternoon Daily		12/6/2012	control / placebo		
Daily am & pm	12/3/12-12/7/12			-	
Morning Daily		12/7/2012	survey failed	Building Intervention (load shedding / DR)	15% with open space lighting only, no HVAC
Afternoon Daily		12/7/2012	survey failed	Building Intervention (load shedding / DR)	15% with open space lighting only, no HVAC

Table 14. Load Shed and Survey Administration Schedule for Building 1 in 2012.

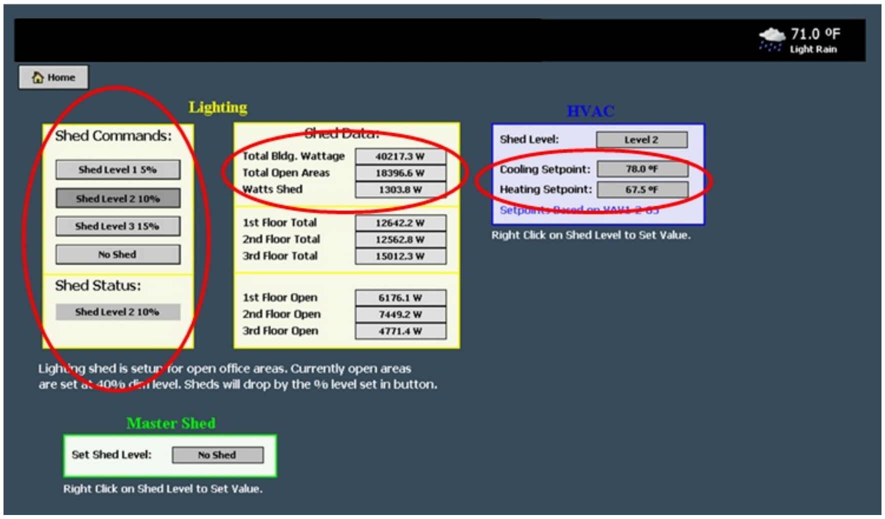


Figure 21. Dashboard Screenshot of Load Shed Programming Capabilities.

In the Building 1 baseline survey, the greatest variability in satisfaction with building environmental conditions occurred regarding temperature, suggesting that the retrofits did not fully assuage thermal comfort dissatisfaction. Specifically, respondents were close to equally split between perceiving actual temperature as cooler than (40%), equal to (32%) or warmer than (29%) their desired temperature. These results were calculated as the difference between respondents perceived and desired temperature based on a 100-point sliding scale --a measure of HVAC effectiveness from the occupant’s perspective (Figure 22).

In Senick et al (2013b), this perceived temperature differential was employed as a predictor of thermal satisfaction in the baseline survey and on load shed and control days (Appendix D). The key result was that most occupants were either more or equally satisfied with temperature on days during which the ambient temperature was permitted to rise above ordinary set points (Figure 23). Only those that had been too hot at baseline, remained unhappy. While alternate explanations are possible, these data strongly suggest that Building 1 occupants – who have consistently reported being too cold – prefer a warmer building temperature that not only is more comfortable for them but more energy efficient as well.

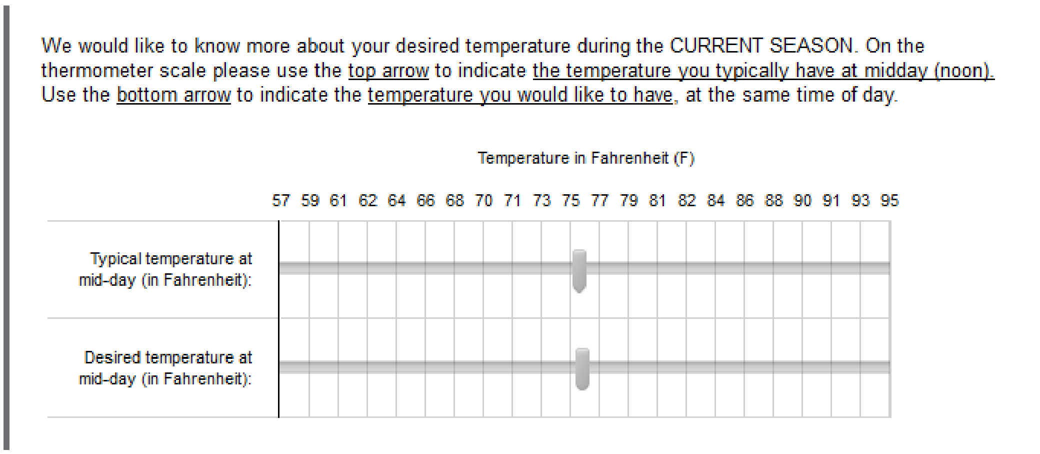


Figure 22. Baseline Survey Slider Scale for Assessment of Temperature Preferences Compared to Perceived Temperature.
Source: Rutgers Center for Green Building Baseline Survey.

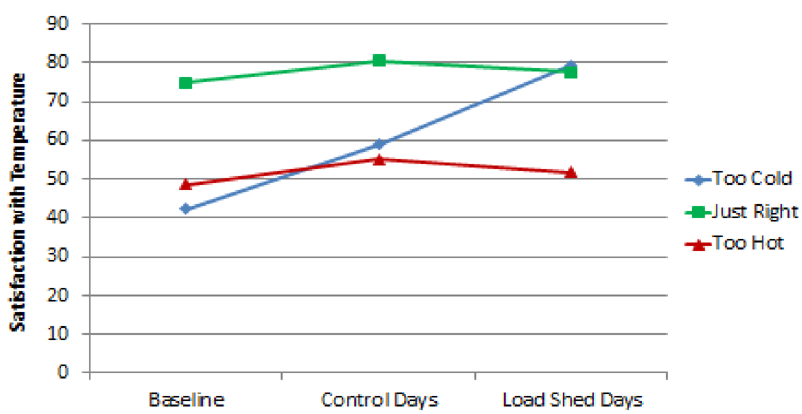


Figure 23. Load Shedding: Temperature Satisfaction (Building 1).
Most occupants were either more or equally satisfied with temperature on days during which the ambient temperature was permitted to rise above ordinary set points.
Source: Senick, J.A., R.E. Wener, I. Feygina, M. Sorensen Allacci, and C.J. Andrews. 2013b, op cit

Additional findings of the load shedding study of Building 1 relate to the possible effects of load shedding on building occupant health and productivity. Senick et al (2013b, op cit) further assessed the impacts on occupant-rated well-being and productivity of load shedding operations. On a statistically significant basis, occupants in Building 1 felt more pleasant and alert, rated their physically and mentally health more positively, and were better able to concentrate and less fatigued on load shed days. Occupants also indicated feeling slightly (but not significantly) more stress on load shedding days in each case. Respondents also rated themselves as having higher work quality, being more productive (both at statistically significant levels), and being more satisfied with their work (though not reaching statistical significance) on load shedding days (Tables 15-16).

Paired Samples Test: Control Days minus Shed Days							
		Paired Differences					
		Mean Difference	Std. Deviation	Std. Error Mean	t	df	Sig. (2-tailed)
Pair 1	Feel Pleasant	-3.53040	7.00178	1.27835	-2.762	29	.010
Pair 2	Feel Alert	-3.00590	11.34526	2.07135	-1.451	29	.157
Pair 3	Physical Health	-1.98072	10.63891	1.94239	-1.020	29	.316
Pair 4	Mental Health	-4.63016	11.73607	2.17933	-2.125	28	.043
Pair 5	Ability to Concentrate	-3.54289	19.87472	3.75597	-.943	27	.354
Pair 6	Stress	2.21780	23.55557	4.37416	.507	28	.616
Pair 7	Fatigue	-8.36795	20.56702	3.81920	-2.191	28	.037

Table 15. Building 1 Respondents Experience Positive Mood and Health Benefits on Load Shed Days. Self-reported data, scale from 0=Very Low/Dissatisfied to 100=Very High/Satisfied, based on Hays (2009), Patient-reported Outcomes Measurement Information Scale variant, op cit. Source: Rutgers Center for Green Building, Senick et al (2013b).

Paired Samples Test: Control Days minus Shed Days							
		Paired Differences					
		Mean Difference	Std. Deviation	Std. Error Mean	t	df	Sig. (2-tailed)
Pair 1	Work Quality	-4.55897	8.78635	1.66046	-2.746	27	.011
Pair 2	Productivity	-7.12292	10.01136	1.85906	-3.831	28	.001
Pair 3	Job Satisfaction	-2.93786	12.76857	2.37106	-1.239	28	.226

Table 16.Building 1 Respondents Report More Favorable Work Results on Load Shed Days. Scale from 0=Very Low/Dissatisfied to 100=Very High/Satisfied. Based on the World Health and Work Performance Questionnaire. Source: Rutgers Center for Green Building, Senick et al (2013b).

Quite unlike the initial experience of the HVAC and lighting retrofits, especially the latter, early experience with the results of EMS/Smart Metering system in Building 1 was positive. While it would be an overstatement to attribute this success solely to use of this technology – as we have seen, satisfaction during load shedding conditions was predicated on occupants' satisfaction with conditions prior to load shedding – the load shedding trials made clear that incremental, managed changes in building conditions are at least tolerated by building occupants. Interestingly, it did not seem to matter whether tenants were notified of the load shedding event in advance, although in cases that rank-and-file employees were aware of the load shed event they tended to be supportive. Most often, if a property manager conveyed notice to the tenant representative the communication stopped there and rank-and-file employees were not in the know.

As regards the energy-savings (effectiveness) of the load sheds in Building 1, the REIT shared with us that they were successful regarding this quality of use metric. While initially the operation of the EMS was limited to a sole REIT employee, over time additional REIT employees developed comfort with the interface and, as such, the efficiency of its use increased.

Building 1. Post-retrofit Site Visit (2012)

Our on-site impressions about Building 1 post-retrofit conditions, collected December 6-7, 2012, largely echoed the survey findings. Over the course of the two days, we approached 57 workspaces and assessed most of them for HVAC and lighting usability. These were split equally in terms of core and perimeter locations and consisted of enclosed offices (13), circulation (20), common spaces (12), and cubicles (11).

Building 1. Thermal Environment and HVAC Usability

Variability in our post-retrofit temperature measures was minimal, even in conditions of load shed, with enclosed offices registering the largest variance (between 73-77°F, n=57). Temperatures were similar on the two days. Most respondents felt that thermal comfort had improved markedly. However, some occupants continued to be dissatisfied with thermal comfort. Also, an audible "hum" from the HVAC system continued to garner notice by several respondents. Humidity levels in enclosed offices ranged from 16-19% across all spatial functions.

Building 1. Lighting Environment and Usability

Post-retrofit lighting measurements (first day only) revealed high illuminance levels on desk surfaces in enclosed windowed offices, relative to the industry recommendation of 400-500 lux. The average in these spaces was 1198 lux and the range was 470 to 2350 lux, depending on exposure, time of day and whether blinds were up or down. Common areas ranged from 195 to 1825 lux and cubicle areas from 415 to 480. The average for windowed cubicle areas was 1072 lux, as compared to areas without access to windows (419 lux).

Many interviewees expressed general satisfaction with lighting levels (n=21), across both days (one overcast, one bright). They characterized lighting as “fine now”, “pretty comfortable”, and “normally fine.” A few found conditions to be too bright. Responses to this condition varied. One first floor occupant had entirely covered the occupancy sensor to prevent the overhead light in that space from turning on, whereas another occupant in the vicinity had unscrewed an offending bulb. Both of these people sat in private enclosed offices and thus were able to take these actions without consulting or affecting their co-workers.

Generally, occupancy sensors received negative usability ratings, for the same reasons we heard about in other buildings – lights going on/off or staying on/off when not desired, etc. In some situations, lighting performance was cited as a safety issue, “light in lab has a long delay,”… “it can be dangerous in the early am when dark.” The lighting consultant attempted to remedy sensor problems through a combination of actions including taping over part of the eye of the sensor to avoid false positives and also relocating the eye, but met with only partial success.

Other problems also proved difficult to fix. For example, a particular circuit needed continual remote rebooting which ultimately depended on the timely availability of a lighting software consultant in Virginia. The tenant would notify the property manager… who would notify the consulting software engineer… who would fix the problem remotely…being sure to consult with the Sustainability Manager to confirm on-site results. Eventually, an affected conference room was taken off this circuit as were other conference rooms where complicated looking switches were re-installed. Since then, we were told, these lights tend to get left on (although the Sustainability Director goes around switching them off). He believes that users are confused about which lights are centrally versus manually controlled rather than inattentive to energy conservation practices.

As compared to six months earlier when the Sustainability Director made lighting level changes through the IP addressable software 3 times per month, he now receives approximately 1 monthly request. As an additional factor, higher level managers in enclosed offices who “freaked out” when their lighting switches were removed had “made enough noise” to get them back, cutting down on adjustment requests.

When asked to account for the extensive trouble with the advanced lighting retrofits, the Sustainability Director blamed the underlying technology, a design for installation that did not correspond with office layout and task needs, and the confusing mix of vendors involved. Regarding shortcomings in the lighting design, his overall feeling was that the building owner did not engage him (i.e., the tenant) sufficiently during the design phase of the project and that both more detailed programming and more detailed installation plans were needed. Quite unlike its billing in the REIT’s SGIG application for retrofit funding, this tenant’s Sustainability Director found the lighting system to be inflexible and thought it would not easily accommodate workspace reconfiguration such as frequently occurs in larger firms like this and/or upon tenant turnover. Shortly thereafter, Tenant 1A vacated and the REIT disposed of this building as part of a larger strategic sale of a large lot of office buildings.

Figure 24. Pair of Unoccupied Offices.
Source: Rutgers Center for Green
Building Photo Archive.

Building 3. Post-retrofit Evaluation

In Building 3, we visited 3 of the previous 5 tenants where we took measurements across 28 individual workspaces and recorded these on building plans (Figure 29). Of these, 10 were enclosed offices, 5 were cubicles, 7 were located in common or open areas and 6 in circulation corridors. Sixteen (16) of these spaces were located in the interior, or core and 12 on the perimeter. The day of the post-retrofit site visit to this building and also Building 4, below, was mostly clear with average temperatures in the mid to upper 40's – a mild winter day, very similar conditions as during the pre-retrofit visits.

Building 3. Thermal Environment and HVAC Usability

Post-retrofit temperatures and humidity levels in these locations demonstrated that cubicles and common areas (typically located in the building core) were warmer and also less humid (more dry). Conversely, private office and circulation areas were less warm and had slightly higher humidity levels. In all cases, our measurements fell within the range intended by building management (e.g., 72-74°F, n=28; 21-25%; n=28). Most interviewees reported that temperature had gotten 'better', although others continued to identify problems with inconsistent heating across seasons and specified building locations, and a consequent need to take adaptive actions such as dressing in layers or using fans or portable heaters. Particularly for those who reported discomfort, an actual or perceived lack of thermostatic control was a source of dissatisfaction. One tenant, "continued to think that the thermostats were not hooked up."

Building 3. Lighting Environment and Usability

Post-retrofit lighting measurements in circulation areas averaged 247 lux and ranged from 300-1020 lux in common spaces. Compared to our baseline readings, these measures suggest reduction in overlit conditions, although they are not strictly comparable given the likelihood of measurement error and also imperfect correspondence in measurement location across the two time periods. Illuminance measures in cubicles and an open "bull pen" ran from 220-920 lux, a wider range, while lighting levels in enclosed offices were pretty similar to pre-retrofit measures, ranging from 180 to 900 lux. Comparing core to perimeter locations, perimeter locations were brighter, as expected, by about 40 lux. This amounts to a fairly large, likely real, reduction from the baseline, presumably a function of the daylight sensors which triggered overhead dimming. Previously, the perimeter was almost 120 lux brighter than the core.

Associated comments about lighting were fairly benign. Occupants of some suites appeared to have more difficulties than others with occupancy sensors, impacting lighting satisfaction on the one hand and system-level effectiveness (energy use) on the other. The most common investment of effort to achieve an effective outcome by office occupants was the waving of hands (a.k.a. "the chicken dance") to prompt the lights to turn back on. There were no comments about excessive brightness except for the inability to turn lights off. Interviewees acknowledged improvements in lighting operation with adjustments by facilities, and continued to expect changes leading to local control over dimmability – "part of the original agreement was to have control."

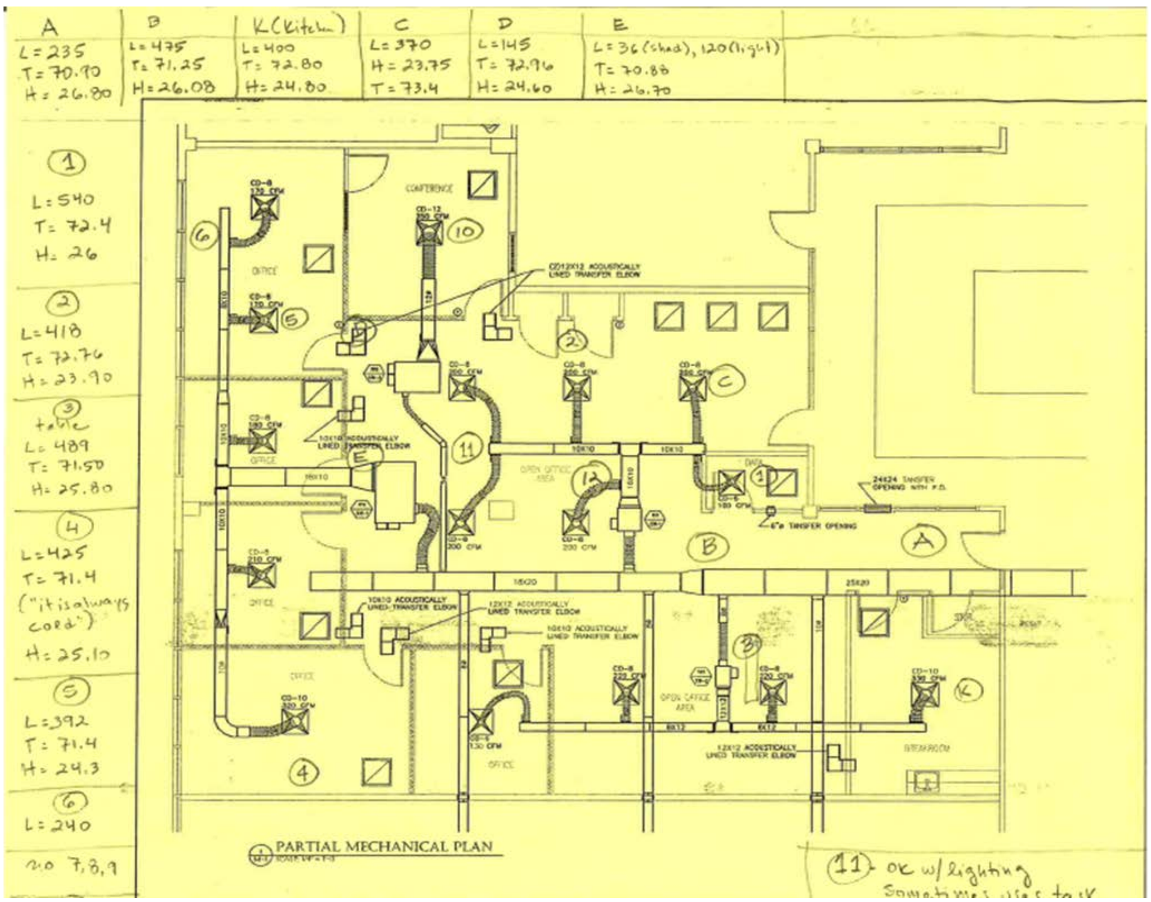


Figure 25. Example of Working Plan with Lux and Location Measures for Post-retrofit Site Visit.
Close up of plan image cropped from original.
Source: Senick et al, 2013a. Post-Retrofit Assessment of Lighting &HVAC Conditions in Three Tenanted Buildings.

Building 4. Post-retrofit Evaluation

We re-visited 4 of the original 6 tenants in Building 4 to collect post-retrofit measures and occupant responses from 17 workspaces on two floors of the building (the third floor remaining unoccupied). We visited 14 perimeter areas and 3 core ones, allocated across enclosed offices (4), circulation (4), common space (6), and cubicles (3).

Building 4. Thermal Environment and HVAC Usability

Our measurements of temperature on the day of our visit ranged from 71-74°F. Once again, occupants' comments regarding thermal comfort were primarily centered on inconsistent and variable temperature outcomes, with several building occupants finding the building overly cool in both winter and summer. The lobby was reportedly too cold for at least one occupant to use for breaks. Some occupants reported continued to use portable heaters and fans as adaptive thermal comfort strategies in addition to wearing layers. One office representative (Tenant 4D) reported calling the REIT to adjust the temperature for this suite and equated loss of control over HVAC settings with the removal of thermostats in this space.

Building 4. Lighting Environment and Usability

Our post-retrofit lighting measurements were not remarkable; the average for a small sample of enclosed offices was 600 lux, and circulation spaces ranged from 600 to 2130 lux. Locations near exterior glass doors and windows had higher light readings, averaging close to 1780 lux. Illuminance in common spaces (e.g., conference rooms) ranged from 260 to 730 lux.

In occupant reports we learned that the "lighting issue is improving," and that there have been continued interventions by facilities management mainly on the topic of sensor management. However, one respondent felt that the occupancy sensors were "just terrible" and several noted that the re-installation of switches in common areas like kitchens and copy rooms would result in greater energy savings; in these areas occupancy sensors were easily triggered by nearby foot traffic and always on as a result. An interesting situation reported by a different tenant concerned a difficulty with giving PowerPoint presentations in sensored environments, such as conference rooms and open plan areas. It was alternately challenging to get lights to dim or to remain on. This participant said he would much prefer a light switch to better enable this frequently performed task. However where switches were (re) installed in conference rooms, their method of use was not always clear and some occupants in Building 4 as well as other buildings we visited struggled with this set-up.

In another suite (Tenant 4C), two occupants in adjacent private offices had developed effective adaptations for realizing increased lighting satisfaction that simultaneously thwarted the performance intent of the daylight sensors; they closed their blinds completely to brighten the overhead electric lighting. The manager of this office also reported closing the conference room blinds at night as sometimes the lights would go on after hours and she felt that with blinds open potential vandals could see that the office was vacant. A respondent for Tenant 4E offered an opinion on the efficiency of occupant effort related to the new lighting system, "lights controlled by internet, this will take too much time, and a password just to control lights?"

Figure 26. Intuitive? Example of a Lighting Control that does not Provide Clear Direction to its User.
Source: Rutgers Center for Green Building Photo Archive.

Figure 27. Better? Second Example of a Lighting Control that is Confusing. It contains both an automatic and manual function but without clear conceptual use model.
Source: Rutgers Center for Green Building Photo Archive.

Figure 28. Affordances? An Array of Temperature, Lighting and Screen Controls with Potential to Result in Confusion and Undesired Outcomes.
Source: Rutgers Center for Green Building Photo Archive.

Summary of Occupant Response to Post-retrofit Conditions in Three Buildings

By the time of our post-retrofit measures, occupant responses to the retrofits were more positive than not, with some areas remaining for improvement (Tables 17-19). Regarding thermal comfort, overly cold and otherwise variable conditions continued to be a problem for some occupants, particularly in Building 1, and underlying usability issues with pre-existing thermostats remained. Regarding lighting, faulty operation of occupancy sensors were an irritation to many occupants in all three buildings. As a result, some individual light switches had been re-installed in private offices and also conference rooms. At this point in the retrofit experience, neither the lighting nor the HVAC measures could be say to have fully delivered on the quality of use objectives depicted in the REIT's SGIG application.

Conversely, the load shedding trial period in Building 1 had gone exceptionally well. Unlike the HVAC and lighting technologies, it is possible to conclude that the EMS/Smart Metering measure did deliver a quality of use experience, satisfying associated innovation factors.

	Relative Advantage	**Trialability**	**Observability**	**Complexity/ Simplicity**	**Compatibility**
Advanced lighting controls (predicted)	**X**	**X**	**X**	**X**	**X**
Eliminate wasted energy					
Three methods of control		+ Some people		Area of Concern	Area of Concern
Improved worker productivity		+ Some people			Area of Concern
Seamlessly integrates and deploys technologies				+Concerns, but improving	+Concerns, but improving
Dynamically adjusts to uses		+ Some people		Area of Concern	Area of Concern
Integrated with smart metering, monitoring			+ Somewhat, some people	(-)Efficiency lacking when need to rely on off-site consultants	

Table 17. Quality of Use Predictions and Intermediate Findings in 3 Buildings for Advanced Lighting Controls Aligned with Innovation Concepts.

	Relative Advantage	**Trialability**	**Observability**	**Complexity/ Simplicity**	**Compatibility**
Web-accessible, open EMS/Smart Metering *Building 1 only*	**X**	**X**	**X**	**X**	**X**
Seamlessly accessible by building occupants through an IP protected address		+ Efficient, Mostly Increased or Neutral Satisfaction based on Lack of Observability!	Not an issue	Not an issue	
Near real time monitoring and data capture	+ Effective, Efficient during load shed trials				+ Effective, Efficient during load shed trials
Dash-board profiles; formatted data for future usage					

Table 18. Quality of Use Predictions and Intermediate Findings in 3 Buildings for EMS/Smart Metering Aligned with Innovation Concepts.

	Relative Advantage	**Trialability**	**Observability**	**Complexity/ Simplicity**	**Compatibility**
Retro-commissioning HVAC	**X**	**X**	**N/A**	**N/A**	**N/A**
Better energy performance, reduced op expenses, fewer callbacks					
Improved occupant comfort and productivity		+ Effective in resolving some issues	(-)Pre-existing challenges not resolved by retrofit	(-)Pre-existing challenges not resolved by retrofit	(-)Pre-existing challenges not resolved by retrofit

Table 19. Quality of Use Predictions for HVAC Retro-Commissioning and Intermediate Findings in 3 Buildings Aligned with Innovation Concepts.

Chapter 10: Looking for Organizational Learning, Year 2 of the POE

By the summer of 2013, retrofits in some buildings had been in place for more than a year, with Phase 3 building retrofits having been more recently completed.

In year 2 of the POE, data collection ran from May through October 2013. During the late summer and early fall, all nine occupied buildings participated in online baseline and load shedding surveys. However, participation from most buildings was minimal with Building 1 accounting for half of all baseline and daily survey responses, and Building 8 about a quarter of them. We conducted 70 intercept interviews and 16 tenant interviews were conducted in 6 buildings. We also took lighting and temperature and humidity measurements and made observations of fit-out/lighting coordination, sensor operations and physical traces of occupants' adaptations to increase satisfaction with environmental conditions. We did not return to Buildings 3 or 4 (Figure 29)

As with the surveys, participation in on-site interviews varied. Some of the interviews were conducted on load shedding days and occasionally on a control day (Appendix E.)

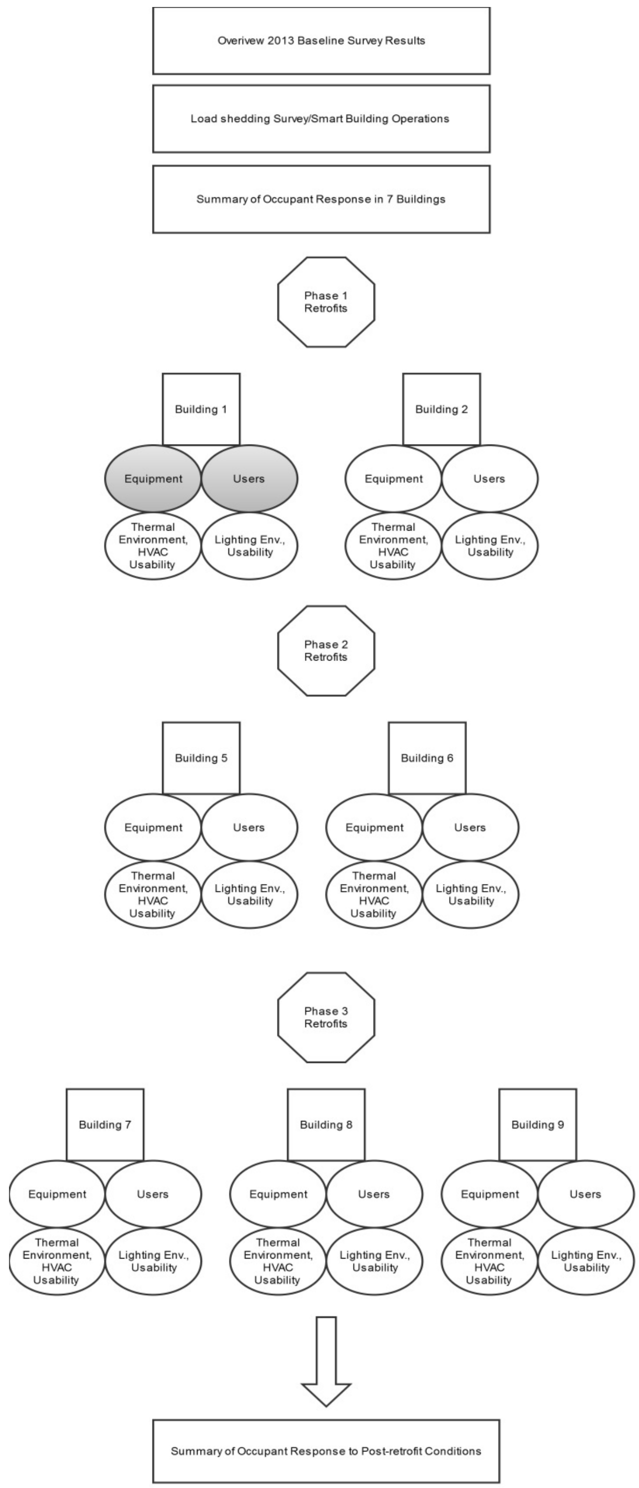


Figure 29. Flowchart Diagram of Data Collection Activities in Chapter 10: Looking for Organizational Learning, Year 2 of the POE.

Overview of 2013 Baseline Survey Results

Occupants from 15 suites across 9 buildings participated in the 2013 baseline survey late summer to early Fall of 2013. Table 20 depicts responses by building, workspace type and physical location of the respondent. Floor and exposure locations are reasonably well represented with greater emphasis on lower floors (some buildings only have 1 floor) and the southeastern exposure. Workspace type is well proportioned based on our on-site observations and intercept interviews in these buildings.

Building	Floor				Workspace Type				Exposure				
	Floor 1	Floor 2	Floor3	Total	Enclosed	Cubicle	Open	Total	NE	NW	SE	SW	Total
1	11	15	14	40	12	25	0	37	13	10	12	5	40
2	6	0	0	6	2	4	0	6	2	1	3	0	6
3	1	0	0	1	1	0	0	1	0	0	1	0	1
4	1	0	0	1	0	1	0	1	0	0	0	0	0
5	5	0	0	5	2	1	0	3	0	0	4	0	4
6	1	0	0	1	1	0	0	1	0	0	1	0	1
7	0	6	0	6	1	5	0	6	4	2	0	0	6
8	6	9	4	19	10	6	3	19	0	5	5	4	14
9	1	1	0	1	1	0	0	1	0	0	1	0	1
Total	32	31	18	81	29	44	3	76	19	18	27	10	74

Table 20. Characteristics of 2013 Baseline Survey Participants.
Source: Baseline survey data.

Participants were asked a series of questions about HVAC and lighting preferences and conditions, and follow-up questions on associated effort and effectiveness of adaptive actions. They were also asked to characterize perceived current temperature and lighting levels, then their ideal of each on the same 100-point sliding scale deployed previously. While the majority of people thought the lighting was sufficient (46%, n=25), 12 people would have preferred dimmer conditions and 7 people brighter ones. Regarding thermal comfort, the majority wished the buildings were warmer (52%, n=30), but a quarter (23%, n=15) wanted it cooler, and 13 people reported no difference between their perceived current and desired temperature..

Figure 30 presents information on respondents' adaptive responses to thermal comfort conditions and how often they are undertaken. The most popular strategies were dressing in layers (n=56) and notifying management (n=31), with clothing adjustments being made more frequently by those who were too cool. Similarly, respondents who found conditions too cool notified management or a supervisor most often, sometimes more than 2 times a day. Respondents who were too cool also reported using a portable heater more often than other respondents.

		Adjust Window Shades						Open or Close Door					
		Never	Not in the last month	1-3 times/ month	1-3 times/ week	1-2 times/ day	More than 2 times a day	Never	Not in the last month	1-3 times/ month	1-3 times/ week	1-2 times/ day	More than 2 times a day
I would like the building to be...	Cooler	3	0	0	2	0	2	3	1	1	1	1	1
	Neutral	3	2	1	1	1	1	4	1	0	0	0	1
	Warmer	7	1	1	1	1	1	5	2	0	0	2	0
	Total	13	3	2	4	2	4	12	4	1	1	3	2

		Dress in layers/Adjust Clothing						Notify Management/Supervisor					
		Never	Not in the last month	1-3 times/ month	1-3 times/ week	1-2 times/ day	More than 2 times a day	Never	Not in the last month	1-3 times/ month	1-3 times/ week	1-2 times/ day	More than 2 times a day
I would like the building to be...	Cooler	1	3	3	3	0	3	5	5	1	1	1	0
	Neutral	0	5	3	4	1	1	4	8	2	0	0	0
	Warmer	0	1	5	3	12	9	14	4	7	0	0	2
	Total	1	9	11	10	13	13	23	17	10	1	1	2

		Adjust Portable Heater					
		Never	Not in the last month	1-3 times/ month	1-3 times/ week	1-2 times/ day	More than 2 times a day
I would like the building to be...	Cooler	4	1	0	0	0	0
	Neutral	2	2	0	0	0	0
	Warmer	6	1	2	2	1	2
	Total	12	4	2	2	1	2

Figure 30. Thermal Adaptive Responses.
Source: 2013 baseline data.

Figure 31 depicts similar activities by occupants regarding workspace lighting conditions and reflects the non controllable nature of the overhead lighting for most occupants and workspace types as well as access to windows (shades), along with reported task light usage.

		Turn On/Off Overhead Light						Adjust Level of Overhead Lighting					
		Never	Not in the last month	1-3 times/ month	1-3 times/ week	1-2 times/ day	More than 2 times a day	Never	Not in the last month	1-3 times/ month	1-3 times/ week	1-2 times/ day	More than 2 times a day
I would like the building to be...	Dimmer	3	0	2	0	0	0	3	0	1	0	0	0
	Neutral	4	5	0	1	1	0	5	3	0	0	0	0
	Brighter	1	0	0	0	0	1	1	0	0	0	0	0
	Total	8	5	2	1	1	1	9	3	1	0	0	0

		Adjust Window Shades						Turn Task Light On or Off					
		Never	Not in the last month	1-3 times/ month	1-3 times/ week	1-2 times/ day	More than 2 times a day	Never	Not in the last month	1-3 times/ month	1-3 times/ week	1-2 times/ day	More than 2 times a day
I would like the building to be...	Dimmer	1	1	3	3	0	0	3	3	2	1	0	1
	Neutral	3	8	7	2	1	2	8	2	1	0	6	1
	Brighter	1	1	0	2	2	0	4	2	0	3	0	2
	Total	5	10	10	7	3	2	15	7	3	4	6	4

Figure 31. Lighting Adaptive Responses.
Source: 2013 baseline data.

As compared with 2012, participants' satisfaction with environmental conditions had improved (Figure 32). Satisfaction with an ability to adjust the workspace environment rated temperature/HVAC usability lower than lighting (Figure 33).

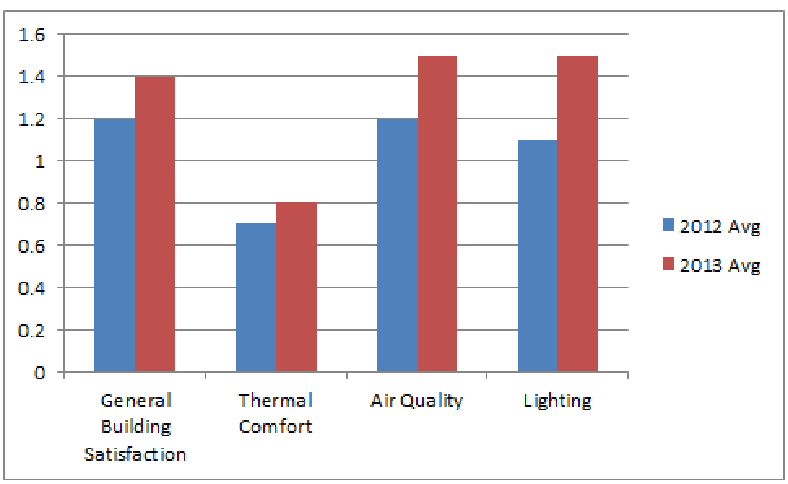


Figure 32. Changes in Occupant Satisfaction between 2012 and 2013, Building 1 only.
Source: Rutgers Center for Green Building.

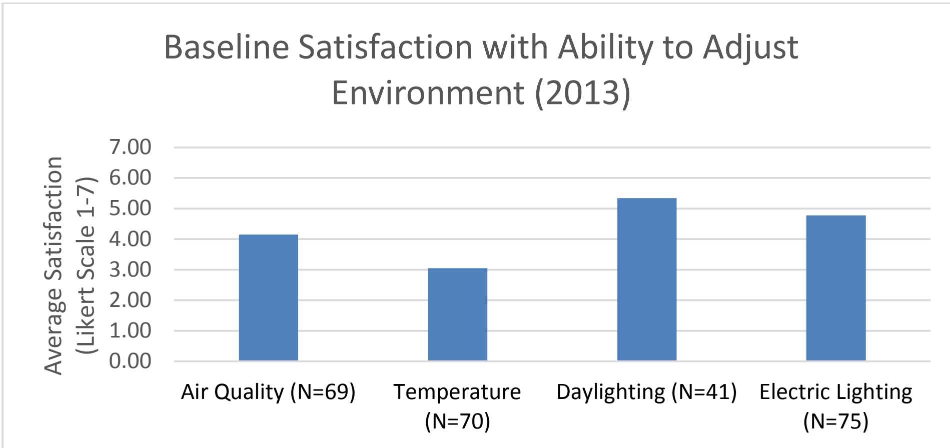


Figure 33. Average Satisfactions with Ability to Adjust Environment.
Year 2, 2013, all buildings.
Source: Rutgers Center for Green Building.

Occupant Perceptions of Smart Building Operations (9 buildings)

During the summer and fall of 2013, the REIT commenced load shedding activities in all nine retrofit buildings. Shed levels and their definitions remained the same; the schedule of load shedding events is given in Appendix E. Also, during this year, the REIT entertained proposals from 3rd party demand response aggregators, choosing one of them, to in turn contract with the regional electricity producer. Under this model, the aggregator bundles several accounts and sells on a future-forward basis specified amounts of electricity that can thereby be "called in" by the electricity producer during periods of grid strain. The REIT also began an internal discussion about revenue-sharing models pursuant to load shedding activities that would include giving some benefit back to the participating tenants.

During these operations, our team collected a total of 554 am and pm load shedding surveys, with Building 1 again dominating the response rate (approximately 50%). There was reasonable participation also from Buildings 8, 5, and 2 (Table 21).

Count

		DayTime		Total
		Morning	Afternoon	
Building	Building 1	155	131	286
	Building 2	21	15	36
	Building 3	8	8	16
	Building 4	8	9	17
	Building 5	29	22	51
	Building 6	13	7	20
	Building 7	16	17	33
	Building 8	43	35	78
	Building 9	9	8	17
Total		302	252	554

Table 21. Daily Survey Counts by Building.
Source: 2013 Daily Surveys.

In Malenchek et al (2014) regression analysis was employed to compare building occupant satisfaction with environmental conditions on 6 load shedding (treatment) days and an equal number of control days (see Appendix F). Six model variations were considered to test for the influence of such attributes as the occupants' location within a building (floor, exposure) and type of workspace. The HVAC treatment coefficient is positive in all but one of the model specifications and significant in two of them; as in 2012, occupants again appear to be too cold in non load shed settings. This result is ascertained with reference to occupants' perceptions of temperature (desired minus perceived) based on data from baseline and load shed days, and how it may influence self-assessments of satisfaction, productivity and health.

With respect to lighting conditions during load shedding, the coefficients mostly are negative, although statistically significant only in one model specification of impact on self-reported health. Thus, the experience of the REIT with load shedding in the second year of the retrofits was positive as well, across a larger base. By and large, tenants were accepting of the resulting conditions and additional revenue was generated from selling of the saved electricity.

Post-retrofit Site Visits (2013)

Summary of Occupant Response in Seven Buildings

The two main themes of these on-site visits were again thermal discomfort and difficulties with the lighting sensors. More participants reported being too cold than too warm. While improvement in the lighting system was noted, some participants continued to experience sensor-based problems and also there were reports of overly bright conditions during the "burn in" period for the bulbs. Notwithstanding vendor literature to the contrary, it appeared that the new bulbs retained their brightest settings for approximately a week before performing consistently at a dimmer programmed setting. Failing to go through this step, resulted in higher bulb failure rates. Although the REIT would have liked to eliminate the burn-in period altogether, as a result of organizational learning REIT employees now communicated to tenants an expectation that the period would be short-lived.

Also as result of these site visits, we learned more about compatibility as a predictor of usability outcomes regarding workspace organization and lighting design. We encountered tenants who reported moving into and accepting a pre-existing layout, and others who configured space to accommodate certain work tasks (i.e., activity-based design) without necessarily considering lighting quantity and quality issues. However, we also encountered tenants who had intentionally coordinated these two aspects of the work environment (Figure 35).

Similarly, we saw and discussed with occupants the sizes of cubicle partitioning walls in relation to lighting comfort (Figure 36). A fairly common situation presented when higher cubicle partitions, serving privacy functions, partially obstructed daylight penetration into the workspace. This lack of coordination in interior fit out and daylighting envelope intent likely resulted in increased electricity use. Another partition design featured shorter partitions and incorporated transparent panels, which facilitates greater daylight penetration. Unfortunately, the new lighting design wherein only one daylight sensor per exposure was installed (Figure 34) turned out to mean that if an enclosed perimeter office had its blinds drawn the daylight sensor would not activate dimming (in appropriate conditions) thereby affecting all fixtures on that circuit. This design flaw was an unintended consequence of the REIT having switched lighting vendors, and illustrates the limits of organizational learning and/or the need for building owners to understand and manage the fine details.

In an attempt to achieve environmental preferences in their workspaces, occupants undertook a variety of adaptive actions (Figure 37). These included layering of clothing, use of portable heaters and fans, deflecting of vents and lights, and removal of light bulbs. More detailed findings from the on-site visits are presented below.

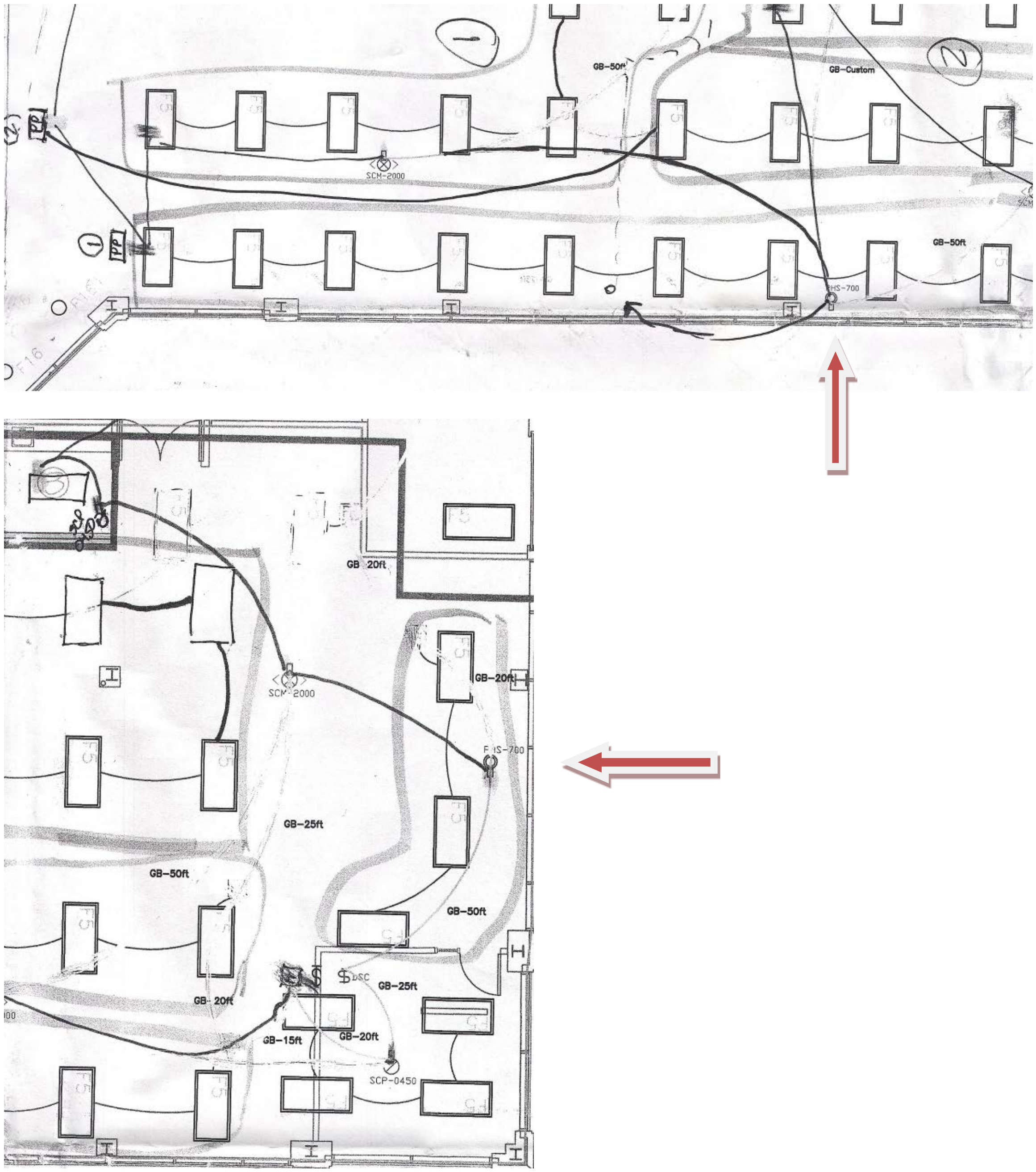


Figure 34. Locations of Single Daylight Sensor along Exposure Walls of Multiple Workspaces and Types. Source: Rutgers Center for Green Building Photo Archive.

Figure 35. Example of Coordinated Lighting with Activity-based Design. Source: Rutgers Center for Green Building Photo Archive.

Figure 36. Solid and High and Transparent and Lower Partitions.
Source: Rutgers Center for Green Building Photo Archive.

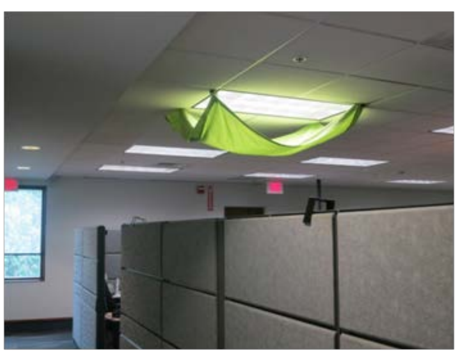


Figure 37. Adaptive Actions.
Source: Rutgers Center for Green Building Photo Archive.

Phase 1 Retrofits (Buildings 1&2)

Building 1

During on-site visits to Building 1 on 8/28/2013 and 10/2/2013, 23 intercept interviews and temperature, humidity and lighting measurements were taken. These attained a good distribution by floor, exposures, and workspace type.

Building 1. Thermal Conditions and HVAC Usability

Even during load shedding events (on both of these days) temperatures pretty uniformly hovered around 75°F with an instance of 78°F. Humidity levels ranged from approximately 35-45%, with one 50% measure. During load shedding activities, a few respondents felt warmer than usual. Generally, however, more occupants reported being more often cold than warm in the building, not only seasonally but year round – "It's pretty steady – too cold all summer and winter and fall and summer."

Whereas the people we interviewed said they were aware of the location of the thermostats, they did not report attempting to adjust them. This struck us as quite different behavior than in most other buildings and suites we visited. One participant's comment implied a lack of efficacy in doing so, "The thermostats only permit a 2 degree offset in any case."

Building 1. Lighting Conditions and Usability

Lighting levels on these days varied, largely due to the fact that the first day was overcast and the second sunny. Most locations had either direct or indirect access to daylighting. The highest reading was taken in an enclosed corner office with two walls of windows, blinds down, louvers open and measured 970 lux in sunny conditions. The lowest reading, also on 10/2, was 169 in an interior cubicle with indirect daylighting.

Those that we interviewed continued to lament the loss of control that resulted from the removal of the light switches and cited examples of lights staying on after occupants have left a space as well as lights not turning on when needed --"I get tired dancing around." Additionally, quite a few participants noted weekend work during which time greater control over building systems would be appreciated. A few occupants on the 1st floor noticed dimmer lights during load shedding period(s).

Building 2

We visited Building 2 for the first time on 9/8/2013, recalling that previously this building was off limits to the research team due to problems with the retrofits there. This building was constructed in 2005 and is on the larger size at 100,000 rentable SF. Its pre-retrofit ENERGY STAR score was a respectable 76, meaning that it ranked in the 76th percentile (with 100th being best) for performance among peer buildings as benchmarked by the REIT's sustainability team.

Building 2. Equipment

Energy retrofits to Building 2 entailed an upgrading of building energy management system controls the addition of a VAV box panel and lighting meters, additional CO2 sensors and variable speed drives (VSDs), and the conversion of lighting ballasts.

Building 2. Users

At Building 2, we conducted interviews of 2 of 6 tenants, and a walk-through of associated spaces utilizing our observational protocol along with a few intercept interviews with measurements (n=3). The office managers had more familiarity with the retrofit systems, at least for lighting. Both had used the computer portal to adjust lighting on at least a few occasions. In the larger of the two suites (Tenant 2B), but with only 2 full-time staff and 60 rotating students, the participant acknowledged receiving emails from the REIT about lighting and HVAC systems.

Building 2. Thermal Conditions and HVAC Usability

Of thermal conditions, we learned that building occupants/their managers consider that the building is usually very cold. One respondent reported using a portable heater all the time, whereas a different one reported wearing layers, a blanket and using a portable heater. The office manager of Tenant 2B was “not sure if the thermostats do anything.”

Building 2. Lighting Conditions and Usability

Of the occupancy sensors, we were told that they go off when people are still, seated at their desks. Blinds were operated for glare control and the window tinting was said to be insufficient for this purpose.

Phase 2 Retrofits (Buildings 3-6)

As previously noted we did not return to Buildings 3 and 4 in 2013, having visited them 2 times previously pre/post retrofit and also due to the limited participation and occupancy of Building 4. Rather, we concentrated our efforts on two buildings we previously had not visited – Buildings 5 and 6.

Building 5

A site visit to Building 5 took place on May 22, 2013, approximately 5 months after the retrofits were completed. This is a 1-story building that was constructed in 1983 and has 46, 697 SF of rentable space. Its pre-retrofit ENEGY STAR score was 51, average compared to its peers in terms of physical structure, but quite low for a managed building.

Building 5. Equipment

In Building 5, HVAC energy conservation measures included the addition of VSD fans to roof top units (RTUs), retro-commissioning of controls and the addition of CO2 sensors. Also, an existing controls system was extended to 3 RTUs. Lighting ballasts were converted for dimming capability. Metering work included tie-ins for the new lighting and HVAC measures.

Building 5. Users

We met with all three tenants of Building 5, one of which is sub metered due to regular weekend hours (a retail showroom), and also the Property Manager who led us on tenant tours. What was noticeably different about 2 of these tenants was their level of engagement in actively engaging in the coordination of lighting fixtures with workspaces or, in the case of the showroom, displays.

Also on 5/22, I had the opportunity to interview this building's Property Manager. What was really interesting was her sense that "this retrofit went well." Evidencing property manager-tenant engagement, she shared that she worked closely with tenants to provide the customized lighting level for which they indicated a preference, over a two week period. This resulted in set ranges of 25-100% depending on the tenant and location within the offices. There was also additional engagement by high-ranking members of the REIT's sustainability and technology team, who sat down with tenants in this and other later-stage Phase 2 building tenants to explain the retrofits, and followed up with more emails on the topic, . Of thermal comfort, the Property Manager felt it was pretty good in this building, with some problems w/ seasonal transitions.

Building 5. Lighting Conditions and Usability

In keeping with the Property Manager's comments, the representative we met with from Tenant 5A reported having seized upon the lighting retrofit as an opportunity to move fixtures to line up with cubicles in cases they previously had not. As a result of the better lighting-cubicle alignment, she told us that her 30-35 employees were happier and that they experienced less glare. Since then, she does not feel a need to adjust the lighting level, and none of her co-workers have requested changes.

Like others in this study, she reported some challenges with the occupancy sensors, calling out the bathroom as a particularly inconvenient place for lights to turn off prematurely. Of daylight harvesting, this participant described the situation at dusk when sufficient daylight is apparently harvested for the lights to remain very dim making it look like nobody is in the perimeter offices. According to her, almost everyone uses an under cabinet or task light.

Tenant 5B expressed essentially the same concern about daylight harvesting – that the electric lighting over-compensated in its dimming – and reported that some occupancy sensors in offices are triggered by hallway occupants. During our walk-through, we did observe some physical traces of lighting adaptations including the covering of bulbs in one enclosed office.

Building 5. Thermal Conditions and HVAC Usability

Regarding thermal conditions, we were told by Tenant 5A that "the new roof unit sounds like it is storming outside" and that one "can't always get a uniform temperature." We also were told that it was easier prior an *earlier* retrofit to understand which thermostat applied to which section of the office, making it necessary to "play with things to decide which of them applies to which." Nevertheless, the HVAC system reportedly performed well enough to support conditions in the conference room, remaining cool even when it was fully occupied.

For Tenant 5B, the main problem was also about too warm temperatures. In particular, was particularly concerned with the AC not keeping up in the conference room, which he called the "big shot room" as it is primarily used by company executives who periodically stop in. He told us (in front of the Property Manager, during the tour part of our visit) that he had placed service calls to the HVAC service vendor 10 times during the last couple of months.

The situation of the remaining tenant (Tenant 5C), is not really comparable to the others. As a retail showroom of home products, the lighting was bespoke and the retrofits did not address it. As a sub metered tenant, 5C sets its own schedule for HVAC operation and makes whatever adjustments were necessary. Although the point was not made so explicitly, we got the impression from this tenant that sub metering was more about ability to control schedule flexibility and not about efficient allocation of cost.

Building 6

The research team visited Building 6, one of the larger buildings of this group at 100,000 rentable SF on 5/22/2013 and 8/28/2013, a load shedding day. During these visits the 2 tenants who agreed to participate in the study were interviewed, and on 8/28/2013 intercept interviews, measurements and observations were conducted in these spaces. The pre-retrofit ENERGY STAR score for this building was 58, in spite of a prior lighting retrofit in 2011.

Building 6. Equipment

Retrofit measures in Building 6 were approximately the same as in other buildings discussed. Specifically, BMS controls were upgraded, lighting ballasts were changed to enable dimming, VSDs and CO2 sensors were added along with an additional meter.

Building 6. Users

The two tenants we visited occupied a combined 87% of the building. Tenant 6A with approximately 200 employees occupies the 4th floor of this 4-floor building. Tenant 6B, with 180 employees, occupies the entire 2nd floor and parts of the 1st floor.

On their interaction with the building owner about the retrofits, the first representative we interviewed (Tenant 6A) told us that a training session about the retrofits was not held (she had, in fact, expected a class), but that she did have an opportunity to discuss sensor locations with the property owner/contractors. She also said that she did not know in advance that light switches would be removed. However, once they were some occupants complained. Generally, those that did so got them re-installed. Also, several occupancy sensors had to be relocated to prevent lights from going off when they were needed.

A different representative of 6A related to us that the building owner had come to help him make both lighting and temperature setting adjustments as needed, post-retrofit. Overall, Tenant 6A appeared to be satisfied with the usability of the retrofits, in the form they ultimately which seemed to have included a bit of adjustment and re-installation. However, the office manager expressed a continuing concern that if people were to work outside of a set schedule this could be problematic, expressing doubt about the flexibility of the lighting and HVAC systems to accommodate this. Of the lighting control panel, she told us she finds it “very easy” to operate and told us that the lighting level for the interior core of the office is set at 30-60%. Of fit-out, she shared an awareness of the trade-off in cubicles between daylight penetration and privacy (shorter and higher partitioning walls). We also learned that Tenant 6A is "on a sustainability campaign, trying to get employees to care", although it wasn't clear the extent to which associated measures carried over to retrofit behavior.

During our interview of Tenant 6B, we learned that this representative, too, had negotiated successfully with the property owner to restore ALL light switches, resulting in a hybrid switch interface permitting both automatic/sensored and manual operation. This new switch design potentially could assuage tension between occupants desire for direct control and automated lighting function. Of the HVAC improvements, this representative told us that they were not noticed by occupants.

Building 6. Lighting Conditions and Usability

According to Tenant 6A, the lighting retrofit at this point in time was well received by her co-workers, notwithstanding the earlier problems. Beyond control issues regarding the loss of light switches, the burn-in period for the new bulbs had been difficult, especially for people prone to migraines for whom it was necessary to remove bulbs. It also become necessary to have the building owner put in override switches in conference rooms in order to view LCD projected images without the lights remaining on. Presently, we were told, lighting is "just right" and the daylight harvesting/dimming system "works well".

In 6B, occupants reported using the manual dimmer switch that was installed as part of the hybrid auto/manual interface. We also saw evidence of occupants operating blinds to restrict glare, prompting the overhead lights to brighten pursuant to the daylight sensor interface.

Building 6. Thermal Conditions and HVAC Usability

With respect to HVAC, Tenant 6A reported that people generally are cold during the summer and that occupants near windows are cold in winter and hot in summer. Whereas previously this tenant experienced significant humidity issues due to limited airflow in their space, with the installation of a new system two years ago this problem was at least partially resolved. Nevertheless, she still receives thermal comfort complaints and notes that many occupants use fans year-round.

Within the workspaces of Tenant 6B, participants had varied opinions on temperature. In a shared office space, the occupant next to the window felt warm (76°F by our measurement) and the one further from the window felt cold (75°F). This occupant reported no direct individual control over lighting or HVAC. An occupant on the 4th floor reported that he "likes it cold" and he had specifically requested the building owner to set his thermostat to result in colder conditions.

Phase 3 Retrofits (Buildings 7-9)

A distinguishing trait of the Phase 3 retrofits was that a different daylight sensor design was implemented wherein only 1 per exposure per tenant was installed. This design change resulted from a change in vendor and was not driven by the REIT. Other than that, the retrofits were fairly standard – dimmable lighting ballasts were added, HVAC retro-commissioning measures were undertaken and metered tie-ins were made to the building management system.

Building 7

Building 7 was visited twice by the research team, on 9/4/2013 and 9/11/2013. On these respective dates, a simulated and actual load shedding event took place. Building 7 was built in 2000, has105, 000 SF of rentable space, and had an ENERGY STAR pre-retrofit score of 65, meaning that it ranked somewhat better than average.

Building 7. Users

A unique aspect of this building in terms of its users is that the subject REIT maintains an office in it, at which the property manager for Building 7 is located. Of the 9 tenants located in Building 7, 2 of them occupying all or parts of 3 floors in the building participated in interviews. Some of the REIT's employees (Tenant 7B) participated in this study (a total of 14 are located in this suite), while the other participating tenant (Tenant 7A) reported having 100 employees.

Beyond the structured tenant interviews, 13 intercept interview and 17 sets of measurements we collected in the building across 3 floors and 4 exposures. All of these took place in cubicles with the exception of 1 private office and 1 reception place, quite unlike the distribution of participants in the pre-retrofit survey but representative of the offices we observed.

Regarding communication about building HVAC and lighting, about half of the interviewed occupants had not received any information, while the rest had received emails either from the REIT or their office manager. Employees of the REIT were more in the know about being at a "lower energy level", during the actual load shed event.

Overall, Building 7 occupants were very complementary about their landlord. While this was true in other buildings as well, it is quite possible that this building gets more attention; indeed, several participants mentioned the property manager by first name and gave the impression of close and frequent contact. Referring back to the literature on this topic, these occupants definitely felt that somebody was in charge.

Building 7. Thermal Conditions and HVAC Usability

Notwithstanding periodic load shedding activities (during which the temperature was allowed to rise), many participants reported too cold conditions. Occupants sitting by windows, irrespective of floor, felt cold. Many participants also felt too warm, in general, and also during load shed events (whether on 9/4, sunny breezy high 70s or on (9/11, sunny humid in the 90s). On the warmest of the two days (9/11), we measured the building at 73-77°F (with range of 36-50% humidity), in various places. Some mentioned there generally being too much air flow and HVAC noise, and one participant indicated that lack of drafts was one of the best features of the building.

Adaptive actions to increase thermal comfort seemed limited. One “freezing” participant reported using a cabinet door to block vents. Only one interviewee mentioned using a portable heater. A handful reported putting on/taking off clothing layers. Others reported taking no adaptive actions, offering that, “It doesn’t cross my mind to make any effort.”, “ I don’t notice a need to change anything”; “I don’t complain; and "I just deal with it". Other participants did share their annoyances and discomforts with us, even if these did not result in adaptive actions. For example, we heard about a “thermostat [that] was installed next to laser printer; “people would print and thermostat would lower temperature.” And, also, a “thermostat [that] was installed in the ceiling.”

Building 7. Lighting Conditions and Usability

According to our data, lighting for many is “just right”. One occupant noticed lights being dimmed (as a result of the load shed). Most occupants we interviewed or observed used task/under cabinet lighting. Across 3 floors, including 2 floors occupied by the larger of the two tenants (7A), lighting measurements varied. Inner cubicle areas measured between 99-179 lux at the desk surface, while desk surfaces nearer to windows measured 200-407 lux (both sunny days). Areas directly in the sun were between 1600-2000 lux.

On the topic of system adjustments, one tenant employee with access to the system shared a recent experience of trying to access the lighting control software that resulted in it being “messed up” and having had to call the Property Manager, who then called the lighting vendor to reset it.

Building 8

On 9/4/2013 and 9/25/2013 the team visited this 3-story 86,150 SF building and conducted intercept interviews and measurements during load shedding events. On 9/4, a Level 2 event was simulated for both HVAC and lighting power reductions. The day was bright, sunny with temperatures in the 80s. On 9/25, a Level 3 event for lighting only was simulated during sunny and milder conditions (mid 70s). Tenant interviews were conducted earlier, on 7/25/2013 and 8/20/2013. The pre-retrofit ENERGY STAR score for Building 8,was the best of the 10 buildings that participated in the retrofits at 79.

<u>Building 8. Users</u>

Judging by the tenant interviews, the retrofit process went reasonably well and overall satisfaction with both lighting and HVAC in Building 8 was reported to us as more positive than not. As with other later phased buildings, there was more evidence of a trial-and-error approach to lighting settings in Building 8 and most people we interviewed seemed satisfied with their level of control over the lighting system and the REIT's responsiveness to lighting problems. However, it was clear that access to the portal was often tightly controlled. An office manager we interviewed pointedly expressed not having control, while a colleague did. A representative of Tenant 8D said he would like to see a dashboard of lighting settings and performance, and told us that he found the available dimming range in the portal to be insufficient (70-75%), resulting in zones that were too dim.

A usability/control theme of these interviews was that even when people did not have lighting control, they knew who did and basically what elements of lighting could be controlled (dimming). Also, some of these locations had dimmer switches that could be operated manually along with other areas that were controlled by the daylighting and occupancy sensors.

Fairly uniform across the interviewed tenants were reports of having received retrofit information from the REIT and generally good communications were indicated. We learned from one tenant that there had been a “huge” meeting for tenants after the retrofits to go over problems they were experiencing. However, there were detractors and one tenant commented there were, “lots of disruptions, more than in previous high-rise: surveys, cleaning, HVAC, lighting, that's what we bought.” This same respondent felt that building technicians were good, but regretted that they could not allow access after-hours, and was trying to get employees to use blinds to manage temperature, a suggestion that had been made by property management.

As a group, these tenants also seemed somewhat active in terms of their sustainability agendas. Beyond recycling efforts, Tenant 8C reported that its managing partner is LEED AP and has shaped a culture of sustainability at the firm since its beginning. Tenant 8A reported the motivation for addressing lights that stayed on in the conference room, post retrofit, as environmental not financial (they don’t pay a utility bill). Tenant 8B has requested the property owner to provide plastic in addition to paper recycling. Another tenant stated that recycling facilities were not available.

Building 8. Thermal Conditions and HVAC Usability

Regarding thermal conditions, impressions were mixed. According to Tenant 8A, people regularly use portable heaters and wear jackets in too cold conditions. However, according to Tenant 8B, this office and also common areas of the building are very comfortable now, as compared to the immediate post-retrofit adjustment period when the building felt too cold and the Monday am start-up sequence reportedly did not work well. Tenant C would like more control over temperature – “we’ve got thermostats that don’t work.” From the perspective of Tenant D, working thermostats also are missed --“we have no control: hot in summer along windows, cold in winter; thermostat controls don’t make a difference", although this participant was pleased with the addition of a CO2 sensor in the conference room and a kitchen vent.

According to the 22 intercept interviews, temperatures generally were too cold on the northern exposure and too warm on the southern one. Overall, there were more "too warm" complaints than in other buildings, whether on load shed days or not. While nobody complained about air flow being too high, two characterized it as too low (again, the load shed might have influenced this perception). Many participants reported having used portable heaters. Most had received information about the HVAC and lighting systems from the REIT or their office manager.

Building 8. Lighting Conditions and Usability

Among several tenants there seemed to be a good fit (compatibility) of the new lighting system with workspaces, and perhaps also with the office work culture/style. For example, Tenant 8B (a 15 person venture capital firm) reported that employees like the automated features and, to the extent that settings needed to be changed, they changed them. The manager for Tenant 8D, who reported having done construction himself and being familiar with retrofits, reconfigured some aspects of the office to better align with lighting. He also reported being dissatisfied with an "insufficient" (ineffective) number of daylight sensors in the suite.

On the other hand, twenty-two (22) intercept interviews of rank-and-file occupants, across the two load shedding days, provided a less rosy picture. Most respondents complained about the function of occupancy sensors and wanted light switches reinstalled. There were several "too dim" complaints and one frustrated occupant said that the area was too dim with blinds closed but too bright with them open. Task lighting was not always an option: “If I had a handy outlet I would put a lamp on desk, as its not bright enough."

Building 9

Building 9 is a 2-story 56,845 SF office building. Its pre-retrofit ENERGY STAR score is a relatively low 53. This means that the energy performance of the building is average compared to its peers, but normally one would expect better of a managed building.

Building 9. Users

Of the 4 tenants, 3 of them (Tenants 9B, C, D) had very large vacant areas in their suites. We were able to briefly interview all 4 tenants and to observe their spaces, but did not conduct intercept interview or collect other measures.

Building 9. Thermal Conditions and HVAC Usability

Passing comments about temperature and HVAC function varied. Whereas one tenant representative whose suite is located on the 1st floor with N/NE exposure said it was “cooler in some places”, another 1st floor tenant with NE and SW exposures reported conditions as “a bit humid”.

Building 9. Lighting Conditions and Usability

Regarding lighting conditions, we noticed in our walk-throughs that the vacant areas referred to above were fully lit; it turned out that the tenants could not control lighting for these areas, or did not know how to do so. In some cases, there was minimal access to daylighting due to exposures and interior space allotments; although in one suite inner hallways had approximately a foot of glass at the top that did allow some daylight penetration. In several instances daylight was blocked by the fit-out – workspaces were divided by tall filing cabinets in one suite whereas another fit-out included very tall cubicle partitions, in excess of 5 ½ foot. We also saw sensors and dimmers throughout a suite that were partially blocked by large boxes. In one enclosed workspace the occupant had disconnected bulbs and used pieces of paper to block sun penetration through the blinds. Other lighting adaptations included the draping of fabric over the light fixture to further diffuse the light. In a different suite, a well-placed post-it note sufficed to prevent the kitchen light from always being on.

Summary of Post-retrofit Conditions in Seven Buildings

While the retrofit process remained challenging, in Year 2 of the POE, organizational learning by the REIT benefitted retrofit quality of use outcomes. Occupant satisfaction with most environmental conditions – lighting, air quality and general building satisfaction – all increased from Phase 1 (Figure 5). This result was largely due to improvements in Building 1 (Figure 32), where the REIT made meaningful financial and other investments to resolve prior retrofit complaints.

There is also strong qualitative evidence of how stepped-up communication between REIT employees and tenants of later phased buildings prior, during and after the retrofits led to improved usability results – in occupant satisfaction and efficiency of effort expended to attain visual and thermal comfort and, ultimately, in the effectiveness of lighting and HVAC systems in producing desired conditions. While the REIT did not achieve the sought after payback of the investment in the energy retrofits, the 3 buildings that performed best are managed by the same Property Manager. Her communication style and frequency in working with tenants to help ensure compatibility between the retrofits, especially regarding lighting placement and workspace organization seems to have paid off even given a less than optimal daylight sensor design.

Another positive indication of organizational learning was seen in the successful expansion of load shedding to all nine buildings, via the smart metering/energy management system, without any notable challenges. For the most part, occupants were no less satisfied during load shed events, many were more satisfied, and the REIT generated additional revenue from these activities.

Less favorable, was the apparent inability of the REIT to respond effectively to HVAC usability (thermostat) and associated thermal comfort complaints. While the retro-commissioning ECM was premised on existing HVAC technology, amounting basically to a tune-up, given the repetitive and insistent nature of occupants' frustration with thermostats that were unresponsive and whose mapping to zones and interface functions were often unclear, a well-timed intervention by the REIT could have made a quality of use difference. Among other possibilities, thermostats with better interfaces could have been installed, some measure of re-zoning work could have been added, and educational measures about current zoning-thermostat control linkages might have assuaged occupant dissatisfaction in this area if even by making more clear issues of thermostatic control.

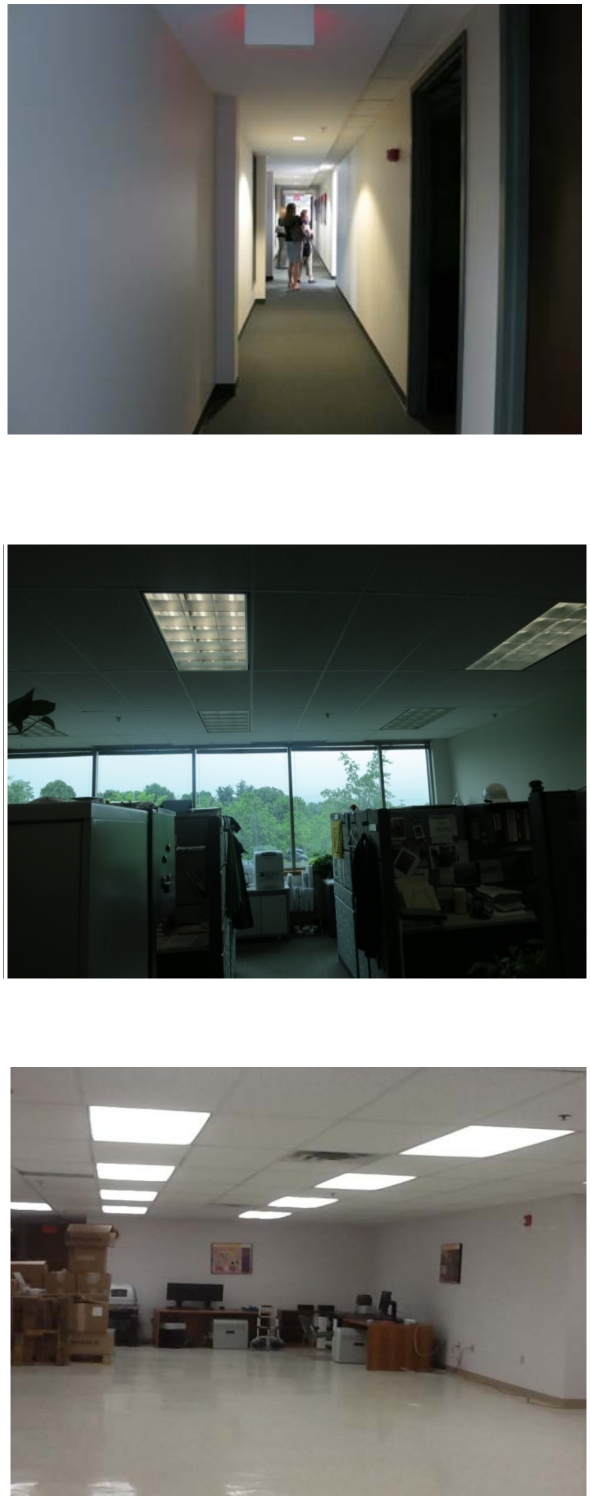


Figure 38. Dim and Overly Bright (lights “all on”) Conditions. Source: Rutgers Center for Green Building Photo Archive

Figure 39. Blocked and Facilitated Daylighting.
Source: Rutgers Center for Green Building Photo Archive.

Chapter 11: Discussion of the Case Study

Summary of Findings

This case study has presented behavioral findings on how building occupants react and respond to energy retrofits in multi-tenanted office buildings (the POE). These data facilitate a better understanding of why energy conservation measures sometimes fail and are oriented towards addressing the two motivating hypotheses of this thesis:

H1) Under-performance of building energy conservation measures is caused in some measure by usability failures.

H2) Innovations that are not compatible with organizational context (use structures) will result in negative quality of use.

Throughout this study, I have associated the experiences of building occupants, operators and the building owner with advanced lighting and smart metering retrofits, and HVAC re-tuning measures with three quality of use metrics – satisfaction, efficiency and effectiveness. Corresponding predictions incorporate innovation concepts, to relate quality of use metrics with innovation outcomes. Office occupants are the primary, lay end-users of building energy technologies; they interface with them more regularly than any other building stakeholder. Organizational characteristics of the building owner and building tenants – e.g., managerial and communications attributes, organizational structure, including the physical formats in which work is carried out -- appear to be equally important in determining the results of installed building technologies. These factors underlie use structures, with which technologies may be (in)compatible.

As was depicted in the retrofit case study, when buildings fail to deliver the environmental conditions occupants want, they sometimes pursue adaptive strategies. These have the potential to result in improved occupant satisfaction and effectiveness, if they deliver the conditions an occupant seeks. However, the need to pursue adaptive strategies can result also in decreased occupant satisfaction and decreased efficiency (here: expenditure of effort). Additionally, occupants' adaptive actions may impact co-workers' satisfaction with environmental conditions (e.g., temperature, lighting) and may result in decreased aggregate effectiveness of the retrofit (e.g., a failure to realize projected energy savings). By way of example, recall the prevalent use of space heaters in some retrofitted office suites and the covering of "too bright" light bulbs. As the design of building HVAC and lighting systems has increasingly inclined away from individual control, the social nature of these technologies has become more evident.

HVAC and lighting quality of use, as demonstrated in this case study, is highly context-driven. When energy conservation measures are incompatible with the use setting into which they are implemented, they are likely to come up short against expectations. Compatibility is a key factor in predicting innovation outcomes. A number of other innovation concepts likewise appear to predict outcomes of building energy technologies. These include the extent to which the technology can be trialed and observed in its function and/or results, and whether the technology is appropriate to the level of complexity of its use structure. The relative advantage of building innovations depend on their usability, in a context. When technologies and use structures do not align, realization of relative advantage is unlikely.

In this case study, some aspects of the energy retrofits were more successful than others. All but one building (Building 8) achieved at least some positive energy savings, although these savings were lower than anticipated in all cases. For most buildings, energy savings were significantly lower than projected. At the same time, the level of effort expended by the building owner was much greater than anticipated entailing contracting changes and the re-installation of light switches, in some cases, along with direct personal involvement of REIT officers in communicating with tenants about the retrofits. These efforts, while not (yet) successful in producing the desired energy savings, do appear to have influenced building occupant satisfaction and reflect organizational learning. In the words of the REIT's sustainability director, "Projects like these are as much about change management as they are about energy efficiency!"

In contrast to disappointing energy savings results, occupants' average ratings of lighting, air quality (related to HVAC function) and overall satisfaction with the buildings across the three phases distinctly improved. Although the sample size is small, these results achieved statistical significance (Figure 5). Not only were occupants more satisfied with lighting and thermal comfort outcomes (a measure of effectiveness), less effort (a measure of efficiency) to achieve these results was reported in interviews of office managers and others whose spaces were retrofit in the 3rd phase. With the various data streams employed in the POE pointing the in the same direction, I consider the conclusion that organizational learning took place across phases of the energy retrofit program to be robust.

The mixed results of the retrofit program demonstrate the underlying complexity of decreasing energy use in tenanted commercial buildings. In the REIT's funding application (Chapter 5), energy savings ambitions were constrained by occupant satisfaction, tenants being the bread and butter of real estate portfolios. In the case study analysis, it was not possible to be conclusive about a correspondence between building energy performance and occupant satisfaction – i.e., the best performing buildings did not necessarily contain the most satisfied occupants. However, the three best performing buildings do share the same property manager (Table 22). In these buildings, both this property manager and several tenants expressed opinions that the retrofit had gone well, describing specific instances of coordination between lighting and occasionally thermostat locations and workspace.

In the innovation literature, communication and managerial styles affect adoption decisions and their outcomes. In this case study, it appears that communication style impacted some quality of use outcomes. While this evidence may be too "soft" to be conclusive, it nevertheless is consistent with key expected relationships between organizational attributes and innovation outcomes and I place a moderate confidence in this finding. An alternate explanation of better building performance is that it is easier to coax energy savings from buildings with initial lower ratings; these buildings were ranked lower to begin with, although they were not the three lowest. A more specific accounting of the predicted usability relationships by building system appears next.

Lighting

As portrayed in Table 7, the advanced lighting controls were expected to convey a relative advantage to the buildings in which they were installed – mainly through increased effectiveness, a usability metric of performance. Based on reported energy results in these buildings (Table 9), and the more detailed breakdown by Energy Conservation Measure (Table 10), the best that could be said is that the lighting investments returned some financial benefit to the building owner.

While point estimates per building were not produced by the REIT, it was expected that the retrofits would produce total savings between 20-30%. These estimates were developed by the REIT's consultant and were based on common assumptions about energy savings associated with particular ECMs. Instead, only one building achieved an energy savings greater than 20%, at 24.8% (Building 7), Building 5 attained a 16.4% energy savings and the remaining buildings achieved single digit energy savings or none at all. Of the overall energy savings that resulted from the retrofits, the lighting ECM made up from 23-96% of the savings. This range is mainly explained by differences in the HVAC retrofit, than in the lighting program itself. Occupancy/vacancy is also an important explanatory factor for lighting/general load usage, although as earlier noted there were some cases wherein parts of offices in the subject buildings were vacant but lighting remained on due to control glitches.

Building	**Year Built** **(1970s-early 2000s)**	**SF** **(50-100k)**	**Number of Tenants/** **Occupancy % (2011)***	**Pre-Retrofit Energy Star Score (2/11)****	**Work Phase/Property Mgr**	**Energy Savings(%)**
Building 1	2004	76,692	1 (prev. 2) 87.6%	71	1/A	9.4%
Building 2	2005	100,000	6 99.54%	76	1/B	7.2%
Building 3	1982	54,623	9 78.08%	74	2/C	4.7%
Building 4	1985	60,645	10 35%	64	2/B	Not calc.
Building 5	1983	46,697	3 100%	51	2/ D	16.4%
Building 6	1971	100,000	5 100%	58	2/ E	5.4%
Building 7	2000	108,675	9 86.63%	65	3/D	24.8%
Building 8	2001	89,165	4 68.22%	79	3/ E	Savings not sign.
Building 9	1977	58,835	4 75.86%	53	3/D	9.6%
Building 10	1988	49,526	vacant	--	3	Not calc.

Table 22. Building Performance and Organizational Characteristics Emphasizing the Role of the Property Manager.

Other predicted relationships regarding the lighting retrofit program included increased user satisfaction, to be realized through enhanced control methods, along with a purported ability of the lighting system to dynamically adjust to variable uses. As shown in the case study, the initial experiences of many building occupants with lighting were not very rewarding. In particular, sensors were either too sensitive or not sensitive enough. Nor was lighting control well understood or shared uniformly across lay end users, with mainly 1-2 people in each suite retaining the password and/or knowledge of control panel use. Resulting dissatisfaction was sometimes tied to this technology's underlying social dynamic. Nevertheless, occupant satisfaction with lighting did improve across the three retrofit phases. This was most clearly measured in Building 1, but reflected also through interviews in the other buildings. What this comparison cannot as confidently assess, is how lighting satisfaction at the conclusion of this study compared with pre-retrofit lighting satisfaction. However, it does appear that lighting satisfaction in the REIT's pre-retrofit survey of some of the buildings went from largely unproblematic to somewhat problematic based on the introduction of more automated technology, that did not always work. Also, occupants responded poorly to the loss of lighting control.

Regarding predictions of efficiency of lighting use, the evidence is similarly mixed. The new lighting system mainly integrated well with the smart metering system installed in these buildings, a major factor that helped to facilitate smooth and generally well-tolerated load shedding experiences. With scant exception, the occupants responding to our surveys and intercept interviews did not notice dimmed lighting levels during the actual or simulated load shedding events. However, a failure of compatibility with the way in which office spaces are used by occupants meant that various lighting designs did not prove robust in terms of their abilities to adjust to different uses – resulting not only in decreased satisfaction but decreased efficiency and overall effectiveness, as well, from the occupant's perspective. This was most clearly seen in the cases where integrated daylight sensors and dimmable ballasts either did not work as anticipated due to a fault in the technology or its installation, or because occupants thwarted the function of the daylight sensors knowingly or unknowingly. The numerous reported issues with the occupancy sensors follow a similar logic in that suboptimal functioning led to decreased occupant satisfaction and decreased efficiency (more occupant effort) and, finally, diminished effectiveness of the retrofit lighting system. These relationships are summarized in Table 23.

Retro-commissioning/HVAC

The adjustments made to HVAC controls in the retrofit buildings, collectively called retro-commissioning, were intended to save resources (energy, money), while increasing building occupant satisfaction. Again, all but one retrofit building produced a decrease in at least some total energy usage, but less than projected. Across the 10 buildings, HVAC savings as a percent of total energy savings ranged from 4-77% (Table 9). Based on the survey data across the 3 retrofit phases, there might have been a small improvement in occupant satisfaction with thermal comfort, but this relationship did not achieve statistical significance, while satisfaction with indoor air quality did improve on a statistically significant basis (Figure 5). Indoor air quality in mechanically ventilated buildings is directly related to HVAC function, so in this sense a comfort benefit was realized, although apparently it was not always enough to overcome unfavorable temperature perceptions.

More generally, occupant dissatisfaction with thermal comfort conditions in both pre and post retrofit conditions was not particularly different than in similar buildings, as reviewed in the literature section of this thesis. Thermal comfort is more difficult than lighting comfort to manage, given the relative ease of localizing the latter. Also, as in other studies, occupants became unhappy when they felt that the user-technology interface did not work – e.g, thermostats that either did not work, about which they did not have accurate information as to their function, and/or which were not well aligned with the fit-out with interior workspace. In some buildings, prior retrofits had been responsible for the removal of some thermostats and disconnecting of others. The more recent retrofit did not address these observability or compatibility thermostat issues. Overall, the retro-commissioning ECM fell short of intended quality of use objectives (Table 24).

EMS/Smart Metering and Smart Building Operations

The integration of lighting and HVAC controls with the Smart Metering system of these buildings was the most successful ECM from a quality of use perspective (Table 25). Specifically, the REIT was able to realize efficiency gains (revenue) through load shedding activities, the technology worked effectively, any initial complexities were overcome, compatibility issues were circumvented by allowing tenants to opt out on any given day, and occupants were generally not made worse off in terms of thermal and lighting satisfaction. Other EMS functions worked less ‘smartly’. For example, lighting circuit connectivity to the building management system in Building 1 presented an on-going complex use program for months, requiring repeated inputs from an off-site consultant (Figure 40). The issue eventually was resolved by a combination of building owner, consultant and the tenant.

Remaining discussion of the case study addresses the retrofit outcomes according to key innovation concepts employed in my quality of use predictions, from the organizational perspective of the building tenants. In these following sections, I also reintroduce select findings from the LEED buildings presented as exploratory case studies, to further support these grounded conclusions.

	Relative Advantage	**Trialability**	**Observability**	**Complexity/ Simplicity**	**Compatibility**
Advanced lighting controls					
Eliminate wasted energy	Effectiveness **(-) Very Limited**				
Three methods of control (***or the fact that somebody is in charge?)***	Satisfaction **Improvement across phases although not fully realized**	Satisfaction **Some people**		Satisfaction **Some cases**	Satisfaction **Some cases**
Improved worker productivity	Efficiency **Improvement across phases,**	Satisfaction, Efficiency **Some people**			Efficiency **Some workspaces; improvement across phases**
Seamlessly integrates and deploys technologies (***although many change orders, some light switches reinstalled)***	Efficiency **+ Mostly**			Efficiency **+Mostly**	Efficiency **+ Mostly**
Dynamically adjusts to uses	Effectiveness **Better but uneven**	Satisfaction **Not generally but in some cases**		Efficiency **Not generally, but in some instances better**	Efficiency, Satisfaction **Not generally but improvement across phases**
Integrated with smart metering, monitoring	+Efficiency +Effectiveness		Efficiency **+ Mostly**	Efficiency **+Improved**	

Table 23. Lighting Quality of Use Outcomes against Innovation Concepts, Year 2 of the POE.
Legend: Red equals a relatively poor outcome, yellow a more mixed outcome, green relatively positive.

	Relative Advantage	**Trialability**	**Observability**	**Complexity/ Simplicity**	**Compatibility**
Retro-commissioning (energy performance, reduced op expenses, improved comfort and productivity)	Efficiency Effectiveness Satisfaction+ **In some cases**	Some Satisfaction and Efficiency gains resulting	Pre-existing challenges not resolved by the retrofit	Pre-existing challenges not resolved by the retrofit	Pre-existing challenges not resolved by the retrofit

Table 24. HVAC Quality of Use Outcomes against Innovation Concepts, Year 2 of the POE. Legend: Red equals a relatively poor outcome, yellow a more mixed outcome, green relatively positive, orange indicates the item is not directly applicable.

	Relative Advantage	**Trialability**	**Observability**	**Complexity/ Simplicity**	**Compatibility**
Web-accessible, open EMS/Smart Metering (IP accessible, near real time monitoring, data capture, dash-board profiles)	+Efficiency +Effectiveness	+Efficiency +Effectiveness	+Efficiency +Effectiveness **(few had access, but mission support a contributing factor)**	+Satisfaction +Efficiency (improvements made)	+Satisfaction +Efficiency

Table 25. EMS/Smart Metering Quality of Use Outcomes with Innovation Concepts, Year 2 of the POE. Legend: Red equals a relatively poor outcome, yellow a more mixed outcome, green relatively positive, orange indicates the item is not directly applicable.

Organizational Theme 1: Compatibility Issues in Design and Implementation

In the buildings where tenants and/or property manager were more actively engaged in achieving compatibility of lighting design and the design of workspaces (fit-out), energy savings were greater. In particular, Buildings 5, 7 and 9 all performed relatively well and benefited from active attempts to achieve this correspondence.

Similar situations occurred regarding two of the new buildings, LEED 1 and 2, presented in Chapter 2, suggesting that new and existing multi-tenanted buildings may not differ markedly in this respect. Specifically, we observed situations in which tenants arranged their offices for daylight penetration (i.e., by employing cubicles with high partitions for privacy but with a clear glass window on top), and others in which the tenant had retained a fit-out inherited from a prior tenant that blocked daylight from penetrating across an otherwise open floor plan.

In LEED 3, envelope and fit-out strategies were well coordinated. While some office suites were fitted out either entirely or partially with cubicles, many had an abundance of private offices and also collaborative workplaces that were easy to reconfigure for purposes of increased correspondence with building environmental systems or for more typical reasons of workplace re-organization. Perhaps partially for this reason, building occupants' overall satisfaction with lighting conditions was high.

As previously noted, the building owner of LEED 3 directly coordinated LEED Gold Commercial Interior certifications of all tenanted spaces. While the building owner of LEED 1 and 2 also was involved in assisting some tenants with their fit-outs, mostly this related to providing recommendations and reinforcing the aesthetic guidelines in the lease terms. This difference in approach appears to have merit, at least in these cases.

Across all of these examples – in the LEED and retrofit POE, there appeared to be a relationship between newer modes of organizing workspaces and an ability to locate compatibility of lighting design. This probably indicates more about the user than the technology in the sense that it was the users – tenants and the property manager – that re-organized work space to fit the technology design and not the fact that the technology design was highly flexible, which it was not.

Users who are familiar with their contexts are a valuable source of information for "evidence based design", and increased compatibility of technology with their use settings. An occupant of Building 1 suggested an additional HVAC zone to remedy a locally-known problem on one exposure. Our interviews and observations in Building 3 suggested that clear enhanced window treatments could help to resolve conflicts between energy use and privacy, an important contextual finding that was otherwise external to the process of energy retrofits. In LEED 1 and 2 sconces were added to common areas that were perceived and reported by users to be underlit, and under-cabinet and other forms of task lighting were added for close-up work. In LEED 4, additional tinting was added to help control reported unwanted glare and heat gain in some workspace areas.

Incorporating a measure of compatibility during the design phase is a relatively small expense and, especially for smaller tenants lacking the resources of a dedicated sustainability manager, arguably needed. While a handful of smaller tenants in the retrofit buildings reported strong engagement in the retrofit process, this is likely the exception to the rule. The alternative, attempting to introduce greater compatibility after construction is complete, is more costly and for other reasons may be unlikely to occur.

Along the same lines, some building owners feel that extra effort and expense at the design phase may be wasted, given frequent tenant turnover and frequent tenant demand for alteration of an existing suite. However, as depicted in both the retrofit and new building examples, many tenants adopt the fit-out the prior tenant left behind – either because they are unsuccessful in negotiating for extensive tenant improvements or because they do not prioritize this aspect of work space, versus, say, location or building amenities. In this sense, building owner attention to compatibility in lighting or HVAC zoning design and workspace locations and uses, either during initial building design or during a retrofit, might not be as short-lived as owners tend to fear, diminishing this obstacle to investment. An optimal solution would entail flexible technologies, capable of being adjusted to changing tenant use structures and uses cost-effectively.

Theme 2: Ease/Complexity of Use and Technology Control in Organizational Contexts

Control over and an ability to adjust environmental settings in the workplace to support specific tasks is associated with building occupant satisfaction and, ideally, efficient and effective results. However, in complex organizational environments, control is socially constrained. Dimming functions may depend on a daylight sensor in a private exterior office in which the occupant keeps blinds closed; daylight penetration into an open interior floor plan may depend on whether blinds and doors of private exterior offices are open/closed and also on whether the private office occupant that effectively controls daylight is at the workspace or telecommuting. Occupant satisfaction is further linked to the notion that at least somebody is in charge of building environmental systems, even if it is not them. With respect to the retrofits, occupant satisfaction was significantly associated with personal control perceptions. In the new LEED buildings, too, this often was the case with the only recourse being to contact a supervisor or the building manager.

A related finding in LEED 4, strongly amplified by the retrofit case study, is that training is an important asset for helping to address complexities of new technology use. Decisions to install sophisticated lighting and HVAC building systems need to consider the skill/training level of the people who will operate them as well as the cost and availability of facilities staff. Beyond building operators, tenants and lay-users stand to benefit from training, particularly if they are to benefit from purported flexibility in controls. In the retrofit buildings, those tenants that received more attention from REIT and/or vendor staff as to the use of the lighting portal seemed generally more satisfied and comfortable with its use. Others never “bothered with it”, perhaps in part because they didn’t understand how they could take full advantage of its customizable properties.

Throughout the retrofit process, many users struggled with occupancy sensors that did not perform effectively, requiring frequent user interventions to keep the light on, or off, as needed. In contrast, occupants of LEED 3 reported satisfaction with dual-mode locally adjustable lighting; light switches that permit automatic or manual use. While it is beyond the scope of this thesis to make detailed design recommendations, the behavioral results of these studies suggest that clear affordances and constraints (á la Norman), are more likely to lead to higher quality of use experiences with building systems with which occupants interface. There were many indications in the retrofit POE of the need for greater trialability and observability of technology functions and their results. This came up regarding thermostats with indeterminate settings and in comments about the need for a more user friendly dashboard for the on-line lighting portal.

A similar challenge existed regarding building-wide scheduling of lighting and HVAC and an ability to accommodate so-called irregular, but increasingly common, work hours. In this sense, too, innovation in energy-saving technologies has not kept pace with popular workplace trends such as flex-time or telecommuting.

Theme 3: Unclear Use Structures and Failure in Relative Advantage

Diffused decision-making and operation over building HVAC and lighting systems is not necessarily a problem; after all most tenants do not seek to be building or facility managers. However, unclear use structures diminish quality of use and threaten the attainment of relative advantage. With respect to the retrofits and similarly in the set of LEED buildings, diffused and unclear control over key building systems was a culprit in sub optimal use experiences. When use structures are unclear, adaptive responses and unintended outcomes are more likely to occur. This social dynamic may explain quite a large amount of the disappointing energy savings results for the retrofit buildings.

In Figure 2, in the Introduction of this thesis, I presented a series of lighting locus of control scenarios. In each, interdependence among building users and/or operators is depicted. Respectively, these place medium or high decision-making and communications demands on the organizations in which the lighting technology is embedded (Thompson, op cit). In all of these situations but the first one – wherein the occupant has 100% control over lights in a singular domain -- some type of social interaction is required to use the technology. To these, I now add a Situation 6 (Figure 40) portraying lighting locus of control as I understood it to exist in Building 1. This structure is wide, deep and requires reciprocal action, which, in turn, requires sophisticated managerial and communications structures to manage. It is hard to imagine that this allocation of control presents a logical, efficient use structure. Nor does it comprehend the typical use structure in U.S. office buildings, which lack the relative endowment of Building 1 -- a Sustainability Director and lay users who are mainly engineers. Based on this case study, it does not appear that the types of lighting and HVAC technologies that are commonly deployed as energy conservation measures in tenanted office settings are designed to accommodate realistic user behavior.

Situation 6: Locus of control resides with off-site consultant who requires on-site coordination to adjust lights.

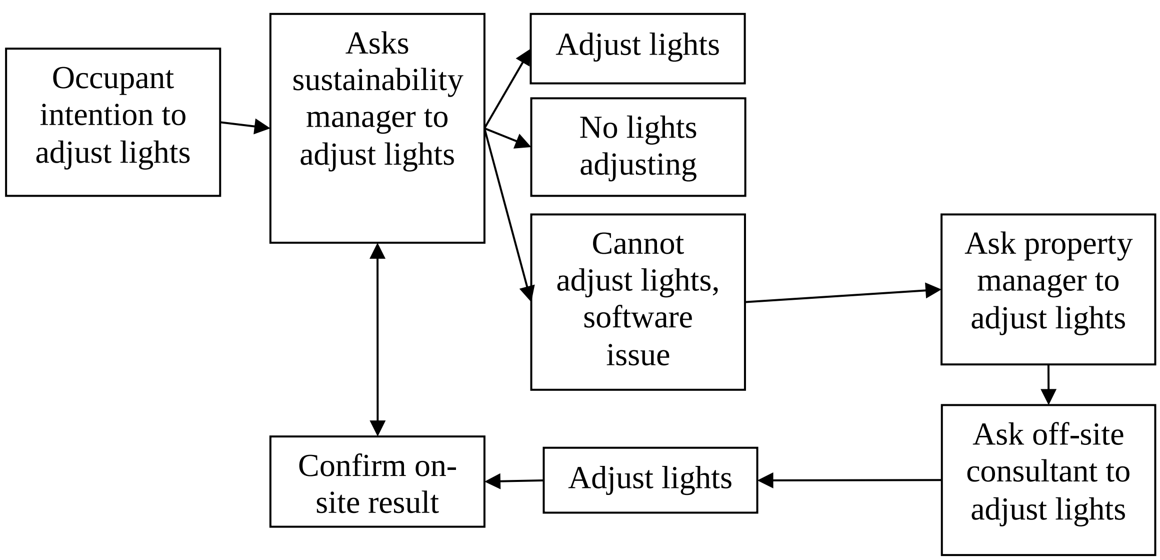


Figure 40: Lighting Locus of Control, Situation 6 Depicting Addition of Off-site Consultant.

Chapter 12: Policy Recommendations Regarding Successful Diffusion of Energy Technologies in Commercial Office Buildings

Challenges of Energy Management in Office Buildings

Energy management in office buildings is challenging, particularly in multi-tenanted ones. These buildings house heterogeneous communities of users who have diverse organizational objectives, individual occupants with varying comfort preferences, and present complex use structures for energy technologies such as lighting and HVAC. A split economic incentive between tenants and their employees, on the one hand, and building owners, on the other, results in a situation in which no party is directly responsible for energy conservation. As a result, commercial office building energy use is a variant of the social- economic dilemma known as the tragedy of the commons (Hardin, op cit).

Moreover, many energy technologies may demand more familiarity in their operation than users possess. A case in point is the IP-based dimmable ballasts that were installed in the retrofitted buildings. While the subject REIT achieved progressively greater comfort in administering this technology, the situation among lay end-users remained mixed. Unfamiliarity was one of several factors that decreased the use experience of the lighting retrofits. Even knowledgeable occupants commented on the inconvenience of having to log onto a program to change a lighting level, remembering the password and process for doing so.

At a macro level, energy conservation technologies have not kept pace with key workplace trends that impact both quantities and qualities of energy use (Chapter 1).

Increased prevalence of telecommuting, flex time and activity-based design demand increasingly more innovative HVAC and lighting approaches. Collectively, these challenges of energy management in commercial office buildings define the need for truly "smart" buildings as ones that will prove more capable of providing user-friendly comprehensible allocations of control systems, responsive to variable user needs.

As demonstrated in this thesis, energy retrofits can be relatively successful where there is willingness to experiment and to capitalize on lessons learned. Building owner and tenant engagement made a difference in some quality of use aspects, including improved occupant satisfaction across the three retrofit phases and perhaps even more effective performance of the retrofits themselves. The implication is that greater user satisfaction and system-wide efficiencies can be attained through effective organizational strategies for change management, including managerial communications and other social protocols that are key to overcoming potentially disparate interests (Orlikowski 1992, 2000).

As discussed in the Introduction, lessons learned about how building occupants respond to changing control conditions over building environment may have implications for control concepts more broadly. In particular, the tension between individual and centralized control over building energy systems is not unique and the insights developed here regarding the efficacious role of frequent and open communication and multi-method information and training delivery may be applied to other examples of control rights contention, such as the privacy debate. While I do not pretend any expertise in this field, it is conceivable that some citizens in the U.S. feel patronized about an inability to manage their own health or financial data, in the same manner that some building occupants responded to the removal of their light switches negatively commenting, “They think we are too dumb to operate a light switch.

Policy Points of Leverage

An implication of this research is that organizational strategies may help to overcome barriers to greater diffusion of energy conservation measures in commercial office buildings. In recent years energy management systems such as ISO 50001 and aspects of ENERGY STAR for Commercial Buildings have been developed as a means to help instill within organizations a standardized yet contextually flexible approach to improving energy performance. These standards seek to increase the efficiency of management engagement, while also helping to increase the effectiveness and especially predictability of results by elevating energy management as a key business process. Energy management within this context is analogous to the way that quality functions were augmented and eventually codified during the earlier quality control movement (Roome, op cit). In this approach, organizational agency is key: as Prindle and Finlinson (op cit) note, “attempting to understand and control energy use based on building type or end-use is less important than understanding how organizations can measure and manage performance across a wide range of building types and end uses” (p. 307). Previous research findings also indicate that organizations that undergo successful transformation benefit more from the adoption of new technologies whereas others often fail to benefit significantly from these investments (Davidson et al, 2007; Markus, 2004).

Unfortunately, many existing policies and programs that aim to help owners develop strategies for implementing organization-wide Energy Management Systems (EnMS) do not cater to tenanted organizations or even the challenge of managing energy in larger and diverse contexts (Senick, Hewitt and Andrews, 2014). This is true also of ISO 50001, which was developed for owner-occupiers. An integrated approach to energy management by tenants as well as building owners is needed not only to better align interests but to diminish the harmful impacts of unclear or disjointed use structures and to decrease quality of use risks. This is an area where public policy can be supportive of nascent industry efforts that are underway to alternately adapt ISO 50001, or develop alternatives, through the provision of R&D research funding and structural alignment with similar industry platforms intended to produce better performing buildings and more satisfied building occupants.

Concurrently, REITs and other building owners are beginning to rethink and revamp tenant improvement protocols in a manner that may facilitate greater investment in energy retrofits at the time when a tenant moves into a building. This is not an easy task; TI (Tenant Improvement) allowances are fiercely negotiated and marked by the same phenomenon as new home buyers specifying granite countertops over more insulation (e.g., flash over substance). Nevertheless, creating an opportunity to discuss energy use and technology features at this critical juncture in a real estate transaction may help to prevent incompatible workplace fit-outs and lighting and HVAC design and to generate tenant buy-in about energy related improvements thereby helping to overcome in this manner split-incentives.

Related to this notion are “green leases”, wherein an attempt is sometimes made to align the financial incentives of the building owner and tenant around energy use in addition to clauses regarding recycling, use of interior materials in re-design and other aspects of “green”. While much progress has been made in developing associated templates, the adoption of green leases is happening only slowly. Reasons include influential industry norms, unwillingness to lose a tenant, the fact that energy use in most office settings is a distinctly secondary concern of tenants and building owners alike.

Strategies to make energy use better known, and visible, to tenants and building operators, too, may help. For example, a portfolio-wide move to a direct metering arrangement would shift price signals to the tenant. More building owners seem to be pursuing this option, but progress is slow due to several factors including high capital cost. On its own, this structural change seems unlikely to result in behavioral change for reasons just discussed – energy use is not a priority for most tenants. Additionally, tenants need to be made aware of their energy use in an easy to understand way, particularly lay-end users whose direct actions are most influential. Building labeling programs, such as ENERGY STAR and LEED help to fill this need, with tenants likely to care most about the evolving ENERGY STAR standard for tenanted spaces and the established LEED CI certification, for Commercial Interiors. If building owners find that they can lease these spaces at a premium, they may invest more effort in working with tenants to certify their spaces. Municipal benchmarking programs, as discussed in Chapter 1, add a competitive and, in the case of disclosure ordinances, required prerogative for building owners and tenants in transacting over office space.

This POE has presented evidence that building occupants who are more fully aware of energy related activities more easily embrace them. This finding is consistent with prior studies, from which we know that building occupants tend to be more tolerant of building conditions generally in green (versus non-green) buildings (Deuble and de Dear, op cit; Leaman and Bordass, op cit). Load shedding in the retrofit buildings provides a particularly compelling example, that one suspects ties also into occupants' willingness to do their part for resiliency and security of electricity supply. Making these connections directly to variable speed fan drives and dimmable ballasts is a stretch, but perhaps there is an opportunity to build on occupants greater good will towards load shedding to develop more better messaging about energy efficiency, generally.

These various policies and organizational strategies are probably best leveraged as bundles – e.g., direct/sub metering, "green' leasing, TI toolkits, building labeling and municipal benchmarking programs, participation in demand-response programs. Together they stand to improve the extent to which energy use is readily observed, understood and responded to in commercial office settings, building upon some success in linking economic policies with public policy and organizational behavior.

This thesis has evaluated the implementation of energy conservation measures in 9 multi-tenanted buildings owned and managed by a REIT, with supplemental data drawn from prior studies of 4 new LEED buildings, also institutionally-owned. Its conclusions are oriented towards tenanted commercial buildings and the organizations that own, manage and reside in them, although additional research is necessary to confirm them.

Future Research Agenda

I started this thesis by asserting and then demonstrating how the social nature of implementing lighting and HVAC energy measures in workplace settings is not well understood, arguing that technology designers conceptualize their use structures as narrow and shallow, when they are wide and deep. Moreover, I have claimed and demonstrated instances wherein the convergence of energy conservation and IT technologies, and changing workplace contexts such as tele-commuting and collaborative/activity-based design, present organizational challenges for the adoption and implementation of energy conserving measures. The main objective of my research was to help fill gaps in knowledge about the processes by which Energy Conservation Measures are deployed and their results, within a usability framework.

Usability-themed studies of the workplace are not new; however, focused research on usability-energy behavior across the multiple scales of a tenanted office building is rare. The findings I have articulated as a result of this case study need further substantiation. A strength of this research has been the ability to hold constant key aspects of organizational context – attributes and structures – at the level of building ownership, in order to study the variable effects of others. Needed is an expansion of this work to additional contexts, such that a fuller typology of contextual effects on quality of use outcomes results. In connecting a usability framework to Roger's innovation concepts, I have paved the ground for future, larger 'n' studies, which are feasible based on recent data developments. In particular, utilities and energy research organizations (e.g., NYSERDA) are showing interest in building behavioral studies and the EIA's

Commercial Building Energy Consumption Survey (CBECS) has added to its collection regime a number of variables about both the interior fit-outs of buildings, the extent of telework, and more organizational description. Along with the energy use data that is already collected through this instrument, it will be possible in the next year or so to evaluate the organizational relationships I have set forth in a fuller way, for potentially thousands of buildings.

More applied research might be tied to evaluation measures of the implementation of Energy Management/Smart Metering Systems among a cohort of building portfolio owners, and also to evaluation of new efforts focused at certifying tenanted spaces. In the case of EMS/Smart Metering installations, experiments that test specific allocations of user control can be run. Regarding tenant certification programs, the key question is how this process and its visible outcomes (certification score, ranking) impact energy behavior of building stakeholders. Another intriguing area of research concerns work process-based analyses of the compatibility of specific ECMs. Illustratively, are auto sensors a better or worse fit in a setting where flex hours are prevalent?

A final arena of research, touched upon in this thesis and needing additional attention, is how building occupants respond to load shedding. Many electrical grids in the U.S. are overburdened, with demand outstripping supply, and additionally subject to equipment failures as they age. Other grid vulnerabilities include terrorist acts. In this research, building occupants responded very differently to the need to shed load than to everyday energy conservation. Although the two are in energy terms connected, this has not yet been made clear to building users whose behavior might correspondingly change.

While the response to building energy systems of any given building occupant might seem trivial, if U.S. commercial buildings were to become even 1% more efficient because of behavioral changes, this would result in annual savings of the equivalent of 2 billion (1,981,494,561) barrels of oil. (All office buildings consumed 1,134 quads (Table 4. Energy Consumed by Office Buildings for Major Fuels, 2003, EIA Office Buildings, op cit.) This is enough to meet all of the domestic economy's daily petroleum needs for 100 days (based on daily consumption of 20 million barrels of oil, EIA).

Brief Reflections on the Research Experience

This thesis has drawn upon over a decade's worth of experience in evaluating how building occupants and other building stakeholders perceive and respond to building systems and design. Over this period of time, I have developed informed opinions about these relationships which at some level may be reflected in my approach to this thesis and its findings. Such biases are impossible to avoid altogether, although awareness of them is a helpful counter-measure. The team nature of conducting the POEs drawn upon here has been beneficial, not only in getting such a large volume of work completed, but also in bringing many perspectives to bear on how the research was conducted and evaluated.

Similarly, my view on what comprises data has influenced the direction of this work. In POE/case study, I am inclined towards the positive value of all data, even if I judge it differently depending on issues with quality, or its source. While this general philosophy is shared by many of my colleagues at the Center, not everyone agrees and a disadvantage of this approach is that relatively stronger findings risk being lost among what some would consider "noise". Several debates on this topic indeed took place over the course of the noted POEs. However, had I not persevered in turning over and over the organizational data I collected on the nine retrofit buildings I might have missed what I consider to be a key finding on the influential role of the property manager. Indeed, the attempt to measure, or at least locate, the systematic influences of specific organizational contexts on the occupant-technology experience in this thesis introduces a new focus for the Center's POE work. These data, as I have previously stated, are relatively "soft" at this stage, resulting in grounded hypotheses for future work.

Similarly, over the last 12 months, I have iterated a great volume of potential evidence regarding the energy retrofits' quality of use metrics – effectiveness, efficiency, satisfaction – in an attempt to develop an original theoretical framework synthesizing usability metrics and innovation concepts. On several occasions I altered my conclusions, slightly, and in this manner the process has led me to refine my opinions about what counts as evidence and how best to characterize it.

As regards next steps for this work, I plan to develop publications on the synthesis of usability and innovation concepts and its results, including how organizational learning takes place, and on building occupant responses to load shedding and how this area may signal an opportunity for re-thinking communication to building occupants and other stakeholders about building energy use. I also plan to continue my work with the REIT community to help evolve a successful change management model for incorporating energy management processes as a core business function.

Appendix A

Green Buildings Baseline Survey Summer 2013

Q1.1 Building Occupant Initial Survey Thank you for agreeing to participate in this US DOE Energy Efficient Buildings Hub survey. The survey takes approximately 10-15 minutes to complete.   Please DO NOT USE THE BACK BUTTON, as it will take you to the beginning of the survey without saving your responses.

Q1.2   Background information about your work

Q1.3   How many years have you worked for this organization?
- ❍ Less than 1 year (1)
- ❍ 1 to 3 years (2)
- ❍ 3 to 10 years (3)
- ❍ 10 to 20 years (4)
- ❍ More than 20 years (5)

Q1.4   How would you describe the work you do?
- ❍ Executive / Managerial (1)
- ❍ Professional / Technical (2)
- ❍ Clerical / Support (3)
- ❍ Other (please specify) (4) ____________________

Q2.1   Background Information (Workspace)

Q2.3 How long have you worked in this building?
- ❍ Less than 3 months (1)
- ❍ 3 to 6 months (2)
- ❍ 6 to 12 months (3)
- ❍ 1 to 3 years (4)
- ❍ 3 to 10 years (5)
- ❍ 10 to 20 years (6)
- ❍ more than 20 years (7)

Q2.4 Where is your workspace located?
- ❍ Floor 1 (1)
- ❍ Floor 2 (2)
- ❍ Floor 3 (3)
- ❍ Other (4) ____________________
- ❍ My building is one story (5)

Q2.5 We would like to know which side of the building your workspace is in. For example, is your workspace located nearest the northwest, southwest, northeast, or southeast wall of the building? Please refer to the site map below.
- ❍ Northeastern exposure (1)
- ❍ Northwestern exposure (2)
- ❍ Southeastern exposure (3)
- ❍ Southwestern exposure (4)
- ❍ Other (Please specify) (5) ____________________
- ❍ Don't know (6)

Q2.6 How long have you occupied your present workspace (e.g., enclosed office, cubicle, or other space that you consider to be your primary work location)?
- ❍ Less than 3 months (1)
- ❍ 3 to 6 months (2)
- ❍ 6 to 12 months (3)
- ❍ 1 to 3 years (4)
- ❍ 3 to 10 years (5)
- ❍ 10 to 20 years (6)
- ❍ More than 20 years (7)

Q2.7 Which of the following best describes your workspace?
- ❍ Enclosed office, private (1)
- ❍ Enclosed office, shared with other people (2)
- ❍ Shared cubicle with high partitions (about five or more feet high) (3)
- ❍ Private cubicle with high partitions (about five or more feet high) (4)
- ❍ Shared cubicle with low partitions (lower than five feet high) (5)
- ❍ Private cubicle with low partitions (lower than five feet high) (6)
- ❍ Workspace in an open office with no partitions (just desks) (7)
- ❍ Other (please specify) (8) ____________________

Answer If Which of the following best describes your workspace? Enclosed office, private Is Selected Or Which of the following best describes your workspace? Enclosed office, shared with other people Is Selected Or Which of the following best describes your workspace? Shared cubicle with high partitions (about five or more feet high) Is Selected Or Which of the following best describes your workspace? Private cubicle with high partitions (about five or more feet high) Is Selected Or Which of the following best describes your workspace? Shared cubicle with low partitions (lower than five feet high) Is Selected Or Which of the following best describes your workspace? Private cubicle with low partitions (lower than five feet high) Is Selected Or Which of the following best describes your workspace? Other (please specify) Is Selected

Q2.8 Do any of your partitions or walls contain transparent panels?

❍ Yes (1)
❍ No (2)

Q3.1 Qualities of the Indoor Environment   Air Quality

Q3.2   How satisfied are you with the following attributes related to environmental quality of your workspace?

	Very Dissatisfied (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	Very Satisfied (7)
Air quality (1)	❍	❍	❍	❍	❍	❍	❍
Air freshness (2)	❍	❍	❍	❍	❍	❍	❍
Air movement (3)	❍	❍	❍	❍	❍	❍	❍
Humidity (too much or too little) (4)	❍	❍	❍	❍	❍	❍	❍

Q3.3 How frequently do you experience the following environmental conditions at your workspace?

	Daily (1)	1-3 Days/Week (2)	1-3 Days/Month (3)	Not in the last month (4)	Never (5)
Air drafts (1)	❍	❍	❍	❍	❍
Stuffiness (2)	❍	❍	❍	❍	❍
Too humid (3)	❍	❍	❍	❍	❍
Too dry (4)	❍	❍	❍	❍	❍
Unpleasant odors (5)	❍	❍	❍	❍	❍
Air quality varies (6)	❍	❍	❍	❍	❍

Q3.5 Comments on air quality:

Q3.6 To improve the air quality in your workspace, how often do you...

	Don't have this feature (85)	Can't be adjusted (86)	More than 2 times a day (91)	1-2 times / day (90)	1-3 times / week (89)	1-3 times / month (88)	Not in the last month (87)	Never (92)
Use an air purifier (1)	❍	❍	❍	❍	❍	❍	❍	❍
Open or close doors (2)	❍	❍	❍	❍	❍	❍	❍	❍
Adjust vents (3)	❍	❍	❍	❍	❍	❍	❍	❍
Adjust windows (4)	❍	❍	❍	❍	❍	❍	❍	❍
Turn on fan (5)	❍	❍	❍	❍	❍	❍	❍	❍
Use non-toxic cleaners (6)	❍	❍	❍	❍	❍	❍	❍	❍
Use air freshener (7)	❍	❍	❍	❍	❍	❍	❍	❍
Use a humidifier or dehumidifier (11)	❍	❍	❍	❍	❍	❍	❍	❍
Notify management (my supervisor, main office or facilities dept.) (9)	❍	❍	❍	❍	❍	❍	❍	❍
Other (please specify) (10)	❍	❍	❍	❍	❍	❍	❍	❍

Q3.9 How satisfied are you with your ability to improve the INDOOR AIR QUALITY in your workspace?

	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)
Very Dissatisfied:Very Satisfied (1)	❍	❍	❍	❍	❍	❍	❍

Q4.1 Temperature

Q4.2 How satisfied are you with the following attributes related to environmental quality of your workspace?

	Very Dissatisfied (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	Very Satisfied (7)
Current temperature (26)	❍	❍	❍	❍	❍	❍	❍
Heating (27)	❍	❍	❍	❍	❍	❍	❍
Cooling (28)	❍	❍	❍	❍	❍	❍	❍

Q4.3 How frequently do you experience the following environmental conditions in your workspace?

	Daily (1)	1-3 Days/week (2)	1-3 Days/month (3)	Not in the last month (4)	Infrequently / Almost never (5)	Never (6)
Temperature too hot in heating season (1)	❍	❍	❍	❍	❍	❍
Temperature too cold in heating season (2)	❍	❍	❍	❍	❍	❍
Temperature too hot in cooling season (3)	❍	❍	❍	❍	❍	❍
Temperature too cold in cooling season (4)	❍	❍	❍	❍	❍	❍
Temperature varies from day to day (5)	❍	❍	❍	❍	❍	❍

Q4.4 Do you ever feel too hot or cold to be able to focus on your work?

	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)
Definitely:Not at all (1)	❍	❍	❍	❍	❍	❍	❍

Q4.6 Comments on temperature in cooling season:

Q89 Comments on temperature in heating season:

Q4.8 We would like to know more about your desired temperature during the CURRENT SEASON. On the thermometer scale please use the top arrow to indicate the temperature you typically have at midday (noon). Use the bottom arrow to indicate the temperature you would like to have, at the same time of day.

______ Typical temperature at mid-day (in Fahrenheit): (1)

______ Desired temperature at mid-day (in Fahrenheit): (2)

Q4.9 Which of the statements below best describes your situation? (check only 1)

- ❍ I have control of a thermostat that adjusts temperature for my workspace only. (1)
- ❍ I share control of a thermostat that adjusts temperature for my workspace as well as that of others. (2)
- ❍ The thermostat that adjusts temperature in my workspace is controlled by my supervisor. (3)
- ❍ The thermostat that adjusts temperature in my workspace is controlled by the building manager. (4)
- ❍ There is no thermostat that adjusts temperature in my workspace. (5)
- ❍ Other (6) ____________________

Q4.10 If the temperature in your workspace is too hot or too cold, what do you usually do? (Check all that apply)

	Don't have this feature (64)	Can't be adjusted (65)	More than 2 times a day (70)	1-2 times/ day (69)	1-3 times/ week (68)	1-3 times/ month (67)	Not in the last month (66)	Never (71)
Adjust thermostat (1)	❍	❍	❍	❍	❍	❍	❍	❍
Adjust air vent (2)	❍	❍	❍	❍	❍	❍	❍	❍
Adjust portable fan (3)	❍	❍	❍	❍	❍	❍	❍	❍
Adjust room air conditioner unit (4)	❍	❍	❍	❍	❍	❍	❍	❍
Adjust ceiling fan (5)	❍	❍	❍	❍	❍	❍	❍	❍
Adjust portable heater (6)	❍	❍	❍	❍	❍	❍	❍	❍
Open or close windows (7)	❍	❍	❍	❍	❍	❍	❍	❍
Adjust window blinds or shades (8)	❍	❍	❍	❍	❍	❍	❍	❍
Open or close door (9)	❍	❍	❍	❍	❍	❍	❍	❍
Dress in layers/adjust clothing (10)	❍	❍	❍	❍	❍	❍	❍	❍
Notify	❍	❍	❍	❍	❍	❍	❍	❍

management (my supervisor, main office or facilities dept.) (11)								
Other (please specify) (12)	❍	❍	❍	❍	❍	❍	❍	❍

Q4.12 How much do you Agree or Disagree with the following statement?

	Very Strongly Disagree (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	Very Strongly Agree (7)	N/A (-999)
It is easy to figure out how the heating, cooling and ventilation systems work here in order to adjust them. (1)	❍	❍	❍	❍	❍	❍	❍	❍

Q4.13 How satisfied are you with your ability to improve the TEMPERATURE in your workspace?

	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)
Very Dissatisfied:Very Satisfied (1)	❍	❍	❍	❍	❍	❍	❍

Q5.1 Lighting

Q5.2 We would like to know more about your desired amount of lighting. On the scale below, where 100 is the maximum possible light available in a workspace (all lights on full, shades open on a bright day) and 0 is complete darkness, please use the top arrow to indicate the amount of light you typically have at midday (noon) and the bottom arrow to indicate how much light you would like to have, at the same time of day.

______ Amount of light you have at midday: (1)

______ Amount of light you want at midday: (2)

Q6.1 Does natural light from the sun or sky provide general lighting in your workspace?

- ❍ Yes (1)
- ❍ No (2)
- ❍ Not sure (4)

If No Is Selected, Then Skip To End of Block

Q6.2 Indicate your agreement with the following statements about daylight in your workspace:

	Very Strongly Disagree (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	Very Strongly Agree (7)	NA (8)
The blinds or other shading devices are effective in blocking out unwanted light from the sun and/or sky. (1)	❍	❍	❍	❍	❍	❍	❍	❍
I am bothered that I lose daylight when I adjust shades/blinds to block out the heat from the windows (3)	❍	❍	❍	❍	❍	❍	❍	❍
Overall, I am satisfied with the daylighting in my workspace (5)	❍	❍	❍	❍	❍	❍	❍	❍

Q6.3 How often do you experience the following conditions in your workspace?

	Daily (1)	1-3 Days / Week (2)	1-3 Days / Month (3)	Not in the last month (4)	Infrequently / Almost never (5)	NA (6)
Daylight too bright, glare (1)	❍	❍	❍	❍	❍	❍
Daylight too dim, gloomy (2)	❍	❍	❍	❍	❍	❍

Q6.4 How satisfied are you with...

	Very Dissatisfied (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	Very Satisfied (7)	NA (8)
Daylighting (1)	❍	❍	❍	❍	❍	❍	❍	❍
Ability to adjust daylighting (2)	❍	❍	❍	❍	❍	❍	❍	❍

Q7.1 How often do you experience the following conditions in your workspace?

	Daily (1)	1-3 Days / Week (2)	1-3 Days / Month (3)	Not in the last month (4)	Infrequently / Almost never (5)	NA (6)
Electric light too bright, glare (1)	❍	❍	❍	❍	❍	❍
Electric light too dim (2)	❍	❍	❍	❍	❍	❍

Q7.2 How satisfied are you with...

	Very Dissatisfied (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	Very Satisfied (7)	NA (8)
Electric lighting (1)	❍	❍	❍	❍	❍	❍	❍	❍
Ability to adjust electric lighting (2)	❍	❍	❍	❍	❍	❍	❍	❍

Q7.3 To adjust the lighting in your workspace, how often do you.....

	Don't have this feature (1)	Can't be adjusted (7)	More than 2 times/ day (2)	1-2 times/ day (3)	1-3 times/ week (4)	1-3 times/ month (5)	Not in the last month (6)	Never (8)
Adjust window blinds or shades (1)	❍	❍	❍	❍	❍	❍	❍	❍
Turn my overhead lighting on or off with a switch (2)	❍	❍	❍	❍	❍	❍	❍	❍
Adjust the level of my overhead lighting with a dimmer (3)	❍	❍	❍	❍	❍	❍	❍	❍
Turn on/off a task light (4)	❍	❍	❍	❍	❍	❍	❍	❍
Notify management (my supervisor, main office or facilities dept.) (6)	❍	❍	❍	❍	❍	❍	❍	❍
Other (please specify) (7)	❍	❍	❍	❍	❍	❍	❍	❍

If Adjust the level of my over... Is Selected, Then Skip To In whose office is the dimmer control...

Q7.5 Where is the dimmer located in your suite?
- On a wall within my workspace (2)
- On a wall outside my workspace (3)
- On my computer screen (4)
- On a computer screen that is in my office suite but not on my computer (5)
- Other ____________________ (7)
- I don't know (6)

If I don't know Is Selected, Then Skip To Does the dimmer control the overhea...

Answer If Where is the dimmer located in your suite? On a computer screen that is in my office suite but not on my computer Is Selected Or Where is the dimmer located in your suite? Other ____________________ Is Selected

Q7.6 In whose office is the dimmer control located (facility manager's office, supervisor's office, etc.)?

Answer If Referring to any dimming capability on overhead lights in... On a wall within my workspace Is Selected Or Referring to any dimming capability on overhead lights in... On my computer screen Is Selected

Q7.7 Does the dimmer control the overhead light in your workspace only?
- Yes (1)
- No, it also controls overhead light in other occupants’ workspaces (2)
- I don't know (3)

Q7.8 How much do you Agree or Disagree with the following statements?

	Very Strongly Disagree (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	Very Strongly Agree (7)	N/A (-999)
It is easy to figure out how the lighting systems work here in order to adjust them. (1)	❍	❍	❍	❍	❍	❍	❍	❍
It is easy to adjust window & shade systems. (2)	❍	❍	❍	❍	❍	❍	❍	❍
It is easy to find ways to override or adjust the light sensors if needed. (3)	❍	❍	❍	❍	❍	❍	❍	❍

Q88 Do you ever feel lighting is too bright or too dim to comfortably perform your work?

	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)
Definitely:Not at all (1)	❍	❍	❍	❍	❍	❍	❍

Q90 Please explain above response

Q8.1 Visual and Acoustic Privacy

Q8.2 From where you sit in your workspace, how satisfied are you with

	Very Dissatisfied (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	Very Satisfied (7)
Access to a view of outside (1)	❍	❍	❍	❍	❍	❍	❍
Visual privacy (what people can see or what you can see from you workspace) (2)	❍	❍	❍	❍	❍	❍	❍
Acoustic privacy (what people can hear or what you can hear from your workspace) (3)	❍	❍	❍	❍	❍	❍	❍
Noise level (4)	❍	❍	❍	❍	❍	❍	❍

Q8.4 If noise affects your workspace, is the noise from (check all that apply):

- ❑ Conversations in adjacent workspaces (1)
- ❑ Conversations in the circulation / lobby areas (2)
- ❑ Background mechanical noise (3)
- ❑ Your communications (4)
- ❑ Other, please specify (5) ____________________
- ❑ Not relevant (6)

Q9.1 Overall Workspace Ratings

Q9.2 The following is asking how important these are to you, not how satisfied you are with them.

	Not All Important (1)	(2)	(3)	(4)	(5)	(6)	Very Important (7)
Noise levels (1)	❍	❍	❍	❍	❍	❍	❍
Temperature (2)	❍	❍	❍	❍	❍	❍	❍
Privacy (3)	❍	❍	❍	❍	❍	❍	❍
Air quality/Ventilation (4)	❍	❍	❍	❍	❍	❍	❍
Size of Work Space (5)	❍	❍	❍	❍	❍	❍	❍
View to the outside (6)	❍	❍	❍	❍	❍	❍	❍
Lighting (7)	❍	❍	❍	❍	❍	❍	❍
Daylight in my workspace (8)	❍	❍	❍	❍	❍	❍	❍
Ability to adjust my workspace to fit my needs (9)	❍	❍	❍	❍	❍	❍	❍
Comfort of furnishings (10)	❍	❍	❍	❍	❍	❍	❍

Q9.3 Taking all things into consideration, how satisfied are you with your workspace environment?

	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)
Very Dissatisfied :Very Satisfied (1)	❍	❍	❍	❍	❍	❍	❍

Q9.4 How well does your building perform in extreme weather conditions?

	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)
Not well at all:Very well (1)	❍	❍	❍	❍	❍	❍	❍

Q9.5 If you have any additional comments on how workspace and building features affect your work, please type in the text box below.

Q10.1 Health and Well-Being The next several questions ask about your health, both in and outside of your workplace. Please answer to the best of your ability and skip any questions you do not wish to answer. Your responses are completely confidential and any identifying information is kept private, and may help guide improvements to the workplace.

Q10.2 General Health Please respond to each item by marking one box per row.

	Poor (1)	Fair (2)	Good (3)	Very Good (4)	Excellent (5)
In general, would you say your health is: (1)	❍	❍	❍	❍	❍
In general, would you say your quality of life is: (2)	❍	❍	❍	❍	❍
In general, how would you rate your physical health? (3)	❍	❍	❍	❍	❍
In general, how would you rate your mental health, including your mood and your ability to think? (4)	❍	❍	❍	❍	❍

Q10.3 How frequently have you experienced the following health problems in your workspace during the work day?

	Daily (1)	1-3 Times/week (2)	1-3 Days/month (3)	Not in the last month (4)	Infrequently/Almost never (5)	Never (6)
Fatigue (1)	❍	❍	❍	❍	❍	❍
Feeling of stress or irritability (2)	❍	❍	❍	❍	❍	❍
Inability to concentrate (3)	❍	❍	❍	❍	❍	❍
Lack of alertness, sleepiness (4)	❍	❍	❍	❍	❍	❍
Feeling unpleasant and out of sorts (5)	❍	❍	❍	❍	❍	❍
Headaches (6)	❍	❍	❍	❍	❍	❍
Eyes discomfort (7)	❍	❍	❍	❍	❍	❍
Symptoms of respiratory or allergy conditions (8)	❍	❍	❍	❍	❍	❍
Dry, itchy skin (9)	❍	❍	❍	❍	❍	❍
Muscular aches or pains (10)	❍	❍	❍	❍	❍	❍

Q11.1 Work Performance and Satisfaction

Q11.6 Do the following factors affect your motivation and ability to get the job done?

	Not at all (1)	Somewhat (2)	Definitely (3)	Very Definitely (4)
Salary (1)	❍	❍	❍	❍
Fringe benefits (2)	❍	❍	❍	❍
Management style (3)	❍	❍	❍	❍
Environmental quality of my workspace, generally (4)	❍	❍	❍	❍

Q11.7 Generally, how satisfied are you with your JOB?
______ (1)

Q11.8 How would you rate the general QUALITY of your work?
______ (1)

Q12.1 Please indicate how much you agree or disagree with the following statements.

	Very Strongly Disagree (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	Very Strongly Agree (7)	N/A (-999)
I feel it is very important for this building to save energy. (1)	❍	❍	❍	❍	❍	❍	❍	❍
Most people who are important to me think that I should save energy whenever possible (2)	❍	❍	❍	❍	❍	❍	❍	❍
Protecting the environment is an important goal in our society. (3)	❍	❍	❍	❍	❍	❍	❍	❍

Q12.2 People weigh many factors when choosing how to do things that use water and energy in their workplaces. Please rate each of the following items in response to the question: How important is it for you to avoid:

	Not Important (1)	Slightly Important (2)	Somewhat Important (3)	Very Important (4)	Supreme Importance (5)
Personal discomfort? (1)	❍	❍	❍	❍	❍
Effort and hassle? (2)	❍	❍	❍	❍	❍
Extra cost and expense? (3)	❍	❍	❍	❍	❍
Environmental impacts? (4)	❍	❍	❍	❍	❍

Q13.1 Background Information (Personal) The following questions are about you. The answers to these questions will help us to further understand your experience in your workspace. Your responses to these and all questions will be held completely confidential. If you are uncomfortable about answering any of these questions please feel free to refrain from answering.

Q13.2 What is your sex?
- ❍ Female (1)
- ❍ Male (2)

Q13.3 What is your age?
- ❍ Under 20 (1)
- ❍ 20 to 29 (2)
- ❍ 30 to 39 (3)
- ❍ 40 to 49 (4)
- ❍ 50 to 59 (5)
- ❍ 60 to 69 (6)
- ❍ 70 and over (7)

Q13.4 What is the highest level of formal education you have completed?
- ❍ Completed grade school or less (1)
- ❍ Some high school (2)
- ❍ Completed high school or received GED (3)
- ❍ Some college (4)
- ❍ Completed college (5)
- ❍ Graduate or professional degree (6)
- ❍ Other____________________________ (-999)

If Completed grade school or less Is Selected, Then Skip To Which of these categories represent...If Some high school Is Selected, Then Skip To Which of these categories represent...If Completed high school or re... Is Selected, Then Skip To Which of these categories represent...

Q13.5 Final major field of study in college (e.g., history, accounting, medicine)?
- ❍ Major: (1) ____________________
- ❍ N/A (-999)

Q13.6 Which of these categories represents your race/ethnic background? (Mark all that apply to you)
- ❑ White (1)
- ❑ Black or African American (2)
- ❑ American Indian or Alaska Native (3)
- ❑ Asian (4)
- ❑ Hispanic, Latino (5)
- ❑ Other (please specify) (6) ____________________

Q14.1 End of Survey If you are satisfied with your responses to the survey please click on the "Submit" button below. Please note that you will not be able to return to the survey once you click on "Submit". We really appreciate the time and effort you spent in answering this questionnaire. Thank you!!

HVAC/Lighting September 2013 **Date**
Interview Guide – Tenant Rep **Location**

Introduction – note that we are interested in design & operation of building & building systems– how well the working environment suits your needs, particularly with respect to lighting and your comfort with heating &cooling. .. Feel free to mention small or big things about your working space or common spaces…

1. Introductions
    a. Name, Title, Organization, Mission, Number of Employees

2. Overview of the study – Jen - note focus on HVAC/Lighting
    a. Hope to provide feedback on how people view HVAC and lighting here (pre and post design)

3. Overall, how satisfied are you with the work environment?
    a. Any surprises (good or bad?)?
    b. What could be improved in your office/suite?

4. Satisfaction with work environment

    In general, how satisfied or happy are you with the lighting – how is the lighting in your work area?
    a. Ambient (overall) lights in your area?

        i. Enough? Too much? Too little?

        ii. Level of control to fit need?

            1. Who can adjust?
                a. You, your office? Fm? No one?

iii.Glare?

iv. Off hours lighting

1. How adjust? Who call?

b. Task (desk) lights?

i.Enough? Too much? Too little?

ii.Level of control to fit need?

iii.Glare?

c. What about thermal comfort (i.e., temperature, humidity)

i. In general, how satisfied or happy are you with temperature/humidity, temperature control, temperature fluctuation here?

ii. Often too hot or too cold here?

1. (at desk? In other areas?)

2. How does it affect your comfort? work?

3. What can/do you do in response?

a. (thermostat? Port. heater, clothes, call FM?)

4. How responsive is management?

iii. Seasonal?

1. When are biggest problems

a. Heating season? Cooling season?

b. Early in morning? Monday? Late in day?

iv. Compared to other places you have worked?

d. Daylight & view
   i. Enough access?

   ii. Glare/control? (shades?)

   iii. Is it important?

e. Air quality (i.e., odors, air flow)

f. Level of personal control (i.e., ability to reconfigure work environment to fit one's temperature preference, etc.)

g. Effort involved in making one's work environment comfortable

h. To what extent is your interior fit out coordinated with the design of this building? In other words, have you sought to maximize daylighting? Thermal comfort? Work process flow? Other?

5. How are the temp & lighting in common spaces (lobby? Parking? Etc.?)

6. Do you feel that your organization receives sufficient information and feedback regarding HVAC and lighting use/consumption? Does the structure of the lease provide you with economic benefits if your organization decreases its energy use?

7. How supportive are people who work here for “green” actions (saving energy, recycling, etc.)? Do you think the views & attitudes of employees (such as their political views) affects how supportive they are of “green” actions?

8. Anything else about these issues we should know?

Intercept Interview Guide

1. What do you think of this building / workspace as a place to work?
    - What are its best features
    - Worst features

2. How would you rate the temperature at this very moment:

    Too warm, too cold, just right?

    In general in your office space? Other areas of the building?

3. What about air flow:

    Too high, too low, just right?

    In general in your office space? Other areas of the building?

4. How would you rate the lighting level at this very moment:

    Too bright, too dim, just right?

    In general in your office space? Other areas of the building?

Bonus Questions

How would you describe the level of personal control over HVAC and lighting that you have? (i.e., ability to reconfigure work environment to fit one's temperature preference, etc.)

1. Lighting:

2. HVAC

How much effort would you say is involved in making your work environment comfortable?

What amount of information have you been provided regarding lighting/HVAC operations/control? $costs?

Is there anything you would change about lighting / hvac?

HVAC

Tenant / Space ID	Zone	Spatial Function	Exposure	Detectable Air Movement	vents	operable vents (attached)	window treatments	Occupant accommodat.ions	Thermost. location	Thermost. / Temp. Interior reading	Temp. outside	Other
# should match index of space on floor plan	1= perimeter location 2=core location	1=office space 2=circulation 3=common area 4=cubes	1=N 2=S 3=E 4=W	0= no 1= yes	0=none 1=ceiling 2=other	Includes baseboard heating but not portable heaters 0=no 1=yes	0=no 1=yes	Includes fans, portable space heaters, sweaters	0=none proximal 1=located proximally			

LIGHTING

Tenant / Space ID	Zone	Spatial Function	Exposure	Overhead rectangular fluorescents	# on/ off/ partial / dim	Task lights	Switch locations	Windows/ day-lighting	Window Tx	Distance & Lux Readings	Other Comment
# should match index of space on floor plan	1= perimeter location 2=core location	1=office space 2=circulation 3=common area 4=cubes	1=N 2=S 3=E 4=W	actual #	0=off 1=partial 2=all	0=None 1=off 2=on	0=none proximal 1=located proximally	0=none 1=Min 2= Moderate 3=Bright	Unless specified, blinds 0=closed 1=partial open 2=open		

GB Morning Daily 2013 - 10/3/13

Q80 Daily Survey: Before Lunch survey This survey is the second component of the 2-part survey protocol in which you have already agreed to participate. There is a morning and afternoon version of the survey. You will receive it 2 times per day approximately 1-3 times per week. Each response you provide will be entered into the pool for the random drawings once the entire study is completed. Please take a few minutes now or before lunch to complete this 3 minute survey. Thank you for your continued participation in this study! ►► PLEASE CHOOSE THE ANSWER THAT BEST REFLECTS YOUR RESPONSE CONSIDERING YOUR TIME AT WORK THIS MORNING.

Q1 How many hours did you spend in YOUR WORKSPACE this morning? (Please round up to nearest hour)
- ❑ 0 (7)
- ❑ 1 (1)
- ❑ 2 (2)
- ❑ 3 (3)
- ❑ 4 (4)
- ❑ 5 (5)
- ❑ 6+ (6)

Q2 How PLEASANT do you feel this morning?
______ (1)

Answer If How PLEASANT do you feel this morning?   Is Empty

Q2.1 Do you want to leave this question without moving the slider? If No, please use the back button to go back and answer the question. If Yes, please select from the following:
- ❍ I want to skip this question (1)
- ❍ My answer choice is "0" (2)

Q3 How ALERT do you feel this morning?
______ (1)

Answer If How ALERT do you feel this morning?   Is Empty

Q3.1 Do you want to leave this question without moving the slider? If No, please use the back button to go back and answer the question. If Yes, please select from the following:

- ❍ I want to skip this question (1)
- ❍ My answer choice is "0" (2)

Q4 How would you rate your PHYSICAL HEALTH this morning?

______ (1)

Answer If How would you rate your PHYSICAL HEALTH this morning?   Is Empty

Q4.1 Do you want to leave this question without moving the slider? If No, please use the back button to go back and answer the question. If Yes, please select from the following:

- ❍ I want to skip this question (1)
- ❍ My answer choice is "0" (2)

Q5 How would you rate your MENTAL HEALTH, including your mood and your ability to think, this morning?

______ (1)

Answer If How would you rate your MENTAL HEALTH, including your moo...   Is Empty

Q5.1 Do you want to leave this question without moving the slider? If No, please use the back button to go back and answer the question. If Yes, please select from the following:

- ❍ I want to skip this question (1)
- ❍ My answer choice is "0" (2)

Q6 How would you rate your ability to CONCENTRATE this morning?

______ (1)

Answer If How would you rate your ability to CONCENTRATE this morning?   Is Empty

Q6.1 Do you want to leave this question without moving the slider? If No, please use the back button to go back and answer the question. If Yes, please select from the following:

- ❍ I want to skip this question (1)
- ❍ My answer choice is "0" (2)

Q7 How STRESSED are you this morning?
______ (1)

Answer If How STRESSED are you this morning?   Is Empty

Q7.1 Do you want to leave this question without moving the slider? If No, please use the back button to go back and answer the question. If Yes, please select from the following:

- ❍ I want to skip this question (1)
- ❍ My answer choice is "0" (2)

Q8 How FATIGUED are you this morning?
______ (1)

Answer If How FATIGUED are you this morning?   Is Empty

Q8.1 Do you want to leave this question without moving the slider? If No, please use the back button to go back and answer the question. If Yes, please select from the following:

- ❍ I want to skip this question (1)
- ❍ My answer choice is "0" (2)

Q9 Have you engaged in PHYSICAL ACTIVITY today (e.g., exercise)?

- ❍ Yes (1)
- ❍ No (2)

If No Is Selected, Then Skip To How would you rate the QUALITY of you...

Q9.1 How long ago was this?

- ❍ Less than an hour (1)
- ❍ 1 hour (2)
- ❍ 2 hours (3)
- ❍ 3 hours (4)
- ❍ 4 hours (5)
- ❍ More than 4 hours (6)

Q9.2 What degree of effort did this physical activity demand?

- ❍ Minimal, light demand (1)
- ❍ Moderate demand (2)
- ❍ Heavy demand (3)

Q10 How would you rate the QUALITY OF YOUR WORK this morning?
______ (1)

Answer If How would you rate the QUALITY of your work this morning?   Is Empty

Q10.1 Do you want to leave this question without moving the slider? If No, please use the back button to go back and answer the question. If Yes, please select from the following:

- ❍ I want to skip this question (1)
- ❍ My answer choice is "0" (2)

Q11 How would you rate your PRODUCTIVITY this morning?

______ (1)

Answer If How would you rate your PRODUCTIVITY this morning?   Is Empty

Q11.1 Do you want to leave this question without moving the slider? If No, please use the back button to go back and answer the question. If Yes, please select from the following:

- ❍ I want to skip this question (1)
- ❍ My answer choice is "0" (2)

Q12 How SATISFIED are you with your JOB this morning?

______ (1)

Answer If How satisfied are you with your JOB this morning?   Is Empty

Q12.1 Do you want to leave this question without moving the slider? If No, please use the back button to go back and answer the question. If Yes, please select from the following:

- ❍ I want to skip this question (1)
- ❍ My answer choice is "0" (2)

Q13 How does the AIR QUALITY in your workspace today COMPARE to:

______ Earlier today (1)

______ The day before (2)

Q14 How SATISFIED are you with the overall AIR QUALITY in your workspace this morning?

______ (1)

Answer If   How SATISFIED are you with the overall AIR QUA...   Is Empty

Q14.1 Do you want to leave this question without moving the slider? If No, please use the back button to go back and answer the question. If Yes, please select from the following:

- ❍ I want to skip this question (1)
- ❍ My answer choice is "0" (2)

Answer If   How SATISFIED are you with the overall AIR QUA...   Is Less Than 0

Q14.2 Which of the following conditions are you experiencing in your workspace?

- ❑ Air Drafts (6)
- ❑ Stuffiness (7)
- ❑ Too humid (8)
- ❑ Too dry (9)
- ❑ Unpleasant odors (10)
- ❑ Air quality varies (11)

Q15 What kind of CHANGES did you make to improve the AIR QUALITY in your workspace this morning?

- ❑ Opened windows (1)
- ❑ Used freshener (2)
- ❑ Contacted facilities (3)
- ❑ Other (4) ____________________
- ❑ No changes made (5)

Q16 How satisfied are you with your ABILITY TO CHANGE the INDOOR AIR QUALITY in your workspace this morning?

______ Neutral (1)

Answer If How SATISFIED are you with your ability to CHANGE the IND... Neutral Is Empty

Q16.1 Do you want to leave this question without moving the slider? If No, please use the back button to go back and answer the question. If Yes, please select from the following:

- ❍ I want to skip this question (1)
- ❍ My answer choice is "0" (2)

Q17 How does the TEMPERATURE in your workspace today COMPARE to:
______ Earlier today (1)
______ The day before (2)

Q18 How SATISFIED are you with the TEMPERATURE in your workspace this morning?
______ (1)

Answer If How SATISFIED are you wit...   Is Empty

Q18.1 Do you want to leave this question without moving the slider? If No, please use the back button to go back and answer the question. If Yes, please select from the following:
❍ I want to skip this question (1)
❍ My answer choice is "0" (2)

Q19 Do you feel TOO HOT OR TOO COLD to be able to FOCUS on your work?
❍ 1 = Definitely (1)
❍ 2 (2)
❍ 3 (3)
❍ 4 (4)
❍ 5 (5)
❍ 6 (6)
❍ 7 = Not at all (7)

Q20 What kind of CHANGES did you make to the TEMPERATURE in your workspace this morning?
❑ Opened windows (1)
❑ Adjusted local controls for vents, fans, thermostats (2)
❑ Adjusted window shades or blinds (3)
❑ Used a portable fan or heater (4)
❑ Contacted facilities (5)
❑ Other (6) ____________________
❑ No changes (7)

Q21 How satisfied are you with your ABILITY TO CHANGE the TEMPERATURE in your workspace this morning?
______ (1)

Answer If How SATISFIED are you with your ability to change the TEM...   Is Empty

Q21.1 Do you want to leave this question without moving the slider? If No, please use the back button to go back and answer the question. If Yes, please select from the following:

- I want to skip this question (1)
- My answer choice is "0" (2)

Q22 How SATISFIED are you with the NOISE level in your workspace this morning?
______ (1)

Answer If How SATISFIED are you with the NOISE level in your work...   Is Empty

Q22.1 Do you want to leave this question without moving the slider? If No, please use the back button to go back and answer the question. If Yes, please select from the following:

- I want to skip this question (1)
- My answer choice is "0" (2)

Q23 How does the LEVEL OF LIGHT in your workspace today COMPARE TO:
______ Earlier today (1)
______ The day before (2)

Q24 How SATISFIED are you with the ELECTRIC LIGHTING in your workspace this morning?
______ (1)

Answer If How SATISFIED are you with the ELECTRIC LIGHTING in you...   Is Empty

Q24.1 Do you want to leave this question without moving the slider? If No, please use the back button to go back and answer the question. If Yes, please select from the following:

- I want to skip this question (1)
- My answer choice is "0" (2)

Q25 Does the LIGHTING allow you to see well at your desk, in order to read, write, and use the computer?

- ❍ 1 = Not at all (1)
- ❍ 2 (2)
- ❍ 3 (3)
- ❍ 4 (4)
- ❍ 5 (5)
- ❍ 6 (6)
- ❍ 7 = Definitely (7)

Q26 How did you ADJUST the LIGHTING in your workspace this morning? (choice, select all that apply)

- ❑ Used switch/dimmer for all overhead lights (1)
- ❑ Used switch/dimmer for some overhead lights (2)
- ❑ Made adjustments on a computer (Liberty Smart Control) (3)
- ❑ Adjusted task light (4)
- ❑ Adjusted the window shades or blinds (5)
- ❑ Other (6) ____________________
- ❑ No adjustments made (7)

Q27 How satisfied are you with your ABILITY TO ADJUST the LIGHTING in your workspace this morning?

______ (1)

Answer If How SATISFIED are you with your ability to ADJUST the LIG...   Is Empty

Q27.1 Do you want to leave this question without moving the slider? If No, please use the back button to go back and answer the question. If Yes, please select from the following:

- ❍ I want to skip this question (1)
- ❍ My answer choice is "0" (2)

Q28 How much does the WEATHER OUTSIDE today affect your indoor work environment?

______ (1)

GB Afternoon Daily 10/3/13

Q1 This is the "End of Work Day" survey: You will receive this daily afternoon survey approximately 2-3 times per week. Each daily takes approximately 2-3 minutes to complete. Each response you provide will be entered into the pool for the random drawings once the entire study is completed. This survey is part of the second component of the 2-part survey protocol in which you have already agreed to participate. Please take a few minutes now or before leaving to complete this survey. Thank you for your continued participation in this study!
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►►►►►►►►►►►►►►►►►►►►► PLEASE CHOOSE THE ANSWER THAT BEST REFLECTS YOUR RESPONSE CONSIDERING YOUR TIME AT WORK THIS AFTERNOON. Please complete this survey sometime before you leave work.

Q2 How many hours did you spend in YOUR WORKSPACE this afternoon (Please round to nearest hour)?

- ❑ 0 (8)
- ❑ 1 (2)
- ❑ 2 (3)
- ❑ 3 (4)
- ❑ 4 (5)
- ❑ 5 (6)
- ❑ 6+ (7)

Q3 How PLEASANT do you FEEL this afternoon?

______ (1)

Answer If How PLEASANT do you FEEL this afternoon?   Is Empty

Q4 Do you want to leave this question without moving the slider? If No, please use the lower back button to go back and answer the question. If Yes, please select from the following:

- ❍ I want to skip this question (1)
- ❍ My answer choice is "0" (2)

Q5 How ALERT do you FEEL this afternoon?

______ (1)

Answer If How do you FEEL this afternoon? - Is Empty

Q6 Do you want to leave this question without moving the slider? If No, please use the lower back button to go back and answer the question. If Yes, please select from the following:

❍ I want to skip this question (1)

❍ My answer choice is "0" (2)

Q7 How would you rate your PHYSICAL health this afternoon?

_______ (1)

Answer If How would you rate your PHYSICAL health this afternoon?   Is Empty

Q8 Do you want to leave this question without moving the slider? If No, please use the lower back button to go back and answer the question. If Yes, please select from the following:

❍ I want to skip this question (1)

❍ My answer choice is "0" (2)

Q9 How would you rate your MENTAL health, including your mood and your ability to think, this afternoon?

_______ (1)

Answer If How would you rate your MENTAL health, including your moo...   Is Empty

Q10 Do you want to leave this question without moving the slider? If No, please use the lower back button to go back and answer the question. If Yes, please select from the following:

❍ I want to skip this question (1)

❍ My answer choice is "0" (2)

Q11 How would you rate your ability to CONCENTRATE this afternoon?

_______ (1)

Answer If How would you rate your ability to CONCENTRATE this after...   Is Empty

Q12 Do you want to leave this question without moving the slider? If No, please use the lower back button to go back and answer the question. If Yes, please select from the following:

❍ I want to skip this question (1)

❍ My answer choice is "0" (2)

Q13 How STRESSED are you this afternoon?
______ (1)

Answer If How STRESSED are you this afternoon?   Is Empty
Q14 Do you want to leave this question without moving the slider? If No, please use the lower back button to go back and answer the question. If Yes, please select from the following:

- ❍ I want to skip this question (1)
- ❍ My answer choice is "0" (2)

Q15 How FATIGUED are you this afternoon?
______ (1)

Answer If How FATIGUED are you this afternoon?   Is Empty
Q16 Do you want to leave this question without moving the slider? If No, please use the lower back button to go back and answer the question. If Yes, please select from the following:

- ❍ I want to skip this question (1)
- ❍ My answer choice is "0" (2)

Q17 How would you rate the QUALITY of your work this afternoon?
______ (1)

Answer If How would you rate the QUALITY of your work this afternoon?   Is Empty
Q18 Do you want to leave this question without moving the slider? If No, please use the lower back button to go back and answer the question. If Yes, please select from the following:

- ❍ I want to skip this question (1)
- ❍ My answer choice is "0" (2)

Q19 How would you rate your PRODUCTIVITY this afternoon?
______ (1)

Answer If How would you rate your PRODUCTIVITY this afternoon?   Is Empty
Q20 Do you want to leave this question without moving the slider? If No, please use the lower back button to go back and answer the question. If Yes, please select from the following:

- ❍ I want to skip this question (1)
- ❍ My answer choice is "0" (2)

Q21 How satisfied are you with your JOB this afternoon?
______ (1)

Answer If How satisfied are you with your JOB this afternoon?   Is Empty

Q22 Do you want to leave this question without moving the slider? If No, please use the lower back button to go back and answer the question. If Yes, please select from the following:

- ❍ I want to skip this question (1)
- ❍ My answer choice is "0" (2)

Q23 How does the AIR QUALITY in your workspace today COMPARE to:
______ Earlier today (1)
______ The day before (2)

Q24 How SATISFIED are you with the overall AIR QUALITY in your workspace this afternoon?
______ (1)

Answer If How SATISFIED are you with the overall AI...   Is Empty

Q25 Do you want to leave this question without moving the slider? If No, please use the lower back button to go back and answer the question. If Yes, please select from the following:

- ❍ I want to skip this question (1)
- ❍ My answer choice is "0" (2)

Q26 Which of the following conditions are you experiencing in your workspace?

- ❑ Air Drafts (1)
- ❑ Stuffiness (2)
- ❑ Too humid (3)
- ❑ Too Dry (4)
- ❑ Unpleasant odors (5)
- ❑ Air quality varies (6)

Q28 What changes did you make to improve the AIR QUALITY in your workspace this afternoon?

- ❑ Opened windows (1)
- ❑ Used freshner (2)
- ❑ Contacted facilities (3)
- ❑ Other (4) ____________________
- ❑ No changes made (5)

Q29 How satisfied are you with your ABILITY TO CHANGE the INDOOR AIR QUALITY in your workspace this afternoon?
______ (1)

Answer If How satisfied are you with your ABILITY TO CHANGE the IND...   Is Empty

Q30 Do you want to leave this question without moving the slider? If No, please use the lower back button to go back and answer the question. If Yes, please select from the following:
- ❍ I want to skip this question (1)
- ❍ My answer choice is "0" (2)

Q31 How does the TEMPERATURE in your workspace today COMPARE to:
______ Earlier today (1)
______ The day before (2)

Q32 How satisfied are you with the TEMPERATURE in your workspace this afternoon?
______ (1)

Answer If How satisfied are you with the TEMPERATURE in your worksp...   Is Empty

Q33 Do you want to leave this question without moving the slider? If No, please use the lower back button to go back and answer the question. If Yes, please select from the following:
- ❍ I want to skip this question (1)
- ❍ My answer choice is "0" (2)

Q34 Do you feel TOO HOT OR TOO COLD to be able to FOCUS on your work?
- ❍ Definitely (1)
- ❍ 2 (2)
- ❍ 3 (3)
- ❍ 4 (4)
- ❍ 5 (5)
- ❍ 6 (6)
- ❍ Not at all (7)

Q35 What kinds of CHANGES did you make to the TEMPERATURE in your workspace this afternoon?

❑ Opened windows (1)

❑ Adjusted local controls for vents, fans, thermostats (2)

❑ Contacted facilities (3)

❑ Other (4) ____________________

❑ No changes (5)

Q36 How SATISFIED are you withyour ABILITY to CHANGE the TEMPERATURE in your workspace this afternoon?

______ (1)

Answer If How SATIS...   Is Empty

Q37 Do you want to leave this question without moving the slider? If No, please use the lower back button to go back and answer the question. If Yes, please select from the following:

❍ I want to skip this question (1)

❍ My answer choice is "0" (2)

Q38 How SATISFIED are you with the NOISE level in your workspace this afternoon?

______ (1)

Answer If How SATIS...   Is Empty

Q39 Do you want to leave this question without moving the slider? If No, please use the lower back button to go back and answer the question. If Yes, please select from the following:

❍ I want to skip this question (1)

❍ My answer choice is "0" (2)

Q40 How does the LEVEL OF LIGHT in your workspace today COMPARE TO:

______ Earlier today (1)

______ The day before (2)

Q41 How satisfied are you with the ELECTRIC LIGHTING in your workspace this afternoon?

______ (1)

Answer If ...   Is Empty

Q42 Do you want to leave this question without moving the slider? If No, please use the lower back button to go back and answer the question. If Yes, please select from the following:

❍ I want to skip this question (1)
❍ My answer choice is "0" (2)

Q43 Does the LIGHTING allow you to see well at your desk, in order to read, write, and use the computer?

❍ Not at all (1)
❍ 2 (2)
❍ 3 (3)
❍ 4 (4)
❍ 5 (5)
❍ Definately (6)

Q44 How did you adjust the LIGHTING in your workspace this afternoon? (choice, select all that apply)

❑ Used switch/dimmer for all overhead lights (1)
❑ Used switch/dimmer for some overhead lights (2)
❑ Adjusted task light (3)
❑ Adjusted the window shades or blinds (4)
❑ No adjustments made (5)
❑ Other (6) ____________________

Q45 How satisfied are you with your ability to adjust the LIGHTING in your workspace this afternoon?

______ (1)

Answer If How satisfied are you with your ability to adjust the LIG...   Is Empty

Q46 Do you want to leave this question without moving the slider? If No, please use the lower back button to go back and answer the question. If Yes, please select from the following:

❍ I want to skip this question (1)
❍ My answer choice is "0" (2)

Q47 How much does the WEATHER OUTSIDE today affect your indoor work environment?

______ 1 (1)

Appendix B: REIT Milestone Table for Retrofits

DESCRIPTION	DATE COMPLETED
Revised Milestones (12/19/2011)	
PHASE 1 – PILOT PHASE - BUILDING 1, BUILDING 2	
ENGINEERING	
Phase 1 - Field Verification and Prelim Schematics	7/1/2010
Phase 2 - 60% Lighting Design (Includes Controls)	7/15/2010
Phase 2 - 60% HVAC Design (Includes Controls)	7/15/2010
Phase 3 - 90% Lighting Design (includes Controls)	8/4/2010
Phase 3 - 90% HVAC Design (includes Controls)	8/4/2010
Phase 4 - Construction Administration	8/16/2011
CONSTRUCTION	
Lighting Installation	**4/1/2011**
Equipment Ordering/Arrival	Dec-10
Meter Installation (occurs simultaneously)	May-11
HVAC Installation	**May-11**
Equipment Ordering/Arrival	Dec-10
Controls Installation	May-11
Retro-Commissioning	**Sep-12**
Punchlist	Dec-11
COMMISSIONING AND REPORTING	
Commissioning Engineer Survey	Sep-12
Performance Reporting Begins	In Progress
PHASE 2 – BUILDING 3, BUILDING 4, BUILDING 5, BUILDING 6	
ENGINEERING	
Phase 1 - Field Verification and Prelim Schematics	4/30/2011
Phase 2 - 60% Lighting Design (Includes Controls)	6/30/2011
Phase 2 - 60% HVAC Design (Includes Controls)	7/31/2011
Phase 3 - 90% Lighting Design (includes Controls)	6/30/2011
Phase 3 - 90% HVAC Design (includes Controls)	7/31/2011
Phase 4 - Construction Administration	1/30/2013
CONSTRUCTION	
Lighting Installation	**9/30/2012**
Equipment Ordering/Arrival	2/1/2012
Controls Installation	9/30/2012

HVAC Installation	**11/30/2012**
Equipment Ordering/Arrival	9/30/2012
Controls Installation	11/30/2012
Retro-Commissioning	**In Progress**
Punchlist	In Progress
COMMISSIONING AND REPORTING	
Commissioning Engineer Survey	In Progress
Performance Reporting Begins	In Progress
PHASE 3 – BUILDING 7, BUILDING 8, BUILDING 9, BUILDING 10	
ENGINEERING	
Phase 1 - Field Verification and Prelim Schematics	Oct-12
Phase 2 - 60% Lighting Design (Includes Controls)	Oct-12
Phase 2 - 60% HVAC Design (Includes Controls)	Oct-12
Phase 3 - 90% Lighting Design (includes Controls)	Nov-12
Phase 3 - 90% HVAC Design (includes Controls)	Dec-12
Phase 4 - Construction Administration	In Progress
CONSTRUCTION	
Lighting Installation	**In Progress**
Equipment Ordering/Arrival	2/28/2013
Installation	In Progress
HVAC Installation	**In Progress**
Equipment Ordering/Arrival	2/28/2013
Controls Installation	In Progress
Retro-Commissioning	**In Progress**
Punchlist	In Progress
COMMISSIONING AND REPORTING	
Commissioning Engineer Survey	
Performance Reporting Begins	

Appendix C: Energy Conservation Measure Retrofit Details by Building

Building Address	Phase	Existing Building Controls	Building Controls Solutions	Existing Lighting	Lighting & Control Solutions	Existing HVAC	HVAC Solutions	Existing Meters	Meter Solutions	Other Ideas	Cap X
BUILDING 1	Phase I - Pilot	Trane Tracer Summit full DDC	Overlay Trane Summit & Commission	3 lamp T8 Deep Cell Parabolic	Convert Ballasts - DALI Controls - Elighting Lighting zones for lobby, exterior, non-fluorescent	(2) New Trane Intellipak RTUs (~130 ton)	Controls, CO2 sensors, replace (2) RTU VSD EF fans	(2) BWAN main meters	Meter HVAC panel, lighting panel, VAV terminal unit panel	Bolts Bang (fixed) consider autoshades. Beta Site	
BUILDING 2	Phase I - Pilot	Trane Tracer Summit - Full DDC terminal	Upgrade Trane BMS	3 lamp T8 Deep Cell Parabolic	Convert Ballasts - Enceliu m 0-10 volt, BMS controls Lighting zones for lobby, exterior, non-fluorescent	(3) 130 ton 190 kw Trane RTU 2004	CO2 sensors and controls on RTUs, VSDs on RTU EF (SAT Reset)	(2) BWAN main meters	Meter (3) RTUs, VAV box panels, lighting panel	(16) existing meters, lobby daylighting	
BUILDING 3	Phase II	Trane Tracer summit on 4 of 7 RTUs	Extend Trane system to 3 RTUs and overlay	3 & 4 lamp prismatic and deep cell parabolic T8 (50% occ sensors)	Convert Ballasts - Lutron DALI Lighting Control, controls Lighting zones for lobby, exterior, non-fluorescent	(7) RTU 2004 & 1997- (5) 30 ton, 20 ton with electric heat	Controls, CO2 sensors and RTU VSD Fans (SAT Reset)	(2) BWAN main meters	Meter HVAC panel, lighting panel, VAV terminal unit panel	Skylight in Lobby, 80% VAVs have DDC	RTU replacement and controls expansion
BUILDING 4	Phase II	Trane Tracer Summit - Full DDC terminal	Upgrade Trane BMS or replace Tridium BAS w/terminal controls	3 lamp T8 Deep Cell Parabolic	Convert Ballasts - Lutron DALI Lighting Control, controls Lighting zones for lobby, exterior, non-fluorescent	(4) Existing Trane Intellipak RTUs and VAV boxes	CO2 sensors and controls on RTUs, VSDs on RTU EF (SAT Reset) - RTU VSDs added under separate project.	(2) BWAN main meters	Meter HVAC panel, lighting panel		Replace older RTUs.

Building Address	Phase	Existing Building Controls	Building Controls Solutions	Existing Lighting	Lighting & Control Solutions	Existing HVAC	HVAC Solutions	Existing Meters	Meter Solutions	Other Ideas	Cap X
BUILDING 5	Phase II	Programmable RTU Thermostats, time clocks & pneumatic VAV thermostats	Upgrade Trane BMS - RTU and VAV box controls	Mix of 2 or 3 lamp T8 (T12) prismatic	Convert Ballasts - Lutron DALI Lighting Control, controls Lighting zones for lobby, exterior, non-fluorescent	1983 (2) 50 ton (no elec), (2) 7.5 ton, (2) 5 ton RTU (4 elec heat).	New Box controllers, Controls, CO2 sensors and RTU VSD fans (SAT Reset) - New RTUs under other cost center	(2) BWAN main meters	Meter HVAC panel, lighting panel, VAV terminal unit panel	Phase monitor, Peco Evaluator - not included	RTU replacement for tenant complaint.
BUILDING 6	Phase II	Trane Tracer Summit - Full DDC terminal	Upgrade Trane BMS	3 lamp T8 Deep Cell Parabolic	Convert Ballasts - Lutron DALI Lighting Control, controls Lighting zones for lobby, exterior, non-fluorescent	(4) 1997 RTUs - (3) 100 ton 190 kW, (1) 20 tons 30 kW	Control Upgrade, CO2 sensors, VSDs on RTU EF (SAT Reset)	(2) BWAN main meters	Meter (3) RTUs, VAV box panels, lighting panel		Replace older RTUs.
BUILDING 7	Phase III	Trane Tracer Summit - Full DDC terminal	Upgrade Trane BMS	3 lamp deep cell parabolic T8	Convert Ballasts - Enceliu m 0-10 volt, BMS controls Lighting zones for lobby, exterior, non-fluorescent	(4) Existing Trane Intellipak RTUs and VAV boxes	Convert Ballasts - Lutron DALI Lighting Control, controls Lighting zones for lobby, exterior, non-fluorescent	(2) BWAN main meters	Meter HVAC panel, lighting panel, VAV terminal unit panel		
BUILDING 8	Phase III	Trane Tracer Summit - Full DDC terminal	Upgrade Trane BMS	3 lamp T8 Deep Cell Parabolic	Convert Ballasts - Enceliu m 0-10 volt, BMS controls Lighting zones for lobby, exterior, non-fluorescent	(10) 2001 RTUs - (3) 130 ton, (3) 110 tons, 30, 20, (2) 5 ton	CO2 sensors and controls on RTUs, VSDs on RTU EF (SAT Reset)	(2) BWAN main meters	Meter RTUs, VAV box panels, lighting panel, submeters		

Building Address	Phase	Existing Building Controls	Building Controls Solutions	Existing Lighting	Lighting & Control Solutions	Existing HVAC	HVAC Solutions	Existing Meters	Meter Solutions	Other Ideas	Cap X
BUILDING 9	Phase III	Exeter WSHP controls with Teletrol HP controls	New Trane BMS Controls, Heat Pumps & Accessories	3 lamp deep cell parabolic T8 - Some various older lenses	Convert Ballasts - Encelium 0-10 volt, BMS controls Lighting zones for lobby, exterior, non-fluorescent	(56) WSHP, 175 ton CT, Gas boiler, (2) MUA units	Keep CT, Boiler, Pumps (add VSDs), replace WSHP controllers, CO2, new MUA units	(2) BWAN main meters	Meter HVAC, Lighting	RCX, 13.2 kV - 750 KVA, meter issue (oversized) - not addressed	Some $ for HVAC or Controls
BUILDING 10	Phase III	Local Trane 7 day programmable (17) RTU thermostats - analog terminal	Wireless RTU Viconics thermostats - Tridium Front end (SAT Reset) Trane	2,3,4 lamp, T8/T12, tight egg crate parabolic (changed just below project)	Convert Ballasts - Encelium 0-10 volt, BMS controls Lighting zones for lobby, exterior, non-fluorescent	(17) York 1989 CV RTUs 5 tons	CO2 sensors and controls on RTU	(2) BWAN main meters	Meter HVAC panel, lighting panel	Spray foam underside of roofing in attic (not accepted), signal to 100 kW, RCX	Lighting and Ceiling upgrade

Appendix D: Occupant Satisfaction with Temperature

Source: Senick et al, 2013b

Differences between Perceived and Desired Temperature

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1.00 Too cold	15	31.9	39.5	39.5
	2.00 OK	12	25.5	31.6	71.1
	3.00 Too hot	11	23.4	28.9	100.0
	Total	38	80.9	100.0	
Missing	System	9	19.1		
Total		47	100.0		

Perceived Temperature Differential as Predictor of Thermal Satisfaction during Baseline, Control Days, and Load Shed Days

	Temperature Differential	**Satisfaction with Temperature**
Baseline	**F (2,35) = 10.552*** **	**OK > Too Hot & Too Cold**
Control Days	**F (2,30) = 5.373***	**OK > Too Hot & Too Cold**
Load Shed Days	**F(2,23) = 1.960, ns.**	**OK & Too Cold > Too Hot (ns)**

***= P<.05 ***= p<.001**

Appendix E: Schedule of Load Shedding (2013)

Week of	LS	Weather	Daily Surveys	Data Downloaded	Control	Weather	Daily Surveys	Data Downloaded	Level	Comments
8/26/2013										
	8/28/2013	rain, overcast	x	am & pm	8/29/2013	cloudy	x	am & pm	I	All bldgs, onsite to Building 1 & Building 6 for LS
	1:30-5pm								HVAC: setpoint +/- 2.5 degrees	
9/2/2013									LIGHTING: 10% reduction	
	9/4/2013	bright, sunny, 80	x	am & pm	9/6/2013	bright, sunny, 70's	x	am & pm	2	All buildings, onsite to Building 8 LR (am) and Building 7 (pm)
	2-5pm								HVAC: setpoint +/- 3.5 degrees	
9/9/2013									LIGHTING: 20% reduction	
	9/11/2013	sunny, very hot and humid, low 90's	x	am & pm	9/10/2013	overcast, humid, low 80's	x	pm only	2 HVAC, 3 Lighting	All bldgs, **actual event (not simulated)**, onsite to Building 7 (pm)
	3pm								HVAC: setpoint +/- 3.5 degrees	
9/16/2013									LIGHTING: 30% reduction	
	9/18/2013	sunny, mid 70's	X	AM & PM	9/19/2013	sunny, mid to upper 70's	x	am & pm	0 HVAC, 2 lighting	All bldgs, Research team onsite to Building 2, 9.18.13 pm
9/23/2013	2:15-5pm								LIGHTING: 20% reduction	
	9/25/2013	sunny, mid 70's	X	AM & PM	9/26/2013	sunny, mid 70's	X	am & pm	0 HVAC, 3 lighting	All bldgs, Research team to Building 8, 9/25 pm 1 participant noted dimmer lights.
	2-5pm									

Week of	LS	Weather	Daily Surveys	Data Downloaded	Control	Weather	Daily Surveys	Data Downloaded	Level	Comments
9/30/2013									LIGHTING: 30% reduction	
	10/2/2013	sunny, upper 70's	X	AM & PM	10/3/2013	partly cloudy, upper 70's	X	am & pm	2	All bldgs, Research team to Building 1, 10/2/13 1 -2 participants noted dimmer lights, warmer conditions
	2:30-5pm								HVAC: setpoint +/- 3.5 degrees	
									LIGHTING: 20% reduction	

Appendix F: Regression Analysis on Building Occupant Satisfaction

Source: (Malenchek et al, 2014)

Regression Analysis of Treatment and Predictor Variables on Satisfaction and Health Scales						
	Environmental Satisfaction		Health		Job Satisfaction/Productivity	
Regressor	**Equation (3)**	**Equation (4)**	**Equation (3)**	**Equation (4)**	**Equation (3)**	**Equation (4)**
HVAC Load Shed	0.13 (1.052)	-0.40 (0.974)	1.94** (0.894)	0.66 (0.655)	2.07* (1.118)	0.92 (0.960)
Lighting Load Shed	0.06 (0.978)	0.37 (0.831)	-1.62* (0.842)	-0.65 (0.579)	-1.63 (1.061)	-0.71 (0.883)
Floor 2	-1.80 (1.892)	0.52 (4.181)	2.85 (1.771)	0.17 (1.717)	0.98 (2.006)	-3.31* (1.978)
Floor 3	6.54*** (1.906)	1.80 (4.275)	2.31 (1.408)	3.85* (2.225)	0.47 (1.843)	-5.66* (2.884)
NW Exposure	7.25*** (2.801)	14.15*** (3.778)	-0.84 (1.821)	-8.59*** (2.161)	-4.30* (2.236)	4.05 (2.882)
NE Exposure	7.66*** (1.946)	6.16* (3.561)	0.79 (1.455)	0.55 (2.026)	-0.48 (1.746)	-6.80*** (2.096)
SW Exposure	21.13*** (5.818)	25.81*** (3.069)	11.85*** (2.589)	3.65 (2.268)	3.29 (3.236)	3.87 (2.693)
Office	14.57*** (1.576)	5.76** (2.247)	8.18*** (1.209)	4.30** (1.724)	7.28*** (1.426)	-1.52 (2.208)
Open space/other	-9.35** (3.893)	-4.60 (4.559)	-5.43* (2.923)	-1.26 (2.835)	-3.96 (3.001)	-2.70 (4.212)
Phase 1	-8.87*** (2.267)	-0.75 (3.210)	-7.01*** (1.374)	-1.01 (1.566)	-8.20*** (1.460)	0.31 (2.026)
Phase 2	5.52 (3.534)	13.94*** (4.104)	-3.97** (1.679)	-5.96*** (2.115)	-4.28* (2.424)	2.06 (2.865)
Morning	1.95 (1.557)	-0.32 (1.460)	3.77*** (0.969)	1.60* (0.963)	2.72** (1.150)	-0.93 (1.118)
Prefered Temp Difference		-0.06 (0.419)		-0.53*** (0.167)		0.54*** (0.160)
Prefered Lighting Difference		0.13 (0.283)		-0.12 (0.083)		0.43*** (0.091)
Environmental Satisfaction		(omitted)		0.17*** (0.049)		2.00 (1.765)
Health		0.40*** (0.116)		(omitted)		-8.59*** (0.343)
Job Satis/Product		0.05 (0.094)		0.55*** (0.069)		(omitted)
Intercept	28.44*** (3.792)	4.51 (5.952)	44.38*** (2.302)	8.51* (4.615)	58.11*** (2.505)	88.41*** (4.801)
N Size	300	177	409	177	435	177
F Statistic	15.23***	26.49***	10.42***	49.65***	7.71***	25.52***
R-sq	0.328	0.594	0.276	0.717	0.188	0.675

All tests include a time variable and an interaction between time and the treatment variables. Robust standard errors are given in parentheses under coefficients. The individual coefficient is statistically significant at the *10%, **5%, or ***1% significance level using a two-tailed test.

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