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REPORT

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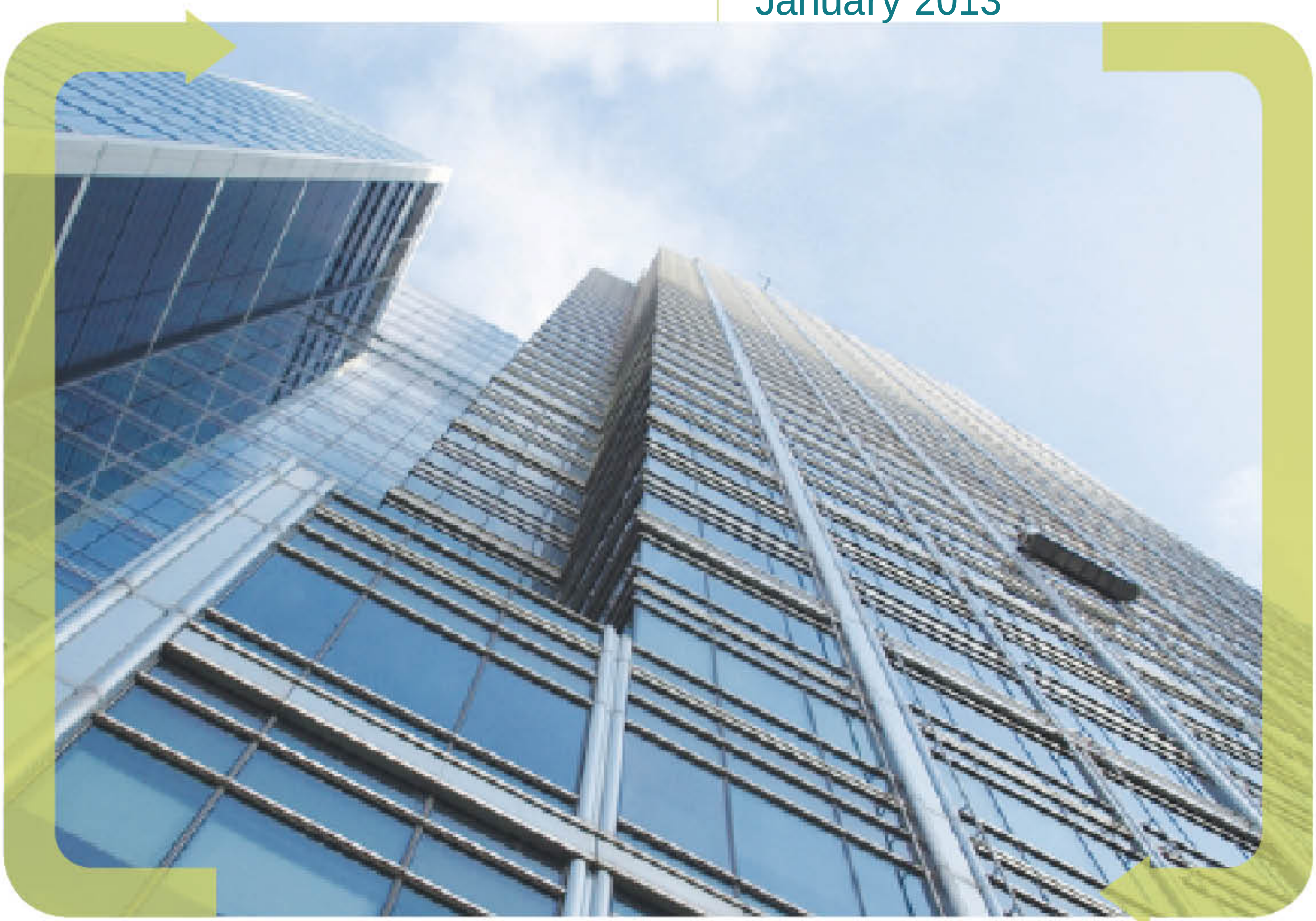
Post-Retrofit Assessment of Lighting & HVAC Conditions in Three Tenanted Buildings- Liberty – PECO Smart Grid Investment Grant Program

January 2013



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For US DOE Energy Efficient Buildings Hub

Post-Retrofit Assessment of Lighting & HVAC Conditions in Three Tenanted Buildings

EXECUTIVE SUMMARY

The objectives of this post-occupancy evaluation (POE) of three commercial office buildings in the greater Philadelphia region were threefold:

1) Enhance the understanding of the roles that occupant behavior plays in building energy performance.

2) Test methodologies for evaluations of energy use and design strategies in office settings.

3) Collect baseline and post retrofit behavioral and observational data regarding HVAC and lighting energy saving technologies as a basis for generating behavioral findings/hypotheses.

Post-occupancy evaluation (POE) is a systematic evaluation of building and systems data, observations, and building users' opinions that highlight factors that can improve the functionality and efficiency of the building as well as inform future design strategies. POEs employ both quantitative and qualitative methods to compare the performance of a site (most typically a building and its users) to theoretically constructed or client-driven objectives. POEs may adopt research designs that are longitudinal (looking at the same site across time) or comparative/cross-sectional (evaluating a site against others involved in the same project, or in existing databases) (Wener, Richard E., McCunn, Lindsay J., & Senick, Jennifer, in preparation).

The overall goal of this POE is to conduct research that supports building design and operating decisions that improve energy performance without sacrificing occupant satisfaction, health, safety or productivity. From the behavioral side, its main focus is on usability of building energy saving technologies. Modern facilities have complex and multi-faceted controls that need careful adjustment to provide user comfort while maintaining efficient use of energy. If the person-system interface for these controls is difficult or obscure (e.g., Norman, 1988) they can be ignored or set incorrectly making users dissatisfied and unproductive, and forcing adaptive responses while at the same time wasting energy. Past studies suggest that usability may be critical in determining the success of innovations for energy related building technology (Blumstein, Krieg, Schipper, & York, 1980; Case, 1984; Wener, 1984; Volink, Meertens, & Midden, 2002). Research has also shown that giving occupants increased control over these systems as they affect their workspaces is critical to their satisfaction with the setting (Michelson, 1977; Weidemann, & Anderson, 1985; Francescato, Weidemann, & Anderson, 1989; Bonaiuto et al., 1999), and that lack of control can lead to decreased productivity (Cole & Steiger 1999; Heerwagen, 2000). When building occupants find systems to be unusable they may become unhappy (unsatisfied), lose time in trying to adjust the systems

(productivity loss) and take adaptive actions that while improving occupant comfort may interfere with building performance.

The sites addressed here hold additional interest because they are tenanted buildings; two are multi-tenanted and one houses only a single tenant. Tenanted buildings are particularly difficult settings with regards to energy management as they are commonly challenged by split incentives (master-metering), fragmented responsibilities, diffused information flows and tension between centralized and localized control of building energy systems, which may have implications for building usability. In multi-tenanted buildings, these challenges potentially are exaggerated.

BACKGROUND

Liberty Property Trust (Liberty), a Malvern-based real estate investment trust, in partnership with PECO, the local utility, secured a US Department of Energy ARRA-funded matching grant to perform energy efficiency upgrades in a portfolio of ten buildings as part of the Smart Grid Investment Grant program (SGIG). This grant was awarded through the "Smart Future Greater Philadelphia – Turning Existing Buildings Into Smart Buildings" promotion. The program focuses on energy efficient lighting and heating, ventilation, and air conditioning (HVAC) upgrades and includes the installation of Building Wide Area Network (BWAN) energy monitoring, load shedding/demand response capabilities and variable frequency drives (VFD's).[1]

While the measures vary slightly by building, the SGIG program calls for the implementation of the following measures in the ten buildings:

- 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 integrated control systems should be capable of responding to centralized commands and utility signals for demand response with light level reductions, power demand limiters, reduced variable speed drives, electric demand reduction, and other strategies.

Research Program

In order to ascertain behavioral response to these energy saving technologies, and to develop evidence-based understanding of how occupant response may impact building energy performance, the Rutgers research team undertook a combined longitudinal/cross-sectional POE, characterized by:

1) A pre-post retrofit research design enabling evaluations of the buildings and their occupants before and after the energy saving technologies were installed; and

2) An evaluation of differences/similarities across the three buildings.

As part of the pre-post design, the team conducted a baseline evaluation of existing conditions and occupant satisfaction with respect to lighting and HVAC systems in two buildings enrolled in the

[1] Personal communication B. Dillon, 2/16/12; Interoperability Demonstrations, Liberty Property Trust, Project Abstract.

SGIG program in February 2012 in Horsham and Malvern, Pennsylvania. Follow-ups to the baseline evaluations of these two buildings were made in December 2012.

A post occupancy evaluation also was conducted at a third property located in Fort Washington, PA (the building with a single tenant), after retrofits had already taken place. This evaluation was also completed in December 2012 and included daily surveys taken by occupants to test behavioral responses to load shedding in this same building. For a detailed account of how the respondents of this building perceived load-shedding conditions, please see *Occupant Behavior in Response to Energy-Saving Retrofits and Operations* (2013) as part of this reporting series.[2]

Liberty Property Trust informed the tenants of the three buildings about the planned retrofits in advance of their taking place, and the Rutgers research team informed the tenants about the project's research objectives. Prior to Rutger's involvement with these sites, Liberty administered a short on-line survey relevant to the planned retrofits. The results indicated mixed satisfaction with temperature comfort and general satisfaction with lighting quality.

Tenant operations in these buildings varied and included sales, service, and product quality and product development offices. The Horsham building (Building Site 3) housed 8 commercial tenants, of which a government and a clinical tenant were excluded by Liberty from this study. Of the two additional buildings, the multi-tenanted Malvern site (Building Site 4) supported 9 tenants while the Ft. Washington location (Building Site 1) contained a single tenant.[3]

Site Visits and Methods

Each of the initial site visits was preceded by a review of available information and archived data about the building (i.e., floor plans, Liberty survey results, retrofit specifications, etc.). Tenant representatives were contacted prior to the site visits to arrange for walk-throughs, observations and lighting and HVAC measurements, and semi-structured interviews. The on-site visits began with a meeting/building tour with the Liberty property manager for the site.

FINDINGS PART 1: Pre-Retrofit

During the baseline or pre-evaluation of the two multi-tenanted building_visits the sky was overcast with average temperature in the mid 40's. During these visits, data was collected in a subset of all office spaces, and the results presented below are representative only of those settings. Comments from interviews and observations were aggregated for each building and evaluated for themes or topics that emerged during the analysis.

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[2] 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.

[3] Note that the numbering system for this building is continuous and overlapping with building designations in *Occupant Behavior in Response to Energy-Saving Retrofits and Operations* (2013).

HORSHAM LOCATION (Building Site 3)

Five offices with 31 individual workspaces were visited at this location and assessed for lighting and HVAC features. Figure 1 depicts the location of the workspaces visited - along the perimeter or in the core of the space.[4] These workspaces were categorized as: Enclosed offices (14), circulation (2), common spaces (9), and cubicles (4) (see Figure 2). Enclosed office work areas represented the largest number of spaces observed, followed by common spaces. Common spaces refer to conference rooms, reception and waiting areas, copy and mailrooms, and kitchen areas.

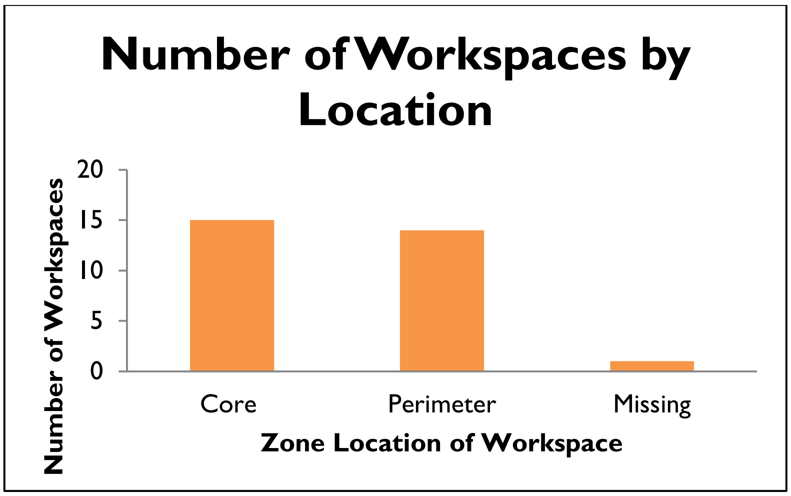


Figure 1: Location of workspaces, Building Site 3. N=29

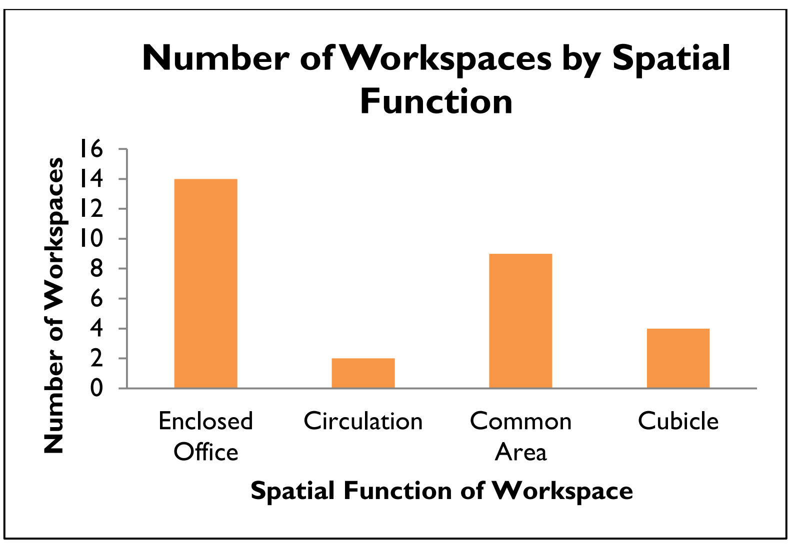


Figure 2. Type of workspaces visited, Building Site 3. N=29

[4] Not all workspaces were observed or measured as part of this pilot study.

Figure 3. High cubicles without aligned lighting fixtures in office with no custom fit-out.

Floor plan changes. In at least two separate office spaces tenants made changes in fit-out that appeared to lack integration with the location of lighting fixtures. As an unintended result, overhead light fixtures were not aligned with occupied cubicles and desk surfaces in a number of cases so that workspaces were not located directly below the light fixtures, leading to inadequate lighting on work surfaces. In some cases, occupants of these spaces reported low lighting levels for their work tasks (see Figure 3).

Lighting measurements. Lighting measurements were taken of a sample of enclosed offices, common spaces, cubicles, and circulation.[5] Of the 92 overhead fluorescent fixtures observed in 29 workspaces, 16 workspaces had lights completely on at the time of our visit, one had lights partially on, and in 10 spaces all lights were turned off. One office occupant indicated that excessive brightness led him to remove a lamp from an overhead light fixture. In two office spaces, where the ceiling lighting fixtures were not aligned with cubicle workspaces, task lighting had been added to increase illumination of work surfaces and mitigate shadows thrown below cabinet shelving. While there are no illumination code requirements, general recommendations for office space work surface lighting are 400-500 lux and very much dependent on task, particularly the extent and type of activity using computer monitors or video display terminals (VDTs) (Newsham, G.; Veitch, J.; Reinhart, C.; & Sander, D. (2004)).[6] The ability to adjust lighting to fit needs that can change from one space to another and among occupants can depend on the availability and usability of switches.

Measurements in other areas showed:

- Lighting levels ranged from 200 to 800 lux in enclosed offices, depending on location.
- The range of luminance levels in circulation spaces was very broad - between 100 lux (9 feet from a light fixture) to as bright as 1150 lux (directly beneath light fixtures).
- Illuminance in common spaces (e.g., conference rooms) had a narrow range - between 650 and 704 lux - again depending upon position relative to the light fixture. One reception area, though, registered levels as high as 900 lux.
- Luminance measures in cubicles and an open "bull pen" area also had a wide range - from 260-720 lux.

[5] Lux is a measure of illuminance, or light density per square foot on a surface.
[6] Please see IES Lighting Handbook (2011) for additional information on Office Facilities Illuminance Recommendations.

Task lighting. Of the subset of 29 workspaces visited, six had task lighting. Four of these task lights were on while two were off at the time of our visit. Figures 4 and 5 illustrate two different uses of task lighting. Lighting measures were taken both with and without task lights on and again showed variability. On the low end, in one cubicle work space measurement at a desktop work area showed only 260 lux, while a few feet away in the same cubicle, but directly under the cabinet task light, we recorded 310 lux. In another cubicle illuminance was 460 lux without task lighting and increased to 680 lux with task lighting turned on.

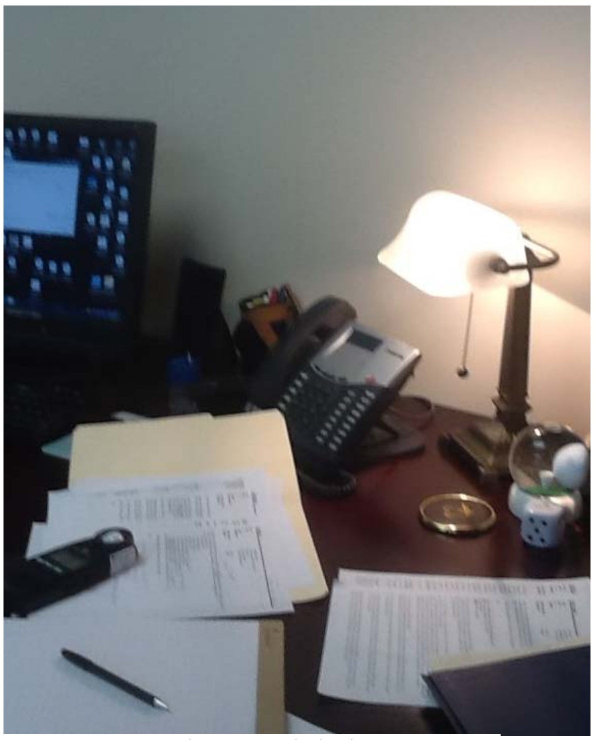


Figure 4. Desktop task lighting.

Figure 5. Under cabinet lighting

HVAC observations. Of 29 workspaces we visited, we were able to access six thermostats, which showed temperature settings between 72^0-80^0. Most of the thermostats we saw had switches with only two settings, - ‘on/off’ or ‘c(ool)/w(arm).’ In some spaces, thermostats that controlled multiple locations were located in the interior of an enclosed single office that was not accessible to many others in the office.

Occupant Response

Lighting. Comments about the lighting were somewhat diverse, suggesting more individual than systemic challenges, but generally positive. While some used task lighting only (two task lights in one case) others found task lights difficult to turn on and off. Some occupants reported excessive brightness. Glare was typically managed with blinds or tinted windows. With few exceptions lighting was found to be "fine", with "no complaints".

Heating. Comments by occupants interviewed overall described inconsistent temperature control in winter, with some improvements with recent updates. There were more reports of problems with winter than summer thermal comfort, especially with cold mornings.

MALVERN LOCATION (Building Site 4)

Four offices were visited in the Malvern (Building Site 4) building. A total of 31 workspaces were observed among these offices on two floors of the building (the third floor was vacant). The building lobby and common areas had been renovated as recently as December 2011 and the current round of retrofits had not yet been scheduled. A number of spaces were empty. Figure 6 shows the number of workspaces that were on the perimeter or in the core of office suites.

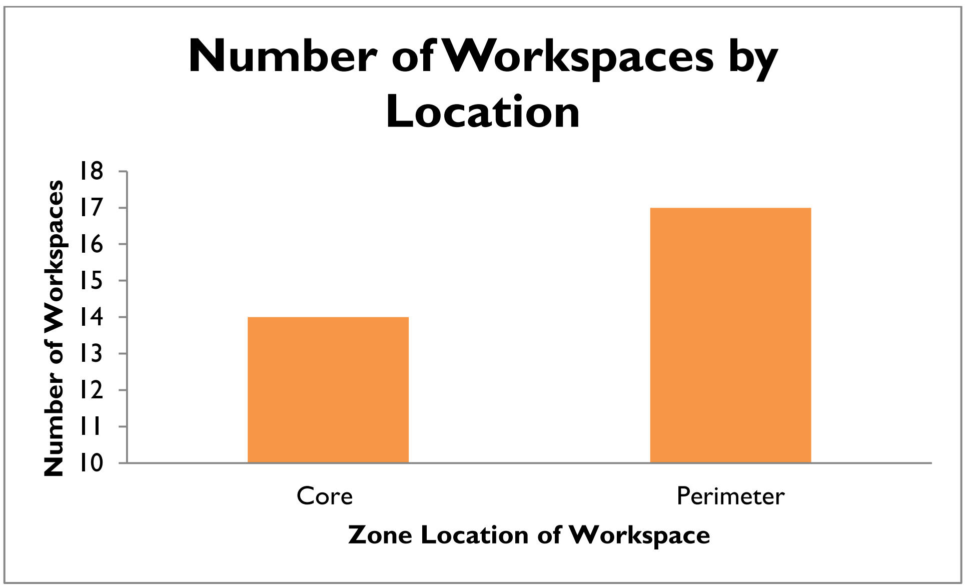


Figure 6. Location of workspaces Building Site 4. N=31.

As with Building Site 3, workspaces observed were categorized as: Enclosed offices (15), circulation (2), common space (12), cubicles (2) (see Figure 7).

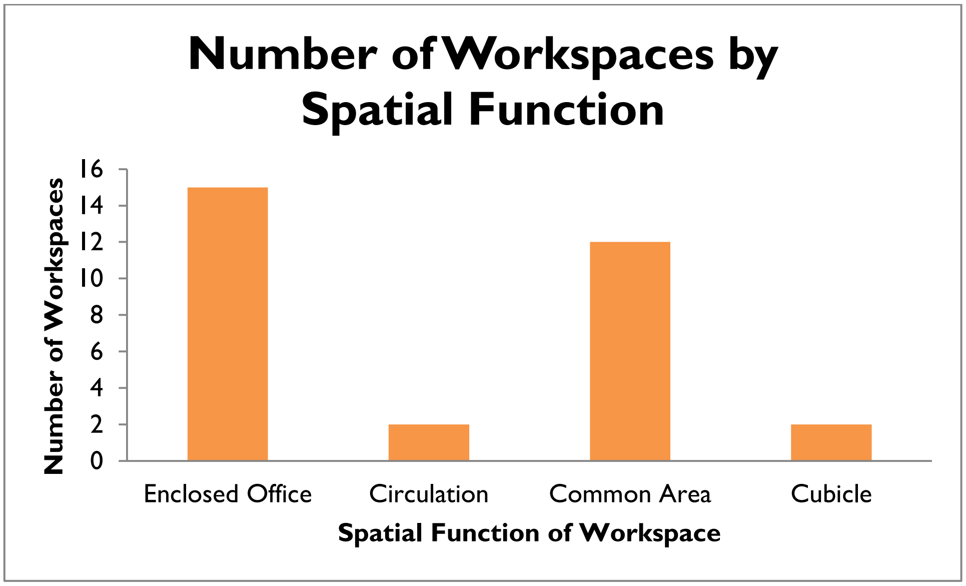


Figure 7. Types of workspaces, Building site 4. N=31

Lighting observations. Of the 31 spaces observed, all of the lights were "on" in 24 of the spaces, while two workspaces had some lights "off", and 4 workspaces (all enclosed offices) had all lights "off". There were 102 total light fixtures in these workspaces.

Figure 8. Lights "all on"

HVAC related observations. As with the Horsham location, the thermostats observed offered only 'on-off' or 'c(old)-h(ot)' options. In one workspace, even though the thermostat was set at the lowest level, heat was coming through the vents. Portable fans were found in more than one space in the Malvern building, as were portable heaters, which were particularly prevalent in the Horsham location (Building Site 3).

Occupant Response. Most occupants had heard about the planned retrofits, in some cases by attending an on-site meeting that presented an overview of the proposed changes, including opportunities to preview the new lighting fixtures. Their recollections varied, however, about exactly what kind of changes would be made. In particular, occupants offered differing reports about how much control they thought individual occupants would have over lighting and HVAC. Some thought that there would be significant levels of individual and/or office control over lighting levels and temperature, while others expected dimmers or sensor lights. In general, occupants reported positive experiences from their communications with Liberty on this and other topics with respect to responsiveness to requests, changes made to the premises, and email updates.

Temperature and thermal comfort. Most respondents from both buildings reported having experienced significant variations in office temperature with emphasis on:

- Cold conditions in the morning, especially on Mondays and days after holidays
- Shifts in interior comfort concomitant with significant changes in the weather
- Warm/hot conditions in the afternoon hours, with or without sun;
- Differences within tenant office space
- Reports of the Lobby space being cold

Many of these comments on thermal comfort were consistent with survey results generated by Liberty prior to our visit. The most extreme variations in thermal comfort were reported by occupants of Building Site 4 concerning both summer and winter seasons.

Occupants of some offices indicated that they were required to contact Liberty management in order to have heating/cooling and lighting of spaces turned on when working after normal hours or on weekends, while other tenants indicated that conditioning in their offices was available during those hours without prior-contact. In both buildings use of portable floor space heaters was common, as reported by occupants and/or observed by research team members. One respondent complained about being "unable to concentrate" in cold office conditions. It was not uncommon for people to report wearing sweaters, coats, hats, and boots in the office.

Thermostat operation. Thermostats were typically few in number (i.e., 2) per tenant space and several times we spoke to office workers who didn't know where thermostats that controlled their office temperature were. Their operation by office occupants was typically limited by:

- Thermostat placement in private office space (which also affects the accuracy of temperature readings, particularly when doors are closed)
- Offsets programmed by the central office
- Design of the thermostat itself which sometimes offered just two discrete settings
- Lack of understanding about where thermostats were located or how they operated

Figure 9. Therostat in Building Site 4.

Respondents noted that in some cases air blowers would not shut off. On the day of the site visit some thermostats were set at the highest level, in settings that were noted by the observers to be quite cool (see Figure 9). The "man in the house" feature depicted in Figure 9 is meant to allow changes in temperature settings during non-normal work hours, but has been disconnected. Some occupants thought that local thermostats were neither connected nor operational.

Lighting. When asked about lighting those occupants queried typically responded that it was "fine", but on further probing often noted that spaces were commonly over-lit, and that in some cases there was only one switch to turn on or off all lights in an area. Occupants also indicated that:

- Workstation location and lighting fixtures were often not aligned, sometimes leading to under-lit conditions.
- They relied more on overhead lighting than task lighting.
- They had a mixed response to potential or actual dimming capability.
- Lighting falling on computer screens frequently caused viewing discomfort.
- The Lobby was too bright (lux measures read 1100).

Windows and Window Walls. The design and use of glazed interior and envelope surfaces were interconnected with issues of temperature, thermal comfort and privacy. Blinds were important components of window performance.

Interior glazed surfaces. Blinds were used for offsetting interior lobby lighting infiltrating into office space as well as serving privacy and aesthetic functions. Occupants told us that multiple panels of blinds in a workspace enabled them to close some blinds for privacy while opening others to afford them the ability to see who might be outside.

In many of the offices, we observed blinds kept in the drawn position but with the louvers partially open, allowing both privacy and lighting (see Figure 10). In other cases, occupants said that they did not manipulate the blinds at all or relied on other office personnel to do so.

Figure 10. Adjusted blinds

Building envelope glazing. Blinds were seen as important for protecting privacy from visitors who were walking around the outside of the building. This seemed particularly true for Building Site 3 that has high profile government and health lab tenants sharing the building. We also heard reports of using the blinds for views to the outside (parking lot traffic), for keeping out direct sunlight and glare, and reducing temperature and heat gain. In one enclosed office space with a northwest exposure, closed blinds were not seen as particularly effective in eliminating glare from direct sunlight. In another office with southwest exposure the addition of tinted windows was successful in reducing glare. While many voiced appreciation for the benefits of windows, drafts and cold during this winter season and excess heat in the summer were noted, particularly in Building Site 4.

Some of the corridor or common spaces we visited appeared to be over-lit with multiple fixtures, lighting areas in which there would not typically 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.

Summary of Pre-Retrofit Evaluation

Concerns about thermal comfort was the predominate theme for pre-retrofit visits to both Building Sites 3 & 4. Occupants we spoke with found that thermostats were limited in their usefulness in improving building conditions and developed adaptive behaviors that ranged from personal strategies (e.g., dressing in layers) to managing blinds that were readily available to control light and heat discomfort, to contacting management, and to using energy-intensive appliances (e.g., portable heaters and fans). Occupants often reported some areas, especially common and circulation areas but also workspaces, as too bright, although cubicles in particular were sometimes not well coordinated with lighting fixtures and less well lit.

FINDINGS PART 2: Post-Retrofit

Site visits were conducted again after the planned retrofits for the buildings had been implemented. Members of the study team visited three of the previous six tenant sites on the single floor at the Horsham location and four of the six on two floors at Malvern due to limited tenant availability. During these visits, lighting measurements were obtained from some of the same spaces as visited during the pre-retrofit evaluation (i.e., floors 1 and 2) in order to compare independent observations with occupant self-reports. Temperature and humidity readings were also taken during the follow-up visits.[7] On the day of the post-retrofit site visits to both the Horsham and Malvern locations, the sky was mostly clear and average temperatures were in the mid to upper 40's, conditions similar to the pre- or baseline visits. In Fort Washington, all floors of the building's single tenant were visited and examined. The visit to the Fort Washington location was also completed December 2012, with temperatures in the low 40's as well.

As with the baseline visit, post-retrofit data were collected in a subset of office spaces, and the results presented below are representative only of those settings. Notes of observations and interviews were recorded on prepared forms as well as on floor plans provided by Liberty. Comments from interviews and observations, obtained where possible in conjunction with measurements, were aggregated for each building based upon themes or topics that emerged during the analysis. Building-level data were then evaluated for broader themes that inform building occupant-behavioral research.

HORSHAM LOCATION

Background. Work on the retrofit of lighting and HVAC had been completed by the time of the follow-up site visit, with the installation of controls wiring, ballast replacement (to enable dimming), and new fixtures were installed in some offices. HVAC work was less visible to building occupants and included the installation of controls for Variable Frequency Drives (VFDs) and rebalancing (personal communication, M. Thalheimer, 2/1/12).

Three offices with 28 individual workspaces were visited at this location and assessed for lighting and HVAC conditions. Figure 11 depicts the location of the workspaces visited - along the perimeter or in the core of the space.[8] These workspaces were categorized as: Enclosed offices (10), circulation (6), common spaces (7), and cubicles (5) (see Figure 12).

[7] Konica Minolta Illuminance Meter T-10, standard receptor head and Fisher Scientific Humidity/Temperature/Dew Point Meter were instruments used for measurements.
[8] Not all workspaces were observed or measured as part of this pilot study.

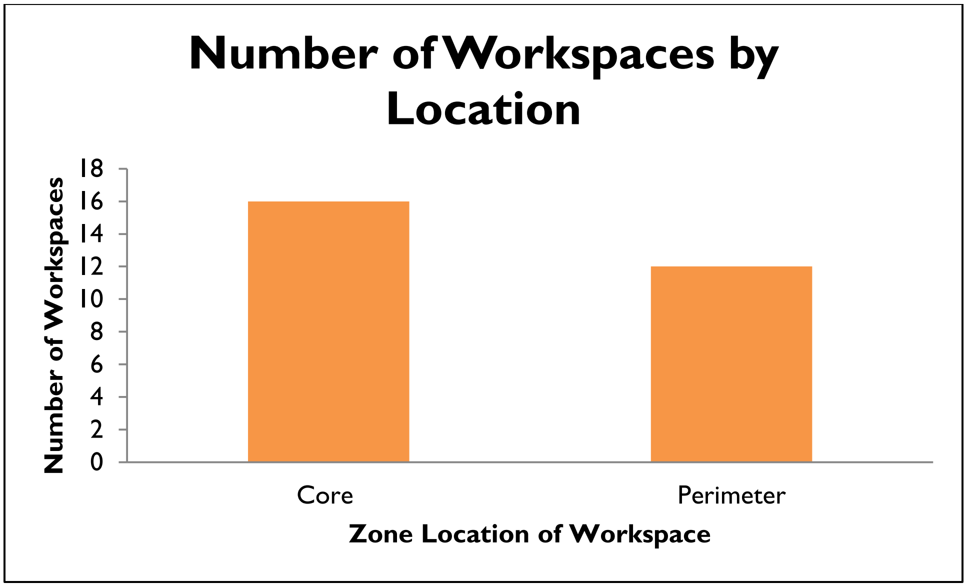


Figure 11: Location of workspaces, Building Site 3, N=28.

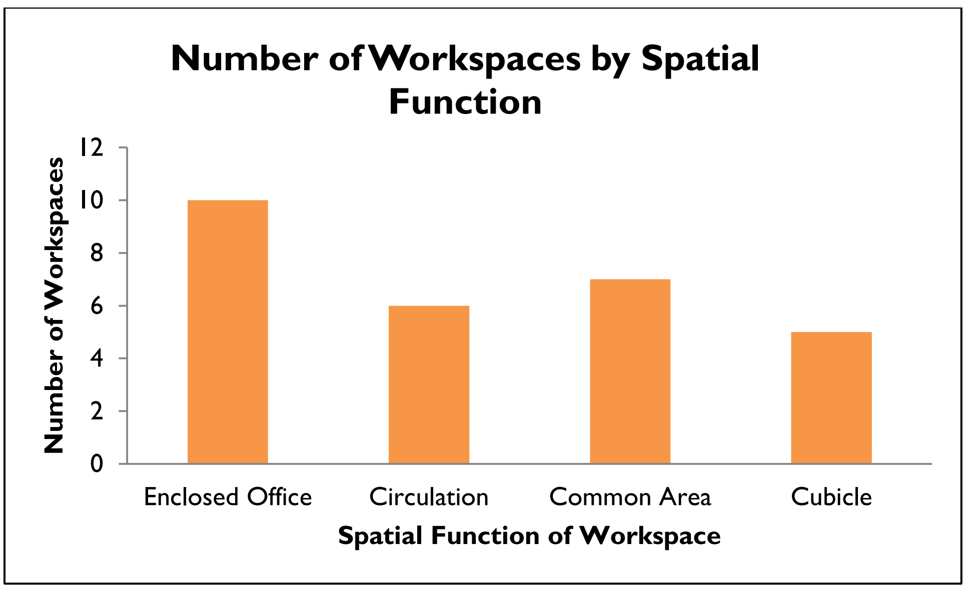


Figure 12. Type of workspaces visited, Building Site 3.

Enclosed office work areas represented the largest number of spaces observed followed by common spaces. Common spaces include conference rooms, reception and waiting areas, copy and mailrooms, and kitchen areas.

Lighting measurements. As in the pre-retrofit baseline, lighting measurements were taken in a sample of enclosed offices, common spaces, cubicles, and circulation areas. The retrofit program included removing light switches and installing occupancy sensors and integrated occupancy daylight sensor systems. A few offices, however, retained switches or received dimmer switches because of occupants' health or scheduling needs.

Measurements were typically taken from work surfaces and at sightline to Video Display Terminals (VDTs), and occasionally from other points (e.g., desk surface near windows). The post-retrofit measurements taken in these areas showed that:

- When just comparing core to perimeter locations, perimeter locations were brighter, as expected, by about 40 lux. This amounts to a fairly large reduction in differences from the baseline, in which the perimeter was almost 120 lux brighter than the core.
- Lighting levels ranged from 180 to 900 lux in enclosed offices, depending on location. This represents an increase in the range compared to the baseline measurements in both directions (previous range 200-800 lux).
- The range of luminance levels in circulation spaces was between 35 and 475 lux, with the average being 247 lux, consistent with general guidelines for relevant activities in the broader field of view (Newsham, G.; Veitch, J.; Reinhart, C.; & Sander, D. (2004)).[9] The baseline readings showed readings from 150 to 900 lux (525 average), suggesting reductions of overlie spaces.
- Illuminance in common spaces (e.g., conference rooms) ranged from 300 to 1020 lux - again depending upon location. One kitchen measurement, directly under a skylight, registered the level of 1020 lux; the next highest measurement was 517 lux. The baseline results were similar, with the kitchen reading being 900 lux.

[9] Please see IES Lighting Handbook (2011) for additional information on Office Facilities Illuminance Recommendations.

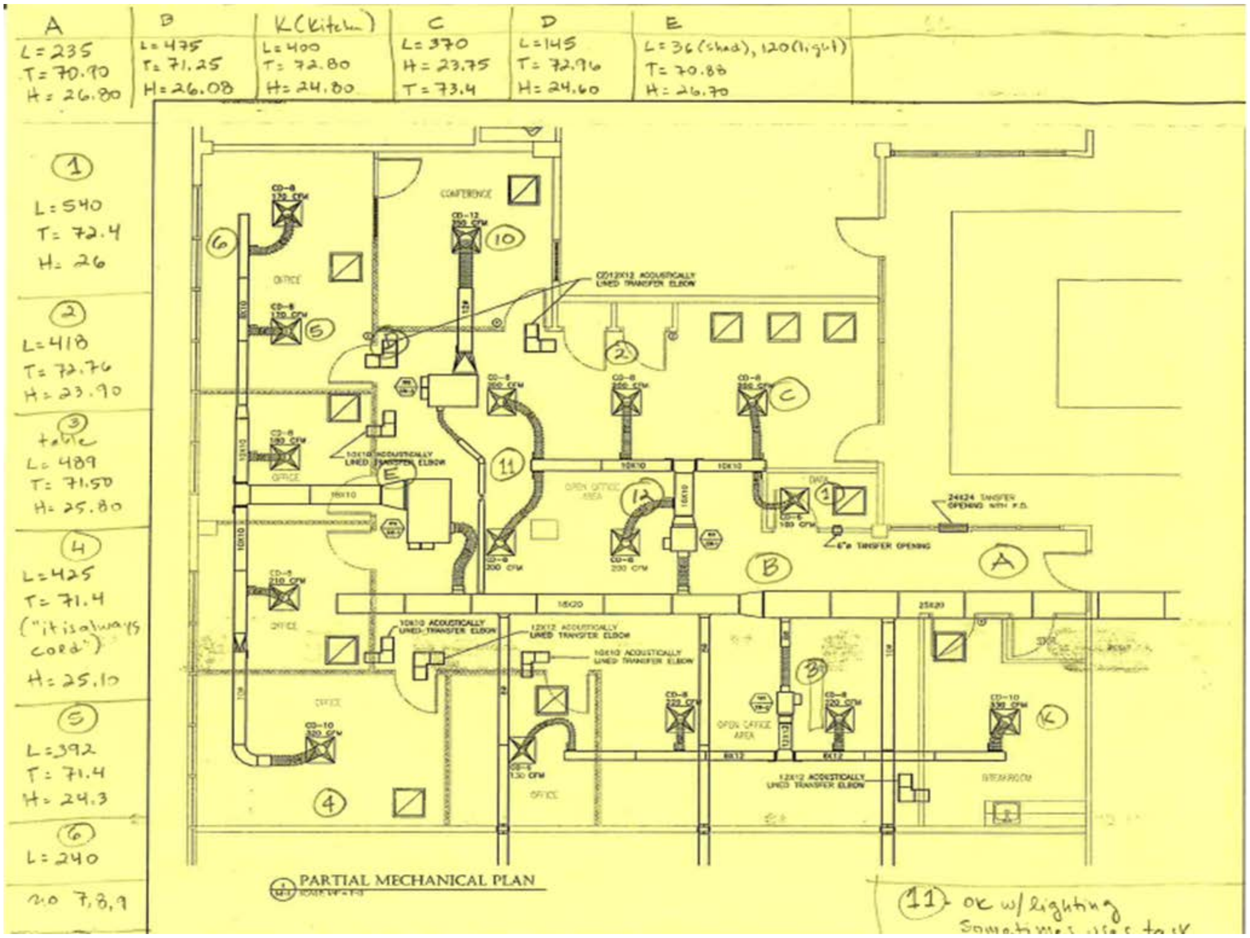


Figure 13: Example of working plan with lux and location measures for post-retrofit site visit. Close up of plan image cropped from original.

- Luminance measures in cubicles and an open "bull pen" area also had a wide range - from 220-920 lux. This compares to the relatively smaller range of the baseline measures (310-600 lux).

Figure 13 provides an example of how a lighting plan was used to measure illumination in one office visited.

<u>Task lighting.</u> Of the subset of 28 workspaces that we visited, 4 were found to have task lighting, none of which were on at the time of the visit.

HVAC observations. The post-retrofit temperatures and humidity levels (percentage in parentheses) taken in the different locations showed that:

- The average temperatures for the three tenants were 72.2 (25%), 73.8 (24.2%), and 75.8 (21.3%) degrees Fahrenheit, with an overall mean of 73 (24.3%) degrees.
- The average temperatures for the four spatial functions were quite similar, ranging from about 72.3 to 74.3 degrees, and the humidity ranging from 22.8% to 24.9%, as seen in Figures 14 & 15.

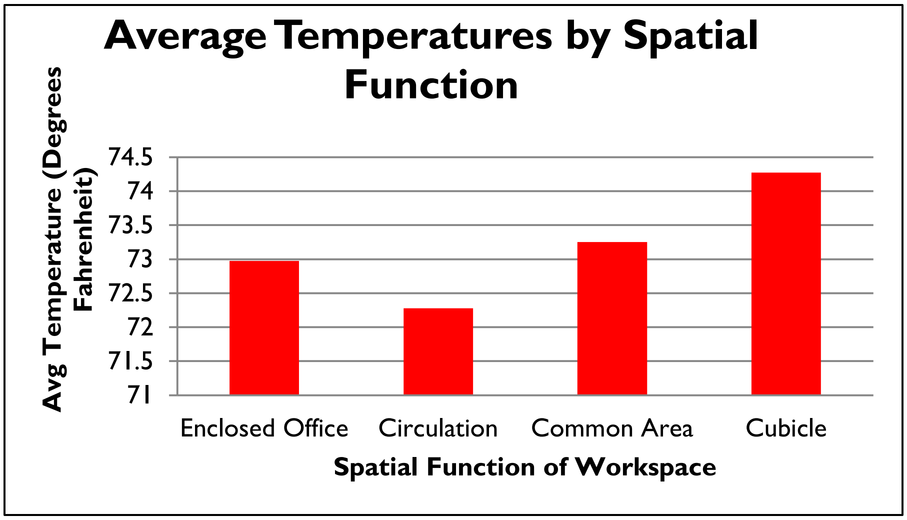


Figure 14. Average temperatures at midday by workspace type, Building Site 3. N=28

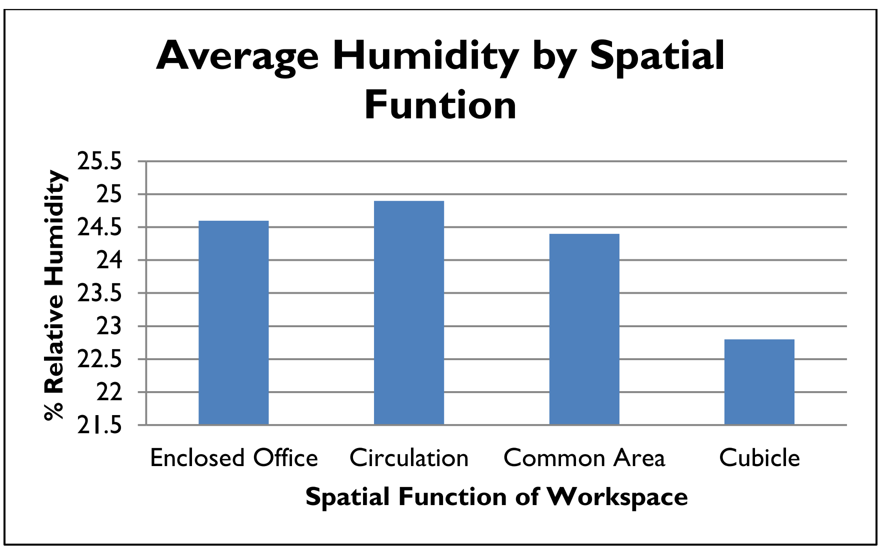


Figure 15. Average humidity at midday by workspace type, Building Site 3. N=28

MALVERN LOCATION

Four offices were visited in the Malvern building. A total of 17 workspaces were observed among these offices on two floors of the building. Figure 16 shows the number of workspaces that were on the perimeter (14) or in the core of office suites (3). As before, workspaces observed were categorized as: Enclosed offices (4), circulation (4), common space (6), cubicles (3) (See Figure 17).

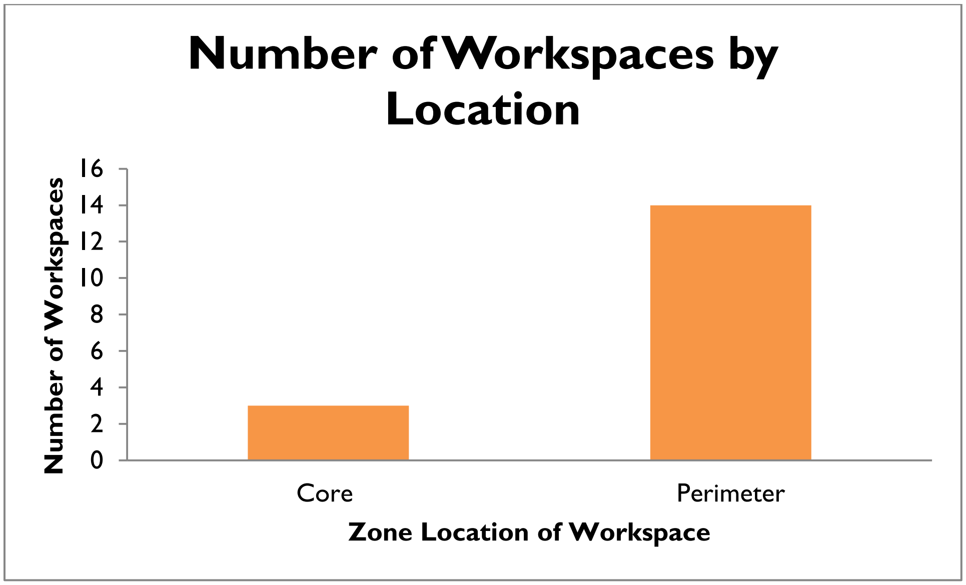


Figure 16. Location of workspaces, Building Site 4. N=17

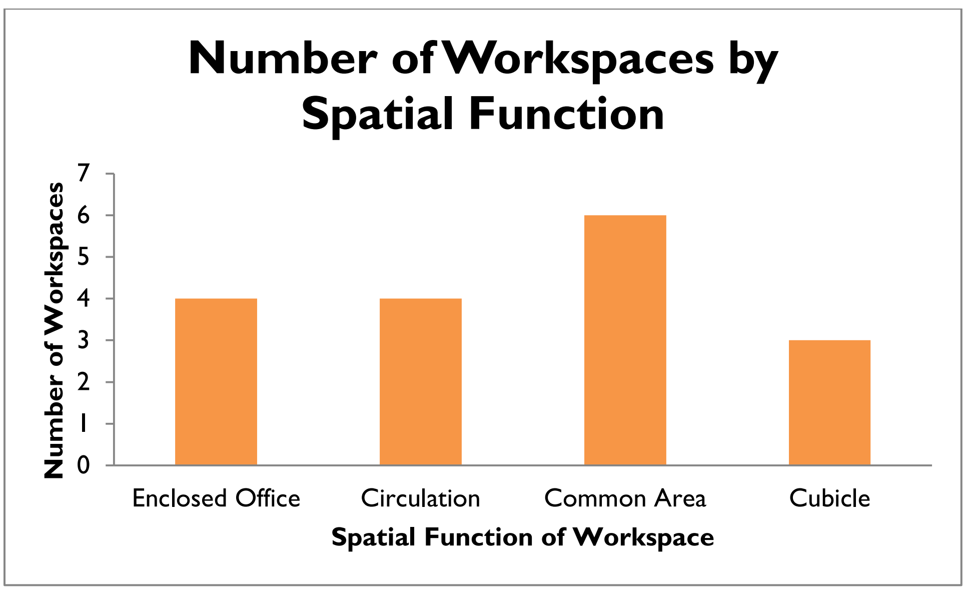


Figure 17. Type of workspaces visited, Building Site 4. N=17

Lighting observations. The post-retrofit measurements taken in these areas showed that:

- Lighting levels averaged about 600 lux in enclosed offices, depending on location.[10]
- The range of luminance levels in circulation spaces was between 600 and 2130 lux. Locations near doors and windows had higher light readings, averaging close to 1780 lux, with less exposed areas averaging 780 lux- over 1000 less.
- Illuminance in common spaces (e.g., conference rooms) ranged from 260 to 730 lux - again depending upon location. The higher ranges (600-700 lux) were located in proximity to windows.

HVAC related observations. The post-retrofit temperatures taken in the different locations and spatial functions showed that:

- The average temperatures for the four tenants were 72.6 (19.7%), 73.7 (19.9%), 73.6 (21.2%), and 70.9 (23%) degrees Fahrenheit, with an overall mean of 72.7 (20.9%) degrees.
- The average temperatures for the three spatial functions (cubicle measures unavailable) differed a bit, ranging from about 71 to 74 degrees, as seen in Figure 18. Humidity ranged from 19.9% to 23% (Figure 19).

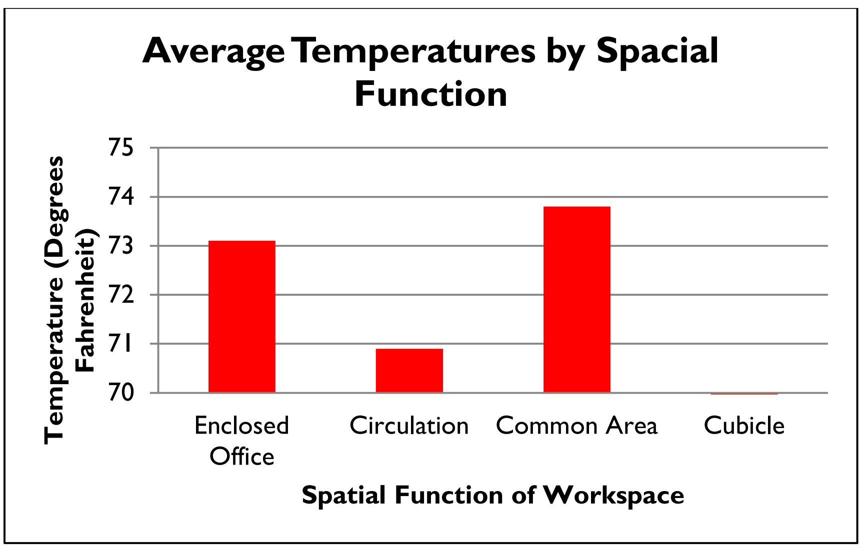


Figure 18. Average Temperatures by workspace type, Building Site 4. N=17

[10] Only two observations were available for the enclosed offices.

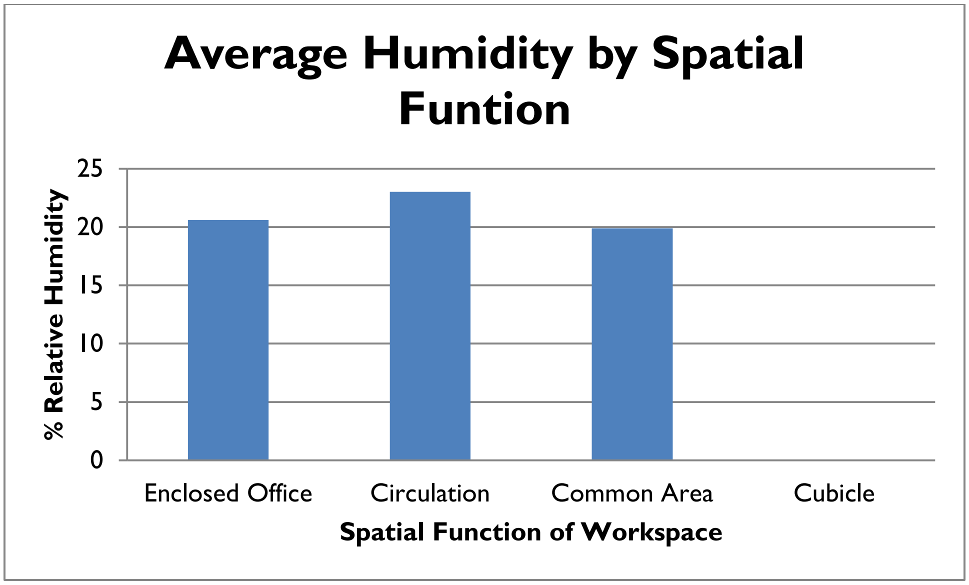


Figure 19: Average humidity by workspace type, Building Site 4. N=17

Occupant Responses

Lighting. Post-retro fit comments acknowledged that the "lighting issue is improving" with continued interventions by facilities management. Sensor management was a repeating theme, described as presenting a challenge for operations: they do not operate reliably, may not be bright enough with at least one occupant closing blinds to brighten electric lighting, have delays in brightening, and will often remain on even when spaces are not occupied.

Heating. Again, comments were primarily centered on inconsistent and variable temperature outcomes. Some rooms were always cold. Portable heaters and fans continued as adaptive strategies in addition to wearing layers. Winter mornings were coldest, while summers were more comfortable, especially with window tinting.

Comparison of Pre and Post Retrofit Temperature and Thermal Comfort

Occupant Responses. Post-retrofit comments seem to be generally more positive, with some interviewees in both buildings reporting that temperatures have gotten 'better' and that complaints have been reduced. However, several occupants continue to identify:

- The need to dress in layers to accommodate temperature fluctuations throughout the day. During this winter-season follow-up, interviewees reported coolest temperatures in the early am and late in the day
- Inconsistent heating in colder months in both buildings
- Use of heaters and fans in both summer and winter seasons.

- Continuing lack of control over thermostats, often reporting that supervisors have final control
- Typically positive results when facilities managers make adjustments
- More comfortable conditions during the summer season as a result of retrofit modifications

Some of these reports might be explained by trade-offs and disconnects, such as having blinds open that provide a view to the outside while allowing greater solar gain that heats up proximal workspaces. Other system-based sources of uneven temperature control need to also be considered. Although the cross-sectional temperature measurements from these two buildings captured data from only one midday point in time, temperatures varied by more than 4 degrees Fahrenheit within one tenant space.

Interviewee responses to the lighting changes were more uniform, with occupants of some tenant offices appearing to have more difficulties than others with occupancy sensors. Reductions in flicker were noted as a welcome improvement. Occupancy sensors, however, were a common source of comment:

- Nice when they came on upon entering
- Individuals being unable to shut off lights altogether, sometimes in response to headaches or unoccupied spaces
- Lighting going off in occupied spaces was described as disruptive and in common spaces where it was expressed as a safety concern
- A security concern when they lit up a closed office
- Lighting being difficult to come back on when off

There were no comments about excessive brightness except for the inability to turn off lights. Interviewees again acknowledged improvements in lighting operation with adjustments by facilities, and continued to expect changes leading to local control over dimmability.

FORT WASHINGTON LOCATION

Background. The Fort Washington office building houses a single commercial tenant. Previously, an additional tenant occupied much of the 2nd floor, but that tenant has left and the remaining tenant has been taking over this space. Work on retrofits to this property had been completed at the time of our visits, with load shedding test procedures also in place. For the results of our load shedding survey, please see *Occupant Behavior in Response to Energy-Saving*

Retrofits and Operations as part of this reporting series *(2013)*. This report focuses on the in-person evaluations performed in December 2012.

Fifty-seven individual workspaces were visited at this location and assessed for lighting and HVAC features. Figure 20 depicts the location of the workspaces visited.

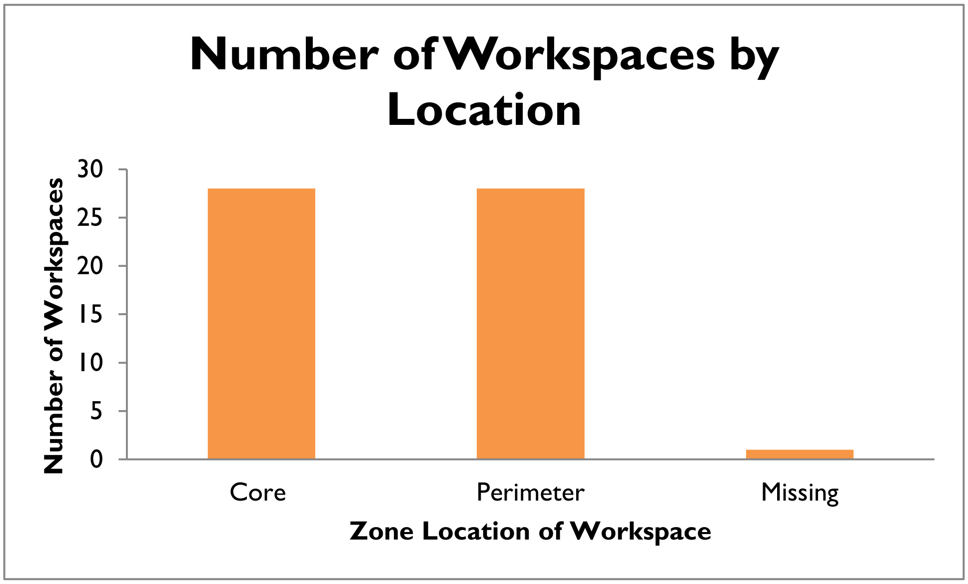


Figure 20. Location of workspaces, Building Site 1. N=57.

These workspaces were further categorized as: Enclosed offices (13), circulation (20), common spaces (12), and cubicles (11) (see Figure 21). The majority of the measurements were taken in circulation areas, with almost equal numbers of measures taken in the other areas.

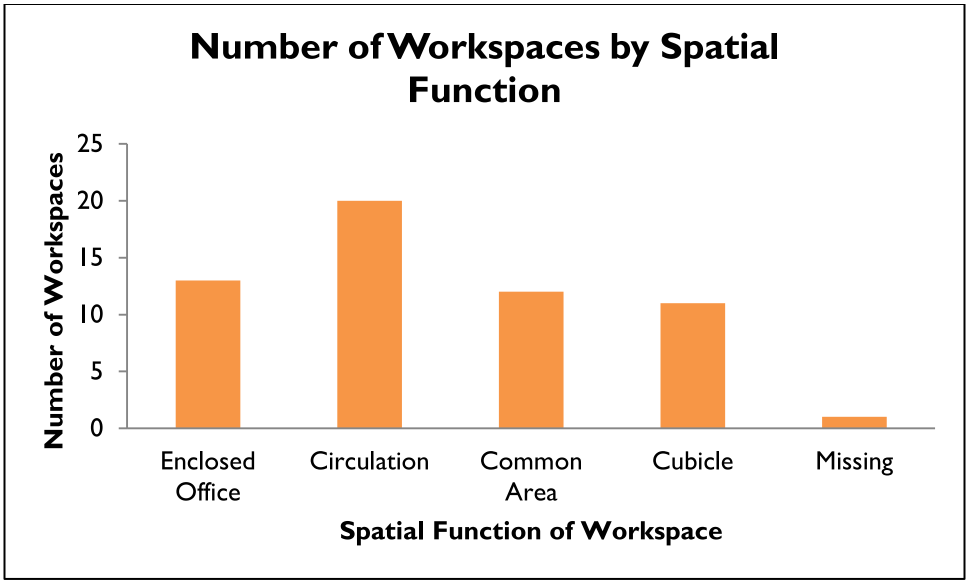


Figure 21. Type of workspaces visited, Building Site 1. N=57

Lighting measurements. Lighting measurements were taken of a sample of enclosed offices, common spaces, cubicles, and circulation. [11] As mentioned above, general recommendations for office space lighting on desk surfaces are 400-500 lux. The post-retrofit measurements taken in these areas showed that:

- Lighting levels ranged from 470 to 2350 lux in enclosed offices, with an average of 1198 lux. These numbers are a bit high, but all offices measured had windows in them, which will add illumination to the area.
- Common areas had lighting levels averaging about 600 lux, with a range 195 to 1825 lux. This average is a little higher but close to the recommendation of 4-500 lux.
- Cubicle areas ranged in levels from 415 to 480, with an average of 445, almost directly between the minimum and maximum suggestions.
- The average lux amount for the windowed areas was 1072, compared to the 419 lux of areas without access to windows.

Those occupants who responded to our interview requests generally expressed satisfaction with lighting levels, whether the day was overcast or bright. Occupancy sensors, however, were a common topic for many of the same reasons as the retrofit buildings described earlier.

[11] Note: The measurements reported here are from the first day of the surveys only, as the natural light conditions match closer to those of the previous two locations.

HVAC. In keeping with data compatible to the previous two sites, there were 48 different temperature measurements taken on days with similar outdoor conditions.[12] The post-retrofit temperatures taken on the different floors and spatial functions showed that:

- The average temperatures between the second and third floor were 74.5 (15%) and 75.8 (17.2%) respectively, with an overall mean of 75.2 (17.8%) degrees.

- The average temperatures for the four special functions were similar, ranging from about 74.3 to 76.5 degrees, with the humidity ranging from 16.4% to 19.4%, as seen in Figures 22 and 23:

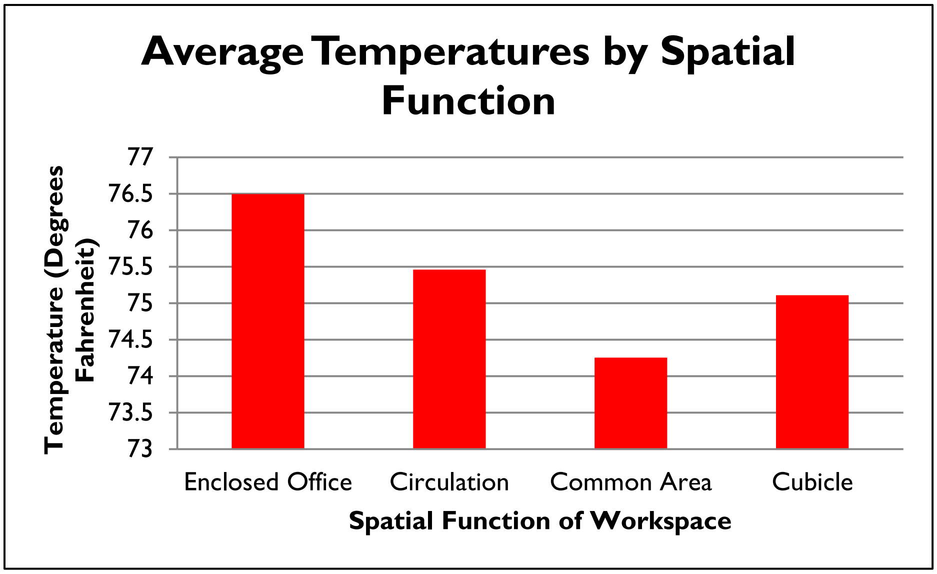


Figure 22: Average temperatures of workspaces, Building site 1. N=57

[12] This data set only has readings from the second and third floors.

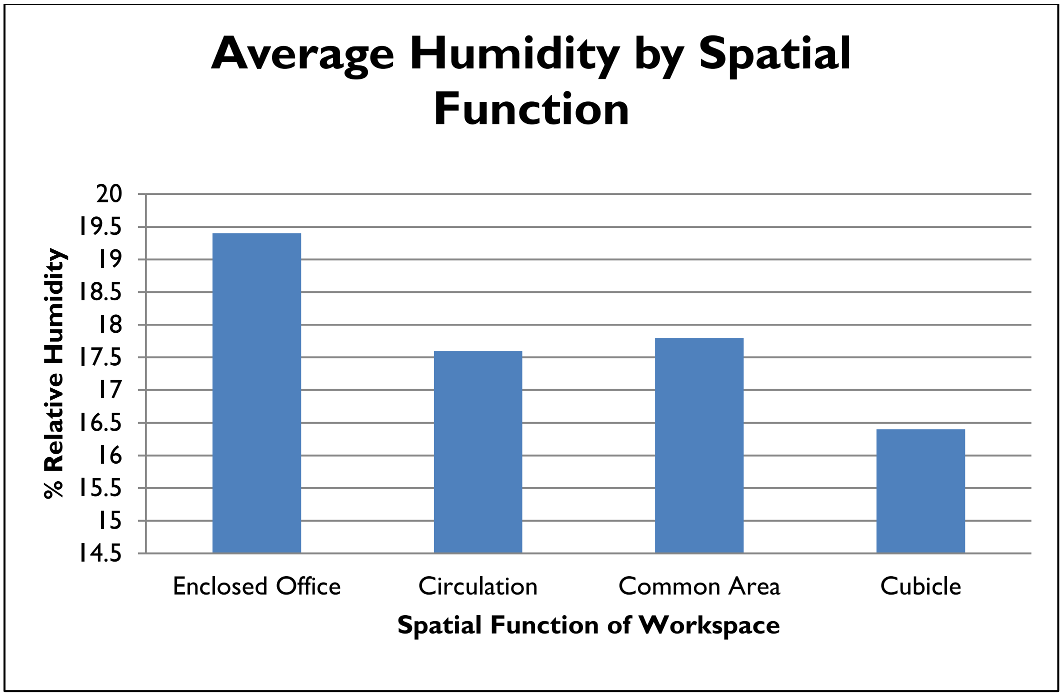


Figure 23: Average humidity by workspaces, Building Site 1. N=57

Occupants spoke of varying levels of thermal comfort, sometimes in contrast to next door co-workers or at the end of the day on a Friday. Also noted was an audible "hum" from the ventilation system that for some obscured announcements from the PA system.

SUMMARY OF COMPARISONS

At the start of the retrofit project building occupants of all three buildings indicated relatively few complaints about lighting and a higher number of complaints about thermal comfort (Liberty survey). The most extreme variations in thermal comfort were reported by occupants of the Malvern building (Building Site 4) concerning both summer and winter seasons. Occupants of each of the three buildings expressed difficulties with thermal comfort. Health concerns and scheduling were key drivers for the ability to manage thermal comfort, with one tenant commenting, "Heating is very personal, you don't want to have to explain it".

Comparison of Pre and Post Retrofit Lighting Conditions

Several occupants, in all three offices visited, indicated that lighting levels were fine at current, post-retrofit levels. However, many occupants in all of the buildings described frustrations with the newly installed sensors:

- Areas in proximity to higher foot traffic the sensors would be triggered even when the room is empty (such as conference rooms).
- Conversely lights would go out in rooms with occupants, forcing them to wave their arms around, or otherwise move around.
- Safety and security concerns were expressed where delays in brightening occurred in labs or other areas where hazards could be encountered or where individuals were alone in a common space (e.g. restroom, reception area).

Usability challenges have, in fact, resulted in some light switches being re-installed in both common space areas (conference rooms) and private offices.

Building occupants also provided feedback that lighting was easier on the eyes, but that the dimmers and/or sensors were not working properly. With post-retrofits, many occupants complained of a lack of control with the lighting where sensors were added. A common interview response to our question(s) regarding lighting operation was that lights would come on when not wanted, and go off when needed. There was one tenant who reported lights going off during a meeting with a client, and not coming back on for an extended period. Others reported closing their window blinds in order to increase the artificial light received – a perfect example of an adaptive action to benefit comfort at the expense of building performance.

Figure 24. Blinds closed, lights on.

The overall 'theme' of lighting comments was a greater desire for individual control, which reportedly would facilitate such actions as turning off lights when not in a room, and keeping them on when needed. As one tenant put it, "it's like [they think] we're not responsible enough [to control a light switch]."

Discussion and Recommendations

This report summarizes behavioral findings from a pre-post retrofit study of three tenanted office buildings in the greater Philadelphia region. We addressed several topics related to energy efficiency retrofits, particularly the quality of lighting, thermal comfort, and control over indoor environmental conditions. We looked to assess occupant responses to lighting and HVAC conditions and provide independent analysis through observations of a sample of workspaces.

Temperature control and variation. In both the baseline and follow up evaluations, respondents spoke consistently about variable temperatures in many of their offices. We observed thermostats that appeared to have limited functionality, and the use of portable heaters and fans to offset an inability to adjust workspace temperature. These findings suggest that:

- HVAC upgrades are somewhat invisible to the occupants and have not fully assuaged thermal comfort issues; on-going systems commissioning and balancing of the systems may help, although diversity in individual temperature preferences makes the management of thermal comfort through centralized controls a daunting task.
- More user-friendly thermostats might help occupants adjust local temperature settings, reducing the need for portable heaters or fans.
- There is potential to improve energy efficiency and thermal comfort through enhanced window and window treatment performance, especially in the Malvern building. A number of individuals described overly warm conditions near windows in the summer that could be exacerbated when peak load shedding occurs.
- A greater understanding of the intricate relationship between fit-out, occupant characteristics and preferences, HVAC operation, and thermal comfort would contribute substantially to developing recommendations for design of workplace systems.

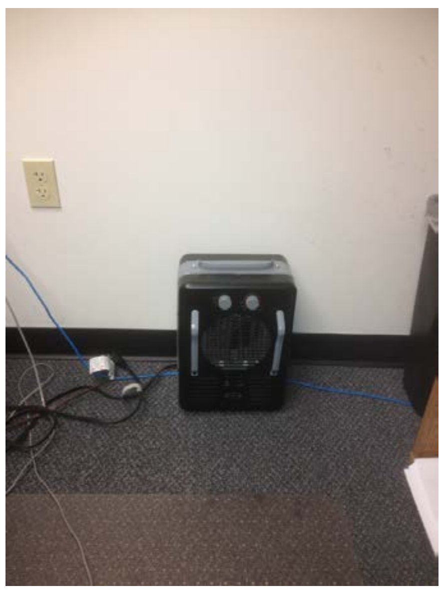


Figure 25. Fan at Christmas time Figure 26. Portable heater

Management of lighting conditions. Occupants were generally satisfied with lighting levels. They also acknowledged some decrease in light flicker. Although there were few actual complaints in any of the buildings during the baseline evaluation, dissatisfaction with the operation of the lighting system became a dominant theme in the follow up evaluation. Occupants seem to be responding to two conditions: the recent *removal* of individual control over lighting and suboptimal performance of the lighting system from the perspective of the occupant. Satisfaction with lighting operations came only as a result of diligent efforts of facilities staff and ongoing adjustments in response to requests by occupants. While interview respondents generally seemed to understand that the perfection of lighting sensor function is a process, some seem to be losing patience with the process.

Our work also suggest that:

- Task lighting as a response to insufficient lighting (sometimes caused by poor interior layout, as noted above) can be useful as a way of adding to occupant control of available light. Findings from the study indicated, however, that this is an underused resource that can be both energy efficient and user controllable. There were few task lights available to and being used by occupants, either because individual occupants had not integrated task lighting use into their workspace or the lighting was not present as an option. In addition, occupants typically relied upon overhead lighting that, in many cases, could not be turned off and would create excess lighting in many circumstances.

- Providing greater control over lighting, whether as planned through the SGIG retrofit with addressable ballasts or by adding more physical switches on a limited basis, can provide opportunities for occupants to reduce brightness when and where it may not be needed.
- Customizable/controllable lighting may also, however, create new social dynamics within workspaces over how control is apportioned, which could affect satisfaction as measured in the next round of survey/interviews.

Figure 27. "Don't touch the lights!"

Figure 28. Social Negotiation of thermal comfort

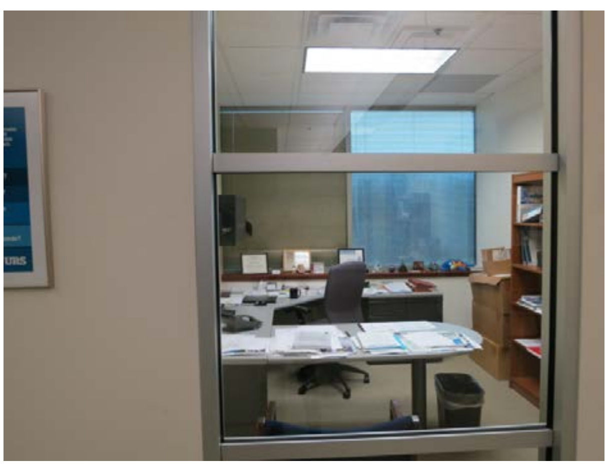
Conclusion

The triangulation of methodologies described here including the pre-survey of occupant satisfaction conducted by Liberty, occupant interviews, and independent observations and measures appear useful in developing information about (1) the use of window performance and window treatments as important features for privacy, glare control, and temperature management, (2) the relationship of level of control over light fixtures for both occupant comfort and energy efficiency, and (3) the quality of local temperature management in workspaces as it affects the use of high-consumption portable heaters as well as personal fan devices.

This summary report has provided an evaluation of three buildings enrolled in the Liberty-PECO lighting and HVAC retrofit program, two multi-tenanted buildings and one single-tenanted one. Based on this data, the differences in how the retrofits played out in the two building types was not stark. What seems to matter more is the organizational capacity of the tenant to work with the property owner/building manager: Larger organizations are better able to dedicate staff time to this function. Larger tenants also may be more likely to sign longer-term leases, which may better align interests between the property owner and tenant.

In this regard, we would be remiss not to comment on the significant effort made by the owner of all three buildings to communicate effectively with tenants before, during, and after the retrofits. For real estate investors and owners, the potential return on investment from collaborating with tenants on energy efficiency upgrades is uncertain (D’Arelli, 2008).

In BP3, the Rutgers team will continue to work with Liberty Property Trust and others to scale up the lessons learned from the BP2 work and to refine characterizations of occupant behavioral response to energy saving technologies.



Figures 29 & 30. Unoccupied offices

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