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Enlighted Technical Proof of Concept Study

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Executive Summary

This report represents the findings on research on the Enlighted lighting control system. New Buildings Institute (NBI) conducted the work on behalf of the Northwest Energy Efficiency Alliance (NEEA) from May 2011 to December 2012. The technical Proof of Concept study aimed to validate manufacturer claims for costs, ease of installation, end user satisfaction and energy savings.

The four primary goals were to:

1) Provide third-party validation of energy savings and costs at three pilot sites.
2) Measure owner/occupant and contractor satisfaction at each operating mode.
3) Measure installer satisfaction with the product and collect installers' feedback about installation issues.
4) Compare energy savings, costs, ease of installation and user satisfaction with manufacturer claims.

Project Description

Researchers investigated three sites in the Pacific Northwest, including the third floor of the Yale Building at the Fred Hutchinson Cancer Research Center in Seattle, Washington; a wing of the REI Headquarters office building in Kent, Washington; and part of the seventeenth floor of the Unico Building in Portland, Oregon, where the Kivel & Howard law firm has its offices. Table 1 shows a summary of the three sites and equipment and installation costs for each.

Table 1: Overview of Pilot Sites and Breakdown of Costs

Site	Location	Size of Installation	Equipment Cost/SF	Installation Cost/SF	Total Cost/SF	Total Cost/ Fixture
Fred Hutchinson Yale Building	Seattle, WA	20,000 SF	$1.44/SF	$1.18/SF	$2.62/SF	$292
REI Headquarters	Kent, WA	15,000 SF	$1.26/SF	$0.45/SF	$1.71/SF	$185
Kivel & Howard Office	Portland, OR	5,418 SF	$1.42/SF	$1.69/SF	$3.11/SF	$280

Note: NBI based the Kivel & Howard costs on total size of the office installation, as well as on total costs for the Enlighted system installation in 6,763 SF of office – not only on the 5,418 SF in the study area.

Two of the sites were simple retrofits of the system that included installation of dimming ballasts and the Enlighted control system. However, the renovation of the Kivel & Howard system involved a more complicated delamping on non-egress fixtures in addition to the reballasting, which increased the installation costs and affected the energy savings estimates.

The Enlighted Technical Proof of Concept Study used a *stepped baseline*, previously utilized by the Office of the Future Consortium, to establish the estimated impact of various stages of control, including the as-is existing condition; the adjusted condition after the dimming ballasts were installed but before controls were activated; the out-of box Enlighted system operation; and the designer preference and user preference settings.

Measured energy performance was not the sole focus of the research. It also included investigations into the use of task lighting, light level measurements, and occupant and contractor surveys. Additionally, NBI conducted a fixture-by-fixture comparison of measured performance from loggers to the occupancy and trending data collected by the Enlighted system.

Results

Measured results of this technical Proof of Concept research reveal that the Enlighted lighting control technology and dimming ballast can deliver significant savings at relatively low cost. The results of the technical Proof of Concept study align with manufacturer claims of low cost, ease of installation and end user satisfaction, though its claims of fifty to seventy percent of lighting energy savings may be optimistic. Measured energy savings of the Enlighted lighting control system over the existing baseline system ranged from thirty-two to fifty-nine percent, though savings at Kivel & Howard (32%) are also attributable to changes to the lighting system.

Total costs of the installations ranged from $1.71/SF to $3.11/SF. Hiring installers holding a California Non-Residential Lighting technical certification with training by the manufacturer was most cost-effective ($0.45 on the low end compared to $1.69 per SF). The REI costs ($0.45/SF for installation and $1.26 for equipment) also benefitted because the project was part of a retrofit of an entire building as opposed to tenant space within a larger building.

Occupant surveys suggest that most people are satisfied with the new lighting system. As expected, this varied depending on the particular circumstances, e.g., whether an office was open or private and the level of control they had before the retrofit. Interestingly, the occupants' perceptions of actual control did not change as expected, since facility managers were still responsible for making any changes to the lighting levels.

In addition to comparing projected annual energy savings, NBI used other methodologies to compare energy use before and after renovation. One is the Daily Consumption Profile, which illustrates the measured lighting power density (LPD, in W/SF) over the course of a typical weekday in the office, providing clarity on the magnitude of energy savings and the approximate time of day that most energy savings occur. Another is the off hours and weekend ratios which provide indication of how well the controls are turning off lights when the space is unoccupied.

In addition to energy savings, costs and occupant/contractor satisfaction, researchers investigated other areas such as task lighting, light level measurements, and the comparison of measured energy use at the fixture level to that reported by the Enlighted system.

- Task Lighting - Researchers estimated an annual task lighting energy use of 15-30 kWh - up to 50% of the overhead fixture energy use. A change in task light behavior could easily affect the estimated energy savings/penalties of a lighting system. However, this research suggested that occupants did not significantly change their task light use after the retrofit.
- Light Levels - Snapshots of light level readings demonstrated a high degree of variability among the sites. While light level readings at the REI site were most likely in the industry standard range of 35-55 foot-candles, the Yale Building often experienced light level

readings both higher and lower than industry standards, and readings at the Kivel & Howard site were much lower.
- Fixture-Level Comparison - Researchers had a unique opportunity to compare detailed fixture-level data to data collected from the Enlighted system, including a measurement of both power and occupancy for each of the Enlighted sensor locations. NBI found a high degree of correlation between the individual fixture-level metered data and that reported by Enlighted. This can allow the establishment of "virtual meters" to quantify energy use in specific areas, such as perimeter versus core zones or private versus open office spaces.

Appendices A, D and E summarize the results for the above findings.

Next Steps
Overall, researchers concluded that the Enlighted lighting control system, combined with a third-party dimming ballast, offers significant energy savings at a low cost. NBI recommends that NEEA, the Regional Technical Forum and utilities consider routes to incentivize implementation of the Enlighted system.

Furthermore, NBI recommends that Enlighted consider adding functionality that integrates the occupancy data collected by the system to manage Heating, Ventilation & Air Conditioning (HVAC) systems and non-essential plug load devices.

Finally, this Enlighted Technical Proof of Concept Study suggests conducting additional research in the area of highly controlled lighting systems. This research might include:

- Understanding how data collected from the Enlighted system may be used to identify patterns in highly controlled lighting use in office spaces
- Correlating how these savings can extend to other systems in the building (like plugs and HVAC)
- Further quantifying the impacts of highly controlled lighting systems in order to increase utilities' and regulators' confidence in the energy savings and persistence of those savings
- Conducting a longer-duration research project to quantify the seasonal impacts of daylighting
- Better understanding task lighting and the impact of switching connected load, not included in lighting power density calculations, to task-based lighting

1. Introduction

This report represents the findings on research on the Enlighted luminaire level lighting control system. New Buildings Institute (NBI) conducted the work for the Northwest Energy Efficiency Alliance (NEEA) from May 2011 to December 2012. The objective was to perform a Technical Proof of Concept to verify manufacturer claims on an emerging lighting technology that could increase the energy savings and project opportunities for Northwest utilities.

Commercial lighting retrofits continue to offer significant energy-saving opportunities, but changes to the national commercial lighting standard will eventually make T8 lamps the norm and a part of the baseline. This leaves a hole in lighting program offerings and jeopardizes an entire industry of lighting trade allies.

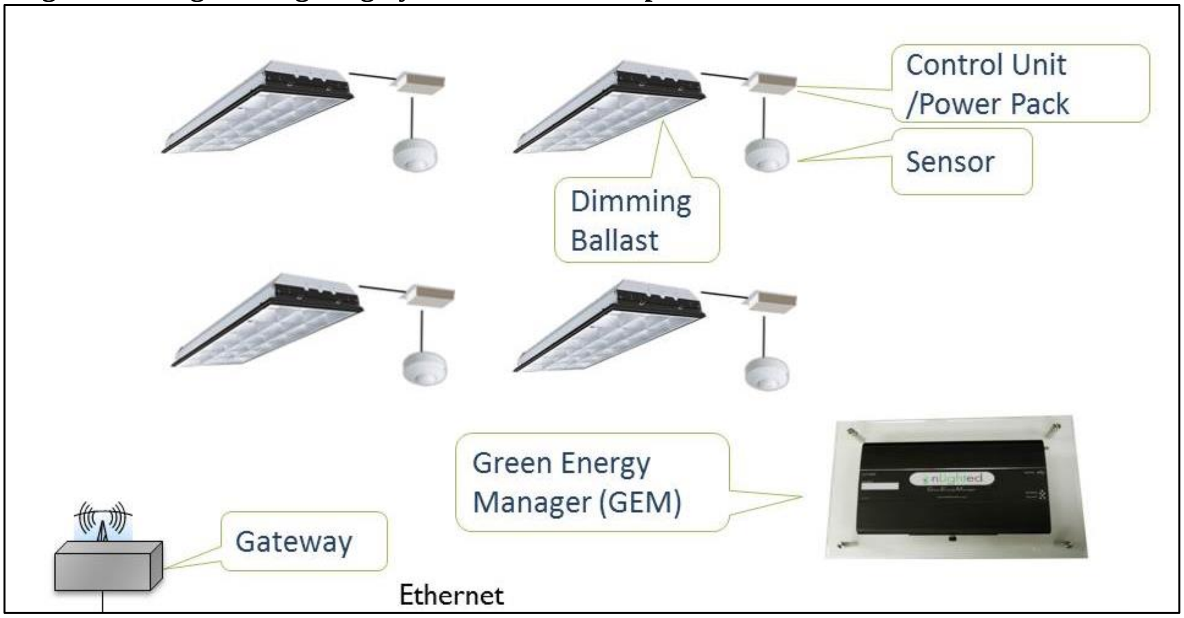
Electrical contractors working on commercial lighting retrofit projects typically have no formal design experience. They rely instead on field experience, rules of thumb and simple one-for-one equipment upgrades. One way to preserve this valuable trade ally network and to ensure a continued energy savings stream for utilities is to identify new savings measures for simple retrofit equipment.

Utility studies and research by NBI and others have shown that lighting controls including occupancy, dimming and daylight detection are able to reduce energy use significantly. However, most commercial lighting control systems are expensive, difficult to install and commission, and provide poor end-user satisfaction. Enlighted claims to remedy these issues. This report aims to compare measured performance to manufacturer claims that the Enlighted System can provide fifty to seventy percent energy savings with low installed cost, easy installation and high occupant satisfaction.

1.1. The Enlighted System

The First Generation Enlighted system is comprised of five main components: Enlighted Sensor, Enlighted Control Unit, off-the-shelf dimmable ballast, Enlighted Gateway and Enlighted Energy Manager, as shown in Figure 1: Enlighted Lighting System Control Components.

Figure 1: Enlighted Lighting System Control Components



The sensor bundle collects data on occupancy, light levels and temperature. The control unit collects energy consumption information and passes this information from the sensor unit to the dimmable ballast. The sensor unit stores the control profile/program and wirelessly communicates with the Enlighted gateway. One Enlighted gateway can cover 50-150 fixtures, depending on the floor plan. The gateway relays information via Ethernet to a dedicated server called the Enlighted Green Energy Manager.

Out of the box, the Enlighted system controls each luminaire independently, but operators can also program the system from a central location in order to maximize user satisfaction and energy savings.

1.2. Technical Proof of Concept Study Approach

The NEEA Enlighted Proof of Concept study had four primary goals:

1) Provide third-party validation of energy savings and costs at three pilot sites.
2) Measure owner/occupant satisfaction at each operating mode and contractor satisfaction with the ease of installation.
3) Measure installer satisfaction with the product and collect installers' feedback about installation issues.
4) Compare energy savings, costs, ease of installation and user satisfaction with manufacturer claims. Specifically, these claims include:
   - Smart
     - Networked independent sensors
     - Pinpoint control

    - Interoperable with all existing lighting types including LED
    - Extensible to other energy services
- Simple
    - Zero lighting design required
    - Simple to install (approximately 20 minutes per sensor)
    - Minimal tenant disruption
    - Rapid commissioning
- Savings
    - 50-70% lighting energy savings
    - Cost-effective installation
    - Low maintenance costs
    - Lower cost per unit
    - Reduction in carbon footprint

1.2.1. Stepped Baseline Approach

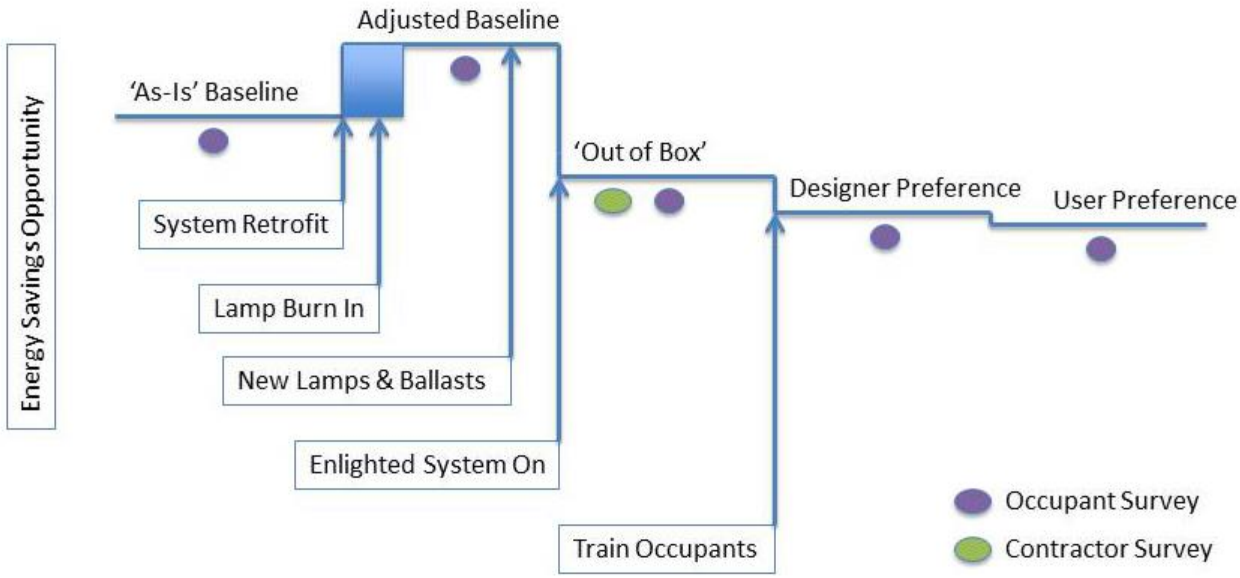
The Enlighted Technical Proof of Concept Study leveraged the approach used to evaluate the effectiveness of lighting controls used by the Office of the Future Consortium. The approach used a *stepped baseline* to establish the estimated impact of various energy conservation measures, in this case the various stages of control.

The steps of the Enlighted research included:

- **Existing Baseline** - Measurement of the existing system as operated
- **Adjusted Baseline** - Measurement of the retrofit system, with new dimming ballasts, lamps replaced and the Enlighted control system turned off
- **Out-of-Box Mode** - Measurement of the retrofit system with the Enlighted system turned to "out-of-box" control settings as explained in the table further below
- **Designer Preference** - For each pilot, a lighting designer did a walk-through of the "out-of-box" mode installation. They collected foot-candle measurements and made recommendations for adjustments to the lighting levels. Lighting designers paid specific attention to corridor lighting and occupied spaces near the windows.
- **User/Occupant Preference** - Measurement of the retrofit system after making adjustments per occupant preferences. Facility managers made all changes of lighting levels using the Enlighted control system based on specific user requests.

The "stepped" baseline quantifies the effectiveness of the controls at each phase, as Figure 2 shows. The hypothesis was that additional savings might be measured at each step in the stepped baseline.

Figure 2: Graphic Representation of the Stepped Baseline Approach



While it may seem counterintuitive, recently renovated lighting systems sometimes use more energy than they did before the renovation. Many existing lighting systems have burned-out lamps that are not drawing full power. Therefore, when the retrofit calls for a one-for-one lamp/ballast change-out, upon replacement more lamps are functioning and the system uses more energy. In addition, some dimming ballasts use slightly more energy than do their non-dimming counterparts.

1.2.2. Details of Enlighted Out-of-Box Default Settings

The Enlighted system ships with pre-programmed default control settings. This study investigated occupant preferences and energy savings associated with the out-of-box settings, shown in Table 2.

Table 2: Enlighted Out-of-Box Settings

Period	Minimum Light Level when on (1-100%)	Maximum Light Level when on (1-100%)	Ramp-Up Time (1-10 seconds)	Active Motion Window (1-200 minutes)	Motion Sensitivity (1-10)	Ambient Sensitivity (0-10)
Weekday Settings						
Morning	0	75	2	10	2	8
Day	20	75	2	20	2	8
Evening	0	75	2	10	2	8
Night	0	75	2	5	2	0
Weekend Settings						
Morning	0	75	2	3	2	8
Day	0	75	2	3	2	8
Evening	0	75	2	3	2	8
Night	0	75	2	3	2	0
Holiday Settings						
Morning	0	75	2	3	2	8
Day	0	75	2	3	2	8
Evening	0	75	2	3	2	8
Night	0	75	2	3	2	0

1.3. Lighting Metrics for Comparison of Controlled Lighting Systems

The most commonly discussed metric for installed lighting power demand is Lighting Power Density (LPD). Historically, the amount of power a lighting system could consume had no limit. As energy consumption in buildings became a target for energy efficiency (following the energy crisis of the early 1970s), building energy codes have used the allowed LPD to control the amount of connected power (in watts/SF) in commercial buildings. Reducing LPD as the prime energy-saving code mechanism for lighting is becoming increasingly difficult.

Lighting controls and dimming ballast systems can reduce lighting demand even further. In order to quantify the effectiveness of the Enlighted lighting control system, this analysis examines 15-minute interval measurements. This research defines weekdays as Monday through Friday and accounts for a typical office schedule of ten workday holidays per year. Weekdays are distinguished from Saturdays, Sundays and the accepted ten holidays.

To provide a common language for analysis and benchmarking of highly controlled lighting systems, this report uses a common set of metrics throughout. The Office of the Future Consortium developed these metrics in 2010; at least seven projects investigating savings associated with lighting controls have used these metrics. Summaries of three methods used to quantify the value of controls appear below:

> **1) Daily Consumption Profile** – The Daily Consumption Profile graphically illustrates the measured lighting power density (LPD, in W/SF) over the course of a typical weekday in the office. Each step of the stepped baseline approach appears on a separate line on the Daily Consumption Profile plot.

The Daily Consumption Profile shows how occupancy use patterns affect lighting power levels throughout the course of a typical office weekday. Increased availability from daylighting may also affect the Daily Consumption Profile. Although the magnitude of this contribution is difficult to determine, it likely contributes during the hours of peak energy use.

To create this plot, NBI averages measurements of lighting power density, at a particular time of the day, for all of the weekdays in the monitoring period. This is repeated for every hour and these results are plotted over the 24-hour daytime/nighttime period to graphically show the average weekday profile. NBI averages the profile for all weekdays over the period to eliminate day-to-day anomalies.

2) Average Lighting Power Density (in W/SF) –The average lighting power density analysis separately examines daytime and nighttime measured LPD, separating weekdays from weekends, and compares the numeric values of these average lighting power densities within a table. For this analysis in office spaces, NBI defines daytime as the 12-hour period of 6:00 AM to 6:00 PM, and nighttime is 6:00 PM to 6:00 AM. “Occupied hours” is another name for the daytime period, since it is the time the office space is most likely to be in use.

In this average lighting power density calculation methodology, the daytime power demand (or occupied hours) is the sum of every 15-minute interval reading between 6:00 AM and 6:00 PM divided by the total number of readings. This calculates an average reading for the entire daytime period. The nighttime power demand is a similar calculation using meter readings between 6:00 PM and 6:00 AM. Since weekend/holiday periods are typically unoccupied, NBI calculated a weekend/holiday power demand over a 24-hour timespan.

Off-Hours Ratio

This is the ratio of weekday nighttime power density to weekday daytime power density, given by: $WperSF_{night}$ / $WperSF_{day.}$

The off-hours ratio describes how effectively a system reduces lighting energy use overnight when the building is lightly occupied. This metric is also affected by occupant behavior and scheduling: sites with employees who work night shifts or late into the evening will affect the off-hours ratio. A low off-hours ratio indicates significantly less lighting use overnight.

Weekend Ratio

This is the ratio of weekend power density to weekday daytime power density, given by: $WperSF_{weekend}$ / $WperSF_{weekday\text{-}daytime}$

The weekend ratio describes how effectively a system reduces lighting energy use during the weekends when the building is lightly occupied. This metric is also affected by occupant behavior and scheduling: sites with employees who work weekend shifts will affect the off-hours ratio. A low weekend ratio indicates will affect the off-hours ratio on weekends.

Peak Demand
Separate from the calculation above, NBI calculates peak demand using a 15-minute rolling average power measurement. NBI documents the maximum 15-minute average during each phase of the stepped baseline as the Peak Demand, in W/SF. This is analogous to how a utility would calculate peak demand charges. Although NBI expects this peak to occur during weekday daytime periods, the analysis methodology allows it to occur at any time during the measurement period.

3) Annual Energy Consumption - The Average Energy Consumption estimates the expected annual energy use given the measurements taken at each phase of the stepped baseline. NBI calculates the estimated annual consumption based on the average 24-hour weekday kWh/day multiplied by 251 weekdays plus the average 24-hour weekend kWh/day x 114 weekend/holiday days. NBI also normalizes this estimated annual consumption by the size of the office in order to allow for easy comparisons among the sites.

1.4. Task Lighting

Task lighting creates complexities for measuring the energy performance of lighting systems because task lights are often not included in the measured lighting circuits. Instead, task lights are typically included in the plug load circuit. Since NBI did not measure plug load circuits in this study, the research required a different approach.

With a goal of assessing the relative impact of task lights, researchers installed loggers on twenty-five percent of the task lights in the space. These “state” loggers recorded whether task lights were on or off to compare task light use before and after deployment of lighting controls to determine whether the use patterns would change as the overhead lighting system dimmed. This methodology was not part of the initial scope and limited the investigation of task lighting impact to two pilot sites.

1.5. Light Level Measurements

Light levels are measured in foot-candles, a commonly used metric to specify and determine if there is sufficient light for the space use. Collecting light-level measurements in the study areas constituted another aspect of the Enlighted Technical Proof of Concept Study. This involved collecting light-level measurements throughout the study area at various phases of the research project.

1.6. Occupant and Contractor Surveys

One key component of the research consisted of surveys of occupants and installing contractors. Occupant feedback surveys provided insights into the satisfaction level with the office space lighting. Figure 2 above shows the point in the research at which occupants completed surveys.

Surveys collected information about the occupants' particular space locations; their perceptions of the lighting comfort and glare; and overall observations.

NBI also conducted contractor telephone surveys for all three pilot sites to clarify the scope of effort associated with the installation, timing and coordination with occupants in an existing office; the specific steps involved in the installation; familiarity and comfort with the products; commissioning; and costs associated with installation.

2. Pilot Site Characteristics and Installed System Costs

This Enlighted Technical Proof of Concept Study investigated three sites in the Pacific Northwest. This report describes each of the pilot sites in further detail, including descriptions and site plans as well as lighting system conditions before and after retrofit. Table 3 summarizes the installations and costs.

Table 3: Overview of Pilot Sites and Costs

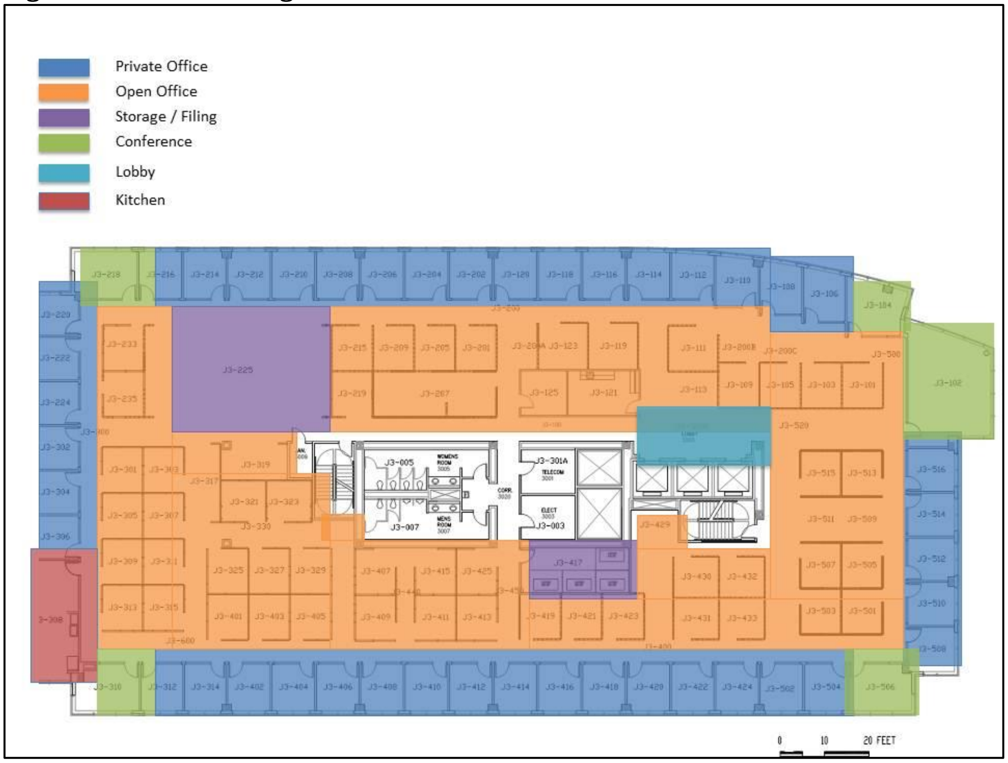
Site	Location	Size of Installation	Equipment Cost/SF	Installation Cost/SF	Total Cost/SF
Fred Hutchinson Yale Building	Seattle, WA	20,000 SF	$1.44/SF	$1.18/SF	$2.62/SF
REI Headquarters	Kent, WA	15,000 SF	$1.26/SF	$0.45/SF	$1.71/SF
Kivel & Howard Office	Portland, OR	5,418 SF*	$1.42/SF	$1.69/SF	$3.11/SF

Note: NBI based the Kivel & Howard costs on total size of the office installation, as well as on total costs for the Enlighted system installation in 6,763 SF of office – not only on the 5,418 SF in the study area.

2.1. Fred Hutchinson Cancer Research Center Yale Building (Yale Building)

The installation at the Fred Hutchinson Cancer Research Center project took place on the third floor of the Yale Building, located at 820 Yale Avenue North, Seattle, Washington (hereinafter the “Yale Building”). Approximately 100 employees occupy 20,000 SF of office space in a mix of private and open office spaces. The floor also includes a kitchen, five conference/meeting rooms, two storage areas and a small lobby/waiting area. The metered space contained 180 T5HO recessed center-basket fixtures. Ten egress fixtures added to the amount of light available in the space but were not included in the metering due to separate circuiting. A site plan depicts the office layout and ratio for the various space uses in Figure 3.

Figure 3: Yale Building Site Plan



2.1.1. Existing Lighting System Characteristics

The existing lighting system included:

- 180 recessed center-basket linear fluorescent fixtures
- 2 T5HO lamps (Sylvania FP54/835/HO/ECO)
- 1 ballast (Sylvania QTP2x54T5HO/UNV)
- Total system watts for each luminaire: 121 watts

The building had sweep timers with override buttons. Private offices have manual wall switches that also had sweep timers with override buttons. Each luminaire (with a two lamp and ballast combination) contributed 121 watts for a total installed capacity of 21,780 watts for the entire lighting system. The 20,000 square foot study area yielded a lighting power density of 1.09 watts/square foot (W/SF).

2.1.2. Retrofit Lighting System Characteristics

The final retrofit lighting system included:

- 180 recessed center-basket linear fluorescent fixtures (existing)
- 2 T5HO lamps (Sylvania FP54/835/HO/ECO)
- 1 dimming ballast (Sylvania Quicktronic Powersense QHE 2x54T5HO/UNV DIM-TCL)
- Total system watts for each luminaire: 116 watts

Each luminaire (with a two lamp and ballast combination) contributed 116 watts for a total installed capacity of 20,880 watts for the entire lighting system. The 20,000 square foot study area yielded a lighting power density of 1.04 watts/square foot (W/SF).

2.1.3. Flickering Issues

One important lesson learned in the Yale Building project pertained to the ballasts. The originally installed Sylvania Quicktronic ballasts experienced flickering issues. Since they were under warranty, Sylvania provided and paid for the installation of Quicktronic Powersense dimming ballasts throughout the site.

The Sylvania Quicktronic dimming ballast originally installed in the retrofit was a seven-wire ballast. This worked fine at full output and even during the out-of-box dimming mode, but as lighting levels dimmed to approximately 50%, some occupants began to complain about lamp flickering.

Staff at Fred Hutchinson attempted to remedy the situation in three ways:

1) Installed alternative Philips and GE lamps, with the same flickering result.
2) Investigated power quality in the building, but found no issues.
3) Tested the Fred Hutchinson campus standard dimming ballast (Advance brand ballast), which immediately remedied the problem. Despite the fact that the Advance ballast worked fine, Fred Hutchinson staff replaced all of the ballasts with Sylvania Powersense Quicktronic ballasts due to warranty coverage issues.

Enlighted and Sylvania were involved in the investigations. Eventually Fred Hutchinson staff replaced all of the originally installed Quicktronic dimming ballasts with Sylvania Quicktronic Powersense dimming ballasts. This resolved the flickering issue; however, no root cause analysis explained the cause of the flickering.

2.1.4. Costs

The total cost for the Yale Building project was $52,494 or $2.62/SF for 20,000 square feet. A breakdown of costs follows in Table 4. This amounts to $292/fixture for 180 fixtures.

Table 4: Summary of Costs at Yale Building

Item	Cost	Description / Notes
Installation	$15,187	191 Fred Hutchinson staff hours, including a licensed electrician
Equipment	$27,500	• 180 Wireless Sensor Units (elf-SU-W-0-0) • 180 Wireless Control Units (elf-CU-W-0-0) • 2 Enlighted Gateway Units (elf-GW-W-0-0) • 1 Enlighted GEM Server (elf-GEM-SAP-1) • 180 two-lamp T5HO dimming ballasts
Training & Clean Up	$7,375	55 Fred Hutchinson staff hours
Small Parts	$1,329	
Corrective Labor	$1,103	Fred Hutchinson staff time to address malfunctioning ballasts
Sub-Total	$52,494	
Cost / Square Foot	$2.62	Based on 20,000 SF

2.1.5. Monitoring Period

The total monitoring period for this site extended from September 5, 2011 through June 19, 2012. Construction work took place over four weekends during the construction period. Fred Hutchinson electricians installed the equipment with support from Enlighted manufacturer representatives. A secondary construction period occurred upon discovery of the need for a ballast replacement, from April 9, 2012 to May 28, 2012. Subsequent tables present a single line for the entire “user preference” period, which reflects operation with both the original and the replacement ballasts, since a separate data analysis showed no change in energy use between the periods with the original and the replacement ballasts. Table 5 below summarizes the monitoring periods by phase of research.

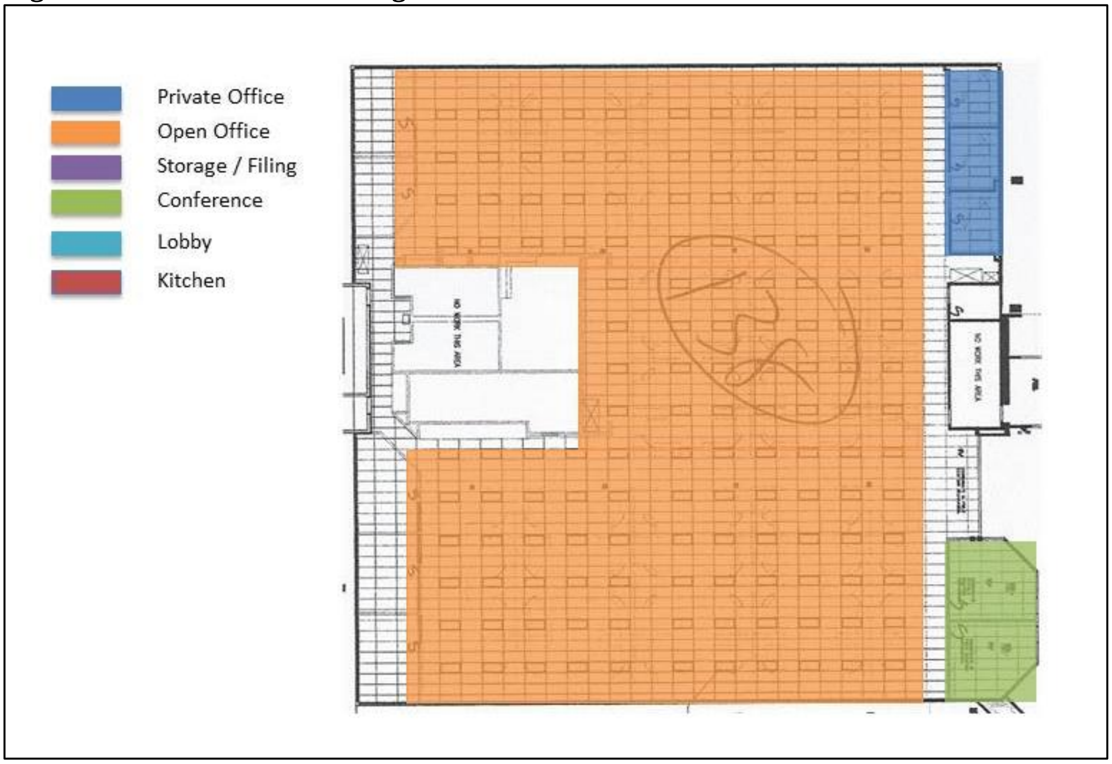
Table 5: Yale Building Monitoring Periods

	Beginning	End	# of Days
As Is Baseline	9-5-2011	10-29-2011	54
Construction	10-30-2011	11-22-2011	23
Adjusted Baseline	11-28-2011	12-17-2011	19
Out-of-Box Operation	12-19-2011	1-13-2012	25
User Preference	1-18-2012	4-9-2012	82
User Preference (with new ballasts)	5-28-2012	6-19-12	22

2.2. REI Headquarters Office Building

REI chose to install the Enlighted system throughout its entire headquarters building at 6750 South 228th Street in Kent, Washington. While the overall building is 79,600 SF, the study area included approximately 15,000 SF of office space on the south wing of the first floor. The space was primarily open office with few private offices and two conference rooms, as shown in Figure 4. This area included about 90 occupants from REI’s Merchandising group in an open office area. The study area at REI included 138 recessed parabolic linear fluorescent fixtures.

Figure 4: REI Reflective Ceiling Plan



2.2.1. Existing Lighting System Characteristics

The existing lighting system included:

- 138 recessed parabolic fluorescent fixtures
- 3 T8 lamps (GE Ecolux Starcoat F32T8/SP35/ECO)
- 1 ballast (GE 78623 GE332 MAX - N/Ultra 277 V)

Each lamp and ballast combination contributed 80 watts for a total installed capacity of 11,040 watts for the entire lighting system. The 15,000 square foot space yielded a lighting power density of 0.74 watts/square foot.

2.2.2. Retrofit Lighting System Characteristics

The retrofit lighting system included:

- 138 recessed parabolic fluorescent fixtures (existing)
- 3 T8 lamps (GE Ecolux Starcoat F32T8/SP35/ECO)
- 1 dimming ballast (GE 75381 GE332MVPS-N-V03)

Each lamp and ballast combination contributed 85 watts, for a total installed capacity of 11,730 watts for the entire lighting system. The 15,000 square foot space yielded a lighting power density of 0.78 watts/square foot.

2.2.3. Costs

The REI research project cost a total $25,587, or $1.71/SF for 15,000 square feet. Table 6 breaks down itemized costs. This amounts to $185/fixture for 138 fixtures.

Table 6: Summary of Costs at REI

Item	Cost	Description / Notes
Installation	$6,141	84 hours (6 staff for 14 hours) with California non-residential lighting technical certification
Equipment	$18,899	• 138 Wireless Sensor Units (elf-SU-W-0-0) • 138 Wireless Control Units (elf-CU-W-0-0) • 2 Enlighted Gateway Units (elf-GW-W-0-0) • 1 Enlighted GEM Server (elf-GEM-SAP-1) • 138 3 lamp GE dimming ballasts • Various unshunted tombstones & Ethernet cables • Washington State Tax $1,639
Lamp Recycling	$546	
Sub-Total	$25,586	
Cost / Square Foot	$1.71	Based on 15,000 SF

2.2.4. REI Building Monitoring Period

The total monitoring period for this site extended from December 20, 2011 through September 27, 2012. Authorized installers of Enlighted handled the installation, and the work took place during unoccupied periods over weekends and in the evenings. Table 7 summarizes the other phases of research.

Table 7: REI Building Monitoring Periods

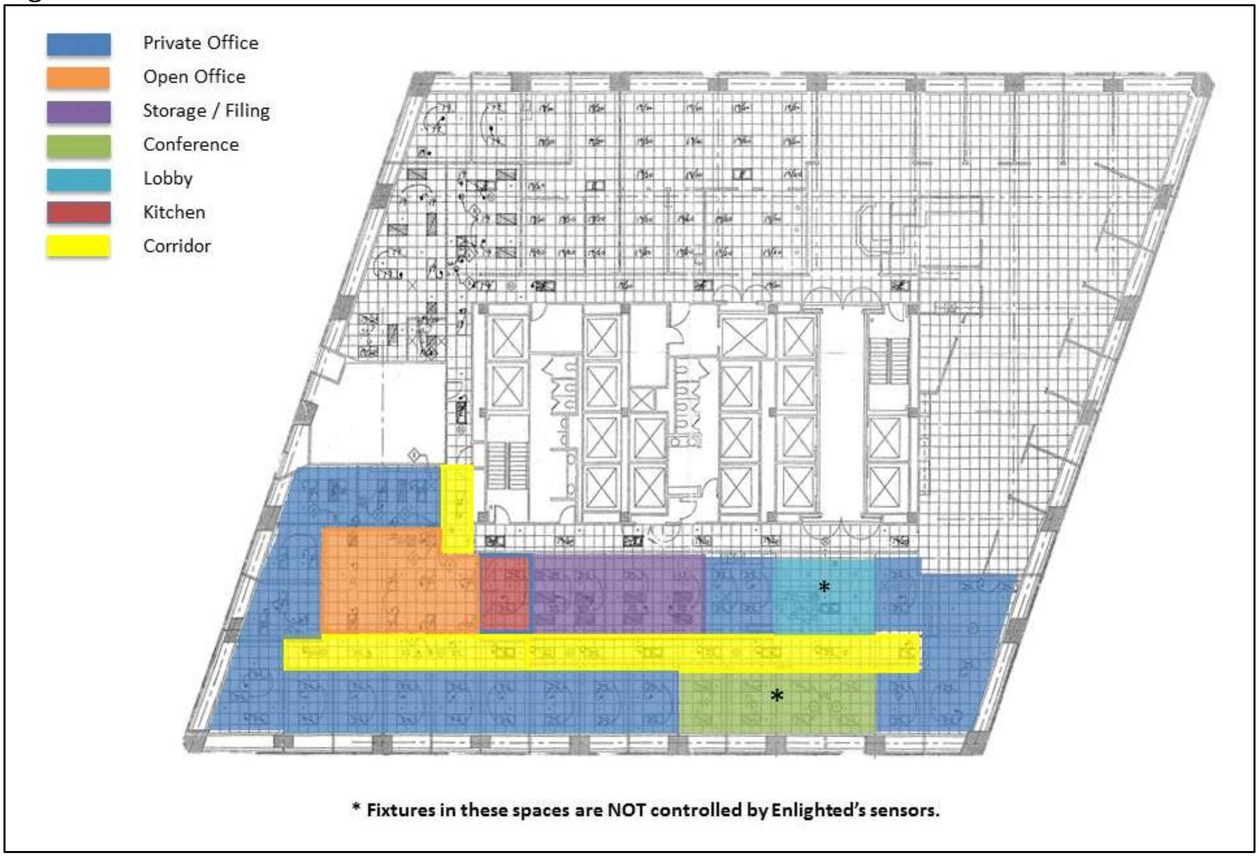
	Beginning	End	# of Days
As Is Baseline	12/20/2011	1/25/2012	36
Construction	1/26/2012	2/3/2012	8
Adjusted Baseline	2/6/2012	3/13/2012	36
Out-of-Box Operation	3/13/2012	6/22/2012	101
Designer Preference	6/23/12	8/10/12	48
User Preference	8/11/12	9/27/12	47

2.3. Kivel & Howard

Kivel & Howard is a law firm located on part of the 17th floor of the US Bancorp Tower in Portland, Oregon. The tenant was in the process of a lease renewal and tenant improvement upgrade at the time of the pilot demonstration opportunity. Unico, the landlord at US Bancorp, had some prior experience with the Enlighted technology; Unico recommended that Kivel & Howard proceed with the installation in return for the NBI research and analysis.

Although the office covers 6,763 total square feet, only 5,418 square feet of the space was included in the study area. The study area space types included roughly half private offices; three conference rooms; a small amount of open office space; storage; corridors; lobby; and kitchen spaces. The study area included 105 fixtures.

Figure 5: Kivel & Howard Site Plan



The Kivel & Howard site experienced a number of complications. Specifically, the circuiting was more complicated than had been understood at the beginning of the pilot, in the following ways:

- The north part of the office shared a circuit with the neighboring tenant and was not metered as part of this pilot study
- All middle lamps (luminaires have 3-lamp cross-sections) in the study area went to a separate circuit that was metered as part of this pilot study
- Egress fixtures were separately circuited and were not metered as part of this pilot study

2.3.1. Existing Lighting System Characteristics

The existing lighting system included:

- 73 - 2 x 4 paracube linear fluorescent troffers
- 3 T8 lamps (F032 / 735 T8)
- 2 ballast (Motorola "1st generation" electronic)
- Total system watts for each luminaire: 96 watts

Plus:

- 2 - 2 x 2 paracube linear fluorescent troffers
- 2 U-tube T8 lamps
- 1 ballast (Motorola "1st generation" electronic)
- Total system watts for each luminaire: 64 watts

Each of the 2x4 fixtures contributed 96 watts and the 2x2 fixtures contributed 64 watts for a total of 7,136 watts of measured connected load. The total 5,418 square foot space yielded a LPD of 1.32 watts/square foot.

2.3.2. Retrofit Lighting System Characteristics

The retrofit lighting system included:

- 69 - 2 x 4 paracube linear fluorescent troffers
- 2 T8 lamps (F032 / 735 T8)
- 1 ballast (GE 75383 – GE232MVPS-H-V03 Ultrastart 100-3% dimming EB 277 Volt circuiting)
- Total system watts for each luminaire: 74 watts

Plus:

- 4 - 2 x 4 paracube linear fluorescent troffers
- 3 T8 lamps (F032 / 735 T8)
- 2 ballast (Motorola “1st generation” electronic)
- Total system watts for each luminaire: 96 watts

Plus:

- 2 - 2 x 2 paracube linear fluorescent troffers
- 2 U-tube T8 lamps is
- 1 ballast (Motorola “1st generation” electronic)
- Total system watts for each luminaire: 64 watts

In addition to the complicated circuiting, the lighting system renovation turned out to be more extensive than simply replacing ballasts and adding controls. Specifically:

- Existing Condition – 3-lamp T8 with two “1st generation” Motorola ballasts (one ballast drove inner lamp and the other ballast drove outer lamps)
- Adjusted Condition – middle lamp and ballast removed (de-lamped from existing condition to two-lamp T8 with single dimming ballast)
- As an important note, the Existing Condition had many lamps out or unplugged. For example, during a walk-through of the Kivel & Howard study area before the renovation, researchers counted only 18 three-lamp fixtures with all three lamps illuminated, 15 three-lamp fixtures with two lamps illuminated, and 30 with only one lamp illuminated. The remaining fixtures were not illuminated.

Each of the 69 2x4 fixtures contributed 74 system watts; each of the remainder of the 2x4 fixtures (that were not retrofitted) contributed 96 watts; and the 2x2 fixtures contributed 64 watts for a total of 5,618 watts of measured connected load. The total 5,418 square foot space yielded an LPD of 1.04 W/square foot.

2.3.3. Costs

The entire Kivel & Howard project cost a total of $21,029, or $3.11/SF. NBI based these costs on total size of the office installation, as well as on total costs for the Enlighted system installation in 6,763 SF of office – not only on the 5,418 SF in the study area. Table 8 shows a breakdown of costs. This amounts to $280/fixture for 75 fixtures.

Table 8: Summary of Costs at Kivel & Howard

Item	Cost	Description / Notes
Installation	$11,439	8 days for two licensed electricians to complete. Work included ballast replacement, Enlighted control installation, as well as delamping.
Equipment	$9,590	• 66 Wireless Sensor Units (elf-SU-W-0-0) • 66 Wireless Control Units (elf-CU-W-0-0) • 2 Enlighted Gateway Units (elf-GW-W-0-0) • 1 Enlighted GEM Server (elf-GEM-SAP-1) • 105 two-lamp dimming ballasts
Total	$21,029	Total costs for the 6,763 SF site
Cost / Square Foot	$3.11	Costs are based on total site costs and total size (6,763 SF), even though only part of this area was in the study area.

2.3.4. Kivel & Howard Office Monitoring Period

The total monitoring period was June 23, 2011, through February 22, 2012. The onsite facility manager installed the Enlighted equipment. This work happened early in the morning with special effort to keep tenant disruption to a minimum. Table 9 below summarized the other phases of research.

Table 9: Kivel & Howard Office Monitoring Periods

	Beginning	End	# of Days
As Is Baseline	6/23/2011	7/26/2011	33
Construction	7/27/2011	8/10/2011	15
Adjusted Baseline*	11/21/2011	11/30/2011	9
Out-of-Box Operation	8/11/2011	11/20/2011	101
Designer Preference	3/1/2012	4/12/2012	42
User Preference	12/1/2011	2/22/2012	83

**Note:* the adjusted baseline took place after the initial system installation and out-of-box operation. This baseline is not representative due to a very irregular occupancy period (Thanksgiving) during the adjustment that did not provide a stable and comparable baseline.

2.4. Installation Summary

The Enlighted Technical Proof of Concept Study involved three research sites in the Pacific Northwest. The analysis included detailed investigations into the before-and-after measured performance of each site using a stepped baseline approach in order to identify incremental improvements. In addition to the baseline performance, other phases of research included the Enlighted out-of-box mode, designer preference and user preferences.

Two sites included investigations into the impacts of lighting controls on task lighting use. This began after the installation of the controls at the Yale Building – therefore no data is available on occupant task lighting use before installation of the controls. At REI, researchers collected task lighting information before and after installation of the controls.

Researchers also collected detailed information about the system characteristics, summarized in Table 10.

Table 10: Summary of Pilot Site Before-and-After Characteristics

Site	Number and Type of Fixture	Lamp Type	Ballast Type	Total System Watts	Lighting Power Density
Yale Building Before Installation	180 recessed center-basket linear fluorescent fixtures	2 T5HO lamps (Sylvania FP54/835/HO/ECO	1 ballast (Sylvania QTP2x54T5HO/UNV)	121 watts	1.09 W/SF
Yale Building After Installation	Same	Same	1 dimming ballast (Sylvania Quicktronic Powersense QHE 2x54T5HO/UNV DIM-TCL)	116 watts	1.04 W/SF
REI Before Installation	138 recessed parabolic fluorescent fixtures	3 T8 lamps (GE Ecolux® Starcoat® F32T8/SP35/ECO)	1 ballast (GE 78623 GE332 MAX - N/Ultra 277 V)	80 watts	0.74 W/SF
REI After Installation	Same	Same	1 dimming ballast (GE 75381 GE332MVPS-N-V03)	85 watts	0.78 W/SF
Kivel & Howard Before Installation	73 - 2 x 4 paracube linear fluorescent troffers	3 T8 lamps (F032 / 735 T8)	2 ballast (Motorola “1st generation” electronic)	96 watts	1.32 W/SF
	2 - 2 x 2 paracube linear fluorescent troffers	2 U-tube T8 lamps	1 ballast (Motorola “1st generation” electronic)	64 watts	
Kivel & Howard After Installation	69 - 2 x 4 paracube linear fluorescent troffers	2 T8 lamps (F032 / 735 T8)	1 ballast (GE 75383 – GE232MVPS-H-V03 Ultrastart 100-3% dimming EB 277 Volt circuiting)	74 watts	1.04 W/SF
	4 - 2 x 4 paracube linear fluorescent troffers	3 T8 lamps (F032 / 735 T8)	2 ballast (Motorola “1st generation” electronic)	96 watts	
	2 - 2 x 2 paracube linear fluorescent troffers	2 U-tube T8 lamps	1 ballast (Motorola “1st generation” electronic)	64 watts	

2.4.1. Summary of Monitoring Periods

The monitoring periods for each site ranged from a low of 19 days to a high of over 100 days for the out-of-box and user preference phases of the Enlighted system study. In total, this research represents 123 days of initial baseline monitoring, over 200 days monitoring the Out-of-Box Operation and User Preference. Table 11 shows the total days of monitoring for the project.

Table 11: Monitoring Time Summary - Number of Days in Each Research Phase By Building

Research Phase	Yale Building	REI	Kivel & Howard	Total Days
As Is Baseline	54	36	33	123
Construction	23	8	15	46
Adjusted Baseline	19	36	9*	64
Out-of-Box Operation	25	101	101	227
Designer Preference	N/A	48	42	90
User Preference	104	47	83	234

*Note: the adjusted baseline took place after the initial system installation and out-of-box operation. This baseline is not representative due to a very irregular occupancy period (Thanksgiving) during the adjustment that did not provide a stable and comparable baseline.

3. Pilot Site Measured Performance Analysis

Through this project and previous lighting monitoring work, NBI has selected and established three methods that enable a comparative performance assessment across a range of metrics. Each method reveals particular insights for how well the lighting controls are working. In representing the energy use, savings and demand, NBI believes these categories and metrics provide a consistent and comprehensive methodology and vocabulary for industry consideration. The three are as follows (discussed below): 1) Daily Consumption Profiles, 2) Average Lighting Power Density and 3) Estimated Annual Energy Consumption.

1) The ***Daily Consumption Profiles*** show the average lighting energy use on weekdays at the various phases of the research project. While this report details patterns at each site, overall this measured performance analysis reveals a few important trends where lighting controls can save significant energy, including the following observations:

- Lighting controls can delay the morning ramp-up of lighting systems to turn lights on only when occupants enter the space.
- Similarly, lighting controls allow the evening ramp-down of lighting systems as occupants exit the space.
- Lighting controls appear to be successfully turning off lights at night to reduce the duration of time when lights are on to accommodate nighttime cleaning crews.
- When given a choice, users prefer less light. Therefore, providing them with the opportunity to influence the light levels in their area can help reduce energy use associated with lighting controls.
- The amount of savings correlates to the amount of time that occupants spend at their desks.

2) The ***Average Lighting Power Density*** analysis provides measured performance metrics that allow further analysis. Overall, the results show that the new Enlighted lighting control systems consistently reduced average lighting power density compared with the existing systems. These savings are more dramatic during nighttime hours than during regular occupied weekday hours. The savings ranged from 14 to 51% during weekdays and from 53 to 79% on weekday evenings, as shown in Table 12.

Table 12: Percentage of Average Lighting Power Density Savings on Weekday Occupied and Weeknight Hours

	Weekday Occupied Hours			Weeknight Hours		
	Out-of-Box	**User Preference**	**Designer Preference**	**Out-of-Box**	**User Preference**	**Designer Preference**
Yale Building	23%	51%	N/A	79%	74%	N/A
REI	14%	23%	16%	66%	70%	63%
Kivel & Howard	21%	27%	27%	53%	59%	59%

The Average Lighting Power Density metrics offer another interesting analysis possibility in the form of the “off-hours ratio” or “weekend ratio.” A lower “off-hour ratio” or “weekend ratio” demonstrates that lighting controls are effectively turning off lights during unoccupied hours. Table 13 provides a summary of the off-hours and weekend ratios.

Table 13: Off Hours and Weekend Ratios

	Yale Building		**REI**		**Kivel & Howard**	
	Off Hours Ratio	**Weekend Ratio**	**Off Hours Ratio**	**Weekend Ratio**	**Off Hours Ratio**	**Weekend Ratio**
Existing Baseline	30%	14%	44%	26%	31%	18%
Adjusted Baseline	23%	10%	48%	35%	38%	15%
Out-of-Box Mode	8%	2%	17%	12%	19%	12%
User Preference	13%	6%	17%	17%	18%	13%
Designer Preference	N/A	N/A	20%	16%	18%	13%

3) The ***Estimated Annual Energy Consumption*** provides insights into potential annualized energy savings given the measured performance results. Savings ranged from 32-59% as outlined in the following table. Please note that savings at the Kivel & Howard site are also attributable to the delamping and are not all associated with the lighting controls. Additionally, Kivel & Howard had no adjusted baseline (where lamps are running at full output after the ballast replacement).

Table 14: Estimated Annual Energy Savings Compared to Existing Baseline

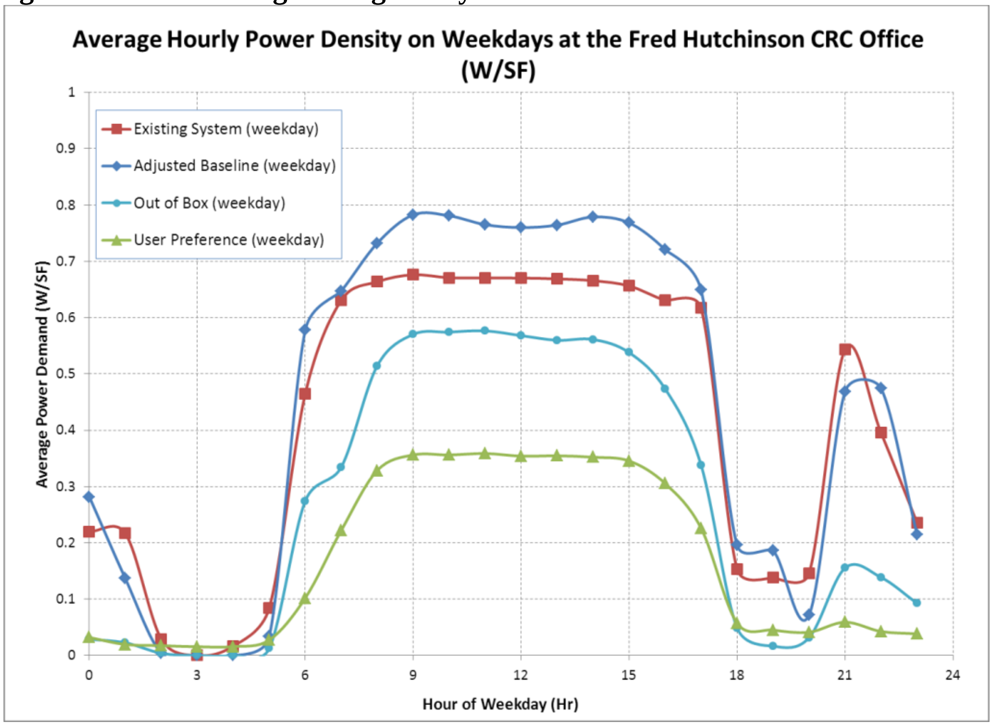
	Yale Building	**REI**	**Kivel & Howard**
Out-of-Box	41%	35%	32%
User Preference	59%	39%	36%
Designer Preference	N/A	35%	37%

3.1. Fred Hutchinson Cancer Research Center - Yale Building (Yale Building)

3.1.1. Yale Building Average Daily Profile

Figure 6 shows the Yale Building average daily profile for each phase of the stepped baseline.

Figure 6: Yale Building Average Daily Profile



The Yale Building's Average Daily Profile clearly depicts energy savings patterns enabled by the new lighting control system. Most importantly, the graph clearly shows a significant reduction in energy use during occupied hours. This may be attributable to a number of factors:

1. Occupants are not at their desks for extended periods at the Yale Building. As part of the survey, occupants reported that they were typically at their desks between four and six hours per day, thus providing many opportunities for the lighting control system to adjust lights when desks are not in use.
2. The Yale Building includes many private offices where lighting controls are able to turn off lights when occupants are not present, thus realizing substantial energy savings opportunities.
3. Another potential factor in the occupied-hours energy savings: when given the opportunity to control their lighting system, the occupants preferred less light.

In addition to the overall drop in occupied-hours lighting energy use of 59% (over the existing baseline), savings occur in three distinct timeframes: early morning, evening and after hours. The morning ramp-up occurs later and is less steep than that observed with the uncontrolled lighting system. The evening ramp-down starts earlier than before. The Average Daily Profile also clearly shows that lighting controls are successful in after-hours energy savings presumably associated with janitorial services. Before installation of the lighting controls, this "janitor bump" was significant in terms of magnitude and duration. The addition of controls minimizes the "janitor bump."

3.1.2. Yale Building Average Lighting Power Density

Table 15 outlines the average lighting power density from measured results during various phases of the study.

Table 15: Yale Building Measured Average Lighting Power Density

	Installed LPD (W/SF)	Weekday Daytime (W/SF)	Weekday Nighttime (W/SF)	Off Hours Ratio (%)	Weekend Holiday (W/SF)	Weekend Ratio (%)	Peak (W/SF)
Baseline	1.32	0.64	0.19	30%	0.09	14%	0.76
Adjusted Baseline	1.04	0.73	0.17	23%	0.07	10%	0.90
Out-of-Box Mode	1.04	0.49	0.04	8%	0.01	2%	0.71
User Preference	1.04	0.31	0.04	13%	0.02	6%	0.49

3.1.3. Yale Building Estimated Annual Energy Consumption

The following table summarizes the estimated annual energy use for the Yale Building during the various phases of the study.

Table 16: Yale Building Estimated Annual Energy Consumption and Percent Savings

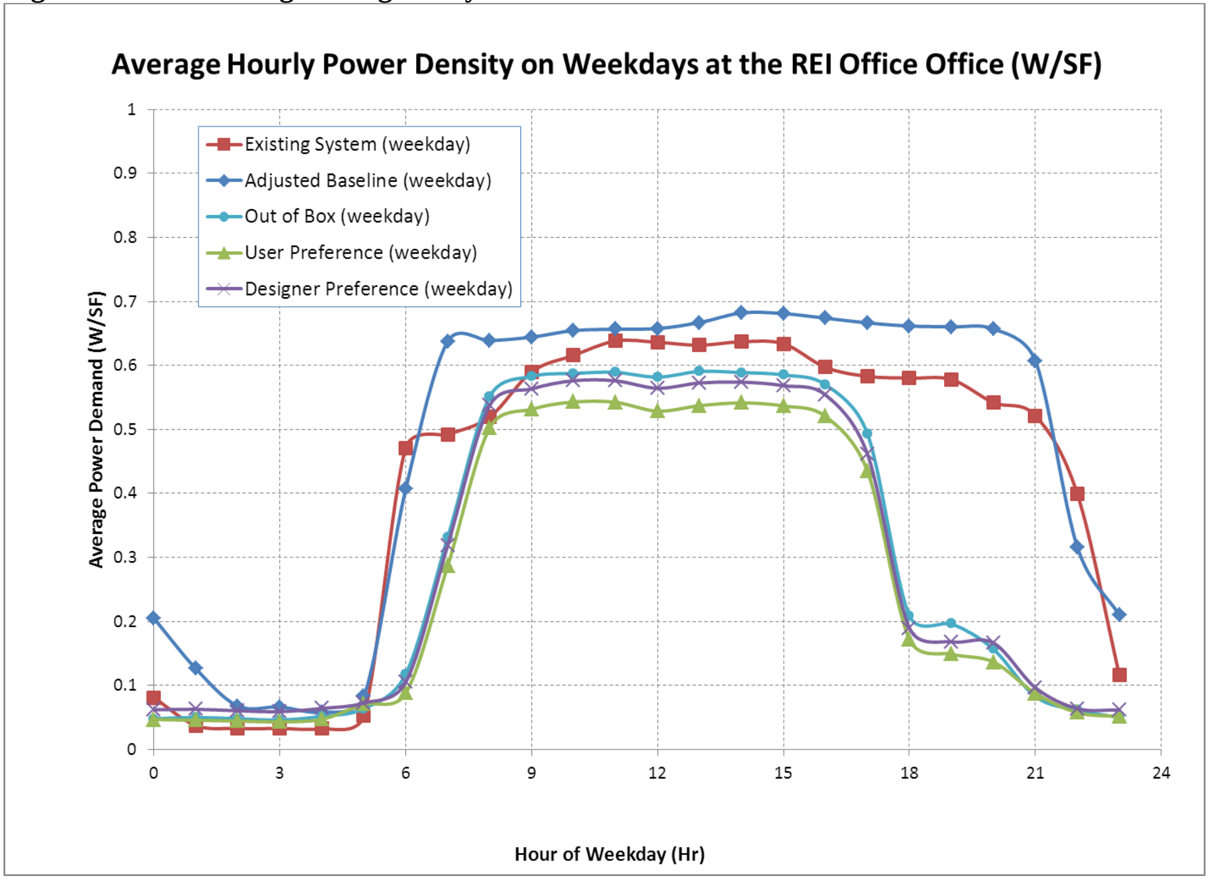
	kWh/Yr	kWh/SF-Yr	% Savings from Existing Baseline
Existing	54,998	2.75	-
Adjusted Baseline	57,847	2.89	-
Out-of-Box Mode	32,625	1.63	41%
User Preference	22,366	1.12	59%

3.2. REI Headquarters Office

3.2.1. REI Building Average Daily Profile

Figure 7 shows the REI headquarters average daily profile for each phase of the stepped baseline.

Figure 7: REI Building Average Daily Profile



The REI Average Daily Profile shows obvious reductions in the before- and after-hours energy use. Lighting controls successfully delayed the energy consumption during the hours of 5:00 to 7:00 AM. Significant savings are attributable to a reduction of lighting energy use between 6:00 PM and 11:00 PM when the office is obviously unoccupied. Savings during the occupied workday are not as dramatic as at the Yale Building, which may attributable to the fact that occupants at REI are mostly in an open office environment and they claim to be at their desks for more than six hours each workday. In contrast, occupants at the Fred Hutchinson Yale Building are more likely to sit in private offices and claim to be at their desks between four and six hours each workday. Appendix A contains additional information about occupant surveys.

3.2.2. REI Building Average Lighting Power Density

The following table outlines the average power density from measured results during various phases of the study.

Table 17: REI Building Measured Average Lighting Power Density

	Installed LPD (W/SF)	Weekday Daytime (W/SF)	Weekday Nighttime (W/SF)	Off Hours Ratio	Weekend Holiday (W/SF)	Weekend Ratio	Peak (W/SF)
Existing Baseline	0.74	0.61	0.27	44%	0.16	26%	0.66
Adjusted Baseline	0.78	0.65	0.31	48%	0.23	35%	0.69
Out-of-Box Mode	0.78	0.52	0.09	17%	0.06	12%	0.69
User Preference	0.78	0.47	0.08	17%	0.08	17%	0.59
Designer Preference	0.78	0.51	0.10	20%	0.08	16%	0.61

3.2.3. REI Building Estimated Annual Energy Consumption

The following table summarizes the estimated annual energy use for the REI building during the various phases of the study.

Table 18: REI Building Estimated Annual Energy Consumption

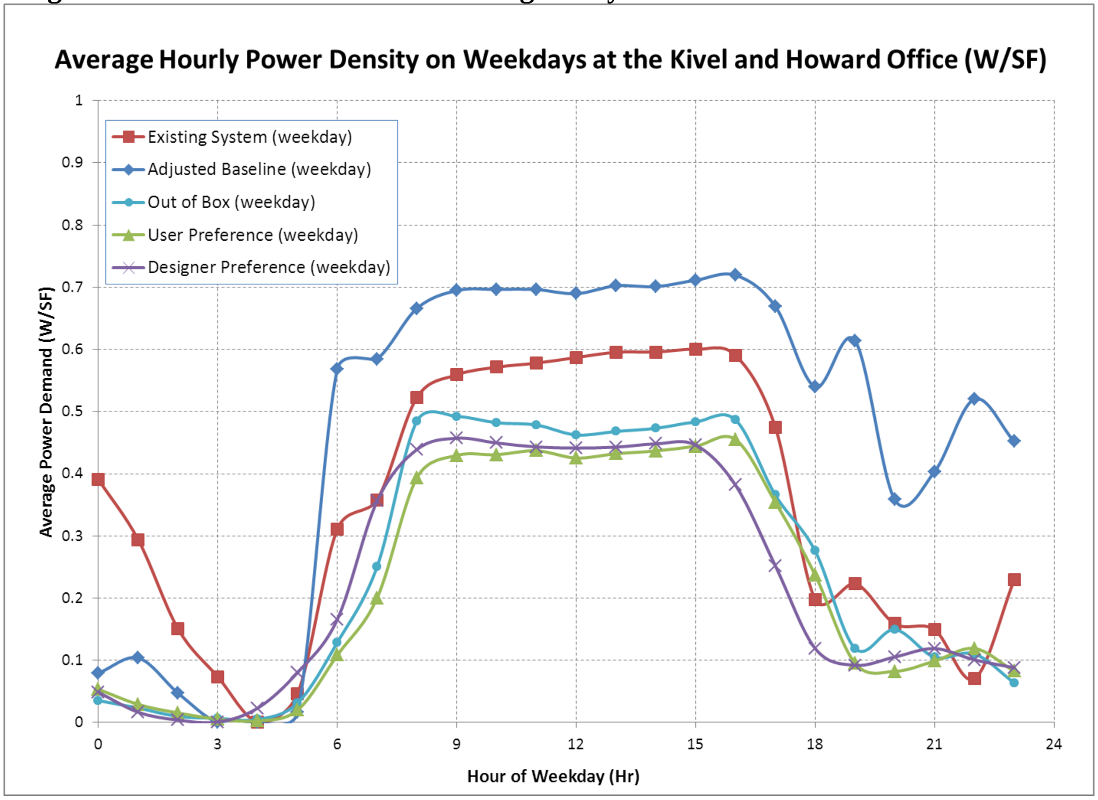
	kWh/Yr	kWh/SF-Yr	% Savings from Existing Baseline
Existing	46,800	3.1	
Adjusted Baseline	52,900	3.5	
Out-of-Box Mode	30,100	2.0	35%
User Preference	28,100	1.9	39%
Designer Preference	30,700	2.0	35%

3.3. Kivel & Howard Office

3.3.1. Kivel & Howard Office Average Daily Profile

Figure 8 shows the Kivel & Howard office average daily profile for each phase of the stepped baseline.

Figure 8: Kivel & Howard Office Average Daily Profile



The reductions revealed in the Average Daily Profile at Kivel & Howard warrant additional discussion. As explained earlier in this report, this site was delamped from a 3-lamp T8 condition to a 2-lamp T8 condition, which obviously affects the savings. While it is difficult to segregate the savings from delamping and controls, the patterns in the Average Daily Profile do graphically illustrate the savings that may be more associated with the lighting controls. For example, notice the delay in the ramping up of the lighting system in the morning. Before installation of the controls, this began at 5:30 AM; in the user preference mode, morning ramp-up started at 6:30 AM. Similarly, the ramp-down at the end of the day starts earlier post-installation of controls than it did with the old system. Another noticeable impact is around the lunch hour, where a “dip” is noticeable in the chart. Finally, after-hours also shows a noticeable drop in energy use, which is also likely attributable to the Enlighted system.

The adjusted baseline period merits an important note in this case. Enlighted initially disregarded this step at this first Kivel & Howard pilot location. Researchers attempted to go back and recreate this situation; however, the data was collected during Thanksgiving week and is likely not representative given irregular occupancy patterns from that particular holiday week.

3.3.2. Kivel & Howard Office Average Lighting Power Density

The following table outlines the average lighting power density from measured results during various phases of the study.

Table 19: Kivel & Howard Measured Average Lighting Power Density

	Installed LPD (W/SF)	Weekday Daytime (W/SF)	Weekday Nighttime (W/SF)	Off Hours Ratio	Weekend Holiday (W/SF)	Weekend Ratio	Peak (W/SF)
Existing Baseline	1.32	0.55	0.17	31%	0.10	18%	0.78
Adjusted Baseline	This baseline is not represented due to a very irregular occupancy period (Thanksgiving) during the adjustment that did not provide a stable and comparable baseline.						
Out-of-Box Mode	1.04	0.43	0.08	19%	0.05	12%	0.66
User Preference	1.04	0.40	0.07	18%	0.05	13%	0.54
Designer Preference	1.04	0.40	0.07	18%	0.05	13%	0.54

3.3.3. Kivel & Howard Estimated Annual Energy Consumption

The following table summarizes the estimated annual energy use for the Kivel & Howard office during the various phases of the study.

Table 20: Kivel & Howard Estimated Annual Energy Consumption and Savings Relative to Existing Baseline

	kWh/Yr	kWh/SF-Yr	% Savings from Existing Baseline
Existing	14,029	2.45	-
Adjusted Baseline	-	-	-
Out-of-Box Mode	9,504	1.66	32%
User Preference	8,977	1.57	36%
Designer Preference	8,813	1.54	37%

3.4. Summary of Annual Energy Consumption

The **Estimated Annual Energy Consumption** provides insights into the annualized energy savings compared to an existing condition baseline given the measured performance results. Savings ranged from 32 to 59%, as outlined in Table 21. Savings at the Kivel & Howard site are also attributable to the delamping and are not all associated with the lighting controls.

Table 21: Estimated Annual Energy Savings Relative to Existing Baseline

	Yale Building	REI	Kivel & Howard
Out-of-Box	41%	35%	32%
User Preference	59%	39%	36%
Designer Preference	N/A	35%	37%

4. Light Level Measurements

Instantaneous light level measurements provide a snapshot of lighting levels at specific moments in time. Researchers took ten light level readings during the Enlighted study, including four at the Yale Building, four at REI and two at Kivel & Howard.

Industry standards suggest that lighting levels for office spaces allow for 35-55 foot-candles. The REI site was the most likely to be in this range with a typical degree of variation across the space. The Yale Building experienced a high degree of variation, likely due to a large amount of daylighting available (weather dependent) in private offices from external windows. Conversely, light levels in the Kivel & Howard office were lower than industry standard recommendations, at the request of the occupants who indicated that they preferred less light. Table 22 provides a summary of the light level measurements by phase.

Table 22: Summary of Instantaneous Light Level Measurements by Site and Phase of Research

	Yale Building	REI	Kivel & Howard
Baseline	9-104 foot-candles	15-56 foot-candles	-
Adjusted Baseline	-	17-53 foot-candles	-
Out-of-Box	2-50 foot-candles	17-66 foot-candles	16-34 foot-candles
Designer Preference	-	13-66 foot-candles	-
User Preference	4-129 foot-candles	-	6-35 foot-candles

5. Task Light Analysis

Task lighting creates complexities for measuring the energy performance of lighting systems because task lights are often not included in measured lighting circuits. Instead, task lights are typically included in the plug load circuit. Since this study did not measure the plug load circuits, the research required a different approach.

With a goal of assessing the relative impact of task lights, researchers installed loggers on twenty-five percent of the task lights in the REI and Yale Building sites. These "state" loggers recorded whether task lights were on or off to compare task light use before and after deployment of lighting controls. The aim was to determine whether the use patterns would change as the overhead lighting system dimmed. This methodology was not part of the initial scope and limited the investigation of task lighting impact to two pilot sites.

The research demonstrates the relative impact of the task lights compared to the overhead fixtures in the office. Annual usage of 15-30 kWh constitutes up to 50% of the overhead fixture energy use. This illustrates the importance of accounting for task lights in future studies. A change in task light behavior could easily affect the estimated energy savings/penalty of a lighting system.

Each site varies in task lighting use. REI used less task light energy than did the Yale Building. This could be due to differences in occupant behavior (note that the Yale Building had a small sample size); type of work typically conducted by employees; workstation layout; balance between open and private office; and/or occupant schedules. Table 203 provides a summary of the annual task light energy use for both sites.

Table 23: Annual Task Light Estimated Energy Use

	kWh/Fixture/Year	
Measurement Period	**REI**	**Yale Building**
Adjusted Baseline	18.6	31.4
Out-of-Box	17.4	25.1
Designer Preference	15.6	N/A
User Preference	16.4	N/A

Despite this potential for increasing combined task and overhead lighting use, researchers concluded that the use of task lights did not significantly change from before to after the renovation of the lighting system at REI. Researchers did not collect data both before and after the renovation at any other pilot site. This finding begins to alleviate concern over a "compensating" effect that leads to increased task light usage as the Enlighted system dims the overhead fixtures. Further analysis for a large set of task lights will bolster this conclusion.

This dataset also demonstrates the relative impact of the task lights compared to the overhead fixtures in the office. Annual usage of approximately 30 kWh per fixture is between 20% and 50% of the overhead fixture energy use measured during the user preference period (depending on whether the comparison is to fixtures in the office core or on the perimeter). This finding illustrates the importance of accounting for task lights in future studies. A change in task light behavior could easily affect the estimated energy savings/penalty of a lighting system.

6. Occupant and Contractor Surveys

6.1. Occupancy Survey Methodology

NBI developed a web-based survey instrument, which it administered multiple times during the research. The survey contained ten questions specifically referencing perceptions of lighting in the space during specific phases of the stepped baseline. The goal was to collect responses during at least three phases of the research (as-is baseline, out-of-box, designer preference and user preference).

Survey questions helped researchers compare respondents' perceptions of lighting comfort based on their locations within the office. Specific areas of inquiry included overall satisfaction with the lighting system including control, glare, reactions such as burning eyes or headaches, and other general questions.

Respondents used a five-point scale to rate their levels of agreement with six statements about their workspace lighting including evenness of lighting; brightness; controls; gloom; room surface brightness and daylighting.

The survey also asked respondents to evaluate various aspects of glare on another five-point scale that included never, sometimes and always. Respondents indicated how often they experience certain glare conditions in their personal workspaces on an average day. The conditions included:

1. Glare reflected from work surfaces
2. Light fixture glare reflected on the computer screen
3. Window glare reflected on the computer screen
4. Direct glare from the window
5. Direct glare from fixtures

Respondents also indicated the extent to which they agreed or disagreed with statements about lighting and controls in their personal workspaces. They rated whether the light fixtures and controls created conditions that were distracting or annoying, if daylight without electric lighting is suitable for working most hours of the day and if a task light is necessary to augment the light most hours of the day.

Researchers administered surveys at all sites. At each site, both the number and the identity of respondents differed from survey to survey. In other words, the same occupants may have taken the survey multiple times. REI experienced excellent survey participation due to a raffle for a $50 gift certificate awarded to one participant during each phase of the research.

Table 24: Overall Survey Completions

Survey	Yale Building	REI	Kivel & Howard	Totals
Baseline	23	66	14	103
Out-of-Box Lighting Survey	14	66	-	80
User Preference Lighting Survey	23	45	13	81
Designer Preference Lighting Survey	-	45	-	45

Perceptions of lighting are personal preferences that depend on many factors such as age, task and the surrounding physical space characteristics. Creating one lighting solution for all people and all tasks is always a challenge. This is one reason that individually controlled systems hold so much promise; such systems allow delivery of only as much light as is necessary for that occupant and that particular task.

6.2. Site-Specific Findings from Occupancy Survey

6.2.1. Yale Building

Survey responses from occupants of the Yale Building allowed for in-depth comparisons of the perceptions between those in private and open offices. Not surprisingly, occupants of private offices located along the window wall felt they had control of their lighting and that daylighting was adequate for working. They were also less likely to describe the lighting as gloomy. However, glare from windows was an issue for the private-office occupants.

Open-office occupants experienced different perceptions of the lighting system. They felt they had less control over the lighting in the space, and one-third expressed dissatisfaction with their levels of control. Most agreed the lighting was too bright before the renovation and appreciated the dimming of the lights, because it seemed to reduce glare. This group noticed the flickering lights and blamed this on the lighting control system (the problem was eventually remedied).

6.2.2. REI Building

REI staff felt that pre-Enlighted light levels were comfortable; this perception increased upon installation of the Enlighted system. Respondents did not consider the lighting gloomy and felt the space experienced even lighting with no very bright or dim spots. They indicated that the controlled system created a pleasant brightness on room surfaces and minimized glare when dimming the lights. While daylighting was not sufficient for tasks at all times of the day, the overhead lights and the opportunity to use task lights gave respondents sufficient grounds to report overall satisfaction with the lighting system.

At REI, the new system seemed to improve perceptions of key comfort issues. Respondents reported decreased perceptions of glare from various sources after installation of the Enlighted system. While the proportions of individuals with burning or tired eyes stayed about the same, only a few individuals experienced headaches attributable to the lighting system.

When asked if the system provided enough light for a variety of tasks, respondents typically felt the light levels were just right; issues typically stemmed from too-bright light levels. A few occupants found the new lighting control system distracting because it dimmed or turned off lights in their areas even when they were present.

6.2.3. Kivel & Howard Building

At Kivel & Howard, researchers also noticed a distinct split between the open office and private office occupants. Contrary to the Yale Building findings, private-office occupants at Kivel & Howard were less satisfied with the lighting after the retrofit. While reports of glare were fewer, private office staff felt the new system resulted in less personal control over their lit environments.

Open office staff at Kivel & Howard had strongly desired a reduction in the lighting levels; therefore, they expressed overall favorable perceptions of the lighting controls. Fewer staff experienced burning, tired eyes or headaches after the renovation. While many perceived the old system as too bright, the new system may have created a reliance on task lights for paper tasks such as reading and filing.

6.2.4. Comparison across All Three Buildings

After installation of the Enlighted controls, occupants generally experienced increased comfort and satisfaction with the light levels and with their ability to control those levels. In general, most thought the new system improved the brightness levels of fixtures originally deemed too bright; decreased the gloominess; increased the pleasantness of the surface brightness; and decreased glare and burning eyes and headaches (except for one site, where headaches increased). Task lighting elicited a diversity of opinions. Most thought the system was an improvement, but that it was too dim to complete high-light tasks, such as reading or filing. A few found the new controls distracting when the lights turned off while they occupied the space. Feedback on daylighting varied depending on the type of office space. Open office occupants typically felt they have insufficient daylight, while occupants in private offices along the window wall considered their levels of daylight sufficient.

6.3. Contractor Survey

Researchers conducted phone surveys of the installers at the three pilot sites shortly after installation. At least one licensed electrician participated in the installations at the Yale Building and at Kivel & Howard. At both of these sites, the installers had little, if any, familiarity with the Enlighted system except for what they learned from the Enlighted representatives on-site during the installations. At REI, the installer had certification under the California Non-Residential Lighting technical standard and also had extensive experience with Enlighted systems.

REI was the only site to use Enlighted-recommended installers (from California); they had more than two months of experience installing the system. This crew of six journeyman/technician level (equivalent) took a total of fourteen hours for installation in the 15,000 SF study area. The entire 79,600 SF REI Headquarters building took the same crew six days at nine hours per day.

The REI installers achieved significant economies of scale directly reflected in the cost of installation, given that the crew lead could describe the exact process used to install the

Enlighted system. In addition, the REI installers successfully addressed one of their primary concerns – cleanliness – by achieving their goal of no complaints.

The fixture itself had an impact on the ease of installation. The recessed T5HO fixture at the Yale Building had a complex process for accessing and replacing the ballast and adding the control system. The installer mentioned that this may have added to the time needed for installation on the project. Installers at Fred Hutchinson noted that they would hire Enlighted-recommended installers for all future installations instead of using campus electricians to do the work.

The Kivel & Howard installer believed that the manufacturer's claim of installing the Enlighted system on two fixtures per hour is optimistic. Instead, he suggested the ballast replacement, control and sensor installation, and delamping on one fixture would take approximately 45 minutes. He noted that adding multiple fixtures to only one controller and sensor (as in a private office situation) took about 65 minutes. A fixture requiring replacement of shunted sockets took about 85 minutes. The installer suspected that economies of scale could be achieved, leading to more cost-effective installations, but noted that was not the case for this project.

At all locations, installers made efforts to avoid disturbing occupants by working either late at night or early in the morning. However, installers at the Kivel & Howard site did work around tenants, which may have contributed to an additional 10-20% on installation costs.

All three sites also had Enlighted staff commission the systems and provide training to the on-site facility managers on how to make changes in the future. Despite the systems' capabilities to allow occupants to modify lighting levels, occupants at all sites needed to contact facility managers to adjust lighting controls.

6.4. Fixture and Occupancy Analysis

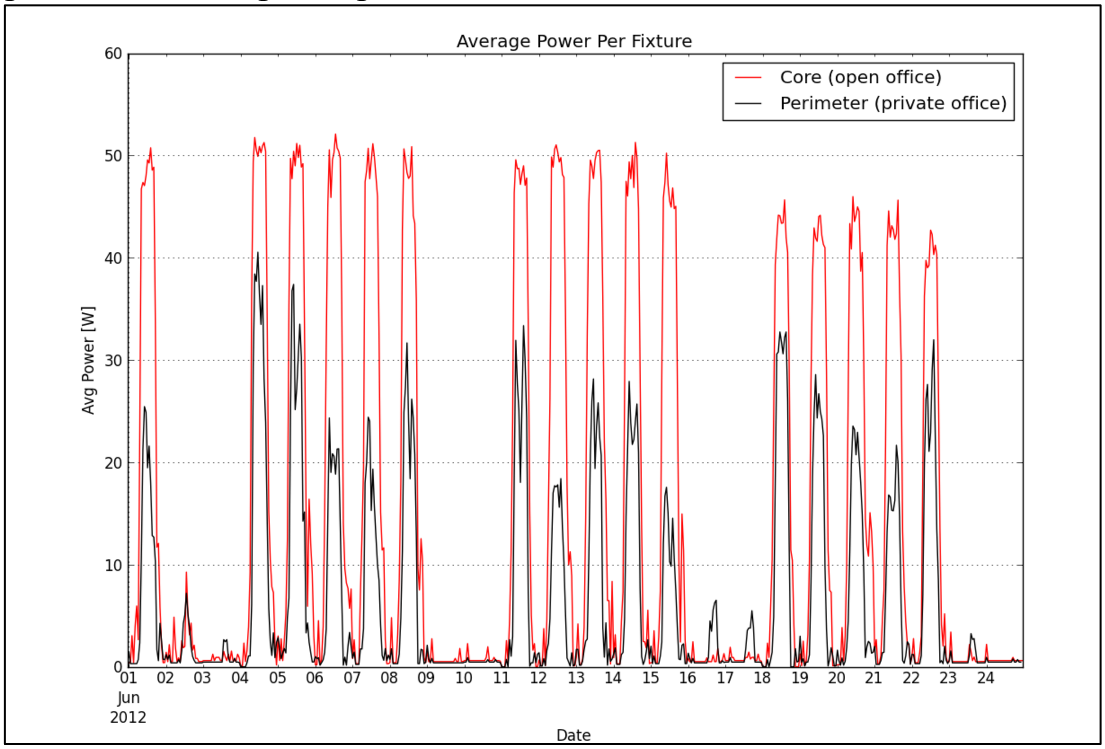
The Enlighted system collects occupancy and estimated energy use information at the fixture level. As part of this research, NBI used meters on individual fixtures at the Yale Building to investigate the representation of the fixture-level information. With confidence in these results, researchers have the unique opportunity to create "virtual meters" by aggregating a number of fixtures into groups.

Using data from the Enlighted system, researchers developed two "virtual meters":

- Core: This meter is composed of nine fixtures. Each fixture is located in the central portion of the office, which is an open floor plan cubicle layout.
- Perimeter: This meter is composed of 12 fixtures. To account for the possible bias of different light levels as the sun moves across the sky, researchers selected three fixtures from each aspect of the building (north, south, east and west). Each fixture is located in a private office.

Figure 9 below provides a high-level overview of the two meters and clearly indicates that the perimeter offices consistently use less power than the core, although this data lacks normalization for size.

Figure 9: Yale Building Average Fixture Power, Core and Perimeter



Introduction of this data may enhance the energy analysis methodology. With a consistent measure of occupancy across a study period, researchers could, for example:

- Assess the total occupancy over a multi-day measurement period. Confirm that occupancy is within a reasonable tolerance level between comparison periods.
- Determine if assumptions about weekday, weekend and holiday use are accurate. Some offices may have more weekend activity or alternative holiday schedules.
- Develop a daily regression model that relates occupancy to energy use. Apply the regression model to energy savings projections.

Collection of this type of granular data allows the industry to bridge the gap between lighting power density and energy use. This is critical to moving beyond lighting power density as the standard metric for lighting energy use.

7. Summary / Conclusions

Measured results of this Technical Proof of Concept research reveal that the Enlighted lighting control technology and dimming ballast can deliver significant savings at relatively low cost. The results of the Technical Proof of Concept study align with manufacturer claims of low costs, ease of installation and end user satisfaction, although its claims of 50-70% lighting energy savings may be optimistic in some circumstances. Measured energy savings of the Enlighted lighting control system over the existing baseline system ranged from 32 to 59%, although savings at the Kivel & Howard site (32%) are also attributable to changes to the lighting system.

Total costs of the installations ranged from $1.71/SF to $3.11/SF. Hiring installers holding California Non-Residential Lighting technical certifications with training by the manufacturer was most cost-effective ($0.45 on the low end, compared to $1.69 per SF). The REI costs ($0.45/SF for installation and $1.26 for equipment) also benefitted because the project was part of a retrofit of an entire building as opposed to tenant space within a larger building. Overall, occupants seemed satisfied with their ability to control the overhead lighting. This allowed facility managers to remove sleeves previously placed over lamps to reduce lighting levels.

Daily Consumption Profiles reveal key opportunities for savings associated with the Enlighted system lighting controls. Enlighted lighting controls successfully shortened the amount of time the lights were on by delaying the morning ramp-up and by turning lights off earlier at the end of the day, based on occupancy. Reduced lighting during after-hours operation, often associated with janitorial services, seems to be another prime energy savings opportunity with the Enlighted system.

A comparison of daytime and nighttime Average Lighting Power Density made clear the distinction between day and nighttime energy use. This analysis relied on the most common lighting metric – lighting power density – calculated separately during occupied and non-occupied hours. Savings in the Enlighted sites are more dramatic during nighttime hours than during regular occupied weekday hours. The savings compared to existing conditions ranged from 14 to 51% during weekdays and from 53 to 79% on weekday evenings.

Light level measurements showed a range of conditions across the three sites, with the REI Headquarters building most likely to fall within industry standards of 35 to 55 foot-candles. The Yale Building experienced lighting levels both much higher and much lower than industry standards, and occupants at the Kivel & Howard site preferred lighting much lower than industry standards.

Generally, occupants were satisfied with the Enlighted system and preferred less light than that provided by their existing systems or even by the out-of-box Enlighted system levels. They reported less glare and experienced fewer burning eyes and headaches after installation of the Enlighted lighting system. However, occupants at the Yale Building experienced a flickering situation caused by defective ballasts, not by the Enlighted system itself.

Notably, it appears that the use of task lights did not increase over the course of this study. Researchers attempted to use data collected during the study to quantify energy use associated with task lighting. They noted such energy use is significant, up to 50% of the energy use associated with the overhead lighting system, and warrants further investigation.

Finally, this Technical Proof of Concept study allowed researchers to compare data collected by the Enlighted system itself to that collected by meters and loggers installed on the site, including "virtual meters" to compare groups of individual fixtures. NBI found a high degree of correlation between these measurements and the Enlighted data.

While not part of this analysis, researchers noted the opportunity offered by Enlighted to conduct much more detailed investigations into lighting control energy savings. For example, with the Enlighted data, NBI can compare energy use in private offices to that in open office space, or core to perimeter, etc. This type of analysis is advantageous as it does not require the installation of expensive metering.

7.1. Next Steps

This Enlighted Technical Proof of Concept Study suggests additional research in the area of highly controlled lighting systems. This research might include:

- Understanding how data collected from the Enlighted system may be used to identify patterns in highly controlled lighting use in office spaces
- Correlating how these savings can extend to other systems in the building (like plugs and HVAC)
- Further quantifying the impacts of highly controlled lighting systems in order to increase utilities' and regulators' confidence in their energy savings and the persistence of those savings
- Conducting a longer-duration research project to quantify the seasonal impacts of daylighting
- Better understanding task lighting and the impact of switching connected load, not included in lighting power density calculations, to task-based lighting

Furthermore, NBI recommends that Enlighted consider adding functionality that integrates the occupancy data collected by the system to manage HVAC systems and non-essential plug load devices. Customers may realize even more significant savings if the occupancy information collected by the Enlighted system is used in an integrated fashion to turn off or turn down systems not in use. Marketing materials explaining the "Fourth Generation" Enlighted system suggest this is possible, however this Technical Proof of Concept study did not confirm this.

Appendix A: Summary of Occupant Survey Results

The Enlighted Technical Proof of Concept study included occupancy surveys at each location to determine changes in perception during project implementation. This study provides a snapshot of conditions before, during and after the installation of the new lighting systems. The survey findings represent feedback from the occupants within the areas affected by the changed lighting system and constitute a key component for assessing the market potential of this new retrofit dimming product. The survey yielded feedback on the users' perceptions of the space lighting and system changes. This summary addresses each building individually.

Site-Specific Findings

Yale Building

Survey responses from occupants of the Yale Building allowed for in-depth analysis comparing the perceptions of those in private and open offices. Not surprisingly, occupants of private offices located along the window wall felt they had control of their lighting and that daylighting was adequate for working. They were also less likely to describe the lighting as gloomy. However, glare from windows was an issue for the private-office occupants.

Open-office occupants experienced different perceptions of the lighting system. They felt they had less control over the lighting in the space, and one-third expressed dissatisfaction. Most agreed the lighting was too bright before the renovation and appreciated the dimming of the lights, because it seemed to reduce glare. This group noticed the flickering lights and blamed this on the lighting control system (the problem was eventually remedied).

REI Building

REI staff felt that pre-Enlighted light levels were comfortable; this perception increased upon installation of the Enlighted system. Respondents did not consider the lighting gloomy and felt the space experienced even lighting with no very bright or dim spots. They indicated that the controlled system created a pleasant brightness on room surfaces and minimized glare when dimming the lights. While daylighting was not sufficient for tasks at all times of the day, the overhead lights and the opportunity to use task lights gave respondents sufficient grounds to report overall satisfaction with the lighting system.

At REI, the new system seemed to improve some key comfort issues. Respondents reported decreased perceptions of glare from various sources after installation of the Enlighted system. While the number of individuals with burning or tired eyes stayed about the same, only a few individuals experienced headaches attributable to the lighting system.

When asked if the system provided enough light for a variety of tasks, respondents typically felt the light levels were just right; issues typically stemmed from too-bright light levels. A few occupants found the new lighting control system distracting because it dimmed or turned off lights in their areas even when they were present.

Kivel & Howard Building

At Kivel & Howard, researchers also noticed a distinct split between the open office and private office occupants. Contrary to the Yale Building findings, private-office occupants at Kivel & Howard were less satisfied with the lighting after the retrofit. While reports of glare were fewer, private office staff felt the new system resulted in less personal control over their lit environments.

Open office staff at Kivel & Howard had strongly desired a reduction in the lighting levels; therefore, they expressed overall favorable perceptions of the lighting controls. Fewer staff experienced burning, tired eyes or headaches after the renovation. While many perceived the old system as too bright, the new system may have created a reliance on task lights for paper tasks such as reading and filing.

Comparison across All Three Buildings

After installation of the Enlighted controls, occupants generally experienced increased comfort and satisfaction with the light levels and with their ability to control those levels. In general, most thought the new system improved the brightness of fixtures originally deemed too bright; decreased the gloominess; increased the pleasantness of the surface brightness; and decreased glare and burning eyes and headaches (except for one site, where headaches increased). Task lighting elicited a diversity of opinions. Most thought the system was an improvement, but that it was too dim to complete high-light tasks, such as reading or filing. A few found the new controls distracting when the lights turned off while they occupied the space. Feedback on daylighting varied depending on the type of office space. Open office occupants typically felt they have insufficient daylight, while occupants in private offices along the window wall considered their levels of daylight sufficient.

Methodology

NBI developed a web-based survey instrument to assess occupant preferences. It administered largely the same survey multiple times to occupants at each of three sites. Researchers aimed to collect responses during at least three of the four phases of the research (baseline, out-of-box, designer preference and user preference).

At each site, the numbers and identities of respondents differed from survey to survey. Additionally, some occupants may have taken the survey multiple times. Each building engaged the occupants differently to encourage survey completion; in some cases, a supervisor directed staff to complete the survey. REI had excellent survey participation due to a raffle for a $50 gift certificate awarded to one participant during each phase of the research, which likely contributed to the high number of responses.

Survey fatigue may have become an issue in this research effort. Researchers asked the same group of individuals to complete a survey on the same topic up to four times. This may have led some to place undue emphasis on survey topics to which they were repeatedly exposed or to answer in manners consistent with their responses to similar surveys earlier in the study. In addition, some may have chosen not to participate in later versions of the survey, as evidenced by the lower number of responses for later surveys noted in Table 25.

Table 25: Overall Survey Completions

Survey	Yale Building	REI	Kivel & Howard	Totals
Baseline	23	66	14	103
Out-of-Box Lighting Survey	14	66	-	80
User Preference Lighting Survey	23	45	13	81
Designer Preference Lighting Survey	-	45	-	45

The survey instrument (included as Appendix B to this report) included questions about:

1. Hours spent in workspace
2. Distance from outside wall
3. Type of office space (private or open)
4. Overall comfort with lighting in the building
5. Quality of the light in work areas (evenness, brightness, controllability, gloominess, pleasantness of wall brightness, satisfaction with lighting, requests to modify lighting)
6. Glare (reflected from work surface, reflected on computer screen from fixtures)
7. Physical reactions to the lighting (e.g. burning or tired eyes, headaches)
8. Light in the primary work location that focused on light levels for various tasks (read paper, read screens, type, filing, overall light)
9. Lighting controls (distracting, enough daylight, overall light levels)
10. Overall observations (satisfaction with light levels and ability to control light; comments on light system appearance; operation; satisfaction with lighting system; comments on survey)

Respondents used five-point scales to indicate the extent to which they agreed or disagreed with a number of statements. They responded to additional questions for the workspace lighting and lighting controls topics. For example, respondents rated their levels of agreement with various statements about their workspace lighting, including lighting evenness; brightness; controls; gloom; room surface brightness and daylighting. Respondents also rated their levels of agreement with statements about the lighting and controls in their personal workspaces. They rated whether the light fixtures and controls created distracting or annoying conditions; whether daylight alone without electric lighting is suitable for working most hours of the day; and whether task lights are necessary to augment the light most hours of the day.

Occupant Survey Results

This section presents the survey findings in two different ways: first the results for all surveys at each of the three buildings, followed by a general summary of similarities among results at the three buildings and perceptions before and after renovations.

Each of the three sites exhibits significantly different work environments. REI has an open plan; the Yale Building has many private offices along a window wall with some interior open workspace; and Kivel & Howard has interior open workspace separated by partitions, with private offices along a window wall. Baseline lighting conditions also differed among the three sites, as described earlier in this report.

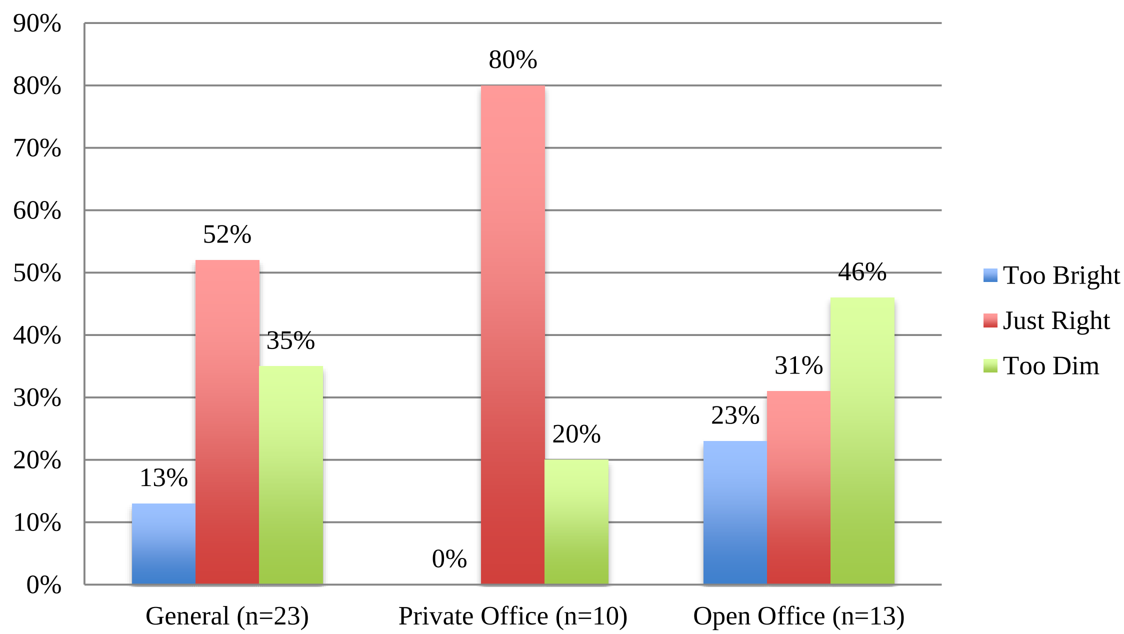
These differences among the workspaces made aggregation of survey results infeasible. Ideally, NBI could have analyzed all baseline responses in one combined set of responses. However, because the respondents experience such different environments, they are answering fundamentally different questions although the wording of the questions is the same. For example, an individual in a private office with a paracube fixture and tinted window at Kivel & Howard works in a significantly different environment than someone in a Yale Building glassy private office with recessed T5 HO fixtures. As a result, this report does not combine survey responses from different buildings; rather, it presents individual analyses for each building.

Fred Hutchinson Yale Building

The Yale Building staff answered three of the four surveys: baseline (n=23), out-of-box (n=14), and user preference lighting (n=23). Staff reported they are typically at their workstations between four and six hours per day; the workstations include many private offices as well as open office areas.

When asked to rate the overall level of light during the user preference mode, about half of respondents (52%) found the overall lighting to be comfortable, with strong distinctions between perceptions of those in open and private offices, as seen in Figure 10. Most private-office occupants (80%) felt the light levels were just right, compared to about one-third of open-office occupants. However, 46% of open-office occupants found the space too dim and 23% too bright during the out-of-box mode.

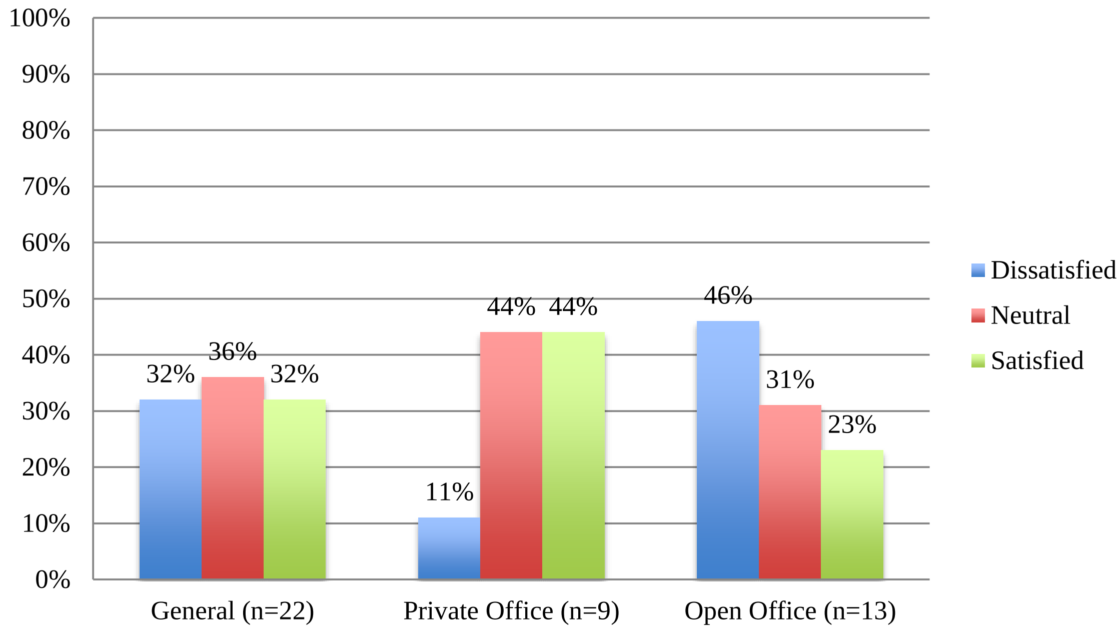
Figure 10: Yale Building: Rating of Overall Level of Light by Space Type During User Preference Phase



Q6e. How would you rate the lighting in your workspace for the following task: Overall level of light

Respondents expressed no strong opinions regarding the light levels and ability to control the levels in their areas. The percentage dissatisfied with the ability to control the light levels dropped to 32% during the user preference phase from 43% prior to the installation of the controls. Figure 11 shows differences in responses to the question "Overall, how satisfied are you with the lighting levels and ability to control the light in your area?" during the user preference phase, based upon where staff sits. Respondents in open office workstations were less likely to be satisfied with their ability to control light levels in their areas than were respondents in private offices.

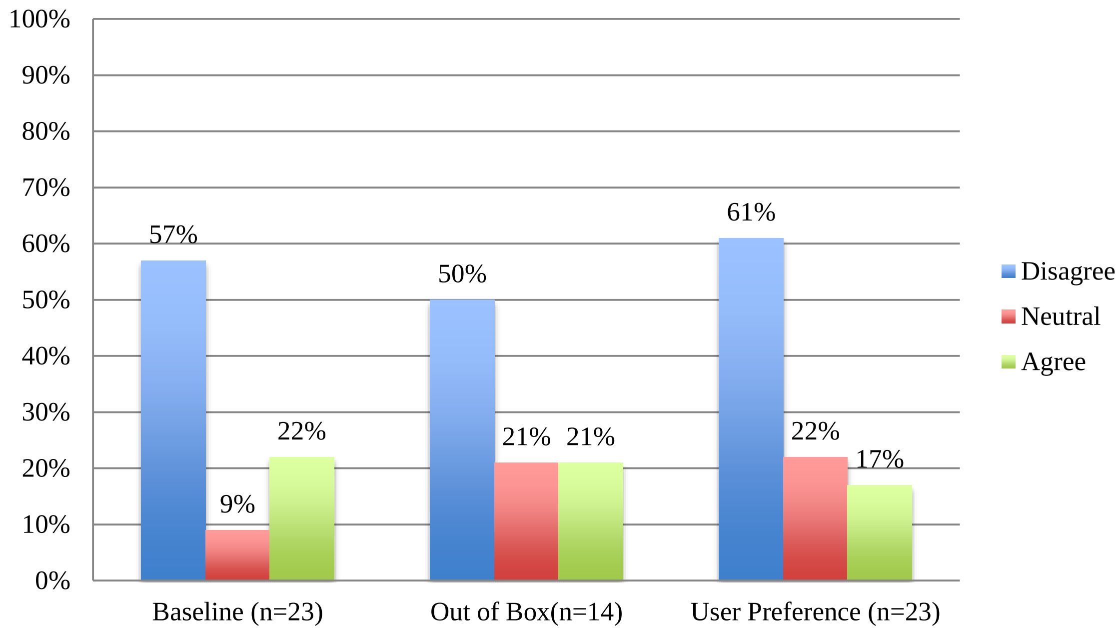
Figure 11: Yale Building: Satisfaction with Lighting Controls by Space Type during User Preference Phase



Q8. Overall, how satisfied are you with the light levels and ability to control the light level in your area?

As Figure 12 shows, approximately 50–60% of the respondents felt they could not create the conditions they wanted with lighting controls even after installation of the new systems; they still had to call facilities for assistance in adjusting the lighting levels.

Figure 12: Yale Building: Lighting Controls Allow to User to Create Lighting Conditions They Want by Phase of Research



Q3c. To what extent do you agree or disagree with the following statement about the lighting in your personal workspace: "The light controls allow me to create the lighting conditions I want."

A majority of respondents in the Yale Building do not feel the lighting is gloomy (52% prior to installation of controls and 64% during the out-of-box mode). Open space occupants considered the lighting gloomy (30%) at a higher rate than did private-office occupants (16%).
The percentage of respondents who felt room surfaces had pleasant brightness increased slightly from 39% to 43% after installation of the new system.

In all three surveys, nearly half or more found the daylight from the windows satisfactory (52% before controls; 64% during out-of-box mode; and 48% during the user preference mode). Not surprisingly, this was especially true of those in private offices along the exterior window wall.

Yale Building respondents reported fewer issues with glare from lighting fixtures on computer screens after installation of the new lighting system. Before installation, the majority of respondents (57%) never or rarely experienced screen glare from light fixtures. The percentage that did have issues decreased significantly from 43% to 29% in the out-of-box mode and to 26% in the user preference mode. The user preference survey found that respondents in open offices (80%) are considerably more likely to experience glare on computer screens than are respondents in private offices (25%).

With regard to glare reflecting from windows, occupants in private offices are much more likely to have glare issues (50%) than are occupants in open offices; ninety-two percent of the latter group reported rarely or never having window glare issues on their computer screen.

Table 26 summarizes the percentages of respondents who experienced particular types of glare during various phases of research.

Table 26: Yale Building: Percentage of Respondents with Glare Issues By Phase of Research

	Baseline	Out-of-Box	User Preference
Glare reflected from work surfaces	48%	28%	26%
Light fixture glare reflected on the computer screen	43%	29%	26%
Window glare reflected on the computer screen	35%	14%	26%

As Table 27 shows, prior to replacement of the lighting system, the majority of respondents (73%) experienced burning or tired eyes after reading or using the computer extensively. After installation of the new system that percentage decreased to 50%; once users could set their preferences, that percentage decreased to forty-four percent.

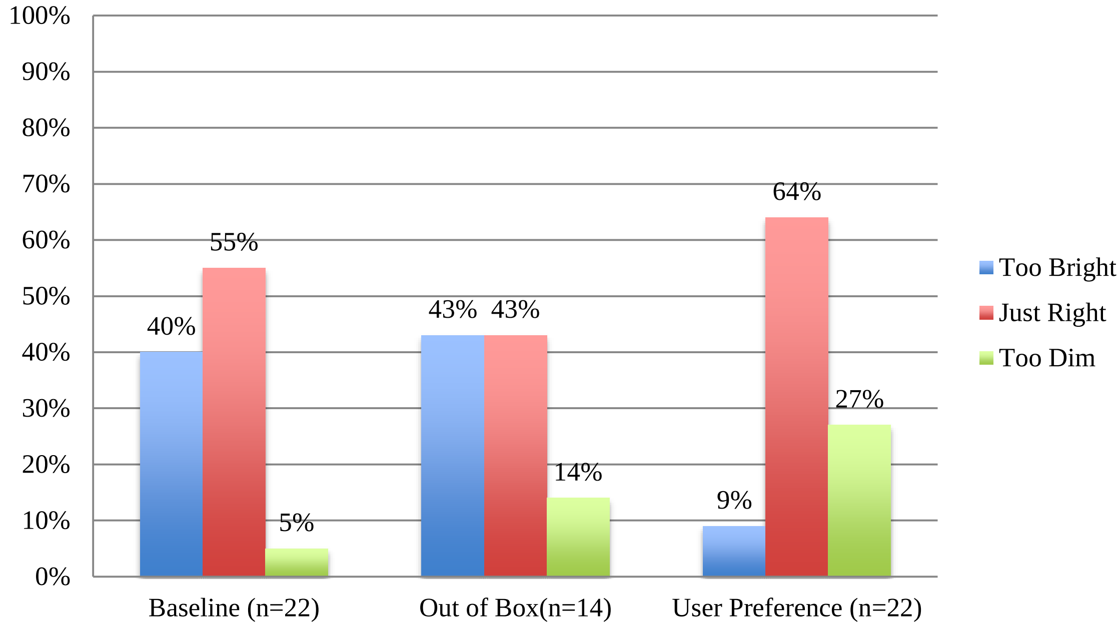
After implementation of users' abilities to set their lighting preferences, the percentage who reported lighting-related headaches decreased to 22% from 35 percent.

Table 27: Yale Building: Light Reactions

	Experienced Burning Eyes	Experienced Headaches
Baseline	73%	35%
Out-of-Box	50%	36%
User Preference	44%	22%

Yale Building respondents rated the lighting in their workspaces from "too bright" to "too dim" on a five-point scale on each of five tasks: reading from a paper; reading from a computer screen; typing on a keyboard; filing or locating papers; and overall level of light. As summarized in or all five tasks, most felt the lighting was just right; concerns before lighting control installation typically leaned toward perceptions of too-bright workspaces. For example, the percentage of respondents who thought the lighting was just right for reading papers increased from 55% before installation of controls to 64% in the user preference mode (with a dip to 43% during out-of-box mode). The percentage who thought the lighting was <u>too bright</u> for reading papers dropped from 41% before installation of controls to 9% in the user preference phase. Conversely, the percentage who thought that the lighting was <u>too dim</u> for reading increased from only 5% before installation of controls to 27% in the user preference phase.

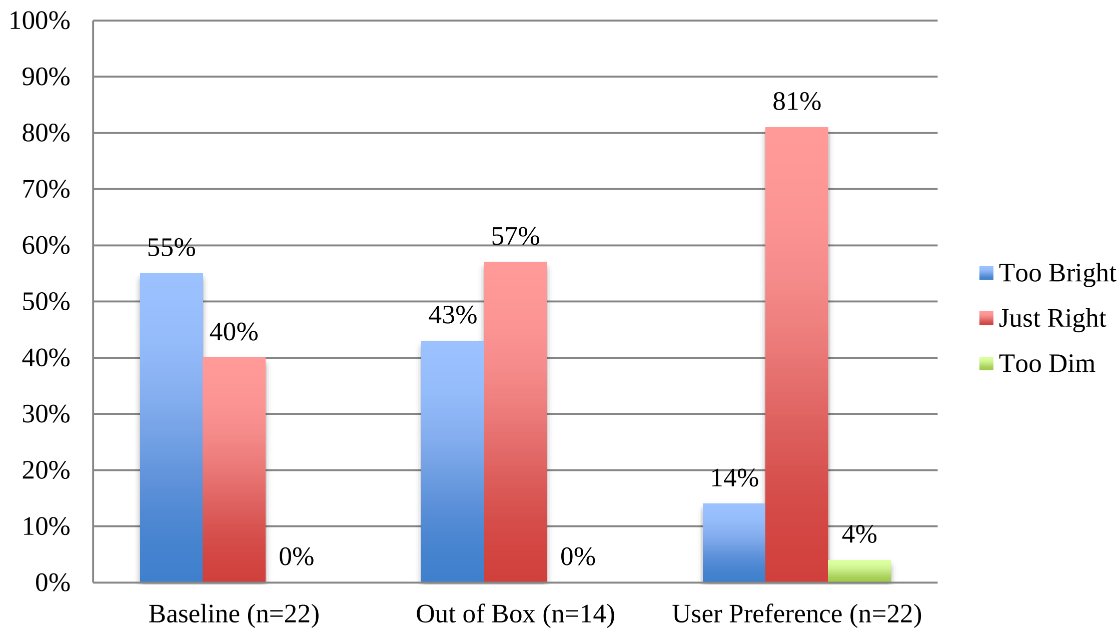
Figure 13: Yale Building: Workspace Lighting for Reading from a Paper



Q6a. How do you rate the lighting in your workspace for reading from a paper?

The percentage that felt light levels for reading from a computer screen were just right increased from 41% before installation of controls to 57% during out-of-box mode, and rose considerably to 82% during user preference mode. Those who thought the lighting was too bright for reading from a computer screen dropped from 55% before installation to only 14% in the user preference phase.

Figure 14: Yale Building: Workspace Lighting for Reading from Computer Screen



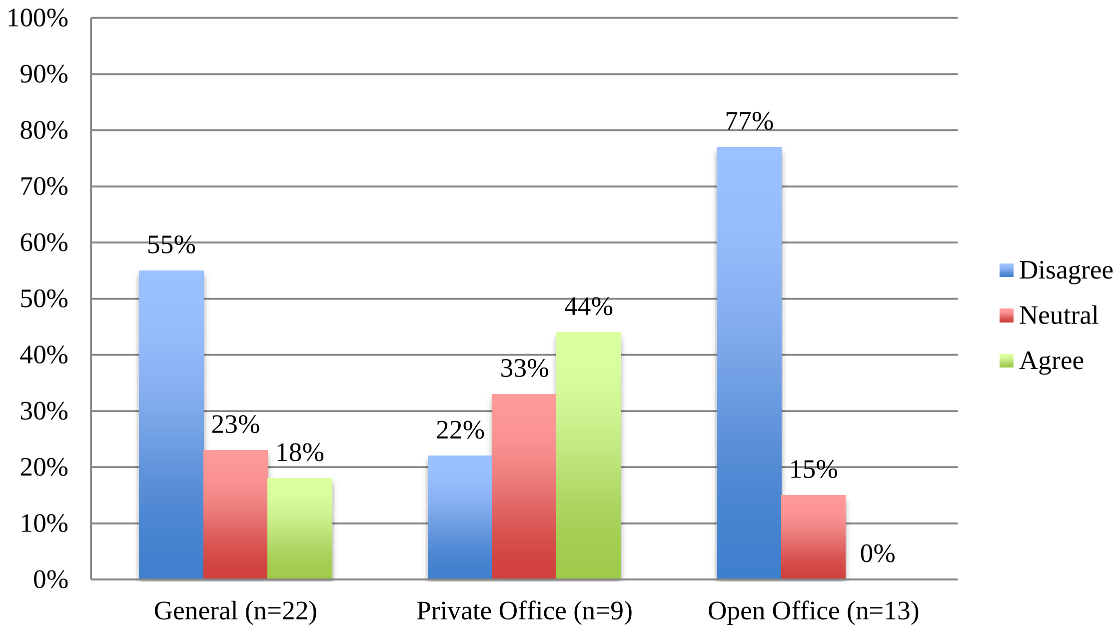
Q6b. How do you rate the lighting in your workspace for reading from the computer screen?

With regard to lighting in their personal workspaces, respondents identified whether the light fixture controls create conditions that are distracting or annoying; whether daylight alone without electric lighting is suitable for working most hours of the day; and whether a task light is necessary to augment the light most hours of the day.

Respondents obviously noticed the flickering lamp issue, with almost 70% agreeing in the user preference phase that the lighting controls created a condition that was distracting or annoying, compared to 38% during the baseline period.

Respondents had mixed reactions to the suitability of daylight alone for working most hours of the day. During the user preference phase, occupants in private offices considered daylighting suitable at a substantially higher rate than did those in open offices, as shown in Figure 15.

Figure 15: Yale Building: Daylight is Suitable for Working Most Hours of the Day during User Preference Phase



Q7b: To what extent do you agree or disagree with the following statement: The daylight alone, without electric lighting, is suitable for working most hours of the day.

Respondents' reactions varied regarding the necessity of task lighting to augment the available light most hours of the day. The proportions relying on task lighting before installation of the system and after the setting of user preferences were similar (38% and 36%, respectively). The percentages claiming <u>not</u> to need task lighting increased from 48% before installation to 59% after setting of user preferences.

Yale Building Occupant Survey Conclusions

Staff at the Yale Building found their light levels to be comfortable, with mixed reactions toward the controllability of the system. They felt that changing out the system was positive because it decreased the brightness level; however, they were not fully satisfied with the controls, and blamed the controls when experiencing flickering issues.

Yale Building occupants' perceptions differed based on whether they sat in an open office workstation or a private office along the window wall. Private-office occupants were more satisfied with the level of daylight and with overall perceptions of the light in the space, but they more commonly experienced glare from windows.

Staff in open-office workstations seemed less satisfied with the lighting overall. While most felt the new system decreased the screen glare from fixtures, they were also more likely to report the lighting was gloomy and that they had less control over their lit environment.

The new system made a difference in respondents' reactions to the light. A lower percentage of respondents had burning or tired eyes after reading or using the computer extensively; they also reported a lower incidence of headaches in the user preference phase. A majority found the light levels with the new system in the user preference phase to be just right. Pre-installation issues typically stemmed from too-bright light levels, while post-installation, the percentage that found the lighting too dim for filing or locating papers increased.

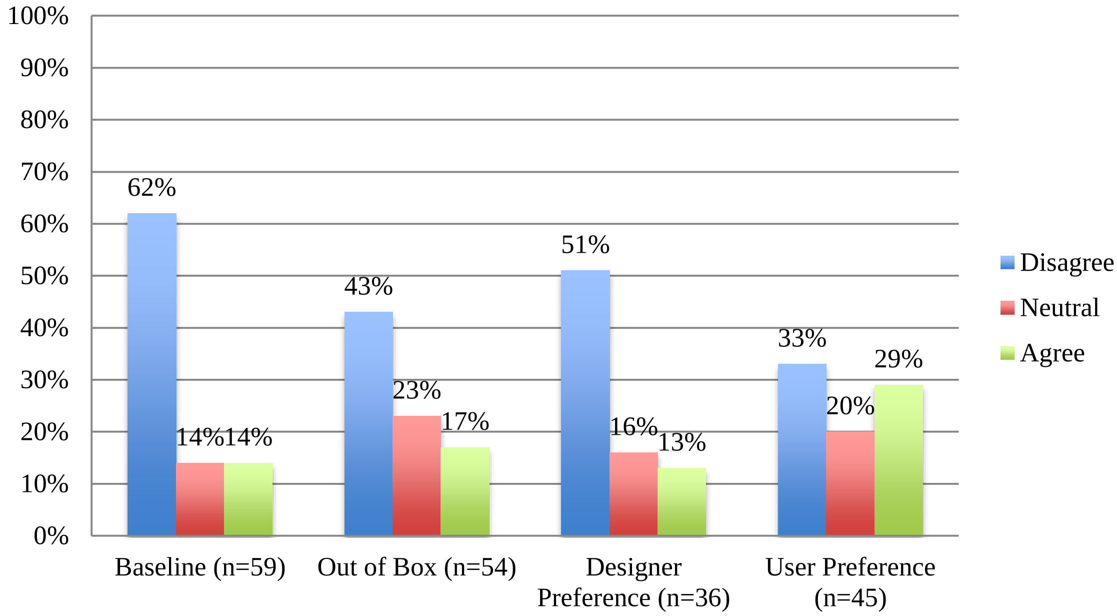
When asked if the system provided enough light for a variety of tasks, respondents typically felt the light levels were just right; A few occupants found the new lighting control system distracting because it dimmed or turned off lights in their areas even when they were present.

REI

REI staff primarily work in open plan office workstations. More than 75% of respondents reported they are typically at their workstation more than six hours on any particular weekday. The majority of REI respondents found their lighting comfortable at any point in time prior to the Enlighted installation. However, their perceptions of comfort increased after installation of the new lighting and control systems, from 84% to 93%.

The percentage of respondents who agreed with the statement "lighting controls allow me to create the lighting conditions I want" increased from 14% before installation of the lighting controls to 29% during the user preference phase. Conversely, the percentage who <u>dis</u>agreed with this statement decreased from 62% to 33% over the same interval, as shown in Figure 16.

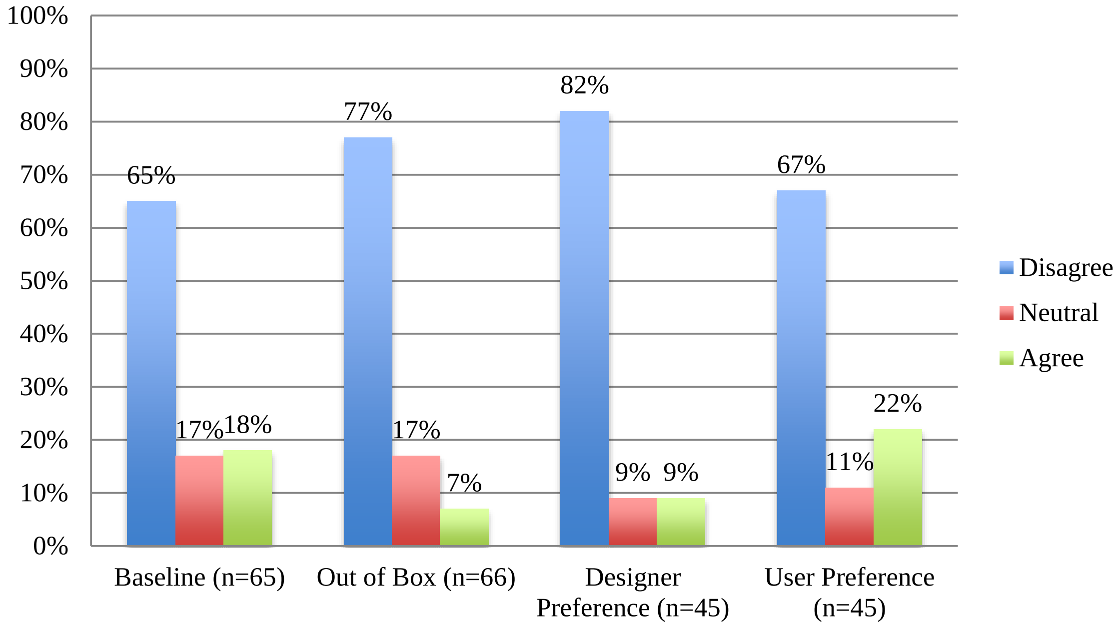
Figure 16: REI: Lighting Controls Allow to User to Create Lighting Conditions They Want by Phase of Research



Q3c. To what extent do you agree or disagree with the following statement about the lighting in your personal workspace: "The light controls allow me to create the lighting conditions I want."

Most REI respondents in all four surveys did not consider the lighting gloomy. As seen in Figure 17, initially 65% disagreed that the lighting felt gloomy; after installation of the new system, a greater percentage (77%) thought it was not gloomy. While even a higher percentage thought it was not gloomy after the designer preference controls were set to provide recommended general light levels, the percentage again decreased (67%) to near the baseline level during the user preference phase. The season in which NBI conducted each survey may have been a factor (baseline period in the winter; the out-of-box and designer preference in the spring and summer; and the user preference in the fall).

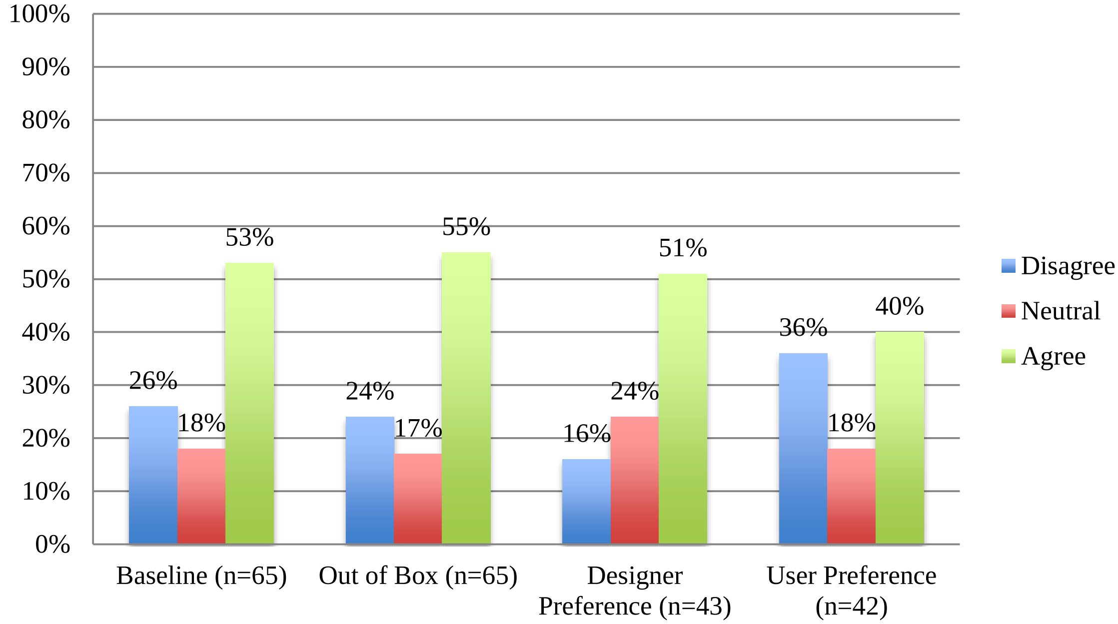
Figure 17: REI: Lighting Feels Gloomy by Phase of Research



Q3d. To what extent do you agree or disagree with the following statement about the lighting in your personal workspace: "The lighting feels gloomy."

Approximately half the respondents in each survey phase agreed that the daylight from windows in their workspace is sufficient; aside from a decline during the fourth (user preference) survey, this percentage varied little, as shown in Figure 18. However, the percentage who disagreed that daylight is sufficient increased from 26% at baseline to 36% in the user preference survey.

Figure 18: REI: Daylight is Suitable for Working Most Hours of the Day by Phase of Research



Q7b: To what extent do you agree or disagree with the following statement: The daylight alone, without electric lighting, is suitable for working most hours of the day.

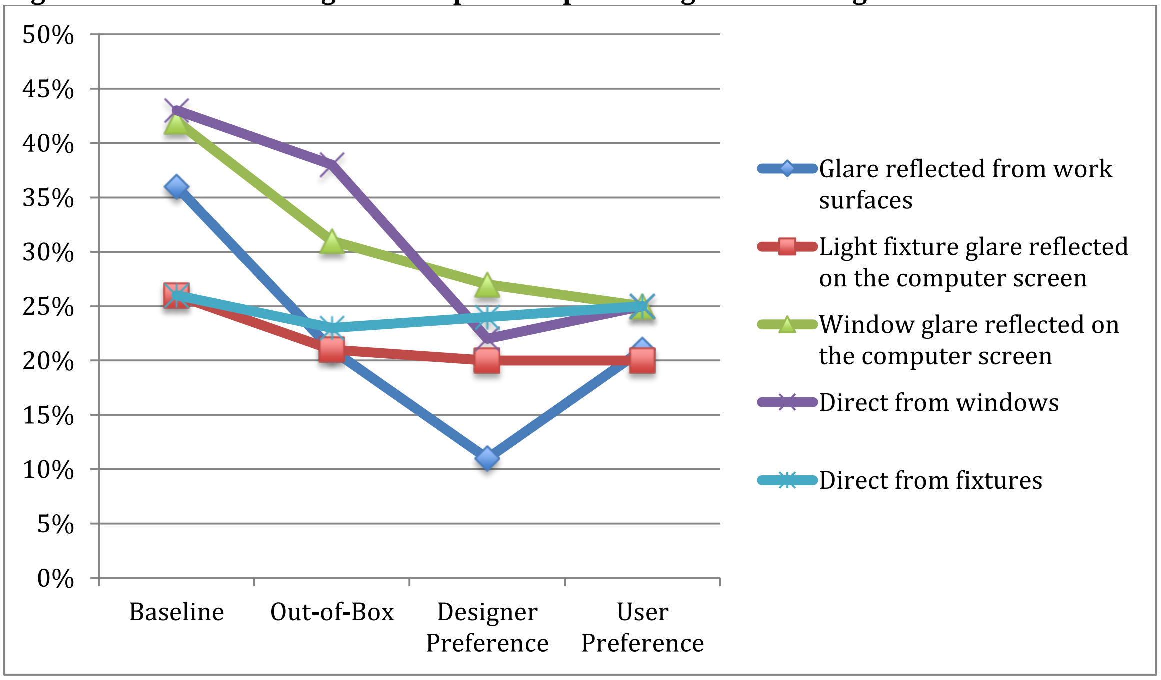
Table 28 summarizes findings on five specific glare conditions respondents experienced in their personal workspaces on an average day. (Figure 19 shows this same data in line graphs to show changes over time.) Window glare reflected on the computer screen and glare direct from windows exhibited the most substantial declines from the baseline to the user preference phase.

Table 28: REI: Percentage of Occupants Experiencing Glare

	Baseline	Out-of-Box	Designer Preference	User Preference
Glare reflected from work surfaces	36%	21%	11%	21%
Light fixture glare reflected on the computer screen	26%	21%	20%	20%
Window glare reflected on the computer screen	42%	31%	27%	25%
Direct from windows	43%	38%	22%	25%
Direct from fixtures	26%	23%	24%	25%

Note: Percentages responding “sometimes,” “often” or “always”

Figure 19: REI: Percentage of Occupants Experiencing Glare during Each Phase



Note: Percentages responding "sometimes," "often" or "always"

Generally, glare seemed a larger issue before the retrofit (i.e., at baseline) than it was after the lighting controls were installed. Just less than half the respondents never considered work surface glare a problem. Installing new fixtures and control systems and further optimizing those controls helped address glare issues that did exist. The most notable decreases in glare issues from the first survey to the last seen in glare direct from windows (43% to 25%); window glare reflected on the computer screen (42% to 25%); and glare reflected from work surfaces (36% to 21%).

A large percentage of respondents in each survey experienced burning or tired eyes after reading or using the computer extensively, with little variation among phases. The percentages of individuals who experienced headaches attributable to the lighting system remained low throughout the duration of the study with a slight dip during the designer preference phase.

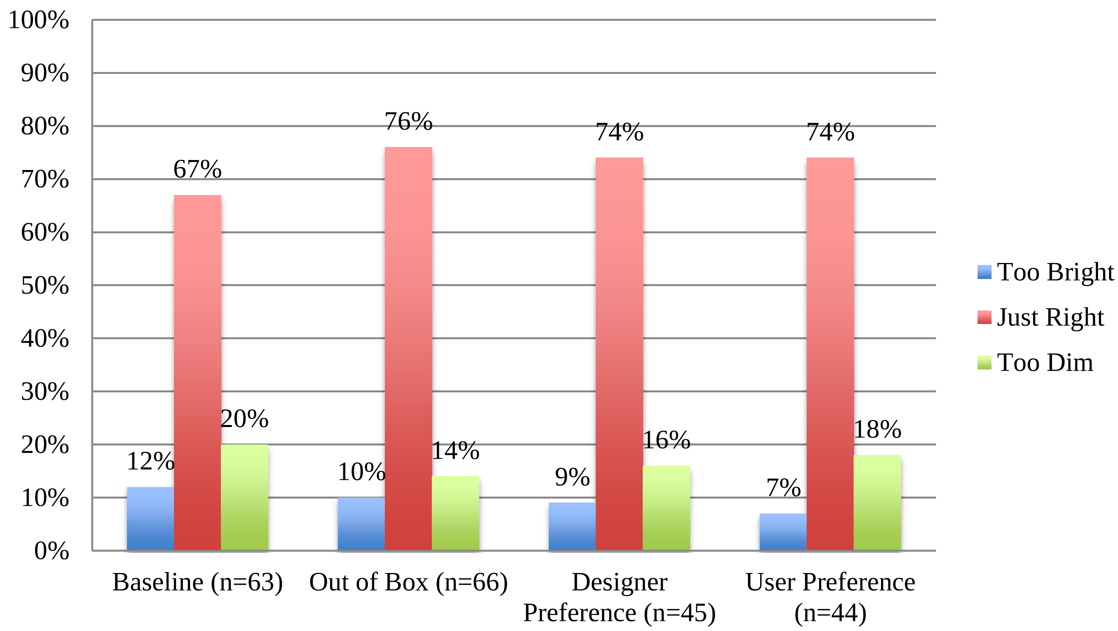
Table 29: REI: Burning Eyes and Headaches

	Experienced Burning Eyes	Experienced Headaches
Baseline	49%	11%
Out-of-Box	42%	9%
Designer Preference	47%	4%
User Preference	45%	10%

Respondents rated the lighting in their workspaces from too bright to too dim on a five-point scale for five tasks: reading from a paper, reading from a computer screen, typing on a keyboard, filing or locating papers, and overall level of light. Figure 20 through Figure 24 below summarize their ratings for pre-installation and post-installation, respectively.

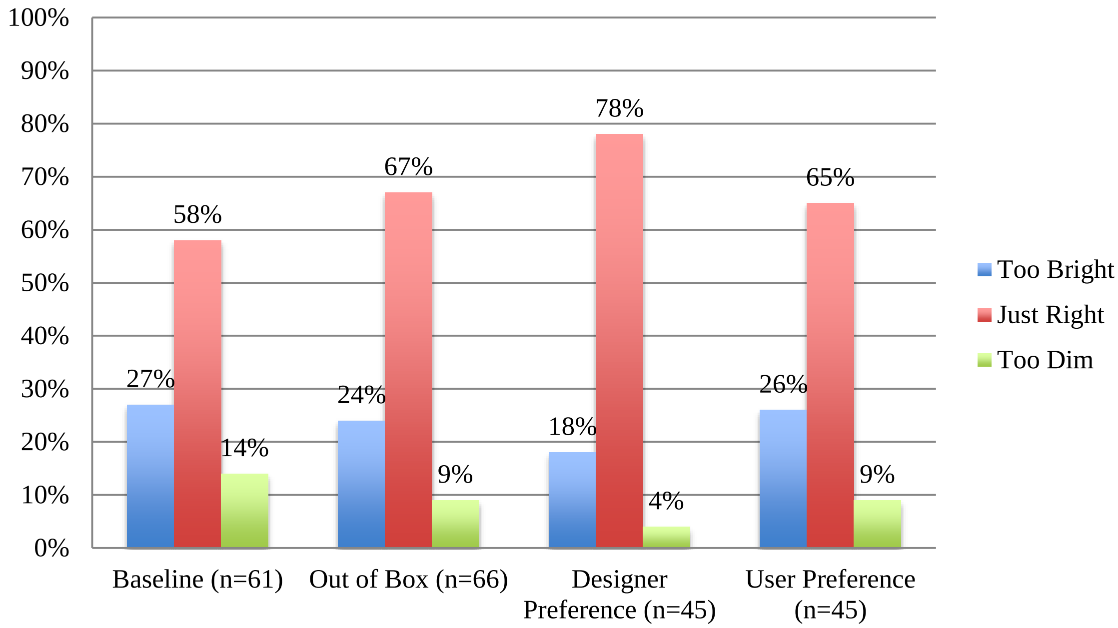
The majority of respondents (62% to 80%, depending on task) deemed the post-installation light levels just about right – substantial increases from the percentages observed for each task pre-installation. The percentages considering the light too bright or too dim for specific tasks varied based on the task. For respondents who had issues with light levels for filing or reading from paper, it was typically too dim. For those who were typing or using a screen, it was typically too bright. This may be a reflection of the difficulty associated with finding one lighting solution to fit all people in all tasks.

Figure 20: REI: Workspace Lighting for Reading Paper



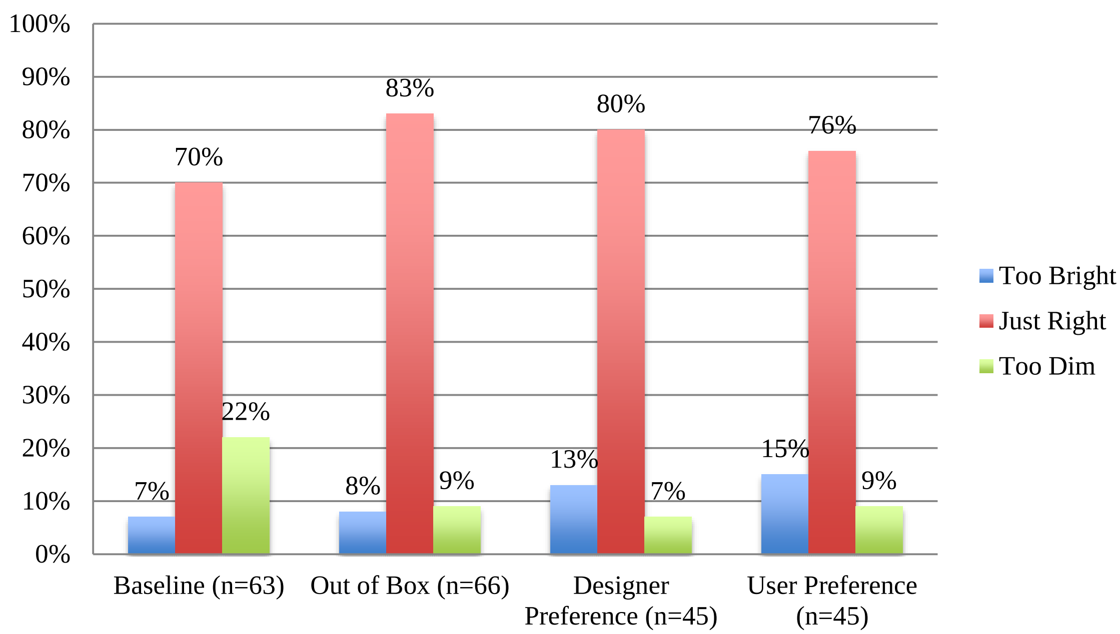
Q6a. How do you rate the lighting in your workspace for reading paper?

Figure 21: REI: Workspace Lighting for Reading from Computer Screen



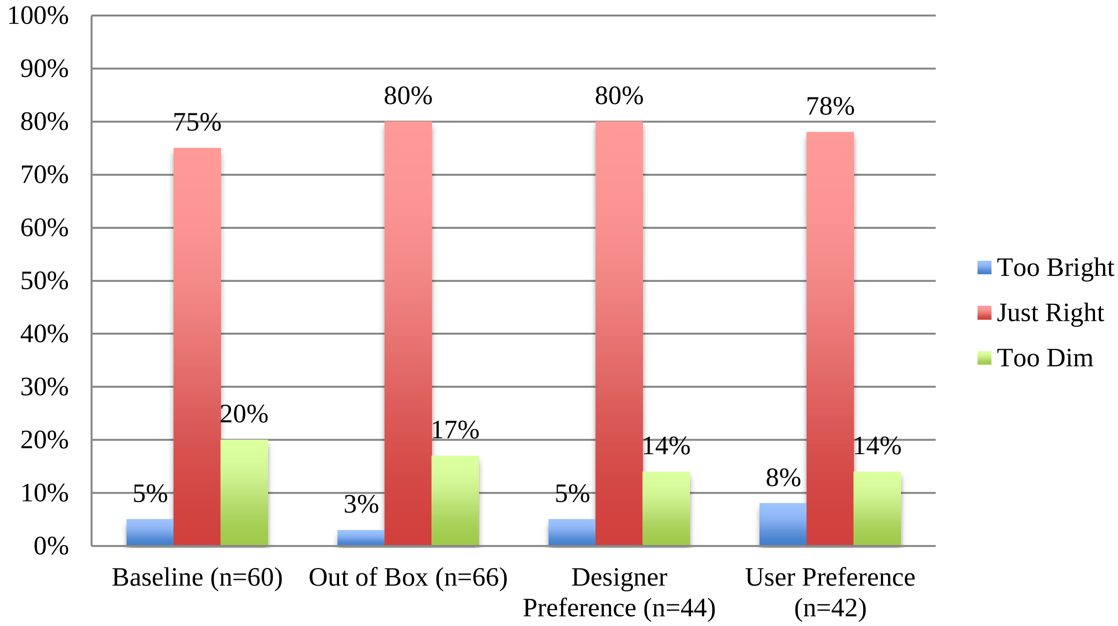
Q6b. How do you rate the lighting in your workspace for reading from the computer screen?

Figure 22: REI Workspace Lighting for Typing



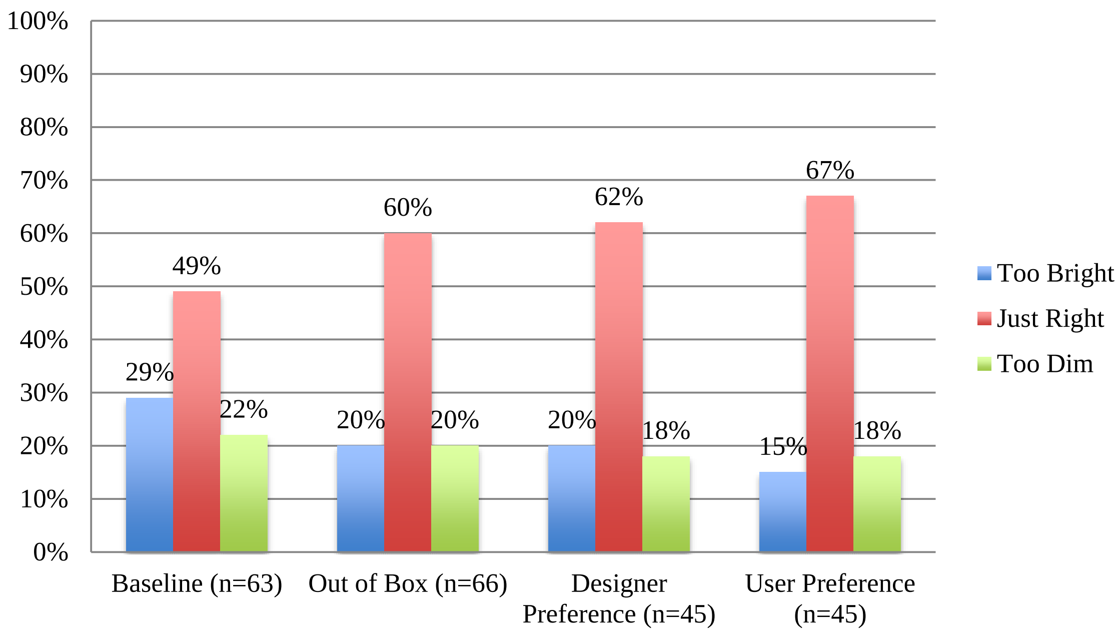
Q6c. How do you rate the lighting in your workspace for typing?

Figure 23: REI: Workspace Lighting for Filing



Q6d. How do you rate the lighting in your workspace for filing?

Figure 24: REI: Overall Level of Light



Q6e. How do you rate the lighting in your workspace for overall level of light?

Prior to installation of the Enlighted system, only 12% of respondents thought the light fixture controls created distracting or annoying conditions; the majority (65%) did not find them distracting or annoying. However, once the new lights and control system was installed, a slightly higher percentage of respondents (20%) found them distracting. Further, eight respondents noted issues related to occupancy sensors in open-ended comments.

REI Occupant Survey Conclusions

REI respondents considered their office light levels comfortable, and even more so after installation of the Enlighted system. While their satisfaction with their ability to control light levels for certain conditions increased to a degree across the four surveys, it remained fairly low. They considered their workspaces evenly lighted with no very bright or dim spots; they did not feel brightness was an issue. Some expressed some dissatisfaction that they could not personally control the lighting conditions.

REI respondents generally felt that the new system created a pleasant brightness on room surfaces. Roughly 40% of respondents in the user preference phase felt daylight was sufficient to work most hours of the day; they want task lights for when daylight is not enough. They also felt that the new system helped alleviate glare issues.

Burning or tired eyes after extensive use affected just under half of the REI respondents, with little change among the phases. Only small percentages experienced headaches due to the lighting system. Respondents typically felt the system provided the right levels of light for a variety of tasks, although some noted light that was too bright by which to file and read or type.

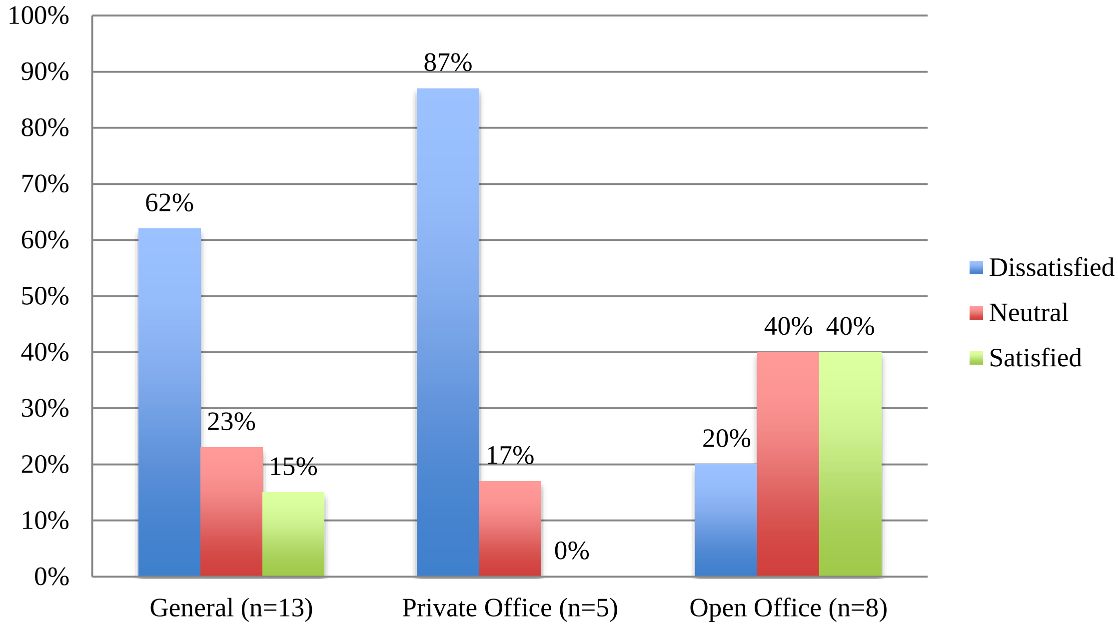
Kivel & Howard

Kivel & Howard staff participated in two surveys: the baseline (n=14) and user preference (n=13). Staff reported they are typically at their workstations more than six hours. The workstations include a few open plan offices with partitions, with most occupants in closed offices.

Impressions of lighting comfort improved slightly post-installation of the new system. Initially, over half (57%) felt the lighting was <u>not</u> comfortable; after installation of the new system, 62% felt the lighting <u>was</u> comfortable. Most open plan occupants (80%) found the lighting comfortable; a lower proportion in private offices (50%) considered the lighting comfortable during the user preference phase.

Over 60% of respondents remained dissatisfied with the light levels and with their ability to control the levels in their areas, both initially and after installation of the lighting new system. As seen in Figure 25 below, those in private offices are considerably more dissatisfied (87%) with their ability to control lights than those in open office space (20% dissatisfied). This may be because private office occupants originally had switches with gave them complete control even before installation of the lighting controls.

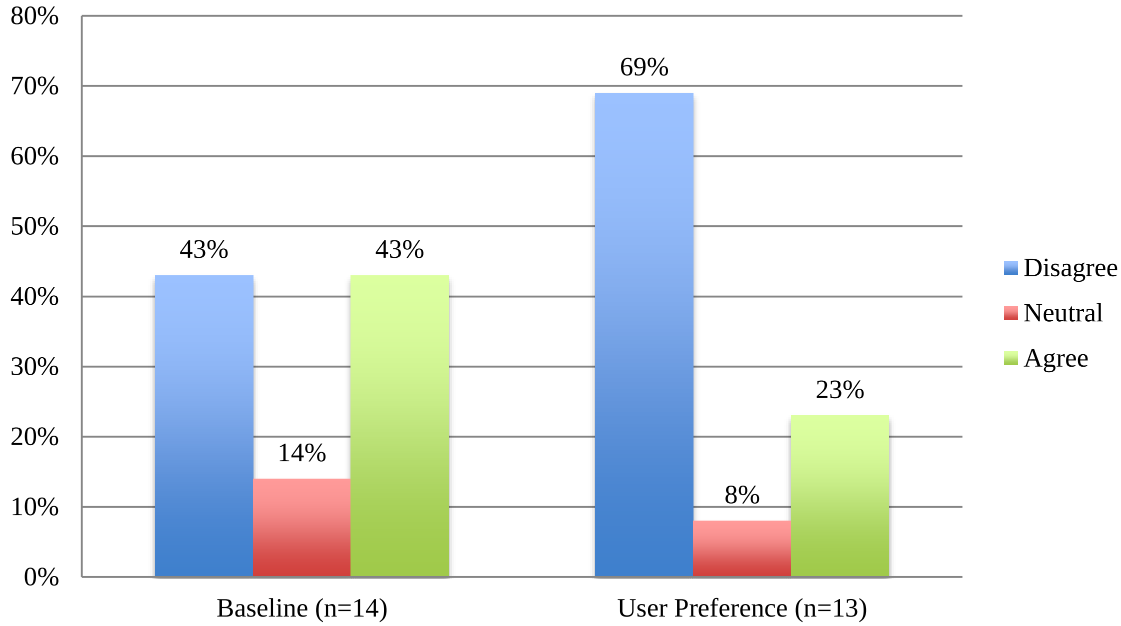
Figure 25: Kivel & Howard Satisfaction with Lighting Control



Q8. Overall, how satisfied are you with the light levels and ability to control the light level in your area?

The percentage that considered the fixtures too bright decreased substantially between the two surveys (from 43% to 23%), as Figure 26 shows; the reverse also held true, in that the percentage who disagreed the fixtures were too bright increased from 43% to 69% from the baseline to the user preference survey.

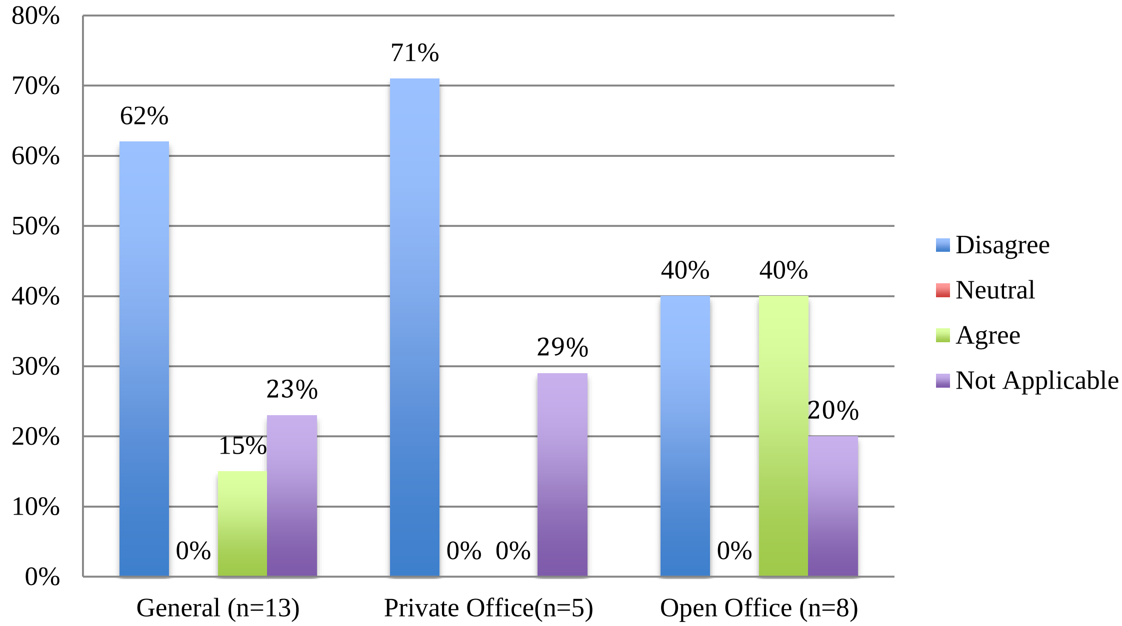
Figure 26: Kivel & Howard: Light in Primary Workstation: Fixture Brightness



Q3b. To what extent do you agree or disagree with the following statements about the lighting: The light fixtures are too bright.

During the baseline period, most Kivel & Howard respondents (64%) felt the light controls did not allow them to create the desired lighting conditions; this perception remained after installation of the new lighting system, with 62% disagreeing with the statement “the lighting controls allow me to create the lighting conditions I want.” Perceptions diverged between those in private offices and in open workstations. Open office staff was more likely to feel (40%) they could create their desired lighting conditions, whereas staff in private offices (71%) did not feel they could create the conditions they wanted.

Figure 27: Kivel & Howard Satisfaction with Lighting Control



Q3c, To what extent do you agree or disagree with the following statements about the lighting: The lighting controls allow me to create the conditions that I want.

After installation of the new lighting system, the percentage indicating that the lighting did not feel gloomy increased from 36% (prior to installation) to 54%. 80% of staff in open workstations disagreed that "the lighting feels gloomy," whereas just over half (57%) of staff in private offices agreed with that statement.

Pre-installation, a substantial proportion of respondents (43%) disagreed with the statement "the room surfaces have a pleasant brightness." This percentage changed little post-installation (39%). Similarly, the percentages that disagreed with this statement moved only a few points (21% pre-installation and 15% post-installation).

The new lighting system led to a slight decrease in the percentage that considered daylight from the windows in their workspaces satisfactory, from 36% to 31%. Most respondents pre-installation (64%) had no issues with glare reflected from the work surface; only 7% always had such an issue, while 29% mentioned it sometimes is a concern. The second survey did not include this question.

Glare on computer screens from overhead light fixtures was a moderate issue both before after installation of the new system. Before the installation, 29% of respondents sometimes experienced glare from light fixtures and 7% always experienced glare. After the installation, 23% sometimes experienced glare from fixtures on computer screens. The percentage that never or rarely experienced glare on computer screens increased from 64% before installation to 77% after.

None of those in open workstations found direct glare from the window an issue, as they had no windows. However, 83% of staff in private offices reported instances of glare from the window reflected on their computer screen.

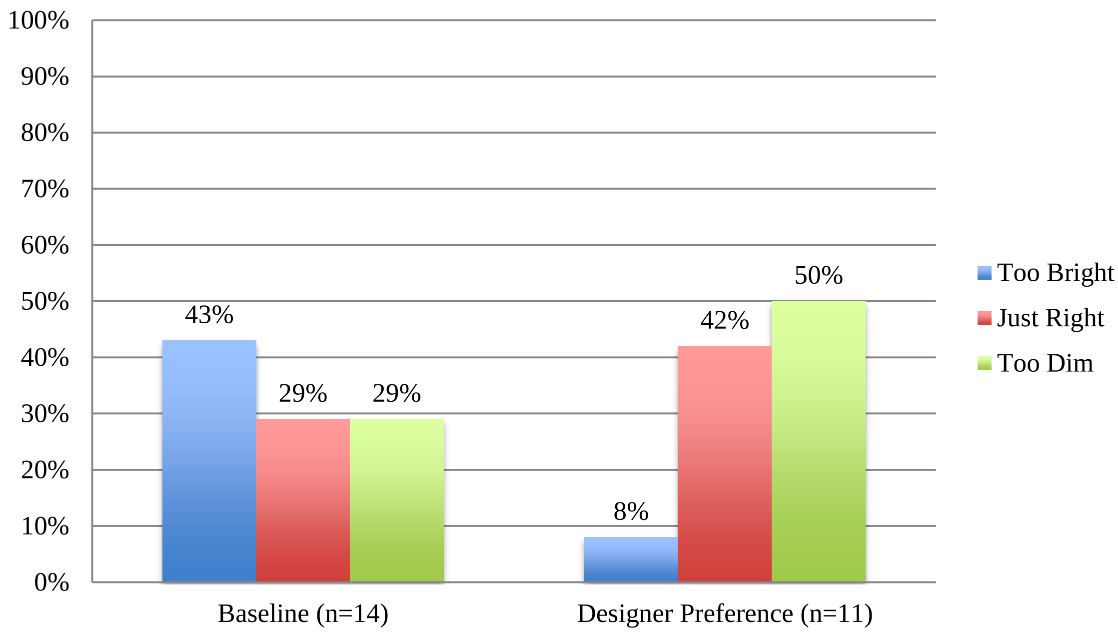
Table 30: Kivel & Howard: Glare Is an Issue Sometimes, Often or Always

	Baseline	User Preference
Glare reflected from work surfaces	36%	-
Light fixture glare reflected on the computer screen	36%	23%
Window glare reflected on the computer screen	7%	25%
Direct from window	14%	-
Direct from fixtures	43%	-

After installation of the new system, the percentage of Kivel & Howard respondents claiming burning or tired eyes after reading or using the computer extensively dropped from 64% to 54%. However, the percentage claiming they experienced headaches <u>increased</u> from 29% to 39%.

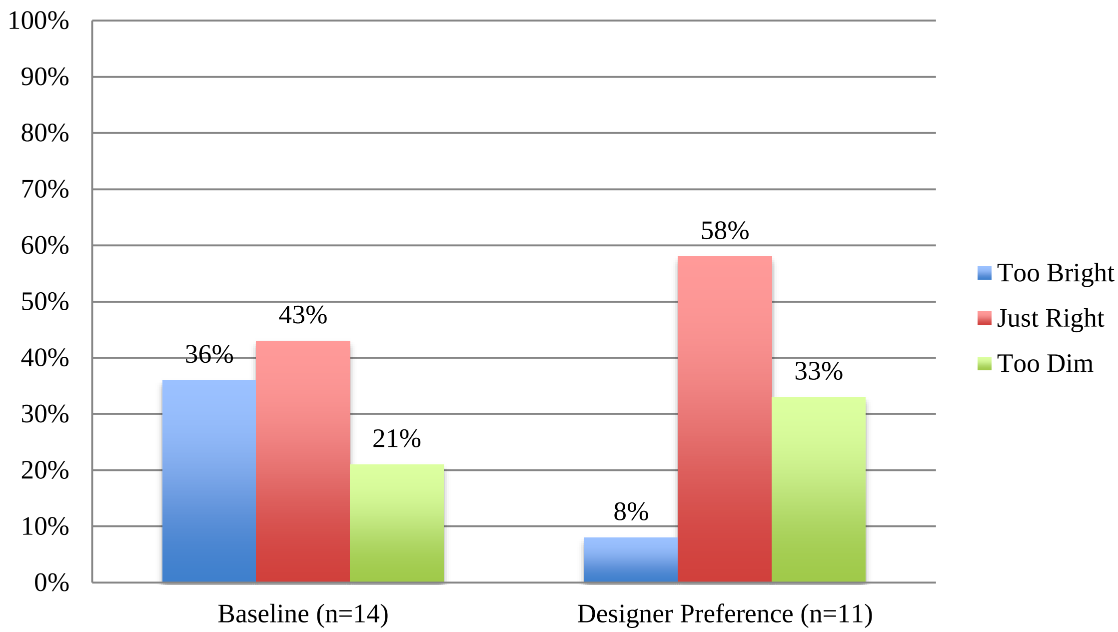
Respondents' perceptions of the workspace task illumination is summarized in the figures below.

Figure 28: Kivel & Howard: Workspace Lighting for Reading Paper



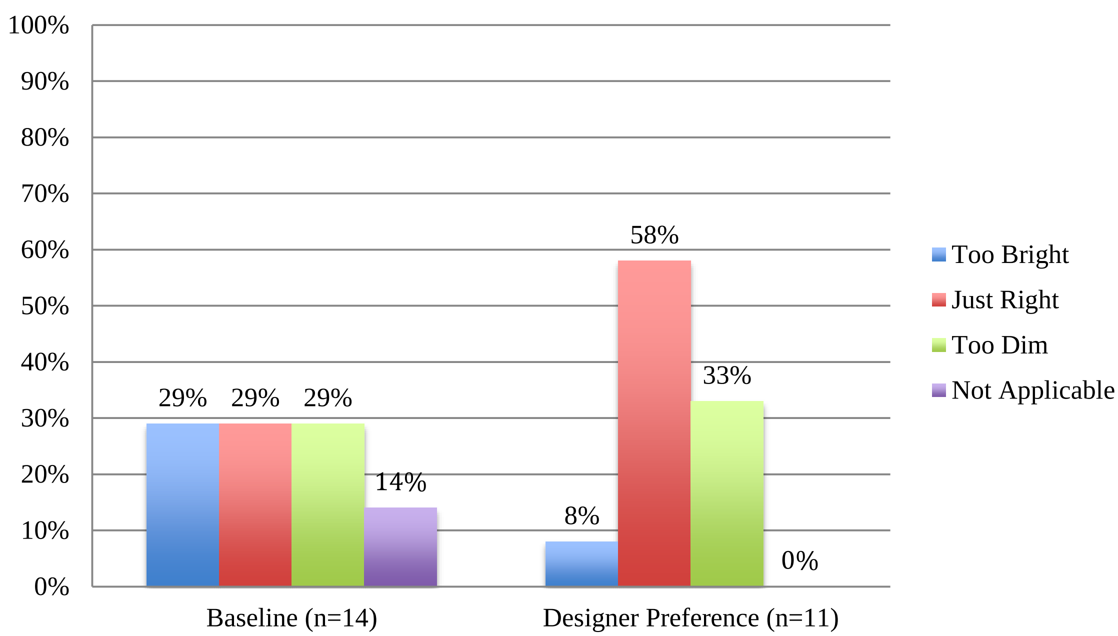
Q6a: How do you rate the lighting in your workspace for reading from paper.

Figure 29: Kivel and Howard: Workspace Lighting for Reading Computer Screen



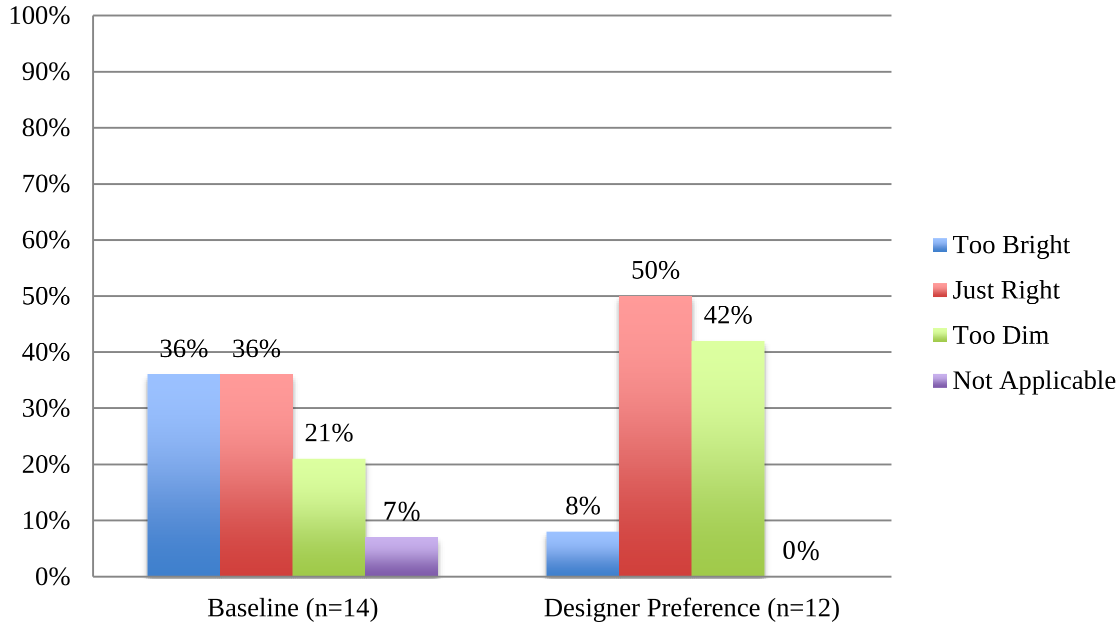
Q6b: How do you rate the lighting in your workspace for reading from computer screen.

Figure 30: Kivel & Howard: Workspace Lighting for Typing



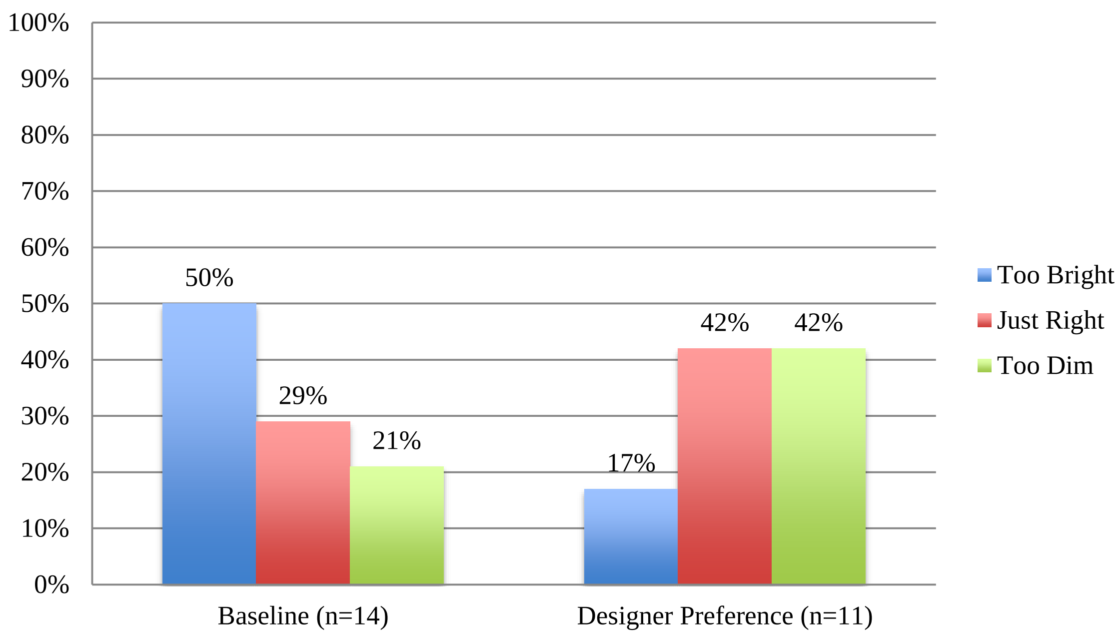
Q6c: How do you rate the lighting in your workspace for typing.

Figure 31: Kivel & Howard: Workspace Lighting for Filing



Q6d: How do you rate the lighting in your workspace for reading from paper.

Figure 32: Kivel & Howard: Amount of Light Overall



Q6e: How do you rate the lighting in your workspace for overall lighting.

After installation of the new system, open office staff generally considered the lighting levels just right (60%), whereas private office staff more commonly found the new systems light levels to be too dim (50%).

Around half (54%) of respondents felt the installation of the new lighting system led to conditions that were distracting or annoying; only 21% felt this way prior to installation of the new system.

Kivel & Howard Occupant Survey Summary

Over half of Kivel & Howard respondents found the light levels comfortable post-installation. Over half claimed dissatisfaction with lighting controls post-installation, in particular those in private offices. Private office occupants were typically not satisfied with the lighting system controls because prior to installation they felt better able to create the lighting conditions that they desired.

Reports of glare from fixtures decreased from 36% before controls to 23% post-installation. The percentage with burning or tired eyes after reading or using the computer extensively also decreased post-installation, while the percentage reporting headaches attributable to the lighting system increased. The percentages finding lighting levels for a variety of tasks “just right” increased across the board post-installation – although the percentages finding the lighting levels “too bright” decreased for all tasks. In addition, 54% found the controls after installation of the new system to be distracting, as opposed to 21% who felt the lighting controls were distracting prior to installation.

Summary across the Three Sites

Open office staff tended to be more comfortable with the lighting controls than private office staff. The open office respondents also tend to be more satisfied with the light levels and with their ability to control the light levels, even when the facilities group has to implement the controls. In general, respondents thought that the new system improved the brightness levels of the fixtures originally deemed too bright; decreased the gloominess; increased the pleasantness of the surface brightness; and decreased glare and burning eyes. Open office space occupants typically do not feel they have enough daylight, while private office staff does. Most considered the Enlighted system an improvement, but felt the light levels from overhead lighting were too dim to complete high-light tasks such as reading or filing.

Appendix B: Occupant Survey Instrument

The occupant survey instrument follows on the next four pages.

1. NEEA Enlighted Evaluation at REI

Dear Occupant,

New Buildings Institute (NBI) is conducting a series of surveys as part of an evaluation project for the Northwest Energy Efficiency Alliance. This will allow us to better quantify the satisfaction level with the office space lighting and to provide a baseline for future comparisons.

This basic survey provides satisfaction levels for different aspects lighting system. The survey takes less than 10 minutes to complete and is fully confidential.

Please do not discuss your replies with colleagues until after you and they have completed the survey. And be sure to add your email address in the last question if you'd like to be entered to win a REI gift certificate. Thank you!

2. General information

On a typical day, how long are you in your personal workspace?

- ◯ More than 6 hours
- ◯ 4 - 6 hours
- ◯ 2 - 4 hours
- ◯ Less than 2 hours

Approximate distance of primary work location to outside wall (select one)

- ◯ Directly adjacent (within 5 feet)
- ◯ 5 - 20 feet
- ◯ More than 20 feet

Type of office or workstation (select one)

- ◯ Private closed office
- ◯ Shared closed office
- ◯ Open plan workstation (with partitions)
- ◯ Open plan workstation (without partitions)
- ◯ Other (please specify)

Overall is the lighting comfortable?

- ◯ Yes
- ◯ No

3. Light in your primary work location

To what extent do you agree or disagree with the following statements about the lighting in your personal workspace? Please check "N/A" if a given question does not apply to you.

My workspace is evenly lighted without very bright or very dim spots.

○ Disagree ○ - ○ Neutral ○ - ○ Agree ○ N/A

The light fixtures are too bright.

○ Disagree ○ - ○ -Neutral ○ - ○ Agree ○ N/A

The light controls allow me to create the lighting conditions I want.

○ Disagree ○ - ○ -Neutral ○ - ○ Agree ○ N/A

The lighting feels gloomy.

○ Disagree ○ - ○ -Neutral ○ - ○ Agree ○ N/A

The room surfaces (walls, ceilings) have a pleasant brightness.

○ Disagree ○ - ○ -Neutral ○ - ○ Agree ○ N/A

The daylight from windows in my workspace is satisfactory.

○ Disagree ○ - ○ -Neutral ○ - ○ Agree ○ N/A

In the past, I have requested that the lighting levels be modified in my work area (e.g. add a sleeve over the lamp to make it less bright).

☐ Yes ☐ No

4. Glare levels

How often do you experience any of the following conditions when in your personal workspace during an average day?

When answering these questions consider the definition of glare to be unwanted light.

Glare reflected from work surface.

○ Never ○ - ○ Sometimes ○ - ○ Always

Glare from the light fixtures reflected on your computer screen.

○ Never ○ - ○ Sometimes ○ - ○ Always

Page 2

Glare from the window reflected on your computer screen.

◯ Never ◯ - ◯ Sometimes ◯ - ◯ Always

Direct glare from the window.

◯ Never ◯ - ◯ Sometimes ◯ - ◯ Always

Direct glare from the light fixtures.

◯ Never ◯ - ◯ Sometimes ◯ - ◯ Always

5. Lighting reactions

How often do you experience any of the following conditions when in your personal workspace?

"Burning" or tired eyes after reading or using the computer extensively.

◯ Never ◯ Rarely ◯ Once per Month ◯ Once per Week ◯ Every Day

Headache that you think is caused by your lighting.

◯ Never ◯ Rarely ◯ Once per Month ◯ Once per Week ◯ Every Day

6. Workspace task lighting

How do you rate the lighting in your workspace for each of the following tasks? Please check "N/A" if a given question does not apply to you.

Reading from a paper.

◯ Too Bright ◯ - ◯ Just Right ◯ - ◯ Too Dim ◯ N/A

Reading from a computer screen.

◯ Too Bright ◯ - ◯ Just Right ◯ - ◯ Too Dim ◯ N/A

Typing on a keyboard.

◯ Too Bright ◯ - ◯ Just Right ◯ - ◯ Too Dim ◯ N/A

Filing or locating papers.

◯ Too Bright ◯ - ◯ Just Right ◯ - ◯ Too Dim ◯ N/A

Overall level of light.

◯ Too Bright ◯ - ◯ Just Right ◯ - ◯ Too Dim ◯ N/A

7. Lighting Controls

To what extent do you agree or disagree with the following statements about the lighting in your personal workspace? Please check "N/A" if a given question does not apply to you.

The light fixtures controls create conditions that are distracting or annoying.

◯ Disagree ◯ - ◯ -Neutral ◯ - ◯ Agree ◯ N/A

The daylight alone, without electric lighting, is suitable for working most hours of the day.

◯ Disagree ◯ - ◯ -Neutral ◯ - ◯ Agree ◯ N/A

A task light, i.e. plug-in desktop lighting, is necessary to augment the light most hours of the day.

◯ Disagree ◯ - ◯ -Neutral ◯ - ◯ Agree ◯ N/A

8. Overall observations

Please complete the following summary questions and comment as you see fit.

Overall, how satisfied are you with the light levels and ability to control the light level in your area?

◯ 1-Dissatisfied ◯ 2 ◯ 3 ◯ 4 ◯ 5-Very satisfied

Please enter any specific comments regarding the appearance, operation, and satisfaction with the lighting system in your office work area.

Please enter any specific comments regarding this survey in the space below. We thank you for your participation.

I would like to be entered in a drawing for a REI gift certificate for taking the time to complete this survey. Please provide your email address to be entered.

Page 4

Appendix C: Contractor Survey Instrument

The contractor survey consisted of the following 15 questions:

1. On what date(s) did the installation take place?
2. How long did it take?
3. How many individuals were involved in the installation?
4. What training or qualifications did each person involved in the installation have? (journeyman, technician, etc.) Are they union members?
5. Did the installation happen before office hours or while the office was occupied?
6. Was there any down time for the office occupants?
7. Did the occupants express any concerns during the installation?
8. Please describe the steps involved in the installation. Did you identify some steps in the process that made the installation go more quickly?
9. Did you re-lamp the office during the installation? What is the make and model of the lamps?
10. Please describe your familiarity with the product before the installation.
11. What training did the manufacturer provide?
12. Did the Enlighted system require any special programming? If so, please describe.
13. Have you received any call backs on the installation?
14. Can you please describe the process for estimating the costs associated with the installation? It would be helpful if you could include all of the factors that were considered in the estimates. Based on experience with the install, could you reduce or eliminate some of the costs that were originally anticipated?
15. What was the cost of the system for:
    a. Equipment?
    b. Installation labor?

Appendix D: Light Level Measurements

At all project sites, researchers took light level measurements at various phases of the project. The numbers represent the foot-candle readings taken at the time and location indicated on the particular figure. General results are summarized below.

Yale Building Light Level Measurements

The Yale Building Light Level Measurements appear in the figures that follow. The measurements show a high degree of variability, specifically the difference between private offices along the exterior window wall and the interior open offices. Some private offices had task lights on, while others had them off, and some had shades drawn. From the measurements, the importance of daylighting on sunny days is notable with very high light level readings on sunny days.

Figure 33: Yale Building Light Levels during As-Is Baseline

Figure 34: Yale Building Light Levels during Construction Period

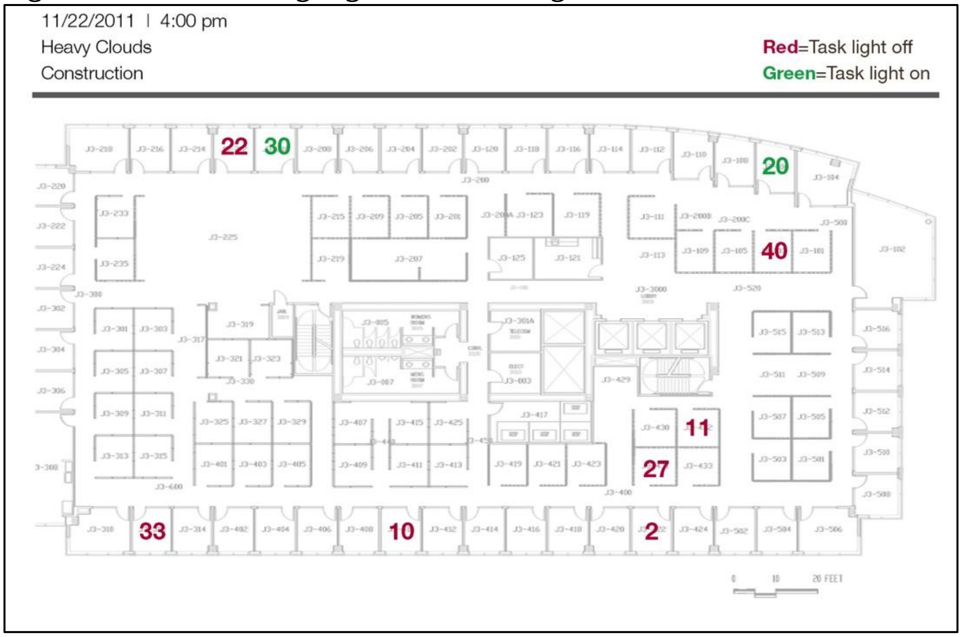


Figure 35: Yale Building Light Levels during Out-of-Box Phase

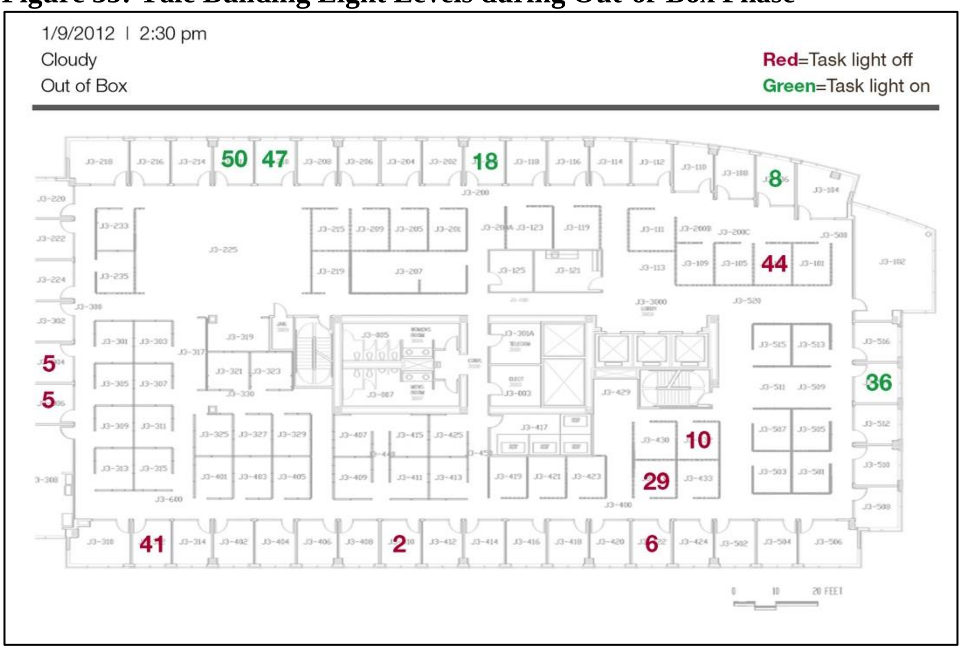
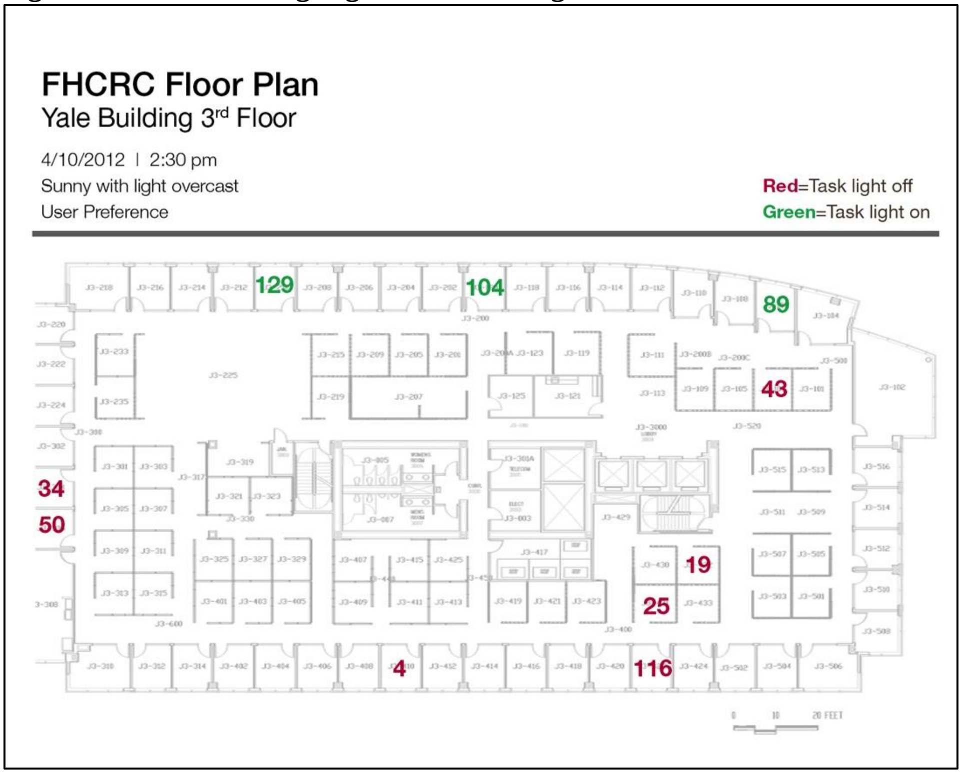


Figure 36: Yale Building Light Levels during User Preference Phase



REI Light Level Measurements

The REI site demonstrates a typical amount of variation expected in office spaces. Light levels are somewhat lower than the 35-55 foot-candle range as recommended by the Illuminating Engineering Society of North America (IESNA). Additionally, the measurements record the impact of the designer preference phase, where the lighting controls were used to dim fixtures near the window walls.

Figure 37: REI Light Levels during As-Is Baseline

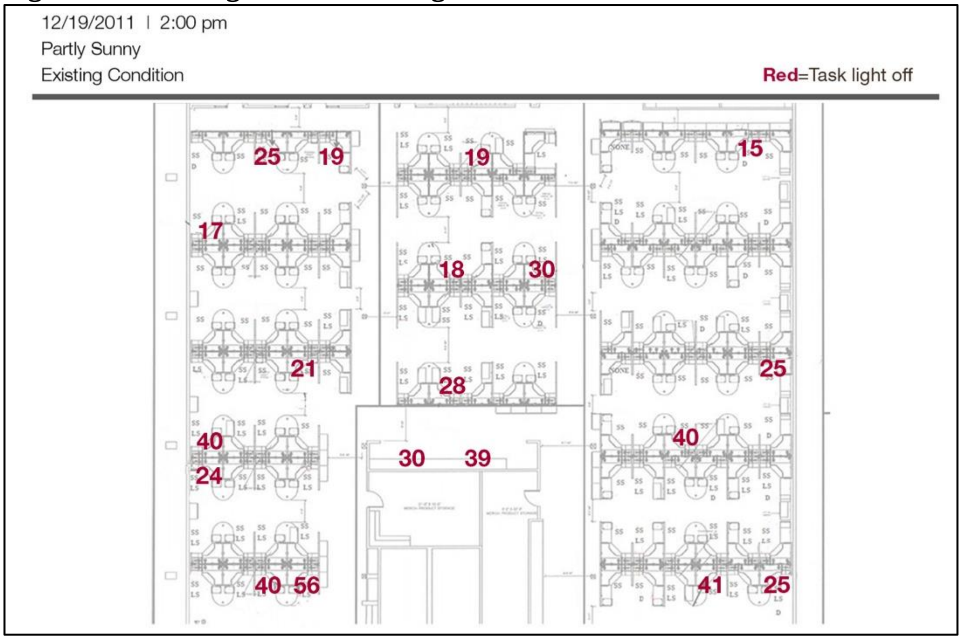


Figure 38: REI Light Level Measurements during Adjusted Baseline Phase

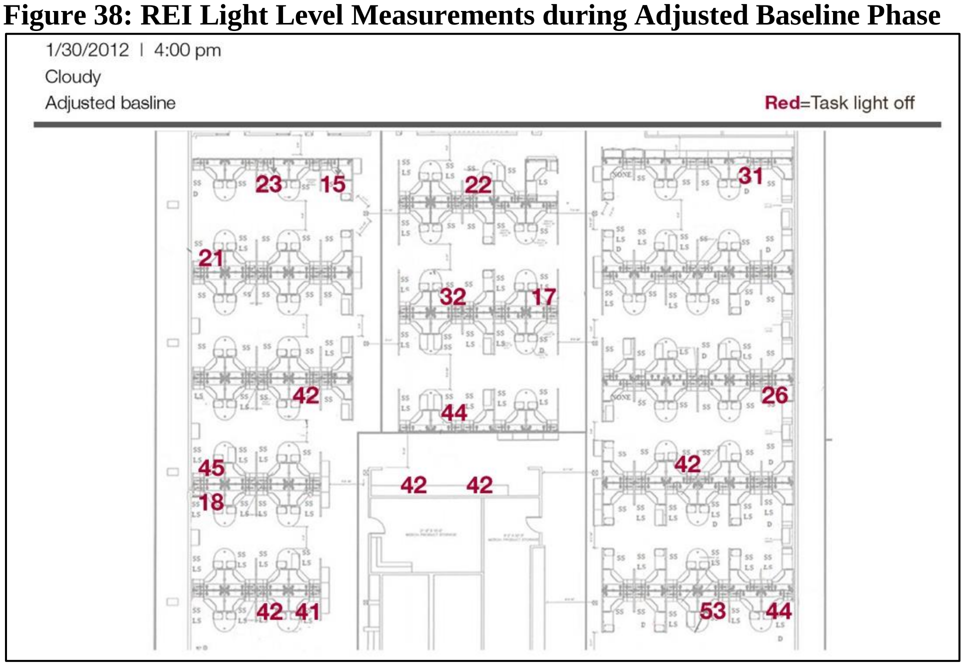


Figure 39: REI Light Level Measurements during Out-of-Box Phase

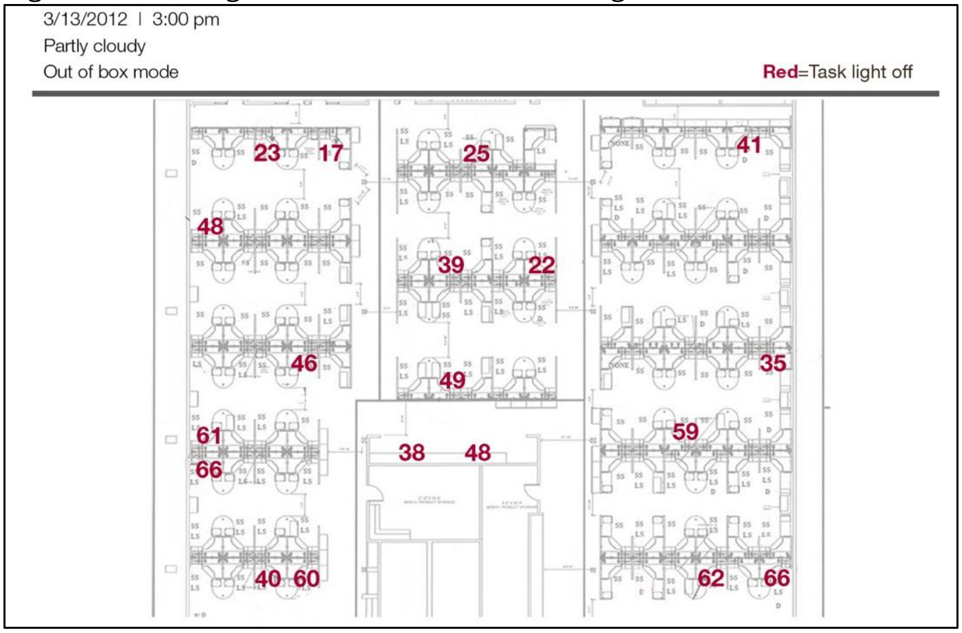
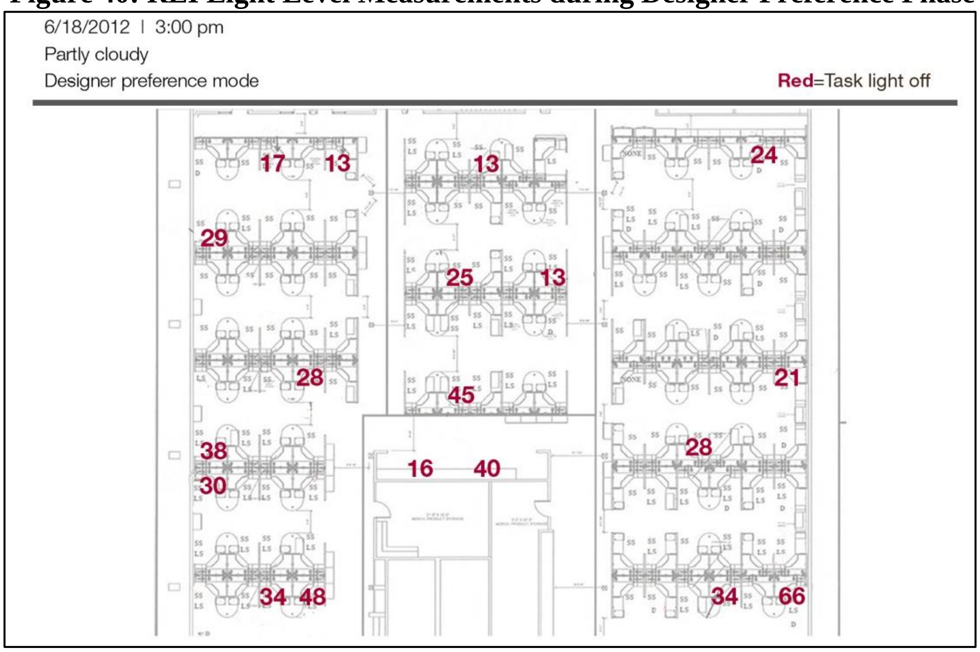


Figure 40: REI Light Level Measurements during Designer Preference Phase



Kivel & Howard Light Level Measurements

Lighting from the paracube fixtures at the Kivel & Howard site was below recommended IESNA office lighting standards. However, measurements revealed that occupants with control of the lighting in their space prefer less light.

Figure 41: Kivel & Howard Light Level Measurements during Out-of-Box Phase

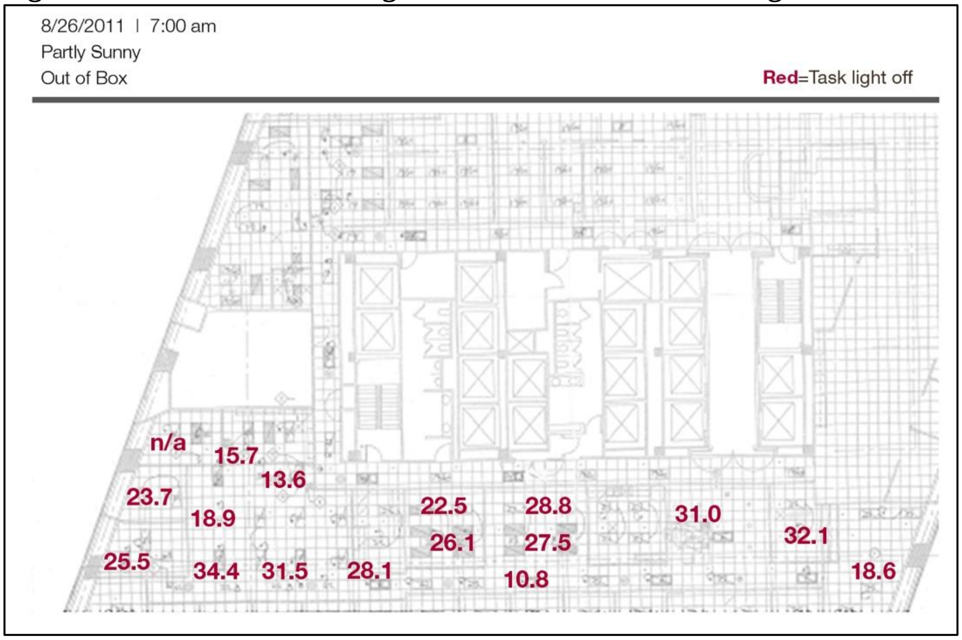
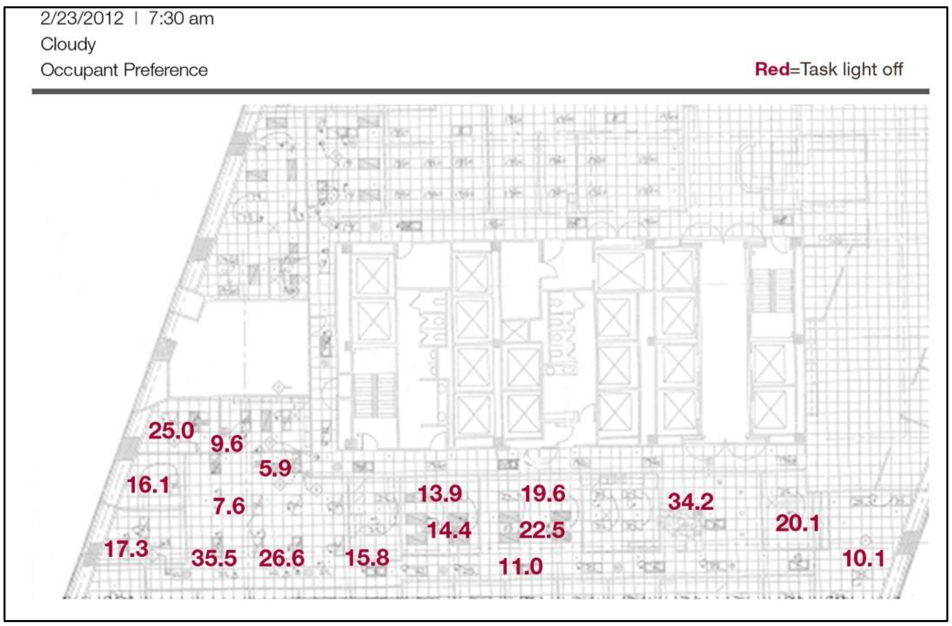


Figure 42: Kivel & Howard Light Level Measurements during Occupant Preference Phase



Summary of Light Level Measurements

Instantaneous light level measurements provide a snapshot of lighting levels at a certain moment in time. Researchers took ten light level readings during the Enlighted study, including four at the Yale Building, four at REI and two at Kivel & Howard.

Industry standards suggest that lighting levels for office spaces allow for 35-55 foot-candles. The REI site was the most likely to be in this range with a typical amount of variation across the space. The Yale Building had a high degree of variation likely due to a high level of daylighting available (weather dependent) in private offices from external windows. Conversely, light levels in the Kivel & Howard office were lower than industry standard recommendations, at the request of the occupants, who indicated that they preferred less light. Table 31 below provides a summary of the light level measurements by phase.

Table 31: Summary of Instantaneous Light Level Measurements by Site and Phase of Research

	Yale Building	REI	Kivel & Howard
Baseline	9-104 foot-candles	15-56 foot-candles	-
Adjusted Baseline	-	17-53 foot-candles	-
Out-of-Box	2-50 foot-candles	17-66 foot-candles	16-34 foot-candles
Designer Preference	-	13-66 foot-candles	-
User Preference	4-129 foot-candles	-	6-35 foot-candles

Appendix E: Task Lighting Analysis

Yale Building Task Lighting Analysis

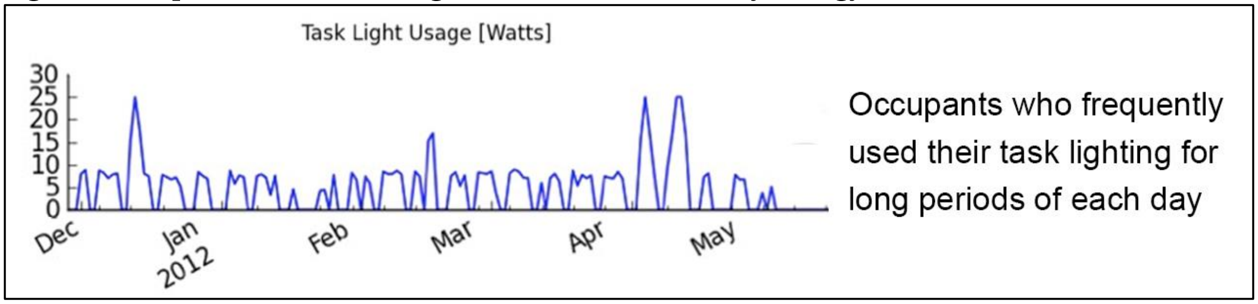
After the adjusted baseline phase of the research, NEEA and NBI agreed to add a task to study the task-level light use at the Yale Building. Researchers installed on/off loggers on 25% of the task lights in the space. However, due to the late addition of the task, researchers only collected baseline data at the REI site. This obviously limits the applicability of the comparisons.

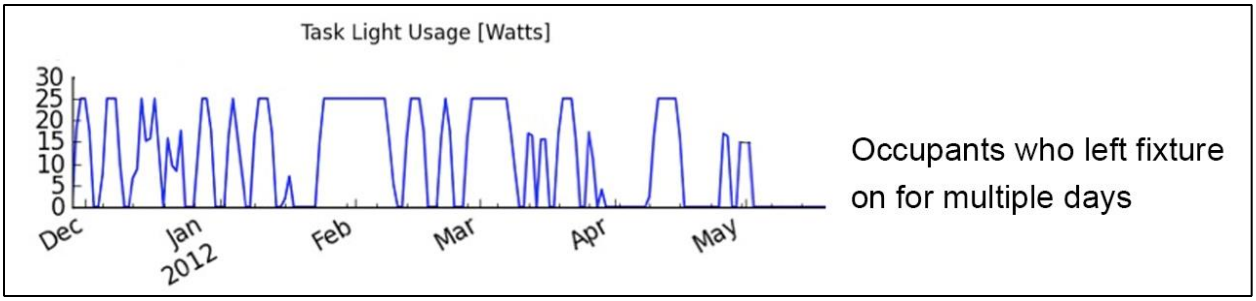
Task light data was further reduced due to data logging errors, and a number of data loggers that were removed from the site during the study and could not be recovered (presumably the occupants removed the loggers, unaware of the ongoing study).

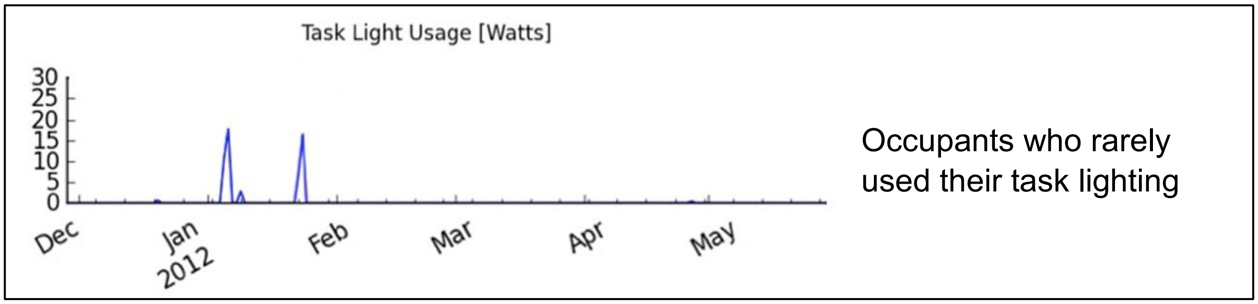
Eleven sensors provided on/off data. Data collection began on 11/28/2011 with inconsistent end dates among the sensors, ranging from 1/12/2012 to 4/30/2012. Fortunately, the available data does cover the two measurement periods of Adjusted Baseline and Out-of-Box, and resulted in 44 days of data collection.

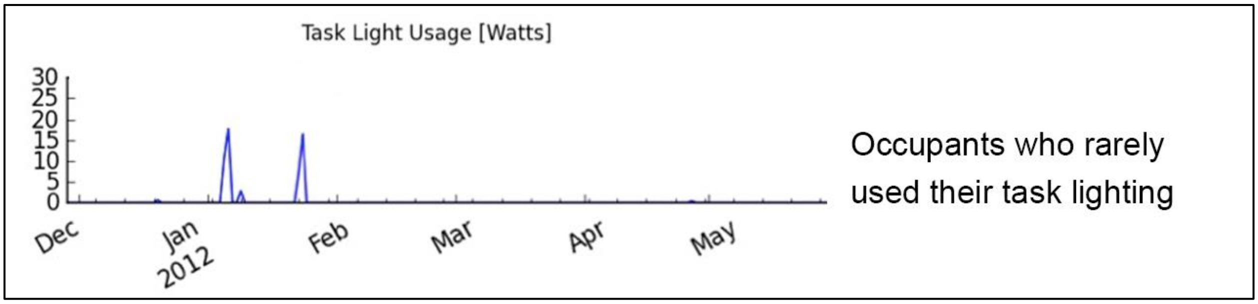
Researchers converted each of the on/off measurements to an estimated measure of power, reported in watts. This estimate assumes that each task light is 25 watts. The following collection of plots provides an overview of the activity on each sensor. Each plot presents the average watts/day recorded by each data logger. This collection of data illustrates a significant diversity of behavior. Figure 43 summarizes typical observations in multiple graphs.

Figure 43: Representative Task Light Use Patterns and Daily Energy Estimates









The hourly load profile charts in Figure 44 and Figure 45 show the expected behavior of task lighting following the occupancy schedule, with a slightly shorter duration than is seen in the overhead lighting data. In general, the nighttime and weekend setbacks are substantial, with energy use approaching zero. However, one exception exists: one task lighting fixture appears to have remained on for a number of days during the out-of-box period. The weekend hourly load profile chart clearly shows the impact.

Figure 44: Yale Building Weekday Hourly Load Profile

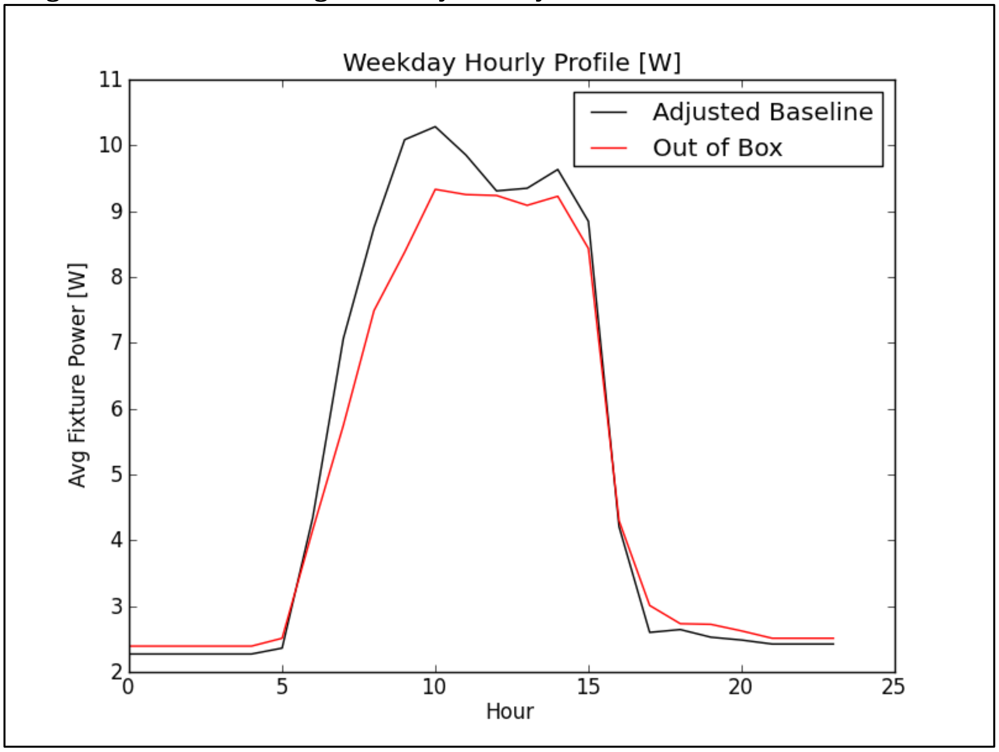
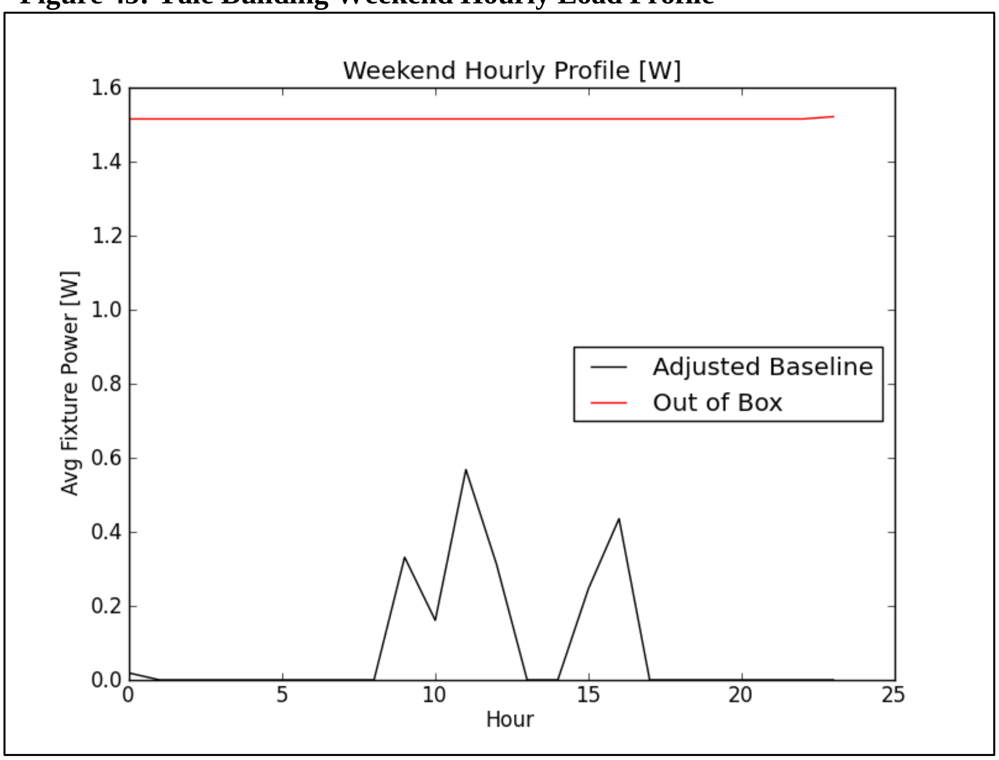


Figure 45: Yale Building Weekend Hourly Load Profile



To better quantify the energy impact of these task lights, researchers calculated an estimated annual usage. Table 32 below presents these results twice, both including and excluding Fixture 4 (the errant fixture that remained on for multiple days).

Due to the small sample size of eleven fixtures (out of approximately 100 task light fixtures in the study area), the impact of any single fixture is significant. Unfortunately, insufficient data exists to establish a strong conclusion as to the relative change (if any) in task light usage between the two measurement periods. The available data does appear to indicate that no significant change in task light use occurred between the adjusted baseline and out-of-box periods. This begins to alleviate concern of a “compensating” effect that leads to increased task light usage as the Enlighted system dims overhead fixtures. Further analysis for a large set of task lights will bolster this conclusion.

This dataset also demonstrates the relative impact of the task lights compared to the overhead fixtures in the office. Annual usage of approximately 30 kWh per fixture is approximately 20% to 50% of the overhead fixture energy use measured during the user preference period (depending on whether the comparison is to fixtures in the office core or on the perimeter). This illustrates the importance of accounting for task lights in future studies. A change in task light behavior could easily affect the estimated energy savings/penalty of a lighting system. It also identified a significant lighting load currently not addressed by a system such as Enlighted.

Table 32: Yale Building Annual Task Light Energy Use per Fixture

	With Fixture 4*	**Without Fixture 4**
	kWh/Fixture/Year	
Adjusted Baseline	31.1	31.4
Out-of-Box	33.7	25.1

**Note:* Fixture 4 remained on for multiple days during the out-of-box period. Due to the small sample size, this has a significant impact on the energy use estimates.

REI Building Task Lighting Analysis

Researchers collected task light data for a sample of task lights in the REI office space. Loggers provided on/off data for 41 sensors between 1/30/2012 and 10/1/2012. This logging period covers the adjusted baseline, out-of-box, designer preference and user preference stages of research. Researchers converted each of the on/off measurements to an estimated measure of power, reported in watts. This estimate assumes that each task light is 25 watts.

The hourly load profile charts in Figure 46 and Figure 47 show the expected behavior of task lighting following the occupancy schedule, with a slightly shorter schedule than that seen in the overhead lighting data – especially during the adjusted baseline period when overhead lighting is not well-controlled. The nighttime and weekend task light setbacks are substantial, with average energy use below 1W per fixture. The average power calculation is the average reading of all 41 metered task lights at any given hour. Another way to think of this chart is as a depiction of how many task lights are on at any given time, averaged across a number of days. For example, if all 41 were on every weekday at 11:00 AM, the average power for that hour would be 25W. If ten lights (or 25% of the metered fixtures) were on every weekday at 11:00 AM, the average power would be 6W. Although the behavior of each fixture may vary from day to day and hour to hour, the aggregate of all 41 fixtures over a number of days represents a very consistent and repeatable pattern.

Figure 46 and Figure 47 show a minor trend between the different measurement periods in the weekday load profile. There is a reduction of about 1W in daytime task light use between the adjusted baseline period and the user preference period. While this difference may possibly be negligible, it may also be due to increasing daylight availability as the seasons change from winter through early fall.

Figure 46: REI Weekday Hourly Load Profile

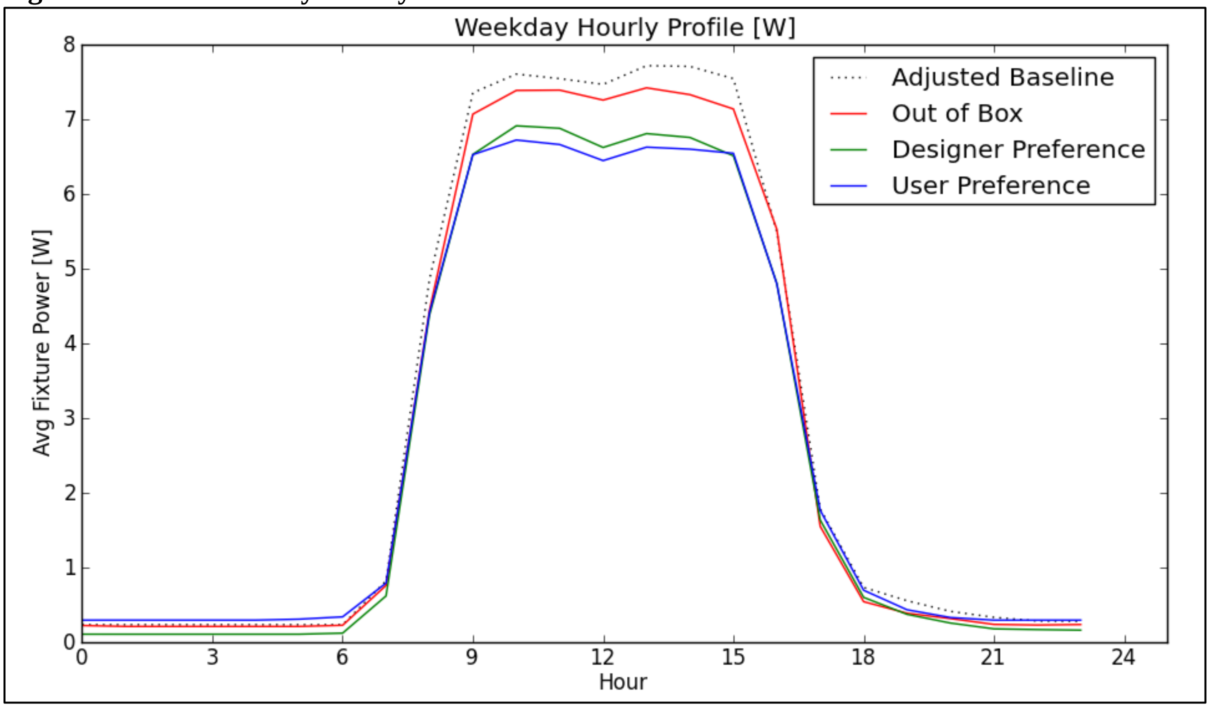
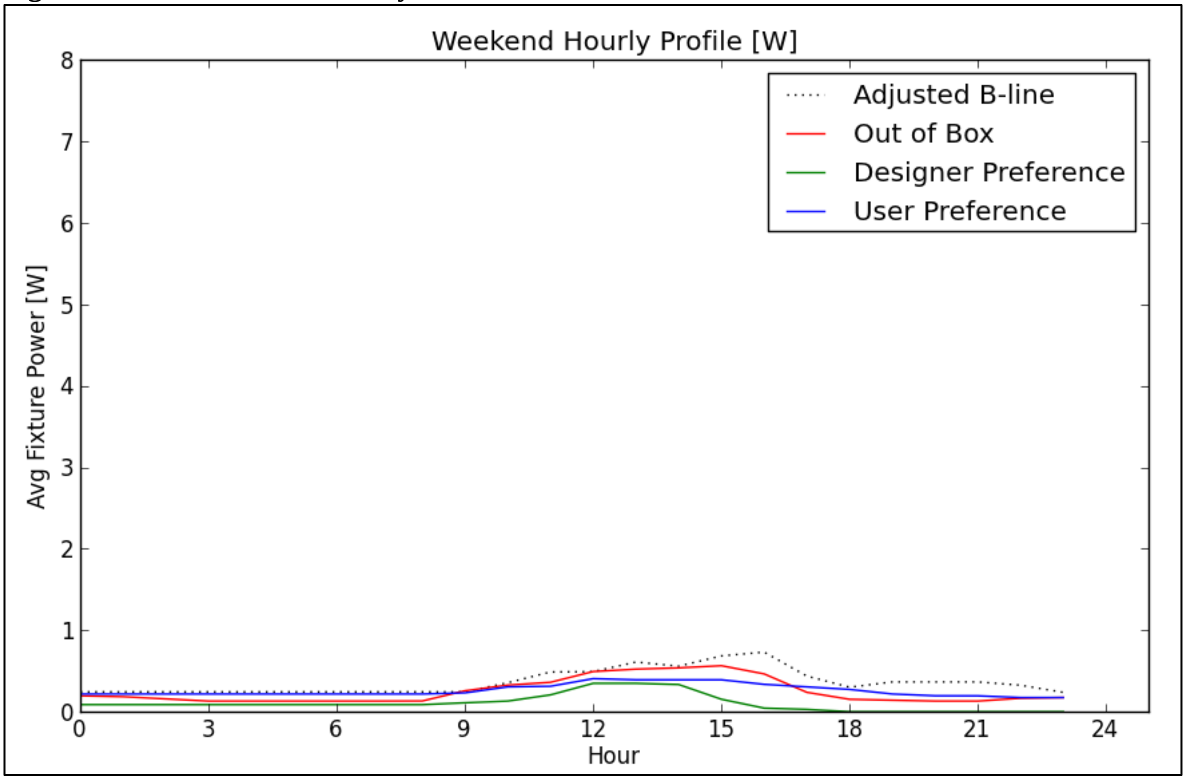


Figure 47: REI Weekend Hourly Load Profile



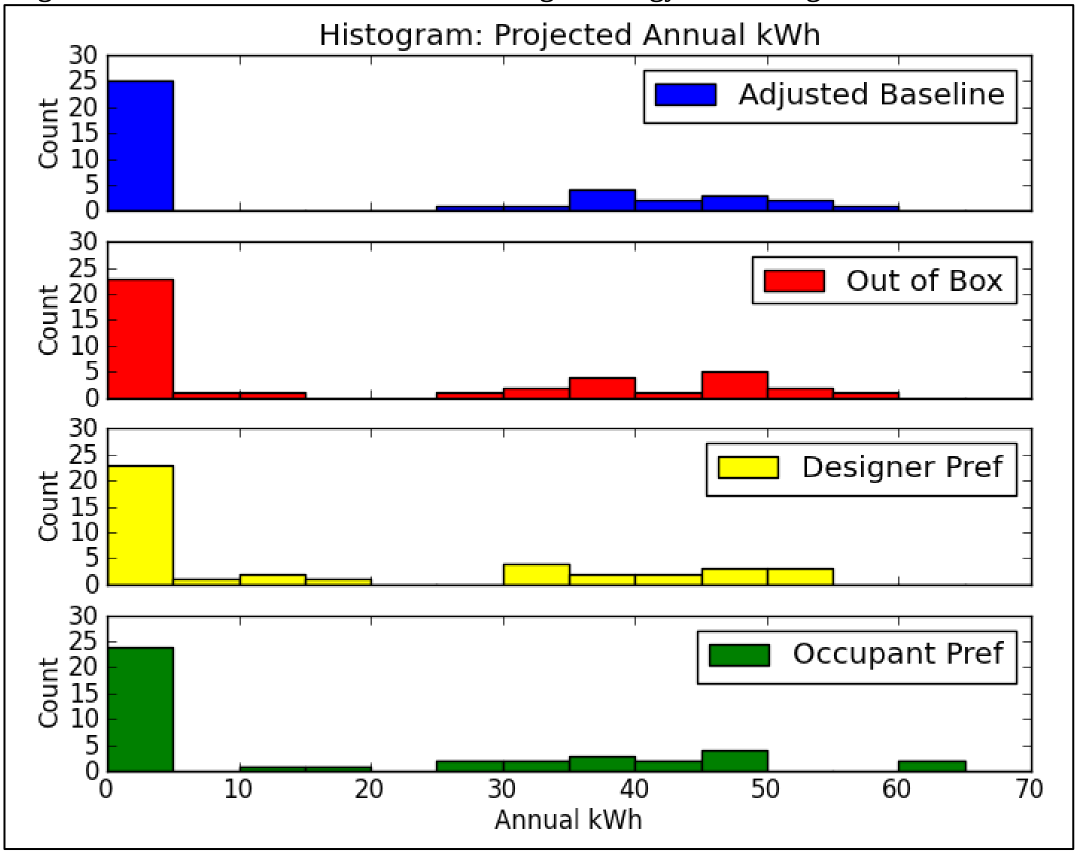
To better quantify the energy impact of these task lights, researchers calculated an estimated annual usage. Table 33 below presents these results. This calculation uses the average weekday energy use and average weekend/holiday energy use, with an assumption of ten holidays per year.

Table 33: REI Building Annual Task Light Energy Use per Fixture

		kWh / Fixture / Year		
Measurement Period	**Count**	**Mean**	**Std. Dev.**	**Max**
Adjusted Baseline	41	18.6	24.9	77.9
Out-of-Box	41	17.4	21.3	59.8
Designer Preference	41	15.6	20.0	53.4
Occupant Preference	41	16.4	21.3	64.7

Figure 48 provides a more detailed perspective of this calculation. To develop this histogram, researchers used the previously discussed methodology to calculate the annual energy use (kWh) for each task light. Then researchers used the distribution of annual kWh among different task lights to generate a histogram. Across all phases of the monitoring period, the majority of task lights are seldom used, with annual energy use estimates of less than 5 kWh. This group heavily influences the mean energy use of approximately 16kWh. When task lights are more frequently used, their annual energy is commonly in the range of 30-60 kWh. The large range of usage demonstrates the influence of behavior, and possibly workstation location and job function, on energy use.

Figure 48: REI Estimated Annual Task Light Energy Use Histogram



Task Light Summary

This dataset demonstrates the relative impact of the task lights compared to the overhead fixtures in the office. Annual usage of approximately 15-30 kWh constitutes up to 50% of the overhead fixture energy use. This illustrates the importance of accounting for task lights in future studies. A change in task light behavior could easily affect the estimated energy savings/penalty of a lighting system. This dataset also identified a significant lighting load currently not addressed by a system such as Enlighted. In addition, REI used less task light energy than did Fred Hutchinson; this could be due to differences in occupant behavior (note that Fred Hutchinson had a small sample size), type of work typically conducted by employees, workstation layout, balance between open and private offices, and/or in occupant schedules. Table 34 provides a summary of the annual task light energy use for both sites.

Table 34: Annual Task Light Energy Use Summary for Yale Building and REI

	kWh/Fixture/Year	
Measurement Period	**REI**	**Fred Hutchinson**
Adjusted Baseline	18.6	31.4
Out-of-Box	17.4	25.1
Designer Preference	15.6	N/A
User Preference	16.4	N/A

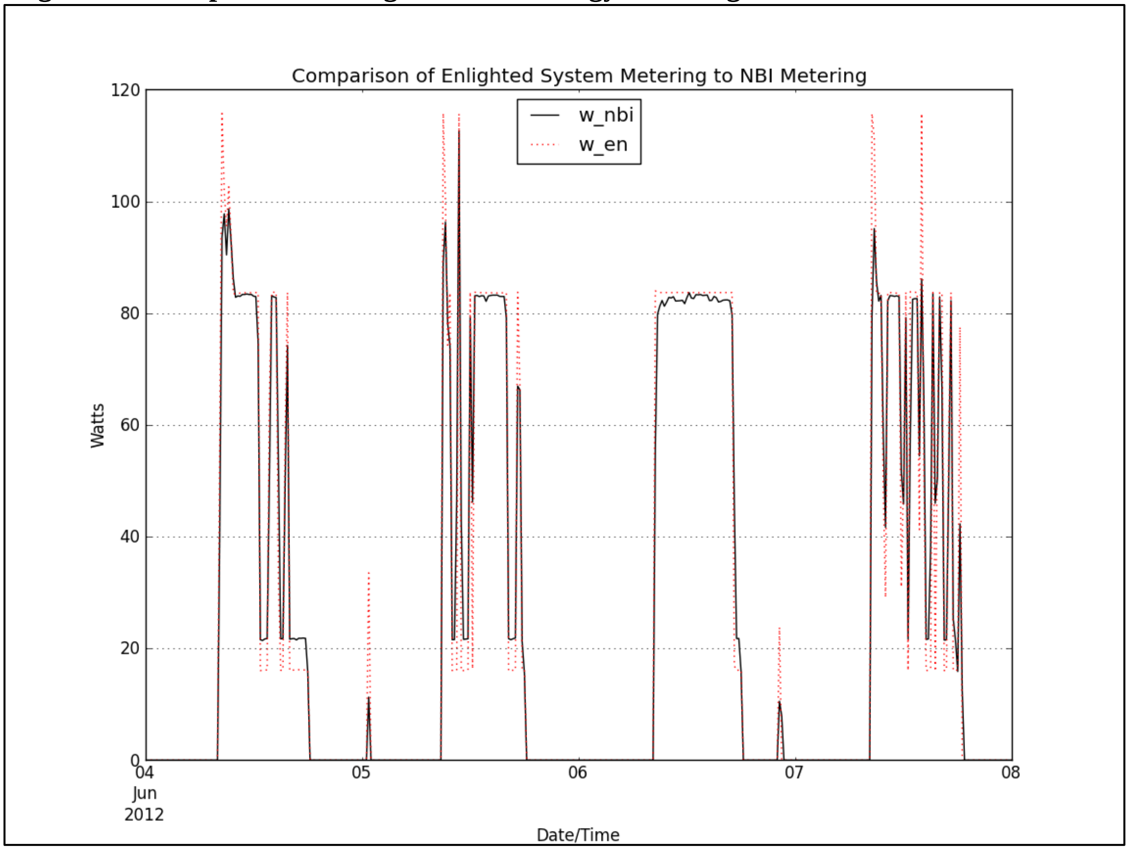
Appendix E: Additional Data Analysis: Fixture and Occupancy Data

Yale Building Fixture-Level Data Analysis

The Yale building presented a unique opportunity to explore detailed fixture-level data, which provide 15-minute-increment analyses of the energy use at each fixture. Enlighted provided a period of detailed system data that includes a measurement of both power and occupancy for each of the Enlighted sensor locations. To provide a degree of redundancy, NBI also installed a stand-alone Hobo U12 data logger on a single light fixture. Since researchers can analyze energy use at such a granular level, they are able to create “virtual meters” by aggregating a number of fixtures into groups. In this analysis, virtual meters help to assess the different energy use patterns seen in private perimeter offices, and in a centrally located open office area.

Before delving deeper into the power monitoring data collected by the Enlighted system, researchers conducted a brief analysis to evaluate the data quality. A stand-alone data logger collected data on power at a single fixture. The Enlighted system used a map of the physical location to identify and collect energy use data. Figure 49 below presents power logging data from both the NBI data logger and from the Enlighted system for a four-day period; Figure 49 shows that the two measurements are in very close agreement. The coefficient of determination, or R2 value, provides an additional measure of agreement between the two datasets. Over this four-day period, R2 is 0.98, indicating a very close fit. The REI site had similar results.

Figure 49: Comparison of Single Fixture Energy Metering



Another means of comparison is to relate the total energy use recorded by the Enlighted system to that metered at the circuit level by NBI. Figure 50 and Figure 51 present this information for the portion of the "user preference" period after new ballast installation (currently the only time period for which Enlighted data is available). The two datasets exhibit close agreement, with slightly higher energy use recorded by the NBI metering. This discrepancy is most likely due to the circuit configuration in the building: a few non-lighting loads may be included on the lighting circuit, or egress or other fixtures that are not part of the Enlighted system may be present. The Hourly Power Density chart indicates that most of the discrepancy occurred during unoccupied periods. An Enlighted representative also indicated this difference may be due to the calibration of the Enlighted power monitoring hardware. The newest generation of the system now uses different hardware that is reputedly more accurate.

Figure 50: Daily kWh for Yale Building – Comparison of NBI and Enlighted Metering

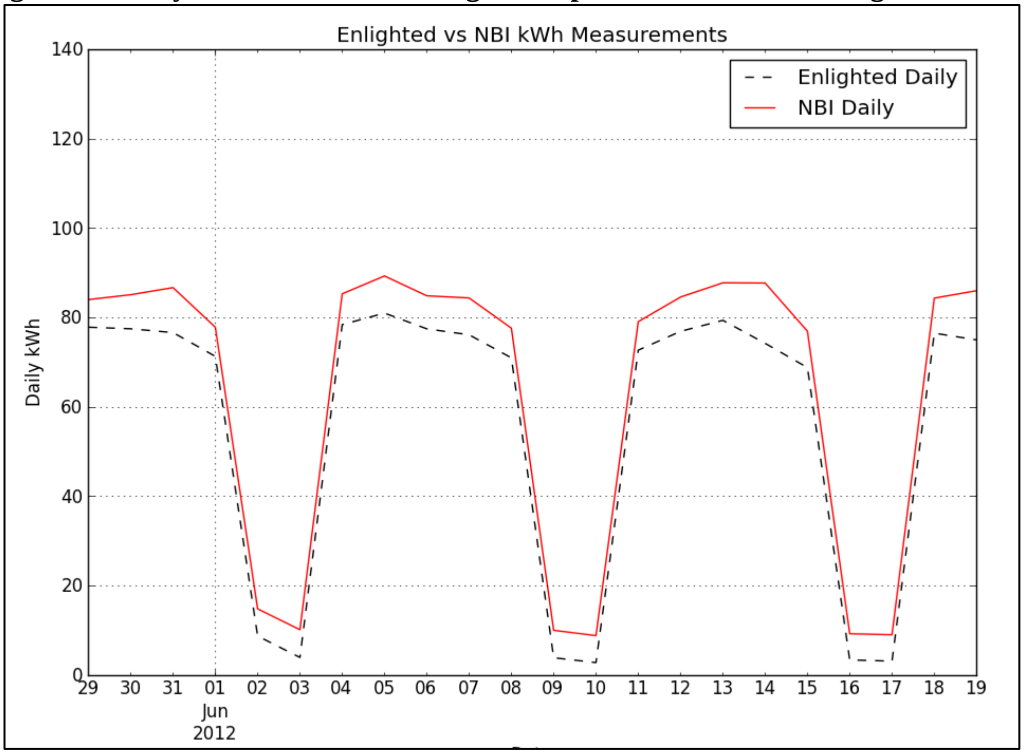
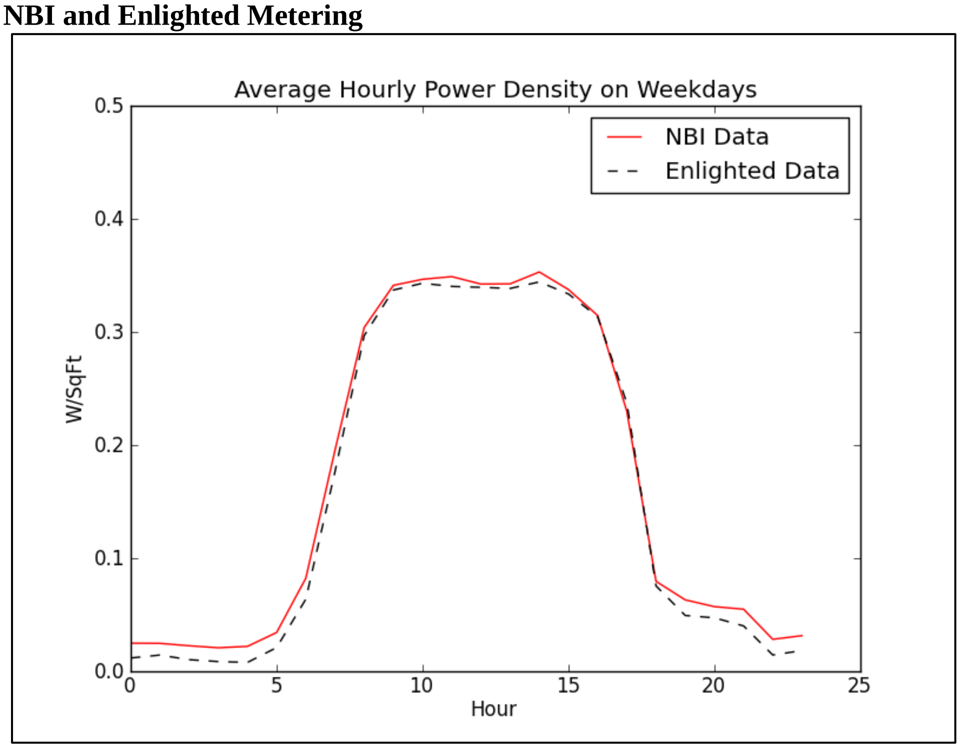


Figure 51: Weekday Hourly Load Profile for Yale Building - Comparison of NBI and Enlighted Metering

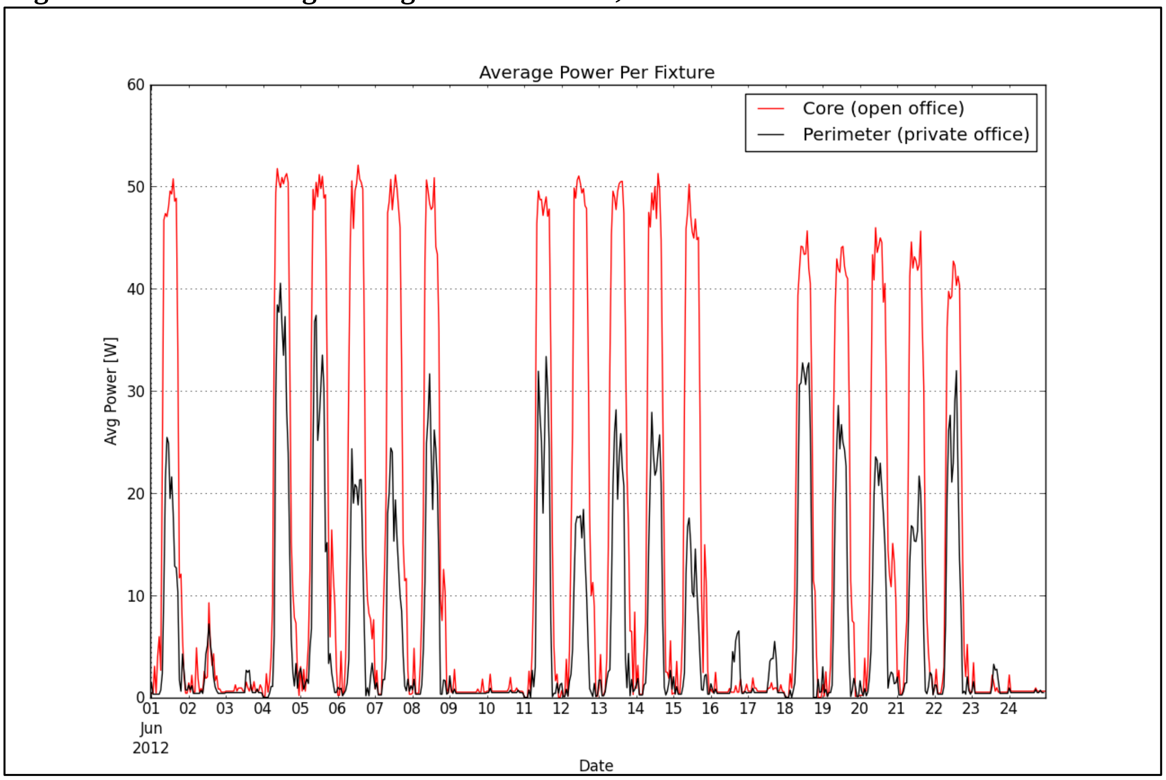


Using power data from the Enlighted system, researchers developed two "virtual meters":

- Core: this meter is comprised of nine fixtures. Each fixture is located in the central portion of the office, which is an open floor plan cubicle layout.
- Perimeter: This meter is composed of 12 fixtures. To account for the possible bias of different light levels as the sun moves across the sky, researchers selected three fixtures from each aspect of the building (north, south, east and west). Each fixture is located in a private office.

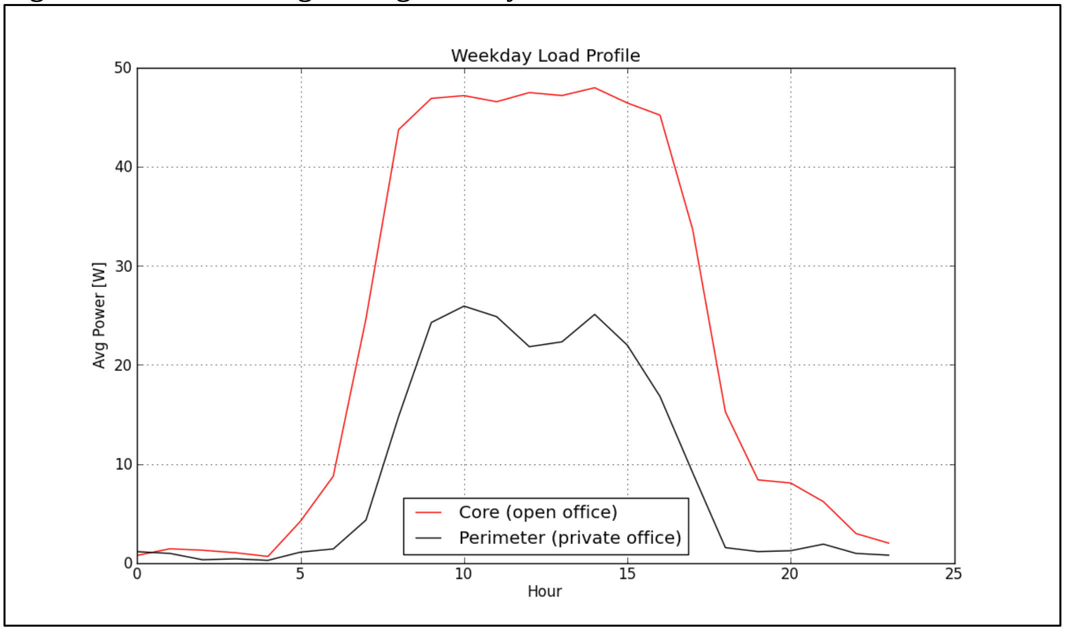
Figure 52 below provides a high-level overview of the two meters, showing that the perimeter offices consistently use less power than the core.

Figure 52: Yale Building Average Fixture Power, Core and Perimeter



Analysis of the average hourly power at each meter is also possible. Figure 53 below presents the average weekday power at each hour of the day. Note that this chart presents the average watts per fixture, and does not attempt to normalize for square feet. This figure depicts that the core fixtures used approximately twice the power of the perimeter office fixtures. Figure 53 clearly shows that the typical schedule was longer in the core, leading to a further increase in energy use.

Figure 53: Yale Building Average Hourly Power, Core and Perimeter



Researchers further quantified these differences by applying some of the metrics used to evaluate each site. Table 35 presents this data. Both the annual and daytime energy use exhibit a difference of more than 50% between energy use in the private perimeter offices and that in the open core office area. The perimeter offices have a higher weekend ratio, indicated more lighting energy use on weekends versus weekdays. However, the core offices have a higher off-hours ratio, indicating more energy use outside of the 6:00 AM-6:00 PM occupancy window. This could be due to the influence of a few occupants on a larger number of overhead fixtures, which would all be in range to detect motion and thus to remain on.

Table 35: Yale Building Metrics for Core versus Perimeter Offices

Metric	Core	Perimeter
Estimated Annual Energy (kWh)	137.6	59
Daytime Power (W)	40.5	17.7
Weekend Ratio	0.04	0.10
Off-Hours Ratio	0.11	0.06

Yale Building Occupancy Data Analysis

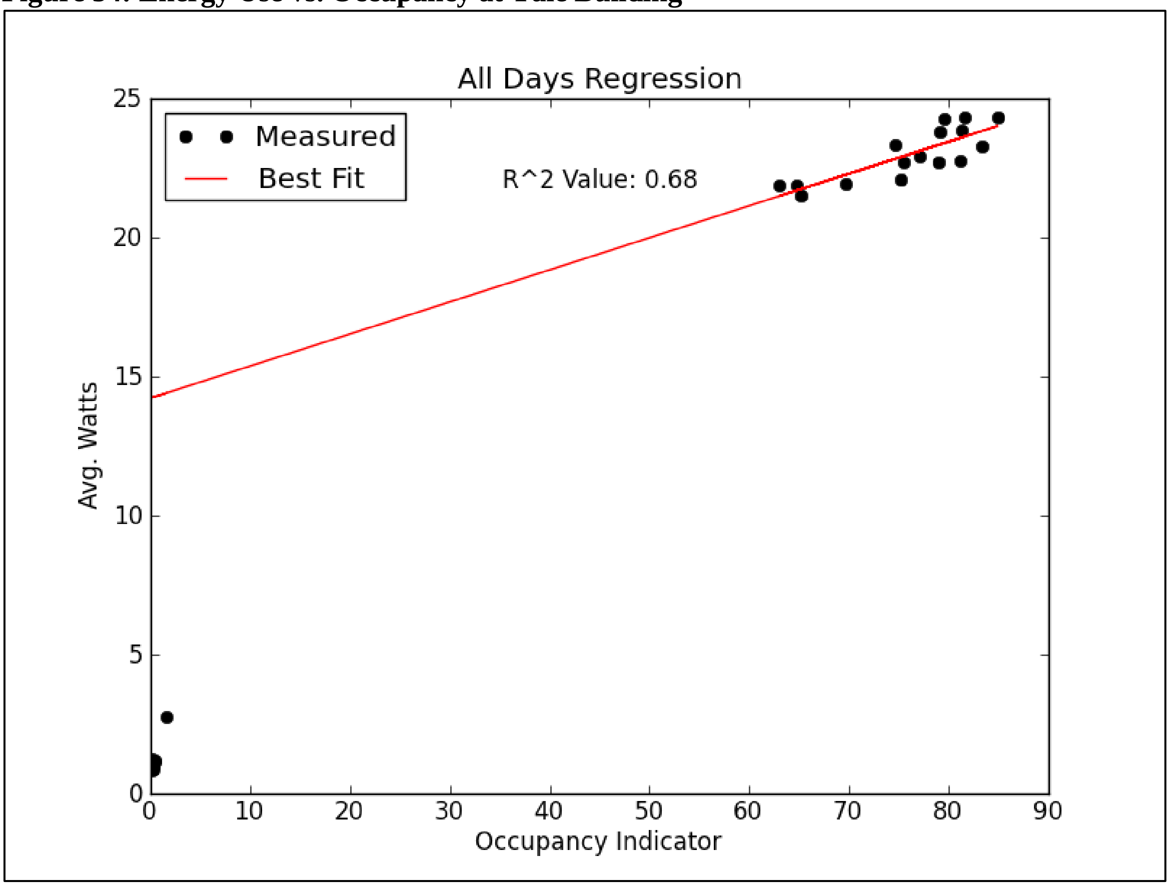
One of the key features of the Enlighted system is the presence of an occupancy sensor used in the control algorithm for each fixture. The data acquisition system also logs the occupancy readings from each sensor at five-minute intervals. For each interval, a binary number is stored that indicates how much motion a sensor observed: higher numbers indicate more motion, and lower numbers less motion.

NBI has started to explore the possibility of introducing this additional data into the energy use analysis methodology. Due to the availability of occupancy data and to the scope of this effort, this section presents the following information at a high level with the intent of demonstrating the potential for an enhanced calculation methodology. If a consistent measure of occupancy were available across all measurement periods, possible applications include:

- Assessing the total occupancy over a multi-day measurement period. Confirming that occupancy is within a reasonable tolerance between periods being compared.
- Determining if assumptions about weekday, weekend, and holiday use are accurate. Some offices may experience more weekend activity or an alternative holiday schedule.
- Developing a daily regression model that relates occupancy to energy use. Applying the regression model to energy savings projections.

In pursuit of a regression model, Figure 54 below presents the occupancy vs. energy use projection for a portion of the user preference period (6/1/2012 to 6/19/2012). Weekday data, with average occupancy idicators of more than 60, can be clearly distinguished from weekend data with occupancy indicators of less than 10. Using a regression model, the weekday energy use can be modeled by the equation: watts = 0.12 * Occupancy + 14.2.

Figure 54: Energy Use vs. Occupancy at Yale Building



Unfortunately, the same type of occupancy data is not available for a baseline measurement period. If it were, researchers could develop a similar regression model and compare energy use between the two periods by plugging the occupancy data from one period into the regression equation for the other period, thus normalizing for any change in occupancy between the two periods. With a sufficient sample size, this analysis would begin to develop a methodology for assessing the savings potential of a system in offices with different occupancy patterns and vacancy rates.