PERKINS+WILL

Research Journal

2014 / VOL 06.01

www.perkinswill.com

SPECIAL ISSUE: INNOVATION INCUBATOR RESEARCH

DESIGN INVESTIGATIONS IN PRACTICE

01.
LIGHTING AND THE LIVING LAB:
Testing Innovative Lighting Control Systems in the Workplace

David Cordell, IIDA, LEED AP ID+C, *david.cordell@perkinswill.com*
Leah Davies, Assoc. AIA, LEED AP BD+C, *leah.davies@perkinswill.com*
Jon Penndorf, AIA, LEED AP BD+C, *jon.penndorf@perkinswill.com*
Haley Russell, IIDA, LEED AP ID+C, *haley.russell@perkinswill.com*

ABSTRACT
This research focused on the use of lighting control systems in an office environment by studying the role of smart lighting strategies and their effects on the office. By sequentially testing these strategies for twelve consecutive weeks, this study worked to determine the ability of each approach to reduce the overall energy consumption, while incurring minimal consequences on productivity and comfort. Using two energy management systems installed in the office – Encelium Lighting Control and Pulse Energy Data – three methods were chosen for this study: task tuning, variable load shedding, and daylight harvesting.

The test revealed successes and limitations for each of the strategies. Task tuning suggested an appropriate relationship between reducing lighting loads and maintaining comfortable light levels in the work environment; load shedding revealed the difficulty to shed "secondary" lights with minimal impact in an open office environment; and daylight harvesting challenged the depth at which natural light may be effective as a primary means of illumination.

While this article was developed as a means to analyze and better understand the potential for smart lighting strategies in a work environment, the results derived from this testing were specific to the physical conditions – including solar orientation and lighting design – of the Perkins+Will Washington DC office and may only be used as suggestive reasoning for energy efficient design strategies.

KEYWORDS: lighting, workplace, energy savings, human comfort, efficiency

1.0 INTRODUCTION
The Perkins+Will Washington DC office is continuously searching for ways to improve not only the quality of work produced within the office, but also the quality of its working environment. By testing, analyzing, and implementing workplace design strategies, the LEED for Commercial Interiors certified Platinum space continually works to reduce its energy demand without negatively impacting the productivity and comfort of its employees.

The goal of this study was to evaluate three of the technologies available through Encelium - task tuning, variable load shedding, and daylight harvesting - in order to gather metrics related to energy savings and determine which technology, or combination, could provide the most beneficial energy savings outcome.

In addition to energy metrics, human behavior with respect to productivity and employee comfort was tested and measured in tandem with Encelium technologies to identify relationships. These observations and measurements were analyzed to provide more informed workplace design solutions.

Finally, the findings of each test are presented as a tool for designers to formulate design and lighting strategies as well as provide recommendations towards the implementation of these solutions to clients.

Encelium, the primary tool used throughout this effort, is a lighting control system designed to simultaneously implement energy management strategies and control interior lighting systems. The system is considered to help reduce lighting energy costs within a building from 50 percent to 70 percent through the use of six potential "smart strategies." For the purpose of this research, three of the six possible strategies (as shown in Table 1) were chosen for testing, implementation and analysis:

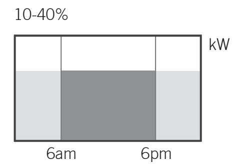
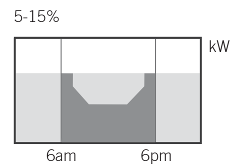
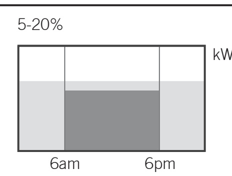
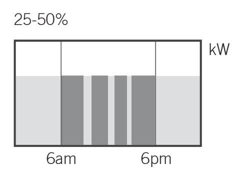
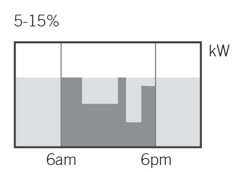
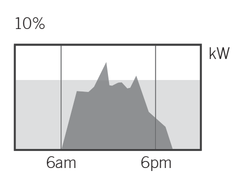
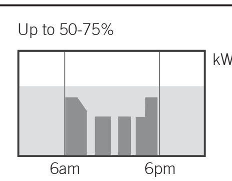
- *Task Tuning:* Setting default (maximum) light levels to suit the particular task or use of a workspace in order to eliminate over lighting[1].
- *Variable Load Shedding:* The automatic reduction of electrical demand in a building by shedding lighting loads dynamically (through dimming or switching) either to shave peak demand or to respond to a utility price or demand response signals. Load shedding can be done selectively by lowest priority areas first[1].
- *Daylight Harvesting:* Through the use of photo sensors, light levels are automatically adjusted to take into account ambient natural sunlight entering the building. Appropriate light levels are maintained and artificial lighting is dimmed when necessary [1].

In addition to Encelium, energy use within the office is monitored and recorded by Pulse, an energy management software. Pulse aims to assist facility managers in properly understanding and managing energy demand and usage within a building or space through recording and comparing real time data. The software is capable of numerically breaking down total energy consumption in order to recognize which loads are acting as the primary contributors. Additionally, Pulse compares this collected data to previously recorded metrics to help establish a pattern in which energy demand can be easily identified.

In the Perkins+Will Washington DC office, lighting is one of the lowest contributing factors to overall energy consumption; however lighting in this office typically uses approximately 200 kW of energy per day (or around 7kW/h), which is about 6 percent of total energy consumption for the office. Using previous metrics recorded by Pulse as a foundation, the team was able to set a baseline for these strategies to be measured against.

The percent energy-use due to lighting is relative to the light fixtures installed in the office; and is capable of significant variance when altered to respond to daylighting conditions. This workplace environment is designed as an open office with minimal interior partitions and a combination of daylight and shared electrical lighting (Figure 1). With floor-to-ceiling glass on its eastern exposure as well as punched openings on the north and south facades and a central atrium, the open office absorbs a high level of natural light throughout the day reducing the amount of electrical lighting needed. Dimmable linear fluorescent fixtures are the primary light source center-mounted over each row of work stations, while supporting ceiling-mounted fixtures line the corridors and adjustable LED task lighting is available at each individual desk.

Table 1: Encelium – a lighting control system used for this research – uses six strategies for lighting control and energy management[1].

Smart Time Scheduling In areas of a building where occupancy sensor control is not appropriate, time scheduled switching or dimming of lights can be employed for zones as small as a room or individual light fixture.	
Daylight Harvesting Through the use of photo sensors, light levels are automatically adjusted to take into account ambient natural sunlight entering the building. Appropriate light levels are maintained and artificial lighting is dimmed when necessary.	
Task Tuning Setting default (maximum) light levels to suit the particular task or use of a workspace in order to eliminate over lighting.	
Occupancy Control Through the use of occupancy sensors, lights are automatically turned on or off or dimmed based on occupancy detection.	
Personal Control Through the Personal Control Software, individuals can control (dim) the light levels in their workspace to suit their personal preferences from their desktop PC.	
Variable Load Shedding The automatic reduction of electrical demand in a building by shedding lighting loads dynamically (through dimming or switching) either to shave peak demand or to respond to a utility price or demand response signal. Load shedding can be done selectively by lowest priority areas first.	
Combined Energy Savings Potential cumulative savings from above strategies.	

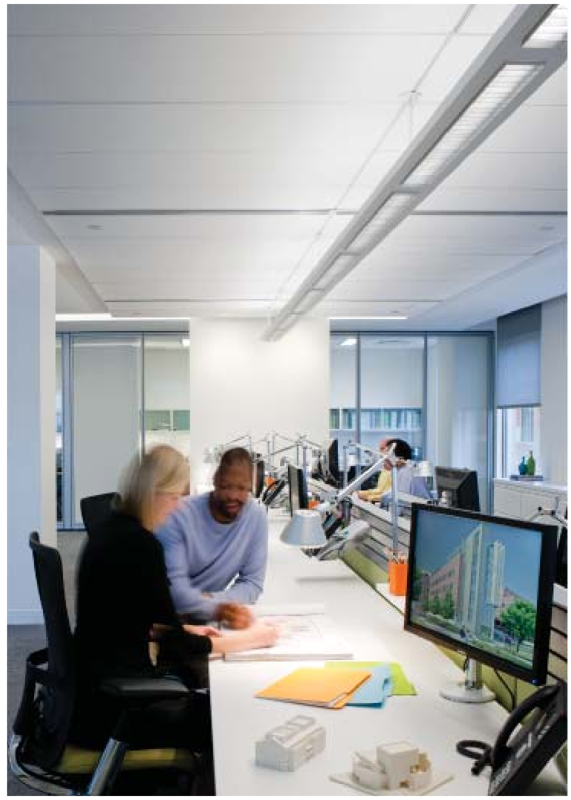


Figure 1: The open studio of the Washington DC office of Perkins+Will uses a combination of fluorescent, LED, and natural daylighting strategies.

Testing was completed over a twelve week period during the summer; each strategy was tested for two consecutive weeks during Phase 1, and another two consecutive weeks during Phase 2. The primary goal of the first phase was to gather data based on lighting and energy levels within the office. Task tuning, load shedding, and daylight harvesting were hypothesized to have different levels of impact on office productivity depending on occupant awareness. Therefore, the second phase included a series of messaging techniques in which office employees were made aware of the testing. In essence, Phase 2 was more specifically geared not only toward gathering numerical and spatial data, but also toward observing human behavior in the Living Lab.

Using a combination of recorded data, evaluation and occupant surveys, the team evaluated each strategy and developed a series of recommendations for future implementation. These recommendations, which evaluate potential applications or a combination of strategies, are outlined at the end of this article.

In order to accurately record data and communicate with office employees a number of tools were used throughout this twelve week testing period, such as a digital light meter and electronic surveys. These tools, while helpful in making design decisions regarding different forms of energy use, ultimately served to generate a larger tool derived from these studies. The findings presented in this report were intended as a reference that can assist and influence design and lighting strategies in future projects as well as provide encouragement toward energy efficient, comfortable lighting solutions to clients.

2.0 TESTING AND PROCEDURES

2.1 Task Tuning

2.1.1 Hypothesis

The team observed that employees rarely used task lighting in the open office environment due to the relatively high ambient light levels. We hypothesized that using task tuning to gradually lower ambient lighting levels in the studio and observing when occupants turned on task lighting for supplemental light would allow us to establish a target range for reducing ambient light levels.

Identifying the range of reduction will allow us to realize maximum reduction in our lighting power consumption with no impact on occupants.

2.1.2 Environment

The open office has an addressable system installed by Encelium that employs several strategies for lighting control. For this test, the team highlighted the task tuning strategy in order to test our hypothesis. Task tuning is defined as “the technology that sets a default, or maximum, light level to suit the particular task or use of a workspace in order to eliminate over lighting”[1]. The most common ways lighting energy is wasted are inefficient lighting systems, too much light for the visual task involved, lack of automatic occupancy controls, and surface finishes that absorb too much light[2]. The over-lighting of spaces is what task tuning aims to correct in order to maximize energy savings while still providing adequate light for the task being performed[1].

The workplace that was studied in this research has benching style workstations with a 42” high center spine. The workstations run east-to-west, perpendicular to an all glass eastern façade. The northern and southern façades have punched windows from 25” to 100” above the finished floor. The studio is anchored by support spaces on the western side of the floor plan. There is direct access to exterior views from 100 percent of the studio.

Linear fluorescent pendant-mounted, direct-indirect fixtures centered over the workstation spines serve as the primary light source for the studio. Supplemental lighting is supplied through linear LED pendants over collaborative areas and wall washers along the partitions at the western end of each workstation run. Additional downlights are located along the primary circulation on the eastern end of the studio. Every workstation has a fully adjustable LED task light connected to an occupancy sensor.

Medium-toned carpet anchors the otherwise white space, which was intentionally designed to maximize light reflectance and increase ambient light levels. This combination of lighting and finishes results in an average range of 20 to 300 footcandles (fc) on the work surfaces, depending on proximity to the exterior and time of day. Various organizations, such as the Illuminating Engineers Society of North America, have set the minimum level of footcandles appropriate for a work surface in an open office environment at 30, with the maximum recommended level at 50 fc[2,3,4]. The lower end of the range is ideal for computer work. Paper intensive tasks are typically easier to preform when footcandle levels are at the higher end of the range.

2.1.3 Methods

Phase 1 of testing was conducted over a two week period from June 11- 22. The office lighting is typically set at 80 percent capacity during normal daily operation. Using this as a baseline the team lowered light levels in the office an additional five percent each day, starting with 20 percent reduction (or 80 percent capacity) on Day 1 and ending with a 60 percent reduction (or 40 percent capacity) on Day 10. The lights were dimmed at the beginning of each day before occupants arrived to make dimming more inconspicuous and less distracting. Thirty-eight workstations out of approximately 100 were selected as testing points throughout the studio (Figure 2). Light level readings, measured in footcandles, were taken at these workstations three times daily at 9:00 AM, 12:00 PM and 4:00 PM over the course of the testing period. In addition to light levels, the team recorded the weather at each reading time. The total number of task lights observed to be on in the studio was also recorded at each reading time to determine if occupants used them to supplement the lowered ambient light levels. Additionally, the office manager was enlisted to track the number of occupant complaints regarding light levels.

Occupants were not informed about the specifics of the test, although the team made no effort to conceal the fact that they were recording light levels. If occupants made inquiries, team members replied that it was part of a lighting level study without providing specifics. No restrictions were placed on occupant control of the manually operated solar shades at the perimeter windows and weather throughout the testing period remained a variable.

Phase 2 followed the same pattern as Phase 1 over two weeks starting on July 23rd and ending on August 2nd. Lighting levels were again gradually lowered by five percent each day, starting with 40 percent reduction on Day 11 and ending with an 80 percent reduction on Day 19. Before Phase 2 testing commenced, an e-mail notification was sent out to all office occupants informing them about the nature of the test. Additionally, the notification stated that a survey would be conducted at the end of the testing period to gather feedback. Data

Figure 2: Zoning diagram for lighting level data collection.

was gathered in Phase 2 in a manner consistent with Phase 1 with the exception that the team also tracked occupant vacancy in the office to determine if there was a correlation between the number of people in the office and the number of task lights turned on.

An electronic survey was conducted on Day 20, including all employees who occupy the open office area in order to gather feedback related to their comfort and ability to perform their job functions throughout Phase 2.

2.1.4 Variables

There were a number of variables throughout both phases that impacted the collected data. These included:

- Weather conditions and resulting daylight levels,
- Occupant interaction with manual perimeter solar shades,
- Type of work being performed ("heads down" paper driven tasks vs. computer driven tasks impacted tolerance to lowered light levels).

2.1.5 Tools

Tools used in various phases of the study included:

- Digital light meter,
- Encelium – lighting control system,
- Pulse Energy – data collection & reporting system,
- Electronic occupant survey,
- Digital messaging (Email),
- Complaints log.

2.1.6 Results

The team evaluated the lighting levels by zone and by time of day in order to establish relationships between the average light levels in the studio with the lighting power reduction. It was noted that the morning readings were consistently higher than the afternoon readings, which is a result of the building's orientation and all-glass eastern façade. Generally, the energy reduction trend was to decline over the testing period at both 9:00 AM and 4:00 PM, even though the weather and window shade locations were variable.

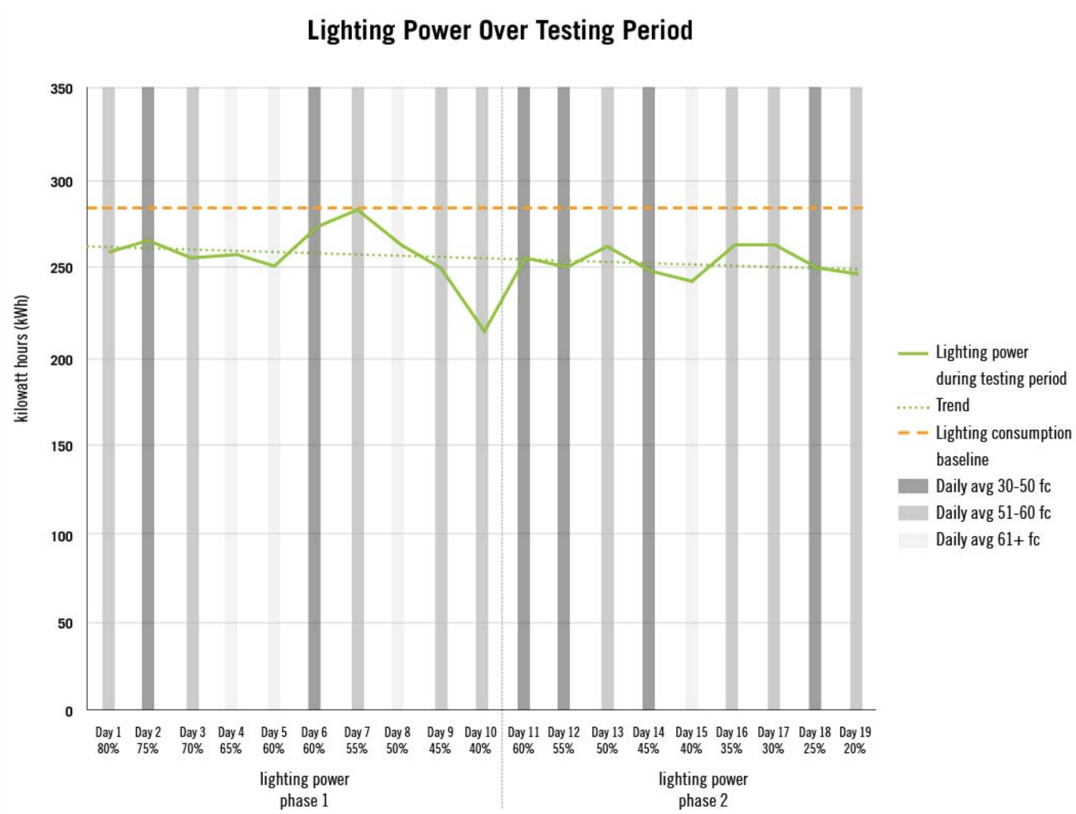


Figure 3: Lighting power over testing period graph for task tuning.

Over the course of the 19-day testing period, the percentage of lighting power reduction was varied from 20 percent to 80 percent, with the percentage varying between Phase 1 and Phase 2. The studio was able to realize a 10 percent energy reduction over the course of the testing period despite the variable percentages. Setting a consistent percentage of lighting power reduction enables the office to experience an even greater energy savings.

The graph shown in Figure 3 represents the actual energy savings as measured through Pulse Energy software for the lighting fixtures in the open office area. In the open office, the linear pendant-mounted fixtures centered over the workstation spines are Peerless Bruno series with one 32 watt 3500K T8 fluorescent lamp per fixture. The days are coded with the average light levels in the studio in order to compare the days where the office average fell within the recommended range of 30-50 fc.

Results from the electronic survey at the end of Phase 2 allowed us to gather feedback related to occupant comfort. Generally, staff felt no change to their productivity, however, most respondents felt the lighting levels were too low at some point during the testing period, but continued to work without taking corrective action. This confirms that a threshold was reached when the lighting levels were too low and the occupants could no longer work without disruption to their comfort. The email sent prior to the Phase 2 testing did not influence most people’s actions, however, a few respondents noted that they would not have turned on their task light had the email not been sent.

Typically, most people do not use their task light, but if it is used it is usually because the general lighting levels are too low. A few people noted, that they use their task light when doing “heads down”, paper-related work. Employees were also given the option to report complaints to the office manager and only two were logged throughout the testing period (both on Day 1).

Ergonomics is an important facet of employee comfort in the workplace and task tuning has the ability to impact an occupant through their posture and eye strain. In lower-lighting scenarios employees may adjust their posture to avoid glare or reflections and cause stress on their backs, necks, or hands[2]. Lighting that may be too bright or too dim also can cause eye strain[5]. An ideal lighting power reduction would minimize negative impacts to employee health while also maximizing energy savings.

Zones D and E currently uses daylight harvesting technology, so we would not recommend task tuning for these zones in order to maximize the benefits of this technology. Zones A and H do not take advantage of the all-glass eastern façade and had consistently lower footcandle ranges so task tuning to lower the lighting power is not recommended in these locations. Zones B, C, F, and G were evaluated based on average footcandles at 9:00 AM, noon, and 4:00 PM for each testing day in order to establish the recommended lighting power reduction that balances energy savings and human comfort.

Because of the building's orientation and all-glass eastern façade, the morning light readings were consistently well above the range of 30-50 footcandles and were not included in the general analysis of these four zones. Zone C had the most consistent lighting levels and was used as the model to establish the recommendation

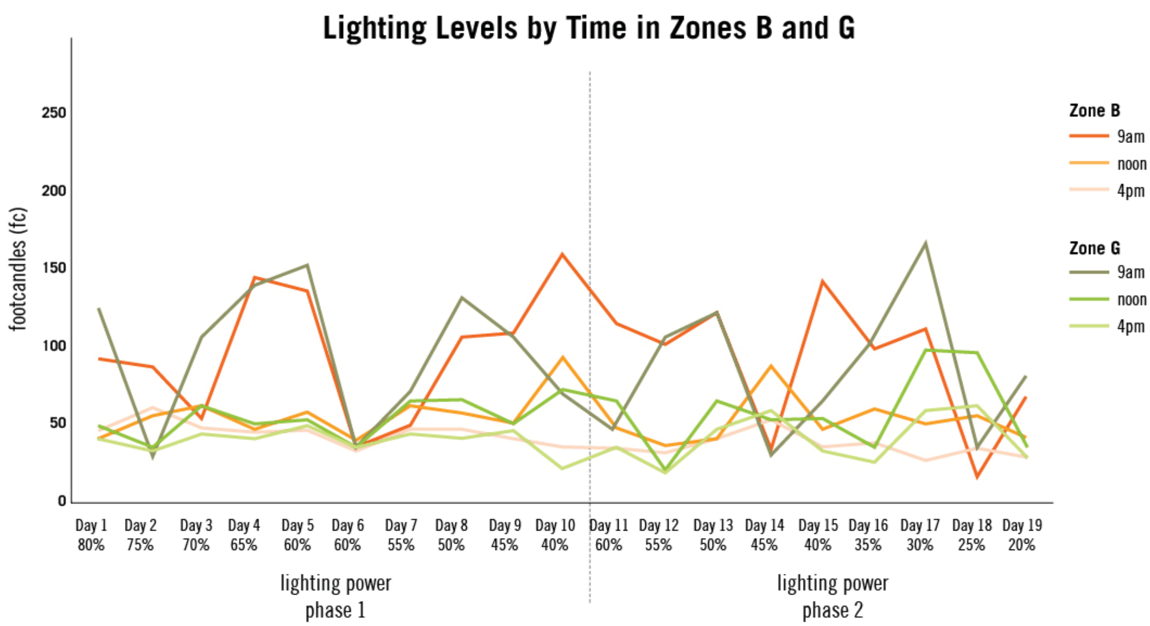


Figure 4: Lighting levels by time of day for Zones B and G for task tuning.

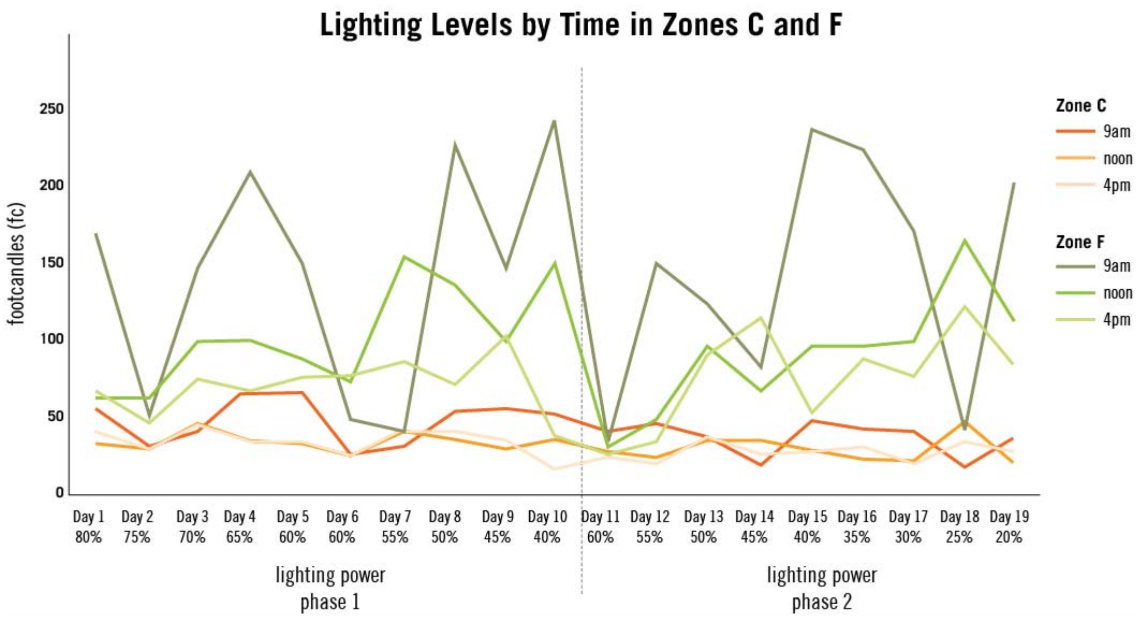


Figure 5: Lighting levels by time of day for Zones C and F for task tuning.

for the surrounding areas. Day 8 and Day 13, both a 50 percent lighting power reduction, provided readings within the ideal range of 30-50 footcandles. Lower lighting power reductions caused Zone C and Zone G to dip below the recommended range.

Light readings in Zone F were consistently higher than their counterparts in Zone C to the north. Similarly, readings in Zone B were higher than their counterparts in Zone G to the south. These readings may be a result of the variables in shading control. The team would still recommend that a lighting reduction of 50 percent be implemented in this area for task tuning. According to an estimate from Lutron, a 50 percent lighting power reduction should result in an energy savings of about 62 percent, based on one CFL 23 watt used 10 hours per day[6]. The lighting power reduction of 50 percent provides a lighting energy use of 264 kWh, which is a savings of about 16 kWh from the baseline.

2.1.7 Recommendations

In an open office environment where the occupants have control over the window shade locations, we would recommend a lighting power reduction of 50 percent in Zones B, C, F, and G in order to maximize the benefits of task tuning without negatively impacting human comfort issues such as task performance, visual comfort, ergonomics, communication, and aesthetic judgment[2].

2.2 Variable Load Shedding

2.2.1 Hypothesis

Prior to implementing variable load shedding in the office, we observed that minimally occupied spaces were maintaining equal light levels as consistently occupied spaces. As a result of this observation, we hypothesized that using variable load shedding in an open office environment results in an energy savings by turning off light fixtures during hours of peak energy demand. The following three hypotheses were tested:

1. Load shedding is an effective way to reduce electrical demand during peak consumption hours.
2. Load shedding has minimal impact on office productivity and comfort.
3. By implementing various forms of outreach and messaging, office employees are more accepting to visual distractions caused by load shedding.

2.2.2 Environment

Variable load shedding is “the automatic reduction of electrical demand in a building by shedding lighting loads dynamically (through dimming or switching) either to shave peak demand or to respond to a utility price or demand response signal. Load shedding can be done selectively by lowest priority areas first"[1]. Although the Perkins+Will Washington DC office does not currently use a variable load shedding strategy, the tools are in place for a programmed lighting system to be implemented.

The level of light in a space, measured both through electrical lighting and the amount of natural light absorbed through translucent fenestration, changes significantly due to the physical qualities of a space. The load shedding portion of this study reflected a series of physical conditions within the office, that influenced the manner and intensity in which changes in the lights were observed by office employees.

As an open office environment, almost all light fixtures are shared by multiple working parties. Hall lights, which in many office environments could be considered secondary spaces separated from working offices, are adjacent to work stations. Similarly, shared work islands are positioned parallel to bench-style rows of individual workstations. This means that as lighting conditions are adjusted in areas typically conceived of as secondary work areas, common areas, or circulation spaces, they are simultaneously affecting lighting conditions directly connected to primary employee work areas.

The office also uses large, floor-to-ceiling glazing along its east facing perimeter and large punched openings along the north, south, and west perimeter in order to allow generous amounts of natural light to enter the space. The eastern exposure along with a southwest-facing atrium strongly influences the light levels within the office throughout the day depending on external conditions. The solar orientation of the office and its relationship to the program of each space in the office was taken into account during this testing period.

Although the majority of work surfaces and walls throughout the office were designed with white finishes aimed to reflect light throughout the space, the flooring as well as the type of work being performed varies throughout the spaces. For example, one area with the least reported discomfort due to load shedding was the café, a common space with southern exposure and a primarily white material palette, which seem to have mitigated the effects of the reduced light levels. In contrast, the library, with content that reduces the visible white surfaces, received the most complaints for lowered light levels.

2.2.3 Methods

The study period of this testing was divided into two, two-week phases. Both phases were designed to observe, record, and analyze the impact of load shedding on human behavior in an office environment, specifically employee productivity and comfort. In an effort to study the naturally observed impact of shedding lighting loads in specific areas of the office, Phase 1 was completed without informing or engaging any of the employees of the testing. Simultaneously, the team observed energy levels within the office to see if load shedding could result in any substantial energy savings.

For both phases, the team assumed a number of areas within the office in which load shedding may have the least effect on productivity and comfort; these zones included hallways, work islands, and common areas such as the café. Additionally, the team studied energy consumption data for a typical day in the office using the Pulse Energy software and determined a threshold for which was considered – for the purpose of this testing – "peak total energy consumption." This threshold was set at 115kW. After establishing this threshold, it was also noted that the highest energy consumption was occurring between the hours of 11:00 AM – 3:00 PM (most likely due to occupancy and HVAC loads). Throughout both weeks in Phase 1, lights in designated zones were switched completely off during these four hours using the office's lighting control system.

Although we are not currently able to achieve a live link between Pulse and Encelium, the process established for this study was theoretically an automated one as Pulse recognizes that the energy consumption level for the office has reached its predetermined threshold, Encelium automatically reduces lighting loads in specified areas.

For the first five days (Week 1), ceiling mounted lights were shut off in office hallways adjacent to the work stations, and ceiling hung linear LEDs were shut off over work islands positioned between workstations. Week 2 continued to shut off the same zones as Week 1, but also turned off a portion of the ceiling mounted lighting in the library and café (Figure 6). Shutting off lights in the library and the café presented a significant change in the lighting conditions in comparison to the open office due to their spatial separation from other working areas. Unlike the hallways and the work islands, the library and the café are not equally exposed to the open office, resulting in less borrowed light.

Through this technique, the team was able to study a series of questions that ultimately helped us to determine the appropriate relationship between load shedding, energy savings, and human comfort and productivity:

- Is reducing shared lighting a more effective (and less distracting) means of load shedding than reducing light in a separated space?
- Are employees less or more likely to notice lighting changes if they are not expecting or aware of it?
- By including two more zones during the second week, is energy consumption being noticeably reduced (as compared to Week 1)?

During Phase 2, similar methods of testing as Phase 1 were implemented; however, the team used a variety of messaging techniques to inform employees of the expected lighting changes and educate them on the potential benefits of load shedding. This communication strategy allowed for a comparison between the level of impact of Phase 1 (in which employees were unaware of the testing) versus Phase 2 (in which employees were made aware of testing).

The areas tested remained constant throughout both phases. The first week of each phase shed loads over hallways and work islands; while the second week shed loads over hallways, work islands, the Library, and the café. The threshold for peak energy consumption also remained constant at 115kW.

In addition to the implementation of messaging techniques, the primary difference between Phase 1 and Phase 2 was the timing and manner in which lighting loads were shed. During Phase 2, the intention was to more realistically simulate a direct relationship between the peak energy threshold (recorded through Pulse) and the reduction of lighting loads (controlled through Encelium). Rather than turning lights off in the specific zones for a designated four hour period each day, Phase 2 turned lights off only when the office reached the threshold of 115kW; and turned lights back on once the office had cleared this threshold, resulting in a more aggressive visual realization of load shedding.

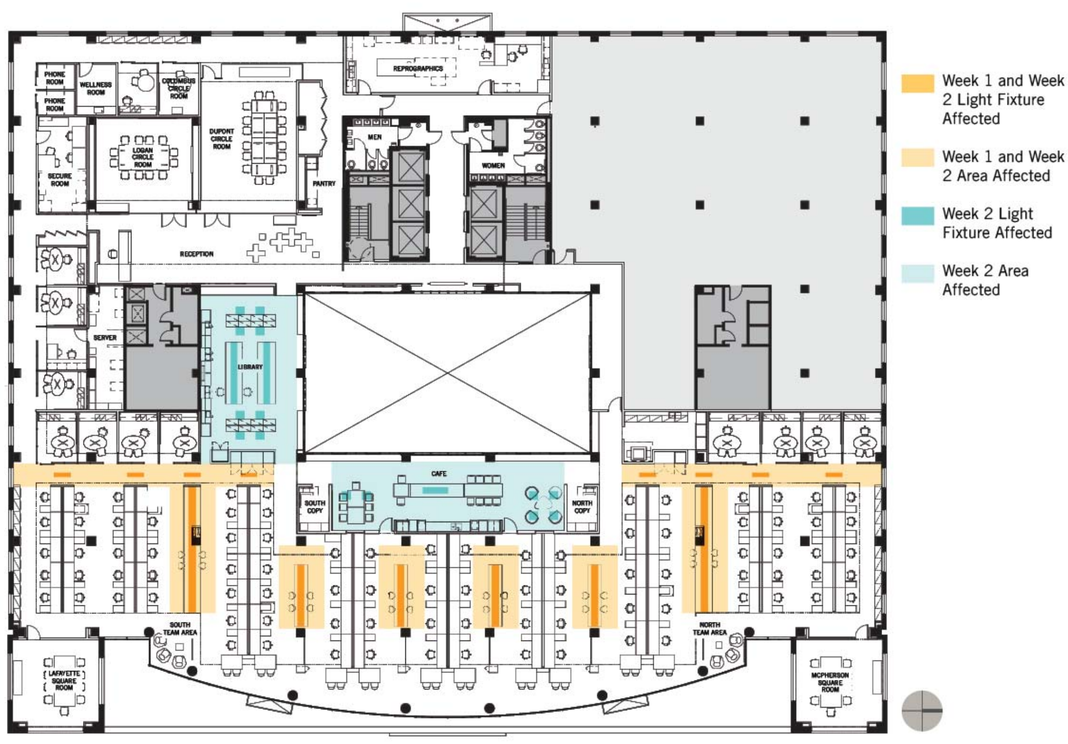


Figure 6: Zoning diagram for areas using load shedding during the first and second weeks of testing.

2.2.4 Variables
Throughout the testing period, there were a number of variables that were assumed or ignored for the purpose of this analysis. These included:
- Daylight levels/weather conditions (amount of natural light entering the office),
- Additional energy loads that determine the peak energy consumption threshold (as HVAC loads increase, as does the frequency in which the office reaches its peak threshold),
- Occupant views, access, and workstation positions relative to lights (proximity to windows affects awareness of internal light levels),
- Type of work being performed (employees working on a computer reported less effect than those reading, writing, etc.).

2.2.5 Tools
Tools used in various phases of the study included:
- Encelium – Lighting Control System,
- Pulse Energy – Data Collection & Reporting System,
- Electronic occupant survey,
- Physical & digital messaging (signage, emails, announcements, etc.),
- Complaints log.

2.2.6 Results
Hypothesis 1: Load shedding is an effective way to reduce electrical demand during peak consumption hours.

Figure 6 shows the areas designated and affected by the load shedding strategy. The fixtures targeted for the study are a combination of dimmable and non-dimmable fixtures. For the purposes of this study, dimmable fixtures output was reduced to 40 percent of maximum, per Encelium recommended parameters. The study shows load shedding in these areas of secondary work and support spaces can yield up to 0.76 kW of savings when fully activated.

The total load shedding achievable in the space when all fixtures in the open office areas are included is approximately 3.6 kW. The total lighting load is 17.88 kW. The highest peak use recorded was 137 kW and lasted for nine hours. On average, the peak use during the load shedding triggered state was 124 kW and lasted approximately 117 hours over the course of the study period. The load shedding test yielded an approximate savings of 6.85 kWh over the study period.

With the load shedding threshold set at 115 kW, this means that on average the peak use was 9 kW higher. Considering the maximum load shedding of 3.6 kW, this means that full load shedding would be insufficient to clear the threshold. Additionally, the absolute lighting load of 17.88 kW would be insufficient to clear the threshold during the peak recorded use.

The difficulty of using the Encelium system as an effective load shedding tool is attributed to the following factors:
- High efficiency, low-wattage, LED lighting systems are already in use.
- Large windows and mostly white reflective surfaces reduce the need for ambient lighting, therefore, a low ambient lighting requirement to begin with.
- HVAC load is the biggest load and variation exceeds the Encelium Load shedding sapability.

Figure 7 shows the average contribution of each load type to the total consumption. Figures 8 and 9 show the total energy consumption for the office, which includes lighting, and a graph of just the lighting energy consumption for the office to compare.

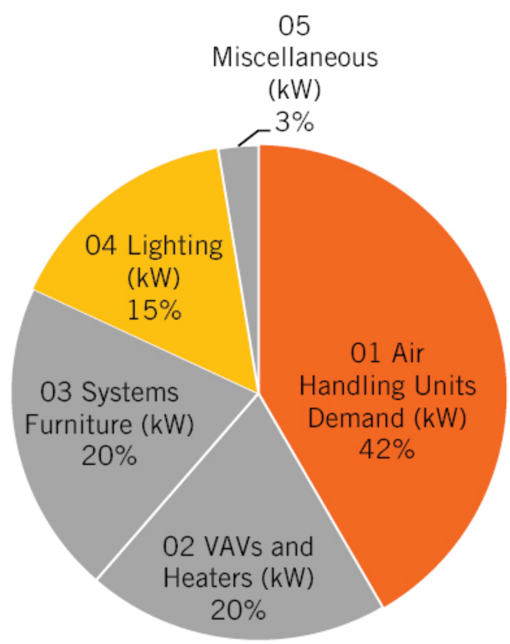


Figure 7: Graph of typical energy consumption breakdown in Perkins+Will Washington DC office.

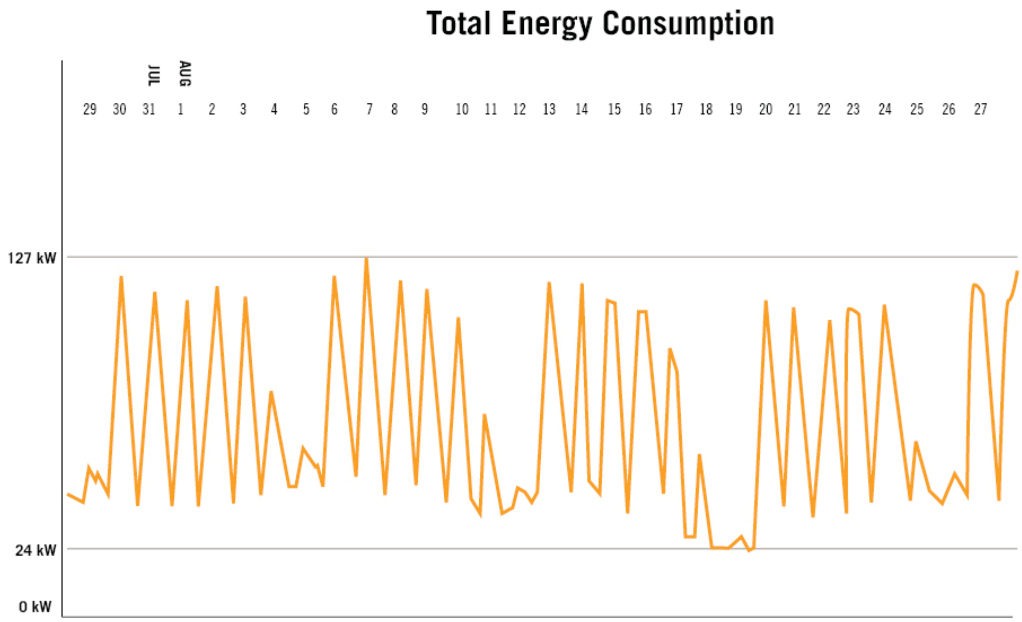


Figure 8: Graph of total office energy consumption provided through Pulse Energy Software.

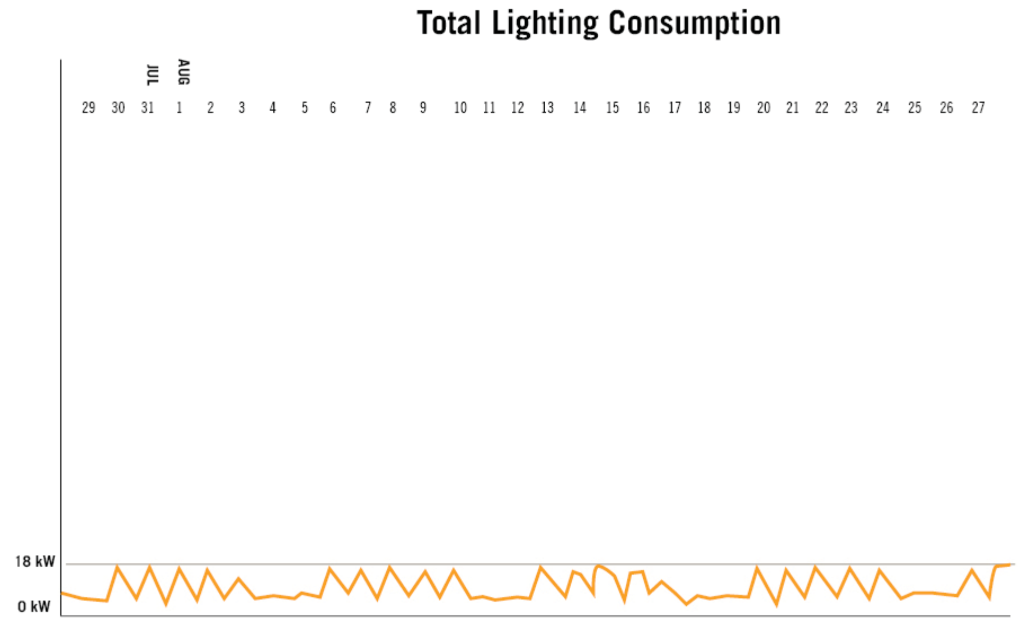


Figure 9: Graph of lighting energy consumption provided through Pulse Energy Software.

Hypothesis 2: Load shedding will have minimal impact on office productivity and comfort.

As part of the analysis, a post-test survey was issued. The survey indicated that the majority of respondents (54 percent) noticed the light fixtures switched off over the work islands, which are part of the target area. Respondents also noticed light fixtures switched off in the café, which was part of the target area in the second week of each phase of testing. However, 40 percent of respondents reported fixtures switched off from the personal work stations, which were not directly targeted during the testing. Two theories are proposed to explain this finding:

1. In a largely open-office environment, light fixtures are readily seen from all areas, both the fixture target area and beyond the affected area identified in the load shedding diagram presented earlier.
2. Respondents are recalling the lighting tests from the other study components, like daylight harvesting when lights were switched on and off to enable lighting measurements.

In the first survey, few respondents found the light changes distracting or uncomfortable. However, in the second set of tests, considerably more respondents found the switching distracting and/or uncomfortable.

Hypothesis 3: By implementing various forms of outreach and messaging, employees are more accepting to visual distractions caused by load shedding.

To mitigate the disruptive effects of the light switching, the study employed and tested four communication strategies:

1. Email communication at the start of the study explaining the load shedding tests and its benefits.
2. Messages prominently displayed on the large monitors in the café area.
3. Small message tents (measuring 8.5” x 5.5”) displayed in the vicinity of each of the target areas.
4. Public announcement broadcast over the loudspeaker signaling the beginning of each load shedding event.

At the conclusion of the load shedding study, a survey asked respondents to identify which communication strategy was effective in communicating the Load Shedding study as well as mitigating any distracting effects. Each communication strategy was then evaluated according to the effectiveness vs. effort/cost matrix (Figure 10). These four strategies were selected for the varying degrees of cost or effort associated with their production or execution.

Respondents found the slide on the office café monitor to be the least effective messaging technique employed with a response score of 16.7 percent. When asked to identify the single most effective messaging technique, this strategy received zero percent of the responses. The effort associated with its production was minimal and involved composing a PowerPoint slide to be incorporated into the regular slideshow of office announcements.

Respondents found the email explanation at the beginning of the study as the most effective messaging technique employed with a response score of 94.4 percent. Additionally, 70 percent of respondents chose it as the single most effective messaging technique.

Respondents found the loudspeaker announcements made at the beginning of each load shedding threshold event to be the third most effective messaging technique (22.2 percent). When asked to identify the single most effective messaging technique, this strategy received 15 percent of the responses. The effort associated with its production was minimal and involved composing a brief email for the office manager to read during each load shedding event. Although it proved effective in communicating the event, some respondents said they found the announcements almost alarming and therefore distracting.

Respondents found the printed signage displayed throughout the load shedding testing threshold event to be the second most effective messaging technique (27.8 percent); however, when asked to identify the single most effective messaging technique, this strategy received zero percent of the responses. The effort associated with its production was minimal and involved editing the digital messaging slide to fit onto 8.5”x5.5” card stock. Additional costs incurred in executing this strategy were in the printing, cutting, and displaying of the messages around the affected target areas.

In summary, email was the best communication strategy and print materials were the worst strategy largely because of their higher associated effort and costs (Figure 10). It should be noted though that email was appropriate considering the relatively brief study period of two weeks. In an actual daily use setting or continuous operation scenario, periodic emails may be necessary to remind occupants of the load shedding strategy, its goals, and its benefits.

Although extraneous to the study’s hypotheses, the team asked respondents whether seeing the load shedding at work motivated any additional reduction

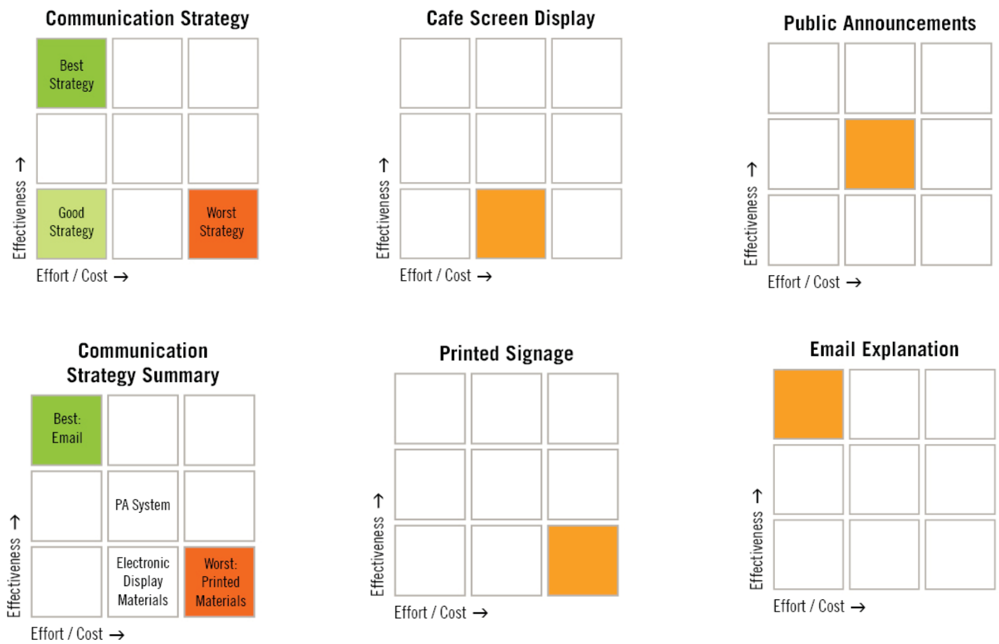


Figure 10: Effort/cost graphic analysis for each communication strategy implemented during the load shedding study.

in personal power use. A majority of respondents (77 percent), reported lack of any impetus to make any changes to their routine or otherwise reduce power use.

Lastly, the study asked respondents to identify areas in the office where it was suitable to shed loads. Minimally used/occupied areas such as back halls were identified by 72.7 percent of respondents and common areas such as the café were identified by 59.1 percent of respondents.

2.2.7 Recommendations

Considering the high efficiency lighting system currently used, its effectiveness in reducing the overall power load is limited especially in the summer months when cooling constitutes the largest share of the electrical load. To be more effective, more aggressive load shedding using more fixtures is necessary.

It can be concluded that the most effective and least costly means of communications for involving occupants in effort to minimize work-place disruption was email. In a continuous operation setting, occupants should consider establishing a schedule to send periodic email reminders to the general office as this engagement can enhance the efforts of achieving load shedding without employee dissatisfaction.

Future load shedding efforts should also explore, when available, technology for using progressive dimming over a length of time. For example, the Encelium system can dim the over-the-workstation lighting fixtures to a predetermined minimum output over a desired time frame. Ideally, the minimum output levels should be set according to available natural light. Consideration should also be given to balancing the decrease in overall ambient lighting with increased use of task lights at the primary work surfaces.

2.3 Daylight Harvesting

2.3.1 Hypothesis

The daylight harvesting testing measures the light levels available from natural light within the open studio space to determine how lighting levels can be stepped down to save energy without sacrificing visual comfort or a change in productivity.

The team hypothesizes that by harnessing daylight and understanding seasonal changes in daylight harvesting ability, a user can decrease lighting energy consumption by at least 20 percent with no decrease in productivity or user visual comfort as well as extend the light fixtures controlled by daylight sensors deeper into the space than the 15’-0” from windows as outlined by LEED[7].

2.3.2 Environment

Encelium defines this strategy as "using photo sensors to automatically adjust light levels to take into account ambient natural sunlight entering the building. Appropriate light levels are maintained and artificial lighting is dimmed when necessary"[1].

For the purposes of this test, the team focused on the open studio space that dominates the floor plan. The open studio predominantly has an eastern sun exposure with direct daylight gain into the space in the morning. The glazing portion of the eastern façade consists of 1" thick clear insulated glazing unit, per the building management company's records. Smaller punched, glazed openings on the north and south ends of the open studio along with proximity of neighboring buildings limit the amount of daylight that enters the space from those facades.

Workstations are organized perpendicular to the exterior wall. As installed, daylight sensors control the first two lengths of lamps in the fixtures above the workstations closest to the exterior wall. Other light fixtures above the workstations are dimmable, but currently not controlled via daylight (or other) sensor.

The ceiling in the open studio space is white, which can reflect light farther into the space if used as part of a daylight harvesting strategy. The floor covering closest to the windows is a medium-toned grey carpet tile and does not contribute to daylight harvesting strategies. User-controlled translucent roller shades can decrease the daylight gain in the space.

The adjoining buildings are clad in lighter colored concrete and masonry, which contributes to reflected light and glare issues in the afternoon hours.

Figure 11: Office floor plan showing locations for recording light levels during daylight harvesting testing.

2.3.3 Methods

Due to the plan configuration of the space, it was decided that the middle five rows of workstations in the open studio would be the optimal locations for measuring daylight. The two rows of workstations at the north and south ends of the studio are shaded from the east by conference rooms. The north-most and south-most rows do receive a small amount of ambient light from exterior windows, but the proximity of the neighboring building in each direction hampers quality harvesting.

For each instance of light level verification, lighting measurements were recorded at the exterior end of each row of workstations and at the third workstation in from the exterior (Figure 11).

During the first two week period (Phase 1), employees were notified of testing and asked for patience and cooperation.

During week one, all roller shades were completely retracted. Studio lights were shut off at 8:30 AM for daylight level readings and the weather noted. The lights were turned back on after readings were taken. Studio lights were shut off at 12:00 PM for daylight level readings. They were turned back on after readings were taken. Weather conditions were noted. Studio lights were shut off again at 4:30 PM for daylight level readings. They were turned back on after readings were taken and the weather was noted.

During Week 2, the process described above was repeated, but the roller shades were extracted to 50% (rolled down half way).

During the second two week period, the data from the first two weeks was analyzed to determine the average number of footcandles recorded by location and by time of day.

The studio staff was notified by email that additional daylight harvesting tests would be taking place in the office, and cooperation was again requested. Additionally, staff was asked to direct comments or complaints about visual comfort to the testing team for resolution. The team would be prepared to offer the following mitigations based on the complaint: adjustment of computer monitors, adjustment of roller shades in immediate vicinity of complaint, and/or ordering of a computer glare-reduction screen.

Electric light levels were adjusted twice each day – once in early morning and once during early afternoon. The goal was a combination of 50 footcandles between the average daily daylight reading and that supplied by the electric lighting. Fifty footcandles is regarded by several organizations as a benchmark or threshold for visual comfort at a desk level[3,4].

The team selected the workstation with the lowest average light level readings from the first testing period in creating the lighting adjustment strategy. That workstation was used to target 50 footcandles.

The following information was recorded daily:

- Weather,
- Overhead light level adjustment,
- Window shade adjustments in the morning and afternoon,
- Comments or complaints from staff,
- Actions taken to resolve staff comments or complaints.

Daylight harvesting, perhaps more than the other tested strategies, is directly affected by seasonal variations. Our first round of testing was completed in June, July, and August of 2012, which obviously allows for longer daylight hours. The second round was completed in the winter over two separate weeks. The intent was to see how seasonal change affected the daylight harvesting strategy adopted in the first round.

The second round of daylight harvesting tests was carried out in winter (December 10 – 14, 2012, and again January 21 – 25, 2013). As was done in the summer, the ambient lighting directly overhead of the five middle rows of workstations in the studio was adjusted from a normal 80 percent light level to 53 percent (the level arrived at during the first round of testing). Light levels were reduced at approximately 8:30 AM each morning to take full advantage of the east orientation of the workspace. Light levels were raised back to 80 percent at varying times throughout the testing periods to determine if staff noticed a difference in ambient illumination, though they were always raised back to 80 percent by 4:30 PM, as the sun would set shortly thereafter and the studio space would be noticeably darker.

2.3.4 Variables

The following variables were either out of the control of the testing team or difficult to control on a daily basis:

- Weather patterns (amount of daylight each day),

- Staff interaction with the manual roller shades,
- Type of work being completed at workstations.

2.3.5 Tools

The following tools were used to carry out the observations and testing:

- Encelium – Lighting control system,
- Pulse Energy – Data collection & reporting system,
- Digital light meter.

2.3.6 Results

Based on Phase 1, light level averages were determined and weather patterns discussed and analyzed. The second week of the first period was more cloudy and rainy than the first, and light level readings were noted as a variable out of the control of the testing team. As such, those values brought the average daylight illumination down, but were a more realistic portrayal of actual variations.

Through use of the light meter and the Encelium controls, the lighting levels were reduced in the studio to 53 percent (normally the lights are set at a fixed 80 percent capacity) at 8:30 AM. Direct daylight gain was greatest in the morning hours (due to east orientation of the space), so the studio could take advantage of that increased daylight level.

After analyzing the light level readings for noon and afternoon from the first two week period, it was determined that the lights should be returned to 80 percent capacity at 2:00 PM each day during Phase 2. The lack of direct gain in the afternoon limited how far into the floor plate the daylight penetrated. Reflected daylight in the afternoon (off buildings across the street) also did not have an effect on how far daylight would enter the space. At times even electric light levels at 80 percent did not achieve the 50 footcandle level targeted.

The energy use in Phase 2 can be charted against the energy use over the same period of time in 2011. This comparison removes the seasonal variable from the equation. Plotting the same dates in the Pulse software shows a reduction in the average lighting energy use of 20.36 kWh (including weekends when lighting was not varied). If we compare the average lighting load over a week's time from early June (prior to all testing data), we see a reduction of energy used by lighting of 5.66 kWh.

Based on the testing conditions, the Pulse Energy Monitoring System showed an overall reduction of energy use for lighting of eight percent over the six days the testing occurred compared to the same six days in 2011 (Figure 12).

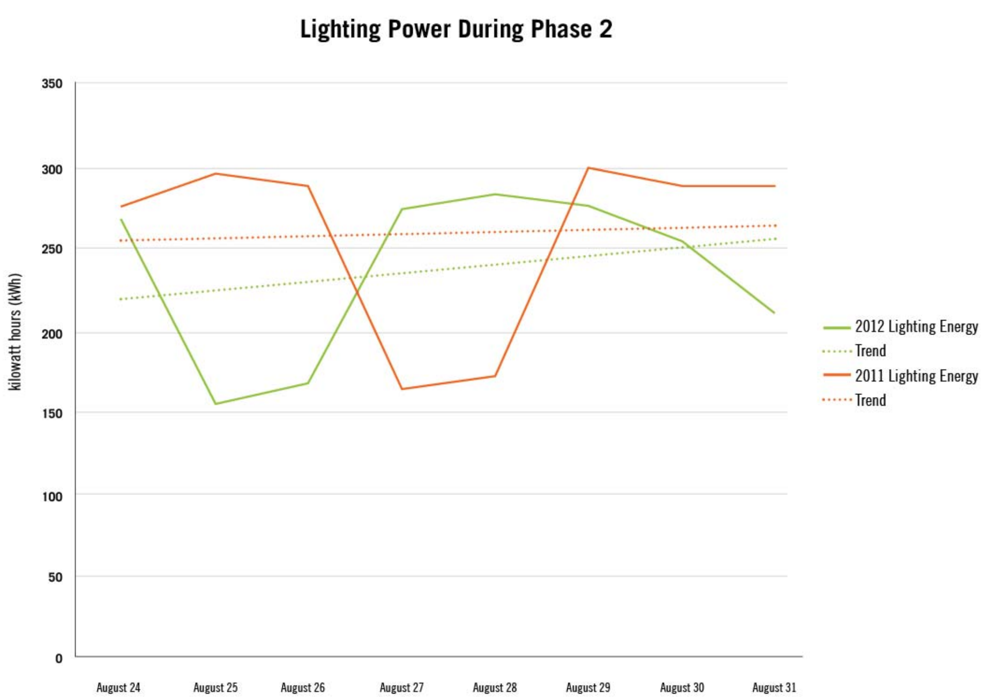


Figure 12: Lighting power measurements from testing in 2012 shown compared to the same calendar dates in 2011.

Figure 13: Diagram for recommended daylight harvesting locations.

Figure 14: Diagram for recommended combined daylight harvesting and task tuning.

The daily lighting energy use went down during Phase 2 compared to the same dates in 2011, but daily results varied greatly. On August 31, for example, the office recorded a drop in energy use from 287.328 kWh to 212.039 kWh, a difference of 75.3 kWh. That represents a 26 percent reduction over the use in 2011. The reduction in energy use on August 24, however, only represents a two percent decrease. These increments do vary, but since the lighting use is measured by day in these cases, employee work patterns may account for some of the variations. Therefore, the average reduction of eight percent over the six day window will be used as the result of this test.

Comments and complaints from the staff were minimal and mostly occurred during the first few days of Phase 2. Complaints the team received were addressed using the roller shades and had minimal effect on the overall light levels – the complaints were more about glare from the brightness of the window wall and not about inability to see a computer screen. Glare screens were not used. When there was a conscious concern about our attempt to maintain maximum daylighting, the shades were rolled back up when glare was no longer an issue. This is important in noting that the visual comfort of the person sitting at the perimeter workstation directly influences the visual comfort level of the person sitting in a more centrally located workstation. This study did not examine thermal comfort issues relating to the direct sunlight.

During the winter testing, no complaints about glare or illumination levels were registered with the testing team. We observed window shades at varying levels of extraction (we did not fix them at a specific level), and on any given day between one and three task lights would be turned on by staff out of 44 workstations in the testing zone.

While there was a definite reduction in lighting intensity within the studio during the two weeks of testing, energy reporting from the Pulse Energy Management software showed a slight increase in energy use for lighting during each week, compared to a similar week in 2011. This could be attributed to a variety of reasons – staff staying in the office later for work and thus requiring lighting longer into the evenings; more conference room use during that time period and other usage issues. The increase from the December 2012 week over a comparable workweek in December 2011 was an average of 6.8 kWh per day. The increase in the January testing period was an average of 1.04 kWh.

2.3.7 Recommendations

The team recommends that daylight sensors can be used to control the light fixtures within the first 30 feet of the windows for the five rows of workstations along the eastern all-glass facade. This doubles the recommended distance as outlined in the LEED guidelines because of the amount of daylight this office space receives (Figure 13).

For this particular space, a balance between use of roller shades 25-50 percent extracted and reduction in electric light use should be investigated to mitigate direct light glare issues and reduce energy use.

Whatever the reasons for the increase in energy consumption over the previous year's baseline, we would still recommend taking advantage of daylight within a space to reduce overall energy consumption in winter as in summer. With no recorded staff complaints and no glare reduction interventions, we conclude the productivity and visual comfort of the studio staff was not affected by the decreased electric lighting provided. Lighting levels may need to be readjusted earlier in the workday to compensate for less daylight hours, but programmable lighting control software would be able to address that seasonal variation.

3.0 CONCLUSION

3.1 General Observations

The team found lighting to account for approximately 15 percent of the energy consumed in the entire office. However, lighting is a conspicuous component of the open office and directly connected to occupant productivity. As indicated in the variables listed for each test, overall lighting levels are impacted by a variety of factors ranging from weather to occupant behavior. Additionally the architectural elements in the space, such as wall type (opaque vs. glass), finishes (light and shiny vs. dark and matte), views of fixtures (seated at workstations vs. in transit) directly impact how light behaves in a space. For these reasons the team recommends that designers looking to employ an addressable lighting control system as part of their energy management strategy should run a daylight model for the space to inform the proper application of the individual lighting reduction strategies covered in this test.

Building system commissioning is a standard activity at project turnover, but frequently focuses on larger items such as mechanical systems. In performing the tests, the team frequently found many electronic controls to be incorrectly set, such as lighting zones controlling extra fixtures. It is difficult to quantify the effect of improperly commissioned controls. The team recommends full commissioning and ongoing audit of an addressable lighting system when it is used on projects in the future.

The team found task lights to be drastically under-utilized. Although task lighting is required to achieve LEED IEQ credit 6.1 Controllability of Systems - Lighting in the 2009 LEED Reference Guide for Interior Design and Construction, general light levels in the studied office were typically high enough to achieve the recommended 30-50 fc range on a work surface without supplemental light (ANSI, GSA, OSHA). The team hypothesizes that initial costs may be reduced by only offering to make task lights available as they are requested. Savings realized from reduced need for task lighting could then be invested towards occupants in other ways, such as for additional ergonomic products or automated shades. This offers a holistic sustainable approach to lighting rather than a design driven by LEED requirements and credit accrual.

3.2 Messaging Observations

The team found that some occupants did respond positively to messaging related to the testing. A concise email was found to be the most effective means of conveying the testing and any action required by the occupants. However, the team also observed that certain tests and messaging protocol were alarming to some occupants. The team hypothesizes that this was partially due to the fact that the messaging was relating to “tests” rather than describing how an integrated system and conservation strategy work. For future testing, the team recommends concise email as messaging method and to forgo alternate strategies described in previous sections.

3.3 Testing Summaries

3.3.1 Task Tuning

The observations and data resulting from this testing period suggest that in offices with ambient daylight and electric lighting such as the Perkins+Will Washington DC office, a possible reduction in electric lighting of up to 50 percent is achievable. Task tuning is relative to the existing lighting conditions of a space, but is recognized in this study as a highly effective means to reduce lighting loads without negatively impacting employee comfort.

3.3.2 Load Shedding

Load shedding is an effective means of recognizing and immediately responding to issues of peak energy demand during certain times of the day. The challenge of this test was to find areas suitable for shedding lighting loads in an open office. In analyzing the findings from this lighting test, the team found that in order to minimize disruptions caused by switching off lights during hours of peak energy use, load shedding should be confined to secondary, support spaces (not areas of primary work). The team hypothesizes if additional testing were to be conducted, gradual load shedding or dimming may be a more effective means of reaching a similar goal.

3.3.3. Daylight Harvesting

After recording the overall footcandles at different depths of the office and observing the amount of natural daylight entering the space, this report challenges the fifteen-foot distance from the perimeter to control light fixtures through daylight harvesting (USGBC). Rather, the team proposes that through a thorough analysis of a building’s orientation, design strategies can be implemented in coordination with efficient lighting design to increase the distance in which daylight may serve as an effective light source within an office.

3.4 Comprehensive Office Strategies

When working to reduce energy consumption of lighting systems in an office environment, it is necessary to maintain adequate lighting conditions that support the work activity. This article determined that the most effective means of achieving this relationship is through a collaborative combination of task tuning, load shedding, and daylight harvesting (Figure 14).

While task tuning provides an opportunity to balance the needs of work and reducing energy demand, load shedding recognizes the real-time element of energy consumption by responding during peak demand. Therefore, the team encourages combining shedding lighting loads from the overhead lighting with task tuning to establish the minimum lighting level required. To reduce the distraction of suddenly dimmed lights in the open workstation environment, load shedding could act as progressive dimming to lower light levels to 50 percent as suggested by task tuning results.

If a 50 percent reduction is to be implemented at all times, it would not be beneficial to use a load shedding strategy in addition; rather task tuning should be used independently.

Maximizing daylight harvesting through light sensors, however, is recommended in combination with either of the previous strategies.

As a collective system, these three lighting strategies can be combined to not only reduce electrical demand, but also create well-lit working environments with less environmental impacts to the occupants.

3.5 Further Testing

After analysis of the results from the three tests, the team identified a number of recommended adjustments to each test that would help to either refine the data or expand the scope of the test to incorporate additional technologies. It was felt that all three tests should be repeated in additional seasons to determine if the results were consistent throughout the year. It was hypothesized that occupants may react differently during shorter daylight hours, particularly in winter.

For task tuning, the team felt any further tests should attempt to capture occupant feedback on the light levels in real time. While the occupant survey at the end of the test was helpful in understanding general impressions over the testing period, it was impossible to pinpoint exact moments of occupant discomfort in relation to specific footcandle levels. While general light levels decreased over the testing period there were significant variations in weather patterns, resulting in fluctuations in the actual number of footcandles in the studio at any given time. It was hypothesized that real time feedback on occupant comfort would allow the team to pinpoint exactly when footcandles dropped below a tolerable level.

For load shedding, the team felt that any further tests should incorporate dimming, rather than simply turning the lights on and off. The survey results indicated that occupants found lights turning on and off in the middle of business hours to be a distraction, rendering the strategy of limited use in an open office environment. It was hypothesized that a gradual dimming of the lights to partial capacity during peak hours would still realize energy savings without disrupting occupant productivity. It was also noted that since lighting is such a small percentage of energy used in the space there may be other loads that could be reduced or eliminated during peak demand, such as mechanical equipment variations.

For daylight harvesting, the team felt any further tests should add additional positions for the manual roller shades aside from completely rolled up and 50 percent down. It was observed that a 50 percent deployment of the shades was often lower than required to simply reduce glare at the workstations along the perimeter. It was hypothesized that adding additional increments to the shade positions in the study would allow the shades to effectively reduce glare while optimizing the amount of daylight penetrating into the studio. The team also felt that implementation of a light shelf would help to reflect light while acting to eliminate glare along portions of the exterior.

3.6 Future Product Development

While analyzing the test results and variables it became apparent that the more intelligent the system, its capacity to adapt to changes in the surrounding environment also increases. The team observed throughout all three tests, occupants lowered the perimeter shades all the way down early in the morning to block glare from direct sun. This condition typically resolved itself no later than 9:00 AM as the sun's elevation in the sky increased. However, the solar shades remained down for the remainder of the day unless purposely altered by a member of the testing team. Motorized shades with solar tracking software would naturally alleviate this condition. It was hypothesized that if integrated with Encelium, the two systems would be capable of responding in harmony to the changing external environment, effectively eliminating many of the variables that were observed to hinder maximum energy savings during the tests.

The team also observed that the capability to monitor light levels at the work surface was an important factor in assessing occupant comfort. Encelium currently has the capacity to respond to daylight sensors, but the test results showed that these devices had only a limited connection to the amount of light landing on the work surface and only on those within fifteen feet of the building perimeter. While industry standard decrees that fifteen feet is the typical measurement that daylight effectively penetrates into a floor plate, the test results showed that the physical characteristics of this office allowed daylight to affect a much larger portion of the floor[7]. Additionally, shared light from corridors impacted the footcandles at adjacent work surfaces. It was hypothesized that if the lighting control system had the ability to read the footcandles at each individual work surface and dim the overhead lights accordingly, maximum energy savings would be achieved with relatively little impact to occupant comfort or productivity. The team is currently unaware if such a system exists and has identified it as a potential opportunity for product development with systems furniture and lighting control manufacturers.

Acknowledgements
The authors would like to recognize Anton Villacorta and Cheryl Moy for their contributions to the original study, and thank Chad Hampton and Monica West for assistance in collection of staff comfort complaints.

REFERENCES
[1] Encelium, (2012). “Energy Management Strategies”, Report, Retrieved on 9/2012 from http://www.encelium.com/en/ems/six-strategies.html.

[2] ANSI, (2004). American National Standard Practice for Office Lighting, New York, NY: Illuminating Engineers Society of North America.

[3] U.S. General Services Administration, (2003). 2003 Facilities Standards (P100), “6.15 Lighting”, Report, Retrieved on 9/2012 from http://www.gsa.gov/portal/content/101308.

[4] U.S. Department of Labor Occupational Health & Safety Administration (OSHA), (2012). “Occupational Health and Environmental Controls Guidelines”, 1926.56(a) table D-3 “Minimum Illumination Intensities in Footcandles”, Table, Retrieved on 9/2012 from http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=10630.

[5] Virtual Medical Centre, (2012). “Office Ergonomics: Preventing Eye Strain”, Retrieved on 9/2012 from http://www.virtualmedicalcentre.com/healthandlifestyle/office-ergonomics-preventing-eye-strain/142.

[6] Lutron, (2012). “Lutron Energy Savings Calculator”, Report, Retrieved on 9/2012 from http://www.lutron.com/Education-Training/Tools/Pages/EnergySavingCalc.aspx.

[7] U.S. Green Building Council, (2009). LEED Reference Guide for Green Interior Design and Construction, “Optimize Energy Performance - Lighting Controls”.