Public Interest Energy Research (PIER) Program

FINAL PROJECT REPORT

DEVELOPMENT AND EVALUATION OF A NEW BUILDING INFRASTRUCTURE TO SUPPORT INNOVATION IN SOLID-STATE LIGHTING

Prepared for: California Energy Commission

Prepared by: Lighting Research Center, Rensselaer Polytechnic Institute

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PREFACE

The California Energy Commission Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

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- Transportation

Development and Evaluation of a New Building Infrastructure to Support Innovation in Solid-State Lighting is the final report for the project of the same name (contract number PIR-08-015) conducted by Lighting Research Center, Rensselaer Polytechnic Institute. The information from this project contributes to PIER's Building End-Use Energy Efficiency Program.

For more information about the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-327-1551.

ABSTRACT

The Lighting Research Center collaborated with Osram Sylvania, Inc. to integrate and demonstrate the use of a novel interior, direct current lighting system using plug-and-play ceiling and wall tiles with built-in light-emitting diodes. The demonstration occurred in a conference room at Paramount Pictures in Hollywood, California.

This field demonstration improved on the prototype initially created in 2004 and demonstrated in the laboratory in 2005 by the Lighting Research Center. This demonstration system consisted of light-emitting diode-lighted tiles that "snap" in and out of a direct current electrical grid built in Paramount's conference room. The demonstration included general ambient white and colored lighting, accent lighting, and back lighting to serve the conference room's activities. The direct current electrical grid in the ceiling is a commercial product; the direct current electrical grid in the wall section, however, is a modified commercial product that was originally designed for shelf lighting. Working with several vendors, the Lighting Research Center adapted commercial wall tiles with and without built-in lighting systems and collaborated with Osram Sylvania, Inc. to identify suitable equipment to power and control the lighting. The lighting systems were mounted on to the electrified grid. Electrical, thermal, and mechanical analyses in the laboratory were conducted on this system.

The demonstration shows promising opportunities for greater energy savings compared to current state-of-the art lighting technologies while satisfying occupant's lighting needs. Saving 50 percent of the energy without sacrificing light levels and occupant satisfaction is feasible even with today's light-emitting diode technology. Efficacy of the white light-emitting diodes used in this demonstration was 85 lumens per watt. Savings are expected to be greater than 2 times higher by 2020 when light-emitting diodes reach 200 lumens per watt. Additionally, this infrastructure allows for easy upgrade of lighting as the solid state lighting systems improve over time.

Keywords: direct current, infrastructure, lighting, LED, tiles, ASSIST, light-emitting diode, solid state lighting

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EXECUTIVE SUMMARY

Purpose

The purpose of this project was to further field test a new building infrastructure system that allows easy incorporation and reconfiguration of solid-state lighting to reduce lighting energy use and improve the effectiveness and comfort of interior lighting in commercial buildings. Such an evaluation would help to enable further development of the concept of a direct current building infrastructure.

Project Objectives

The overall objectives of this demonstration were to evaluate three real-world criteria—energy savings, occupant acceptance, and installation process—of a low-voltage direct current infrastructure grid to power movable light-emitting diode-lighted tiles. The following were the specific project objectives:

- The new building infrastructure system can be retrofitted into a variety of existing building infrastructure types and be used in new construction.
- By appropriately incorporating conductive materials into ceiling and wall components, heat from LED sources will be effectively dissipated.
- By using different types of tile materials and tiles of various sizes, the new building infrastructure system will be able to conform to edges and curved surfaces within buildings and interior spaces of various sizes and shapes, thus making the new infrastructure easily retrofitable.
- Using a variety of methods (i.e., textured surfaces, non-linear edges) to join tiles to the infrastructure, walls and ceiling components will integrate easily into a variety of building interior styles and designs.
- "Given projected efficacies for solid-state lighting of 150 lumens per watt by 2010, the new infrastructure system and associated lighting will reduce lighting energy use in existing buildings by up to 50% compared to current state-of-the-art lighting technologies. It will also improve lighting quality and occupants' opinions of the lighting in spaces in which the system is installed.
- Building occupants will be able to interchange ceiling and wall 'tiles' within the infrastructure in less than one minute, including a reconfiguration of controlled locations.
- The system will allow for the simple integration of lighting controls including occupancy sensors, dimmers, and daylight harvesting controls.

Project Outcomes

The Lighting Research Center collaborated with Osram Sylvania, Inc. in the manufacture of the equipment installed at the selected demonstration site, a conference room located on the Hollywood campus of Paramount Pictures. The Lighting Research Center, after surveying the demonstration site and interviewing the people using the space, developed lighting renderings to guide the design of the new building infrastructure and light-emitting diode-lighted tiles.

The system was designed to provide the multiple layers of lighting that are needed for conference rooms (Figure 1). The light-emitting diode luminaires built into the tiles included downlights and diffuse lights (or "cloud") for general lighting, linear up-lighting, linear sidelights for creating colored halo on the ceiling, linear accent lights for wall washing and lighting a whiteboard and a television set niche, and back lights for lighting transparent posters.

In this demonstration, the ceiling section is composed of a commercial electrified direct current electrical grid designed for drop ceiling applications and modified commercial metal tiles. Osram Sylvania, Inc. modified some of the metal ceiling tiles to include built-in light-emitting diode luminaires and controls designed and built by their engineering team. Each luminaire was controlled individually with wireless controllers that were powered by the action of pushing the switch (piezoelectric), thus not requiring batteries or wiring. All lighted tiles of similar type were designed to be controlled together by a single switch, regardless of their position on the grid. Programmable dimmers were mounted on the wall at familiar positions, as well as on a moveable console.

A commercial electrified direct current grid designed for shelf lighting applications was modified to hold and power the wall tiles. Custom-designed mounting brackets were built into the modified commercial metal tiles for the wall system. The direct current grid, mounting system, and wall tiles with lighting were integrated by the Lighting Research Center.

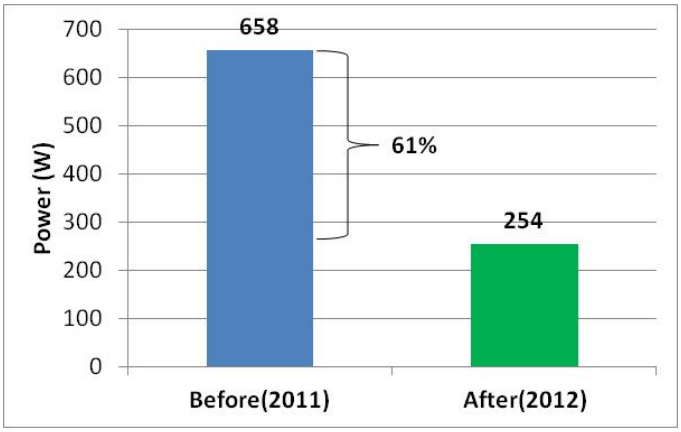
Engineering staff from Osram Sylvania, Inc. and the Lighting Research Center supported the Paramount staff during installation of the new prototype lighting infrastructure in December 2011.The lighting in the conference room before and after installing the new infrastructure are shown in Figure 1.

Figure 1: Before (left) and After (right) Conditions

Prior to the removal of the original lighting system and the installation of the new lighting infrastructure, the Lighting Research Center evaluated power demand with the original lighting system, documented light level and distribution, and surveyed occupants' opinions regarding the lighting. The evaluations conducted with "Before" conditions were compared with the "After" conditions to understand the performance of the new lighting infrastructure.

Power Demand Comparison: Comparing the average power demand in the conference room, the "After" condition uses far less power (61 percent lower) than the "Before" condition during the period when lights were turned on in the conference room (Figure 2). However, the new direct current infrastructure showed 14 percent energy savings with 2011 light-emitting diode products due to parasitic loads associated with the direct current power supply and wireless devices that continue to operate when the conference room was unoccupied. Savings are estimated to increase to 60 percent once timer controls are implemented on these parasitic loads when the room is vacant.

Figure 2: Average Power Demand for Before and After Conditions During the Period Lights Were on in the Conference Room

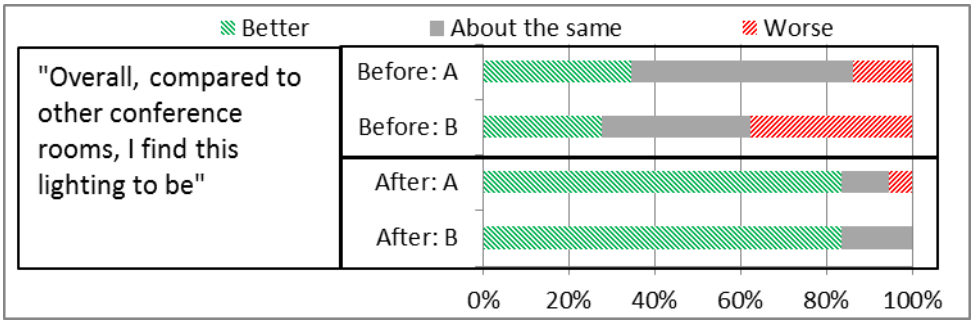


Occupant Feedback: Occupants answered questionnaires about the conference room lighting for the "Before" and "After" conditions. In both cases, the occupants were presented with two

lighting conditions, A and B, where condition A is suitable for general lighting and condition B is suitable for slide presentations. The same questions were asked in each case.

As shown in Figure 3, overall, 83 percent of respondents thought the "After" condition lighting was better than other conference room lighting they experienced for both conditions. However, in comparison, only 34 percent and 28 percent, thought the "Before" condition lighting was better than other conference room lighting for the two conditions.

Figure 3: Occupant Survey Results



Room lighting reconfiguration: One of the key features of this new lighting infrastructure is that it is easy for the room's occupants to reconfigure room lighting by moving the snap-in and -out tiles on the grid, without requiring an electrician. Figure 4 shows Lighting Research Center staff moving wall tiles to rearrange the lighting. However, codes and standards required by the State of California for earthquake stabilization were met by securing each tile. As a result the ease of configuring the room lighting was not studied. In future developments, it will be important to address the need for earthquake stabilization while still maintaining the occupant's ability to move tiles easily without hiring a professional electrician.

Figure 4: LRC Researchers Moving Wall Tiles to Rearrange the Lighting

Overall, the demonstration showed promising opportunities for greater energy savings while satisfying occupants' lighting needs with the use of a direct current, plug-and-play

infrastructure in buildings with solid–state lighting. Energy savings of over 50 percent are possible with today's light-emitting diode technology and occupancy controls. This can be done without sacrificing light levels and occupant satisfaction. Today's light-emitting diode technology provides 85 lumens per watt. Lumens per watt is a measure of the amount of light produced for each watt of electricity consumed. Savings are expected to be greater than 2 times higher by 2020 when light-emitting diodes reach 200 lumens per watt. Additionally, users will find greater benefit with an infrastructure that allows easy rearrangement of lighting and upgrade of lighting as the solid state lighting systems improve in performance over time.

Recommendations

Lighting Research Center recommends that manufacturers pursuing a strategy of solid state infrastructure address concerns about energy use when the luminaires are turned off. Future development needs to address better controls strategy for the powered tiles with less power demand. An option is to use energy harvesting products that don't require external power. Another option is to reduce the number of transceivers by group controlling tiles with similar functions. In the future, other power supplies with negligible quiescent power need to be investigated or developed. Alternatively, it would be valuable to implement a method to turn off power supplies when the room is not in use.

Benefits to California

According to the California Commercial End-Use Survey, lighting constitutes about 35 percent of a commercial buildings electricity use. Reducing lighting energy usage in commercial buildings would lower electricity costs for businesses. Additionally, reductions in lighting energy use reduces statewide greenhouse gas emissions and helps California meet lighting energy reduction goals of 60-80 percent by 2020 as stated in the California Energy Efficiency Strategic Plan.

CHAPTER 1: Introduction

1.1: Background

Current building construction processes do not allow for effective, energy-efficient lighting practice over the life of the building. The placement of lighting is decided very early in the construction or renovation process, long before interior design plans are finalized. Once the luminaire locations are fixed and built in, it is difficult and expensive to move or upgrade new energy-efficient luminaires as the needs of occupants change.

Solid-state lighting, particularly light-emitting diode (LED), offers good opportunities for architectural lighting. LED is a rapidly advancing light source technology that can be successfully used today in a number of lighting applications, where it shows greater energy efficiency, longer life, and better lighting quality.

Each year, many new LED lighting products enter the market. Although manufacturing one-for-one replacement lamps allows for an easy transition to LED lighting, it is not the ideal scenario for realizing the full potential of LED lighting. Placing LED replacement lamps into existing luminaires has drawbacks, most notably the likelihood for heat buildup inside the lamp because the existing luminaire was not designed to conduct the heat away. Heat can reduce the lamp's efficiency and shorten its life, negating the whole purpose for the replacement. Therefore, realizing the potential of LED and solid-state lighting requires looking beyond replacements for existing sockets and traditional, discrete luminaires that serve as add-ons to a space. The entire concept of the interior building infrastructure must change, and the benefits of this new building infrastructure must be fully apparent.

1.2 Concept and Prototyping History

For their operation, LEDs require an electronic driver to transform alternating current (AC) power into direct current (DC) power. Many other electronic devices, such as flat screen TVs, wireless speakers, laptop computers, and sensors, also require this AC to DC conversion. When each low power device performs this conversion, the conversion efficiency is low. One possible way to make power conversion of multiple low power devices more efficient is to have it performed by a converter in a central location, which would then distribute DC power to all devices through a building's infrastructure.

In 2004, the Lighting Research Center (LRC) initially developed the concept of using centralized DC power to create a new interior building infrastructure for LED lighting and other electronic devices.[1,2] LRC developed prototypes on behalf of a consortium of sponsors, the Alliance for

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[1] "ASSIST group develops snap-in scheme for LED lighting." *LEDs Magazine* Dec. 15, 2005. Internet: http://ledsmagazine.com/news/2/12/20. And. *Electronic walls and ceilings offer adaptable solid-state lighting*. Lighting Research Center website, SSL program. Internet: http://www.lrc.rpi.edu/programs/solidstate/or_adaptableSSL.asp.

Solid-State Illumination Systems and Technologies (ASSIST), which then provided seed money for a small room demonstration of the concept. A full-scale mockup was built at the LRC's laboratories in 2005. This mockup featured a ceiling and walls consisting of thin LED-lighted panels ("future tiles") that could snap in and out of a DC modular electrical grid and provide different lighting distributions, including general, task, accent, and decorative. The lighted tiles could be rearranged simply and rapidly by the occupant to cater to changing room layouts or personal preference, without the need to hire an electrician to move lighting and without being tethered to the fixed locations of wall sockets for portable lighting (Fig. 5).

Figure 5: 2005 Concept Demonstration at the Lighting Research Center of a DC Interior Building Infrastructure for LED Lighting with "Snap in" Modular Lighted Tiles

While a full-scale mockup in a laboratory was informative, it could not provide real-world data about energy savings, occupant acceptance, and installer feedback. The next step was to develop a real-world demonstration, along with a more refined aesthetic appearance. In 2009, several industrial partners agreed to collaborate with the LRC on such a demonstration at Paramount's Hollywood campus.

1.3: Project Goals and Objectives

The goal of this project was to further develop and field test a new prototype lighting infrastructure system that allows easy incorporation and reconfiguration of solid-state lighting to reduce lighting energy use by up to 50 percent and improve the effectiveness and comfort of interior lighting in commercial buildings.

The overall objectives of this demonstration were to evaluate three real-world criteria—energy savings, occupant acceptance, and installation process—of a low-voltage DC infrastructure grid to power moveable LED-lighted tiles providing several layers of light. Such an evaluation would enable further development of the concept of a DC building infrastructure.

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[2] *Electronic walls and ceilings offer adaptable solid-state lighting.* Lighting Research Center website, SSL program. Internet: http://www.lrc.rpi.edu/programs/solidstate/or_adaptableSSL.asp.

Objectives:

- The new building infrastructure system can be retrofitted into a variety of existing building infrastructure types and be used in new construction.
- By appropriately incorporating conductive materials into ceiling and wall components, heat from LED sources will be effectively dissipated.
- By using different types of tile materials and tiles of various sizes, the new building infrastructure system will be able to conform to edges and curved surfaces within buildings and interior spaces of various sizes and shapes, thus making the new infrastructure easily retrofitable.
- Using a variety of methods (i.e., textured surfaces, non-linear edges) to join tiles to the infrastructure, walls and ceiling components will integrate easily into a variety of building interior styles and designs.
- The new infrastructure system and associated lighting will reduce lighting energy use in existing buildings by up to 50% compared to current state-of-the-art lighting technologies. It will also improve lighting quality and occupants' opinions of the lighting in spaces in which the system is installed.
- Building occupants will be able to interchange ceiling and wall "tiles" within the infrastructure in less than one minute, including a reconfiguration of controlled locations.
- The system will allow for the simple integration of lighting controls including occupancy sensors, dimmers, and daylight harvesting controls.

To address these objectives, the following tasks were established:

- Task 1: Administer project tasks
- Task 2: Visit site, develop lighting design, discuss with manufacturing collaborators
- Task 3: Develop prototypes of building infrastructure and solid state lighting equipment
- Task 4: Install at field evaluation site
- Task 5: Conduct field evaluation
- Task 6: Disseminate project results; manufacturing partner develops product commercialization plan

CHAPTER 2
Task 2: Visit Site, Develop Lighting Design, Discuss with Manufacturing Collaborators

In September 2009, a meeting was held at the Paramount campus in Hollywood, California. Four potential sites were considered. Attendees included LRC, Osram Sylvania Inc. (OSI), Paramount contacts, and Los Angeles Department of Building and Safety.

In October 2009, a kickoff meeting was held between LRC and California Energy Commission (Energy Commission) on contract Task 1.1 in which the results of the initial site visit were presented.

In January 2010, LRC and research collaborators met to discuss the merits of the four potential demonstration sites and establish a collaborative work flow. The site that was selected was expected to be the most promising for several reasons. The room has a neutral architectural character that is applicable to most other commercial sites. The room is large enough to enable demonstration of diverse lighting effects but small enough that the material was expected to be provided within budget. The walls in the site provided ample mounting space, as opposed to other sites with extensive glazing. The site was expected to have many, intermittent users who could offer their feedback.

For these reasons, the team selected a conference room located in the Gene Roddenberry office building as the demonstration site. The conference room is approximately 436 sq. ft. (Figure 6 below). The focus of the room is a flat screen television and a motorized wall-to-wall projection screen, both located on the north end of the room. A whiteboard is located on the west side. Movie posters are displayed on the east side of the room; these are not merely decorative, but rather represent the entertainment product being marketed by the occupants of this office. There is no daylight penetration; thus, all illumination is electric.

Conference rooms require flexible lighting; rooms are used for audio/visual presentations, face-to-face meetings, and even festive celebrations. These uses have different lighting needs. For audio/visual presentations, typically a separately-controlled lighting layer is needed to enable lower ambient lighting with task lighting on the table for note-taking. It is important that lighting for audio/visual presentations limit light from shining on the display (e.g., flat screen television or projector screen). For other types of meetings a general lighting mode is needed to enable occupants to see each others' faces, to read writing on whiteboards or flip charts, and to make the room look pleasant. Some conference rooms display artwork or examples of their work for visiting clients. Therefore, at least two "layers" of light, general ambient and task accent, are typically needed in a conference room, controlled separately.

The original room lighting in the Roddenberry conference consisted of two layers of light. General lighting was provided by linear fluorescent (T8) pendant uplights with fluorescent dimming ballasts (640 watts total). Recessed incandescent downlights and halogen track lights

(528 watts total) were controlled separately. Switches were provided at the entrances, of which one was a dimmer.

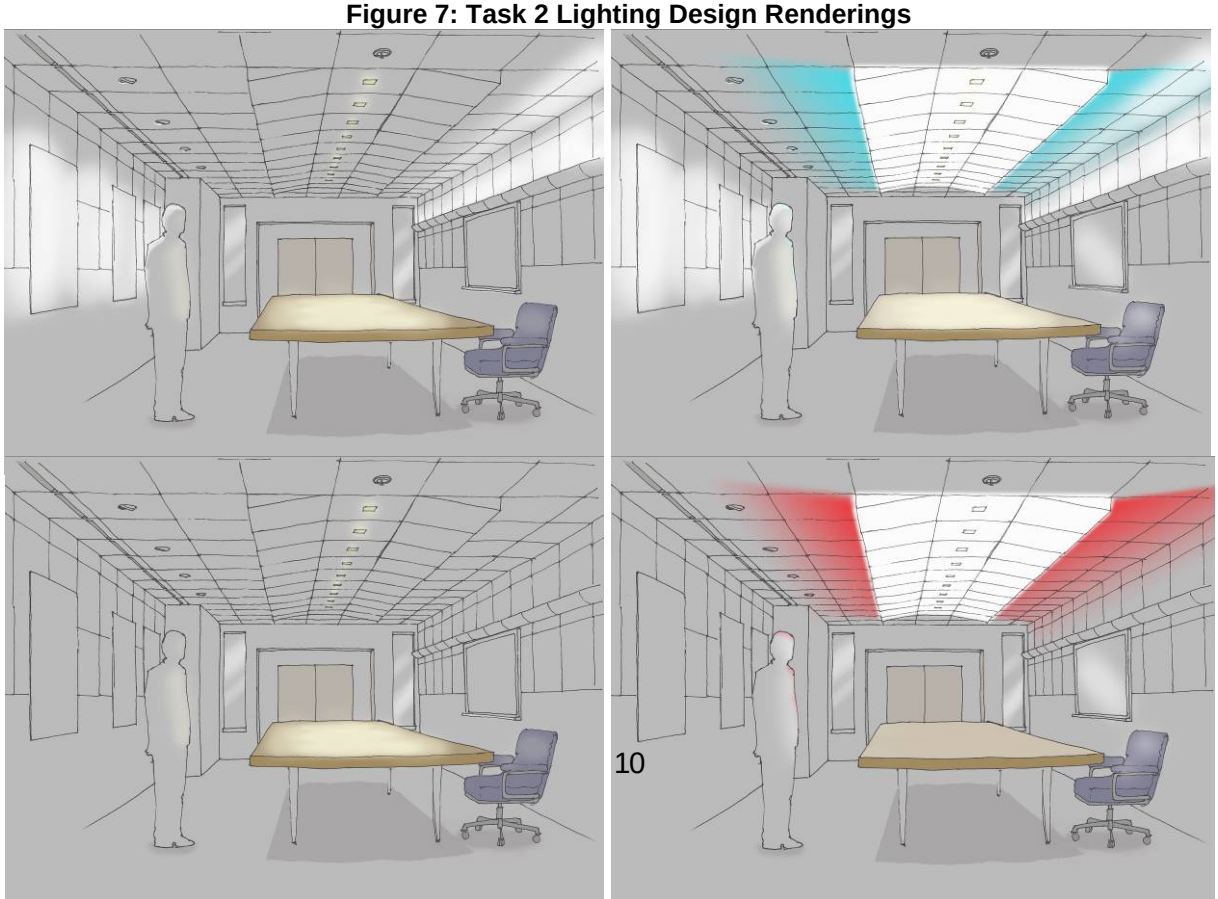
Figure 6: Lighting Conditions Before Demonstration

Fluorescent pendants (turned on in left photo) and incandescent down lights and track heads (turned on in right photo)

LRC developed lighting designs and renderings to guide the development of the new building lighting infrastructure demonstration (Figure 7).

While the distribution of the light is different from the original lighting, the purpose of the lighting is same; to provide several layers of light to accommodate the multiple functions in a conference room. It was necessary to accommodate the geometric structure and the position of the lighted tiles, so the new tiles have different shape than the original luminaires and are aimed in different directions.

Figure 7: Task 2 Lighting Design Renderings



CHAPTER 3
Task 3: Develop Prototypes of Building Infrastructure and Solid-state Lighting Equipment

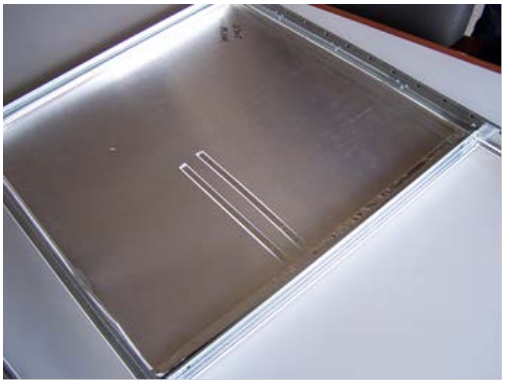
3.1 Prototype System Development

The LRC collaborated closely with OSI in the integration of the components installed at the demonstration site. The system has ceiling and walls made up of 2′x2′ tiles of which some tiles had built-in LED luminaires. These tiles snap in and out of a DC modular electrical grid. The team took advantage of commercially available building materials including standardized commercial 2′x2′ metal ceiling tiles.

3.1.1 Ceiling Grid System

LRC considered a ceiling grid similar to a typical suspended ceiling system with T-bars and tiles. The main objective is to transport DC power to the tiles anywhere on the grid. Several options were investigated, including, metal ribbons on the grid and tiles to conduct DC power (Figure 8) to the LEDs built into the tile. This strategy was not selected, mainly due to unreliable connectivity. This solution relied on gravity to maintain proper contact between the tiles and the grid for power, so vibration could cause lights to flicker. Alternatively, if the tiles were firmly attached to the grid the ease of moving the tiles from one location to another is lost. Another issue was limits in current carrying capacity by the metal tapes. Finally the team chose to work with a commercial DC power distribution grid and connectors for the ceiling section. Here, each lighted tile uses a commercial clip-type plug to access the power in the DC grid.

Figure 8: Metal Ribbon in the Back of a Metal Tile



By using standard 2′x2′ modular ceiling tiles, the system can accommodate conventional heating, ventilating, and air conditioning (HVAC) diffusers. The dropped ceiling system conceals ducts, wires, and other building infrastructure to provide a clean, cohesive appearance when viewed from the bottom. Non-lighted locations of the ceiling had acoustic tiles. Notches and other diverse architectural conditions on the periphery of the room were accommodated by using modified partial tiles. While curves were not intrinsic to this site, curves could have been accommodated with acoustic tile in fills. Sprinkler heads are accommodated by field cutting holes into the acoustic tiles. Filling in the non-lighted portions of the grid with acoustic tiles also

makes for good acoustic conditions as it minimizes reverberation. The objectives of this study concerning accommodation of typical room geometries new and retrofit were met.

3.1.2 Wall Grid System

While the project objectives stated that the wall and ceiling tiles should be interchangeable, in practice there was no commercial DC powered wall grid system that can accommodate the same tiles. It was not possible to use the same grid system used in the ceiling, because the tiles rested on the T-bars and made contact due to gravity. Therefore, LRC investigated other options to integrate a wall grid system to reliably mount tiles on the wall, in a manner that ensures proper power connection, can be easily moved, and would maintain a cohesive room appearance.

The concept that LRC adopted was a solution that uses a sturdy shelf hook and a power feed (Figure 9). This early prototype showed the feasibility of the moveable tile concept. Subsequently, LRC identified a commercial shelf lighting product with the required functionalities (Figure 10). In this product the wall brackets carry DC power, which travels through metal mounting hooks to lighted shelving. This product has been available in the industry for several years. LRC worked with this shelf lighting manufacturer to modify the shelf brackets such that they can be mounted to the 2′x2′ metal tile that was selected for the ceiling section. Using these modified brackets the 2′ x 2′ metal tiles were securely hung on the vertical DC power grid. Once a successful wall grid and mounting scheme was developed, LRC designed a customized frame and hook for the 2′x2′ metal tiles. The shelf lighting manufacturer custom manufactured the brackets based on the design and technical drawings supplied by LRC. The custom hooks (Figure 12) allowed the power connectivity to the LEDs mounted to the tiles. LRC mounted linear LED lights provided by OSI to the top of wedged shaped tiles to provide uplighting. The metal tiles matched those used in lighted ceiling tiles to create a cohesive appearance.

Figure 9: Wall Tile Prototype, with Conventional Shelf Hooks, and Separate Power Distribution

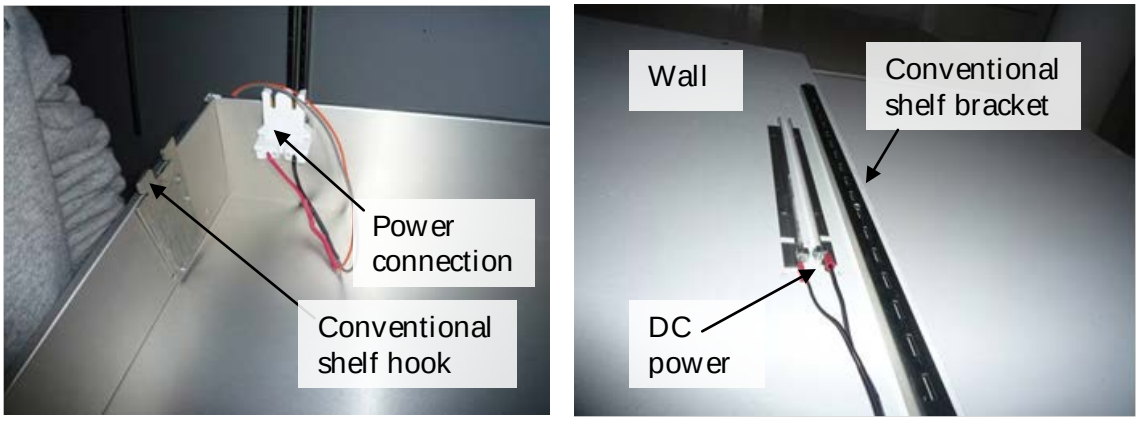
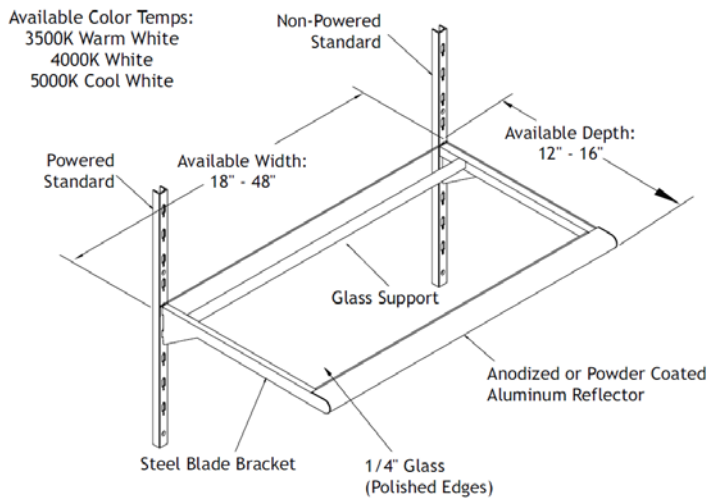


Figure 10: A Commercially Available Shelf Lighting Product



Source: Courtesy of Stylmark, Inc.

Figure 11: Final Prototypes for Flat Tile

Non-illuminated on the left and illuminated wedge tile (Type C) on the right.

Figure 12: Cut and Welded Bracket in the Back of a Wedge Tile

The uplight tiles (wedge shaped) have a square steel frame that not only prevents the thin metal skin from warping, but also allows for power feed and sturdy mounting of LEDs, wireless controls, and other equipment (Figure 11). LRC fastened the mounting brackets to the modified metal tiles (Figure 11). As shown in Figure 12, powered tiles have a special hook on one side of the tile. The hook provided a robust power connection to the power grid. However, the shape of the hook created the need for space above and below the tiles. To fill these spaces between flat, unpowered tiles and wedge shaped uplight tiles (Figure 11), an additional piece of trim was developed. This trim also helped to standardize the distance between the pairs of mounting

standards. It was important that brackets be spaced at an exact distance (Figure 13) so that the wall tiles can be repositioned.

LRC ordered several modified metal tiles from USG Corporation. Modifications included specific window apertures on the wedged shaped tiles for light emission, and removal of flanges to enable integration with wall mounting hardware.

Figure 13: Mounting Hardware (Left), Conducting Hook (Center), and Finished Uplight (Right)

3.1.2 LED Tiles

Following the lighting designs and the specifications in Task 2, OSI engineers designed and installed LEDs into the metal tiles. The ceiling section used two types of tiles, flat and wedge shaped. In addition, OSI integrated the lighting controls.

Figure 14 shows the final lighting plan that LRC developed for the demonstration room. Table 1 describes each of the prototype LED tiles. Six types of lighted tiles were created, providing up to nine layers of light. These layers can be controlled separately; for example, all the type C uplight tiles are programmed to be controlled together with a press of a button. In keeping with the project objectives, if the type C uplights were to be moved to another location on the wall, it would remain controlled by the same dimmer switch. Likewise, type A and type B tiles that provide a diffuse "cloud" lighting are programmed to operate on a single switch. However, Type A tiles have directional downlights, operated by a separate switch.

Most tiles provide white light, but the Type B wedge-shaped tiles also provide colored light (by mixing red, green, and blue LEDs). Type B tiles project below the ceiling plane to allow colorful light grazing of the textured acoustic ceiling tiles.

Figure 14: Plan View of Lighting Demonstration

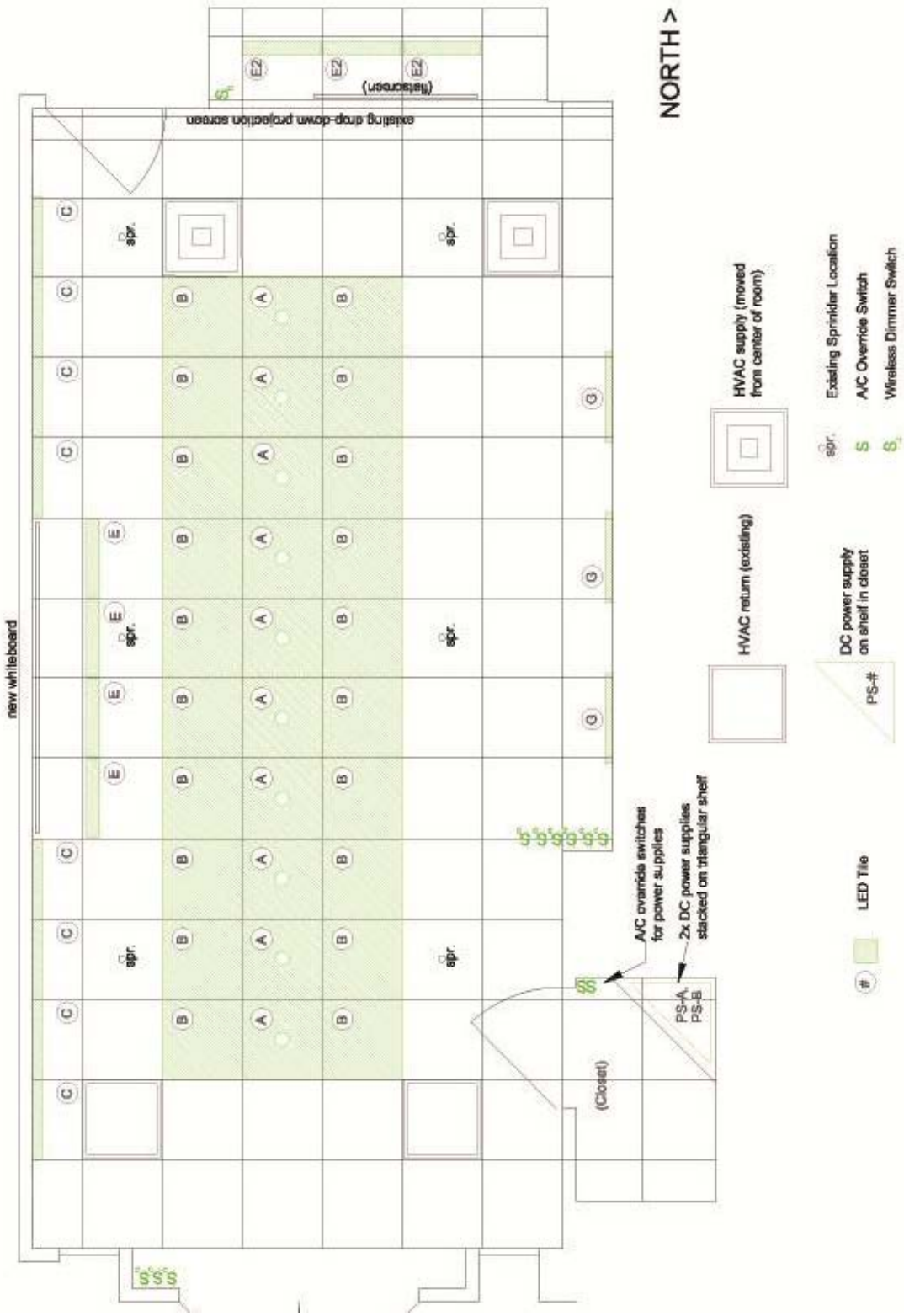
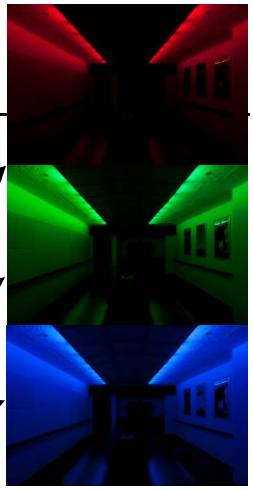


Table 1: Lighting Equipment Schedule

Type	Description		Power Per Tile (W)	Quantity Installed	Reference Thumbnail
A	Two, separately controlled light sources	Downlight: White LED downlight	13 W	10	
		Cloud: White LED cloud, with sandblasted clear acrylic 2x2 lens	6 W		
B	Two separately controlled light sources	Cloud (matching Type A)	7 W	20	
		Halo: Red, Green, Blue halo effect, in outer edge of sloped ceiling tile	Red:3W Grn:5W Blue:4W		
C	Wall sconce uplight, mounted in sloped metal tile, mounted to modified powered shelf-mounting grid.		16 W	8	
E	Wall wash task light for whiteboard. Frosted acrylic diffuser, 2" wide x 2' long.		17 W	4	
E2	Same housing Type E; mounted in TV niche for subtle wash. White LEDs with temporary blue theatrical filter gel.		8 W	3	
G	Commercially available, self-luminous poster frame, modified for compatibility with DC demonstration. 27" x 41"		35 W	3	

3.1.3 Thermal Considerations for the Light Sources

The performance of LED sources is affected by heat and therefore proper thermal management is very important for reliable long term performance. Operating the LEDs at lower temperature maintains higher light output and life, and also reduces heat stress to other components in the system.

The temperature at the LED junction was kept low by keeping the wattage of the luminaires in each metal tile low and by mounting the luminaires to the metal infrastructure. The circular downlight module also uses a finned heat sink to remove heat. The strip-type LEDs are fastened to thick metal plates or thick steel housings.

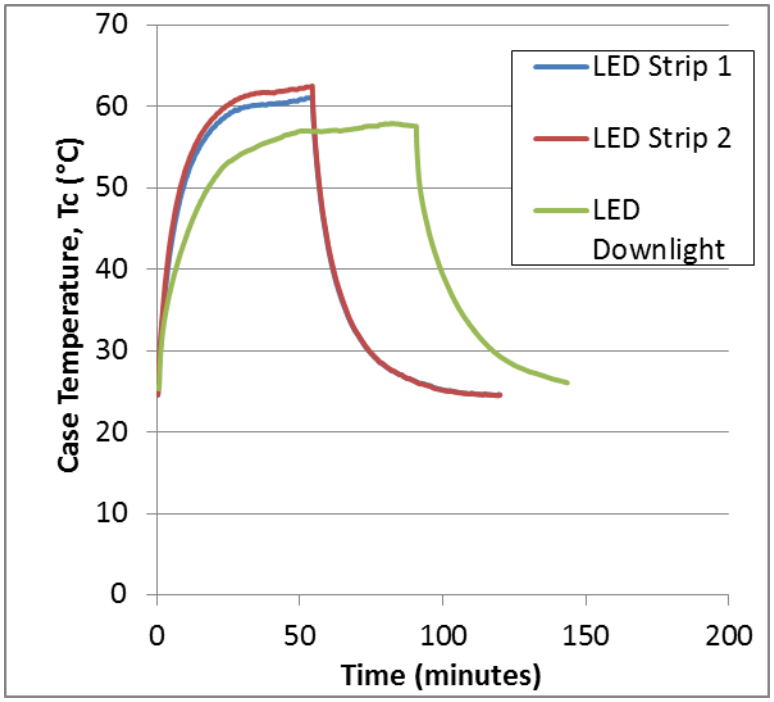
LRC tested three LED samples used in this demonstration to simulate the actual operating conditions (Figures 15-16). The manufacturer's data sheet recommends keeping the LED case temperature (Tc) below 90°C to maintain warranty (5 years, 50,000 hours). LRC confirmed that the Tc stabilized at 61°C for the strip-type LEDs and 58°C for the downlight modules (see Figure 17). Based on these results, the LEDs were expected to perform well at the demonstration site.

Figure 15: Thermal Testing of Strip Type LED Module

Figure 16: Thermal Testing of Downlight Module Used in Type A Tile

(Lens enclosure removed for inset photo)

Figure 17: Temperature Profile of LED Samples



3.1.4 Power Supply Considerations

A commercially-available DC power supply was selected based on several criteria. LRC and OSI chose to work with low voltage (24V) to support the project goals of being able to move the LED tiles without an electrician. Use of low voltage is also consistent with previous LRC demonstrations and other industry DC efforts.

In addition to 24V DC output, it was important that the power supply be a standard, commercially-available product, and Underwriters' Laboratory (UL)-rated, with a warranty. A power supply was identified that met these criteria[3].

The power supply that was selected has additional benefits. It segregates channels in limited output to allow Class II wiring. It can be combined with other upgrade equipment in the future, such as photovoltaic charging, microturbines, and fuel cells. It can be upgraded to provide remote monitoring through a computer-based scene controller. It has the ability to communicate with future lighting control devices using a common wireless communication protocol ("ZigBee XBee Series 2").

The manufacturer's data sheet reports high efficiency (90%) and low quiescent power (7 watts [W]), features that were desirable in this demonstration. However, the demonstration did identify field conditions in which this power supply was not designed to operate optimally, thus other products may exist that could save more energy. (See Section 5.2.7)

3.1.5 Controls Considerations

A lighting controls system was selected based on several criteria. It was important that the controls system supported the project goal of being able to move the tiles. Wireless controls allow tile movement while providing orchestration of groups of tiles. Wireless controls also simplify wiring connections, since only DC power, not controls commands or switching relay devices, need to be accommodated in the physical infrastructure.

In addition to wireless communication with lighted tiles, it was important the controls system accommodate the human interface (switches, dimmers) and occupancy sensors. It was important that the system not use specialized software that would require a dedicated computer. It was important that the communication system be re-programmable without a technical support engineer.

A suite of products[4] was selected to meet these goals. Wireless transceivers were installed in most LED tiles. Some LED tiles use a dedicated driver[5] that provides both current regulation and communication, using the same wireless protocol (EnOCEAN[6]). Dimmer switches can be mounted anywhere in the room, as they are powered not with a physical wire, but by the action of pressing the button. An occupancy sensor communicates using the same wireless protocol.

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[3] Power Supply Model 1600 from Nextek Power Systems of Detroit, MI

[4] Illumra of Orem, UT

[5] PRO-flex LED drivers from OSRAM-SYLVANIA of Danvers, MA

[6] EnOCEAN GmbH of Munich, Germany

CHAPTER 4

Task 4: System Installation at Site

In September 2011, LRC and OSI met with Paramount staff to review the planned demonstration. The following week, LRC sent the drawings and installation instructions to Paramount staff to complete estimates for installation cost and scheduling.

In October 2011, the materials were shipped to the site (Figure 18). Most materials and equipment were commercially available and modified for this demonstration. OSI provided all the LED tiles that mount in the ceiling. OSI also provided two power supplies, all the controls equipment, power distribution equipment, powered ceiling, and self-luminous poster frames. LRC provided the wall-mounted tiles and the mounting brackets. Other equipment provided by LRC included acoustic tiles, and a new whiteboard.

Figure 18: Wall Tile Material Shipment

While two weeks were allotted for installation, the majority of the work was completed during the first week (Figure 19). OSI and LRC were present at the installation in December 2011 to support the Paramount staff. A new ceiling was installed to provide DC power distribution. Wall mounting brackets were successfully installed.

Figure 19: Installation, December 2011

As described in Section 3.1.5, the demonstration uses wireless dimmer switches. They can be mounted in any position, because these are powered by the action of pressing the button. A set of dimmer switches is labeled and adhered to the walls of the Roddenberry Conference Room (Figure 20). Dimmer switches were also integrated into a custom-designed, movable console (Figure 21) typically resting in the center of the conference table.

Figure 20: Wireless Dimmers Mounted in Familiar Wall Positions

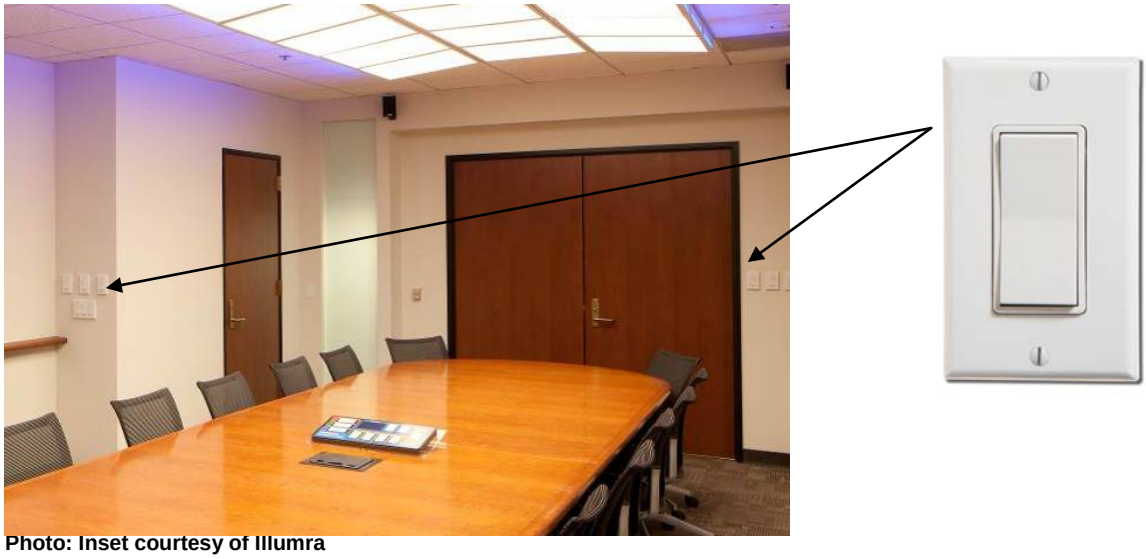


Photo: Inset courtesy of Illumra

Figure 21: Additional Console Integrates Wireless Dimmers

Photo: Inset courtesy of Illumra

4.1 Installation Feedback

After the installation, the Paramount installers offered feedback. While the installers generally characterized the installation as easy, they did offer suggestions to further facilitate installation and ongoing maintenance. These suggestions included improvements for some fasteners, mounting equipment, and electrical connections.

4.1.1 Comments from Installers

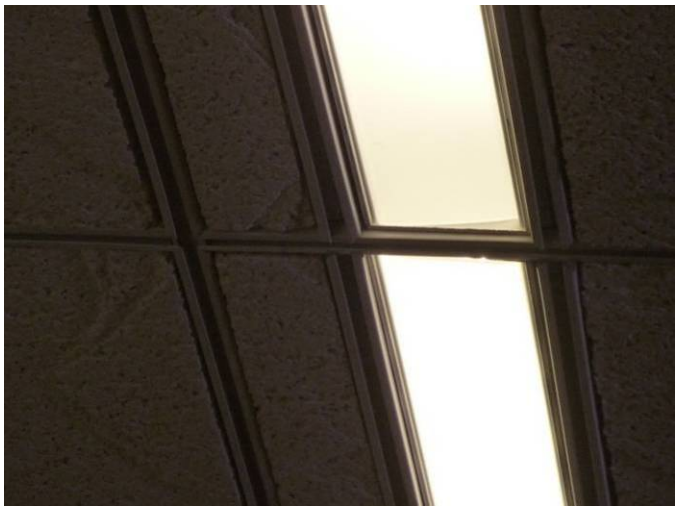
The electrician reported that, according to the local code inspector, ceiling tiles must be permanently fastened to the mounting grid, with earthquake wires and also self-tapping screws. This has several consequences. Moving the tiles will be more difficult than intended. Since they are semi-permanently mounted, it will be difficult to access Type A center tiles without removing adjacent Type B tiles. The process of using the self-tapping screws did cause a few of the tiles' reflectors to deflect.

Installers indicated that clips holding the lenses in place were not easy to work with; it's not possible to replace individual LED modules in the "cloud" without removing the whole tile. One electrician recommended using a hinge on the lens to enable access from below, without removing the whole tile.

The installers indicated that, uplight wall-mounted tiles (Type C) will probably be fed from the ceiling in future installations, so the wire feed should come from the top, rather than the bottom. In this case, the electricians rewired the feed inside the mounting standard.

It is possible to connect DC wires in reverse polarity, which may damage LED tiles. On Type E wall washers, the electricians had to devise a mounting bracket (Figure 22) because the commercially-available powered ceiling grid does not have a notch to mount cross supports at intervals less than 12".

Figure 22: Installers Devised a Bracket to Mount Type E Tiles



4.1.2 Feedback from Other Technicians at Paramount

After installation, LRC and OSI held a presentation for other technicians at Paramount. They asked whether the technology can be used in ceilings that run HVAC, internet wiring, and other systems. (Physical conflict would not be greater than conventional ceilings.) They asked what would happened if a tool were dropped on the grid, whether the grid would short-circuit. (This is unlikely because the power is run on opposing vertical sides of the ceiling grid. Furthermore, an OSI engineer explained that the DC power supply has a feature to protect against short circuits.) Lastly, the technicians recommended a modular connector for wires exposed above the ceiling.

CHAPTER 5
Task 5: Field Evaluation

The field evaluation included photometric measurements, energy analysis, and occupant feedback.

5.1 Photometric Measurements

The LRC performed photometric measurements to assess the light levels in the conference room "Before" and "After" installation. The two lighting conditions (A and B, where condition A is suitable for general lighting and condition B is suitable for slide presentations) were measured in September 2010, before the new lighting system was installed. There was no cleaning or changing of lamps or other alterations to the photometric conditions for the "Before" measurement. In February 2012, two months after the new lighting system was installed, each of the four white lighting conditions were measured separately in the conference room (Cloud, Center downlight, Wallwash, and Uplights, per Tables 2 to 4 below).

Photometric measurements showed that the new lighting aims more light down towards the table (147%) and less towards the wall (75%), compared to the original lighting system. The measured light levels or illuminance are summarized below (measured in lux (lx) which equals 1 lumen per square meter).

Table 2: Average Horizontal Illuminance Values on the Conference Table

Before*		After**		
Fluorescent Pendants	599 lx	Cloud	545 lx	
Incandescent Accents	33 lx	Center downlight	274 lx	
		Wallwash	50 lx	
		Uplights	59 lx	
	632 lx		928 lx	147%

* Existing lamps, lumen depreciated **New LEDs, no lumen depreciation

Table 3: Average Vertical Illuminance Values on the Walls

Before*		After**		
Fluorescent Pendants	324 lx	Cloud	129 lx	
Incandescent Accents	15 lx	Center downlight	44 lx	
		Wallwash	56 lx	
		Uplights	27 lx	
	339 lx		256 lx	75%

* Existing lamps, lumen depreciated **New LEDs, no lumen depreciation

Table 4: Average Vertical Illuminance Values on the Whiteboard

Before*		After**		
Fluorescent Pendants	418 lx	Cloud	161 lx	
Incandescent Accents	13 lx	Center downlight	54 lx	
		Wallwash	129 lx	
		Uplights	21 lx	
	431 lx		366 lx	85%

* Existing lamps, lumen depreciated **New LEDs, no lumen depreciation

5.2 Energy

5.2.1 Energy Monitoring Methodology

LRC worked with Paramount to install current transformers and battery-powered monitoring devices[7] on the circuit(s) feeding power to the demonstration room. The devices measured circuit current every 2 minutes over the course of approximately 6 weeks. The data collection period before renovation was January to February 2011; the period after renovation was monitored January to February 2012. Because the monitoring devices recorded the circuit current, the resulting data do not enable distinction for usage of specific luminaires on the circuit.

While the monitoring equipment is designed to work at a range of currents (0-50A), bench tests at LRC showed that the equipment underestimates current at low values (<2 amps). Also, when the power demand is low (<100W), the power factor provided by the power supply drops from 0.9 to 0.35. Therefore, LRC performed laboratory testing of the same power supply, with a range of loads, to establish a correction function to translate measured current (amps) to demand (watts)[8]. This correction procedure was necessary for the monitoring of the "After" condition (because current was low, demand was low), but not the "Before" condition. In the "Before" condition, the conventional procedure was used, multiplying the measured current (amps) by the nominal circuit voltage and power factor (provided by personnel at the site[9]).

Each resulting power measurement was multiplied by measurement time interval (2 minutes). Daily data for weekends and holidays were distinguished from normal weekdays. Times with

[7] Onset Corp., Split Core AC Current Transformer CTV-B 0-50 AMPS AC, with Hobo 12 (U12-012) Data Logger

[8] $y = 216.95x + 2.8695$, where x=HOBO current measurement, in Amps and y=power, in Watts

[9] Personnel at the site reported power factor of 0.9. Field measurements confirmed that voltage was within 3% of the nominal; Before voltage was 117V and After voltage was 214V. Calculations assumed nominal voltage, 120V in the Before condition, and 208V in the After condition.

lights on were distinguished from lights off. Power use comparisons were performed using 27 working days and 11 weekend days.

5.2.2 Usage Profile

The occupants do in fact change their lighting in the conference room; as shown in Figure 23, power usage changes considerably from one day to the next. Both "Before" and "After" conditions provided multiple layers of light and dimmers, so the power use varied. These data confirm what was learned in occupant questionnaires: the occupants do in fact take advantage of the lighting flexibility, by using the dimmers and/or changing to different lighting layers.

Figure 23 shows that this conference room is mostly in use during core business hours, (9AM-7PM) intermittently rather than continuously. Greater than 80% of the time, the lights are turned off.

Figure 23: Power Profile with the New Lighting for a Typical Week (January 23-29, 2012)

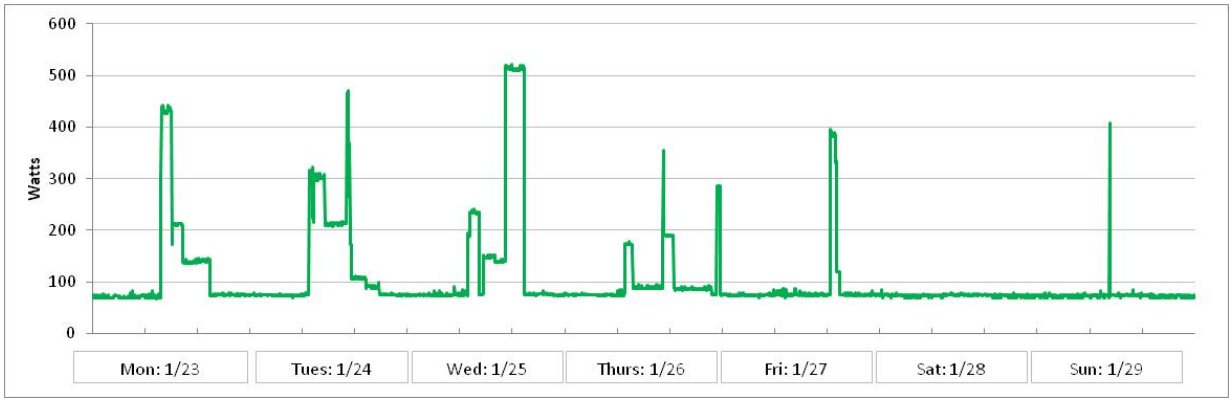


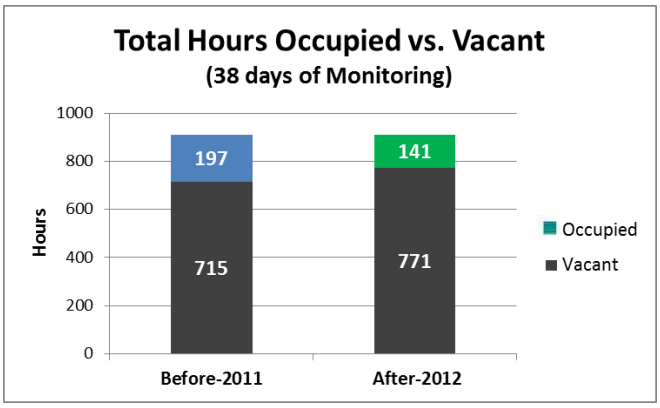
Figure 23 also shows another important point about power use in the demonstration room. When the lights in the room are not in use, the system uses approximately 82W continuously. This consists of approximately 43W for wireless communication devices, and the remainder for the two DC power supplies.

5.2.3 Hours of Use Comparison

For the 38 days evaluation period, "Before" and "After" installation, the data revealed the number of hours the conference room was used. As shown in Figure 24, the conference room was used for more hours before (197 hours) than after (141 hours) the installation. Thus, for annual energy comparison calculations, it was necessary to assume the same annual hours of use for both before and after the installation. The midpoint[10] between these usage patterns (6.2 hours per work day) was used for calculation purposes.

[10] 6.2 hours per work day, 250 work days per year, 1550 hours per year

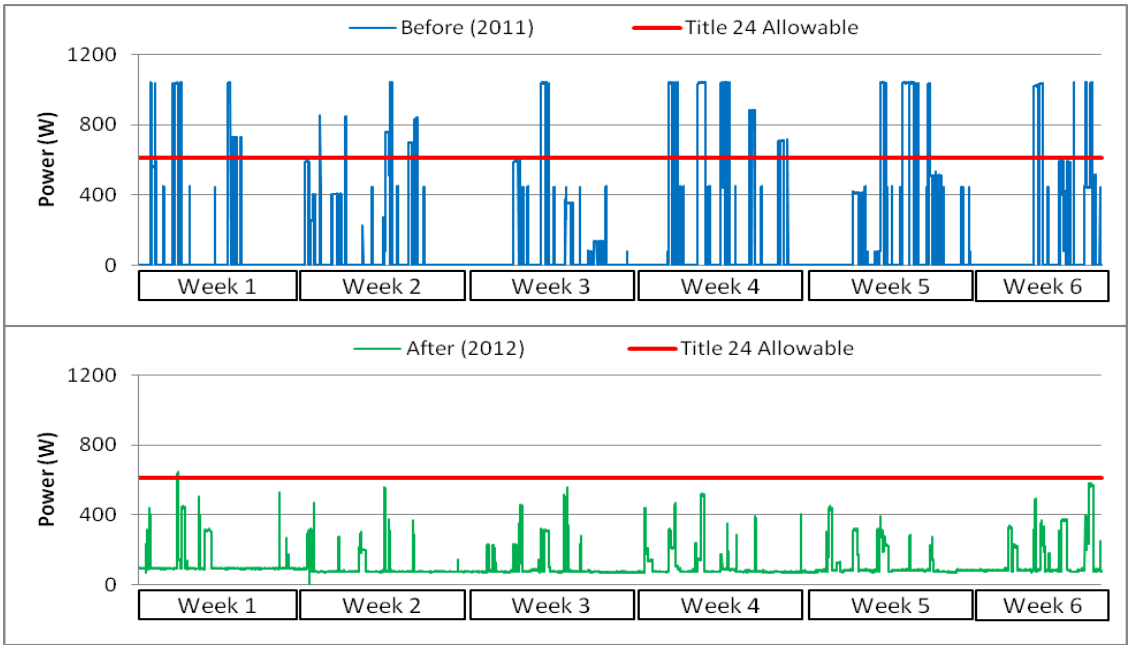
Figure 24: Total Hours Occupied (lights on) vs. Vacant (lights off) during 38 days of Monitoring



5.2.4 Power Comparison

The occupants voluntarily chose lighting modes that use considerably less power than the previous lighting. While the lighting in the "Before" case may have met code when built in 1991, it did not conform to current requirements in 2011. In the After case, the power demand is nearly always less than the limit allowed by California's Title 24 (610 W).[11] While this research demonstration did install more than 610W of lighting for testing purposes, Figure 25 shows that the occupants' lighting needs were met usually without exceeding the 610 W limit except for one instance in "week 1", when 649W was measured.

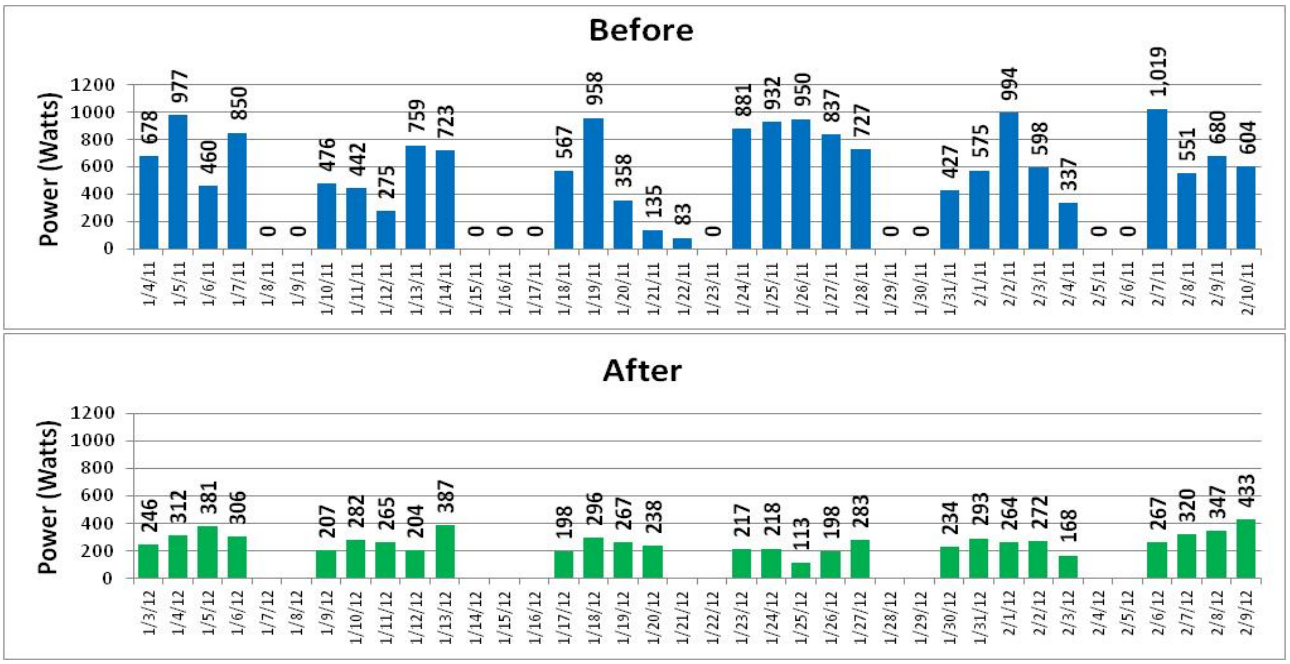
Figure 25: Power Measurements (38 days)



[11] Per California Title 24-2008, 1.4 W per sq. ft. is presently allowed for conference rooms. 1.4 W per sq. ft. x 436 sq. ft. = 610 W. When the Before lighting was originally installed (approx. 1991), this limit would not have been in effect.

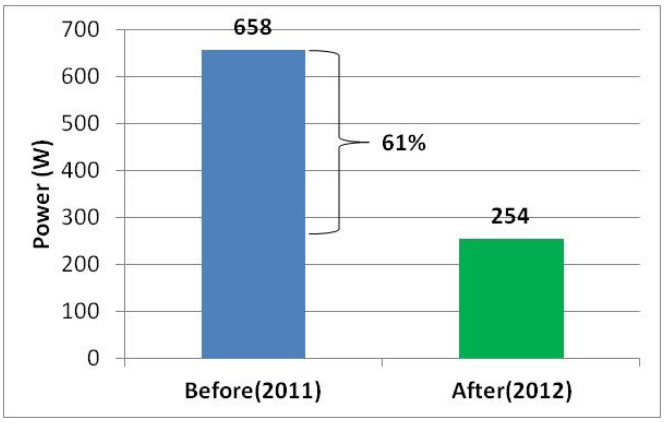
The average power demand when lights were on was calculated for each day of monitoring (see Figure 26). It should be noted that the "After" condition power includes demand from power supplies, wireless control devices, and LED tiles.

Figure 26: Average Daily Power Demand (During Occupied Hours), Before and After Installation



The average of these daily averages was used to calculate average power when the room is occupied (Figure 27). These figures show that the occupants voluntarily chose lighting modes that typically demanded 61% less power than the "Before" condition (see Figure 27).

Figure 27: Average Power Use (During Occupied Hours), Before vs. After

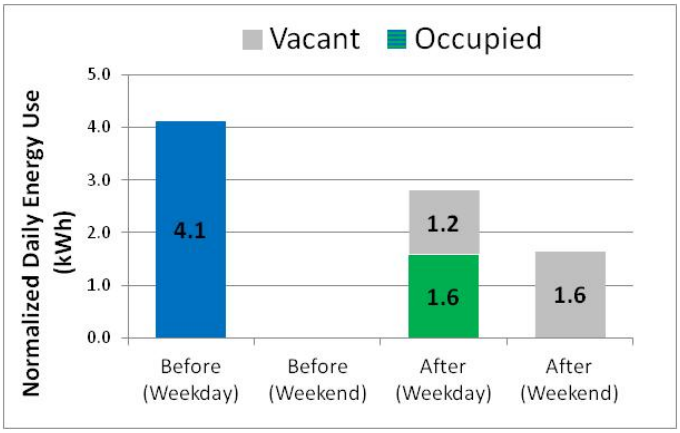


For the purposes of this demonstration and for future upgrade, two power supplies were provided at the demonstration site. However, the entire installation could have been accommodated by one power supply. The following energy calculations assume that one power supply would be used (68W, including wireless devices) rather than two (82W, including wireless devices). Figure 27 above is for the case of one power supply.

5.2.5 Daily Energy Use

Figure 28 shows the "Before" and "After" comparison of daily average energy use. To calculate energy for the After condition, it is important to account for power use when the lights are off (68W). On a typical day, the new lighting system uses much less energy (1.6 kilowatt hours [kWh] vs. 4.1 kWh) when turned on. However, the new system continues to use energy when all lights in the room were turned off during nights (1.2 kWh) and weekends (1.6 kWh), due to the DC power supply and wireless devices in each LED tile.

Figure 28: Daily Energy Comparison

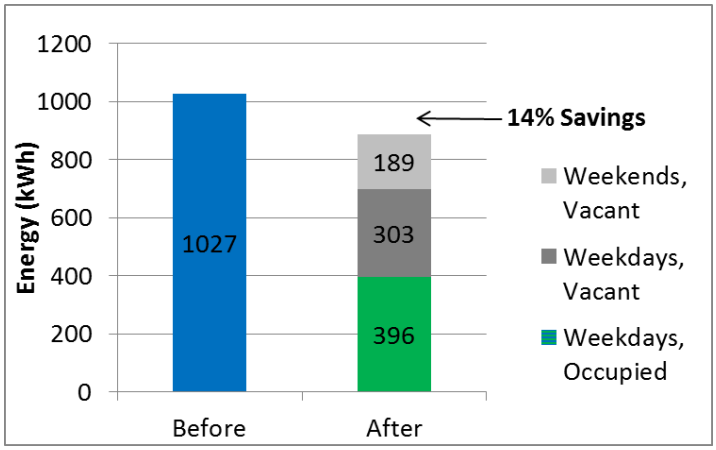


5.2.6 Estimated Annual Energy Use

To estimate annual energy use, the average power demand shown in Figure 27 was multiplied by the estimated daily hours of use (6.2 hrs), and the assumed (250) work days per year.

These results (Figure 29) show that the demonstration system with LED lighting in this conference room does in fact save energy, relative to the original lighting. The energy use with LEDs is approximately 14% lower than the original lighting system with linear fluorescent and halogen/incandescent technologies, assuming the same annual hours of use.

Figure 29: Annualized Energy Comparison



5.2.7 Energy Discussion

A considerable portion of the estimated annual energy use (55%) in this conference room comes from the dormant state, when LEDs are not turned on and the room is (presumably) vacant. Opportunities for further energy saving in future development of this infrastructure may therefore best be targeted at minimizing dormant energy use. The wireless transceivers contributed about two-thirds of the annual energy use, and the power supply, the remaining third.

Wireless transceivers built into the lighted tiles use about 0.33 W per device and a total of 129 devices were used in this conference room, resulting in 42.9 W of continuous power demand. Several tiles had multiple lighting effects built in, necessitating a separate controller for each effect. Because project objectives established that it was important that tiles be movable and modular, it was important that each tile be controlled independently. Future development needs to address better controls strategy for the powered tiles with less power demand. An option is to use energy harvesting products that don't require external power. Another option is to reduce the number of transceivers by group controlling tiles with similar functions.

In the future, other power supplies with negligible quiescent power need to be investigated or developed. Alternatively, it would be valuable to implement a method to turn off power supplies when the room is not in use. If power to the power supply was turned off entirely when the room is not in use, energy use could be reduced by 61% relative to the original lighting. One of the cost effective solutions to minimize dormant energy use would be to install override switches (or an additional occupancy sensor) to control the AC power feeding the DC power supply. This strategy will eliminate power demand by quiescent power of the power supply and the wireless transceivers, thus saving the continuous 68W. One of the downsides for turning power off is that the power supply performs a diagnostic test on all circuits when powered on from the override switches. This process takes approximately 10 seconds and results in sequential flashing of each of the lighted tiles. Such a delay, accompanied with lights flashing, may not be acceptable to room occupants.

Another alternative is a time clock or building automation system that can turn off the power during nights and weekends when the room is not used. This would minimize the instances during which occupants would be exposed to diagnostic flashing. A time clock that turns off power for 12 hours on weeknights and 24 hours on weekends, based on the use pattern of this conference room, would save 60% energy relative to the original lighting system. Upgrading with a time clock strategy would surpass the project objective of up to 50% energy savings.

Overall, the demonstration shows greater energy savings while satisfying occupant's lighting needs with the use of DC, plug and play infrastructure in buildings with solid–state lighting. Potential savings of 50% or more energy is possible with occupancy controls for power supplies and wireless transceivers. This is without sacrificing light level and occupant satisfaction with today's LED technology. Efficacy of the LEDs used in this demonstration is 85 lumens per watt. Savings will be greater than 2 times higher by 2020 when LEDs reach 200 lumens per watt. One of the key benefits of this infrastructure is being able to upgrade LED tiles as the LED system performance improves over time at a reduced cost.

5.3 Occupant Feedback

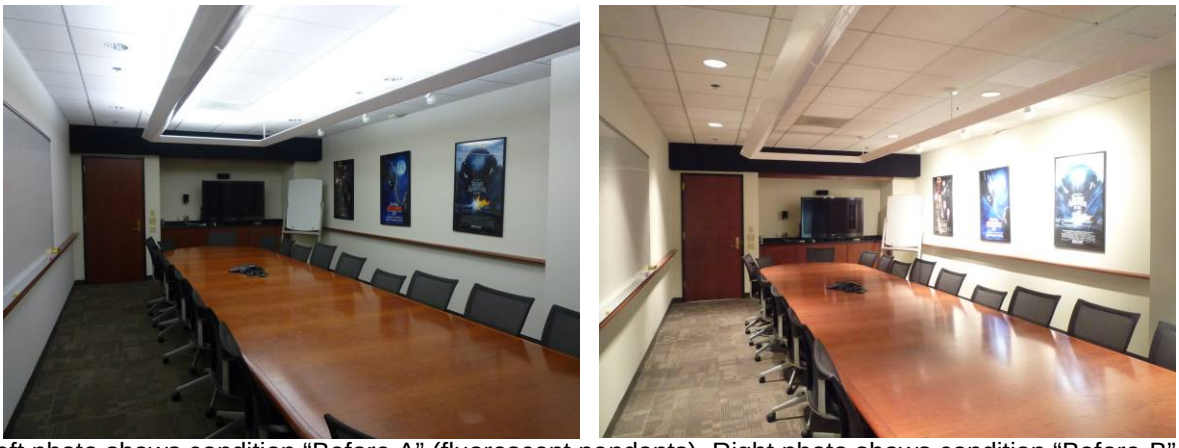
5.3.1 Occupant Survey

A questionnaire was developed to assess whether each lighting system, before and after the installation of the new lighting infrastructure, met their lighting needs in the conference room. These objectives included: ability to see faces, render skin tone as natural, minimize glare, allow note taking during visual presentations, see visual presentations, and see important displayed objects in the room (e.g., tables, whiteboards, and display posters).

LRC administered the questionnaire to occupants that normally use the Roddenberry conference room. Respondents were volunteers, not required by their employer to participate. The questionnaire was first administered with the conventional lighting as shown in Figure 30, before the new lighting system was installed. The questionnaire was administered again two months after the new lighting system was installed (February 2012). Respondents answered the same 14 questions twice for two lighting conditions, both before and after installing the new lighting infrastructure (Figure 31). One lighting condition was suitable for general lighting mode, and the other lighting condition was suitable for audio/visual presentations.

In the "Before" questionnaire, survey respondents were presented with two lighting conditions: "Before-A" (fluorescent pendants) and "Before-B" (incandescent downlights and track lights). (See Figure 30.) Condition A was expected to be suitable for general lighting, while Condition B was expected to be suitable for audio/visual presentations.

Figure 30: Lighting Conditions Presented During "Before" Questionnaire



Left photo shows condition "Before A" (fluorescent pendants). Right photo shows condition "Before-B" (incandescent downlights and track)

As shown in Figure 31, in the After questionnaire, occupants were presented with lighting condition "After A" (cloud, blue halo, and posters) and condition "After B" (center downlight, wall-mounted uplights, whiteboard, television niche, and posters). Once again, Condition A is suitable for general lighting, while Condition B is suitable for audio/visual presentations.

Figure 31: Lighting Conditions Presented During "After" Questionnaire

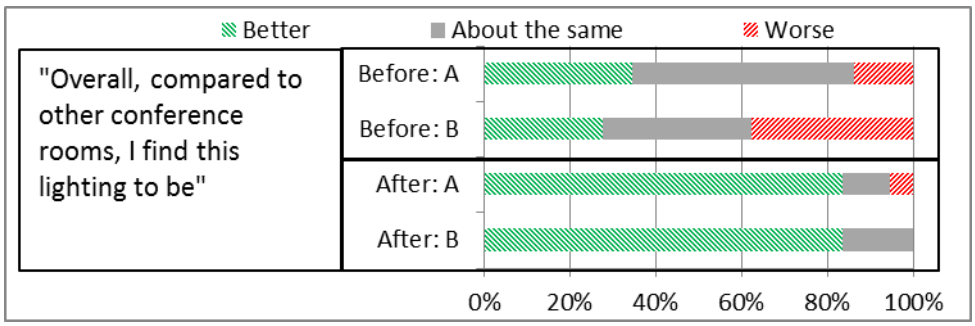
Left photo shows condition "After A" and right photo shows condition "After B".

5.3.2 Occupant Feedback Results

Twenty-nine occupants answered the questionnaire for the "Before" conditions. Eighteen people answered for the "After" questionnaire. A few of the "After" respondents participated in the "Before" questionnaire, but most were different respondents. The LRC researcher was present for the questionnaires. Most respondents took about 5 minutes to answer the questionnaire.

As shown in Figure 32 below, overall, 83% of respondents thought both After conditions were "Better" than other conference rooms, compared to only 34% and 28% under the original lighting.

Figure 32: Overall Questionnaire Results



Summary of the questionnaire results:

1. Most of respondents stated that they use the conference room 1-4 times per week, 45% in the before case and 61% in the after case.
2. Before the installation, 69% of respondents used fluorescent and about 48% used the incandescent lighting. After the demo, 72% reported that they use the cloud, 61% use the posters, and 56% use the center downlight. After the demo, use of the colored light feature was reported by 44% of respondents.

3. A small percentage (38% in the "Before" case and 11% in the "After" case) report that they use the dimmer and adjust light levels.
4. Before the demo, all of the respondents reported the light levels under the fluorescent lighting were sufficient to see faces of others in the conference room. Under the incandescent Before case, 35% felt this was insufficient for seeing faces. After the demo, all respondents thought both lighting conditions were sufficient for seeing faces.
5. Before the demo, all respondents agreed that the table looked bright enough under the fluorescent lighting, but only 45% under the incandescent condition. After the demo, all respondents agreed for Condition A, and one (6%) disagreed for Condition B; as shown in Section 5.1, illuminances on the table in this condition were lower (33 lx) than Before-A (599 lx) and the After conditions (545 lx, 383 lx).
6. Before the demo, most (79% and 90%) agreed that the lighting enabled them to see posters. After the demo, agreement rates were slightly lower (67% and 83%).
7. Before the demo, most people agreed that they could see the whiteboard (96% and 82%). After the demo, agreement rates were lower (44%). This is not likely due to the amount of light on the whiteboard; as shown in Section 5.1, the average illuminance on the whiteboard was much lower in condition Before-B (13 lx) than After conditions (A-161 lx, B-204 lx). Thus it is not clear whether these responses were due to light distribution, veiling reflection from the randomly chosen seating position, or simply individual differences of opinion in the population participating in the "After" questionnaire.
8. Before the demo, most or all agreed that they could see A/V presentations (76% and 100%). After the demo, all respondents agreed.
9. Before the demo, a minority of occupants (38% and 41%) reported that they liked the appearance of the luminaires. After the demo, most or all (89% and 100%) reported liking the appearance.
10. Before the demo, visibility of the flat screen TV monitor was not a concern (29% and 14%). After the demo, visibility of the flat screen TV monitor remained not a concern (22% and 0%)
11. In the "Before" case, glare was more of a concern for the fluorescent condition (46%) than the incandescent accent condition (18%). In the "After"case, glare concern (22% and 0%) was less. As shown in Section 5.1, in the before case, fluorescent Before condition aimed all light upward, and produced higher illuminance on the walls (324 lx) than the incandescent Before condition (15 lx) and the two After conditions (A-129 lx, B-127 lx).

The results showed that in most cases, the demonstrated LED lighting met the visual needs of the occupants equal to or better than the previous lighting system.

Many respondents commented that they liked the colored lighting grazing the textured ceiling tiles. Because several different lighting effects can be mounted in a single tile and controlled separately, this infrastructure can provide different lighting effects that may be considered attractive.

5.4 Ease of Use and Configuration

To confirm ease of configuration per project objectives, LRC interviewed installation and maintenance personnel. LRC also confirmed that the lighted wall tiles can be moved by the occupants without need for an electrician.

One issue with the installation should be addressed for future development of this infrastructure. As discussed in Section 4.1, without prior discussion, the installers used screw-type fasteners to semi-permanently mount the ceiling tiles to the ceiling grid. This was reportedly done due to concerns for earthquake stabilization, in addition to conventional earthquake wires. As a result of these fasteners, these ceiling tiles will not be as easy to move as was originally intended..

5.5 System Functioning

LRC confirmed that tiles were designed and functioning as intended prior to shipping. LRC were present for the installation in December 2011. During the site evaluation in February 2012, LRC confirmed that the system was functioning. In the subsequent months, LRC has periodically contacted personnel at the Paramount site to confirm that the demonstration is working.

There was a problem with one type of electronic component that required replacement after installation. The problem caused two different tiles to flash in a repeated pattern. To address this problem, maintenance staff affiliated with OSI visited the site to replace the faulty component.

As of this writing, there are no subsequent operation problems with this demonstration.

CHAPTER 6:

Task 6: Disseminate Project Results and Develop Product Commercialization Plan by Manufacturing Partner

6.1 Commercialization

The commercial objective of this project was to better understand the issues of closely integrating LED lighting into ceilings (building materials) and architectural interior design, while considering the practical aspects of installation, commissioning and ease of construction. The project used combinations of LED light sources, controls, DC power sources and wireless controls for user-interface and sensors.

With LED lighting, there is increasing focus beyond the light or luminaire to value-added products and services, based on building solutions. Such an approach includes lighting, controls, communications, and user interface that is highly integrated or even embedded in the materials of construction. The potential viability of DC power has become an additional driver, permitting the eventual use of low voltage DC grids.

Participating in this project has provided OSI with practical design and implementation experience that has already been reflected in new products. For example, the wireless-controlled LED lighting prototype drivers used in this installation have been commercialized as the PRO-Flex RF™ announced in May 2012. This LED lighting driver is controlled wirelessly by enOCEAN™ wireless devices such as rocker switches, occupancy sensors and daylight sensors. Using a computer, the output current of the PRO-Flex RF driver can be programmed wirelessly with the PRO-Flex RF Programming Tool or a similar enOCEAN configuration tool.

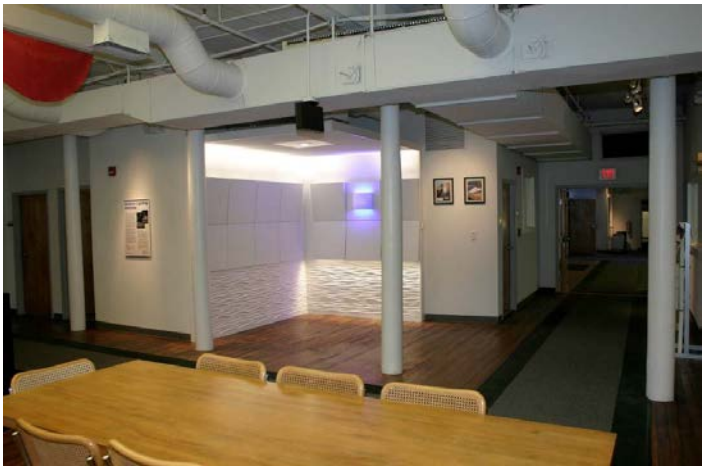
For solid state lighting, being able to accurately predict the performance of lighting in a space has been a challenge. A commercially important aspect of this project was the ability to take an initial design (Figure 7), create an accurate computer model of the prototype LED fixtures, render the full installation and accurately match the computer model and the final outcome (Figure 33).

Figure 33: Computer Rendering (left) and Photo (right) (images courtesy of OSI)

6.2 Dissemination

LRC is displaying prototypes of movable tiles at its facilities in Troy, NY (Figure 34).

Figure 34: Movable Tile Display



Installation funded by Alliance for Solid-State Illumination Systems Technologies (ASSIST)

In July 2012, a cover story was published in LEDs Magazine showing the demonstration (Figure 35). This article is available for download from the publisher's website[12].

In Fall of 2012, LRC submitted an article to a lighting trade journal (LD&A) showing the results of this demonstration. The article was published in print in June 2013[13] and online in July 2013[14]. LRC posted a press release on its website[15]. Subsequent to acceptance of this report, LRC will post this report on its website.

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[12] OSRAM and LRC partner on Paramount Pictures SSL project – *LEDs Magazine* July/August 2012, p. 9 (http://ledsmagazine.com/features/9/7/8?cmpid=EnlLEDsJuly112012)

[13] Office mod squad – *LD+A Magazine* June 2013, p. 57

[14] Modular LED tiles show promise for offices, study finds. *LD+A* online, July 2013 http://www.ies.org/lda/HotTopics/LED/16.cfm

[15] LRC Demonstrates Advanced Building Infrastructure for Solid-State Lighting in Hollywood. *LRC Press Release*, http://www.lrc.rpi.edu/resources/newsroom/pr_story.asp?id=264

Figure 35: July 2012 Cover Story in LEDs Magazine

CHAPTER 7

Results Summary

7.1 Objectives and Results

Objective: "The new building infrastructure system can be retrofitted into a variety of existing building infrastructure types and be used in new construction."

Results Achieved: Because the system is modular, it can accommodate typical commercial room geometries. By using a 2x2 module, the system can accommodate HVAC diffusers. By using a dropped ceiling, the system conceals ducts, wires, and other building infrastructure. While the system is composed of modular parts, the use of controls creates a cohesive appearance.

Objective: "By appropriately incorporating conductive materials into ceiling and wall components, heat from LED sources will be effectively dissipated."

Results Achieved: For the systems developed for this demonstration, temperature was managed by limiting wattage and mounting LEDs on metal plates and housings to extract heat. Thermal management was achieved within the recommendations of the manufacturer and the lighting industry.

Objective: "By using different types of tile materials and tiles of various sizes, the new building infrastructure system will be able to conform to edges and curved surfaces within buildings and interior spaces of various sizes and shapes, thus making the new infrastructure easily retrofitable."

Results Achieved: By using acoustic tiles in non-lighted locations of the ceiling, incomplete tiles at the edges of the room were easily accommodated. Notches and other diverse architectural conditions on the periphery of the room are accommodated. While curves were not intrinsic to this site, curves could have been accommodated with this strategy. Sprinkler heads are easily field cut in acoustic tiles. Filling in the non-lighted spaces with acoustic tiles also makes for good acoustic practice, as it minimizes reverberation. Occupants indicated that they were able to hear colleagues both before and after retrofit. The wall-mounted tiles followed a similar acoustic practice, as it mounts over standard wall material.

Objective: "Using a variety of methods (i.e., textured surfaces, non-linear edges) to join tiles to the infrastructure, walls and ceiling components will integrate easily into a variety of building interior styles and designs."

Results Achieved: Installers characterized the installation as easy. Use of textured acoustic tiles in the ceiling not only created an attractive lighting effect, but also enabled field-cutting of incomplete tiles at the edge of the room. Because the system is modular, tiles can be developed in a range of styles and finishes. The wall mounting system includes trim pieces to fill gaps and create a cohesive appearance.

Objective: "Given projected efficacies for solid-state lighting of 150 lumens per watt by 2010, the new infrastructure system and associated lighting will reduce lighting energy use in existing buildings by up to 50% compared to current state-of-the-art lighting technologies. It will also improve lighting quality and occupants' opinions of the lighting in spaces in which the system is installed."

Results Partially Achieved: Lighting quality and occupants' opinions were clearly improved. While average power demand is 61% lower than the previous conditions, annual energy savings was estimated to be 14% due to standby power demand when the room is not in use. Energy savings are estimated to increase to 60% with a time clock to limit standby power use on nights and weekends as discussed in Chapter 5. While efficacy of the commercially-available bare LEDs was approximately 100 lumens per watt, system efficacy of was 85 lumens per watt.

Objective: "Building occupants will be able to interchange ceiling and wall 'tiles' within the infrastructure in less than one minute, including a reconfiguration of controlled locations."

Results Partially Achieved: Wall tiles can quickly and easily be moved. Ceiling tiles are semi-permanently fastened in place to the need for seismic protection. Future development will need to address ceiling tile movement in collaboration with seismic requirements.

Objective: "The system will allow for the simple integration of lighting controls including occupancy sensors, dimmers, and daylight harvesting controls."

Results Achieved: Because the control system is wireless, components such as occupancy sensors and dimmers were easily incorporated. Upgrades are possible to an orchestrated scene controller. While daylight was not intrinsic to this site, daylighting controls could have been incorporated. Wall tiles are easily moved without need for reprogramming of controls. Familiar-looking dimmer switches are programmed to operate groups of lights cohesively. Users take advantage of controls to adjust the lights to their preference.

7.2 Benefits to California

According to the California Commercial End-Use Survey, lighting constitutes about 35 percent of a commercial buildings electricity use. Reducing lighting energy usage in commercial buildings would lower electricity costs for businesses. Additionally, reductions in lighting energy use reduces statewide greenhouse gas emissions and helps California meet lighting energy reduction goals of 60-80 percent by 2020 as stated in the California Energy Efficiency Strategic Plan.

GLOSSARY

Term	Definition
AC	Alternating current
ASSIST	Alliance for Solid-State Illumination Systems and Technologies
DC	Direct current
LED	Light-emitting diode
LRC	Lighting Research Center
lx	Lux
OSI	OSRAM Sylvania, Inc.
SSL	Solid-state lighting
UL	Underwriters' Laboratories

REFERENCES

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Electronic walls and ceilings offer adaptable solid-state lighting. *Lighting Research Center website, SSL program.* Internet: http://www.lrc.rpi.edu/programs/solidstate/or_adaptableSSL.asp.

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