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GATEWAY Demonstrations

Tuning the Light in Senior Care:

Evaluating a Trial LED Lighting System at the ACC Care Center in Sacramento, CA

August 2016

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Prepared by:

Pacific Northwest National Laboratory

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Prepared in support of the DOE Solid-State Lighting Technology GATEWAY Program

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Pacific Northwest National Laboratory
U.S. Department of Energy
Sacramento Municipal Utility District
ACC Care Center

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Preface

This document is a report of observations and results obtained from a lighting evaluation project conducted under the U.S. Department of Energy (DOE) GATEWAY Program. The program supports field evaluations of high-performance solid-state lighting products in order to develop empirical data and experience with in-the-field applications of this advanced lighting technology. The DOE GATEWAY Program provides independent, third-party data for use in decision-making by lighting manufacturers, users, and other professionals. Though products used in the GATEWAY Program may have been prescreened for performance, DOE does not endorse any commercial product or in any way provide assurance that other users will achieve similar results through use of these products.

Acknowledgements

This project would not have been possible without the full collaboration and cooperation of the ACC Care Center staff and residents, and the authors are very grateful for their support and encouragement throughout. In particular, we acknowledge the significant support of Melanie Segar, ACC Care Center Administrator, Jeff Clay, ACC Care Center Plant Operations Director, and Tamara Kario, ACC Care Center Director of Nurses.

Executive Summary

This report summarizes the results from a trial installation of light-emitting diode (LED) lighting systems in several spaces within the ACC Care Center in Sacramento, CA. The Sacramento Municipal Utility District (SMUD) coordinated the project and invited the U.S. Department of Energy (DOE) to document the performance of the LED lighting systems as part of a GATEWAY evaluation. DOE tasked the Pacific Northwest National Laboratory (PNNL) to conduct the investigation. SMUD and ACC staff coordinated and completed the design and installation of the LED systems, while PNNL and SMUD staff evaluated the photometric performance of the systems. ACC staff also track behavioral and health measures of the residents; some of those results are reported here, although PNNL staff were not directly involved in collecting or interpreting those data. The trial installation took place in a double resident room and a single resident room, and the corridor that connects those (and other) rooms to the central nurse station. Other spaces in the trial included the nurse station, a common room called the family room located near the nurse station, and the ACC administrator's private office.

Solid-state lighting technology provides new opportunities for controlling the intensity, distribution, and spectrum of light in healthcare and other applications. Tunable white LED systems enable adjustments in spectral power distribution and light output that are much easier to implement than with conventional fluorescent lighting technologies. The availability of these new systems combined with the growing understanding of the importance of the non-visual effects of light has created awareness and excitement about new potential applications and benefits for lighting systems in healthcare, education, residential, and other types of facilities. While DOE has published a CALiPER report summarizing laboratory product testing of several tunable white luminaires, the ACC Care Center project provided an opportunity to study the performance of tunable white systems in a real-world application.

The incumbent lighting systems in all of the spaces in the trial installation used linear fluorescent lamps, except some of the bathroom luminaires which used compact fluorescent lamps. The solutions implemented for the trial installation were developed by the SMUD staff, working closely with the ACC administrative and facilities staff as well as the installing contractor. The Beetle luminaire from Samjin was selected for one-to-one replacement of the incumbent fluorescent luminaires in the corridor, nurse station, family room, and administrator's office. This luminaire can continuously vary the correlated color temperature (CCT) within the range of 2700 to 6500 kelvin (K), with full-range dimming possible at each CCT, and with a rated color rendering index (CRI) of 83. The luminaires in the nurse station, family room, and administrator's office were controlled manually, so that the occupants of those spaces could adjust the spectrum and intensity of light from a wall-mounted controller.

The corridor lighting system was designed to change the CCT and light output levels automatically through a programmed script. A wall controller enabled staff to override the script if desired; if changes were made manually, the script resumed at the next scheduled change. The script called for the luminaires to be tuned to 2700 K and dimmed through the evening and night to minimize melatonin suppression. The short-wavelength content and intensity of light was increased during the morning and daytime to support melatonin suppression.

The specified control script was:

7 AM – 2 PM: 6500 K at 66% output

2 PM – 6 PM: 4000 K at 66% output
6 PM – 7 AM: 2700 K at 20% output

For ambient lighting in the two resident rooms, a tunable white cove lighting system was installed near the top of the wall at the beds and on the side walls. A total of 44 ft of this cove fixture (Philips Color Kinetics iW Cove MX Powercore) was installed in the two rooms, providing indirect lighting onto the ceiling. The cove provides CCT tuning from 2700 to 6500 K, with a 2400 K night light option, and was programmed based on the following script:

7 AM – 2 PM: 6000 K
2 PM – 6 PM: 4100 K
6 PM – 8 PM: 2700 K
Night light option: 2400 K (if turned on between the hours of 8 PM and 7 AM)

This script ran automatically, but had a manual override, allowing the resident or a caregiver to change the CCT for any reason. After an override, the cove system returned to its programmed script at the next scheduled time change.

Near the beds in the residents' rooms, the 4-ft-long Chrysalite® LED patient room wall light from Acuity's Healthcare Lighting® brand was wall mounted at the head of the bed, in the same position as the prior fluorescent headwall luminaire. White tunable luminaires were not available in this luminaire type at the time of this project, so a fixed CCT of 3500 K was specified. For the task lighting needs of nurses or other caregivers at the bed, the uplight chamber of this luminaire is hinged and can be raised to a position that directs the light along the length of the bed, greatly increasing the illuminance delivered. In addition, an optional 3 W LED chart light was included at one end of each luminaire, with a separate switch located directly on the luminaire. This feature enabled nurses or family members to perform visual tasks such as reading a medical chart or medication label without turning on other room lighting that could disturb the resident's sleep.

To enhance nighttime safety, amber LED rope lights were installed under the beds, and recessed wall amber LED night lights (ConTech Lighting STPL Step Light Accent Series) were installed at about 18 in. above the floor in the resident rooms. All of these were controlled by motion sensors. The main purpose of these lights was to provide enough illumination for the residents to safely navigate to and from the bathroom at night, without having to use the overhead lighting. The amber color was selected because it avoids wavelengths that have the most potential to make it more difficult to go back to sleep. Inside the bathroom, amber LED lighting was integrated into new handrails (Efficient-Tec International, MYRIS Stainless Steel System) and controlled by motion sensors, providing additional low-level lighting to facilitate safe navigation.

Key results from the trial installation at the ACC Care Center included the following:

- Energy savings for the tunable white LED luminaires used in the corridors was 68% relative to the fluorescent system based on the LED system's reduced power and the automatic dimming implemented.
- Illuminance levels in resident rooms and bathrooms were inadequate with the older fluorescent system but exceeded IES recommendations for the over 65 age group with the LED system.
- Color consistency for the tunable white LED luminaires used in the corridors, nurse station, family room, and administrator's office was very good among luminaires and very good over the dimming range.

- The combination of spectral tuning and dimming with the LED systems in the residents' rooms, the adjacent corridor, and the nurse station provided the opportunity to stimulate the ipRGCs (intrinsically photosensitive retinal ganglion cells) during the times of day when melatonin suppression is desirable (morning and mid-day), and to reduce stimulation of the ipRGCs during times of day when melatonin production is desirable (evening and night).
- The amber LED lighting installed under the beds and in the bathroom handrails, controlled by motion sensors, proved very effective for providing low-level nighttime lighting that supported safe navigation while likely minimizing the stimulation of the ipRGCs.
- Although this pilot study involved a very small number of rooms and residents, ACC Care Center staff documented important health-related benefits that may have been (at least in part) attributable to the lighting changes. For example, target behaviors such as yelling, agitation, and crying were reduced by an average of 41% for the three residents. Nursing staff noted that all three residents had been consistently sleeping through the night since the installation, and that psychotropic and sleep medication use had been significantly reduced for one of the residents whose room was included in the trial installation.

ACC, SMUD, and the DOE all learned important lessons from the trial installation of LED lighting at the ACC Care Center. The ACC Care Center plans to incorporate many of the strategies implemented in the pilot study in their future expansion and remodel project. According to Melanie Segar, the ACC Care Center Administrator,

> "ACC will be incorporating many of the lighting solutions piloted in this project as best practices in terms of fall risk, sleep enhancement, and non-pharmacological approaches for behaviors related to dementia."

Acronyms and Abbreviations

BTU	British thermal unit(s)
CCT	correlated color temperature
CRI	color rendering index
DOE	U.S. Department of Energy
EML	equivalent melanopic lux
EUI	energy use intensity
IES	Illuminating Engineering Society
ipRGC	intrinsically photosensitive retinal ganglion cell
K	kelvin
kWh	kilowatt-hours
LED	light-emitting diode
lm	lumen(s)
lx	lux
m-lx	melanopic lux
R&D	research & development
SMUD	Sacramento Municipal Utility District
SSL	solid-state lighting

Contents

1. Introduction

1.1 Project background

This report summarizes the results from a trial installation of light-emitting diode (LED) lighting systems in several spaces within the ACC Care Center in Sacramento, CA. The Sacramento Municipal Utility District (SMUD) coordinated the project and invited the U.S. Department of Energy (DOE) to document the performance of the LED lighting systems as part of a GATEWAY evaluation. DOE tasked the Pacific Northwest National Laboratory (PNNL) to conduct the investigation. SMUD and ACC staff coordinated and completed the design and installation of the LED systems, while PNNL and SMUD staff evaluated the photometric performance of the systems. ACC staff also track behavioral and health measures of the residents; some of those results are reported here, although PNNL staff were not directly involved in collecting or interpreting those data.

The SMUD Building Leadership Talent Team worked with SMUD's Energy Research & Development (R&D) Department to implement the ACC project, as part their broader effort to support Alzheimer's organizations in the local SMUD service territory. The Energy R&D Department works with customers, manufacturers, and researchers to evaluate new or underused technologies in real-world environments, and was interested in exploring the connections between lighting and health. The trial installation project with ACC provided an opportunity for a collaborative, real-world evaluation of many aspects of LED lighting technology, combining the respective expertise of the ACC, SMUD, and PNNL staff.

1.2 The ACC Care Center

The ACC Care Center provides rehabilitation and nursing care services in a residential atmosphere, and has been serving seniors in the Sacramento area since 1986. The average age of the current residents is 87 years and most of them are wheelchair bound. Many of the residents have been diagnosed with dementia. The Center currently has 99 beds and is planning a major remodel and expansion project within the next few years. ACC was interested in collaborating with SMUD to explore new lighting concepts for possible inclusion in the planned expansion project. Specifically, ACC was interested in lighting strategies that might improve safety by reducing the number of falls, improve sleeping habits of their residents, and improve care by better supporting ACC staff caregivers.

Architecturally, the ACC Care Center has an entry lobby and five primary corridors, which extend spoke-like from a hexagonal hub at the central nurse station (see Figure 1). The patient rooms along one corridor serve as short-stay units for patients who have been discharged from a hospital but need further care before returning home. The other four corridors access rooms for long-term residents who receive full-time nursing care. A dining room and other common spaces are located at the end of one of the corridors.

One of the long-term care corridors, designated within the facility as Cherry Lane, was used for the trial LED lighting system installation, along with a double resident room and a single resident room along that corridor. Other spaces in the trial included the nurse station, a common room called the family room located near the nurse station, and the ACC administrator's private office.

Figure 1: Aerial view of the ACC Care Center, showing the hexagonal central nurse station, the entry lobby to the right of the nurse station, and five corridors that extend from the nurse station. (Credit: Google Maps)

1.3 Lighting in healthcare

Healthcare facilities in the United States are among the highest ranked facility types in terms of energy use intensity (EUI). Hospitals, for example, have been estimated to have an average EUI of 259,000 British thermal units per square foot (BTU/ft^2), ranking a close second to food service facilities. Assisted-living inpatient care facilities such as nursing homes have an average EUI of 143,000 BTU/ft^2, ranking fourth in the U.S. behind food service, hospitals, and grocery stores. (For reference, the average EUIs for common facilities such as offices, schools, and retail stores are all less than 100,000 BTU/ft^2.) Lighting systems represent the largest electricity end use in healthcare, as shown in Figure 2.[1]

[1] *Advanced Energy Retrofit Guide – Healthcare Facilities*, U.S. Department of Energy, data from the U.S. Energy Information Administration, Washington, DC, September 2013.

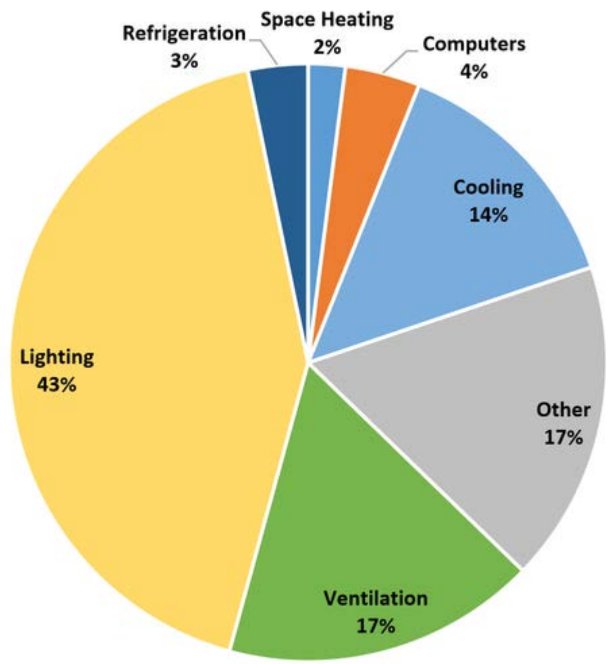

Figure 2: Average electricity end uses in healthcare facilities, as a percentage of total electricity use.

The relatively high EUI of healthcare facilities, combined with a rapidly aging global population, indicates that energy use for this sector will almost certainly continue to increase, as the increased demand for healthcare drives a need for new facilities and renovations of existing facilities. The United Nations estimated that the percentage of the global population over the age of 65 will dramatically increase in the next 30 years, partly driven by the aging of those born during the post-World War II baby boom. Although that percentage has been increasing for several decades, it will remain below 10% through the year 2020, but will increase to 16% by the year 2050.[2] The U.S. Census Bureau estimates that 46 million people living in the U.S. in 2014 were age 65 or older; that number is projected to increase to 98 million by 2060, representing 24% of the U.S. population at that time.[3] This aging population almost certainly will require more healthcare facilities, with an expected corresponding increase in electricity use for lighting these facilities.

At the same time that the demand for healthcare and the corresponding lighting energy use are increasing, understanding of the many visual and non-visual effects of light is also growing. The aging population not only means that more people will require healthcare, but it also results in a “graying” workforce, placing a growing emphasis on lighting that meets the demanding visual needs of both those seeking care and those providing care. However, lighting for healthcare spaces can no longer only address visual needs. The relatively recent discovery of the intrinsically photosensitive retinal ganglion cells (ipRGCs) in the human eye has produced new research and knowledge of the non-visual effects of light, including the importance of light to the natural cycle of sleeping and waking.

Light that stimulates human photoreceptors, including the ipRGCs, is known to play a role in suppressing the release of melatonin, a hormone produced by the pineal gland that helps control the sleep and wake cycles.

[2] *World Population Prospects,* United Nations Department of Economic and Social Affairs, Population Division, New York, 2015.

[3] *Projections of the Size and Composition of the U.S. Population: 2014 to 2060*, SL Colby and JM Ortman, Current Population Reports, P25-1143, U.S. Census Bureau, Washington, DC, 2014.

Normally, melatonin levels begin to rise late in the day, remain high for most of the night, and then decrease in the early morning. Exposure to light, especially short-wavelength light, can stimulate the ipRGCs, suppressing melatonin. Therefore, exposure to high light levels during the day can help support normal sleep-wake cycles, while exposure at night can disrupt this natural cycle. While the relative sensitivity of the ipRGCs to different wavelengths of light has been documented, the exact nature of the mechanisms that cause non-visual effects in humans such as the suppression of melatonin are not yet fully understood. These non-visual effects seem to depend on the spectrum, intensity, duration, timing, and history (temporal pattern) of light exposure. Furthermore, these effects seem to be affected by all of the photoreceptors, not just the ipRGCs.

While the suppression of melatonin at night may contribute to sleep problems for the general population, concerns about this possibility are heightened for residents of senior care facilities and nursing homes, where disturbed sleep patterns are common. Normal aging processes and common ailments such as Alzheimer's disease contribute to disruptions in the normal sleeping and waking cycles:

> "The disturbed sleep seen in nursing home residents may be due to changes in circadian rhythms. Human circadian rhythms are biological cycles of about 24 hours that include sleep/wake, body temperature, and melatonin secretion cycles. Circadian rhythms are controlled by the supra-chiasmatic nucleus (SCN) of the hypothalamus. In normal aging and in Alzheimer's disease (AD), the SCN deteriorates, contributing to alterations in circadian rhythms."[4]

These effects of aging and Alzheimer's on circadian rhythms have created particular concerns about providing appropriate lighting for these populations, which was one of the motivating factors for the trial installation at the ACC Care Center. One of the primary goals for the SMUD and ACC project team was to leverage the emerging tunable white LED technology to avoid lighting with high potential to suppress the production of melatonin during the evening and at night. In designing the lighting and control systems, the SMUD staff decided to follow the guidelines for senior care published by Figueiro,[5] which include:

- No more than 100 lux (lx) at the cornea from a circadian-ineffective white light source in the evening hours
- Low-level night lights to allow safe navigation through the space, without disrupting sleep

As discussed later in this report, these guidelines were considered especially important in the resident rooms and the corridor, since the lighting in those spaces was expected to affect residents the most during the evening and night. The script developed by SMUD that controlled the lighting systems for these spaces was based directly on the Figueiro recommendations.

Solid-state lighting technology provides new opportunities for controlling the intensity, distribution, and spectrum of light in healthcare and other applications. Specifically, a growing number of tunable white or color-tunable LED luminaires and systems have been introduced into the market recently. These systems enable adjustments in spectral power distribution and light output that are much easier to implement than with conventional fluorescent lighting technologies. The availability of these new systems combined with the growing understanding of the importance of the non-visual effects of light has created awareness and excitement about

[4] Effect of light treatment on sleep and circadian rhythms in demented nursing home patients, S Ancoli-Israel, JL Martin, DF Kripke, M Marler, and MR Klauber, *Journal of the American Geriatric Society*, February 2002, 50(2):282-289.
[5] A proposed 24 h lighting scheme for older adults, MG Figueiro, *Lighting Research & Technology*, 2008, 40:153-160.

new potential applications and benefits for lighting systems in healthcare, education, residential, and other types of facilities. While DOE has published a CALiPER report summarizing laboratory product testing and developed some educational materials on these systems,[6] the ACC Care Center project provided an opportunity to study the performance of tunable white systems in a real-world application.

1.4 Project goals

Although most projects undertaken by the SMUD Energy R&D Department focus on energy efficiency, the ACC Care Center project focused on broader goals that were specific to ACC and SMUD. While the LED systems implemented for the trial installation are more efficient than the incumbent lighting systems, energy efficiency was a secondary goal. Working collaboratively with key ACC staff, SMUD identified the following primary goals for the trial installation:

- Investigate, evaluate, and identify potential lighting products and techniques for ACC's planned remodel and expansion.
- Learn more about how tunable-white lighting affects the sleep patterns, nighttime safety, and other behaviors of residents, including those with Alzheimer's or related dementias.
- Better equip the caretakers and nursing staff to provide excellent care by improving the quality of lighting (e.g., reduce glare, improve controllability) in the trial spaces, relative to the incumbent lighting.
- Train ACC staff members on lighting needs, considerations, and challenges for seniors.

DOE selected this project for a GATEWAY evaluation because healthcare lighting represents a significant national energy use, because tunable spectrum LED products are an important emerging aspect of LED systems, and because advances in lighting technology provide opportunities to significantly improve healthcare lighting solutions. PNNL staff performed the following for this project:

- Existing conditions evaluation (pre-installation) – documented the luminaires and controls used, conducted field measurements of illuminance and color quality, and provided a survey for ACC staff on attitudes and opinions about lighting.
- LED equipment specification – reviewed and gave feedback on materials provided by SMUD.
- New conditions initial evaluation (post-installation) – conducted initial field measurements of illuminance and color quality at different control settings to assess the performance of the new systems.
- Energy analysis – compared the estimated energy use of the existing systems with the new LED systems in several trial installation spaces.

[6] The DOE CALiPER test report and other materials may be accessed at http://energy.gov/eere/ssl/led-color-tunable-products.

2. Original Conditions and Incumbent Lighting System

2.1 Cherry Lane corridor

The Cherry Lane corridor extends out from the central nurse station directly opposite the entry lobby. The only daylight available comes from the clerestory windows above the nurse station and from the glazing alongside the exit door at the far end of the corridor. The incumbent electric lighting consisted of nine surface-mounted fluorescent wrap-around luminaires. Each luminaire used 2-32 W T8 fluorescent lamps and an electronic ballast (Universal Triad model B232-120RH-A), for a total luminaire power of 58 W. All of the luminaires in the corridor were controlled by simple on-off switches located at the end of the corridor closest to the nurse station. The luminaires were operated at full power from 7:00 AM to 8:00 PM daily; staff typically switched off four of the luminaires at 8:00 PM and switched them back on at 7:00 AM. Figure 3 shows the incumbent fluorescent lighting in the Cherry Lane corridor.

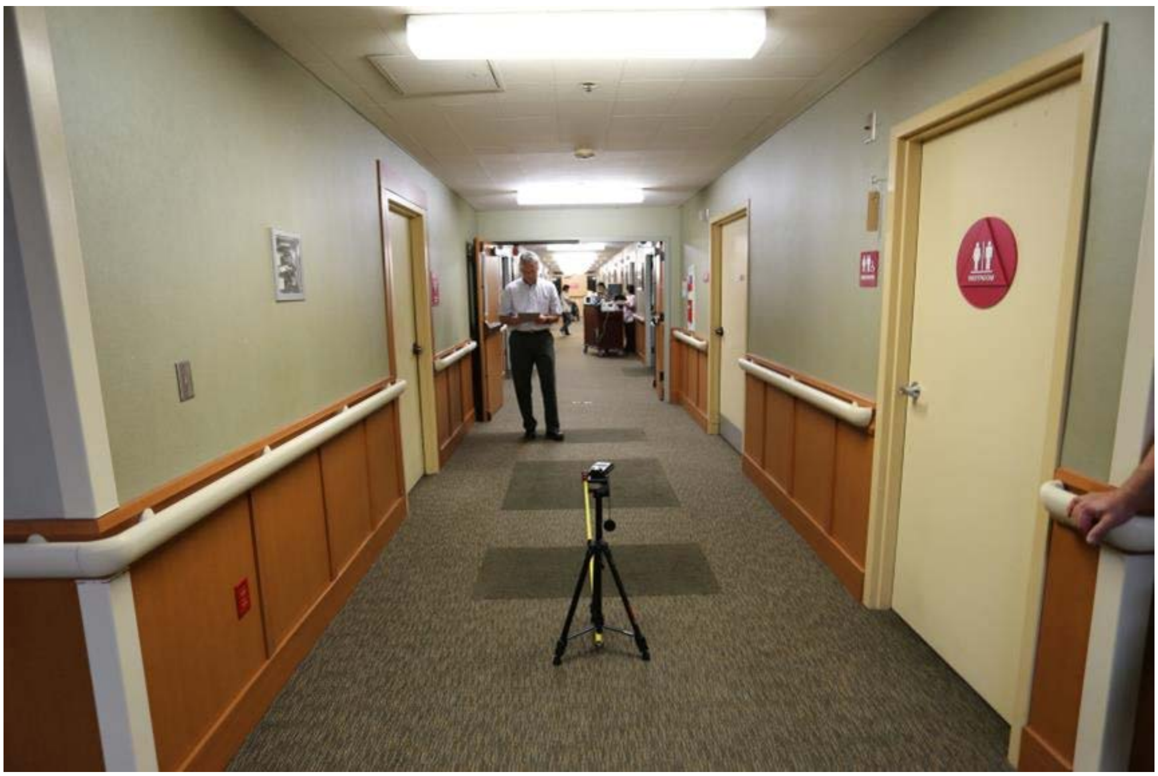

Figure 3: Cherry Lane corridor with incumbent fluorescent lighting system.

2.2 Nurse station

A nurse station is located centrally in the facility. It is a hexagonal-shaped space, with the five primary corridors emanating from it, and the sixth side opening to the facility's entry lobby. A wooden wagon-wheel style superstructure defines the space; above this structure, the hexagon shape continues to a raised roof, with six clerestory windows providing daylight to the space.

The central nurse station had six 3-lamp fluorescent troffer-style luminaires, one in each of the outer sections of the hexagonal structure. These luminaires used 32 W T8 lamps and a single 3-lamp electronic ballast (Philips Advance Optanium model IOPA-4P32-SC) for total input power of 90 W. Similar to the corridors, the luminaires at the nurse station had a simple on-off switch and operated at full power nearly all of the time.[7] Figure 4 shows the incumbent lighting system at the nurse station.

Figure 4: Incumbent fluorescent lighting in the central nurse station.

2.3 Family room and administrator's office

The family room is located near the nurse station, at the beginning of one of the corridors (not the Cherry Lane corridor). This is a social space for visiting with family, playing games, watching TV, and other social activities for patients and residents. It is also used by the attending physician for patient discussions, and the physician expressed interest in having a tunable white lighting system in this room for his patient meetings and to provide opportunities for him to prescribe that some patients spend some time in the room under specific lighting conditions. (This physician had previously prescribed that at least one of his patients be taken outdoors for several hours each morning to improve sleep patterns.)

Six surface-mounted 3-lamp fluorescent luminaires comprised the incumbent system in the Family Room; the luminaires were similar in style to and used the same lamp/ballast combination as the luminaires in the nurses' station. The total connected lighting load was therefore 540 W (six luminaires at 90 W each). The room had a single wall switch to control the lighting; ACC staff estimated that the room was in use for 12 hours each day of the year for an estimated total of 4380 annual operating hours. Figure 5 shows the fluorescent system in the family room.

[7] ACC staff reported that they would occasionally switch the nurse station lighting off during the afternoon hours on a hot summer day. DOE estimates that this practice reduced the annual operating hours by about 200 hours.

Figure 5: Incumbent fluorescent lighting system in the family room.

The administrator's office is a private office that had three fluorescent luminaires of the same model as those in the corridor, with luminaire input power of 58 W each.

2.4 Resident rooms and bathrooms

The ACC Care Center has both single (private) rooms and double rooms for residents. The incumbent lighting system in the resident rooms consisted of a wall-mounted 2-lamp fluorescent luminaire located on the headwall above each bed. These were the primary luminaires in the rooms, and each luminaire had separate switching of the uplight and downlight lamps, with the downlight lamp controlled by a pull chain on the luminaire and the uplight lamp controlled by a wall switch near the door. The lamp/ballast combination used in the resident room luminaires was similar to that of the incumbent corridor luminaires, with input power of 58 W per luminaire. Figure 6 shows the incumbent lighting in the double room that was included in the trial installation.

For the two bathrooms included in the trial installation, the incumbent lighting was very similar, although the physical configuration was different between the two rooms. Each single room has a private bathroom with sink, mirror, and toilet, while each double room has a sink and mirror in the residents' room and shares a bathroom with a second double room, connected through the common bathroom. The shared bathroom only has a toilet. In both cases, the area near the toilet was illuminated by a single ceiling-mounted spherical luminaire with a 60 W incandescent lamp that was operated by a wall switch in the bathroom. The sink and mirror area was illuminated by a wall-mounted luminaire (with two 17 W fluorescent lamps) that was operated by a wall switch near the sink. Figure 7 shows the incumbent bathroom lighting.

Figure 6: Incumbent fluorescent lighting in the double resident room. The single room had a similar wall-mounted luminaire above the bed as the only lighting in the room.

Figure 7: Incumbent bathroom lighting for both the single room and the double room. Although the physical configuration differed, the lighting for the two spaces was similar.

3. Trial Installation Lighting Systems

The project goals stated in Section 1.4 informed the review of lighting product and system options for each space included in the trial. Since the ACC Care Center remained open throughout the construction process, the proposed lighting solutions needed to be integrated into the existing architectural and electrical building infrastructure without incurring high labor cost for the installation, and avoiding any lengthy disruption to the facility's operation or inconvenience to the residents and workers. The lighting solutions for each area included in the trial are described below. These solutions were developed by the SMUD staff, working closely with the ACC administrative and facilities staff as well as the installing contractor.

3.1 Cherry Lane corridor

The design criteria for the corridor included providing task lighting that meets current Illuminating Engineering Society (IES) recommendations for the nursing staff, who often prepare the materials and medications needed for resident care in the corridor before entering the rooms, and to provide tunable white lighting so that the spectrum and intensity of light could be varied based on the time of day. While the incumbent fluorescent system provided adequate task lighting for the staff, it did not provide the flexibility of spectrum and intensity that the project goals required. The corridors also provided an opportunity to reduce lighting energy use, since the incumbent system used fluorescent luminaires that operated at full power for more than 13 hours each day, with about half remaining on at full power for 24 hours each day.

At the time of design and luminaire specification, there were very few tunable spectrum luminaires available that were suitable for replacing the incumbent fluorescent systems in the ACC Care Center. (Many of the early tunable white luminaires on the market were downlights, which did not provide suitable lumen output or form factor for the ACC project.) The Beetle luminaire from Samjin (product code BT14-032-SK-CT-USR4) was selected for one-to-one replacement of the incumbent fluorescent luminaires in the corridor. This luminaire can continuously vary the correlated color temperature (CCT) within the range of 2700 to 6500 kelvin (K), with full-range dimming possible at each CCT, and with a rated color rendering index (CRI) of 83. When operated at full light output, this luminaire has a rated input power of 32 W, and the rated light output is 3350 lumens (lm). (The product information does not specify possible variations in the ratings for different CCT settings.)

The CCT and light output from the nine corridor luminaires were controlled by a proprietary controller from the luminaire manufacturer, which uses a DMX control protocol. A wall-mounted control station was installed at the end of the corridor near the nurse station; this controller was connected to the nearest luminaire with only low-voltage wiring (Ethernet cable). The control station was powered by that luminaire, which in turn communicated the control signal to the other corridor luminaires via a wireless signal. During commissioning, the corridor luminaires were assigned the same digital address so that they received the proper control signal since the trial installation used multiple control stations in different areas.

The corridor lighting system was designed to change the CCT and light output levels automatically through a programmed script. The wall controller enabled staff to override the script if desired; if changes were made manually, the script resumed at the next scheduled change. The script called for the luminaires to be tuned to 2700 K and dimmed through the evening and night to minimize melatonin suppression. The short-wavelength content and intensity of light was increased during the morning and daytime to support melatonin suppression.

The initial light output settings were estimated based on the desired illuminances, and can be field adjusted as needed.

The specified control settings were:

7 AM – 2 PM: 6500 K at 66% output
2 PM – 6 PM: 4000 K at 66% output
6 PM – 7 AM: 2700 K at 20% output

Figure 8 shows the new corridor lighting system at the three settings used in the programmed script.

Figure 8: New tunable lighting in the corridor, illustrating the morning setting (specified as 6500 K at 66% output, left), the afternoon setting (specified as 4000 K at 66% output, center), and the nighttime setting (specified as 2700 K at 20% output, right). The corridor system operates on a programmed schedule, but the staff can override the programmed settings from a wall-mounted control station. The actual CCT at each setting is discussed in Section 4.1.

3.2 Nurse station

The project team selected the Samjin Beetle luminaire to replace the six incumbent fluorescent luminaires at the nurse station, but in this case the 24 W version was selected (product code BT14-024-SK-CT-USR4). This version has the same characteristics as the 32 W version used in the corridor, with the ability to continuously vary the CCT within the range of 2700 to 6500 K and provide full-range dimming at each CCT, and a rated CRI of 83 at all CCTs. When operated at full light output, this luminaire has rated light output of 2650 lm. (The product information does not specify possible variations in the ratings for different CCT settings.) A wall-mounted controller of similar design to the corridor controller was mounted within the nurse station, but in this case, the CCT and output (dimming level) were manually controlled (no script). The nurses were free to vary the CCT and light output according to their preferences, and they received training on the current state of the science regarding possible effects of the different CCT and intensity settings on melatonin suppression. Figure 9 shows the tunable LED luminaires at the nurse station.

Figure 9: Tunable lighting system at the nurse station, shown at the 2700 (left) and 6500 K (right) settings. The nurses have manual control over the CCT and light output at all times for these luminaires.

3.3 Family room and administrator's office

The six luminaires installed in the family room were the same make and model as those in the corridors, with rated input power of 32 W, rated light output at the maximum setting of 3350 lm, and a CCT range of 2700 to 6500 K with full range dimming at each CCT (product code BT14-032-SK-CT-USR4). Figure 10 shows the family room system. Similar to the nurse station, the luminaires in the family room operated only by manual control of the CCT and light output, using a wall-mounted controller located near the entry door. Manual control was selected in part at the request of the attending physician, who sometimes meets with residents in the family room, so that he could vary the lighting as needed.

Figure 10: Tunable lighting in the family room, shown at the 2700 (left) and the 6500 K settings (right). These luminaires are manually controlled from a wall-mounted control station near the entry door from the corridor.

The same luminaire type was also installed in the administrator's office, replacing the three incumbent luminaires on a one-for-one basis. Again, these luminaires operated only by manual control of the CCT and light output, using a wall-mounted controller located near the entry door. The ACC Care Center administrator uses this system to educate the staff, current residents, potential residents, and family members about the tunable white LED lighting used at ACC.

3.4 Resident rooms and bathrooms

The trial installation included two resident rooms (one double room and one single room) and their associated bathrooms. The design goals established by SMUD and ACC for these spaces included the following:

- Improve the task-oriented illuminance levels, since initial measurements of the incumbent system showed that the illuminances did not meet current IES recommendations. Tasks in these spaces include reading in bed, nurse evaluations of resident skin tone and general health, and personal grooming at a sink and mirror.
- Provide tunable CCT lighting, scripted to satisfy the project goals explained in Section 1.4.
- Provide motion-based lighting for nighttime navigation, with an appropriate light level and spectrum that reduces the possibility of melatonin suppression.
- Improve the overall lighting quality in the room by increasing the light levels and uniformity at task areas, and by selecting luminaires and controls that allow layering of the ambient and task lighting for a more pleasant space than that provided by the incumbent fluorescent system.

The limited availability of different types of tunable LED luminaires and the constraints imposed by the existing luminaire locations and room wiring made developing a practical solution challenging, and there were several design iterations prior to the final solution. The solution implemented addressed four key areas: room ambient lighting, room task lighting, bathroom lighting, and night lighting.

Room ambient lighting. Ambient room lighting in each resident room was provided through a tunable white cove lighting system that was installed near the top of the wall at the beds and on the side walls. A total of 44 ft of this luminaire (Philips Color Kinetics iW Cove MX Powercore) was installed in the two rooms, mounted inside a wall-mounted plastic gutter that served as a cove to house the luminaire, providing indirect lighting onto the ceiling. The light was then reflected throughout the room, providing overall ambient lighting. The purpose of the cove system was to provide low-level ambient lighting; it operated at full output for all settings except the night light setting. The cove provides CCT tuning from 2700 to 6500 K, with a 2400 K night light option, and was programmed based on the following script:

7 AM – 2 PM: 6000 K
2 PM – 6 PM: 4100 K
6 PM – 8 PM: 2700 K
Night light option: 2400 K (if turned on between the hours of 8 PM and 7 AM)

This script ran automatically, but had a manual override, allowing the resident or a caregiver to change the CCT for any reason. After an override, the cove system returned to its programmed script at the next scheduled time change. Figure 11 shows two of the scripted settings.

Figure 11: Ambient lighting for the resident rooms, using an LED CCT tunable cove built into a plastic wall-mounted gutter assembly. The left image illustrates the LED cove set to a dimmed level at 2400 K for nighttime use, while the right photo illustrates the system set at the morning setting of 6000 K.

Room task lighting. For visual tasks performed by the residents at the bed, the 4-ft-long Chrysalite® LED patient room wall light from Acuity's Healthcare Lighting® brand was selected and wall mounted at the head of the bed, in the same position as the prior fluorescent headwall luminaire. The luminaire was specified with two rows of LEDs in the uplight chamber and two rows of LEDs in the downlight chamber, for a total rated input power of 126 W and rated initial light output of 9000 lm. CCT tunable luminaires were not available in this luminaire type at the time of this project, from Acuity or other manufacturers, so a fixed CCT of 3500 K was specified. The luminaire was finished with an anti-microbial white paint.

The downlight portion of each of these luminaires was controlled by the resident from the bed through a low-voltage "pillow" switch, and the uplight portion was controlled by a simple on-off switch on the wall near the entry door to the room. In the double room, the uplight portion for both luminaires was controlled by the wall switch, while each bed had its own local controller to separately switch the downlight portion for that respective bed. This feature enabled residents to independently switch localized task lighting on and off for reading or other visual tasks.

For the task lighting needs of nurses or other caregivers at the bed, the uplight chamber of this luminaire is hinged and can be raised to a position that directs the light along the length of the bed, greatly increasing the illuminance delivered. In addition, an optional 3 W LED chart light was included at one end of each luminaire, with a separate switch located directly on the luminaire. This feature enabled nurses or family members to perform visual tasks such as reading a medical chart or medication label without turning on other room lighting that could disturb the resident's sleep.

Figure 12: Wall-mounted luminaire to provide task lighting at the resident's bed. The uplight compartment is shown in its normal position, providing uplighting into the room, but it can also be tilted up to direct its light onto the bed for increased task lighting for caregivers. The downlight compartment provides task lighting for reading and is switched by the resident using the low-voltage push button switch shown at the pillow.

Bathroom lighting. For the lighting near the sink and mirror in each room, the Medmaster™ Vanity Mirror (VL23 Series) from Kenall was installed. (In the double room, the sink and mirror are in the residents' room, while the toilet is in a bathroom that is shared with another double room. In the single room, the sink and mirror are in the separate, private bathroom, with the toilet.) This unit is wall mounted, 35 in. high by 28 in. wide, with a full length strip of LEDs integrated into each side of the mirror surface (see Figure 13), and has 38 W input power at full output. The LEDs are rated for 3000 K CCT and 90 CRI, and are fully dimmable with a 0-10 V controller.

For the general lighting in both types of bathrooms, the incumbent ceiling-mounted globe luminaire was replaced by a Medmaster Auracyl™ Sconce (MAS Series) from Kenall. This luminaire is 8 in. wide and 26 in. long with depth of 4 in., and at the specified CCT of 3000 K, it has rated light output of 2016 lm and rated input power of 54 W. The luminaire was specified with a decorative acrylic lens with a natural leaf pattern. Figure 13 shows the LED bathroom lighting in the private bath associated with the single resident room.

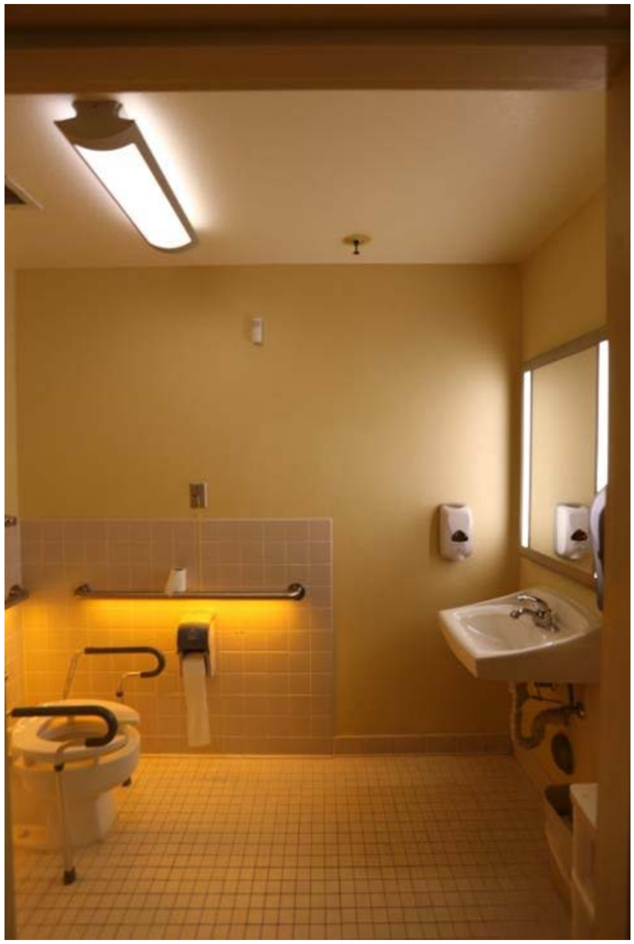

Figure 13: Bathroom lighting in the private bath for the single resident room. A mirror with integrated LED lighting was installed above the sink, and a surface-mounted LED luminaire with decorative lens was installed above the toilet area. The same luminaire types were used in the bathroom areas of the double room. The amber LED night lighting that was integrated into the railings is also shown.

Night lighting. To enhance nighttime safety, amber LED rope lights were installed under the beds, and recessed wall amber LED night lights (ConTech Lighting STPL Step Light Accent Series) were installed at about 18 in. above the floor in the resident rooms. All of these were controlled by motion sensors, so that they would be activated when the resident placed his or her feet on the floor near the bed, or when a nurse entered the room. The main purpose of these lights was to provide enough illumination for the residents to safely navigate to and from the bathroom at night, without having to use the overhead lighting. A secondary purpose was to provide low-level navigation lighting for nurses who entered the room at night, without the need to turn on additional lighting that could disrupt the residents' sleep. The amber color was selected because it avoids wavelengths that have the most potential to stimulate the ipRGCs and suppress melatonin, potentially making it more difficult to go back to sleep. Inside the bathroom, amber LED lighting was integrated into new handrails (Efficient-Tec International, MYRIS Stainless Steel System) and controlled by motion sensors, providing additional low-level lighting to facilitate safe navigation while mitigating melatonin suppression. Figure 14 shows elements of the night lighting system.

Figure 14: Nighttime lighting elements that promote good sleep hygiene. Amber rope lights were installed underneath each bed, controlled by motion sensors that would respond at night to someone getting out of bed or to a nurse entering the room (left photo). Amber LED lighting was also integrated into new handrails in the bathrooms, controlled by motion sensors to provide low-level lighting when someone entered the bathroom (right photo).

4. Trial Installation: Results and Discussion

PNNL and SMUD staff evaluated the incumbent fluorescent systems on August 26, 2015, and the trial LED systems on December 7, 2015. Illuminance and color measurements were taken after dark, except in the resident rooms, where measurements were taken during dinner to minimize disruption to the residents. For these rooms, the windows were covered with opaque material to minimize any contributions from daylight.

4.1 Illuminance

4.1.1 Cherry Lane corridor

Table 1 shows the average horizontal illuminances (from 11 points measured 2.5 ft above the floor, with 6 points directly beneath a luminaire and 5 points between luminaires) and average vertical illuminances (from 4 points measured 5 ft above the floor) in the Cherry Lane corridor. The LED system was evaluated at all three of the scripted settings; results from two of those settings are shown: the morning setting of 6500 K at 66% light output and the night setting of 2700 K at 20% light output.[8]

Table 1: Measured illuminances in the Cherry Lane corridor. The LED settings shown are the CCT and % light output levels established on the script for the controller, and are not measured conditions in the field.

MEASUREMENT	FLUORESCENT (lx)	LED 6500K 66% (lx)	LED 2700K 20% (lx)
Average E_H	330	280	100
Average E_V	120	100	35

IES recommendations for corridors in healthcare facilities differentiate between day and night levels. For applications where more than 50% of the occupants are over the age of 65, IES recommends an average horizontal illuminance on the floor of 200 lx during the day and 100 lx at night, and an average vertical illuminance at 5 ft above the floor of 100 lx during the day and 40 lx at night.[9] These recommended levels are reduced by 50% for the 25 to 65 age group, which is more representative of the nursing staff, who primarily use the corridor at night. While the fluorescent system provides more than enough light for daytime or nighttime use, the ability to adjust the output of the LED system allows it to more closely match the IES recommended levels, reducing the amount of light from the corridor that enters residents' rooms and avoiding the wasted energy associated with over-lighting the space.

4.1.2 Nurse station

Lighting at the nurse station has manual control to allow the nurses to vary the CCT and light output. Because the nurses have full range dimming and CCT control at all times, illuminance was not considered a major concern in this area, but the project team documented illuminances for the incumbent and the LED systems. To avoid undue disruption to the nurses working during the time of measurements, the LED system was evaluated at a single condition. The setting used for the daytime condition in the adjacent corridor was selected for evaluation at the nurse station (4150 K at 66% output), since the CCT of that setting was very similar to the incumbent fluorescent CCT of 4200 K. The average measured horizontal illuminance (of seven points on the work surface) at the nurse station for the fluorescent system was 410 lx, while for the LED system at the selected setting the

[8] The LED system was also measured at the 4150 K, 66% setting, and the results were nearly identical to those for the 6500 K setting.
[9] Table 27.2, Health Care Facilities Illuminance Recommendations, 10th Edition of the *IES Lighting Handbook*, was used for all of the IES recommended illuminances cited in this section.

average horizontal illuminance was 319 lx. Both systems produced lower illuminance than the IES recommended value of 500 lx. This was not a concern because the output of the LED system could be increased if desired (it was measured at the 66% output setting), there is often abundant daylight in this space, and many of the visual tasks are computer-based rather than paper-based.

4.1.3 Resident rooms and bathrooms

Table 2 shows illuminances in the double resident room, and Table 3 shows the illuminances measured in the single resident room. Illuminance contributions from the headwall LED luminaire were measured separately from the contributions of the LED cove luminaire, since they are independently controlled. When both of those luminaires are turned on, the total illuminance is the sum of the wall and cove values shown. The top section of the LED wall luminaire was in the uplight position, rather than flipped over into the examination position (directing its light downward toward the bed). The cove luminaire was at the 7:00 AM to 2:00 PM (6000 K) setting at full light output. The illuminances are shown for each bed, with the “bed center” value from a single horizontal measurement at the center of each bed and the “bed reading” value from a single vertical measurement 2 ft from the head of each bed, with the meter facing the wall, to measure the illuminance that would be present on reading material held by someone in the bed.

Table 2: Measured illuminances in the double resident room. E_H is horizontal illuminance; E_V is vertical illuminance. The ambient illuminance shown is an average of 12 points measured at 2 ft spacing.

MEASUREMENT	FLUORESCENT (lx)	LED WALL (lx)	LED COVE (lx)
Ambient average E_H	93	283	70
Bed 1 center E_H, E_V	186, 184	789, 994	108, 68
Bed 1 reading E_H, E_V	477, 393	1816, 1340	117, 54
Bed 2 center E_H, E_V	275, 335	938, 912	89, 62
Bed 2 reading E_H, E_V	819, 693	1837, 1306	117, 47

In the private room, the room entry area was not directly illuminated by any of the luminaires in the room, but the room often has spill light from the corridor or bathroom. Since the doors were closed during measurement, the measured values in that area are lower than normal.

Table 3: Measured illuminances in the private resident room. E_H is horizontal illuminance; E_V is vertical illuminance. Ambient illuminance was measured in two different areas; those areas are reported separately as Ambient entry and Ambient room. Ambient entry shows the average of three points along a line through the entry area, and Ambient room shows the average of eight points from the entry along the foot of the bed and near the bed along the window wall, all at 2 ft spacing.

MEASUREMENT	FLUORESCENT (lx)	LED WALL (lx)	LED COVE (lx)
Ambient entry average E_H	6	32	5
Ambient room average E_H	68	257	51
Bed center E_H, E_V	192, 255	556, 856	79, 76
Bed reading E_H, E_V	530, 397	1353, 1390	114, 63

As shown in the tables, the LED systems greatly increased the illuminances in the residents’ rooms relative to the incumbent systems. Whenever a caregiver needs to examine a resident, IES recommends a horizontal illuminance of 500 lx (for caregivers in the 25 to 65 age group) and a vertical illuminance of 200 lx across the full bed. The incumbent systems produced horizontal illuminances much lower than the recommended values at the center of the beds, and the levels decreased further toward the foot of the beds. This finding was consistent with anecdotal reports from the ACC staff, indicating difficulty in examining residents’ feet and legs under the incumbent lighting. The LED systems met IES recommendations, and the illuminances for examination would be even greater with the LED system when the top section of the luminaire is in the examination position.

For reading in a patient bed, IES recommends a horizontal illuminance of 400 lx and vertical illuminance of 200 lx for an age group of over 65 years. While the incumbent and LED systems satisfy these recommended levels, a higher value may be appropriate given the advanced ages of the ACC residents (average age of 87 years), and the LED systems provide the ability to achieve higher levels, along with the flexibility to reduce the level (and related energy use) when desired.

Table 4 reports three illuminance values for each of the two bathroom areas evaluated. As explained earlier, the sink for the double room is in the residents' room while for the private room it is in the bathroom. The "bathroom average" is the average of three horizontal illuminances measured at 2 ft spacing. The "sink center" value is the horizontal illuminance measured at a single point at the center of the sink. The "sink, at face" value is the vertical illuminance measured at a single point about 5 ft above the floor, with the meter aimed toward the mirror.

Table 4: Measured illuminances in the bathroom areas. E_H is horizontal illuminance; E_V is vertical illuminance. Values related to the bathroom areas for the private room are shown as (P), while those for the double room are shown as (D). LED values show the dimmable mirror luminaire at full output, although the luminaire would normally be dimmed during use.

MEASUREMENT	FLUORESCENT (lx)	LED (lx)
Bathroom average E_H (P)	136	962
Sink center E_H (P)	175	1775
Sink, at face E_V (P)	200	3901
Bathroom average E_H (D)	71	144
Sink center E_H (D)	237	2324
Sink, at face E_V (D)	306	3871

For the over 65 age group, IES recommends an average horizontal illuminance of 100 lx in bathrooms, a horizontal illuminance of 300 lx at the vanity, and a vertical illuminance of 400 lx at the face in the vanity area. The incumbent system in the bathroom for the private room met the IES recommendation for average horizontal illuminance, but did not meet the IES recommendations for the vanity area. The incumbent system in the double room bathroom areas failed to meet any of the IES-recommended illuminance levels. The LED systems exceeded IES recommendations in all areas. The mirror luminaire affects the bathroom average illuminance in the private room and the sink illuminances in both bathrooms; this luminaire was evaluated at full light output for measurement consistency. *The project team expects that residents will dim this luminaire to more appropriate illuminances than those reported here, which far exceed IES recommendations.*

4.2 Color properties

To document the color properties of the LED luminaires used in the corridor, nurse station, family room, and administrator's office, detailed measurements were made of the six luminaires in the family room. The luminaires in each of these spaces use the same tunable white system and controller; the family room luminaires were selected because the measurements could be made with the least disruption to the ACC staff. The color measurements were conducted to document the luminaire-to-luminaire color consistency at several CCT settings, and to document the color stability over the dimming range at several CCT settings. Nine measurements were made of each luminaire: a measurement was made at the 100%, 50%, and 9% output settings for each of three CCT settings (6500, 4500, and 2700 K). Each measurement documented the full spectral power distribution of the luminaire using a calibrated Konica Minolta CL-500A illuminance spectrometer (model 10002008).

Table 5 summarizes the CCT and D_{uv} measurements[10] for the family room luminaires. For each of the three CCT settings, the "Overall" rows show the average value of the 18 measurements at that setting (three output settings for each of the six luminaires). The "ANSI C78.377 tolerance" row shows the allowable tolerance for a product rated at the given CCT. The "Range over luminaires" rows document the luminaire-to-luminaire variability by showing the range of values (maximum-minimum) for the six luminaires, at the stated output.

Table 5: Summary chromaticity data for the six luminaires in the family room.

CCT on control setting ➡	**2700 K**		**4500 K**		**6500 K**	
Summary metric ⬇	**CCT (K)**	**D_{uv}**	**CCT (K)**	**D_{uv}**	**CCT (K)**	**D_{uv}**
Overall average	2690.0	0.0016	4686.4	-0.0029	6799.9	0.0037
Overall range	32.4	0.0004	236.7	0.0015	255.5	0.0022
ANSI C78.377 tolerance	±145.0	±0.006	±243.0	±0.006	±510.0	±0.006
Range over luminaires at 100%	9.2	0.0002	67.1	0.0004	125.8	0.0007
Range over luminaires at 50%	16.8	0.0003	105.0	0.0003	114.7	0.0007
Range over luminaires at 9%	13.1	0.0002	201.3	0.0005	106.5	0.0007

The average values of the 18 measurements of each luminaire show that the actual CCTs of the 4500 and 6500 K settings were higher than intended, by about 200 and 300 K, respectively. This discrepancy was not considered important by either ACC or SMUD, but could be field adjusted if desired to bring the actual CCT closer to the value specified for the installation. The positive average D_{uv} values for the 2700 and 6500 K CCTs indicate that the chromaticity coordinates were slightly above the Planckian locus at those settings, while the negative average D_{uv} value at the 4500 K setting indicates that the chromaticity coordinates were slightly below the Planckian locus at that setting. As explained in the CALiPER report on these product types (discussed in Section 1.3), this behavior is typical of a linear control strategy for white tunable LED products.

The range in CCT (maximum CCT to minimum CCT) over the six luminaires was very small for the 2700 K setting, showing that the luminaire-to-luminaire color consistency was excellent at that CCT. The greatest variation in color consistency over the luminaires was at the 9% output setting at 4500 K, where the range was just over 200 K. Although this variation may be visible, it is less than the tolerance specified by ANSI C78.377[11] and was not considered a concern by ACC or SMUD.

[10] CCT measures the position of the chromaticity coordinates *along* the Planckian locus, and D_{uv} measures the distance of the chromaticity coordinates *from* the Planckian locus, with positive values indicating coordinates that are above the locus and negative values indicating coordinates that are below the locus. See the DOE Fact Sheet, *LED Color Characteristics*, April 2016, for more information.

[11] *Specifications for the chromaticity of solid-state lighting products*, ANSI C78.377-2015.

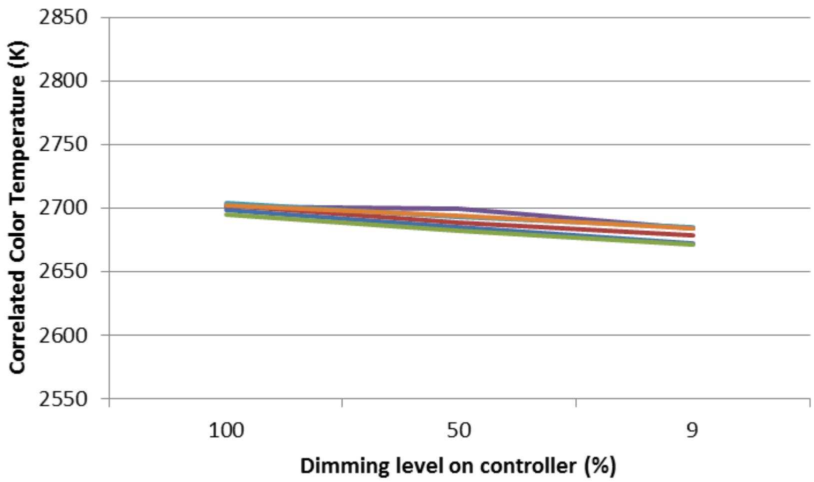

Figure 15: CCT variation over dimming for the 2700 K setting. Each line shows one of the six luminaires.

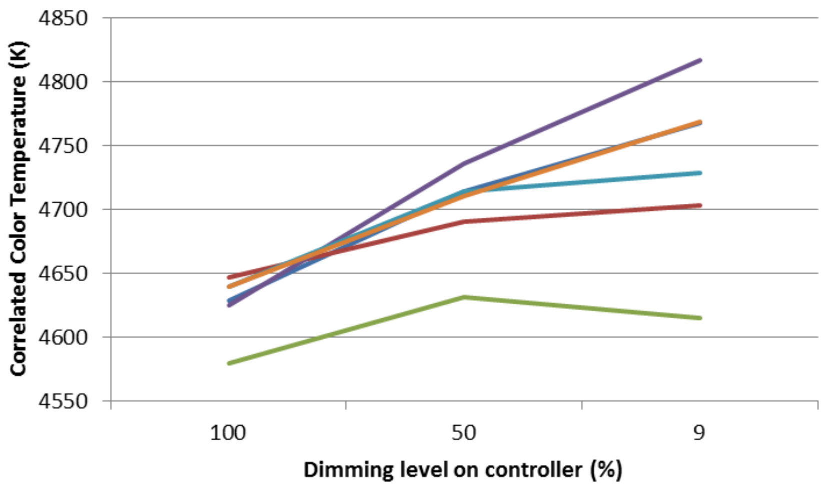

Figure 16: CCT variation over dimming for the 4500 K setting. Each line shows one of the six luminaires.

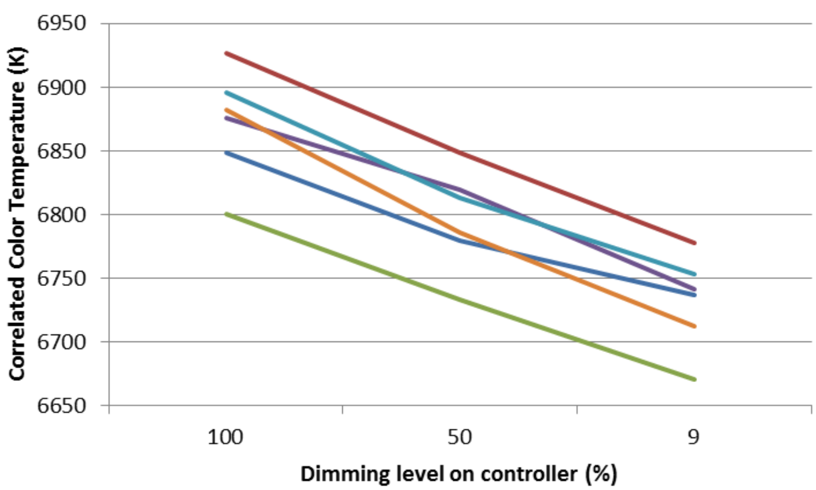

Figure 17: CCT variation over dimming for the 6500 K setting. Each line shows one of the six luminaires.

Figure 15 through Figure 17 show the effects of dimming on CCT for the 2700, 4500, and 6500 K settings, respectively. The vertical axis on each of these figures was set to a 300 K range for easier comparisons among the settings. Dimming at the 2700 K setting produced a very small decrease in CCT (less than 30 K), while dimming at the 6500 K setting produced decreases in CCT of 139 K on average. Dimming at the 4500 K setting produced increases in CCT ranging from 51 K for the luminaire with the least change to 192 K for the luminaire with the greatest change, and the range of CCT values among fixtures increased with dimming. Even so, the variations in CCT with dimming for all settings remained well within the tolerances specified in ANSI C78.377, and were not considered a concern by ACC or SMUD for this application.

4.3 Equivalent melanopic illuminance

As discussed in Section 1.3, one concern in lighting spaces such as senior care centers is the possible effect of lighting on the suppression of melatonin, and the related effects on residents' sleep-wake cycles. While the full relationship between light and melatonin suppression is not yet understood, several techniques have emerged to estimate the possible relative effects of different light sources based on their spectral power output. For example, the WELL Building Standard[12] uses the equivalent melanopic lux (EML) unit, which is derived from a technical paper and spreadsheet toolbox published by Lucas et al.[13] This method determines the melanopic illuminance (EML) by weighting the spectral power distribution of the light source by the spectral response of the ipRGCs. A ratio of the EML to the standard visual illuminance (determined by weighting the source spectral power distribution by the photopic visual response, V(λ)) can then be calculated for each light source.

Using this technique, the ratio of the EML and the standard visual illuminance was determined for the incumbent fluorescent system and for the corridor LED system at each of the three scripted CCT settings. This ratio was also determined for the amber night lights used in the bathroom railings. Table 6 shows the results.[14]

Table 6: Ratio of melanopic to standard illuminance for light sources at ACC.

Light Source	Ratio of Melanopic to Standard Illuminance
Fluorescent 4100 K	0.61
LED 2700 K	0.43
LED 4500 K	0.79
LED 6500 K	0.98
Amber LED Nightlight	0.11

Based on these ratios, the EML can be estimated for the Cherry Lane corridor. As shown in Table 1, the average of the measured vertical illuminances at eye height in the corridor for the incumbent system was 120 lx; using the ratio from Table 6 produces an EML of 73 melanopic lux (m-lx). Similarly, the measured average vertical illuminance of 100 lx for the 6500 K LED system setting (morning) produces an equivalent melanopic illuminance of 98 m-lx, while the measured average vertical illuminance of 35 lx for the 2700 K LED system setting (night) produces an equivalent melanopic illuminance of 15 m-lx.

[12] International WELL Building Institute, *The WELL Building Standard, v1 with May 2016 addenda*, May 2016.
[13] Measuring and using light in the melanopsin age, Lucas et al., *Trends in Neuroscience*, January 2014.
[14] GATEWAY notes that the EML unit is not compliant with the International System of Units (SI), since illuminance and its unit of lux are defined only in terms of the standard visual response in the SI system. As a result, the International Commission on Illumination (CIE) has approved an alternate, SI-compliant method for evaluating melanopic content based on irradiance (CIE TN 003:2015, *Report on the First International Workshop on Circadian and Neurophysiological Photometry, 2013.*). GATEWAY uses the method from the WELL Building Standard in this report.

These values indicate that the morning setting of the LED corridor system may be more likely to suppress melatonin than the incumbent fluorescent system (98 vs. 73 m-lx), while the night setting of the LED corridor system may be less likely to cause melatonin suppression than the incumbent fluorescent system (15 vs. 73 m-lx). In general, the greater melanopic illuminance in the morning occurs during a time of day when melatonin suppression is desirable, while the reduced melanopic illuminance at night occurs during a time when the production of melatonin is normal and desirable. However, melatonin suppression is based on a combination of variables, including the spectrum, intensity, duration, and prior exposure to light, and the project team made no attempt to measure the actual biological effects of lighting on the ACC Care Center residents. Consequently, the effect of the different levels of melanopic illuminance are not known, but the LED system does change the melanopic illuminance as appropriate for different times of day, and in that sense the LED system is an improvement compared to the unvarying incumbent system.

4.4 Health-related outcomes

PNNL was not directly involved in measuring any health-related outcomes, and to protect residents' privacy, ACC staff shared only aggregated results with the project team. Many factors may have contributed to the measured outcomes other than the specific lighting changes described here, and application of the results to other projects is limited by the fact that only three residents in two rooms were directly affected by the trial installation. With those caveats in mind, aggregated data collected in the 3 months prior to and the 3 months following the installation of the LED lighting systems are summarized here.

The ACC Care Center uses the PointClickCare® electronic health records software for medical record keeping, and documents medications on a Medication Administration Record (MAR) each time they are administered. Behaviors that are targeted by medications are documented on the health record for each resident by each nursing shift. Falls are documented both in the health record and on ACC internal risk reports.

For the 3 months following the LED trial installation, target behaviors such as yelling, agitation, and crying were reduced by an average of 41% for the three residents, relative to the 3 months immediately preceding the installation. Nursing staff noted that all three residents had been consistently sleeping through the night since the installation, and noted that one resident now slept through the night in his bed, although he had previously refused to sleep in his bed and instead slept in his wheelchair. ACC staff also noted that psychotropic and sleep medication use had been significantly reduced for one of the residents whose room was included in the trial installation.

Beyond the measures related to the three residents whose rooms were part of the installation, ACC reported several observations related to the Cherry Lane corridor. In this corridor, five falls were recorded during the 3 months prior to the LED installation, while three falls were recorded during the 3 months following the installation, and no additional falls were recorded during either the 4th or 5th month following the installation. Residents whose rooms are located in other corridors at the Care Center are now spending time "hanging out" in Cherry Lane, either wheeling themselves to that area or asking a staff member to take them to Cherry Lane.[15]

[15] For further details, see the companion report on this project produced by SMUD, available at https://www.smud.org/assets/documents/pdf/ACC-Care-Center-Lighting-Project.pdf.

4.5 Energy

As mentioned in Section 1.4, although energy savings was a goal for this project, other goals of SMUD and the ACC Care Center were the primary focuses. Because the existing illuminance levels in the resident rooms were below IES-recommended levels, improving the quantity and quality of light in those spaces was more important to the project team than energy savings. For spaces such as the resident rooms, the family room, and the administrator's office, the actual usage patterns of the incumbent and the LED systems were difficult to estimate, and implementing measurement strategies to track this usage was beyond the scope of the trial installation. However, for the corridors and nurse station, where reliable estimates of daily usage were possible, the energy implications of converting from the incumbent fluorescent systems to the trial LED systems were evaluated. These evaluations will help inform future decisions regarding LED implementations by the ACC Care Center and others.

Based on the operating characteristics described in Section 2.1, the incumbent system in the Cherry Lane corridor had an estimated annual energy use of 3641 kilowatt-hours (kWh). The LED luminaires reduced the input power of each luminaire from 58 to 32 W, with a script that specified that they operate at 66% during the morning and afternoon, and at 20% during the evening and night. The resulting annual energy use is estimated to be 1182 kWh,[16] a 68% reduction relative to the incumbent system.

For the nurse station, the input power for each luminaire was reduced from 90 to 24 W, yielding 73% annual energy savings for the same operating hours, although with reduced illuminances as discussed in Section 4.1.2. However, the dimmable nature of the LED system is expected to produce savings even greater than this, depending on how often and to what extent the nursing staff chooses to dim the luminaires. With abundant daylight often available in this area, the probability of deeper energy savings through the controls is very high.

[16] Input power at each setting was estimated for this analysis based on the specified reduction and was not verified with laboratory or field measurement.

5. Conclusion

5.1 Key results

This GATEWAY evaluation studied a trial installation of LED lighting systems in the ACC Care Center. The spaces included in the trial installation were a long-term care corridor, a double resident room, a single resident room, a nurse station, a common room called the family room located near the nurse station, and the private office of the ACC administrator. ACC collaborated with SMUD and DOE on this project to explore new lighting concepts for possible inclusion in a planned future expansion project. Specifically, ACC was interested in learning about lighting strategies that might help improve safety by reducing the number of falls, improve sleeping habits of their residents, and improve care by better supporting the needs of the ACC staff caregivers. Key results from the trial installation included the following:

- Energy savings for the tunable white LED luminaires used in the corridors was 68% relative to the incumbent fluorescent system based on the LED system's reduced power and the automatic dimming implemented.
- Illuminance levels in resident rooms and bathrooms were inadequate with the older fluorescent system but met or exceeded IES recommendations for the over 65 age group with the LED system.
- Color consistency for the tunable white LED luminaires used in the corridors, nurse station, family room, and administrator's office was very good among luminaires and very good over the dimming range.
- The combination of spectral tuning and dimming with the LED systems in the residents' rooms, the adjacent corridor, and the nurse station provided the opportunity to stimulate the ipRGCs during the times of day when melatonin suppression is desirable (morning and mid-day), and to reduce stimulation of the ipRGCs during times of day when melatonin production is desirable (evening and night).
- The amber LED lighting installed under the beds and in the bathroom handrails, controlled by motion sensors, proved very effective for providing low-level nighttime lighting that supported safe navigation while minimizing potential stimulation of the ipRGCs.
- Although this pilot study involved a very small number of rooms and residents, ACC Care Center staff documented important health-related benefits that may have been (at least in part) attributable to the lighting changes.

5.2 Lessons learned

In addition to the key results, implementing this trial installation in an existing facility posed several practical challenges, and the initial experiences of the ACC residents and staff with the newer LED technologies provided important insights. The following are some of the lessons learned from this project related to the tunable white lighting systems and their associated controls:

1. *Contractors are not yet familiar with tunable systems and controls.* The trial installation included tunable white LED systems from two different manufacturers, both of whom provide proprietary controls and user interfaces with their systems. The installation and initial commissioning of these systems proved difficult for the installing contractors, who had little to no prior experience with these systems, and who had difficulty interpreting the manufacturers' instructions. As one example, the settings for the wireless interactions between the luminaires in the corridor, nurse station, and administrator's office required

several adjustments after installation when it was discovered that some luminaires in one space had inadvertently been assigned to a controller in a different space.

2. *Controls must be simple.* While the user interface for the tunable white LED system used in the corridor, nurse station, family room, and administrator's office was relatively clear and quickly learned by the ACC staff, the interface for the residents' rooms was not necessarily intended for this type of application and was overly complex. This was particularly challenging considering the ages of the residents, and necessitated detailed signage and repeated education. Another issue was that the low-voltage controller for the headwall luminaire was similar in appearance to the nurse call button, confusing some residents.

3. *Commissioning of tunable white LED systems requires extra care and proper instruments.* The normal practice for commissioning lighting controls seems to be that the person doing the commissioning establishes the programmed settings based on control settings internal to the system, without measuring the output of the luminaires. Instruments to measure spectral data and illuminance (as a proxy for light output) are necessary to verify that the specified settings are being achieved, but at present are not commonly used by commissioning agents.

4. *Finding the proper balance of automatic vs. manual tuning of lighting spectrum and intensity is a complex problem.* Properly addressing concerns about providing the appropriate lighting for natural sleep-wake cycles requires automating some of the changes in lighting spectrum and output based on time of day. However, user acceptance of these tunable white LED systems depends on some degree of manual control, especially in highly personal spaces such as residents' rooms. Manual control, however, provides the opportunity for an individual to tune the lighting to a spectrum and/or output that may be inappropriate for the time of day. Specifiers and manufacturers of these systems need to carefully consider the proper blending of automatic and manual control of spectrum and output for each application.

Other lessons were based on some unique aspects of the installation:

5. *Wall-mounted lighting can be difficult to install in a retrofit project.* Elements of the trial installation such as the LED tunable white cove in the residents' rooms were critical to the overall goals of the project, yet were very difficult to implement because of the wiring and required wall accessibility involved.

6. *Night lights installed near the floor may have limited effectiveness.* Although the LED recessed wall "step lights" used in this trial installation have become common for healthcare applications, their locations within the room must be carefully considered. In the ACC resident rooms, it was observed after the installation that the light from these luminaires was sometimes completely blocked when a chair or other object was placed in front of the luminaire, rendering them ineffective in accomplishing their purpose of providing low-level night lighting.

7. *The amber rope lights installed under the beds were highly effective at providing nighttime navigation lighting.* ACC staff provided positive feedback about this feature. However, the caregivers sometimes inadvertently unplugged these lights while moving the beds for cleaning.

8. *Implementing new lighting solutions in senior care facilities requires both initial and ongoing education for residents and caregivers.* The success of the trial installation at the ACC Care Center very much depended on the engagement of a few staff members who learned the underlying principles and goals, and then continuously observed user behaviors and intervened when necessary with further education. While initial education of all users (staff and residents) was important, the ongoing involvement of one

or more “champions” helped ensure that the new lighting systems were used according to the intended purposes, helping achieve the vision for the trial installation.

5.3 Summary

Solid-state lighting technology provides new opportunities to control the intensity, distribution, and spectrum of light in healthcare and other applications. Tunable white LED systems enable adjustments in spectral power distribution and light output that are much easier to implement than with conventional fluorescent lighting technologies. The availability of these new systems, combined with the growing understanding of the importance of lighting spectrum to the non-visual effects of light, has created awareness and excitement about new potential applications and benefits for LED lighting systems in healthcare, education, residential, and other types of facilities.

The relatively high EUI of healthcare facilities, combined with the demographics of a rapidly aging population, indicates that energy use for healthcare in the U.S. will likely continue to increase, as the increased demand for healthcare drives a need for new facilities and renovations of existing facilities. The aging population not only means that more people will require healthcare, but also results in a “graying” workforce, placing a growing emphasis on lighting that meets the demanding visual needs of both those seeking care and those providing care. In facilities such as the ACC Care Center, these demands are heightened by the advanced age of many of the residents. In many existing facilities, the incumbent lighting systems provide light levels that do not satisfy current recommendations for an aging population, making it more difficult to save energy when implementing lighting upgrades, and making it important to continue to increase lighting source and system efficacies.

While exposure to bright light at night and the possible corresponding suppression of melatonin may contribute to sleep problems for the general population, concerns about this possibility are heightened for residents of senior care facilities such as ACC, where disturbed sleep patterns are common. Normal aging processes and common ailments such as Alzheimer’s disease contribute to disruptions in the normal sleeping and waking cycles. Tunable white LED lighting systems provide a new technology platform for addressing a range of visual and non-visual needs.

ACC, SMUD, and the DOE all learned important lessons from the trial installation of LED lighting at the ACC Care Center. The ACC Care Center plans to incorporate many of the strategies implemented in the pilot study in their future expansion and remodel project. According to Melanie Segar, the ACC Care Center Administrator,

> “ACC will be incorporating many of the lighting solutions piloted in this project as best practices in terms of fall risk, sleep enhancement, and non-pharmacological approaches for behaviors related to dementia.”