EBD Using Daylight-Mimicking LEDs for Improved Health Outcomes in Older Adults at St Francis

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ABSTRACT: The American Medical Association recently declared that light at night results in adverse health outcomes. The effects of light at night are particularly relevant for the characteristic long-term care or skilled nursing facility that is in operation 24 hours per day, 7 days per week. Clinical trials are underway at St. Francis Country House to evaluate the efficacy of using daylight-mimicking LEDs to stimulate human receptivity to the non-visual aspects of light to enhance cognitive functioning and improve health outcomes for the older adults in residence there. This 24hour/7day per week lighting system will be installed in the Transition Wing of the 4th floor dementia unit at St Francis and evaluated using clinical trial methods. The Evidence-Based Design (EBD) research will evaluate the efficacy of the LED lighting system to help ameliorate the residents' symptoms of dementia.

KEYWORDS: circadian rhythms, dementia, health, LED lighting, older adults

INTRODUCTION

In June 2012 at their annual meeting in Chicago, the House of Delegates (HOD) of the American Medical Association (AMA) declared that light at night results in adverse health outcomes (Blask 2012). The Council on Science and Public Health recommended that the AMA support the need for developing and implementing light technologies at home and work to minimize circadian disruption while maintaining visual efficiency. Adverse light effects can be minimized by using natural daylight or daylight-matching electric light during the day and a new HOD policy recommends dim red lighting in the nighttime indoor environment.

Research has shown that individuals working in natural sunlight are more productive, more effective, and happier than those who work under the current generation of artificially-generated lights (Perrin 2004).. Natural changes in daylight synchronizes the body's various circadian rhythms, which regulate all aspects of physiology and behaviour, such as sleeping and eating patterns, brain wave activity and hormone production (McEachron, 2012). Disrupting circadian rhythms can lead to jetlag, Seasonal Affective Disorder (SAD), delayed sleep phase syndrome (DSPS), and is implicated in various diseases and disorders, including cancer (McEachron, 2012). Furthermore, the Council on Science and Public Health recognizes that exposure to excessive light at night, including extended use of various electronic media, can disrupt sleep or exacerbate sleep disorders, especially in children and adolescents (Blask 2012).

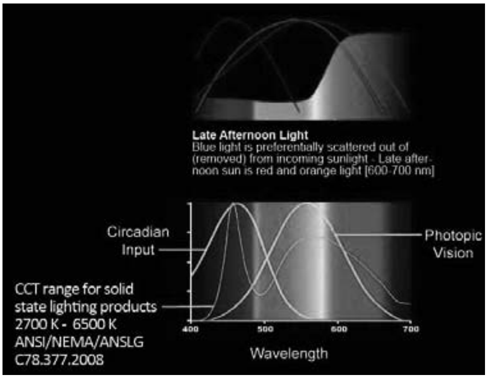

Figure 1. Correlated Color Temperature (CCT) for solid state LED products compared with optimal range for circadian effect and photopic vision. Most of the late afternoon light spectrum is in the red to orange range (adapted by Author from various sources 2011).

Researchers have partnered with lighting industry to develop an LED luminaire that mimics natural daylighting in its full diurnal changing color spectrum and light intensity during the day and changes to dim red lighting during the nighttime hours. The unique characteristics of LEDs include: compact size, long life and ease of maintenance, resistance to breakage and vibration, good performance in cold temperatures, lack of infrared or ultraviolet emissions, instant-on performance, and the ability to be dimmed and to provide color control. Mixed LED sources have a higher theoretical maximum efficiency, potentially longer life, and allow for dynamic control of color (DOE 2013). Compared with either electric filament or gas lamps, LEDs most closely match the full spectrum of natural daylight (Figure 1). The 24/7 LED luminaire being developed mimics the full spectrum of natural daylight in both color temperature and light intensity. Through a combination of white and RGB (red, green, blue) LEDs the luminaire is programmed to change color throughout the day to mimic the full spectrum of natural daylight from dawn to dusk; to change in color from the amber rising sun to the red setting sun and to illuminate the indoor environment with a low-intensity red light throughout the nighttime hours (Ellis et al. 2013b).

Clinical trials at St. Francis Country House are under way to demonstrate the efficacy of the daylight-mimicking LED luminaire to improve sleep and global function of individuals with dementia, potentially opening a lucrative market for photobiology therapy. This integrated daylight-mimicking LED luminaire will be installed at St. Francis Country House. The discussion to follow describes the Evidence-Based Design (EBD) research underway, which is ongoing and provisional research. EBD methods are being used to evaluate effects of the LED luminaire on health outcomes. The research at St Francis will fine-tune the lighting spectrum and levels required to help ameliorate symptoms of dementia in the elderly and improve sleep patterns to establish a lighting “prescription” that can improve health outcomes for this population.

1.0 PROJECT BACKGROUND

1.1. Older Adults and Alzheimer’s Disease

There are 50 million people in the U.S. that have sleep disturbances in addition to the 5.3 million Americans that have some form of Alzheimer’s disease (AD) or dementia, which is the sixth leading cause of death (Alzheimer’s Association 2010). More than 50% of people aged 65 years and over experience sleep changes, due in part to alterations in circadian rhythms. The elderly are at particular risk for circadian rhythm disruption due to a combination of reduced retinal light sensitivity (Turner 2008, Shikder 2011) and deterioration of internal clock function (Farajnia 2012, Schmidt 2012). Such abnormalities appear to be even more pronounced in persons with AD (McCurry 2000). The development of disturbed sleep-wake rhythms, reverse day-night patterns, and agitation frequently result in institutionalization of persons with dementia.

Residents in dementia units have special needs beyond the provision of assistance with activities of daily living (ADL). Alzheimer's residents experience "sundowner's" (agitated behaviour toward the end of the day), difficulty sleeping at night, and a need for mobility and wandering possibly due to disrupted circadian rhythms (Ellis 2013a). These symptoms not only reduce the quality of life of the individual with dementia, such sleep disruptions and behavioural disturbances also contribute to the burden on family and formal (paid) caregivers. The hypothesis is institutional lighting levels fail to provide residents with the full spectrum of changing lighting levels throughout the day and fail to provide total darkness at night, which contributes to circadian disruption and, in turn, exacerbates dementia symptoms. The hypothesis is that human circadian systems evolved in an environment with a gradually changing light spectrum and intensity (including darkness at night) and it is this environment which best synchronizes those rhythms and maintains internal temporal coherence. Light therapy is a highly promising treatment alternative for AD and individuals with sleep disturbances. The use of therapeutic light has the potential to improve the quality of life of persons with sleep disturbances and dementia, including their family caregivers, and delay institutionalization.

1.2. LED Luminaire Solution

A daylight-mimicking, energy-conserving integrated light-emitting diode (LED) luminaire for commercial and residential applications is being developed to reduce the symptoms associated with dementia in Alzheimer's disease and to increase sleep efficiency in individuals with sleep problems and Seasonal Affective Disorder (SAD). This daylight-mimicking luminaire is a retrofit fixture that can easily replace the standard 2' x 2' and/or 2' x 4' fluorescent luminaire characteristically installed in the suspended acoustical tile ceiling systems of most commercial and institutional applications.

2.0 ST. FRANCIS COUNTRY HOUSE CLINICAL TRIAL

2.1. St Francis Existing Conditions

St. Francis Country House is a 273 bed skilled nursing facility located in Southeastern Delaware County near Philadelphia. St Francis offers physical therapy, occupational therapy, speech therapy, post-surgical care and IV therapy, as well as post-acute care services to support the transition from hospitalization to home. The research team was invited as an Alzheimer's disease consultant to evaluate its fourth floor dementia unit to make interior design recommendations that could support quality care for the older adult population living there. The initial site visit noted low lighting levels and a lack of access to natural daylight for the majority of the residents, which resulted in an initial recommendation to reconsider the lighting system. The research team has been working with hospital administration and nursing staff since then to develop a lighting program that can help ameliorate symptoms of dementia for the residents.

2.2. LED Lighting design Parameters

The fourth floor dementia unit has (14) 3-Bed rooms, (2) 2-Bed rooms and (2) 1-Bed rooms to accommodate a total of 48 residents (figure 2). The daylight-mimicking LED lighting system will be installed on the Transition Wing, the southwest wing of the fourth floor, which has eight residents total in (2) 3-Bed rooms and (2) 2-Bed rooms (figure 3). Although the lights are off in the resident rooms at night, the corridor lights are always on. The daylight-mimicking LED lights will be installed in the adjacent corridor but not in resident rooms. Instead, the four resident rooms have red night lighting in the room to assist with going to the bathroom at night when the lights are off. The windows are fitted with blackout shades to prevent any incident light at night entering the rooms from street lights or other external sources. The end condition of the Transition Wing has been redesigned to provide for a Remote Dining Room, which is where all the residents take their meals. All residents will be affected by the lighting system during mealtimes, except in those rare instances when a resident might be unable to leave the sleeping room. Sixteen light fixtures will be installed in the Remote Dining Room and seven light fixtures in the Corridor (figure 4). The eight residents will be exposed to the LED lighting system 24 hours per day/7 days per week.

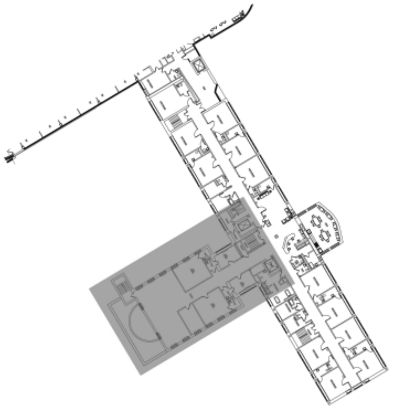

Figure 2. Floor Plan of Fourth Floor Dementia Unit at St. Francis Country House (shaded area Transition Wing). Source: (Author 2010).

Typical Schedule for the 4th floor dementia unit:

7-9:30AM Residents wake up
7:30AM BREAKFAST – Trays come up for breakfast
The goal is for all 48 residents to eat breakfast in the Remote Dining room
11:30AM LUNCH
2:00PM Snoezelen or Sensory Room for lowest functioning/agitated residents
This room is used for individuals who need stimulus – may be unnecessary with new lights
5:00PM DINNER

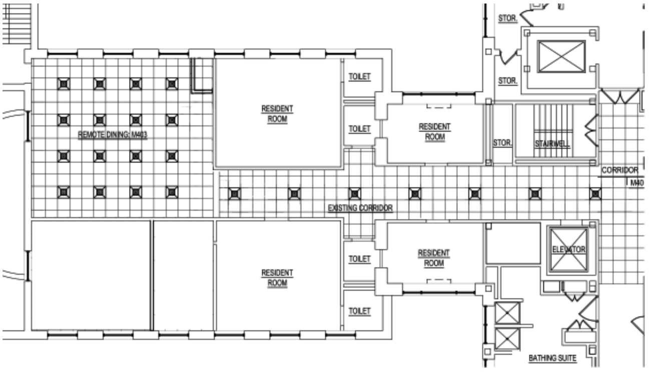

Figure 4. Reflected Ceiling Plan of Transition Wing. Source: (Author 2013).

3.0 LIGHT THERAPY FOR OLDER ADULTS WITH ALZHEIMER'S DISEASE

Aside from providing illumination for visual processing, environmental lighting has a number of additional impacts on human behaviour and physiology. These can be classified as: 1. Direct stimulus-response; 2. Phase-shifting of biological, especially circadian, rhythms; and 3. Altering the underlying frequency of circadian rhythms. When considering the design of environmental lighting, it is critical to weigh these impacts in terms of desired outcomes.

3.1 Direct stimulus-response

Humans are primarily diurnal organisms and react positively to the presence of light. Experiments have shown that exposing humans to bright light, especially in the blue-green range, will increase alertness and performance (Vandewalle 2006, Perrin 2004).

3.2 Phase-shifting of biological, especially circadian, rhythms

Phase-shifting effects are related to the primary mechanism by which organisms synchronize themselves with the geophysical cycle of day and night (a process called entrainment). Circadian systems vary in light-sensitivity across their circadian frequencies (which are typically close to, but not exactly, 1 cycle/24 hours). To entrain to day/night cycles, circadian systems typically undergo a repeating pattern of phase shifts which align the internal circadian clock with the external environmental cycle. Light exposure at times other than those promoting synchronization can shift rhythms dramatically, increasing the chances of both external and internal desynchronization (See McEachron, 2012 for review).

3.3 Altering the underlying frequency of circadian rhythms

Many circadian systems, including the human circadian clock, show a sensitivity to light intensity by altering the internal frequencies based upon the intensity to which the organism is exposed. This involves both absolute intensity and duration. Thus, the frequency expressed by the human circadian clock differs with respect to seasonal changes in photoperiod resulting in changes in the observed daily rhythm. For example, during the summer, the period of the underlying circadian rhythm becomes longer and this is expressed in a phase delay of the entrained rhythms; in winter, the opposite occurs, resulting in a phase advance.

All of these impacts, as well as typical visual processing, occur within a complex system of multiple clocks and oscillators that are not yet fully understood. That these factors impact human behavior and physiology, however, is quite evident. For example, a repeating depression known as Seasonal Affective Disorder (SAD) is associated with changes in photoperiod. The version of SAD which occurs during the winter months has been successfully treated using light therapy, exposing the individuals to light in order to either phase advance certain rhythms or lengthen the photoperiod (Magnusson 2003). These results have promoted a wider consideration of chronotherapeutics in the treatment of various mood disorders (Benedetti 2011).

3.4 Light therapy for Alzheimer’s and dementia

Light therapy has been used on numerous occasions in an attempt to ameliorate symptoms of depression and cognitive dysfunction in elderly residents living in residential or nursing facilities. The majority of studies have followed the winter SAD model, exposing residents to light boxes for fixed periods at certain times of day (Royer 2012, Riemersma-van der Lek 2011). Most studies reported a significant improvement in mood or cognitive variables over placebo although not all (Loving 2005). Both mathematical models of biological rhythms and experimental observations of circadian rhythms in organisms support the hypothesis that a gradual onset and offset of light intensity will generate a far more powerful and sustained synchronization than light pulses (McEachron, 2012, Chapter 6). Thus, the lighting system described should create a more sustained effect on rhythms and, therefore, the cognitive and mood issues experienced by elderly residents.

Two aspects of entrainment are of importance in this design: light perception and timing. In terms of perception, photoreceptors known as the intrinsically photosensitive retinal ganglion cells (*ip*RGCs) have been identified to perceive light that cues the circadian system via the suprachiasmatic nuclei (SCN) for the purpose of synchronizing internal circadian clocks with day-night cycles (Berson 2002). Interestingly, these cells have an absorption spectrum shifted towards the blue-green section of the visual spectrum (Turner 2008, Figure 1). This means that visual and circadian light sensitivities are slightly offset from each other justifying the use of the luminaire approach which provides wavelength adjustments matching the appropriate spectrum for maximum effects. In terms of timing, imposing a typical square wave lighting system (such as turning lights on at 6 am and off again at 6 pm generating a LD 12/12 cycle) might be used, but such an approach is not optimal for entrainment of circadian rhythms. The signals generated by such a LD (light/dark) cycle are perceived by the circadian clock not as a single timing signal but rather as a mixture of many sine and cosine waveforms (consider the Fourier analysis of a square wave pattern). These conflicting signals reduce the efficacy of the LD cycle as a synchronizing agent (McEachron 2012, See Chapter 6). Thus, the use of a more appropriate sinusoidal light intensity waveform with suitable wavelengths represents the most powerful approach that can be practically implemented in this setting

4.0 ENGINEERING CRITERIA FOR LIGHT THERAPY METHODOLOGY

The therapeutic effects of light are widely reported for Seasonal Affective Disorder (SAD) (Sumaya 2001) as well as for Alzheimer's disease and related dementia (ADRD) patients (Hanford 2013). However, the mechanism by which light therapy ameliorates symptoms of dementia in older adults is not yet understood (Deschenes 2009) and the intensities, timing and durations of light therapy have not been precisely identified for this population (van Hoof 2012, Forbes 2009, Fahey 2006). It is clear that further research should be conducted to determine the minimum light levels and duration required to impact the circadian systems of those patients – essentially a lighting "prescription". To date, there has been no long-term day-to-day study where the lighting environment is a permanent built-in 24/7 solution that can be reprogrammed and adjusted to optimize health outcomes based on occupant response. Furthermore, as identified by van Hoof (2012), the criteria needed to characterize the indoor lighting environment are complex and varied with numerous possibilities for error in evaluating results. Considering the engineering methodological issues to address and the technical pitfalls to avoid, the research at St. Francis to document and evaluate the effects of light therapy to help ameliorate symptoms of dementia in its elderly residents includes: 1) description of the light measuring device, 2) establishing light evaluation parameters, 3) description of the building and its interaction with natural light, and 4) identification of lighting design standards for older adults.

4.1. Light measuring devices

Color temperature, the spectral distribution or composition of the light in Kelvin, is measured by a colorimeter or chromameter. Color temperature is an important aspect of color appearance that characterizes how "cool" (bluish) or how "warm" (yellowish) nominally white light appears. Correlated Color Temperature (CCT) is a metric that characterizes the color of the emitted light from a source and is given in Kelvin (K). However, CCT distills a complex spectral power distribution to a single number, which can create discord between numerical measurements and human perception. For example, two sources with the same CCT can look different to the naked eye, one appearing greenish and the other appearing pinkish. The wavelength or spectrum of light is measured using a spectrometer, for example, the data shown in Figure 1. A spectrophotometer measures the Color Rendering Index (CRI), which is a measure of fidelity or how "true" a light source appears when compared to a familiar, or reference, source. A score of 100 indicates that the source renders colors in a manner identical to the reference. However, two light sources with the same CCT and CRI may not render colors the same way (colors may still look different). The light measuring device used in this research is the Konica Minolta Illuminance Spectrophotometer model CL-500A, which measures CCT, CRI, illuminance levels (lx), and conforms to both DIN and JIS standards.

4.2. Light evaluation parameters

Color Rendering Index (CRI), indicated by R_a, is the quantitative measure of the ability of a light source to reproduce the colors of various objects faithfully in comparison with an ideal or natural light source. Correlated Color Temperature (CCT) can shift of up to 2,000K due to a change in ambient temperature. Light Reflectance Value (LRV) is the total quantity of visible light reflected by a surface (e.g. floorings, ceilings, walls and furniture), *at all wavelengths and directions* when illuminated by a light source. Illuminance is measured in lux-units (lx), E_h = horizontal illuminance (table top) and E_v = vertical illuminance (gaze direction). Lumens (lm) are the luminous flux, which is a measure of the total "amount" of visible light emitted by a source. For example, 1 lx = 1 lm/m^2. The difference between the units *lumen* and *lux* is that lux takes into account the area over which the luminous flux is spread. A flux of 1000 lumens, concentrated into an area of one square meter, lights up that square meter with an illuminance of 1000 lux. The same 1000 lumens, spread out over ten square meters, produces a dimmer illuminance of only 100 lux.

4.3. Clinical trials at St Francis Country House

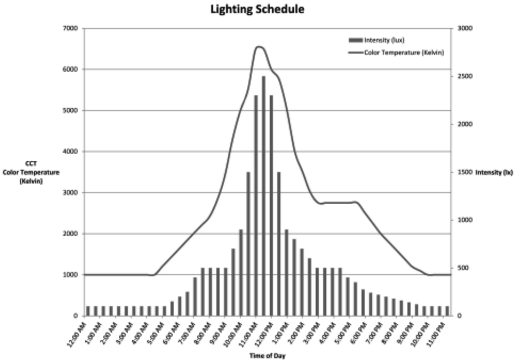

Figure 5. 24-hour day Lighting Schedule indicating changes in color temperature (CCT) and intensity (lux) with respect to time of day. Source: (Authors, 2013)

The test site for the daylight-mimicking LED luminaire lighting system intervention is the Remote Dining Room and the corridor approach located on the 4th floor Transition Wing of the Dementia Unit. The corridor receives no other light except the LED luminaires in the reflected ceiling above. The Remote Dining Room is exposed to daylight from the northwest and the southwest, which could affect indoor lighting conditions after 2:00PM. However, since the objective of the lighting system is to match natural lighting conditions, this should not greatly affect indoor lighting measurements and is considered negligible for the purposes of this study. More germane, could be the effect of light at night entering the four resident rooms. For this reason, these rooms have black out shades to prevent incident light from street lights. Night lights to guide the residents to the bathroom located in these rooms are red. Lighting levels are as per the Lighting Schedule in Figure 5. Lighting levels will shift from low-intensity red during the nighttime hours, to amber at sunrise, peaking at 2500 lux at 6500K during the noontime hour when the residents are having lunch, light intensities will reduce in the afternoon, and the lighting will slowly shift back to amber then red in the evening. It will be important to characterize the interior environment of the Remote Dining Room and the Corridor by measuring the CCT and CRI of the luminaire and the LRV of all the horizontal and vertical surfaces.

4.4. Lighting design standards

The Pennsylvania Department of Health Long Term Care Facilities Licensure Regulations sets the minimum illumination standards for skilled nursing facilities and refers to the Pennsylvania Code Title 28 Health and Safety to determine requirements for existing and new construction, including special electrical requirements. The Pennsylvania Code, Chapter 205 Physical Plant and Equipment Standards for Long-Term Care Nursing Facilities Section 205.68, provides the minimum lighting levels for long-term care facilities. On the other hand, the ANSI/IESNA RP-28-07 *Recommended Practice for Lighting and the Visual Environment for Senior Living* recommends slightly different levels. In general, ANSI/IESNA guidelines recommend slightly higher illumination levels for active resident areas and lower illumination levels at night in areas where resident sleep quality might be impacted (Table 1). ANSI/IESNA is a comprehensive analysis of the visual environment for the elderly that provides the complex criteria to design indoor environments to promote both visual acuity and improved living conditions. For example, although ANSI/IESNA recommends higher lighting levels in some instances, emphasis is also placed on the quality of the light and considerations such as discomfort/disability glare, flicker, light/dark contrast, shadows, and backlighting.

Table 1: Lighting levels as per code. Source: (Authors 2013)

	Pennsylvania Code	**ANSI/IESNA RP-28-07**
Area	**ambient light in lux-units (lx)**	**ambient light in lux-units (lx)**
Public Areas		
Administrative and lobby areas, day	500	300 (500 at task surfaces)
Administrative and lobby areas, night	200	100
Therapeutic Areas		
Physical therapy	200	300
Occupational therapy	300	300
Group Activity Areas		
Recreation area	500	500
Dining area	300	500
Barber and beautician areas	500	500
Chapel or quiet area	300	300
Nurse's Station		
Nurses' station, general, day	500	300
Nurses' station, general, night	200	100
Nurses' desk, for charts and records	700	500
Nurses' medicine cabinet	1000	1000
Circulation		
Corridors and interior ramps	200	300 (day) / 100 (night)
Exit stairways and landings	50 (on floor)	300
Doorways	100	100
Resident Rooms		
Resident care unit (or room) general	100	300
Resident care room, reading	300	750
Toilet and bathing facilities	300	300 (600 shaving/make-up)

The Pennsylvania Code for Long-Term Care Nursing Facilities specifies illuminances for skilled nursing facilities, but the standard does not specifically include color temperature or wavelength. Furthermore, the standard lighting levels are *minimum* requirements, not necessarily optimal solutions. Most literature recommends light levels in the range of 2,500 to 3,000 lx (ten times the minimum requirement by code, see Table 1) (Sloan 2007) at a color temperature in excess of 6,500K (van Hoof 2012, Sinoo 2011, van Hoof 2009) within the blue spectrum of a shorter wavelength in the range of 460nm (Brainard 2001). The minimum averages required by code are horizontal illuminances (E_h) measured at 30 inches above the floor, which is not necessarily where the eye of the older adult actually is. To adequately measure light coming into the eye, the lighting level must be measured as a vertical illuminance (E_v), or in the "gaze direction", which still is not necessarily where the eye of the older adult is *looking* (for example, the person may be looking down at a tabletop, at the floor or across the room).

5.0 EVIDENCE-BASED DESIGN RESEARCH METHODS

The study consists of five phases: screening procedures and informed consent, collection of baseline data, the experimental condition, the collection of post-test data, and the collection of follow-up data at two points in time following the experimental condition and post-test data collection. A pre-test/post-test design will be used to determine the effects of LED luminaire on patient's global function, and sleep and activity pattern.

Measures. Sleep and activity pattern will be measured using wrist actigraphs. An interview schedule with open ended questions will ask staff caregivers about their perceived changes (positive or negative) of a patient's mobility, language, alertness, motor coordination, time spent doing purposeful activities, self care abilities, level of anxiety, or agitation will be used to assess global functioning of patients.

Phase 1. After obtaining Institutional Review Board (IRB) approval, the study will be explained to potential participants deemed competent to make medical decisions and to their legal guardian(s). Full consent will be obtained from patient's legal guardian(s) and participants who are deemed eligible to participate. Residents will be medically cleared for study participation by the facility medical team.

Phase 2. Baseline data on sleep and daytime sleepiness will be collected for 7 consecutive days on the nursing home residents. A wrist actigraph will be worn continuously for 7 days to collect data on sleep characteristics; measures of daytime sleepiness will be collected at each meal.

Phase 3. Daylight-matching LED luminaires will be installed in the Remote Dining Room and in the corridor leading to it (Figure 4). As per the Lighting Schedule (Figure 5), starting with the dim red-light night condition (100 lux at 1000K), the lighting will gradually increase in intensity to the bright noontime condition (2500 lux) color-shifted toward the blue range (6500K) to stimulate the residents' circadian clocks. The lighting levels will gradually decrease and then maintain ANSI/IESNA recommended lighting levels (500 lux) for the rest of the day to support visual acuity for the aging eye. At dinner, the lighting will gradually decrease in intensity and begin the shift toward red nighttime light to prepare the residents for sleeping.

Phase 4. The fourth phase includes data collection on sleep and activity pattern, and global function 30 days after intervention.

Phase 5. The fifth phase includes data collection on sleep and activity pattern, and global function 3 months and 6 months after intervention.

Data Analysis. Descriptive statistics, including frequency distributions, percentage distributions, and means and standard deviations will be used to describe the sample of participants with dementia. The impact of the luminaire on global function will be explored through interviews with staff caregivers for each participant by using a descriptive qualitative approach. Baseline value corresponding to response variable will be used as covariate in univariate analyses. The adjusted means will be used for calculation of effect sizes.

CONCLUSION

The EBD research at St Francis will advance knowledge in design of the indoor environment by establishing a new, dedicated metric for quantifying light for circadian regulation for the elderly, by evolving a new lighting design for modern healthcare design, and by demonstrating how architectural interiors can become indoor ecologies that improve building occupant health outcomes. Clinical trials at St. Francis Country House and Evidence-Based Design research will validate the broader application of a daylight-matching luminaire to aid in sleep and global function of individuals with dementia and will open a lucrative market for this potentially FDA-approved luminaire for photobiology therapy. Additionally, this EBD research has the potential to impact current and forthcoming safety guidelines offered by the Illuminating Engineering Society (IES).

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