Transforming Healthcare and Wellbeing through Lighting Workshop Report*

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Illuminating Engineering Society and the Center for Lighting Enabled Systems & Applications

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1 WORKSHOP PURPOSE AND OBJECTIVES

1.1 Purpose

Over the last decade, research has unveiled substantial evidence on how the spectral composition of light, illumination levels, and the timing / duration of light exposure impacts human health, physiology and behavior. New Solid-State Lighting (SSL), and in particular, Light Emitting Diode (LED) lighting technology has the ability to dynamically control both light level and the spectral power distribution (SPD) of the light source, opening important research avenues for how LEDs can potentially impact human health and performance outcomes. Presently, the need for spectral tuning control (combined ability to control SPD and light level) is most apparent from extensive research on lighting’s impact on human circadian rhythm regulation, and a full psychophysiological understanding of the mechanisms and human health impacts has yet to be developed.

Emergent evidence from both fundamental and applied research suggests that dynamic management of lighting system spectral composition, illumination levels, and timing affects patient outcomes and healthcare worker alertness and productivity. Commercial firms show significant interest in developing spectrally tunable illumination systems specifically for healthcare and eldercare markets to realize these potential benefits. Although this is an exciting field of scientific study that has great social and commercial potential, the research basis for lighting and control design requirements, lighting specifications, and value propositions for broad market adoption of these new lighting system tools are lagging.

This Transforming Healthcare and Wellbeing through Lighting Workshop was co-sponsored by the National Science Foundation (NSF)-funded Rensselaer Polytechnic Institute (RPI) Center for Lighting Enabled Systems and Applications (LESA) and the Illuminating Engineering Society (IES) to address the research, design, specification, and adoption challenges of new lighting applications for maximizing healthcare benefits and improving healthcare operations. The IES and RPI LESA Co-Chairs brought together leading researchers, selected lighting company representatives, lighting designers, healthcare standards organizations’ representatives, and hospital facility directors to discuss the status, barriers, opportunities and market needs / value propositions for developing lighting standards and specifying / installing lighting systems that can benefit both patients and healthcare providers in healthcare facilities.

The importance of the impact that light has on human health is highlighted by the IES and the Commission Internationale de L'Eclairage (CIE, Austria) in separate strategy and roadmap documents released in 2016. The February 2016 IES Strategic Research Plan\(^1\) identified research to help “understand the impact of light exposure on human health” as one of four prioritized research goals for the next five years. The May 2016 CIE Research Roadmap for Healthful Interior Lighting Applications\(^2\) echoed this sentiment with “recommendations for healthful lighting and non-visual effects of light” as being a research topic as “needing immediate attention” by the research community in support of developments in lighting technology and application.

The current research and development landscape for lighting and health topics is complex, driven by strong differences of opinions between qualified researchers; active commercialization of new lighting products promoting health benefits with limited or no supporting clinical evidence; and unclear or unproven value propositions for adopting new lighting standards for healthcare/eldercare facilities. Some of these complexities are evident in sections of this report, written by recognized experts who have differing points of view. Given the scope of this workshop, this report should not be considered as a comprehensive representation of the subject matter. That said, this report on the workshop proceedings, the available online materials presented by the attendees, and the annexes that were requested by the workshop panelists and produced by some of the workshop attendees, is hoped to be of value to the lighting and health community at large. The organizers feel it is an accurate representation of the challenges in developing a broad, evidence based platform for lighting specifications in healthcare environments and the value propositions needed by healthcare facilities operators to drive broad adoption of future lighting systems that can improve human health and wellbeing.
1.2 Objectives

The Lighting Workshop’s objective was to identify a list of near-term (NT, 1-2 years); mid-term (MT, 3-5 years); and long-term (LT, 5-10 years) research needs to address barriers to and opportunities for SSL applications in the healthcare field on the basis of improving health and wellbeing in these environments. Many experts in this field agree that this identification is critical to establishing the scientific and economic basis for the broad adoption of spectrally tunable SSL lighting, which has demonstrated significant potential. This whitepaper, based on the findings from this workshop, argues for expanding research, coordinating new standards development, and broadening awareness of what advanced SSL lighting systems can offer the healthcare ecosystem for the improvement of patient outcomes, staff performance, staff health, and general wellbeing through building the evidence-based scientific and economic justification for adoption.

The workshop sponsors invited experts in lighting research, architectural lighting design, lighting and facility healthcare standards, and hospital facility operations to assess the current state-of-the-art (SOA) lighting systems and their potential use within the healthcare environment. By centralizing relevant experts across lighting and healthcare ecosystems, and coordinating the discussion specifics, the broader workshop objectives were to expand perspectives across the lighting community, increase cross-community communications, and identify action items to accelerate progress toward the development of evidence-based standards for lighting in healthcare. The workshop participants were also encouraged to move forward as advocates in establishing key collaborations for enhanced educational outreach with the goal of increasing the broader community knowledge and public awareness of this topic. The objective of increased communications also includes contributing to technical road-mapping and program initiation with sponsoring agencies, aiding the acceleration of R&D and new technology applications, and assistance in evolving lighting standards commensurate with new lighting systems advances.

2 WORKSHOP DISCUSSIONS

The workshop sponsors invited three expert panels in i) lighting research for healthcare and Eldercare; ii) architecture/lighting design and specifications; and iii) healthcare operations and standards. The panelists were asked to assess the current SOA, barriers to adoption of new lighting standards, and opportunities for new lighting system advances. Workshop observers were also invited to participate in the three panel discussions. Each of the panelists was provided with specific briefing requests with intended panel outcomes to facilitate discussion and review given the short briefing times and the limited duration of the workshop. To wrap up the workshop, the workshop Co-Chairs invited all workshop participants to identify barriers, action items and recommendations for task groups to move the field of lighting system advances progressively forward in the fourth panel session. Summaries of the four panel sessions are provided in this section, and the workshop agenda is provided as an appendix to this report.

2.1 Panel 1: Light and Health Research

2.1.1 Panel 1 – Background

Six experts in lighting for healthcare and Eldercare research were invited to present data-driven briefings outlining recent research and their visions for continued research on lighting impacts in the healthcare field. Each presenter was asked to summarize research results showing how light impacts human physiology, health, patient care, Eldercare, caregiver performance, and other relevant healthcare/Eldercare outcomes, and to assess what is required to significantly expand understanding and awareness of potential lighting-healthcare benefits in the next 1 to 3 years. The intended panel outcomes were to i) provide an up-to-date view of research on lighting and healthcare outcomes; ii) provide evidence from recent research on the potential role that lighting plays in optimizing healthcare and patient outcomes; and iii) identify opportunities for expanding understanding and awareness of light-health benefits.
2.1.2 Panel 1 – Discussion

Numerous lighting intervention research studies have shown measurable impacts on three psychophysiological dynamics in a variety of healthcare settings; i.e., i) biological response, e.g., sleep duration; ii) functional capabilities, e.g., alertness and reaction time; and iii) subjective emotional perceptions, e.g., caregiver and patient satisfaction. Generally speaking, changes to the three dynamics can vary with age and daytime versus nighttime shift work. Research results over the last ~15 years have also shown that intrinsically photosensitive Retinal Ganglion Cells (ipRGCs) play a significant role in signaling the circadian system, yet the interdependence of ipRGCs, circadian, neuroendocrine and neurobehavioral changes with light, disease and other human health and performance factors remain to be fully elucidated.

Furthermore, some of the current evidence remains inconclusive with respect to potential benefits versus harmful effects of differing exposures to lighting profiles because of the difficulties in drawing side-by-side comparisons between studies. A vast majority of the research has been dominated by small sample sizes and short duration studies, employing primarily fluorescent lighting with a multitude of correlated color temperature (CCT) variations, and a lack of a common vernacular, metrics, and standardized research practices. In particular, many studies do not report adequately calibrated light-level measurements for the spectral composition of light with a complete SPD, instead using the grossly oversimplified metric of CCT. Furthermore, lighting levels often are not measured at the eye. Opportunities for specific spectral tuning of SSL systems also remains largely unexplored, and although potential beneficial trends are apparent, evidence-based understanding remains nascent with respect to the complex interplay between bio-signaling, multiple light characteristics and human interaction (e.g., patient versus caregiver, day versus night shift exposure, alertness, and the like).

An immediate need exists for i) standardized testing protocols and characterization methods for measuring light exposure conditions (e.g., spectrally resolved retinal irradiance) and psychophysiological benefits / impacts; and ii) the use of a common set of quantitative metrics for reporting illumination conditions and the outcome from multiple types of psychophysiological evaluation methods. Additional systematic evaluations of short- and long-duration laboratory-controlled studies and real-world environments are required to further assess factor interdependence and the potential for acute and chronic effects.

The lack of common standardized testing protocols resulting in ambivalent results remains a concern for developing more defensible standards regarding light and health interactions. In the future, the workshop participants anticipate that individual requirements for light relative to other populations will be considered, potentially resulting in a need for different standards, e.g., patients versus caregivers, very young versus the elderly, daytime versus nighttime shift workers, and medication-induced sensitivities.

The Panel 1 members also discussed the “blue light hazard” frequently cited as being a potential health hazard related to potential retinal damage from lighting, and specifically age-related macular degeneration (AMD). Regarding the latter as a potential hazard, the panelists generally agreed that any indoor light source is unlikely to exceed the blue light exposure outdoors on a cloudy day, so risk to eye safety / health with respect to the impact of LED blue light on the retina is considered extremely unlikely. It was, however, noted that lighting SPD may play a role in hyperopia, as has been documented in animal studies.38
2.1.3 **Panel 1 – Summary**

The six Panel 1 members were asked to address the following question: *Based on the current body of research of lighting system effects on human health and productivity, do you believe we know enough to rewrite the lighting system standards for healthcare / eldercare facilities?*

- **If yes:** What new lighting system standards would you recommend be implemented in the next 1-3 years based on current research in lighting systems advances on personal and professional health and productivity (e.g., both patients and healthcare workers)?

- **If no:** What further research evidence of lighting system benefits on human health and productivity is required to reach the point of rewriting standards in the next 1-3 years?

The panelists generally agreed that current lighting standards could be revised and there is sufficient knowledge to develop some initial lighting guidelines for healthcare standards. The Panel’s general consensus; however, was that additional research is required to support the development of more specific recommendations. In the interim, the panelists recognized two American National Standards Institute (ANSI) / IES standards, Recommended Practice (RP)-28, *Lighting and the Visual Environment for Senior Living,* and RP-29, *Lighting for Hospital and Healthcare Facilities,* both of which have been updated in 2017. It was further believed that the adoption of the recommendations outlined in Lucas, et al.’s 2014 publication and the subsequent CIE Reportership in 2015 be brought forward for IES adoption as a resource for standardizing lighting measurements in light and health research. The IES Light and Human Health Committee is currently reviewing TM-18-08, *Light and Human Health: An Overview of the Impact of Light on Visual Circadian Neuroendocrine, and Neurobehavioral Responses,* for updating and are furthermore debating the ability to develop Recommended Practice documents.

2.2 **Panel 2: Architecture / Lighting Design and Specifications**

2.2.1 **Panel 2 – Background**

Seven experts in Panel 2 from an array of architectural, lighting company and healthcare design firms presented briefings outlining their visions for new lighting systems to benefit patient, caregiver and facility operations. Each presenter was asked to highlight data-based outcomes from their lighting systems development and design work, and, where possible, identify emerging standards and best practices. The intended panel outcomes were to i) show how lighting systems capabilities have dramatically advanced; and ii) demonstrate how illumination systems are poised to deliver a wide range of powerful new capabilities to healthcare providers and facility operators that go beyond simple LED energy savings.

2.2.2 **Panel 2 – Discussion**

For decades, people have been exposed to increasing nighttime light exposure as personal and professional environments were extended into the 24/7 realm and access to handheld electronics became the norm – leading to potentially significant circadian disruptions on a routine basis. Studies of the impact of nocturnal lighting variations on circadian regulation are increasing our understanding of potential harmful impacts of longer or off-cycle light exposure, e.g., the potential for increased incidence in breast cancer and diabetes for long-term nightshift workers. Conversely, a small pilot study with CCT variable lighting suggests potential psychophysiological benefits for elderscare, with other studies showing benefits for nursing staff and pediatric patients and families. Results such as these underscore the tremendous potential for preventative healthcare that future spectrally tunable SSL lighting systems represent. Yet, we do not have a complete understanding of the acute and chronic psychophysiological impacts of these changes on the average population.
Although limited in availability, today’s new lighting advances are evolving to multi-channel, spectrally tunable SSL systems that can more closely mimic the natural light spectrum and diurnal cycle we would experience on a daily basis. Although the most recent SSL advances have other advantages over the more readily available, variable CCT fluorescent systems, consumer selection is driven by product availability, fiscal, operational and safety challenges that dominate the landscape for architectural design and facilities operations, e.g., installation, operation, maintenance, replacements renovation / retrofit, patient versus caregiver operation and energy efficiency standards. As a result, only simple variable CCT (fluorescent and SSL) systems are just now beginning to be installed, and the economic benefits of adopting new and more costly SSL systems have yet to be simply and concisely outlined for industry leaders and end-users.

A commensurate change is also required in existing lighting industry standards, guidelines, and metrics, specifically with regard to the use of the standard lighting metrics system (i.e., lux, candelas) that is inaccurate for characterizing light stimuli that elicit the ipRGC-mediated responses.\textsuperscript{18,19} This was mentioned in the Panel 1 discussion; however, Panel 2 participants amplified the need to establish design criteria and product specifications. Panel 2 also noted that lighting designers and architects must have a clear understanding of how to reasonably justify and implement any new changes to the lighting standards and guidelines. This knowledge would allow the designers / architects to optimize selection of lighting systems and persuade end-users of the economic benefits of these new choices. Additional challenges identified include the design of both the lighting and the required control system that would ensure optimized utilization.

\subsection*{2.2.3 Panel 2 – Summary}

The panelists were also asked to address the following questions: \textit{Are today’s lighting systems’ products for the healthcare industry capable of delivering human and wellbeing benefits as defined by the current body of research evidence?}

- \textbf{If yes:} What is needed to accelerate early adoption within healthcare / eldercare facilities within the next 1-3 years?
- \textbf{If no:} What consumer pull is needed to help propel the development in the lighting industry to be able to achieve product availability stage in the next 1-3 years?

On the whole, the panelists agreed that in addition to a cost-benefit analysis of using advanced lighting systems, more evidence-based SSL design results from real-time application studies are required to persuade industry leaders and end-users to adopt new technologies. Although the ease of use and cost of implementing SSL technologies continues to improve, product availability remains a challenge, and only limited research results specifically related to the use of SSL systems are available to-date.

The Panel recommended that researchers in partnership with architectural and lighting design leaders need i) to increase the broader communities’ awareness of new technologies and benefits; and ii) to assess use and integration in current and planned facility designs. As noted in Panel 1, the Panel 2 members also felt more emphasis is required on achieving quantifiable patient / staff outcome results using a standard set of metrics to allow for side-by-side comparisons between studies. Further, Panel 2 advised increasing the understanding of how spectrally tunable SSL systems might compensate in areas where access to natural light is either limited or unavailable. The panelists also recommended revised standards that set a different lighting efficacy minimum requirement for healthcare installations by allowing for potential exemptions from existing energy efficiency product standards, e.g., DesignLights Consortium (DLC) SSL product certifications. These exemptions should be periodically revisited as the technology and an understanding of benefits and impacts continues to advance.
2.3 Panel 3: Healthcare Standards and Hospital Facilities Organizations

2.3.1 Panel 3 – Background

Five panelists representing healthcare operations and standards presented briefings on lighting standards critical to high-level facilities operations including examples of cases in which a new capability has proven to drive either new standards and / or operational benefits for patients, caregivers or providers. In particular, each presenter was asked to discuss lighting system standards, including i) the level of evidence needed to drive adoption of new standards in lighting systems; ii) the level of evidence needed by facilities operators to install or upgrade lighting systems; and iii) lighting standards and facilities requirements that researchers, architects and lighting companies need to consider. The intended panel outcomes were to i) provide an up-to-date view of research on lighting and healthcare outcomes; ii) provide clear evidence of how recent research results show how lighting plays a strong role in optimizing healthcare and patient outcomes; and iii) identify opportunities to expand understanding and awareness of light-health benefits.

2.3.2 Panel 3 – Discussion

To-date, some early LED technology adopters have experienced disappointments with early failures and increased replacement costs, leading to disincentives to adopt new technologies. The economics of increased cost for implementation, especially control systems, and limited supply availability and a lack of real-world application data for long-term benefits reduces the adoption of these new spectrally tunable lighting systems. Nonetheless, Panel members urged that community advocates seek opportunities for demonstrating the benefits of spectrally tunable SSL lighting systems advances for new builds and potential building upgrades and / or repurposing. An example of a repurposed hospital space designed with technologies replicating natural light access showed clear emotional benefits to patients and families. To date, however, there is little or no data on patient outcomes tied to lighting systems that deliver variable spectral distribution, illumination level, and timing capabilities beyond simple CCT cool white / warm white switchable systems.

In addition to cost-effectiveness, hospital facilities and operational personnel want to identify if additional behavioral and personnel and patient tracking benefits may be achieved in the context of large urban hospitals facing challenges with vulnerable populations. Many urban healthcare facilities face significant challenges in dealing with transient patients that may come and go without any formal release process, but it is unclear how lighting (without occupancy sensing / tracking capabilities) could address those issues. Also, current equipment-based regulations do not account for behavioral health challenges, although early indications suggest there may be movement in that direction (see Annex 3).

2.3.3 Panel 3 – Summary

The panelists were also asked to address the following questions: Based on what we know today, is the current evidence of the health and productivity benefits and contributions to patients and healthcare personnel enough to drive changes in lighting systems?

- **If yes:** What is needed to accelerate earlier adoption of new lighting systems within the healthcare / eldercare industry in the next 1-5 years?

- **If no:** What else is needed to accelerate the adoption of this body of research in the healthcare/eldercare industry in the next 1-5 years?

Overall, the Panel 3 members noted that the U.S. trails behind Europe in adoption of lighting system advances, driven in part by differences in cultural expectations and norms with respect to the wellness and health benefits of natural light exposure in indoor environments. The panelists also generally agreed there are sufficient indicators from U.S. research and abroad showing beneficial results for both
patients and caregivers. These results provide evidence for stronger advocacy for improved lighting standards to address these issues.

On the whole, the Panel and workshop members felt that accelerating the adoption of new SSL technologies will require a multi-prong approach to enhance the awareness of industry leaders across multiple organizations, including assessing potential beneficial impacts for implementation by regulatory bodies and impacted industries such as utility (energy savings) and insurance companies (patient benefits). Furthermore, the panelists recommended that more conclusive evidence of long-term benefits from real-world field research is needed with a focus on addressing the immediate, highest priority challenges. These include but are not limited to understanding the distinct differences in lighting requirements for daytime versus nighttime shift workers. Panelists also suggested that more partnerships are needed between researchers and operational facilities for future in situ studies. Workshop participants further noted that lighting designers and architects need to be considered an integral part of early design concepts and proposal bids to ensure that technology advances are incorporated and research budgets are appropriately developed. Panelists also proposed that the new illuminance guidelines in development by the Facility Guidelines Institute (FGI) should also be considered in new design builds and renovations.

2.4 Panel 4: Planning Session for Overcoming Gaps

2.4.1 Background

The workshop Co-Chairs presented the following focus questions to workshop participants with the goal of identifying barriers and research gaps as well as potential opportunities in the short-term, 6 months to a year; NT, 1-2 years; MT, 3-5 years; and LT, 5-10 years to move the field of lighting system advances progressively forward.

- What further research understanding is required in the next 1-5 years?
- How can we work together holistically as researchers and standards organizations to drive and introduce new lighting systems standards?
- How do we educate the broader field on the opportunities in the new lighting capabilities for human health and wellbeing?
- Do the necessary lighting/control systems exist? If not, what needs to happen to get the lighting companies interested in making them?
- What kinds of Return on Investment (ROI) metrics make these lighting systems advances attractive to healthcare facilities and operations managers?
- What else can be done (more futuristic concepts – lighting based actigraphy, asset tracking, interfaces to EMR, other)?
- What can we most effectively do in the next 6 months to a year as a community of industries, industry associations, researchers and research centers to actively pursue more R&D funding for this field?
- Which entities do we pursue first?
- What actions are you willing to take to assist with this?

2.4.2 Discussion

Workshop participants discussed each of the above questions as the basis for identifying barriers, opportunities, and potential action items. The participants identified the need to assess and summarize six topics of existing knowledge that provide baseline reference material for research moving forward. Five Task Groups composed of workshop participants were identified to prepare Task Group reports,
which constitute the first five annexes within this paper. The sixth annex summarizes barriers identified by the participants during the fourth panel review. The Panel also identified key research needs for short-term, NT, MT, and LT objectives specifically tailored to the better understanding of lighting needs in healthcare facilities.

2.4.3 **Panel Summary**

Workshop Report summaries from the task groups are provided in Section 3.0. Identification of barriers, and short-term organizational actions and research needs follow thereafter in Section 4.0.
3 WORKSHOP REPORTS

A short summary of each of the six reports follows in the order they are presented within the Annexes section.

3.1 Annex 1: The Circadian Phase Response to Light

There is a need to define the term “circadian” when used in light and healthcare research. Annex 1 provides a description of circadian phase response curves (PRCs) and the characteristics of light exposure that determine the PRC response.

3.2 Annex 2: Reporting Mechanisms for Research on Dynamic Lighting and Healthcare Lighting

There is a need to develop a standardized set of reporting metrics for research on how light affects human health. Annex 2 sets forth a set of reporting guidelines from which standards could be developed for lighting research, thereby yielding results that can be compared between all studies using these metrics and methods.

3.3 Annex 3: Emergent Study Review

There is a need to succinctly describe the state of research emergent studies that demonstrate the potential for dynamically controlled spectrally tunable lighting. Annex 3 provides a summary of studies performed to date, upon which future studies can build upon.

3.4 Annex 4: Standards Development - Lighting Working Group with FGI and IE

There is a need to develop a path forward for developing lighting standards for healthcare facilities, in anticipation that future research will reach conclusions that could lead to prescriptive lighting design recommendations that will benefit patients and healthcare workers alike. Annex 4 provides a pathway for developing these standards.

3.5 Annex 5: Developing a Business Case for New Lighting Systems in Healthcare

It will be necessary to develop approaches for estimating the ROI that could be expected by healthcare facilities managers if new lighting systems and operating specifications designed to impact patient recovery and improve healthcare worker performance were installed. Annex 5 proposes a formal approach for establishing ROI scenarios for facilities managers considering new lighting systems with new SPD, illumination level, and timing capabilities.

3.6 Annex 6: Barriers Identification

Annex 6 lists the barriers identified by the workshop attendees that limit medical staff, design practitioners, and facility managers from implementing new lighting measures that could provide benefits to patients and / or healthcare workers.
4 RECOMMENDATIONS FOR FUTURE RESEARCH

Workshop participants were also asked to identify action items in the short-term, NT, MT, and LT to overcome potential barriers to success that are described in Annex 6. Suggested times are from the release date of this white paper. These actions items are identified in this section, delineated between organizational actions and research needs.

4.1 Short Term Organizational Actions (6 months – 1 Year)

Several short-term organizational actions were identified to be addressed within the next six months to a year. Thereafter a determination will need to be made as to how often these items need to be reviewed and revised.

4.1.1 Lexicon (IES)

Establish a common set of lighting systems research definitions and lexicon for community use, including the fundamental definitions for Phase Response Function in Annex 1. This effort can be headed by the IES through the various lighting committees and Recommended Practice RP-16, Nomenclature and Definitions for Illuminating Engineering.

4.1.2 Reference Compendium (IES)

Generate and provide access to a bibliography of research reviews and seminal reference papers. The IES will build upon and integrate previously created reference lists and update this resource through their information management system, using input from this document, IES Standards committee members, and other research institutions.

4.1.3 Develop Standard on Metrics and Methods for Light and Human Health Research (IES)

Define common metrics and reporting standards for research studies to allow for side-by-side comparison of results. Annex 2 could be used by the IES in developing a Recommended Practice (RP) for Light and Human Health Research Measurements and Methods. This RP could include:

- Hard metrics (for biological and functional needs using standard technical reporting guidelines);
- Soft metrics (for emotional and comfort needs, such as the Hamilton depression scale\(^{21}\)); and
- Spectral distribution, illumination level, and timing lighting metrics, including development of criteria used for weighting functions and eye safety metrics (e.g., for blue-light hazard concerns).

4.1.4 Publish a Paper Describing the Phase Response Function (IES)

Publish a consensus white paper on the Phase Response Function and its importance in light and human health research as described in Annex 1. This stand-alone document is desired to promulgate an understanding of these issues to a broad audience and set criteria for the use of the terms in medical research.

4.1.5 Joint FGI and IES Lighting Standards Working Group (FGI, IES)

As described in Annex 4, an IES Lighting Working Group has been established to work with the FGI, to coordinate the efforts between the four IES committees involved with light and human health, and healthcare facilities. This Working Group will develop new methods for integrating research findings into standards through the FGI and IES consensus process.
4.1.6 **Research Gap Analyses (IES, LESA, and other Organizations)**

Compare emergent research studies in Annex 3, and review recommendations in CIE 218:2016 to identify gaps in current understanding and research study needs in the NT, MT and LT. This gap analysis will provide a good starting point for defining new studies that adhere to recommended metrics and methods for light and human health research (see Annex 2).

4.1.7 **Qualified Test Bed / Research Facility Listing (IES, LESA)**

Compile and provide access to a list of available academic and industry research facilities available for potential R&D collaboration and partnerships that use best practices and reporting methods (e.g., HKS Human Experience Lab, Well Living Lab, Light Research Program at Thomas Jefferson University, LESA UNM Hospital Room Testbed, Circadian Light Medical Research Center, and others). This list will also include large academic programs without formal testbed capabilities with a strong track record for lighting and healthcare research.

The listing will report facility capabilities, staffing, research areas of interest, samples of recent published findings, and whether the testbed is open or closed to external collaborations).

4.1.8 **Stakeholder Identification and Support**

The findings from this workshop clearly indicate the need for focused research to move forward in this important area of light and its effect on human health in healthcare facilities. This work is necessary to identify essential partners and key innovators for:

4.1.8.1 **Advocating Research and Raising Public Awareness**

Examples include the American Association of Retired Persons (AARP), the Joint Commission, insurance companies, large healthcare organizations such as Kaiser Permanente and similar companies, medical professional organizations such as the American Medical Association (AMA) and American Nurses Association (ANA), and healthcare committees found within professional societies, e.g., the American Institute of Architects (AIA), the American Society of Interior Designers (ASID), the Center for Health Design (CHD) and the American Society for Healthcare Engineering (ASHE).

4.1.8.2 **Working with Federal, State and Private Agencies**

The focus of this effort will be to advocate for the expansion of funding opportunities for targeted and qualified research based on the impact of illumination on health and wellbeing outcomes, with a particular focus on creating a strong evidence-based foundation for eventual commercialization and standardization of lighting for healthcare facilities. One part of this effort would be to help funding agencies adopt best practices and reporting standards, described in Annex 2, for more efficient comparison of findings from different research groups.

4.2 **Research Needs**

4.2.1 **Near-Term (NT) Research Needs, 1-2 Years**

NT research needs include studies for which a background of reliable information has been developed, and can be accomplished through a targeted funding approach. The research needs in this category will help accelerate the formulation of research protocols for MT and LT studies. In fact, many of these studies may continue as MT to LT studies.

4.2.1.1 **Economic / Business Case**

Develop a comprehensive economic / business case for healthcare, and eldercare facilities that defines the economic drivers and cost / benefits analysis criteria by which lighting systems can be designed when considering the potential impact that lighting and lighting controls have on health...
and wellbeing, electrical systems integration, and facilities operations. The results of such a study would be used as a set of guidelines to assess the ease and/or difficulty in market transformation of a proposed product and/or method of integrating lighting systems into healthcare facilities. Such a business case should utilize concepts in Annex 5 and work to address the Barriers Identification in Annex 6.

4.2.1.2 Population Studies

Some studies have provided indications of differences between groups of people. To gain a better understanding of how lighting design might affect healthy people without eyesight anomalies in healthcare facilities, studies could be conducted or collected to identify potential population differences of lighting guidelines for:

- Individual needs versus average norms (by assigned age groups)
- Needs by chronotype
- Daytime versus nighttime shift workers
- Patient versus caregiver
- Young children versus the elderly
- Medication-induced photosensitivity

4.2.1.3 Real-World Longitudinal 24-Hour Exposure to Spectral Distribution, Illumination Level, and Timing

Conduct research to measure actual spectral distribution, illumination level, and timing exposure to eye incident light over multiple 24-hour days in the workplace, home and other environments to establish actual real-world exposure patterns. This will require portable measurement and recording devices that measure raw data (e.g., narrow 1-5 nm bins) and not just processed results, i.e., CCT, Circadian Stimulus (CS) index so that the real-world spectral distribution, illumination level, and timing exposure profiles can be determined in various populations (e.g., patients, staff, etc.) under different, properly characterized lighting environments.

4.2.1.4 24-Hour Exposure Simulation Studies

Conduct research in controlled environments to assess the effects of different tightly controlled spectral distribution, illumination level, and timing conditions (e.g., continuous conventional blue-rich LED versus circadian alternating evening/night blue-depleted LED and daytime blue-rich LED versus circadian color tuned LED) on i) circadian phase/disruption markers (e.g., melatonin, core body temperature); ii) disease end markers, e.g., DNA oxidative damage marker 8-hydroxydeguanosine (8-OH-dG), gene markers, and glucose tolerance test measured insulin resistance; and iii) subjective user mood and acceptance metrics. This research would be used to devise optimized spectral distribution, illumination level, and timing profiles to guide lighting environment installations.

4.2.1.5 Real-World Longitudinal 24-Hour Optimized Spectral Distribution, Illumination Level, and Timing Lighting Validation Studies

Conduct research of the occupants (e.g., patients and staff) of facilities equipped with optimized circadian spectral distribution, illumination level, and timing lighting to measure i) actual spectral distribution, illumination level, and timing exposure to eye incident light over multiple 24-hour days in the workplace, home and other environments (to confirm targets are met); ii) circadian phase/disruption markers (e.g., melatonin, core body temperature) and disease end markers, e.g., DNA oxidative damage marker 8-OH-dG, gene markers, and glucose tolerance test measured insulin
resistance; and iii) subjective user mood, and acceptance metrics. This research would be used to validate successful transfer of technology and research from controlled laboratory simulation conditions to real-world applications, and adjust spectral distribution, illumination level, and timing protocols to achieve desired circadian and health marker outcomes.

4.2.2 Mid-Term Research Needs, (MT), 3-5 Years:

4.2.2.1 Expanded Population Studies

Based on research gaps identified in the NT action review, well-controlled clinical trials (> 100 individuals) beyond current emergent studies will need to be conducted.

4.2.2.2 Refinement of PRCs

Measurement of the PRCs to polychromatic white light that has various percentages of short wavelength light in the range of peak ipRGC sensitivity, in differing population groups, with a focus on defining confounding variables that can impact the assessment of lighting effect on PRCs.

4.2.3 Long-Term (LT) Research Needs, 5-10 Years:

4.2.3.1 LT Expanded Population Studies

Based on research gaps identified in NT action review, well-controlled clinical trials (> 100 individuals) will need to be conducted, and under longer durations to assess LT effects.

4.2.3.2 LT Matched Population Studies

Prospective health studies of matched populations (e.g., age / gender / occupation / work schedule / prior health) illuminated and not illuminated by specific spectral distribution, illumination level, and timing conditions to assess the development of disease markers and clinical outcomes over 5-, 10-, 15-years. Subgroups include:

- Shift workers with more than 5 nights per month of 12-hour shifts illuminated by blue-rich LED light versus LED light with reduced blue light content;
- Residential facility occupants; and
- Evening workers regularly exposed (5 evening per week) to blue-rich LED light versus LED light with reduced blue light content.
5 ANNEXES

NOTE: The subject of lighting and circadian impacts continues to be a rapidly moving research area with differing (and frequently strongly held) views by subject matter experts as to what the current understanding does or does not allow one to conclude in terms of lighting impacts, product benefits or new lighting standards. This matter is further complicated by a strong market pull for “healthy lighting” from the global lighting industry, sometimes with products launching ahead of careful clinical studies. This white paper acknowledges that there are differing views held by subject matter experts in this domain, and where possible, differing views will be noted.

5.1 Annex 1: The Circadian Phase Response to Light

5.1.1 Introduction – Defining “Circadian”

The word “circadian” has recently entered into lighting industry vernacular often with limited understanding of its precise meaning. This limited awareness can create confusion for both lighting designers and healthcare professionals due to the complexity of the relationship between lighting SPDs and human health and wellbeing.

All electrical light emitting systems can have an impact on human circadian performance over a range of time scales. A circadian lighting system may be defined as a system that seeks to promotes human health, performance and well-being by controlling the emitted intensity, spectrum and timing of light across the 24-hour day to either i) maintain stable circadian rhythm entrainment to a desired day-night cycle, or ii) to accelerate a shift to a new defined day-night schedule. These interactions of light with the human circadian system can be partially characterized by PRCs that define the delays and advances in circadian clock time that are induced by light exposure at different times of day. These PRC characteristics of the circadian effects of light can also be used to distinguish circadian effects from other physiological effects of light.

Merely adjusting CCT, light intensity, or even SPD with time of day does not qualify a lighting system as circadian with regard to an ability to improve human health and wellbeing. Aesthetic benefits may be achieved by CCT color tuning products; however, they should not be labelled “circadian” unless they have been demonstrated through properly designed clinical trials (see section 5.2) to be capable of optimizing the phase, amplitude and / or entrainment of the circadian system to promote human health and wellbeing.

This brief introduction summarizes the complex interactions of natural and electric ambient light with the human circadian timing system and the spectral wavelengths that are most effective in adjusting the phase, amplitude and / or entrainment of circadian rhythms. While visible light across a wide range of spectral wavelengths can regulate on the circadian system, there is a broad peak of spectral sensitivity centered at approximately 480 nm in the blue appearing portion of the visible spectrum.

5.1.2 Circadian Timing System

The circadian timing system of internal pacemakers, “circadian clocks,” neural and endocrine temporal communication pathways, and cellular circadian rhythms evolved in response to the 24-hour rotation of our spinning planet. Over millions of years of evolution, animal survival relied on establishing temporal and geographic niches to accurately predict dawn and dusk and avoid being vulnerable in adverse lighting conditions. For our human ancestors, the temporal niche was to remain active and alert during daylight, hunting and gathering, in contrast to sleeping in a safe location at night when their relative poor senses of nocturnal vision, hearing and smell made them more vulnerable to predators.

The evolutionary solution was to develop an internal biological clock. The primary circadian pacemaker in mammals is the suprachiasmatic nucleus (SCN) in the hypothalamus, which regulates approximately 24-hour rhythms in almost every aspect of physiology and behavior. This circadian pacemaker also
adjusts to the seasonal changes in daylight timing and duration, and migrations across latitude and longitude. While this pacemaker can keep time independent of external time cues such as the geophysical light / dark cycle, and may be modified by light exposure during evening and night hours, it normally entrains to the solar light-dark cycle at the latitude and longitude where the individual is located for any extended period (i.e., weeks) of time. This synchronization of circadian clocks to local solar time by adjusting them forward or back in time as needed each day is mediated by all wavelengths of light, and predominantly by a broad spectral band of blue wavelengths, falling on our ipRGCs. The ipRGCs, contain the photopigment melanopsin with a spectral sensitivity centered at ~ 480 nm. While the ipRGCs are distributed across the whole retina and their extensive dendritic structures are filled with melanopsin, forming a “photoreceptive network,” there appears to be more sensitivity for acute melatonin suppression of ipRGCs to light in the human retina’s lower half that primarily detect the incident irradiance from overhead light sources such as the sky or indoor lighting. After detection, the ipRGCs transmit the retinal irradiance information via a special direct neural pathway, the retinohypothalamic tract (RHT) to the SCN, the location of the master circadian pacemaker as well as a number of other regulatory nuclei in the brain. Our brains and bodies are thus predominantly informed on whether it is day or night not only by the intensity of light but also by whether the ambient light is blue-rich or blue depleted.

Ever since the introduction of blue-rich energy-efficient light sources, whether LEDs, fluorescents or other technologies, understanding the circadian system interactions with electric light during both day and night has become paramount. A growing body of scientific information, including epidemiological studies, human laboratory and animal research has shown that disruptions of the circadian system from exposure to light outside the normal solar day is associated with phase shifts, amplitude and periodicity changes in circadian rhythms. Exposure to light at night that is capable of disrupting the circadian system also can disrupt nocturnal melatonin and sleep. These disruptions have been shown to contribute to the pathogenesis of a number of significant medical conditions including obesity, diabetes, reproductive problems, heart disease and hormonally-influenced tumors such as breast and prostate cancer.

5.1.3 Circadian versus Neuroendocrine and Neurobehavioral Effects of Light

The misuse of the circadian term and potential misinterpretation of data are, in part, a result of the fact that light does have different effects (not all circadian) on human psychophysiological behavior through the ipRGC-melanopsin photoreceptor system that involves rod and cone photoreceptor input. Establishing a clear distinction between the different light effects is critical to understanding how to properly design lighting systems for improving human health and wellbeing. In lighting design, circadian effects are generally considered due to longer-term exposures (e.g., the SPD of a lighting system during a normal working shift).

- **Circadian light effects** are defined as those that cause a sustained change in the phase, period and / or amplitude of the SCN and internal circadian timing system.
- **Neuroendocrine and neurobehavioral light effects** are direct effects of light that may or may not be independent of the circadian system. These effects often involve shorter-term alterations in physiological or behavioral parameters that can have health consequences.

For example, light can elevate alertness and mood, and alter physiological variables such as saliva or blood melatonin levels. Such changes may or may not have sustained effects on the circadian system.

Distinguishing between the circadian, neuroendocrine and neurobehavioral effects is important for the design of spectrally engineered lights. For example, Gooley, et al. showed with an extended 6-hour exposure protocol to either monochromatic green (555 nm) or blue (460 nm) light, that both the green
and blue light had a similar suppressive effect on melatonin over the first hour. The green light induced melatonin suppression; however, rapidly decayed while the blue-light exposure caused a sustained suppression of melatonin. Extended exposure to 6.5 hours of 460 nm monochromatic blue light also induced a two-fold greater circadian phase delay than 6.5 hours of 555 nm monochromatic green light of equal photon density. Spectral sensitivity curves used in designing circadian lighting should be based on studies with long-term (multiple hours) exposures where possible. Unfortunately, a complete analytical action spectrum for regulation of the human circadian phase shifting, entrainment or amplitude has yet to be published. Parsimonious comparisons of selective wavelengths with longer exposures have been published that are reasonably consistent with the results from shorter-term exposures of 30-90 minutes of light that currently comprise most of the published literature on the spectral sensitivity of the ipRGC receptors. Further, research has shown that short-term exposure to light can also impact the human PRC.

Note: There is not complete agreement between researchers on the paragraph above. The challenge to lighting designers who wish to address the physiological, behavioral and health impacts of light is to understand the predominant themes of current published biomedical literature and to be vigilant to emergent literature in this rapidly developing field. Ideally, existing lighting organizations will work to craft new evidence-based standards reflecting new research findings in a timely manner.

5.1.4 Light Interactions with the Circadian Phase Response Curve (PRC)

The interactions of light with the circadian phase resetting system can be characterized by PRCs. The human circadian pacemaker can be effectively modelled, mathematically as a biological oscillator. Depending on the circadian phase of the SCN, light exposure can either phase advance the oscillator (“shift eastward” to an earlier time), phase delay it (“shift westward” to a later time), or have minimal effect. In daytime-synchronized humans, increased evening light exposure produces progressively larger phase delays as night is approached. Then during the individual’s circadian night (the time of normal exposure to darkness and sleep) the SCN’s response switches direction to trigger phase advances which increase in magnitude as dawn is approached, and then diminishes during the morning hours, before the light response reverses back to phase-delays as the evening approaches.

The predominant role of blue light centered at approximately 480 nm in resetting the circadian system has been quantified in studies that compare the PRCs generated by broad spectrum white fluorescent light (4100 K) versus studies that use 480 nm monochromatic blue light. Approximately 75% of the phase resetting efficacy of 10,000 lux white light was achieved by using 480 nm light using only ~4% of the irradiant energy. This means the monochromatic blue centered at 480 nm had approximately 20-fold greater circadian clock resetting potency than white light.

This daily dusk and dawn nudging of the circadian pacemaker phase by the natural light evolved to keep us in synchrony with earth’s 24-hour rotation. Since the advent of electric light, however, we have disturbed our natural circadian rhythms. People are often inadvertently exposed to weak or physiologically disrupting light signals. The loss of a robust and regular day-night environmental light-dark signal, can result in increased sensitivity to the melatonin suppressing and circadian phase-shifting effects of light exposure at night, resulting in a loss of stable entrainment, flattening of the circadian rhythm amplitude and disruption of sleep and other health disorders. These disruptions can be reduced by provision of bright and / or blue rich light during the daytime hours for people who normally sleep at night.

PRC responses are measured with reliable circadian timing system phase markers such as measuring the time of dim light melatonin onset (DLMO) or the time of the core body temperature rhythm nadir. The time of these circadian phase markers with respect to geophysical clock time is measured before a light
stimulus is applied, and for one or more subsequent days after the light stimulus to determine the magnitude of the phase shift.

For example, human PRCs have been derived for one-hour, 8,000 lux ceiling, white light exposure,\textsuperscript{47} and for 1.5-hours, 185 lux, blue light.\textsuperscript{48} A comparison of the results shows that the magnitude of the phase effects (both advance and delay) for approximately 1-1.5 hours, 185 lux, blue light (peak 467 nm) for three days was equivalent to those for 8,000 lux, polychromatic white light. As discussed above, a more direct comparison by Ruger, et al.,\textsuperscript{49} showed 6.5 hours of 480 nm monochromatic blue light at 4% of the irradiant energy generated a PRC with maximum phase shifts about 75% of that achieved by 6.7 hours of 10,000 lux white light. These studies emphasize the importance of blue-wavelength light with regard to circadian regulation and health management.

5.1.5 Characteristics of Light Exposure that Determine the PRC Response Include:

5.1.5.1 Spectral Composition

The blue wavelength irradiance in the visual spectrum is the predominant determinant of the circadian phase response to light exposure. Even at the same CCT, polychromatic white light can have a wide variety of SPDs, some rich in blue wavelength light and some depleted in that region of the spectrum. Therefore, CCT cannot be used as a metric of circadian effect.

5.1.5.2 Intensity of Light

The greater the light irradiance (particularly the blue light component of the irradiance) emitted by a light source, the greater the phase shifts that are produced. It is important to use radiometric measures such as irradiance to quantify the light SPD rather than traditional illuminance measures, such as lux or foot candles, since these do not correlate well with human brightness perception or circadian effect. The photopic curve used for lux meters is centered around 555 nm and significantly underrepresents the most circadian active, short wavelength region of the visible spectrum. Therefore, comparing two lux levels cannot accurately measure the circadian effect without also measuring the SPD.

5.1.5.3 Timing of Light Exposure

For a person synchronized to the local environmental day-night cycle, light in the evening hours delays the circadian clock, and light in the latter half of the night advances clock time. The response to light depends on the individual’s internal circadian phase with respect to geophysical time at the time of the light exposure, so an individual who has just crossed multiple time zones, or has been exposed to sufficiently bright light during nocturnal hours may have a shifted PRC function, and therefore will respond differently, according to the timing of their individual PRC. In such circumstances, each phase shifting light exposure resets the timing of the PRC; so, you are actually “shooting at a moving target.”

5.1.5.4 Duration of Light Exposure

Greater phase shifts are produced by longer exposures to light, provided the light exposure falls within a PRC time window that produces same-direction phase shifts (i.e., all phase advance or all phase delay). Proportionately more phase shifting occurs, however, in the first few minutes of exposure to bright light so that the effect of extended light duration on the magnitude of the phase shift is non-linear.\textsuperscript{49}
5.1.5.5 **Prior Daytime Light Exposure**

Brighter light exposure during daytime hours decreases the sensitivity to light exposure at night. Therefore, for people who are active during the day and asleep at night, a circadian lighting system should provide both brighter light enriched in the blue wavelength portion of the visible spectrum during the daytime and dimmer light in the evening that is depleted of blue wavelengths, and complete darkness during the intended sleeping period.

5.1.5.6 **Season of the Year**

There are changes in human psychophysiological behavior and function that are influenced by the duration of daylight exposure, especially in susceptible individuals.\(^{49}\)

5.1.5.7 **Genetic Phenotype**

There appear to be inter-individual variations in the timing and shape of the PRC that account for the differences in endogenous periodicity and phase-resetting by light;\(^{30}\) the most reliable studies of circadian effects therefore examine the same subjects with and without light treatments.

5.1.6 **Summary**

For people with regular daytime personal and professional schedules and sleeping at night, it is important to maximize the contrast between lighting spectrum and irradiance during the day (brighter and enriched in the blue portion of the wavelength spectrum) and lighting spectrum and irradiance in the evening (dimmer and weaker in the blue wavelengths). Doing so helps boost the amplitude and phase stability of the circadian system, enhance daytime alertness and mood, and maximize the quality and duration of sleep at night.\(^{44; 45; 51; 52}\)

Spending the day outside in bright blue-rich daylight, and the nights in the dark, is the healthy ideal. Unfortunately, many modern workplaces and living environments, especially residential facilities, are characterized by thousand-fold dimmed light during the day (e.g., 50-100 lux inside, as compared to 50,000 – 100,000 lux outside) and thousand-fold brightening during the night (10 lux inside as compared to 0.01 lux outside in the pre-electric world). In such an environment, the lack of a robust circadian entraining signal and the associated circadian misalignment may cause disrupted sleep, mood decrements and health risks.\(^{52}\)

For individuals working night shifts or rotating schedules in 24/7 businesses the disruption by night time light exposure is more extreme. During the biological night, they may be exposed to 500 lux or more of blue-rich LED or fluorescent lights where 20-30% of total visual irradiance is in the blue-appearing part of the spectrum. This can significantly disrupt the circadian system, suppress melatonin and disturb sleep, potentially impacting health and well being.\(^{30}\) Bright blue-rich LED light on the night shift may elicit shorter-term benefits in alertness, vigilance, performance and mood, but may disrupt circadian alignment, melatonin regulation and sleep physiology with potential health consequences.

For a lighting system to best support circadian regulation it should provide a sufficiently large contrast between high blue irradiance during the solar day, and low blue irradiance during the solar night to be effective in entraining the circadian timing system. The spectral engineering challenge of such circadian lighting is not to lose the primary purpose of electric lighting, i.e., to provide high quality white illumination to support visual functions, while controlling the timing of delivery of blue wavelengths that support circadian regulation. Lighting systems seeking to provide these benefits are now entering the market and require a careful scientific assessment.
5.2 Annex 2: Reporting Mechanisms for Research on Dynamic Lighting and Healthcare Lighting

5.2.1 Introduction - Measuring Light for Circadian, Neuroendocrine and Neurobehavioral Regulation

To gather and share data on the non-visual effects of light on human health, it is important for researchers, scientists and application specialists to have common vocabularies and to communicate the parameters relevant to the circadian response, especially when documenting research on human subjects. Different levels of measurement and reporting rigor are required for different levels of studies. The intent of this report is to articulate the important principles and parameters that need to be communicated for good quality studies.

The principles include the following: i) light levels relevant to biological effect need to be measured at the plane of the subject’s eye, not on a horizontal task plane; and ii) data normally collected when documenting light exposure for human visual responses (such as candelas, lumens, lux, cd/m²), are not relevant to the biological and behavioral effects of light, since those units are weighted with V-lambda (the human response curve for resolving visual tasks) peaking at 555 nm. It is important to measure raw SPD of the experimental light sources from 380 nm to 780 nm in no greater than 5 nm increments. Ideally, the incident light at the eye is measured with a spectroradiometer in situ. When a spectroradiometer is not available, SPD data provided by the lighting manufacturer may be used, combined with irradiances or illuminances measured with an instrument at the plane of the eye. Directly measured SPDs, however, are preferable to relying on historical data from manufacturers. More rigorous studies may require reporting of the spatial distribution of the radiances in the visual field, duration of light exposure, time of day of light exposure relative to subjects’ own circadian cycle, light history of the subject, pupil size, and characteristics of the subject that could affect his or her response to light and dark.

Over the past 15 years, seminal discoveries have elucidated the fundamental anatomy and physiology of the photosensory system that supplies input to the circadian, neuroendocrine and neurobehavioral systems. Specifically, a small population of dispersed retinal ganglion cells contain a vitamin A photopigment, melanopsin, that is directly responsive to light. These iRGCs project information to the SCN as well as other regulatory nuclei in the central nervous system. Although light detection for the “non-visual” effects of light is mediated chiefly by the iRGCs, studies on genetically manipulated rodents, normal monkeys, and humans, clearly demonstrate that the visual rod and cone photoreceptors also have a role in modulating this physiology.

Photopic lux is an internationally accepted unit for the measurement of light in terms of daytime vision for humans. At present, there is not a single, standardized, measurement unit available for quantifying light that regulates the circadian, neuroendocrine and neurobehavioral effects of light in humans. A recent consensus position was developed across many of the laboratories that have studied wavelength regulation of the physiological and behavioral effects of light in humans and rodent species. That consensus identified best practices for measuring and reporting light stimuli relative to the circadian effects of light. That consensus also provided a freely available web-based toolbox that permits calculation of the effective irradiance for each of the human iRGC, cone and rod photoreceptors that are capable of driving physiological effects. Subsequently, this consensus was adopted and distributed by the CIE.

Although it would be desirable to have a single metric for quantifying light that elicits circadian, neuroendocrine, and neurobehavioral responses, it is not feasible at this time for two compelling reasons: i) strong evidence shows that the melanopsin iRGCs are functionally and anatomically interconnected with the rods and cones that support vision; and ii) light-induced neurophysiological responses reflect input from all of the retinal photoreceptor classes, with the relative importance of each being highly labile within and between response types. As a consequence, the spectral sensitivity of this recently elucidated photoreceptive system is fundamentally context-dependent.
5.2.2 Reporting Standards and Metrics – Where to Measure

The illuminance / spectral measurement needs to be measured at the eye of the subject, orthogonal to the plane of the eye. Ideally, the exposure time to the light source is recorded, and if head movement is involved, the subject’s direction of view, head movements and eye movements need to be documented and factored into a calculation of average realistic light exposure at the eye.

5.2.3 Reporting Standards and Metrics – Photometry and Radiometry

When documenting light exposure, lighting data must include an SPD of the light source under each condition presented, and if there are multiple sources in a test space at any given point, a composite SPD can be collected at the eye of the subject. A spectrophotometer needs to be used and the data downloaded to the CIE spreadsheet calculator as a series of radiant watts at each 5 nm (or less) increment of wavelength across the visible spectrum (380 nm to 780 nm).

The SPD can then be weighted by V-lambda (the photopic luminous efficiency function) to yield the illuminance incident on the spectrophotometer probe. At the same time, the spreadsheet calculates the radiant watts based on each of the luminous efficiency functions of the five photoreceptors (cyanopsin, rhodopsin, melanopsin, chloropsin, and erythropsin). Knowing the photopic illuminance and the five specific radiant watt values, a constant ratio of specific photoreceptor radiant watts-to-photopic lumens can be created and used throughout the research study. From then on, as long as the SPD of the source does not change, a high-quality illuminance or irradiance meter can be used to collect illuminance or irradiance at the eye. Those measured values then can be referenced back to the SPD for calculating input to the photoreceptors. As a good practice, repeating spectrophotometer measurements of each light setting at the end of the experiment ensures the lighting products or controls have not drifted in their spectral delivery over time.

Alternatively, a spectrophotometer that is capable of collecting absolute spectral power at no greater than 5 nm increments across the visible spectrum can be used for all measurements at the eye throughout the research. These data can be resolved into both illuminance and any radiant power with any desired weighting (i.e., melanopic radiant power, rhodopic radiant power, and the like). At a minimum, all light measurement equipment should be calibrated annually. Calibrations need to be done with a standard lamp traceable to the National Institute of Standards and Technology (NIST) or some other recognized standards organization.

Note: Subject-worn instruments are available for collecting continuous readings of light exposure, but these may automatically weight spectral input using the standard observer, parsed bins of spectral input, or a specific model of circadian stimulus, rather than collecting raw irradiance at all wavelengths. These instruments can be useful for assessing dynamic light exposures of subjects before and during experiments. They are limited, however, in their utility for providing SPDs that can be used for calculating the response of the five known human photoreceptors for circadian photoreception.

5.2.4 Reporting Standards and Metrics – Lighting Equipment, Room Geometry and Finishes, and Subject Location

There are many well-conducted research studies of light on physiological or behavioral responses whose data and results cannot be used today because insufficient information was reported in journal papers about the lighting system used or its spectral characteristics. Furthermore, spectral data on a product may evolve from year to year, so even a precise catalog number product may imply different SPDs when purchased 5 years apart.

Whether documenting lighting used in research experiments, or case study information in architectural spaces, reporting details about the sources of light are essential, whether that is the light from lamps passing through the optics of a luminaire (aka light fixture), or luminaires with dedicated LED source(s). Records and publications, at a minimum, should include photos of the luminaire and provide a specific manufacturer name and detailed catalog number so that readers and other researchers can glean details.
in the future if needed. If the luminaire uses separate lamps (e.g., fluorescent or incandescent or LED),
document the manufacturer name and full catalog number of these items, too, (e.g., Philips F32T8/TL41
fluorescent lamps in two-lamp 2x4 recessed fluorescent troffer with K12 acrylic prismatic lens and
generic electronic ballast, Lithonia 2SP32-K12-GE). Because the luminaire’s optical media may filter
some of the spectral emission from the lamp, collect SPD measurements of luminaires as the light is
passed through the luminaire’s optical media (e.g., lenses), or as the light is incident on the eye of the
subject.

Records and publications should also include documentation on the geometry of the lighting system
relative to the subject’s location and view. Scaled layout of the room and luminaires, in plan and section,
also allow for rapid understanding of the space.

For archiving purposes, provide extensive photos of the test room or space, including finishes, windows,
location geometry of light fixtures, and how the subject interacts with the direct or reflected light from
luminaires, objects, and surfaces. Also document the subject’s orientation, e.g., Is the subject reading,
looking down at the desktop, or sleeping horizontally in bed with eyes closed, or in a classroom facing
the teacher, with head tilted slightly above horizontal? Fish-eye photos from the eye of the subject with
the subject’s normal direction of view are effective communication tools for this.

5.2.5 Reporting Standards and Metrics – Data on Test Subject(s)

Individual characteristics, health and personal light exposure history can influence responses to light.
We recommend consideration for documenting the following:

- General health of study subjects and all Institutional Review Board (IRB) exclusion criteria;
- Age and any measure to estimate the pre-receptoral filtering of the subject’s visual
  system;
- Color vision normalcy, visual acuity and eye health; and
- Specifics of the subject’s chronotype (lark or owl), normal daily schedule (including
  regular work hours and sleep / wake cycle).

For more extensive information on documenting the physical and lighted environment in human factors
research, see CIE 213:2014, Protocols for Describing Lighting\textsuperscript{55}, and Section 3.1.1 of the CIE TR TC3-46-2016,
Research Roadmap for Healthful Interior Lighting Applications\textsuperscript{4} for addressing the stimulus specification.
5.3 Annex 3: Emergent Study Review

5.3.1 Discussion

The physiologic effects of light on humans under controlled laboratory settings are well documented. These effects range from changes in gene expression to overt behavior and can be applied to everyday settings to improve people’s wellbeing. For example, in a baseline adjusted cross-over design study, 104 participants were tested in their everyday office environment for 8 weeks during which they received either standard 4000 K fluorescent lighting at ~300 lux illuminance at the work surface for 4 weeks or blue-enriched 17000 K fluorescent lighting at ~450 lux illuminance at the work surface also for 4 weeks. As compared to the standard white light (4000 K) setting, the blue-enriched white light (17000 K) at 50% higher light levels significantly improved the subjective measures of alertness, positive mood, performance, and concentration, and decreased evening fatigue, irritability and eye discomfort. Daytime sleepiness was significantly reduced, and the quality of subjective nocturnal sleep was significantly improved under blue-enriched white light. Similar benefits are observed with lighting interventions in healthcare settings including hospitals and eldercare facilities.

The effects of light can be broadly dichotomized into acute direct (e.g., changes in the immediate near-term alertness and circulating hormone levels) and pacemaker-mediated effects (e.g., the daily timing of physiologic rhythms such as sleep and alertness). In humans, both type of effects start at the retina. These effects are mediated primarily by the ipRGCs that send projections along a dedicated neural pathway, the RHT, to diverse centers of the brain that regulate these functions including the endogenous clock located in the SCN. The ipRGCs express the photopigment melanopsin which are preferentially sensitive to short-wavelength (blue) light (λ_max ~480 nm) and less sensitive to longer wavelengths (e.g., green at ~555 nm and red at ~650 nm). This differential sensitivity can be effectively utilized to achieve the desired physiologic effects by adjusting the spectral characteristics of light. For example, blue-enriched light used in the morning can enhance alertness whereas blue-depleted light used prior to bedtime can reduce alertness and facilitate subsequent sleep. In addition to the spectral properties affecting these effects, the timing (day or night), intensity (dim or bright), duration (long or short pulses) and pattern (continuous or intermittent) of exposure also modulate the physiologic effects of light exposure. In addition, ocular and neural factors such as pupillary dilation, lens transmittance, amount of retinal field exposure and the geometric relationship of the eyes to a light source play a role in determining the efficacy of photic stimuli. As discussed below, there is growing evidence of tailored lighting, including spectral and intensity modulation, which improve health and wellbeing in patients and care providers.

Several studies have documented a significant association between inadequate light (i.e., dim lighting environments) and increased fatigue and mood disturbance in hospitalized patients. Over the course of a year, using a descriptive correlational design, 40 men and women who were admitted to a large academically affiliated U.S. hospital were monitored for 72 hours for light exposure, sleep-wake patterns and mood along with subjective pain scores from medical records. Daytime light intensity ranged from ~10 lux to ~700 lux, with a mean average across the year of ~100 lux. Importantly, total mood disturbance scores and fatigue ratings were inversely associated with light intensity. Pain levels were high and positively associated with fatigue, but not directly with light exposure. In another observational study, resident behavior was monitored across 53 Alzheimer’s disease Special Care Units to characterize the association between aspects of the staff and physical environment and resident agitation levels. The study was designed to control for resident cognitive and functional status and found significantly lower residents’ agitation levels with brighter light.

Other clinical outcomes also have been correlated to lighting conditions as follows. In a randomized prospective study, patients undergoing elective cervical and lumbar spinal surgeries were admitted to...
the bright or the dim side of the same hospital unit postoperatively. Patients staying on the bright side of the hospital unit were exposed to 46% higher-intensity sunlight on average and reported less perceived stress, less pain, required 22% less analgesic medication per hour, and had 21% less pain medication costs. As an another example, in a retrospective study of myocardial infarction patients in a cardiac intensive care unit treated in either sunny rooms or dull rooms found that female patients stayed a shorter time in sunny rooms (2.3 days in sunny rooms, 3.3 days in dull rooms), and mortality in both sexes was ~5% lower in sunnier, brighter rooms as compared to dim rooms.

Planned interventions to improve lighting environments, including daily regimens of bright light exposure in the morning, can also improve mood and reduce agitation. Daytime exposures to bright light, from either sunlight or a few hours of bright-light therapy also have been shown to improve recovery; reduce delirium, depression, anxiety, and analgesic use; and shorten length of stay. These studies suggest that there are at least two important factors to consider for designing dynamic lighting environments. First, how to provide adequate light exposure / intensity during the day and second, how to provide an appropriate spectral distribution of lighting throughout the day. In assessing future options and potential standards, it is important to compare and contrast to the current standards and guidelines for lighting systems in patient rooms with recommended horizontal illuminance thresholds in the range of 100–300 lux. These thresholds are orders of magnitude lower than typical daytime outdoor illuminance (~100,000 lux on a cloudless summer day). In contrast, at night, these thresholds are too high since half-maximal phase resetting of the human circadian pacemaker can be achieved with 100 lux light in dim-light adapted individuals.

Ideally, use of dynamic lighting conditions would allow for a change in intensity and spectral characteristics to optimize bright blue-enriched light exposure during the morning and daytime and use of dim blue-depleted light during the evening. Studies have shown that these lighting conditions are generally well tolerated in clinical settings and can improve mood in both patients and care providers, as shown with the following examples.

In one study, thirty-five individuals with Alzheimer’s disease and related dementia (ADRD) and their caregivers, living at home, were followed for 11 weeks. Baseline measures of depression and sleep quality were collected for one week using validated questionnaires and objective data on light exposure levels and sleep-wake activity. Thereafter, data was collected following the installation of a dynamic lighting system. The system provided for moderate intensity (350-400 lux corneal exposure) blue-enriched (~9000 K) light exposure during the day and reduced lighting in the evening. Study results showed significantly improved circadian stability and sleep efficiency, and reduced symptoms of depression in the participants with ADRD. The caregivers also exhibited an increase in circadian stability and improved sleep with the lighting intervention.

A similar lighting intervention was provided for ADRD patients living in nursing homes with moderate intensity blue-enriched white light exposure designed to deliver high circadian stimulation during the daytime. The intervention was applied in 14 nursing home resident rooms for 4 weeks. Light-dark and rest-activity patterns were monitored objectively. Sleep duration and efficiency estimates were obtained from the rest-activity data. Measures of sleep quality, depression, and agitation were collected using standardized questionnaires, at baseline, at the end of the 4-week lighting intervention, and 4 weeks after the lighting intervention was removed. The intervention significantly improved self-reported sleep quality and increased objectively assessed total sleep time and sleep efficiency. The lighting intervention also improved circadian stability and reduced clinical measures of depression and agitation.

In another controlled clinical trial, the effects of patient-room lighting on sleep were investigated for 196 cardiac patients. Patients were either assigned to a room with standard fluorescent illumination with static light levels or to a room with an interventional fluorescent lighting system offering a dynamic
24-hour light-dark schedule. The interventional lighting schedule included automated gradual changes in illuminance and CCT (3000–6500 K) across the day with low nocturnal light exposure, bright, blue-enriched white light (1750 lux, 6500 K) between 10:30 am and 12:30 pm, and a 45-minute post-lunch illuminance of 100 lux (3000 K) on the bed. Patient and staff lighting appraisals in the intervention rooms were better as compared to the control rooms with standard lighting. Objectively assessed sleep duration of patients improved by 5.9 minutes per hospitalization day, and after 5 days of hospitalization, sleep duration in the lighting intervention rooms increased by 29 minutes, a 7.3% improvement as compared to the control room condition with standard lighting.

Additional studies have shown that appropriately timed exposure to bright light improves sleep in patients with beneficial responses for both adults and neonates. For example, dynamic lighting schedules in neonatal intensive-care units have been shown to improve sleep and weight gain among preterm infants. In one study, 41 preterm infants in structurally identical critical care units (CCUs) were provided either dynamic or static (constant light levels during the day and night) lighting. As compared to infants in the static lighting condition, there was greater rate of weight gain, improved and earlier ability to be fed orally, reduced number of days on the ventilator and phototherapy, and enhanced motor coordination in infants assigned to the CCUs with dynamic lighting conditions. These studies clearly show the benefits of dynamic lighting schedules on various patient populations.

Emerging evidence also supports the use of dynamic lighting schedules for improved work performance in care providers. Dynamic lighting effects on sleep quality and salivary melatonin levels was examined in 113 intensive care unit (ICU) nurses. In the control group, nurses received standard fluorescent illumination with a static lighting schedule, whereas the intervention group received a dynamic lighting schedule resulting in receiving more light, both during the day- and night-shifts. In the dynamic schedule, lighting during the day imitated natural daylight spectral characteristics, with a corresponding change in the evening and night light spectral characteristics to prevent the suppression of melatonin production. There were no significant differences between the two groups regarding personal characteristics, and no significant differences in objectively measured total sleep efficiency or melatonin levels. Yet, the intervention group felt more rested, with an odds ratio (OR) of 2.03, and assessed their condition on awakening as better than the control group (OR = 2.35).

5.3.2 **Summary**

While these studies suggest a strong association between dynamic lighting interventions and improved clinical outcome, the results are not consistent. Systematic reviews and meta-analyses have suggested marginal benefits of light therapy on improving sleep in dementia patients. Although the exact reasons for inconsistent findings are not clear, possible contributors are small sample sizes (reduced statistical power), unequal or skewed gender distribution (sleep and circadian characteristics differ between genders), wide age ranges (sleep and circadian characteristics differ between young and old adults), minimal characterization and / or adjusting for comorbidities, including sleep disorders, and medication use. The collective results of the studies warrant detailed investigations using controlled clinical trials with appropriate statistical power. Additionally, pragmatic clinical trials are warranted to show the effectiveness of such interventions.
5.4 Annex 4: Standards Development - Lighting Working Group with FGI and IES

5.4.1 Discussion

The IES is an accredited ANSI Standards Developing Organization responsible for developing illuminating engineering standards, including two recently updated recommended practices, RP-29, Lighting for Hospital and Healthcare Facilities,10 and RP-28, Lighting and the Visual Environment for Senior Living.5 The FGI is responsible for developing standards for healthcare facilities, including Hospitals and Outpatient Facilities, and Residential Health, Care, and Support Facilities.

Ellen Taylor, Vice President for Research Center for Health Design, introduced Brian Liebel, Director of Standards and Research, IES, to Douglas Erickson, CEO, FGI, to start discussions about how the IES and FGI might collaborate to include IES Standards within future versions of the Facility Guidelines. Mr. Erickson identified the best model for IES to collaborate with the FGI is to form a Memorandum of Understanding (MOU). After the MOU is established, the IES would develop a Lighting Working Group.

The most recent IES Standards are ANSI approved and will be on continuing maintenance, which means that the IES committee can and will continue to update the documents on an as-needed basis as new science and practice techniques are approved through the IES Standards process. The FGI documents are at the end of their 4-year cycle, however, and new information cannot be introduced for the 2018 editions by a new FGI / IES Lighting Working Group. The Lighting Working Group would therefore begin with the next FGI cycle and would use the current rendition of the IES Standards as information for the FGI documents. This will promote lighting as a more integral design consideration in healthcare facility design, and given the potential for research advances over the next 4 years, could result in recommendations for dynamically controlled, spectrally tunable lighting with advanced control capabilities that may provide benefits to patients and healthcare workers.

5.4.2 Summary

Actions being taken include:

- There is agreement between the IES and FGI to develop an MOU that will allow the Lighting Working Group to collaborate with FGI on possible white papers and interim guidance regarding their standards.

- FGI will identify a member of their Health Guidelines Revision Committee that will serve as the liaison to the IES Lighting Working Group.

- Several members of the IES Light and Healthcare Committee have volunteered to participate in this effort and are working on the structure within the existing committees to align with the FGI documents and process.
5.5 Annex 5: Developing a Business Case for Advanced Lighting in Healthcare

The goal of the business case for advanced SSL systems (e.g., variable spectral composition, illumination levels and timing capabilities) in healthcare needs to be premised on the *incremental* differences to a baseline condition of daylight or other electric light sources with a fixed SPD. In this phase, the goal is not to make the business case; rather, it is to establish a framework for future development. This approach might leverage the position taken by Berry, et al., in the “Fable Hospital” to establish hypothetical design interventions and outcome targets with outlined assumptions (e.g., see Tables 1 and 2 below).

Table 1: Incremental Cost to Achieve a Better Building, excerpted from Berry et al. Figure 1.112

<table>
<thead>
<tr>
<th>Changes</th>
<th>Additional Costs ($)</th>
<th>Calculations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Larger Private Patient Rooms</td>
<td>4,717,500</td>
<td>Based on assumption of an increase of 100 square feet for each of 255 single-patient rooms. Fifteen percent of the beds (45) are in an ICU configuration: 100 sq. ft. x 255 beds @$185 / sq. ft.</td>
</tr>
<tr>
<td>Acuity - Adaptable Rooms</td>
<td>816,000</td>
<td>Assumes additional medical gases and monitor mounts in every room to provide ICU / stepdown capabilities with plug-in monitors: 255 @ $3,300 / rm</td>
</tr>
<tr>
<td>Larger Windows</td>
<td>150,000</td>
<td>The typical 3’ x 5’ patient room window is increased to 5’ x 8’: 300 @ $500 / ea.</td>
</tr>
<tr>
<td>Larger Patient Bathrooms with Double-Door Access</td>
<td>1,509,600</td>
<td>The larger space allows two staff members to assist a heavy patient to the toilet, and the enlarged doorway allows patient beds to be rolled in a sitting configuration closer to the water closet. Additional 32 sq. ft. / toilet x 255 = 8,160 sq. ft. @ $185 / sq. ft.</td>
</tr>
</tbody>
</table>

Table 2: Incremental Cost to Achieve a Better Building, excerpted from Berry et al. Figure 2.112

<table>
<thead>
<tr>
<th>Evidence</th>
<th>Savings ($)</th>
<th>Calculations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient falls: Reduced</td>
<td>2,452,800</td>
<td>• Patient falls are common and can cause significant harm. Falls result from patient instability, confusion, unfamiliar surroundings, lack of assistance, poor lighting and slippery surfaces.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• The national unlitigated average cost of a fall is $10,000 (Hendrich, 1995113); litigated falls can cost in the millions. Assuming payment for care is on a case-rate basis (e.g., Medicare), the cost of patient falls goes directly to the bottom line.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• The national median rate of acute care falls is 3.5 falls / 1,000 patient days; this is the rate experienced by Fable’s predecessor hospital. Fable reduced patient falls by 80% by locating toilets closer to the patient, putting double doors on bathrooms, using bed exit features that notify a nurse when a patient is out of bed, decentralizing nursing stations, and locating supplies close by to reduce the amount of time the nurse is away from the patient. Fable’s reduced patient fall rate is similar to that experienced by Pebble partner Clarian Health Partners Methodist Hospital, Indianapolis (Hendrich, Bender, Nyhuis 2003114; Flynn 2003115).</td>
</tr>
</tbody>
</table>

**Savings:** 300 beds at 80% occupancy = 240 beds = 87,600 patient days / 1,000 x 3.5 = 306 falls / year x $10,000 = $3,066,000 Reduced by 80% = savings of $2,452,800.
The first stage to develop a business case for SSL for dynamic lighting in healthcare settings would be i) to gather and assemble the available information, e.g., research and best practice studies; and ii) to establish the relevant interventions and variables. This would also inform research gaps.

The challenge will be to i) establish study variables; ii) evaluate hypothesized outcomes; and iii) assess the outcomes with respect to potential financial impact, which, in many cases, does not exist in the currently available research. For example, improved sleep may result in reduced length of stay, resulting in cost savings; however, studies on sleep quality may not measure the resulting reduction in length of stay. Beyond patient benefits, dynamic lighting may have other benefits related to staff health and wellbeing, reduction of medical error rates and increased staff retention (particularly for shift workers). Different lighting designs and performance expectations may be required for different areas of a given facility. Assumptions will need to be made and clearly stated relative to the incremental contribution of the lighting intervention(s) due to the complexity of potential confounding variables. An initial framework for the LED business case is proposed as follows.

Tables 3 and 4 present rough outlines of variables that can be considered for many different scenarios and space types when developing a business case for lighting system alternatives. The general concept is to evaluate traditional lighting economics that consist of comparisons of system cost and benefits principally derived from capital, operational, and energy expenditures (non-human interaction). Thereafter, a research team would need to develop economic outcomes tied to the light-human interactions via subjective and objective evaluations of comfort, performance, health and wellbeing. For each light-human interaction economic variable, the research team would develop a business case, including how metrics might be developed, tested, and translated to economic factors and contribute to the overall analysis.

Table 3: Preliminary Framework to Develop the Business Case for Dynamic Lighting Systems.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Measured by</th>
<th>Financially-Associated Outcome</th>
<th>Baseline (daylight / other electric light)</th>
<th>Min. to Max. Incremental differences with LED (+/- % and associated $ value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital Costs</td>
<td># luminaires, installation cost (labor, etc.), interest rate, years of service</td>
<td>First Cost</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Variable Costs</td>
<td>Energy costs, # luminaires, price of electricity, annual burning hours, luminaire power, lamp and ballast, # lamps, lamp price, lamp life, etc.</td>
<td>Life Cycle Costs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy Cost</td>
<td>“</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group Replacement Cost</td>
<td>“</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spot Replacement Cost</td>
<td>“</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Service Costs</td>
<td>“</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduced Energy Consumption</td>
<td>“</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Disposal</td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
Table 4: Preliminary Framework to Develop the Business Case for LED Lighting and “Circadian-Equivalent” illuminance Values.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Measured by</th>
<th>Financially-Associated Outcome</th>
<th>Baseline (daylight/ other electric light)</th>
<th>Min. to Max. Incremental differences with LED (+/- % and associated $ value)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>STAFF</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Staff Visual Performance / Discomfort</td>
<td>Tracked errors based on misreading</td>
<td>Errors (e.g., medication type,</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>dosing quantities and timing,</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>time off-task)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Staff Stress</td>
<td>Nurse Stress Scale (NSS)(^{116})</td>
<td>Errors (e.g., medication type,</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Perceived Stress Scale (PSS)(^{117; 118})</td>
<td>dosing quantities and timing,</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>time off-task)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Staff Fatigue / Alertness</td>
<td>Stress / Arousal Adjective Checklist (SACL)(^{119; 120})</td>
<td>Errors (e.g., medication type,</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>dosing quantities and timing,</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>time off-task)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Staff Mood</td>
<td>Survey</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Staff Satisfaction</td>
<td>Survey</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Staff Perceived Health / Well-Being</td>
<td>Survey / Absentee data</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>PATIENT</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Patient Visual Discomfort</td>
<td>Occupant surveys / complaints</td>
<td>Errors, complaints, time off-task</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Patient Sleep Quality, Sleep-Wake Disturbances</td>
<td>Survey (many exist); wearables (actigraph, etc.)</td>
<td>Length of stay, perceived pain, etc.</td>
<td>Likely tie to other variables, e.g., line of sight (LOS)</td>
<td></td>
</tr>
<tr>
<td>Patient / Resident Activity (e.g., Increased in Day, Decreased Night)</td>
<td>Observation, nurse notes (Survey to be developed with input from nursing staff)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Patient Falls</td>
<td># Patient / resident falls</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Patient Recovery Time</td>
<td>Length of stay, post-procedure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Infection</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Patient Perceived Pain</td>
<td>Amount / types medications, survey</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Patient Behavior (e.g., Agitation, etc.)</td>
<td>Observation / clinical notes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Patient Mood</td>
<td>Survey</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Patient Satisfaction</td>
<td>Survey</td>
<td></td>
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</tr>
</tbody>
</table>

As Tables 3 and 4 are expanded and populated with specifications and/or research findings, it should be possible to establish a business foundation for the adoption of dynamic SSL systems and controls, though many of the metrics will exhibit considerable scatter due to variations in experimental design and/or the design of the specific protocols used to evaluate outcomes. To advance the rigor of the speculative outcome(s), a Monte Carlo simulation could be run to evaluate the range of outcomes and certainty levels of the outcomes. A Monte Carlo simulation allows for people to account for risk in decision making by calculating a range of possible outcomes.
and the probabilities they will occur for any choice of action. The method illustrates both the average and the extreme possibilities by substituting a range of values — a probability distribution — for any factor that has inherent uncertainty. Thousands of iterations are run using a different set of random values from the probability functions with a result showing the distributions of possible outcome values with the likelihood of each outcome. The analysis also allows a differentiation of variables with the most influence on outcomes (sensitivity analysis). This simulation tool would need to be built, and a research team and advisory council should be established to provide expertise in informing the project approach, with lighting designers engaged to provide the necessary input, including risk model scenarios.

5.6 Annex 6: Barriers Identification

Workshop Organizers

5.6.1 Discussion

SSL technology has been primarily developed to significantly reduce lighting energy consumption and lighting system maintenance, owing primarily to the development of very efficient, highly reliable LEDs. SSL also offers a new host of capabilities never before available in a lighting system, in particular, electronic control of the lighting SPD. While the role of lighting in human comfort and performance is well known, the variable spectrum capabilities now available with SOA SSL systems open new possibilities for impacting healthcare outcomes, and lighting companies are looking to capitalize on this new capability with lighting products claiming to improve health, albeit with little clinical evidence.

In parallel to the emerging dominance of SSL as the lighting platform of choice (for reasons of energy efficiency and maintenance reduction) for almost any illuminated environment, new research on the impact of lighting SPD on human physiology (in particular, short wavelength lighting impacts on circadian regulation) has opened interest in the use of variable illumination SPD for impacting patient outcomes and improving the wellbeing of healthcare providers. Because variable SPD SSL lighting systems are so new (and more expensive), most of the limited clinical research involving lighting, health and human performance, to date, has been performed using simple fluorescent systems with different CCTs.

One of the deliverables of this workshop was to combine inputs from lighting and health researchers, healthcare facilities designers, and health systems operations experts (each group represented by one of the first three workshop panels) to define barriers to the adoption of advanced SSL systems for improving healthcare outcomes and operations (the object of the combined experts in the fourth workshop panel). Summaries of each of the four panel discussions were provided in Section 2.0 of this report. Developing an enhanced understanding of needs and barriers is instrumental for assessing market adoption opportunities. The following barriers were identified during the workshop.

5.6.2 Research

Research related to SSL advances in influencing healthcare outcomes and operations is limited, though a small number of studies suggest that potential benefits on both patients and staff could be significant. The ability to dynamically control lighting SPD is recent, and additional research is needed in several areas:

- Assessing the complex interplay between lighting SPDs and ipRGCs in a dynamic polychromatic (e.g., normal white lighting and natural daylight), including timing and dose, and the impact of other biological factors known to impact human comfort and wellbeing;
• Designing and executing well-designed clinical studies with a range of populations to establish statistically based evidence for variable SPD lighting impact on patient recovery and/or caregiver health and job performance; and

• Establishing a lexicon for reporting both experimental conditions (in particular, properly calibrated lighting SPDs and appropriate measurement methods) and patient outcomes with confounding variables listed and properly taken into account.

Barriers to performing suitable research include:

• Availability of suitable tunable lighting systems with adequate illumination SPD control and training in their installation and use;

• Incomplete understanding by researchers with respect to the design, data collection and analysis of complex human factors studies involving illumination;

• Cost and complexity of large-scale clinical studies; and

• Buy-in from the medical community to support/participate in lighting and health research.

5.6.3 Manufacturers and Suppliers

The lighting industry responds to market needs. Manufacturers and suppliers can support products that can meet customer needs while providing economic benefits; however, there are many barriers in healthcare facilities due to uncertainty in emerging lighting standards and the inability of researchers to fully quantify benefits of new lighting systems. The following barriers are those that impede this sector from more rapid deployment of new lighting products:

• The lack of evidence-based specifications for advanced healthcare lighting systems that would enable manufacturers to build such new products;

• The lack of a healthcare business model that would drive end-users to make decisions on lighting systems that might positively affect staff and/or patient health and wellbeing;

• Competing interests of lighting energy efficiency versus lighting for healthcare needs, leading to differing standards for lighting products;

• Cost of product development and manufacturing, especially in the face of uncertain adoption by the healthcare industry (e.g., no clear ROI to customer);

• Development of new control systems for lighting systems with spectral distribution, illumination level, and timing properties optimized for health and wellbeing improvements;

• Cost of education and distribution for newly developed lighting and control products; and

• Risk avoidance of new technologies in the healthcare space.

5.6.4 Regulatory and Operational Guidelines and Standards – How to Change/Develop Guidelines/Requirements:

Standards organizations rely on consensus, which in turn relies on repeatable and reliable research findings and product capabilities. Specifically, with healthcare, it is important to ensure that no standard adds risk to the patients and/or workers; thus, the key ingredient is being connected with those researchers in the field to ensure development and maintenance of appropriate standards for these facilities. Barriers include:
• Uncertainties of research findings, sometimes based on inconsistent reporting of metrics / methods and / or inconsistent results;
• Lack of communication between research institutions and the standards development institutions;
• Competing interests of lighting energy efficiency versus lighting for healthcare needs, leading to differing standards for lighting products;
• Lack of coordination between some organizations and agencies to develop a common path for operational and regulatory guidelines / standards;
• The need for a model of standards and regulatory interfaces that allow for evolution as knowledge correlating variable lighting spectral distribution, illumination level, and timing and improved healthcare patient and / or healthcare worker outcomes develop;
• Existing regulatory standards for lighting do not generally allow for exemptions based on unique population and / or facility needs, which can be very important in healthcare and eldercare facilities; and
• In general, the healthcare industry is not a proponent of driving the health and wellbeing principles of lighting design that may result in higher energy use relative to currently available SSL fixed spectrum lighting systems.

5.6.5 **Lighting Designers and Commercial Building Architects**

Designers of buildings and lighting systems are constantly driving to improve the quality of the illuminated environment for the benefit of their clients. Barriers to designing lighting systems that might provide additional benefits in healthcare / eldercare facilities include:

• Unwillingness to specify new lighting systems in the absence of an evidence-based customer benefit;
• Inadequate information and training materials to educate healthcare and eldercare facilities owner / operators on the benefits of new lighting technologies;
• Concern about the stability and long-term availability / maintenance of new lighting systems created specifically for the healthcare field;
• Issues regarding lighting distributors and electrical contractors, who are often not trained to install new products and often try to value-engineer new lighting products out of lighting designs in order to simplify installation;
• Availability and high cost of new products are inhibiting acceptance by designers; and
• Difficulties in the ease of use and operation by caregivers and / or patients.

5.6.6 **End-Users:**

• Absence of strong evidence-based lighting impacts on improved healthcare outcomes and improved healthcare provider wellbeing makes it hard to justify installation (e.g., unclear value proposition);
• Absence of clear evidence-based standards for new lighting systems for healthcare and eldercare facilities (e.g., research outputs not meeting the threshold for creation of new standards); and
• Facilities designers and architects unwilling to specify new lighting systems without vetted standards and / or clear evidence of product reliability, long-term availability and demonstrated ease of use.
## 6 APPENDICES

### 6.1 Appendix A: Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>8-OH-dG</td>
<td>8-hydroxydeguanosine</td>
</tr>
<tr>
<td>AARP</td>
<td>American Association of Retired Persons</td>
</tr>
<tr>
<td>ADRD</td>
<td>Alzheimer’s Disease and Related Dementia</td>
</tr>
<tr>
<td>AIA</td>
<td>American Institute of Architects</td>
</tr>
<tr>
<td>AMA</td>
<td>American Medical Association</td>
</tr>
<tr>
<td>AMD</td>
<td>Age-related Macular Degeneration</td>
</tr>
<tr>
<td>ANA</td>
<td>American Nurses Association</td>
</tr>
<tr>
<td>ANSI</td>
<td>American National Standards Institute</td>
</tr>
<tr>
<td>ASID</td>
<td>American Society of Interior Designers</td>
</tr>
<tr>
<td>CCT</td>
<td>Correlated Color Temperature</td>
</tr>
<tr>
<td>CCU</td>
<td>Critical Care Unit</td>
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<tr>
<td>CEO</td>
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<td>CIE</td>
<td>Commission Internationale de L'Eclairage (or International Commission on Illumination)</td>
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<tr>
<td>CR</td>
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<td>CS</td>
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<td>DLC</td>
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<td>DLMO</td>
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<td>FGI</td>
<td>Facility Guidelines Institute</td>
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<tr>
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<tr>
<td>IESNA</td>
<td>Illuminating Engineering Society of North America</td>
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<tr>
<td>ipRGC</td>
<td>Intrinsically photosensitive Retinal Ganglion Cell</td>
</tr>
<tr>
<td>IRB</td>
<td>Institutional Review Board</td>
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<tr>
<td>LED</td>
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<td>LESA</td>
<td>RPI’s Center for Light Enabled Systems &amp; Applications</td>
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<tr>
<td>LT</td>
<td>Long Term, 5-10 Years</td>
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<tr>
<td>LOS</td>
<td>Line of Sight</td>
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<tr>
<td>MOU</td>
<td>Memorandum of Understanding</td>
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<tr>
<td>MT</td>
<td>Mid Term, 3-5 Years</td>
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<tr>
<td>NT</td>
<td>Near Term, 1-2 Years</td>
</tr>
<tr>
<td>NIST</td>
<td>National Institute of Standards</td>
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<tr>
<td>NSF</td>
<td>National Science Foundation</td>
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<td>OR</td>
<td>Odds Ratio</td>
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<td>PRC</td>
<td>Phase Response Curve</td>
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<td>ROI</td>
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<td>RP</td>
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<td>SOA</td>
<td>State-of-the-Art</td>
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<td>Solid-State Lighting</td>
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<td>VA</td>
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6.2 Appendix B: Meeting Agenda and Panelists

Transforming Healthcare and Well-Being through Lighting Workshop
Hyatt Regency Grand Cypress Hotel, Regency Rooms 8 & 9, Orlando, Florida
Saturday – Sunday, Oct. 22-23, 2016

SATURDAY, OCTOBER 22, 2016

- 1:00-2:00 pm Check-In and Refreshments
- 2:00-2:15 pm Workshop Introduction
- 2:15-5:00 pm **Panel 1: Research Status Presentations** Lighting for Healthcare / Eldercare Research
  - 2:15-2:35 pm: George (Bud) Brainard, Ph.D., Director, Light Research Program and Professor of Neurology – Thomas Jefferson University121
  - 2:35-2:55 pm: Shadab Rahman, Ph.D., Instructor in Medicine at Harvard Medical School and Associate Neuroscientist at Brigham and Women’s Hospital122
  - 2:55-3:15 pm: Bianca van der Zande, Ph.D., Proposition Developer and Project Manager – Philips Research123
  - 3:15-3:30 pm Break
  - 3:30-3:55 pm: James Sheedy, O.D., M.S., Ph.D., F.A.A.O, Director, Vision Performance Institute – Pacific University123
  - 3:55-4:15 pm: Eunice Noell-Waggoner, B.S., L.C., President – Center of Design for an Aging Society124
  - 4:15-4:35 pm: Karen Lee, B.S., M.S., LC, LEED-AP, Applications Marketing – Osram Sylvania125
  - 4:35-5:00 pm: Session Q&A and Wrap-Up
- 5:00-6:00 pm Cocktails and Networking
- 6:00-8:00 pm Dinner: Brief introduction by hosts, Robert Karlicek, Director of LESA ERC at RPI and Brian Liebel, Technical Director of Standards, IES

SUNDAY, OCTOBER 23, 2016

- 7:00–8:00 am Breakfast Buffet **Regency Hall 3**
- 8:00-8:15 am Brief Recap of Research Status
- 8:15-10:00 am **Panel 2: Architecture & Lighting Design Perspective Presentations:** Architecture / Lighting Design & Specifications
  - 8:15-8:35 am: Martin Moore-Ede, MD, PhD, Chairman & CEO – Circadian126
  - 8:35-8:55 am: Dorene Maniccia, MS, LC, Leed-AP, Senior Project Leader, Lighting Solutions and Services – Philips Research- NA127
  - 8:55-9:15 am: Karyn Gayle, MBA, BBA., EDAC, Vice President – Healthcare Vertical, Acuity Brands128
  - 9:15-9:25 am Break
  - 9:25-9:45 am: Mary Alcaraz, M.S., B. Arch. Eng., Senior Project Manager – Children’s Hospital of Philadelphia129
  - 9:45-9:55 am: Karen Murphy, B. Arch. Eng., Senior Lighting Designer – HDR130
  - 9:55-10:05 am: Ellen Taylor, PhD, AIA, MBA, EDAC, Vice President for Research – Center for Health Design131
  - 10:05-10:15 am: Jason Schroer, Master of Architecture, Bachelors of Environmental Design, AIA, ACHA, LEED-AP, Director – HKS Architects, Houston Office132
  - 10:15-10:30 am: Session Q&A and Wrap-Up
- 10:30-10:45 am Break

Workshop facilitation and report preparation services were provided by Perspectives, Inc.
• 10:45-12:00 pm **Panel 3: Healthcare Operations Perspective Presentations:** Healthcare Operations / Standards Experts
  o 10:45-10:55 am: Ellen Taylor for Doug Erickson, BS, CEO – Facility Guidelines Institute (FGI) 131
  o 11:15-11:25 am: Gary Giovinazzo, Alliance Director, CBRE – NYC H+H Corporation134
• 12:00-1:00 pm: Session Q&A and Wrap-Up

• 1:00-4:15 pm **Panel 4: Planning Session for Overcoming Gaps – Discussion: Focus Questions**
  o 1:00-1:30 pm What further research understanding is required in the next 1-5 years?
  o 1:30-2:00 pm How can we work together holistically as researchers and standards organizations to drive and introduce new lighting systems standards?
  o 2:00-2:30 pm How do we educate the broader field on the opportunities in the new lighting capabilities for human health and wellbeing?
  o 2:30-3:00 pm Do the necessary lighting / control systems exist? If not, what needs to happen to get the lighting companies interested in making them?
  o 3:00-3:15 pm Break
  o 3:15-3:45 pm What kind of ROI metrics make these lighting system advances attractive to healthcare?
  o 3:45-4:15 pm What else can be done (more futuristic concepts – lighting based actigraphy, asset tracking, interfaces to EMR, other)?
  o 4:15-4:45 pm What can we most effectively do in the next 6 months to a year as a community of industries, industry associations, researchers and research centers to actively pursue more R&D funding for this field?
    • Which entities do we pursue first?
    • What actions are you willing to take to assist with this?
• 4:45-5:00 pm Next Steps for Report Preparations (Assignments & Schedules) and Closing Remarks
• 5:00-6:00 pm IES Reception in the Portico West at Hyatt Grand Cypress Hotel
6.3 Appendix C: References


*Workshop facilitation and report preparation services were provided by Perspectives, Inc.*


Perspectives was honored to provide workshop facilitation support and report preparation services for the:

**Transforming Healthcare and Wellbeing through Lighting Workshop Report**

About Perspectives:

Perspectives is a management consulting firm focused on the external intelligence and assessment needs of R&D organizations and government agencies.

We excel at rapidly gaining competence in varied fields to assist program managers and principal investigators with information, planning, and decision-making. The firm provides advisory services to science and technology organizations across the breadth of biological, physical, chemical, and information sciences.

We are proud to work with accomplished research teams on a variety of cutting-edge topics.

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<tr>
<th>Mark Huey, Principal</th>
<th>Deanne J. Idar, Director, Special Projects</th>
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<tr>
<td><a href="mailto:mark@perspectivesweb.com">mark@perspectivesweb.com</a></td>
<td><a href="mailto:deanne@perspectivesweb.com">deanne@perspectivesweb.com</a></td>
</tr>
<tr>
<td>720-227-9315</td>
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