Photo Credit: Ryan Kurtz

Cincinnati Children's Hospital Medical Center

The Story of the Critical Care Building Neonatal Care Spectral Lighting System

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Foreword by Dr. James Greenberg and Dr. Richard Lang

These are exciting times for healthcare lighting design. A confluence of new scientific knowledge and engineering advances allow for the realization of lighting systems that incorporate key features of natural daylight that is aesthetically sound and biologically aware. Our white paper, The Story of the Critical Care Building Neonatal Care Spectral Lighting System, shares our journey toward the creation of a lighting system that supports our knowledge of human biology and will teach clinicians, scientists, designers, and engineers how light can optimize human health and healing. Our story is the first of many chapters to come — we still have much to learn. We share this account of our work in the spirit of collective inquiry with the intent of stimulating interest and discussion around the application of biologically aware lighting in the built healthcare environment and beyond. We look forward to your feedback and insights.

Photo Credit: Ryan Kurtz

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1. Critical Care Building Design

In May 2016, Cincinnati Children's Hospital Medical Center (CCHMC) engaged ZGF Architects, LLC, and GBBN Architects, Inc., along with a team of 20 consultants to partner with hospital leadership and staff on the design and construction of a major clinical care facility expansion at its Burnet Campus in Cincinnati, Ohio. Known as the Critical Care Building (CCB), the 745,000 SF project (609,000 SF new construction / 136,000 SF renovation) capitalized on the 2013 Master Plan and strategic planning work completed by CCHMC. The goal of the project was to provide an operationally efficient and cost-effective facility to expand and redevelop its main campus for new critical care beds and support services.

Siting and Massing

To accommodate the CCB, CCHMC expanded to the north of their existing campus. The building placement on the site was driven by three criteria: the site boundaries, the functional connections back to the existing buildings, and the overall size and shape of the new building footprint.

The integrated design process produced a 48-bed floor layout that resembles an 'H' shape, where the four arms of the H each make up a 12-bed wing. These wings or arms are rotated apart to take advantage of views and daylight and to minimize solar heat gain. The H shape also has a fifth arm that acts as the connector back to the existing Building B and corresponding service lines. The unique and expressive footprint of the bed unit floors influenced the overall massing of the new tower. The footprint of the bed unit continues down from Level 6 to Level 1. Below Level 1, three additional levels—L1, L2, and P—follow the outline of the bed units and infill the space between the two wings for added floor area. The mechanical level (Level 7) follows the bed unit footprint but is recessed from the building edge.

Project Program

The CCB program includes 249 critical care beds with clinical support spaces, a cardiovascular operating room (CVOR) suite, space for support services, and several public and family amenities. A description of the building program is provided below, in order of descending level:

- **Level 7:** Mechanical support, helipad
- **Level 6:** 48 beds for Cardiac Intensive Care Unit (CICU); CVOR suite
- **Level 5:** 48 beds for Bone Marrow Transplant (BMT)
- **Level 4:** 57 beds for Neonatal Intensive Care Unit (NICU)
- **Level 3:** 48 beds for Pediatric Intensive Care Unit (PICU); shell space for future Operating Rooms
- **Level 1:** 24 beds for Complex Airway (CA) Unit; 24 beds for NICU; public amenities
- **Level L1:** Lab, Sterile Processing Department, Pharmacy, Milk Lab, Clinical Engineering, building support
- **Level L2:** Emergency/Urgent Care with Imaging
- **Level P:** Parking, Transport Team

Photo Credit: Ryan Kurtz

Building Requirements and Guidelines + Best Practices and Clinical Expertise

The CCB was designed in accordance with the requirements of the building codes, standards, and regulations adopted by the State of Ohio and the City of Cincinnati. The following codes were applicable to the project:

- Ohio Building Code with Cincinnati amendments
- Ohio Fire Code with Cincinnati amendments
- NFPA 101 Life Safety Code, 2021 edition, as adopted by Centers for Medicare and Medicaid Services (CMS), The Joint Commission (TJC), and Ohio Department of Health (ODH)

Several healthcare-specific guidelines and standards informed the design of the NICU by providing industry best practices and technical requirements, including:

- The Facility Guidelines Institute (FGI) Guidelines for Design and Construction of Hospitals
- Recommended Standards for Newborn ICU Design, Eighth Edition
- Guidelines for Perinatal Care, Eighth Edition

Level 4

The design team also gathered clinical expertise through the integrated design process to inform the new NICU design, specifically the patient rooms. Through a series of design workshops that utilized full-size patient room mock-ups, a multidisciplinary user-group of physicians, nurses, clinicians, and support staff developed the design of the patient room to best support the NICU's model of care. The user group reviewed all aspects of the room design, including room zoning for staff, patient, and families; quantity and location of medical gases, power outlets, and other vital clinical equipment; location of the patient bed within the room; and location of lighting controls for optimized workflow.

CCHMC Neonatal Intensive Care Unit (NICU) Design Overview

The new NICU's location on Level 4 allows the unit to expand horizontally from the existing NICU, maintaining direct connection and adjacency to the CCHMC Fetal Care Center.

Early in the design process, CCHMC committed to providing single, private patient rooms for the NICU. This represented a significant shift in approach to NICU's model of care, as the existing NICU included a combination of single private patient rooms and pod-style patient rooms. The factors supporting the move to single private patient rooms included:

- Improved infection control
- Improved family satisfaction
- Standardization with other patient rooms in the CCB
- Better accommodation of caregiving and clinical workflow
- Reduction in patient transfers between rooms
- More opportunities for exterior windows and daylight

Fifty-six (56) patient rooms are provided on Level 4, 55 of which are single private patient rooms. One patient room provides two patient positions to allow for the accommodation of twins. A headwall with medical gases and other necessary utilities is located at each patient position. Each patient room includes a dedicated wardrobe, toilet/shower room, and sleeping space for family members, to better support families during their stay.

The 56 patient rooms in the CCB will be complemented by a future renovation of the existing NICU in Building B, providing an additional 28 single private patient rooms. Renovation of the existing NICU will begin in 2022, with completion anticipated in 2024.

During construction of the CCB, the NICU leadership identified a need for additional patient beds due to an increase in admissions, acuity, and average length of stay of their patient population. To address this need, CCHMC assigned 24 patient rooms on Level 1 to NICU that were originally planned to support general overflow for all departments in the CCB.

Once the renovation of the existing NICU in Building B is complete, the NICU will support 109 patient positions in 108 patient rooms. The distribution of patient rooms will be as follows:

- CCB Level 4: 56 patient rooms (55 single private patient rooms/1 twin patient rooms) / 57 patient positions
- Building B Level 4: 28 patient rooms (28 single private patient rooms) / 28 patient positions
- CCB Level 1: 24 patient rooms (24 single private patient rooms) / 24 patient positions

View outside in typical NICU Patient Room

Photo Credit: Ryan Kurtz

NICU Patient Room Design Features

Each patient room in the NICU provides the same features and amenities for patients, caregivers, and families.

The headwall is standardized in all rooms to provide the same utilities, equipment, and configuration for all patients. Dedicated charting stations and work areas are provided for nurses and clinical staff. Each room has a pass-through accessible both inside and outside the room, allowing supplies to be located close to patients and minimizing stocking disruptions in the room. A handwashing station is located adjacent to the entry door.

Families have a dedicated space within the room, located near the exterior window. Wardrobes for patient and family storage, a sleeper sofa, convenience outlets, areas for personal displays/photos, and a TV are provided. Each patient room also has a dedicated toilet/shower room to support families rooming in with the patient.

Charting alcoves are located directly outside the patient rooms, providing nurses a workspace close to patients, while allowing families and patients privacy. View windows with integral blinds are located between the charting alcoves and patient rooms to enhance staff visibility of the patient.

The 24 patient rooms on Level 1 and 48 of the patient rooms on Level 4 are a standard size and footprint to match the patient rooms in other departments of the CCB. Located in the east and west wings of the building, these patient rooms have exterior windows providing natural light into the room.

View to interior in typical NICU Patient Room

Photo Credit: Ryan Kurtz

On Level 4, the remaining 8 patient rooms, located in the connector between the CCB and Building B, do not have exterior windows.

The future NICU patient rooms in Building B will provide the same features and amenities to patients and families. Due to the constraints of the existing building, 8 of the 28 patient rooms will have exterior windows.

Visual Lighting

The lighting design approach was to provide multiple layers of light within the room to support patient care while allowing it to be turned down to create a less clinical environment when not required.

Two exam lights were centered on either side of the bed that allow for two different light levels. An indirect wall light was centered on the patient's bed to provide a soft level of lighting when the higher levels of lighting were not required and/or an ambient light that the patient (or family member, in this case) could control for reading. This fixture also contains a color changing light, allowing patients to cycle through colors and have control over the color of their environment. A decorative feature light was also provided within the footwall casework to simulate a playful nightlight that a child could have in their own room at home. Additional can lights over the family area and staff handwashing stations for focused lighting can be turned off to not disturb the patient if they are resting.

The interior finishes were selected to create a warm and playful environment to support healing. Neutral floors ground the patient rooms, while wood look casework brings a natural element into the space. A neutral but playful pattern was developed for the headwall to provide a positive distraction, texture, and to help the clinical components blend in. Accent colors help define the family areas and can be changed over time as color preferences change.

Non-Visual Lighting

In schematic design, ZGF and Pivotal Lighting Design investigated circadian lighting that targeted 24-hour program areas, including patient rooms, corridors, and care team stations. The system accommodated cycled intensity between day and night. Spectral tuning for increased melanopic daytime light was evaluated but value engineered in late 2017.

A confluence of events in mid-2018 restarted the conversation: Dr. Richard Lang's lab had a string of discoveries related to light sensitive opsins that could improve neonate development; ZGF completed the circadian lighting in the Medical Behavioral Unit at Children's Hospital of Philadelphia, demonstrating an integrated approach to non-visual lighting in healthcare; and with all of this in mind, Dr. James Greenberg re-positioned the CCB project as an opportunity to "research biologically aware lighting in a clinical setting."

The project brief was to mimic and control a daylight spectrum from any latitude or season indoors with particular emphasis on violet and blue light to meet timed non-visual and visual requirements. This would involve multiple LED chips and a custom user interface to the controls that approximate daylight for clinical trials and patient care. The entire system would need to integrate with the existing lighting; be commissioned over time with spectrometers; and require education for staff, family, and patient buy-in. The following lessons learned have been compiled as a basis of design for spectral lighting based on daylight.

Photo Credit: Ryan Kurtz

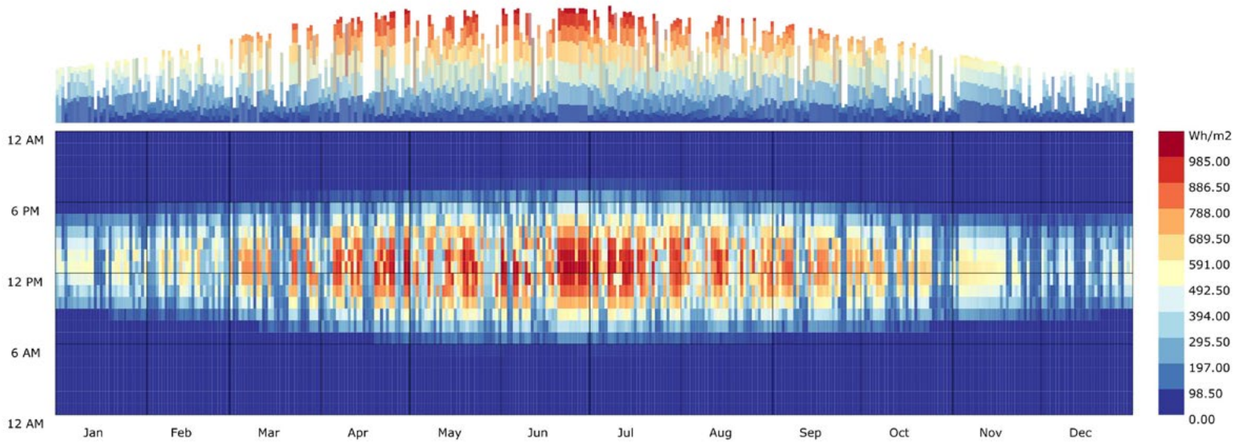


Figure 1. Cincinnati Airport Annual Solar Radiation

Defining Daylight and Limitations for Research Lighting

There are two ways to deliver architectural light: a combination of sunlight and skylight through a window and/or electric illumination. The first strategy is a full spectrum (380-750 nanometer) circadian light source that can change daily in duration according to latitude and time of year. The spectral composition is a complex interaction of photons scattering in the atmosphere based on solar altitude, weather conditions, air pollution, light pollution, and the absorption spectrum of local landscapes or built environments[1].

Sunlight and daylight can cause visual and thermal comfort or discomfort. Additionally, the thermal load of sunlight on a hospital impacts annual operational energy use. The architects must balance the need to minimize solar heat load while maximizing access to views and daylight and give occupants adequate control of brightness with window treatments.

Understanding and defining daylight was an early conversation in the CCB project as it is the primary exogenous zeitgeber—or external stimuli from the environment that influences our biological cycles and rhythms—based on intensity, biologically active spectra, and diurnal delivery. However, the available daylight in the CCB would not support research purposes for the following reasons:

1. Cincinnati is 39.1 degrees north of the equator with a fluctuating daylength of 8 hours at the winter solstice and 14 hours at the summer solstice. Furthermore, Cincinnati climate experiences seasonal, overcast skies with reduced solar radiation (Fig. 1).
2. Much of the violet content of daylight between 380nm-420nm is filtered by architectural glazing (Fig. 2.)
3. A fabric shading system and blackout curtain may be deployed by family or staff at any time.
4. Daylight is diminished based on the crib location inside the patient room.
5. Patient view is angled up at the ceiling.
6. Room material optical properties including an acrylic cover over the crib or Giraffe isolette.

Building a Collaborative Team

Successfully building and deploying a custom spectral lighting system requires a broad, experienced team and buy-in from all project stakeholders from leadership to the building users. For example, ZGF worked closely with Swedish to co-develop the circadian lighting design for Swedish Medical Center Ballard Behaviorial Health Unit, customizing lighting and controls with Acuity Brands®; evaluating non-visual metrics and schedules with the former Lighting Research Center (LRC); and coordinating spectral lighting post-occupancy evaluations with the Pacific Northwest National Lab[2] (PNNL). Pivotal had a similar experience with the LRC and was in communication with BIOS, a light engine manufacturer.

For the CCB project, the client was the research partner in discovery biology, circadian medicine, and advocating innovation in translational medicine delivered by light. The client also brought a knowledgeable facilities team with expertise in lighting, controls, security, IT, clinical engineering, and nursing.

Pivotal led the process to develop a performance-based request for proposal, and Acuity Brands and BIOS were specially invited to present. Both groups were selected for their experience, ability to meet the project requirements, and willingness to partner. Pivotal took a lead role coordinating meetings throughout the duration of the project. ZGF supported with coordination of architectural integration, daylighting research, spectral measurement, construction administration, and commissioning.

Defining Visual and Non-Visual Metrics

Design teams can request the spectral power distribution (SPD) of light sources from manufacturers and evaluate them in various Excel tools for visual and non-visual performance. The IES TM-30-18 Excel toolkit reports a suite of color rendering metrics useful for medical observation and visual design goals. Evaluating light for OPN4 melanopsin has matured over the years with various excel tools including the irradiance toolbox[3] for calculating melanopic lux or the Circadian Stimulus Calculator[4]. The International Standard CIE S 026/E:2018, “defines spectral sensitivity functions for … retina-mediated non-visual effects of light in humans[5]”.

There is widespread agreement on minimum melanopic lux for daytime adults, which has been adopted by the International Well Building Institute (IWBI) WELL standard[6,7]. The Lang Research Laboratory, part of the Cincinnati Children’s Research Foundation, has developed tools and metrics to evaluate SPDs for violet and blue light content measured in photon flux to meet biological needs.

Evaluating the Spectral Reflectance and Transmittance of all Materials in Field of View

The SPD of any light source can be multiplied by the SPD of any intervening material to calculate the resultant SPD. This is true of daylight through a window or electric light bouncing off a ceiling. In the case of the CCB, the acoustic ceiling tile is spectrally neutral with over 90% reflectance. Therefore, there is 90% reflectance of the full spectrum light source to the patient's eye and skin.

Dr. Lang requested the design team assess the violet transmittance through the insulated glazing units (IGU) in the patient rooms. ZGF had glazing samples of the building façade delivered to the Lang Lab so they could measure the transmitted spectrum with a controlled light source provided by BIOS. Additionally, ZGF simulated the glazing assemblies using Optics6, an open-source software developed by the Lawrence Berkeley National Laboratory (LBNL). The software includes an up-to-date version of the International Glazing Database[8], which catalogues SPDs for various glazing products submitted by manufacturers after testing. The measurements taken by the Lang Lab "confirmed the data predicted by the optical models," according to Dr. Lang (Fig. 3). It also confirmed there was minimal light transmission in the violet range. This is an area of future study to investigate high performance glazing assemblies that meet project specifications for energy efficiency, safety, UV protection, acoustics, aesthetics, and allow violet light to transmit for biological functions.

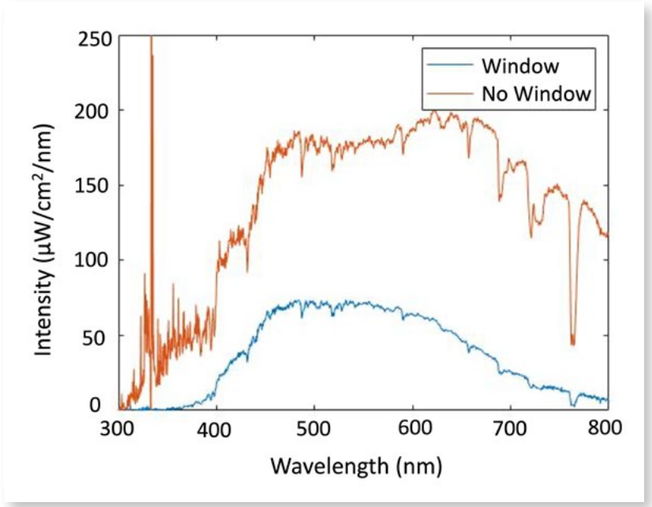


Figure 2. Sunlight transmittance through CCB glazing assembly.

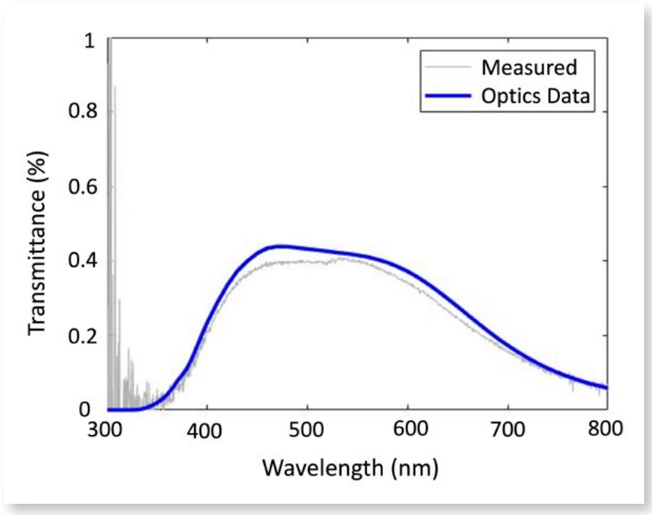


Figure 3. Comparison of measured vs simulated Sunlight transmittance through CCB glazing assembly.

Collecting Spectral Data for Design and Commissioning

One morning, the Lang Lab recorded twilight and sunrise with an Ocean spectroradiometer at 1-minute intervals from the top floor of a parking garage, and post-processed the data to evaluate the violet and blue components. ZGF had been piloting a portable Wavego spectrometer developed by Ocean and started conversations between the client and the spectroscopy manufacturer to develop two types of spectroradiometers to support ongoing project research at CCHMC.

Room Spectrometer

The client wanted to measure light conditions in the existing NICU (Building B) and repeat the measurement protocol in the new unit (CCB) as a basis of the research. Multiple rooms would be evaluated from different viewpoints to capture a spatial representation of spectrum and intensity throughout a day. Ocean developed a custom device that was essentially four flame vis spectrometers (Wavelength Range: 350 - 800nm) in a single 3d-printed box. The device would have four ports: front, sides, and top. One port included a fiber optic with a cosine corrector for remote sensing and flexibility to position within the bassinet. Data would be stored in an on-board computer for periodic download from an ethernet connection.

Roof Spectrometer

The client had questions on diurnal and seasonal spectral shift local to Cincinnati. ZGF shared research on daylight spectral composition and variability based on an active collaboration with Dr. Mehlika Inanici at the University of Washington. This included mathematical daylight models for a range of color correlated temperatures[9-12]. Acuity Brands noted that it was feasible to adjust the spectral lighting with real-time spectral data. ZGF recommended the client engage Ocean to develop a roof-mounted spectroradiometer in Cincinnati. Through a series of discussions, Ocean advised the following components, beginning indoors and ending outdoors:

- A laptop for data collection connected by USB to a spectroradiometer
- A 200' fiber optic cable between end points
- A cosine corrector at the outdoor end of the fiber
- A plastic weather protection dome

The dome was mounted to a mast at the highest point of the hospital with unobstructed views to sunrise and sunset with a small shadow cast by the lightning protection air terminal. The entire system was optically factory calibrated to a NIST standard and good for more than 12 months of operation. A 5-10% drift in measurement accuracy is to be expected. The system can be disconnected and shipped back to Ocean for calibration or calibrated in place. Ocean provided software to automate the frequency of dark and light measurements with a specified integration time. Data is collected at 1-minute intervals 24 hours a day and downloaded weekly by the Lang Lab for archive, calibration, and visualization using custom Matlab scripts. The Lang Lab worked with Ocean to increase the signal- to-noise ratio in the violet range. ZGF has teamed up with the University of Washington Applied Research Consortium to repeat the experiment in Seattle to analyze and publish the data.

Roof Spectrometer

Photo Credit: Ryan Kurtz

2. Recent Discoveries on Mammalian Opsins and Associated Light Response Pathways

The opsin family of G-protein coupled receptors (GPCRs) are the predominant light sensors of multi-cellular organisms. Until recently it was thought that mammals only had opsin-expressing, light sensing cells (photoreceptors) within their eyes. This view has changed with Lang Lab discoveries showing that mammals have light sensing cells within the skin, central nervous system, and adipose tissue[1–3]. Three atypical opsins, encephalopsin (OPN3, blue light sensitive), melanopsin (OPN4, blue light sensitive) and neuropsin (OPN5, violet light sensitive) are the non-visual light sensors in mammals.

OPN4 and OPN5 regulate light-dependent vascular and refractive development within the eye[4–6]. These findings suggest light stimuli might be used to treat retinopathy of prematurity and to prevent myopia. Our studies also show that OPN3 and OPN5 regulate key elements of metabolism including energy storage and thermogenesis[2,3]. The expression patterns and functional biology of OPN3 and OPN5 implicate them in several important pediatric diseases including growth failure, obesity, diabetes, and neurological disorders. The OPN3 and OPN5 GPCRs are very attractive therapeutic targets because their ligands (photons) are non-toxic and their delivery is easily controlled with a well-designed lighting system.

Spectrally Tuned Lighting in the CCHMC Critical Care Building

In late 2017, a brief conversation between Drs. Lang and Greenberg about lighting in the CCB evolved into the idea that we could establish a unique research capability at CCHMC if we installed new lighting technology inspired by our biological discoveries. A close collaboration between Greenberg and Lang, working with CCB architects ZGF, Pivotal, and the lighting companies BIOS and Acuity Brands, resulted in the development, design, and installation of the research grade, spectrally tunable lighting system that is described in this document. This system allows us to closely mimic natural sunlight and most notably, produces the violet light wavelengths found in concentration during twilight that stimulate OPN5[5]. The general benefit of rhythmic lighting in the NICU has been established[7,8] but the new lighting system advances many steps beyond this basic idea and provides precise spectral tuning for unique patient and study populations. Protocols for use of the lighting are currently in development and we are educating NICU staff in the benefits and use of the system.

Photo Credit: Ryan Kurtz

3. Neonatal Care

NICU Care and Goals

Across the human life span, the neonatal period (defined as birth-28 days) presents significant challenges to survival that do not occur again until old age. The vulnerability of the neonate is a function of 1) the unique challenges of human parturition, 2) the dramatic physiologic changes that accompany the transition from placental circulation to air breathing, 3) immature immune and nervous system functionality, and 4) absolute dependence upon maternal care. Since the advent of modern neonatal intensive care in the 1970's, these vulnerabilities have been substantially mitigated, especially for neonates born prior to term gestation. This care is provided in specialized intensive care units (NICUs) staffed by neonatologists and specialized nurses. Typical diagnoses requiring NICU admission include respiratory problems and feeding difficulties. Often these are consequences of preterm birth or congenital malformations. Inborn errors of metabolism, genetic abnormalities and infections represent other major categories of NICU diagnoses.

Despite decades of advances in neonatal care, numerous challenges remain for patients, families and their caregivers. Growth in the NICU, especially among those born extremely preterm (<28 weeks gestation) remains challenging. Even with the availability of sophisticated intravenous and enteral feeding methods, most preterms do not match ideal growth behavior when compared to in utero growth curves. Neonates with chronic lung disease of prematurity display alterations in body mass composition that persist into infancy. Preterms remain at risk for abnormalities of retinal development that can cause life-long visual impairment. Later in life, NICU graduates are more likely to develop learning disabilities and psychiatric disorders.

Lighting in the NICU

The primary goals of neonatal intensive care focus on reduction of morbidity and mortality in an environment that optimizes normal physiology and neurodevelopment. Early versions of NICUs emphasized the provider perspective to achieve these goals. Units were brightly illuminated 24 hours/day to promote close observation and monitoring. Cursory attention was devoted to sound suppression. Monitors, ventilators, IV pumps and other devices generated frequent visual and audible alarms. As NICU design evolved, subsequent decades saw an emphasis on recreating the intrauterine environment. Many NICUs became darker and quieter. Some NICUs adopted cycled lighting, typically on a 12-hour on/off schedule. However, darkness, especially for preterm neonates was emphasized, in part because it was thought to conform to the intrauterine environment. Here, the logic is that the preterm infant "ought" to still be in the womb. Therefore, that environment should prevail in the NICU.

A primary problem with these approaches lies in how intrauterine life is conceptualized. Logically the uterus is a low light environment. However, the fetus develops early components of circadian neurophysiology during the second trimester. Maternal circadian information is transmitted through diurnal body temperature and hormonal fluctuation. Low-level but measurable environmental

light exposure also play important roles in fetal development. When a baby is born too early, these signals are disrupted, and the preterm neonate is left with little to no circadian input. Traditional NICU design has done little to address how to best replace this lost circadian information for patients.

Moving from Standard to Biologically Aware Lighting

A growing body of preclinical and clinical data create a compelling rationale for the creation of biologically aware, cycled lighting environments. By biologically aware, we refer to lighting environments that 1) recapitulate the spectral composition of daylight as it progresses from dawn through dusk and 2) interact with human light-sensing proteins. Clinical studies of cycled lighting environments in the NICU support its use to promote better weight gain and decreased length of stay. These are complemented by sophisticated preclinical studies of non-visual opsins. In mice (and humans), these light-sensing proteins are present in diverse anatomic locations ranging from deep brain structures to adipose (fat) tissue. Non-visual opsins are discussed in more detail in chapter 2. The aggregate of epidemiologic, clinical and preclinical data demonstrate that these proteins are clearly relevant to human health and wellness.

The connections between opsin biology and key aspects of human physiology and development makes the NICU an ideal setting for further studies. The neonatal period is the most rapid, dramatic period of growth and development during the human lifespan. The average length of patient stay is approximately one month. Growth and development are closely monitored and represent key patient outcomes no matter the admitting diagnosis.

In order to effectively study the relationship between these outcomes and environmental lighting exposure, we conceived of lighting technology capable of delivering full or partial spectrum lighting conditions. Further, we envisioned a system that could recapitulate date/light cycles to reflect seasonal variation in length of day. Finally, we desired a light engine that would faithfully reproduce the evolution of daylight spectral composition during the progression from dawn to midday to dusk.

Photo Credit: Ryan Kurtz

4. Electric Lighting Design

Pivotal, the architectural lighting design studio within Affiliated Engineers, Inc., was instrumental in developing lighting solutions that respond specifically to the needs of varying space types in the new CCB, from public areas to patient care. Drawing upon extensive experience in healthcare lighting design, Pivotal collaborated with the larger project team to create unique patient environments that are comfortable and functional for patients, family, and staff.

During the early stages of the project, the design team explored several specialty lighting concepts, including red, green, blue (RGB) color-changing lighting in pediatric patient rooms for diversion and interest, and white light circadian-supportive lighting in selected areas, including the NICU rooms. The pediatric color-changing luminaire was implemented as part of the main project, and the idea of a dynamic circadian lighting system — though tabled at the time — remerged following a major research breakthrough.

Exploring the Concept

Nearly 18 months later—just as final construction documents were being issued—CCHMC's breakthrough research revealed fascinating new connections between light and human health. Conducted by Dr. Lang and his team at the Lang Lab, this innovative discovery sparked renewed project interest in circadian lighting. Responding to the research, project stakeholders began to revisit the NICU lighting system, exploring options and developing new concepts for a dynamic-spectrum circadian lighting system.

Engaged by ZGF to continue expanding upon the initial design, Pivotal assisted in identifying potential luminaire, LED, and control system manufacturers that would be appropriate for the proposed spectral lighting system. Providing oversight, industry expertise, and an in-depth understanding of the original lighting intent, Pivotal ensured a cohesive design that aligned with early project decisions while creating new opportunities for enhanced patient outcomes and continued research by Dr. Greenberg, Dr. Lang, and CCHMC research teams.

Defining the Details

With an overall concept defined, the team began cross-discipline collaboration to inform a design that effectively translated Dr. Lang's research into the built environment. Because the proposed research would require the delivery of tailored light stimulus at specific wavelengths, initial discussions focused on available LED chips and their spectral properties. In response to the research requirements, six discrete LED chips are included within the final fixture, used in combination to facilitate a wide range of customizable spectral distributions.

In addition to more monochromatic spectra targeted to elicit response from specific photoreceptors, the luminaire is also capable of producing very high-quality, broad spectrum white light at a 3500K color temperature. Implemented as a base point for daytime operations, this white light mode facilitates all NICU-related patient care and procedures while maintaining consistency with the architectural illumination throughout the CCB.

Technical lighting requirements were derived from industry best practices and various regulatory sources, including the Recommended Standards for Newborn ICU Design — guidelines issued by the FGI and a multidisciplinary team of medical professionals, state health planning officials, consultants, and architectural designers.

Specific requirements address color temperature, TM-30 Fidelity Index Rf (>80), TM-30 Gamut Index Rg (85-100), and chromatic distance from the black body curve Duv (< 0.001). A Cyanosis Observation Index (COI) threshold of < 3.3 was required for effective clinical evaluation of neonates for cyanosis, with the specific threshold being based on Australia/New Zealand standard AS/NZS 1680.2.5:2018.

Curating an Approach

Integrating the spectral lighting fixture within the context of the NICU patient rooms required a strategic approach. The team collaborated on the development of a wall mounted luminaire design with a fully indirect distribution, eliminating direct high-brightness illumination that could potentially cause discomfort or eye damage given the sensitive nature of neonatal patients.

Positioning the luminaire at the headwall provided numerous benefits:

1. It created an ideal angle for illuminating the ceiling directly above each patient, optimizing the delivery of reflected light.
2. It prevented physical interference between the spectral luminaire and nearby independent exam lighting—located within the ceiling—maintaining the overall aesthetic and functionality articulated by the original design.

Aside from the ceiling-based exam lighting, the remaining light sources within the NICU were positioned to focus light away from the patient, preventing any direct interference with the illumination delivered by the spectral luminaire.

Specific design requirements for the fully custom luminaire included:

- Linear form factor
- Minimal projection from the wall
- Inclusion of a dust cover for infection control
- Cleanable white finish
- No visible fasteners
- An overall length of roughly six feet

In addition to fulfilling the technical requirements, these parameters ensured the fixture's physical appearance resembled the headwall luminaires implemented in non-NICU patient rooms and other clinical areas. Pivotal's final design selections contribute to visual consistency throughout the hospital, complimenting the overall architectural aesthetic as well as the CCHMC brand.

Testing the Options

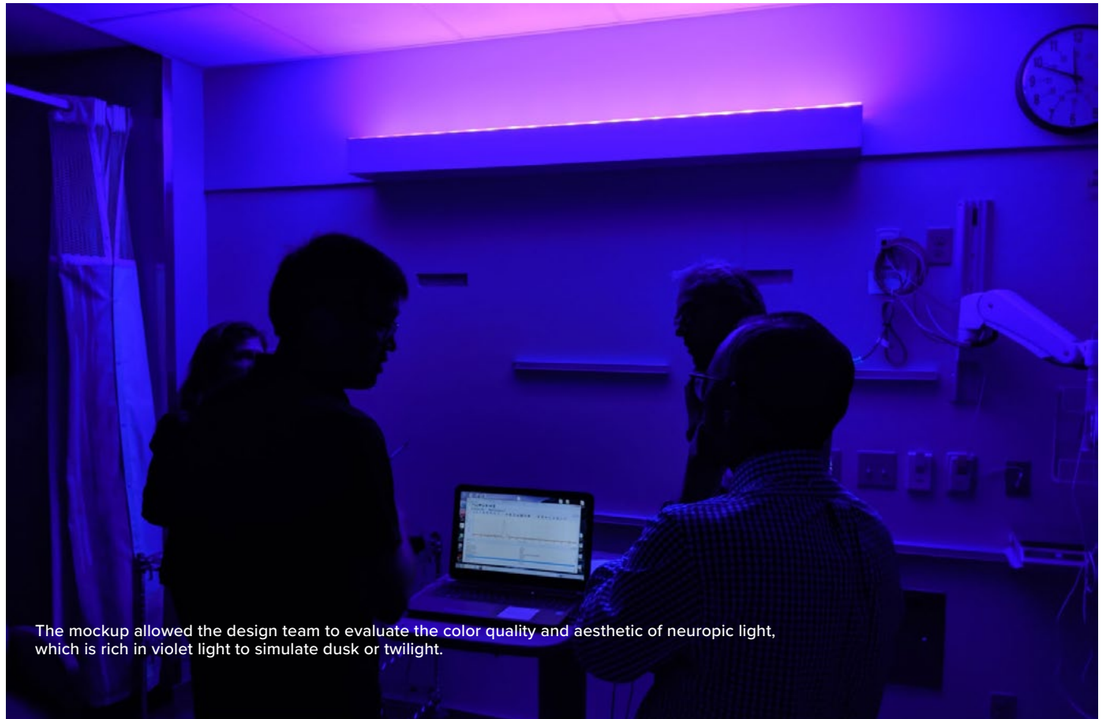
Once the spectral and luminaire design parameters were defined, Pivotal issued a request for proposal to select qualified lighting manufacturers capable of implementing this unprecedented design. Through a collaborative partnership with Acuity Brands and BIOS Lighting, the integrated team further refined the design to ensure optimal effectiveness, manufacturability, and safety.

Given the indirect distribution of the proposed luminaire, the specifics of how light interacts with the surrounding materials, particularly the ceiling, was of crucial importance. Similarly, the spectral transmission properties of all lensing within the fixture required careful analysis and evaluation to ensure that the light produced by the LED chips was escaping the fixture without being color-shifted or absorbed. Faced with limited data on spectral reflectance and transmission characteristics of the materials, particularly in the non-visible portions of the spectrum, Pivotal collaborated with the team to execute an in-situ mockup. This approach ensured design and operational integrity, ease of installation, and direct measurement of the incident light at the patient position.

A luminaire prototype was installed within the full-scale mockup of the patient room, which served as an interactive tool for design feedback throughout the course of the project. The space provided opportunities for real-time simulation of actual conditions in patient rooms, as well as the associated materials, properties, and physical relationships characteristic of these environments. Detailed light level and spectral measurements were taken at various potential patient positions during the mockup, with preliminary, real-time analysis provided by Dr. Lang and his research team. While taking measurements within the mockup environment, an isolette cover was lowered into place—one of multiple possible patient positions evaluated—revealing that the emitted light would be partially blocked, causing the light reaching the patient's eyes to fall below acceptable levels. As a result of this observation, the team developed an additional portable version of the wall-mounted luminaire to provide positional flexibility to accommodate different equipment layouts—effectively eliminating any potential obstruction from the isolette. Not only did this innovative second version prompt new opportunities for temporary implementation in patient rooms without the permanently installed wall fixtures, it also created potential for future expansion and increased flexibility for space allocation.

Though the portable luminaires were designed to offer the same lighting capabilities as the permanent wall fixtures, additional coordination was required with the hospital staff responsible for maneuvering and maintaining the devices. Based on valuable feedback from the staff, the architectural team was able to develop a visually complementary, effective, and minimally obtrusive design that—working in parallel with its permanent counterpart—provided full functionality and the greatest benefit to each NICU patient.

Over the course of the design process, three distinct mockup devices were produced: two for the wall-mounted luminaire and one for the portable version. These innovative, tangible solutions were indispensable to the success of the project, affording the opportunity to elicit valuable feedback, finetune the design, and make focused adjustments before final implementation.



The mockup allowed the design team to evaluate the color quality and aesthetic of neuropic light, which is rich in violet light to simulate dusk or twilight.

Navigating the Challenges

In addition to the spectral luminaires themselves, lighting controls were an essential component in the overall success of the project. Running concurrently with the luminaire development, the team was also refining the required control parameters to ensure the system could adapt to varying user needs and facilitate the intended research protocols.

Initial discussions of the controls were very open-ended, allowing the design team to develop a “wish list” of desired features and functionalities. A core requirement was programming to facilitate the curation of customized spectral light formulas and detailed dynamic lighting schedules, which would allow the lighting system to accommodate individual patient needs.

It quickly became evident that customized interfaces and sophisticated programming would be required to not only achieve the unique controls associated with a lighting control system of this scale and complexity but also provide an intuitive and efficient user experience. DGLogik, a subsidiary of Acuity Brands, offered expert guidance to address and navigate these complex operational parameters and challenges. Control demonstrations during the luminaire mockups allowed the software team to engage the larger group for their feedback and input. The final design includes dedicated control data feeds installed in select patient rooms to synchronize the portable luminaire light schedules with the primary permanent fixtures.

Achieving the Goal

The successful implementation of Cincinnati Children’s innovative, custom spectral tuning luminaire represents the culmination of outstanding team collaboration and a profound commitment to advancing pediatric care and patient outcomes. This project required facilitation of transparent communication among a wide range of multidisciplinary experts and fields, including architecture, lighting design, control systems, daylighting, electrical engineering, luminaire design and manufacturing, LED chip design and manufacturing, software development, IT, construction, facilities management, data collection, biology, and neonatal medicine.

Over the course of four years, countless in-person and virtual meetings, phone calls, and email messages kept this large group of varying project entities and individual team members aligned and working together toward a common goal. In the later phases of design and production, which spanned nearly two full years, Pivotal led monthly, full-team virtual meetings to ensure all major project stakeholders remained informed and were able to quickly adapt and respond to pertinent new developments or logistical challenges. Pivotal is committed to a thorough approach with various checkpoints of quality control, providing detailed documentation regarding project decisions and strategies, and ultimately shaping long-term project success as it becomes operationalized by the Cincinnati Children’s team.

5. Spectrum of Light and Biology

The sun is the single most important element to sustaining life on earth. Its warmth provides adequate temperature for life; its energy is needed for plants to survive; and its light is critical for sight. For humans, however, sunlight provides more than just vision.

Discovery of a novel sky-blue sensing photopigment (melanopsin) changed our understanding of light as it revealed that receptors in the retina of the eye are used for something other than vision. Now, we understand that there are several types of photoreceptors, called intrinsically photosensitive retinal ganglion cells (ipRGC), in the eye that use melanopsin to send signals throughout the brain. These ipRGCs directly support daytime functions such as elevated mood, vigilance, alertness, cognition, and synchronize our circadian rhythms that are vital to sleep and overall health and wellbeing[1–3].

Further evidence indicates that more novel photoreceptors exist in the retina and throughout the body (see chapter 2). Neuropsin is a violet sensing receptor in the retina and the skin. It has been shown to be important for eye development, body temperature regulation, and other physiologic activities. Encelaphopsin, another sky-blue sensing receptor, modulates the metabolic activity of fat and other body tissues.

Visual brightness is characterized by the luminous efficiency function with a peak sensitivity in the green-yellow region of the visible electromagnetic spectrum. Lumens are a metric to measure the brightness of a light source and lumens per watt is a metric to define the energy efficiency of a light source.

Electric lighting represents a large portion of the energy used in the built environment driving efforts to make electric lights more energy efficient. This was first achieved with fluorescent tubes that used specific blends of phosphors to achieve white light with an emphasis on the green-yellow region of the visible spectrum. As a result, early versions of fluorescent lights generated a green hue. Now, as the world has moved to Light Emitting Diodes (LEDs), lights have become even more energy efficient. Again, with strong focus toward green-yellow, but with better balance to eliminate the green tint. What is common amongst these two light sources, is that they are each tailored toward vision with no regard for other biological responses of light.

What are the consequences of lighting that is only focused on visual efficiency with no regard for biological responses of light? We understand that sleep-aids are on the rise, with a $84.9 billion market that is growing 5.1% each year[4]. More than 40% of Americans are myopic, or near sighted—a number that is rapidly rising[5]. We will not truly know how large of a role lighting plays in each of these ailments until we replace our lights with biologically aware lighting.

This is precisely the aim of the biologically aware lighting system installed in the CCB, where we have created spectrally tailored LED lighting to exactly match the needs of each of the newly discovered photoreceptors to provide the ultimate solution in supporting proper development of NICU patients.

BIOS developed LED lighting that can generate an electromagnetic spectrum to activate these photoreceptors and balance vision such that the lighting does not appear any different than traditional lighting. Figure 1 shows the spectral capability of the system, which contains 405nm LEDs, SkyBlue (490nm + Far-red) LEDs, 465nm-peaked 17,000K LEDs, Warm White (450nm-peaked 3,000K) LEDs, phosphor-converted (PC) Green LEDs, and phosphor-converted (PC) red LEDs. The 405nm LED is used to pinpoint OPN5 while complying with material interactions (common optical plastics do not transmit 380nm light).

Figure 2 illustrates the daytime spectrum. This spectrum combines the SkyBlue LEDs, which are specifically designed by BIOS to blend with warm white light LED to create OPN4 enriched white light that maximizes cyanosis observation index. Combining this with the 405nm LEDs creates an ideal spectrum for daytime NICU use. The resulting color of this spectrum is 3500K, neutral white light with a CRI greater than 80, R9 greater than 90, and COI less than 3.3.

Figure 3 shows a snapshot of the twilight transition. The fixture is capable of dynamically shifting from day spectrum to night spectrum, while passing through a blue colored sky effect reminiscent of a sky during sunrise or sunset. The 465nm-peaked 17,000K LEDs are specifically designed by BIOS to create a biologically potent

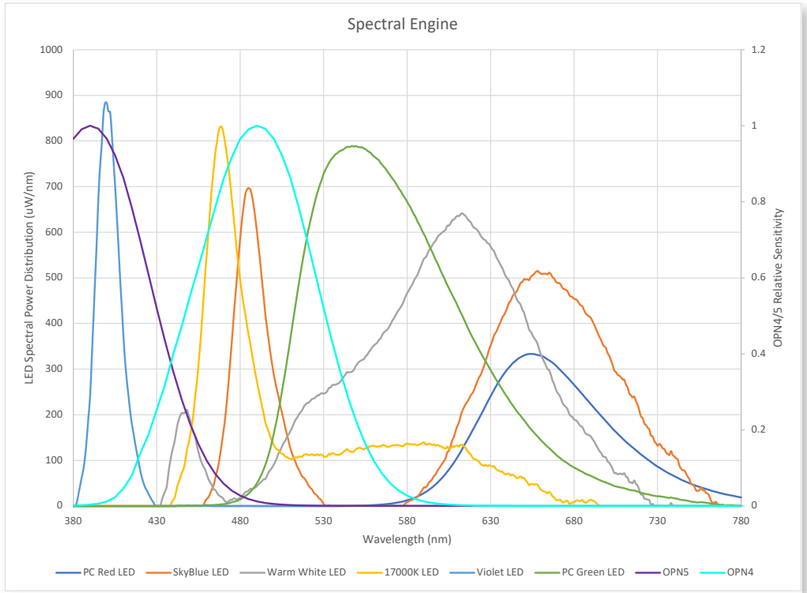


Figure 1. *Spectral power distribution of the LEDs compared to sensitivities of non-visual photoreceptors OPN4 and OPN5 (dashed lines).*

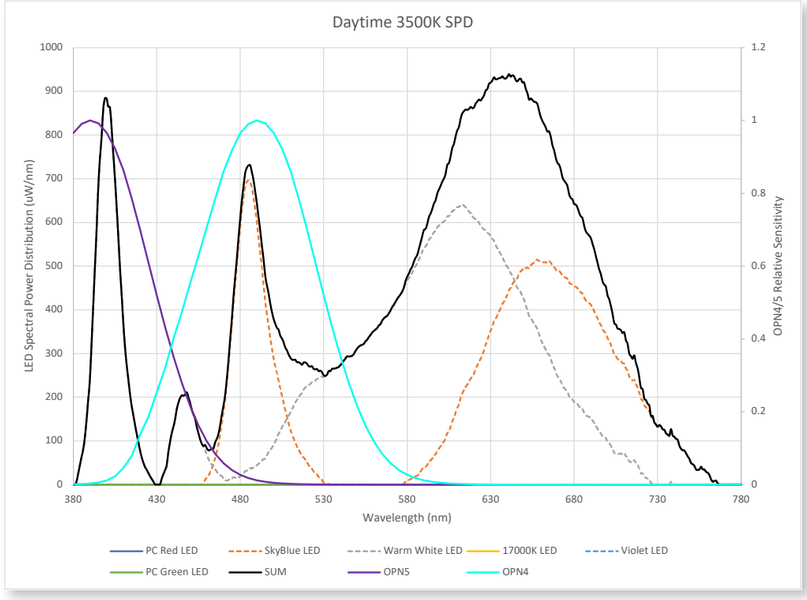


Figure 2. *A daytime spectrum (black line), which pairs a high visual efficiency (lumens per watt) warm white LED (grey dashed line) with a SkyBlue LED (orange dashed line) and a 405nm LED (blue dashed line). This spectrum achieves a good rendition of cyanosis for clinical evaluation, as well as proper daytime stimulation of OPN4 (cyan solid line) and OPN5 (violet solid line).*

sky-blue color useful for these twilight transitions at the end of the day. This LED is combined with the 405nm LED to change the OPN5 to OPN4 ratio, a noted phenomenon that occurs in nature. This combination of color and OPN5/OPN4 ratio[6-8], consistent with latest literature denoting that end of day color changes create an amplified circadian response via specific retinal amacrine circuitry and OPN5 activity, facilitates circadian synchronization.

The phosphor-converted green and phosphor converted red LEDs are used to create a blue depleted nighttime scene, as shown in figure 4.

Additionally, each LED spectrum is individually controllable and provides the flexibility to produce nearly any biologically aware spectrum for research purposes. For simplicity, we do not show the interaction of these photoreceptors with color perception, but it is one of the key considerations for end user compliance. For example, cold color temperature lights such as 6500K, or sometimes referred to as “daylight,” can appear visually off-putting to occupants of the space, despite its spectral composition. By pinpointing the key spectrums for biological significance, we can test the benefits of biologically aware lighting while creating a visually comfortable environment. Some of this color interaction is summarized in a journal paper Frontiers in Neuroscience[9].

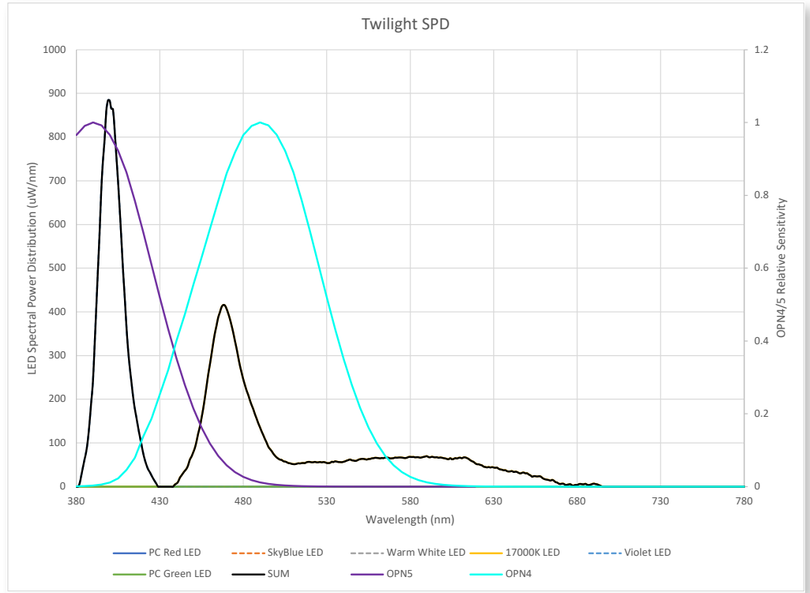


Figure 3. *A snapshot of the twilight transition having more OPN5 stimulation than OPN4 stimulation. This SPD is created with a combination of the Violet LED and the 17,000K LED.*

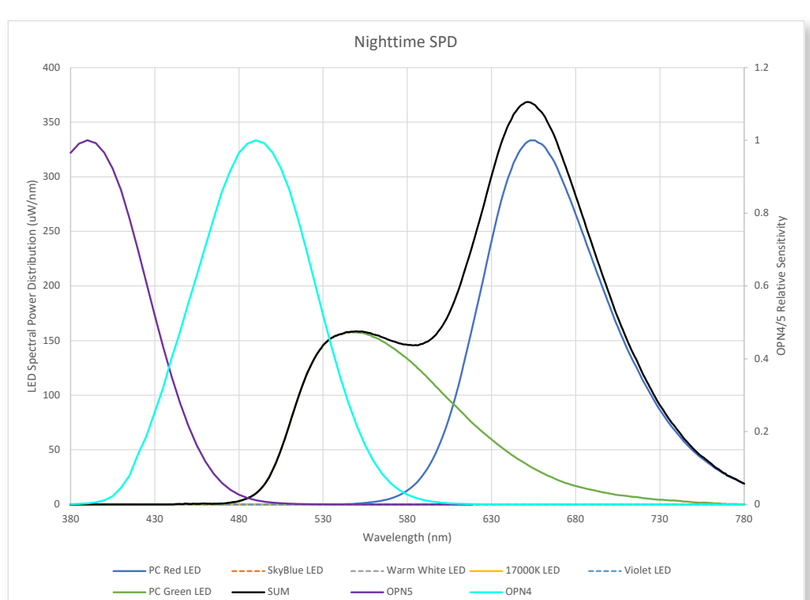
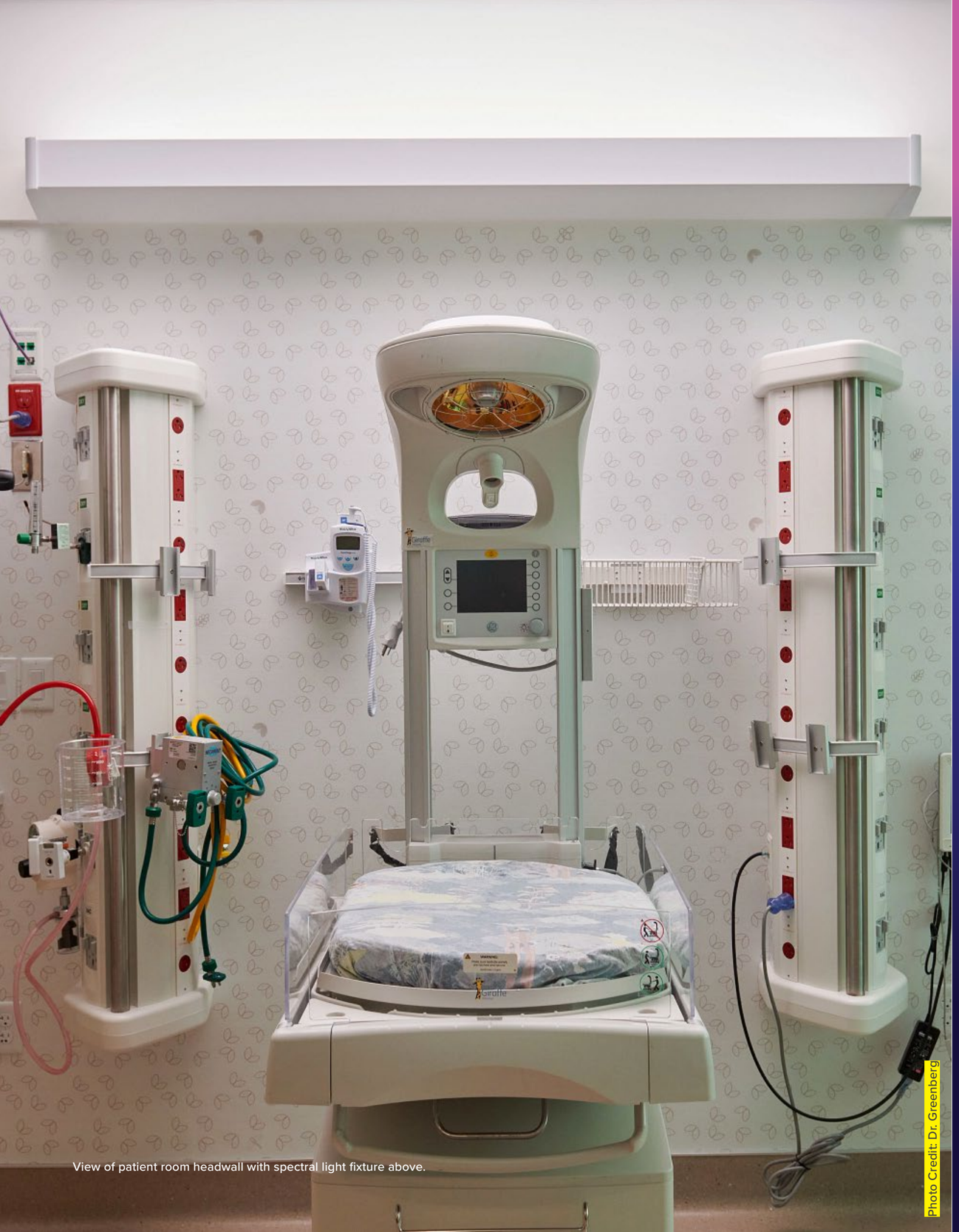


Figure 4. *A blue depleted nighttime spectrum comprised of PC green and PC red LEDs.*



View of patient room headwall with spectral light fixture above.

Photo Credit: Dr. Greenberg

6. Lighting Product Development, Manufacturer, Controls and User Interface

Acuity Brands' journey with the CCHMC NICU spectral lighting project began in November 2018 well into the design phase of the CCB that ZGF and Pivotal Lighting had mapped out to meet the stringent project requirements.

The unique lighting system specified for this project had to deliver on specific identified spectral requirements as a treatment protocol for patients, and it also needed to deliver precise wavelengths in sufficient quantity while simultaneously producing high quality white illumination for the visual comfort of patients, family, and staff. Equally important requirements of the lighting system were delivering a distribution of light that would provide overall pleasing illumination in the room and a luminaire design that maintained an aesthetic compatible with other design elements, robustly constructed to meet the environmental demands of a patient care space. The lighting system also needed to support the visual requirements of medical observation by caregivers.

Beyond the lighting system performance, the lighting controls needed to enable interactions from a variety of stakeholders and perspectives, including conventional in-room manual lighting controls and a web-based user interface. At the initial stage, given the quantity of luminaires and knowing that the spectral lighting system would require at least six channels per luminaire, a DMX control was selected for its ability to handle at least 726 channels. In-room manual lighting controls would consist of button stations for individual on/off control of each permanently installed wall-mounted patient or family luminaire. Button stations were required to have override capability by the nursing staff through the custom user interface software to ensure the patient is receiving the proper dosing from the spectral lighting system. At the onset of the project, the user interface requirements were defined at a high level to map out the needs for the admitting and nursing staff, the patient and family members, and the research staff.

To understand the scope and complexity, Acuity Brands quickly mobilized experts across the company to assess the requirements and develop a team that could confidently respond to the project request for proposal in January 2019.

Designing a solution that could meet the challenges and requirements of this project required deep, concept-level development. The process began with a preliminary design of the thermal and mechanicals for the LED boards capable of providing the correct spectral content. This included TM-30 benchmarks of Rf >/= 80, Rg 85-100, Duv less than +/- .001, 400nm & 480 nm at a relative proportion based on D65 noon light, 660nm to achieve a COI (Cyanosis Observation Index) <3.3. The result included detailed concept drawings for the luminaire, a baseline proposal for the lighting controls hardware based on Acuity Brands' Fresco™ controls architecture, and a high-level scope of services to develop a custom web-based user-interface that would utilize Fresco hardware.

Room Spectrum History Report

By February 2019, the team was deeply engaged in refining the overall design, with a great amount of attention paid to ensuring the control system and user-interface requirements would be met. Ultimately, it was determined that the Fresco system would use DMX to control the lights. A DGLogik custom user interface would utilize BACnet that would run on a dedicated hospital network and essentially instruct the Fresco controllers on how to operate all the DMX channels.

During this phase and through rigorous discussions both internally and with the design team and CCHMC, a final proposal for the entire system was submitted. After a rigorous review process, Acuity Brands was selected for its ability to meet all technical requirements as well as provide the level of services and capabilities to work in tandem with the design team and CCHMC to execute and collaboratively evolve the design through the whole project.

Full development of the lighting system and controls began in April 2019. The first challenge was to embark on a prototyping phase for the LED boards and wall-mounted luminaires. The process started with photometric testing of prototype LED boards to get a handle on the output and spectral content of each of the six LED channels individually as well as some specific lighting recipes to target the final white light and therapeutic recipes the hospital intended to use. After multiple rounds of testing, both with and without optics, it was determined that in order to meet the light output requirements (approx. 2000 lumens per foot) the luminaire would need to house three, 6-channel boards in parallel per foot. (The original concept had been based on two 3-channel boards used in tandem for 6 channels per foot.) As a result, the luminaire design was further refined to maintain the sleek form factor and optical performance while adding in the driver capacity to power all the LEDs sufficiently. Once that was achieved, the next stage was a full-scale mockup.

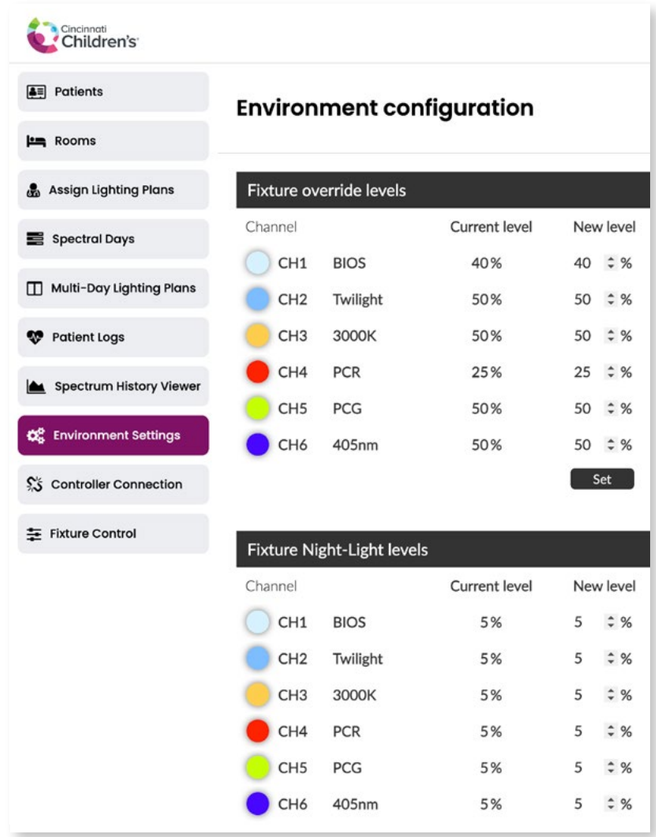
In May 2019, Pivotal issued an RFP for a mockup of a working prototype. The prototype system was installed in a full-scale mockup of a NICU patient room and included a wall-mounted luminaire prototype and working simulation of the user interface. All parties involved in the project attended an in-person mockup review to see a demonstration of the luminaire and user interface prototypes.

During the mockup, it was discovered that certain patients required a particular type of bed that would block the light from the wall-mounted luminaire. Acuity Brands proposed the addition of a portable luminaire that could be used in these situations, which was added to the scope of the project, but which also necessitated new features be added to the scope of the user interface. As a result, development of the portable luminaire began with the first concept drawing developed in October 2019.

After several refinements, a mockup for the portable luminaire was produced and sent to CCHMC for review, which included the clinical staff for usability and extensive testing of output and distribution by the research staff. By early 2021, the portable design was approved and went into production. The portable unit can be activated and placed in service in any location that has the infrastructure to physically connect to the dedicated hospital network running the DGLogik custom user interface.

Other observations during that initial mockup included an aesthetic and performance review of the wall-mounted luminaire. These observations led to some design refinements that were iteratively developed with the design team, leading to a second mockup of the wall-mounted luminaire. Another factor that needed to be addressed from the first mockup was in response to extensive testing by the research staff, who ultimately determined that the relative output of the various LED channels needed to be adjusted for greater flexibility in adjusting the overall spectral content for therapeutic reasons. This input led to some refinements on the LED boards and adjustments to power output per channel.

Knowing the importance of getting the spectral characteristics just right for the clinical function and the desire to evaluate the refined overall aesthetic changes in response to the first mockup review, the design team requested a second mockup luminaire. This mockup was sent to CCHMC in July 2020. Due to COVID restrictions, the design team and Acuity Brands were not able to view it in-person, but the mockup was extensively tested by the research staff. Aesthetics were reviewed through photographs and other individuals onsite. This version was fully approved and went into production engineering at the end of 2020.

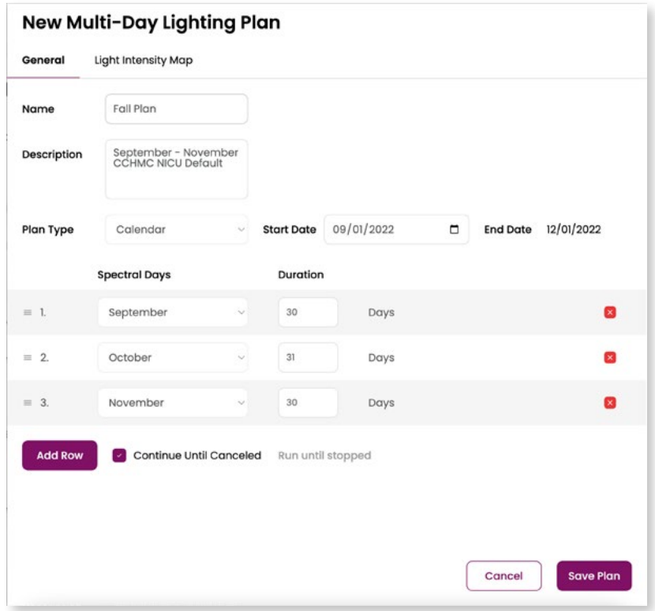


Environment Settings

The core design of the wall-mounted luminaire is based on two critical extrusion profiles that were uniquely designed and tooled for this application. Several intricate and inter-reliant design requirements/ elements had to be balanced and coordinated with the extrusion supplier to ensure all aesthetic and functional performance requirements were met. Luminaires first shipped beginning in March 2021, with individual shipments timed to phase with the construction plan as sections of the new NICU were completed. The last shipment of wall-mounted luminaires was completed in May 2021, including all wall-mounted luminaires required for the entire scope of the CCB project, Dr. Lang's research laboratory, and the future renovation phase for the existing NICU in Building B.

For both the wall-mounted and portable luminaires, it was crucial to the project's success that spectral characteristics and relationships are identical between luminaire types and the light distribution produces the same character of light at similar output with respect to the patient. Meticulous design and engineering testing at Acuity Brands' production facility preceded all mockup reviews by the design team and the precise verification testing performed by CCHMC clinicians and researchers.

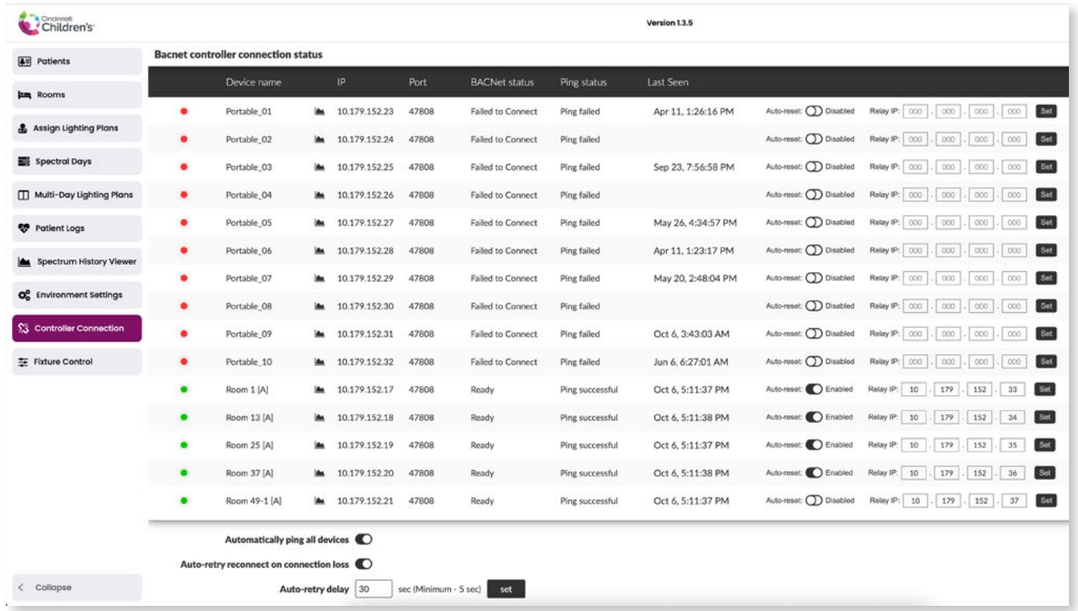
Because of the high lumen density and multiple channels, both luminaires presented significant thermal challenges that required complex and innovative techniques to overcome. Due to the placement of LEDs and drivers within both luminaires, each thermal path had to be optimized for efficiency. Cutting-edge thermal materials to maximize thermal dissipation were refined and selected through extensive and rigorous R&D thermal testing, performed through several iterations during the design phase to finetune and ultimately land on final mechanical and thermal designs for both luminaire types.



Light Plan Configuration

The complex wiring for both luminaires presented a manufacturing challenge that was addressed through extensive wiring diagrams, advanced wire harnesses, and in-line testing protocols. Additionally, several components in the portable luminaire were only possible using advanced manufacturing techniques, leveraging extensive CNC equipment and skills of experienced artisans at the Acuity Brands' production facilities throughout the manufacturing processes, including part blanking, welding, and assembly.

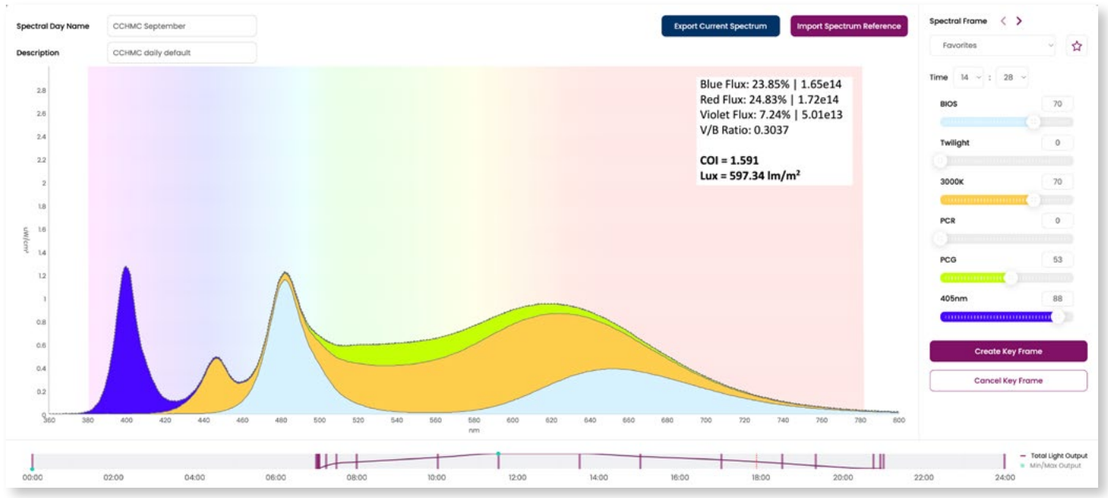
Alongside the luminaire development, the controls system was being refined to track with the final scope of the project, which now included the new CCB, the renovation for Building B, and the research laboratory, both wall-mounted and portable luminaires. The final Fresco system architecture came together in April 2020. Commissioning for the lighting controls began well before the first luminaires were ever shipped.



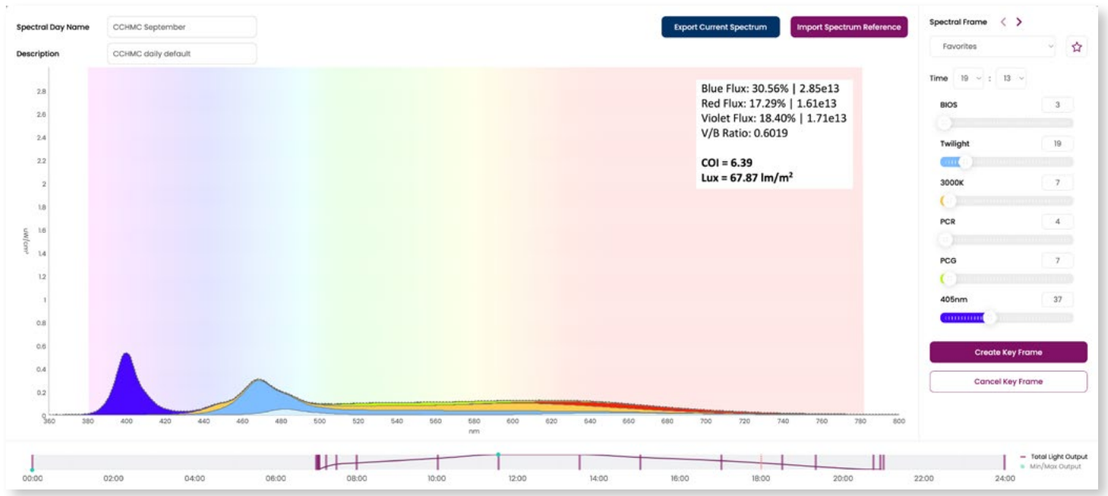
Controller Health Monitoring Report

Once the final light engine and luminaire designs were known, both the Acuity Brands' Controls (Fresco) and DGLogik teams received their own test rig to begin development work, both individually for separate hardware and software development, and to work collaboratively to iron out the execution of never-before created features. The test rigs included a functional section of the luminaire, a Fresco controller and button stations. The foresight of these design teams as well as the flexibility of the Fresco DMX control system allowed Acuity to pre-configure the lighting control software before stepping on site. Pre-configuration included set-up of room-by-room exposure, switch control, slide dimmer control, and BACnet configuration. IP settings, although they could have been configured at this stage, were set up later when that information was available from the CCHMC IT department.

The commissioning team coordinated with the electrical contractor to be on-site for the installation of the first wall-mounted luminaires in late April and early May 2021. Sections of the NICU wing were installed and commissioned in phases through a coordinated effort between the electrical contractor and Acuity Brands. Two commissioning engineers were deployed on-site to expedite DMX addressing for each luminaire as they all needed to be uniquely addressed. With all the upfront work in planning and pre-configuration, the only installation issues encountered were typical DMX/RDM communication inconsistency. This situation was swiftly identified and remedied with the addition of 120ohm end-of-line resistors as is typically required for DMX communication. From there, all wall-mounted luminaires became discoverable and were addressed through the Fresco control stations deployed in the project. The BACnet integration occurs over a dedicated network managed by the CCHMC IT department. The portable luminaires were assigned IP addresses directly and connected to the network via an Ethernet connection port located in the NICU patient rooms and throughout the hospital.



Daily Light Profile



Example of Dusk Spectrum

Beginning in late fall 2020, after having developed a well-received proof of concept, DGLogik began development of the custom user interface, working directly with CCHMC. The user interface had to encompass various functions for individual use groups, including the nursing staff, administrators, and researchers. These functions were defined and refined through regular collaboration sessions with Drs. Lang and Greenberg, as well as CCHMC nursing staff.

A full-fledged static mockup of the future interface was developed and refined until various workflows and research requirements were satisfied. When development of the actual interactive interface was underway, additional features were added to the interface, some were dropped, and various database and backend decisions were made. In July 2021, as more information became available about actual room configurations and equipment, additional refinements and adjustments were made to accommodate multiple fixture operation as well as family area lighting options.

While development of the user-facing aspect of the interface started winding down in August 2021, work on the back-end engine that controls each light independently every second of the day was gaining steam. User interface is designed for three roles: Nurse, Researcher, and Admin. Nurse interface allows user to create patients in the system, assign patients to a room, and override light system as needed to accommodate various procedures or other needs. Researcher role provides all the functionality of the nurse role plus the ability to create daily lighting profiles to replicate various required light spectrums throughout the day. Researcher can then use those daily lighting profiles to construct a lighting plan that consists of one or more daily lighting profiles that can run for predetermined lengths of time, or indefinitely, and can be either calendar-based, where daily profiles change on specific calendar days, or duration-based profiles, where each daily profile runs for predetermined lengths of time from plan start. These plans start executing when assigned to a patient, which is also performed by a researcher role. In addition to constructing daily light profiles and lighting plans, researcher also has access to reporting utility to keep track of light performance over time and monitoring the number of manual overrides initiated either from a physical switch in the room or via nurse user interface. Admin interface allows access to functions of Nurse and Researcher roles plus additional tools, such as patient logs, database administration, spectrum history viewer, environment settings, physical controller connection health monitoring, and individual manual fixture control. In addition to all these features, more are currently in development as application functionality keeps evolving based on field use. For example, planned features include room and light utilization report.

Photo Credit: Ryan Kurtz

7. Acknowledgments

Cincinnati Children's Hospital Medical Center

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Photo Credit: Ryan Kranz

8. References

Chapter 1

1. Spitschan, M. et al. Variation of outdoor illumination as a function of solar elevation and light pollution. Sci. Rep. 6, 26756; doi: 10.1038/srep26756 (2016)
2. Wilkerson et al (2017). GATEWAY Report Brief: Evaluating Tunable LED Lighting in the Swedish Medical Behavioral Health Unit. United States. https://doi.org/10.2172/1378308
3. Lucas et al (2014). Measuring and using light in the melanopsin age (Trends in Neurosciences 37(1):1-9).
4. Rea et al. Modelling the spectral sensitivity of the human circadian system. Lighting Research and Technology 2012; 44: 386–396.
5. CIE international Standard (CIE S 026/E:2018) "System for Metrology of Optical Radiation for ipRGC-Influenced Responses to Light"
6. Brown et al. Recommendations for Healthy Daytime, Evening, and Night-Time Indoor Light Exposure. Preprints 2020, 2020120037 (doi: 10.20944/preprints202012.0037.v1).
7. International WELL Building Institute. 2021. The WELL Building Standard v2 - metric, November 2021. https://www.wellcertified.com/, Accessed September 2021
8. Lawrence Berkeley National Laboratory, International Glazing Database, https://windows.lbl.gov/materials/IGDB. Accessed November 2020.
9. Judd, Deane B.; MacAdam, David L.; Wyszecki, Günter (1964). "Spectral Distribution of Typical Daylight as a Function of Correlated Color Temperature". JOSA. 54 (8): 1031–1040. doi:10.1364/JOSA.54.001031.
10. CIE Technical Report (1999). A Method for Assessing the Quality of Daylight Simulators for Colorimetry. 51.2-1999 (including Supplement 1-1999). Paris: Bureau central de la CIE. ISBN 978-92-9034-051-5
11. Munsell Color Science Laboratory. 2002. Excel Daylight Series Calculator. http://www.rit-mcsl.org/UsefulData/DaylightSeries.xls [20 December, 2021].
12. Hernández-Andrés, J., Romero, J., Nieves, J. L. & Lee, R. L. Color and spectral analysis of daylight in southern Europe. J. Opt. Soc. Am. A 18, 1325, doi: 10.1364/josaa.18.001325 (2001).

Chapter 2

1. Buhr, E. D., Vemaraju, S., Diaz, N., Lang, R. A. & Van Gelder, R. N. Neuropsin (OPN5) Mediates Local Light-Dependent Induction of Circadian Clock Genes and Circadian Photoentrainment in Exposed Murine Skin. Curr. Biol. 29, 3478-3487.e4 (2019).
2. Nayak, G. et al. Adaptive Thermogenesis in Mice Is Enhanced by Opsin 3-Dependent Adipocyte Light Sensing. Cell Rep. 30, 672-686.e8 (2020).
3. Zhang, K. X. et al. Violet-light suppression of thermogenesis by opsin 5 hypothalamic neurons. Nature 585, 420–425 (2020).
4. Rao, S. et al. A direct and melanopsin-dependent fetal light response regulates mouse eye development. Nature 494, 243–246 (2013).
5. Nguyen, M.-T. T. M. T. T. et al. An opsin 5–dopamine pathway mediates light-dependent vascular development in the eye. Nat. Cell Biol. 21, (2019).
6. Jiang, X. et al. Violet light suppresses lens-induced myopia via neuropsin (OPN5) in mice. Proc. Natl. Acad. Sci. U. S. A. 118, (2021).
7. Vásquez-Ruiz, S. et al. A light/dark cycle in the NICU accelerates body weight gain and shortens time to discharge in preterm infants. Early Hum. Dev. 90, 535–540 (2014).
8. Brandon, D. H., Holditch-Davis, D. & Belyea, M. Preterm infants born at less than 31 weeks' gestation have improved growth in cycled light compared with continuous near darkness. J. Pediatr. 140, 192–199 (2002).

Chapter 5

1. Brainard, G. C., Hanifin, J. P., Greeson, J. M., Byrne, B., Glickman, G., Gerner, E., & Rollag, M. D. (2001). Action Spectrum for Melatonin Regulation in Humans : Evidence for a Novel Circadian Photoreceptor, 21(16), 6405–6412.
2. Fernandez, D. C., Fogerson, P. M., Ospri, L. L., Michael, B., Layne, R. M., Severin, D., … Hattar, S. (2019). Light affects mood and learning through distinct retina-brain pathways, 175(1), 71–84. https://doi.org/10.1016/j.cell.2018.08.004.

3. Brown, T. M. (2020). Melanopic illuminance defines the magnitude of human circadian light responses under a wide range of conditions. Journal of Pineal Research. https://doi.org/10.1111/jpi.12655

4. BCC Research (2021). Sleep Aids: Technologies and Global Markets.

5. Vitale, S et al. 2009. Increased prevalence of myopia in the United States between 1971-1972 and 1999-2004. Arch Ophthalmol 127(12): 1632-1639

6. Sara Patterson, James A Kuchenbecker, James Anderson, Maureen Neitz, Jay Neitz; An S-cone amacrine cell in the primate retina sets the circadian clock at sunrise and sunset. Invest. Ophthalmol. Vis. Sci. 2019;60(9):1373

7. Ota, W., Nakane, Y., Hattar, S., & Yoshimura, T. (2018). Impaired Circadian Photoentrainment in Opn5-Null Mice. IScience, 6, 299–305. https://doi.org/10.1016/j.isci.2018.08.010

8. Spitschan, M., Aguirre, G. K., Brainard, D. H., & Sweeney, A. M. (2016). Variation of outdoor illumination as a function of solar elevation and light pollution. Nature Publishing Group, 1–13. https://doi.org/10.1038/srep26756

9. Soler R, Voss E. Biologically Relevant Lighting: An Industry Perspective. Frontiers in Neuroscience. 2021 Jun 7;15:637221. doi: 10.3389/fnins.2021.637221. PMID: 34163318; PMCID: PMC8215265.

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